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The relationship between body fat percentage and difference in caloric expenditure as measured by indirect calorimetry and estimated by an elliptical trainer

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ABSTRACT

Objective: This study examined the effects of increased body fat percentage on the difference between estimated and measured caloric expenditure. **Materials and Methods:** In total, 34 adults participated in the study. The exercise was completed on an elliptical machine for 30 min: 5 min warm-up, 20 min exercise at 64-76% of maximum estimated heart rate, and 5 min cool-down. Indirect calorimetry was measured and recorded every 5 min along with ratings of perceived exertion. Heart rate was monitored throughout the exercise session. Body composition was measured using BodPod. Analysis was completed using SAS 9.4 to calculate the correlation between the difference at each time point and body fat. **Results:** No significant relationships between body fat and the difference in caloric estimate overall or at any time point ($P = 0.06$-0.10) were found. There was a consistent negative correlation between body fat and caloric estimate difference (-0.31 overall, -0.24 to -0.36 for the intermediate time points). No significant differences in caloric estimates based on obesity classification were found. **Conclusions:** Individuals with lower body fat percentage need to be cautious when relying on caloric estimates from exercise equipment, and those who near their weight goal will be less able to rely on the caloric estimates from exercise equipment. It is important to enter as much information as possible for increased accuracy when using an exercise machine.

KEY WORDS: Caloric expenditure, elliptical, exercise, obesity

INTRODUCTION

Aerobic exercise is generally accepted as part of a weight management program [1]. A critical aspect of this exercise in relation to weight management is energy expenditure. Reducing kilocalories consumed while increasing kilocalories expended is common advice as part of a weight management program. Balancing energy expenditure is dependent upon accurate information derived from both of these components. Tracking caloric consumption is relatively accessible as foods are labeled with nutritional values or have nutritional information available. However, caloric expenditure is more difficult to assess. Most modern pieces of exercise equipment display kilocalories expended during exercise, but the accuracy of this information is debatable.

To increase the caloric deficit, exercise is critical to the management of obesity [1,2]. Exercise on an elliptical machine may be a preferred method for the overweight and obese as ratings of perceived exertion lag behind indicators of physiological intensity [3]. This lag may result in the individual exercising longer or at a higher intensity than other exercise modalities. In addition, the elliptical reduces the weight-bearing aspect of exercise [4], thereby reducing the excess load on the knees that accompanies gait in the overweight and obese [5]. Elliptical-style exercise machines have demonstrated higher energy expenditure than other options [6]. There have been discrepancies found between energy expenditure estimated by the equipment and indirect calorimetry [7]. However, the role of body composition in this discrepancy has not been evaluated. There has been a strong correlation observed between machine estimates and measurements of energy expenditure based on oxygen consumption [8]. It should be noted that the elliptical machine does elicit a similar stimulus for cardiovascular fitness as the treadmill [9]. This combination of factors (generally feels easier, reduced weight-bearing, higher energy expenditure, and equivocal fitness stimulus) makes the elliptical machine an ideal modality for exercise for individuals using exercise as part of a weight management plan. However, if individuals rely on the questionable machine calculations for energy expenditure values, this could cause long-term frustration as the lack of accurate information leads to errors in balancing caloric intake and expenditure. As a prior investigation, indicated a difference between measured and estimated caloric expenditure [7], the purpose of this study was to examine the effects of increased body fat percentage on the difference in caloric expenditure values. It was hypothesized (1) there would be a significant correlation between body fat percentage and the difference in caloric expenditure between the two methods; (2) there would be a significant difference between the average discrepancy between the machine reading and indirect calorimetry measurements for overweight versus normal-weight participants; and (3) the ratings of perceived exertion would not be correlated to either the difference in caloric expenditure between the two methods or body fat percentage.

MATERIALS AND METHODS

Participants

Participants were 34 adults [Table 1]. Prior to data collection, participants completed a health history questionnaire to ensure they could safely exercise at a moderate intensity. This study was approved by the Institutional Research Board at Sam Houston State University. All participants provided written informed consent.

