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The Relationship between the Metabolic Responsiveness to a High-Fat Meal and an Acute Bout of Moderateintensity Exercise among Postpartum Women

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THE RELATIONSHIP BETWEEN THE METABOLIC RESPONSIVENESS TO A HIGH-FAT MEAL AND AN ACUTE BOUT OF MODERATE-INTENSITY EXERCISE AMONG POSTPARTUM WOMEN

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I dedicate this thesis to my parents, Sivakumar Tadakaluru and Rajasri Tadakaluru for all their Love and Sacrifice.

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Background: There has been very little research regarding the metabolic health of women during the postpartum period. Metabolic flexibility is the physiological ability to alter substrate oxidation in response to substrate availability and is a good indicator of overall metabolic health. Metabolic flexibility can be assessed by placing metabolic demands on the body and observing metabolic responsiveness- two examples of such metabolic stressors are lipid oxidation rates in response to a high-fat meal and as well as exercise. However, it is unknown whether postpartum women will respond similarly to these two different types of metabolic stressors. This information will allow researchers and clinicians to understand whether postpartum women can be considered more or less metabolically flexible based on one of these tests alone, or if both types of metabolic stress should be incorporated into research designs and/or clinical practice to fully understand one's metabolic health during this critical time period.

Objective: To determine the association between the metabolic responsiveness to a high-fat meal and a 30- minute continuous, moderate-intensity exercise among women during the sixth- month postpartum period.

Methods: Seventeen healthy, postpartum women (age: 32 ± 4.5 year; body mass index: 24.74 ± 3.97 kg/m²) participated approximately six months after delivery. Metabolic measurements VO_2 and VCO_2 (L. min^{-1}) were measured and used to calculate the rates of lipid oxidation (g. min^{-1}) at baseline, two-hour post consumption of a high-fat meal and during a moderate-intensity exercise for 30-minutes.

Results: A correlation was found between the lipid oxidation fold change in response to a high-fat meal and exercise (r= 0.45, p= 0.08; however, it was not statistically significant. There was a significant effect of time on lipid and carbohydrate oxidation rates ($p<0.001$) during baseline, after consumption of a high-fat meal and during a 30-minute exercise bout.

Conclusion: A trending relationship was observed between the metabolic responsiveness to a high-fat meal and a 30-minute moderate-intensity exercise bout among women during the six-month postpartum

INTRODUCTION

The postpartum period is defined as the period between the birth of the newborn and the return of pregnancy processes to normal the non-pregnancy state (Lowdermilk and Perry, 2004). Numerous metabolic changes occur in women during pregnancy and postpartum (Butte, Hopkinson, Mehta, Moon and Smith, 1999). Universally, women are concerned about the impact pregnancy and gestational weight gain will have on postpartum weight retention (Gunderson and Abrams, 2000). Average postpartum weight retention ranges between 0.5 to 3kgs (Gore, Brown and West, 2003). Evidence suggests that postpartum weight retention may increase the risk of chronic disease like metabolic syndrome, obesity, and cardiovascular disease (Davenport, Giroux, Sopper and Mottola, 2011). Therefore, it is important to understand the metabolic health of women during the postpartum period that could contribute to postpartum weight retention.

Higher pre-pregnancy weights have been linked with increased risk of postpartum weight retention (Gore, Brown and West, 2003). Previous studies of pre-pregnancy obesity among different states in USA indicate that the prevalence of pre-pregnancy obesity nearly doubled from 1993 to 2003, increasing from 13.0% in 1993 to 22.0% in 2003 (Kim, Dietz, England, Morrow and Calladhan, 2007). More recent research indicates that 27.8% of women entering pregnancy are obese. In addition, pre-pregnancy obesity also increases the risk of developing hypertension and diabetes among postpartum women (Gregor, Remington, Lindberg and Ehrenthal, 2016).

