Energy Availability of Female Varsity Volleyball Players

Sarah J. Woodruff and Renee D. Meloche

Female athletes should aim to achieve energy balance to maintain health and have a high performance output. The purpose of this study was to investigate energy availability (EA) among members of a medium-size Canadian Interuniversity Sport women’s volleyball team and to describe exercise energy expenditure (ExEE) during practices, game warm-ups, and games. Total daily energy expenditure was assessed over 7 days using the Bodymedia Sensewear Mini armband, while energy intake (EI) was measured with dietary food logs. Body composition was assessed using air-displacement plethysmography (Bod Pod). Energy availability was calculated using the equation EA = (EIkcal – ExEEkcal)/kg fat-free mass (FFM). Participants consumed 3,435 (± 1,172) kcal/day and expended 3479 (± 604) kcal/day. Mean EA was 42.5 kcal · kg FFM–1 · d–1 across all 7 d, and 2 participants fell below the 30-kcal · kg FFM–1 · d–1 threshold. Furthermore, participants expended 511 (± 216), 402 (± 50), and 848 (± 155) kcal during practices, game warm-ups, and games, respectively. Overall, the participants were relatively weight stable and should be encouraged to continue fueling their exercise and high ExEE needs with appropriate nutritional strategies.

Keywords: total energy expenditure, exercise energy expenditure, energy intake, body composition, elite athletes, women

The achievement of energy expenditure, which occurs when energy intake (EI) is equal to total daily energy expenditure (TEE), is important for athletes to maximize performance while minimizing the adverse health effects of overtraining and fatigue. Particularly important among female athletes, negative energy availability (EA) has been associated with menstrual dysfunction (Tomten & Hostmark, 2006), reproductive disorders (Loucks, 2004), low iron intake (Ahmadi, Enayatizadeh, Akbarzadeh, Asadi, & Tabatabaee, 2010), and loss of bone mineral density (Nichols, Sanborn, & Essery, 2007). For example, Loucks reported that it is not necessarily the intense training (although a significant contributor to EE) that causes reproductive disorders in female athletes but the low EA. EA is defined as dietary EI minus the energy expended during exercise (ExEE) normalized for fat-free mass (FFM); thus, the amount of energy available to the body to perform all other functions after exercise training expenditure is subtracted. Low EA can result from low EI and/or high TEE/ExEE. Furthermore, health consequences of reproductive disorders may be associated with the female athlete triad (Nattiv et al., 2007), ultimately leading to bone-health problems.

There are limited data for female volleyball athletes concerning EA. All published studies that included elite female volleyball players mainly reported EI or energy balance (i.e., EI = TEE), suggesting a negative energy balance (Beals, 2002; Hassapidou & Manstrantoni, 2001; Papadopoulou, Papadopoulou, & Gallos, 2002; Tomten & Hostmark, 2006), with the exception of Hassapidou and Manstrantoni, who reported a state of energy balance during competition (yet found a negative energy balance during training). For example, Beals collected 3-day diet and physical activity diaries from 21 female elite-ranked adolescent (14–17 years) volleyball players and reported a negative energy balance of 567 ± 362 kcal/day; however, both EI and TEE measures were based on self-report data, which limits the interpretation. A more recent study on female volleyball players (Anderson, 2010) obtained nutrient intake and body-composition status of female NCAA Division II volleyball players for 2 years (preseason, in-season, and postseason; Year 1 without nutrition counseling, followed by a second year of nutrition counseling) and reported EI's (via 3-day food diaries) during the season of ~2,700 kcal/day (Year 1 EI = 2,889 ± 216 kcal/day and Year 2 EI = 2,535 ± 249 kcal/day). Unfortunately, TEE or ExEE was not measured to assess overall energy balance (Anderson, 2010). Hassapidou and Manstrantoni reported EI during training (1541 ± 311 kcal/day) and competition (2,346 ± 766 kcal/day), with the use of repeated 7-day food records. Similarly, others have reported EI's among elite female volleyball players of 2,013 ± 97 kcal/day (Papadopoulou et al., 2002), 2,248 ± 414 kcal/day (Beals, 2002), and 2,266 ± 836 kcal/day (Ahmadi et al., 2010) using 3-day diet records (training status not mentioned). However, no studies could be found that have reported objective TEE/ExEE or EA data among elite female volleyball players.