Materials

A Precor EFX 883 elliptical (Precor, Woodinville, WA USA) exercise machine was used for the exercise portion of this study. This model has static arms for the upper body and an adjustable ramp and resistance for the lower body. Resistance may vary from 1 to 20, with 20 being the greatest amount of resistance. Ramp level also varies from 1 to 20 with 20 being the highest incline. This model uses a formula based on one developed by the American College of Sports Medicine to predict caloric expenditure factoring in stride rate, resistance, weight, and age [10]. A FitMate Pro (COSMED USA, Concord, CA USA) was used to collect indirect calorimetry information along with a Hans-Rudolph Oro-Nasal 7450 V2 Mask (Hans-Rudolph, Shawnee, KS USA) that covered the mouth and nose and an exercise turbine and flowmeter (C02560-01-04, COSMED USA, Concord, CA USA). The Fitmate Pro has demonstrated acceptable validity in similar forms of data collections [11,12]. The Fitmate Pro has a testing option to measure energy expenditure, which was used for this study. Heart rate was monitored using a wireless monitor (Model SZ990, COSMED USA, Concord, CA USA). A BodPod (Model 2006, COSMED USA, Concord, CA USA) was used to assess body composition. Quality control measures were conducted daily prior to testing. A standard balance scale with stadiometer (Health-O-Meter Model 400KL, Boca Raton, FL USA) was used to measure height (in meters) and weight (in kg). Weight was also measured using the calibrated scale that accompanies the BodPod for body composition estimation.

Table 1: Demographic information

Variable	Overall (n=34)	Normal weight (n=23)	Overweight (n=11)
Age (years)	25.03±7.28	24.52±6.87	26.09±8.31
Height (m)	1.69±0.09	1.69±0.09	1.68±0.10
Weight (kg)	71.28±15.63	69.64±14.21	74.72±18.50
Body fat (percentage)	23.84±9.03	18.52±5.94	33.53±4.23

Note: Overweight was defined as over 24.2% of males and over 28.4% of females. All in M±SD, M: Mean, SD: Standard deviation

Testing Protocols

Height and weight

Height and weight were measured without shoes wearing lightweight attire (example: Shorts and a t-shirt). Weight was measured while facing the scale; height was measured while facing away from the scale.

Exercise testing

Moderate intensity exercise was selected to avoid limiting the participant pool due to potential inability to complete the exercise session and to keep the exercise intensity at a safe level. Exercise intensity was monitored via heart rate and rating of perceived exertion (RPE). For heart rate, the estimated maximum heart rate was calculated using the formula developed by Gellish *et al*. [13]: Maximum heart rate=207 − (0.7 × age). This formula is reported to be appropriate for adults with a broad range of fitness [13]. Moderate intensity was then set at 64-76% of the predicted heart rate maximum. Heart rate was monitored continuously throughout the exercise session (warm-up, moderate intensity, and cool-down). The Borg CR10 Ratings of Perceived Exertion scale [14] was used for RPE. The scale was displayed on the display panel of the elliptical, as well as on a wall, for quick access. Participants were instructed on the usage of the scale and allowed to ask questions as needed until the scale was understood. Ratings (RPE) were collected during the last 30 s of each 5 min block of the exercise session (warm-up, 0-5 min of moderate exercise, 5-10 min of moderate exercise, 10-15 min of moderate exercise, 15-20 min of moderate exercise, and cool-down).

The exercise session consisted of 30 min on an elliptical trainer. The "quick start" function was used to ensure the default caloric expenditure calculation was used. Although the addition of demographic information (age, etc.) might increase the accuracy of the caloric estimates, the amount of information that can be entered varies from machine to machine and many people choose not to enter any additional information and simply begin exercising. A warm-up of 5 min was used to prepare the participant for moderate exercise. Resistance was set at level 1, and the ramp level was set at 5. During the warm-up, the participant was instructed to keep the heart rate below moderate intensity. Heart rate was also monitored, and participants were alerted to reduce the intensity if the moderate intensity was reached. After the warm-up, the participant immediately began 20 min of moderate intensity exercise. During the moderate exercise portion, the resistance was set at 5, and the ramp level was set at 10. Immediately upon completing the 20 min of moderate intensity exercise, a 5 min cool-down period was begun. The resistance and ramp settings were the same as the warm-up period (1 and 5, respectively).

Participants were asked to drink as normal prior to the exercise session, but to refrain from substances containing caffeine. Participants were also asked not to eat a large meal within 2-3 h of their scheduled testing time. It was also requested that lightweight exercise clothing be worn.

Body composition testing

Body composition testing was conducted separately from the exercise session, but could be completed on the same day. Participants were instructed to drink as normal but to refrain from eating and exercising within 2 h of the scheduled testing time. It was requested that tight-fitting clothing be worn. Researchers ensured that all participants wore clothing appropriate for usage with the BodPod (example: Compression shorts for males, compression shorts and a sports bra for females). Participants also wore a swim cap during testing as described in the manual for the BodPod. Males were identified as overweight if body fat percentage was ≥24.2%; females were identified as overweight if body fat percentage was ≥28.4% (normal weight $n = 23$; overweight $n = 11$) [15].