EA has been reported among some female athletes (albeit mainly endurance athletes, e.g., runners, cyclers,
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Concord, CA). plethysmography (Bod Pod, Life Measurement, Inc., body composition were detected using air-displacement than 30 kcal · kg FFM–1 · day–1 may suppress reproductive and disorders (Loucks, 2004). ing schedules and prevent the onset of health problems and knowledge. It is necessary to ensure that all athletes have adequate EA to support their intense train-

The current study was designed to measure EI, TEE, ExEE, EA, and body composition among female varsity volleyball players over a 1-week period. Bodymedia Sensewear Mini armbands (Pittsburgh, PA) were used to measure TEE over 7 days concurrently with food diaries to measure EI. EI was measured using Food Processor Nutrient analysis software (ESHA, Salem, OR), which processed food-intake data based on portion-size definitions of the 2007 Canadian Nutrient File (Health Canada) database. Over the study period, EA was assessed using the equation \( EA = (E_{Ikcal} - ExEE_{kcal})/kg FFM. \) Changes in body composition were detected using air-displacement plethysmography (Bod Pod, Life Measurement Inc., Concord, CA).

Subjects

All procedures were approved by the University of Windsor Research Ethics Board. Data were collected in January 2011. Active consent was obtained for all participants. Ten female Canadian Interuniversity Sport volleyball players (mean age 20.9 years, range 19–23) from a medium-size Canadian university participated in the current study. The team was ranked in the lower quadrant of Ontario university athletics and was considered to be rebuilding to become more competitive. All data were collected 3 months into their 6-month season. At the pretest, participants had a mean height of 1.77 m (± 0.05 m), weight of 75.0 kg (± 9.7), and body fat of 25.2% (± 6.9%). All participants reported being weight stable (i.e., for the past 3 months/start of the season) and were not actively trying to gain or lose weight. While menstrual cycle status was not obtained (i.e., date of their last period), the researchers did inquire about regular/irregular menses, and all participants reported being eumenorrheic (with the exception of 1 participant reporting past irregular menses).

Methods

Experimental Approach to the Problem

The current study was designed to measure EI, TEE, ExEE, EA, and body composition among female varsity volleyball players. Furthermore, because TEE was measured continuously, a second objective was to describe ExEE during practices, game warm-ups, and games to further advance sport-specific training and knowledge. It is necessary to ensure that all athletes have adequate EA to support their intense training schedules and prevent the onset of health problems and disorders (Loucks, 2004).

Procedures

Body composition was measured twice, 1 week apart (pre- and posttesting), using air-displacement plethysmography (Bod Pod, Life Measurement Inc., Concord, CA) according to the manufacturer’s instructions (e.g., calibrated on the day of testing). All participants were tested at least 2 hr postprandial, voided before testing, and were measured wearing only form-fitting clothing (all according to the manufacturer’s instructions; Life Measurement, Inc., 2010). The participants wore identical clothing for both the pre- and posttest. Total gas volume was measured (according to the manufacturer’s instructions) for each participant during the pretest only (value was used during the posttest to maintain consistency and reduce testing error). The Bod Pod has good validity against other body-composition methodologies (e.g., no differences were observed in percent body fat among 71 female Division II college athletes and controls compared with dual-energy X-ray absorptiometry; Ballard, Fafara, & Vukovich, 2004).

EI was estimated with self-report food diaries based on standard household measurements. Each participant was instructed on how to record her diet in great detail (i.e., preparation method, cooking oils, beverages, quantities, etc.). Each food diary was reviewed and clarified with each participant on completion. All participants were familiar with food diaries from previous work with their sport nutrition coach (S. Woodruff). They were also instructed to eat and drink as they would during a typical week but to ensure that they did not leave any foods or beverages unrecorded. To account for underreporting of food intake, 16 daily energy intakes (out of a possible 70 days) were removed from the sample (i.e., 2 participants maintained all records, 3 participants had one record deleted, 1 participant had two records deleted, 2 participants had three records deleted, and 1 participant had four records deleted) if reported EI was <1.35 × estimated basal metabolic rate, as outlined by Goldberg et al. (1991). Basal metabolic rate was estimated using the widely adopted Schofield prediction equations (Schofield, Schofield, & James, 1985).

TEE was measured using a multisystem sensor; participants were instructed to wear the armband on their nondominant arm (per the manufacturer’s instructions) at all times between pre- and posttesting, with the exception of swimming and showering. The portable armbands measure biaxial accelerometry, body heat loss, and galvanic skin response and automatically calculate minute-by-minute TEE and metabolic equivalents (METs). ExEE was extrapolated out of the TEE measurements based on the dates and times of the practices, warm-ups, and games. Relative ExEE was calculated by normalizing ExEE by body weight. The armband has...
been validated among several populations including free-living adults (Fruin & Rankin, 2004; Johannsen et al., 2010) and children (Arvidsson, Slinde, & Hulthen, 2009; Dorminy, Choi, Akohoue, Chen, & Buchowski, 2008). For example, compared with doubly labeled water (i.e., the current gold standard for measuring TEE), the multisystem sensor measured TEE to within 22 kcal/day among 30 free-living adults over 14 days (Johannsen et al., 2010). Furthermore, the armband seems to be valid with low- to moderate-intensity activities (Fruin & Rankin, 2004; King, Torres, Potter, Brooks, & Coleman, 2004) and seems well suited to volleyball players. All participants wore the armband for more than 98% of the data-collection time period (with the exception of 1, whose armband fell off during the night, thus only recording data for 91% of the time), indicating good compliance with the methodology.

### Statistical Analyses

Paired *t* tests were used to determine differences in pre- and posttesting demographic variables. Separate one-way ANOVAs, with a Tukey’s comparison, were used to determine differences between TEE (absolute and relative)/METs and player positions during practices, game warm-ups, and games. All statistical procedures were completed using Minitab 14 computer software (State College, PA) with the level of significance set at *p* < .05.

### Results

Pre- and posttesting participant demographics are displayed in Table 1. There were no significant differences for body weight, fat mass, or percent body fat between pre- and posttesting, yet FFM increased by 0.7 kg (*p* = .036). Mean EI, TEE, EA, and observed body-weight changes are described for each participant in Table 2. Based on all 7 days, the mean EA for all participants was 42.5 kcal · kg FFM⁻¹ · day⁻¹. Two participants had mean EAs below the 30-kcal · kg FFM⁻¹ · day⁻¹ threshold, and only 2 participants had EAs above 45 kcal · kg FFM⁻¹ · day⁻¹.

Table 3 illustrates ExEE (absolute and relative) and average METs during six practices, two game warm-ups, and two games among starting, reserve, and all positions. On average, participants (*N* = 10) expended 511 (± 216), 402 (± 50), and 848 (± 155) kcal during practices, game warm-ups, and games, respectively. Absolute ExEE (*p*...
Table 3  Energy Expenditure (EE) of Practices, Game Warm-Up, and Games by Starting and Reserve Positions, *M* (*SD*)

<table>
<thead>
<tr>
<th></th>
<th>Starting Position (<em>n</em> = 7)</th>
<th>Reserve Position (<em>n</em> = 3)</th>
<th>All Positions (<em>N</em> = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Absolute EE (kcal)</strong></td>
<td><strong>Relative EE (kcal · kg⁻¹ · min⁻¹)</strong></td>
<td><strong>METs</strong></td>
</tr>
<tr>
<td>Practices (1–2 hr, <em>n</em> = 6)</td>
<td>493 (219)</td>
<td>0.075 (0.016)</td>
<td>4.5 (0.9)</td>
</tr>
<tr>
<td>Game warm-up (1 hr, <em>n</em> = 2)</td>
<td>392 (47)</td>
<td>0.090 (0.009)</td>
<td>5.4 (0.6)</td>
</tr>
<tr>
<td>Game (2 hr, <em>n</em> = 2)</td>
<td>892 (145)*</td>
<td>0.081 (0.010)*</td>
<td>4.9 (0.6)*</td>
</tr>
</tbody>
</table>

*Note.* MET = metabolic equivalent.