Statistical Analysis

Statistical analysis was completed using SAS 9.4 (SAS Institute Inc., Cary, NC). The difference in caloric expenditure was calculated as caloric expenditure estimated by the elliptical minus caloric expenditure measured by the Fitmate Pro (elliptical – Fitmate Pro = difference in caloric expenditure). The correlations between the difference at each time point and overall, body fat, and average RPE for the exercise session (excluding warm-up and cool-down) were calculated. A repeated measures Analysis of Variance was also calculated for the difference in caloric expenditure for normal weight versus overweight. A *t*-test was used to examine differences in RPE between the two groups. Model assumptions were found to be tenable or presumed to be tenable in the case of model assumptions about the population. Significance was set at $P < 0.05$. There was not a difference between males and females.

RESULTS

There was not a significant relationship between body fat and the difference in caloric estimate overall or at any time point ($P = 0.06$-0.10) [Table 2]. However, there was a consistent non-significant negative correlation between body fat and caloric estimate difference: −0.31 overall, −0.24 to −0.36 for the intermediate time points [Table 3]. There were no significant differences in caloric estimates based on obesity classification ($F_{1,28} = 1.16, P = 0.29$). There was not a significant correlation between average RPE during the exercise session and either caloric expenditure difference ($r = 0.01$, $P = 0.95$) or body fat percentage ($r = 0.20$, $P = 0.29$). The average RPE was not different when comparing normal weight to overweight ($t_{32} = -0.66$, $P = 0.51$).

Table 2: Differences in caloric expenditure in kilocalories between machine estimations and indirect calorimetry for each time point and overall for total group and split by obesity classification

Time point	Overall (*n*=34)	Normal weight (*n*=34)	Overweight (*n*=11)
5 min	19.04±5.65	19.54±5.96	18.17±5.24
10 min	44.52±11.22	45.49±11.69	42.76±10.63
15 min	69.68±16.42	71.48±16.30	66.40±16.91
20 min	95.10±21.14	98.05±20.52	89.73±22.16
25 min	120.42±26.59	124.65±25.76	112.73±27.55
Overall	128.09±33.54	132.65±33.44	118.54±33.23

Note: Overweight was defined as over 24.2% of males and over 28.4% of females. All in M±SD kilocalories, M: Mean, SD: Standard deviation

Table 3: Correlation between difference and body fat percentage

Time point	Correlation (*P*)
5 min	−0.24 (0.23)
10 min	−0.32 (0.10)
15 min	−0.31 (10)
20 min	−0.35 (0.07)
25 min	−0.36 (0.06)
Overall	−0.31 (0.09)

DISCUSSION

There was not a significant correlation between body weight and the difference in caloric expenditure calculations, nor was there a significant difference between the two methods for overweight versus normal weight adults. There is little research in this area, but these findings are consistent with those of Mier *et al.* [7] that machines tend to overestimate energy expenditure. Participants were able to complete the exercise session at the given intensity without having higher ratings of perceived exertion. This is in line with findings about RPE and elliptical exercise equipment [3,16]. There was not a difference in RPE for normal weight versus overweight participants, nor was there a relationship between body fat percentage and RPE. The RPE findings support previous research indicating elliptical machines are likely a good exercise choice for the overweight and obese [3,16], particularly since the physiological response is similar to fully weight-bearing methods [6,9,16]. It should be noted that differences in pedaling efficiency could have been a factor as efficiency has been related to relative power output on both elliptical machines [17] and cycling [17,18]. Stride rate was not held constant in this study to allow individuals to remain in the specified intensity range. Keeping the stride rate constant between participants should be investigated further in regard to both caloric expenditure and efficiency, but this would potentially require allowing more variability in physiological (and perceived) intensity. Thus, additional safety precautions would be needed to accommodate individuals for whom higher intensity exercise might be problematic.

Although the results were not significant, there are several practical applications of this study. The first is that the difference between caloric expenditure, as measured by indirect calorimetry and estimated by cardiovascular exercise equipment, may be very important for those trying to manage their weight. The average difference following a 20 min exercise session at moderate intensity, including a 5 min warm-up and a 5 min cool-down, was over 100 kilocalories. There was also a consistent negative correlation between body fat percentage and difference in the caloric expenditure. This indicates that those with lower body fat percentage need to be very careful when relying on caloric estimates from exercise equipment. There are also implications for those trying to manage their weight that as they near their weight goal, they will be less able to rely on the caloric estimates from exercise equipment, and may want to invest in more accurate methods of estimating caloric expenditure. It is also important for those managing their weight to enter as much information as possible if they intend to rely on the caloric estimates provided by exercise equipment for entering this information may increase the accuracy of the machine estimates. This study also supports the recommendation of utilizing the elliptical exercise machine for exercise in the overweight and obese as overweight participants were able to complete the exercise session and exhibited responses similar to normal weight participants.

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