*Significantly different between starters and reserve, *p* = .028. *Significantly different between starters and reserve, *p* < .001.
players. Although the preferred method to measure TEE
continuously monitored among elite female volleyball
using 3-day physical activity diaries. We believe that
kcal/day during training and competition, respectively,
strantoni (2001) estimated TEE at 2,211 kcal/day and 2,396
elite volleyball players. For example, Hassapidou and Man-
is much higher than what has previously been estimated for
et al., 2010), due to the strenuous nature of their sport, and
active outside of regularly scheduled volleyball activity. TEE
differing appetites (not measured in the current study).
within each participant over the 7 days. While one might
expect daily variability of EI, participants were able to
stabilize their EI to TEE over the course of the week. The
deviations during the games, yet none were observed between
practices and game warm-ups. Mean time spent over 3
METs (threshold for physical activity as determined by
the armband) for all 7 days was 5 hr and 16 min (± 1 hr
16 min), and mean sleep time was 6 hr and 59 min (± 1
hr and 4 min).

Discussion
TEE and EI were measured in 10 female Canadian Inter-
university Sport varsity volleyball players over a 1-week
period during in-season play. On average, participants
reported consuming 3,435 kcal/day. Self-reported EI is
higher than what others have reported among volleyball
players (Ahmadi et al., 2010; Anderson, 2010; Beals,
2002; Hassapidou & Manstrantoni, 2001; Papadopoulou
et al., 2002). The observed values in this investigation
may be more true to actual intakes than in other investiga-
tions (that often allude to underreporting), as we removed
16 daily food records based on implausible data before
any data analyses. Furthermore, all participants were
very familiar with food diaries due to their experience
and comfort with their sport nutrition coach (i.e., having
done multiple food diaries in the preceding 2 years).
While food journaling may lose resolution after 3 or 4
days, many others have used this 7-day recording meth-
ology (e.g., Kopp-Woodruffe et al., 1999; Laughlin &
Participants were motivated to complete the study for the
benefit of their own performance as athletes, and informal
check-ins with all participants occurred two or three times
during the data-collection period to ensure accurate and
continued recording. There were large ranges for daily EI
within each participant over the 7 days. While one might
expect daily variability of EI, participants were able to
stabilize their EI to TEE over the course of the week. The
large variability may have been due to busy academic
and training schedules (e.g., not enough time to eat),
living arrangements (e.g., on own vs. living at home), or
differing appetites (not measured in the current study).

On average, participants expended 3,479 kcal/day
and spent 5 hr and 16 min/day above 3 METs. Based
on the training schedule, participants were scheduled in
volleyball-related physical activities 2 hr on practice days
and 4.5 hr for game days, suggesting that they were also
active outside of regularly scheduled volleyball activity. TEE
is much higher than in the average population (Johannsen
et al., 2010), due to the strenuous nature of their sport, and
is much higher than what has previously been estimated for
elite volleyball players. For example, Hassapidou and Man-
strantoni (2001) estimated TEE at 2,211 kcal/day and 2,396
kcal/day during training and competition, respectively,
using 3-day physical activity diaries. We believe that
this was the first time that TEE has been objectively and
continuously monitored among elite female volleyball
players. Although the preferred method to measure TEE
is through either indirect calorimetry or doubly labeled
water, the practical nature of those methodologies limits
measurement in the field (Koehler et al., 2011).

The armband has been shown to be valid for activi-
ties of daily living (Johannsen et al., 2010) and low- to
moderate-intensity exercise (Fruin & Rankin, 2004; 
King et al., 2004). However, it reportedly underestimates
TEE at higher intensities (Drenowatz & Eisenmann,
2011; Koehler et al., 2011), and it has been suggested
(Drenowatz & Eisenmann, 2011) that the threshold for
accurate measurements seems to be around 10 METs.
The highest observed MET value of any participant in
the current study was 6.4 (during a game warm-up ses-
tion), suggesting that armband was capable of measuring
the intensity of the sport of volleyball, likely due to the
anaerobic nature of the sport (e.g., repeated high-intensity
bursts). Regardless, the use of an objective validated mea-
surement tool is superior to self-report physical activity
diaries with estimated energy costs.

On average, participants were mainly in a state of
energy balance, as evidenced by no statistical differences
in body weight, fat mass, or percent body fat over the
7-day testing period. Although some small differences
were observed within each participant, the differences
were well within the normal error associated with the
Bod Pod. There are limited data for test–retest reliability
using the Bod Pod, especially in female athletes. Among
15 Division IA male college football players, the correla-
tion coefficient for test–retest reliability was .994 with
a technical error rate of 0.448% (Collins et al., 1999),
while others have reported correlation coefficients of
.992 (Vescovi et al., 2001) and .982 (Sardinha, Lohman,
Teixeira, Guedes, & Going, 1998) among adult popula-
tions. Furthermore, the small differences observed in the
current study could have been due to differences in size
and time of last meal (even though 2 hr is thought to be
sufficient for testing, we did not standardize the last meal
before testing) or bowel or bladder fullness.

Furthermore, while none of the participants were
actively trying to lose or gain weight, the small individual
differences in body weight (nonsignificant), fat mass (p = .036), fat-free mass (nonsignificant), and percent body
fat (nonsignificant) observed in the current study are
well within the normal daily weight fluctuations, self-
reported EI error, and errors associated with entering
the exact foods consumed into Food Processor (ESHA
Research, Salem, OR). For example, error may have been
introduced when entering the food items into the nutrient-
alysis software, because some brand names were miss-
ing and, therefore, a generic brand was used instead; some
food items were missing completely; and some cooking
methods were absent (e.g., breaded chicken strips had to
be substituted for homemade breaded chicken because
this food item was not present in the software). While we
believe that the participants were comfortable reporting
all food consumed due to the preexisting nature between
themselves and their sport nutrition coach, it is possible
that some social desirability of food reporting could have
occurred, which is why the 16 daily food records were
eliminated before analysis. Finally, although we did not provide the participants with prepared food and beverages (similar to Horton et al., 1994), they were encouraged to consume typical food and beverages, even though it would limit the researchers’ control.

To determine whether the participants were meeting their ExEE needs, EA was estimated to be 42.5 kcal · kg FFM–1 · day–1 across all 7 days. Two participants fell below the 30-kcal · kg FFM–1 · day–1 threshold over the course of 7 days, which is concerning. However, on further investigation, Participant 3 (i.e., lowest mean EA observed was 19.9 kcal · kg FFM–1 · day–1) had 4 days of EI removed from further analysis due to suspected underreporting, leaving only 2 game days and 1 rest day. Participant 2 had a mean EA of 26.9 kcal · kg FFM–1 · day–1, with an exceptionally low 5.2 kcal · kg FFM–1 · day–1 on one of the game days (thus lowering her overall mean). This participant, in particular, has difficulties with consuming food in general (e.g., difficulties with textures, food allergies, and food aversions), which is constantly a concern for her athletic performance. On the other end of the spectrum, Participant 9, who had a mean EA of 79.2 kcal · kg FFM–1 · day–1, with 3 days of EAs greater than 80 kcal · kg FFM–1 · day–1, was cautioned about weight gain if this were to continue for a prolonged period of time. EA studies to date have mainly used endurance-type athletes (e.g., runners, cyclists, and triathletes) and reported EAs in the range of 30 kcal · kg FFM–1 · day–1 across all 7 days. Two participants (i.e., lowest mean EA = 10) expended 511 (± 216), 402 (± 50), and 848 (± 155) kcal during practices, game warm-ups, and games, respectively. Female volleyball players need to account for this high level of ExEE with adequate nutrition before activity to be able to maintain a high performance output. Similarly, athletes should be encouraged to consume energy during practices and games, given their long duration (e.g., 2–2.5 hr), for maximal sport performance.

In conclusion, EA is a critical component to investigate for athletes expending high amounts of energy who may be at risk for low EIs relative to ExEE. Athletes need to be encouraged to consume enough energy to cover the cost of repeatedly elevated ExEE. Our data suggest that while most previously published articles report that female elite volleyball players are in a state of negative energy balance, the new and more sophisticated technology and the inclusion of the EA analysis in this study have shown that this may not necessarily be the case. Although expending a high level of energy throughout their sport, particularly on game days, athletes need to consume adequate energy. Optimal levels of athletic performance, as well as a decreased risk of menstrual dysfunction and bone pathologies, tend to be achieved with an EA above 30 kcal · kg FFM–1 · day–1. Future research should examine body-composition changes, as well as the diet composition of each athlete, more often over the season and include metabolic markers of bone and menstrual health.

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References