There has been very little research regarding the metabolic health of women during the postpartum period. Metabolic responsiveness (i.e. metabolic flexibility) to metabolic demands is a good indicator of overall metabolic health. Metabolic flexibility is defined as the physiological capacity of a living organism to alter substrate oxidation in response to substrate availability (Galgani and Ravussin, 2008) and to changes in activity and/or metabolic demand (Goodpaster and Sparks, 2017). In contrast, metabolic inflexibility is defined as an impaired capacity to alter the use of substrates depending upon substrate availability. Metabolic inflexibility is characterized by low lipid oxidation rates during fasting conditions (Berk et al, 2006) and low carbohydrate oxidation rates in response to a meal and exercise of increasing intensity (Prior et al, 2014). Higher rates of carbohydrate oxidation during exercise reduces the contribution of lipid oxidation (Holloszy, Kohrt and Hansen, 1998) and may predispose to excess lipid accumulation and weight gain (Mitchell et al, 2013).

In lean, lipids are predominantly oxidized for the energy production during an overnight-fasted condition and in response to high-fat meals (Achten et al, 2004). There has been a growing interest in assessing the influence of metabolic flexibility to lipids in response to different meal challenges. For example, work by Schrauwen et al and Berk et al has focused on metabolic responses to studies emphasized the rate of lipid oxidation and its adaptation to a low-fat versus a high-fat diet and found increases in lipid oxidation in response to high-fat diet. In addition, increased tendency to oxidize carbohydrates with decreased reliance on lipids was observed in response to low-fat diets. Evidence suggests that not all individuals respond to a high-fat meal challenge similarly. For example, the skeletal muscle from severely obese women does not upregulate lipid oxidation to the same extent (compared to muscle from lean women) when presented with a lipid overload (Maples et al, 2015). This dampened ability to upregulate lipid oxidation in response to lipid overload likely contributes to a positive fat balance, weight gain and poor metabolic flexibility (Galgani, Moro and Ravussin, 2008). Therefore, the rate of lipid oxidation in response to a high-fat meal challenge can be used as a means of assessing metabolic responsiveness and may be useful in predicting postpartum weight retention.

Exercise is another metabolic challenge that requires metabolic flexibility. Metabolism increases, and substrate oxidation shifts dramatically to accommodate the energy demand created during an acute bout of exercise. Exercise intensity and duration mainly determines the substrate utilization during an acute bout of exercise (Goodpaster et.al, 2017). Lipids are predominantly oxidized for the energy production during low- to moderate-intensity exercise (Achten et al, 2004). An increase in exercise intensity decreases lipid oxidation progressively and increases carbohydrate oxidation as exercise intensity continues to increase (Mittendorfer, 2003). Concerning the duration of the exercise, little is known about the effectiveness of shorter bouts (Teeman, 2016) between 20 and 60minutes of moderate intensity exercise in promoting lipid oxidation among postpartum women.

Therefore, the broad purpose of the study is to develop a better understanding of the overall metabolic health women during postpartum. Specifically, in an effort to assess metabolic health, we will investigate and describe the metabolic responsiveness of women during the postpartum period to two different metabolic challenges: 1) a high-fat meal challenge and 2) an acute bout of moderate intensity exercise. We hypothesized that lipid oxidation fold changes in response to a high-fat meal will be correlated with the lipid oxidation fold changes in response to a 30-minute moderate-intensity exercise.

REVIEW OF LITERATURE

Lipid oxidation during pregnancy and postpartum period:

Berggren, Presley, Amini, Mouzon and catalano (2015) conducted a study among twenty-one women aged (20 – 45 years) to determine whether the metabolic changes like decreased insulin sensitivity and increased insulin resistance during pregnancy are reversible at one year postpartum. Eleven women conceived during the study and were metabolically assessed for fasting lipid and carbohydrate oxidation rates (mg/min FFM), basal metabolic rate (BMR), and body composition (body fat %) during preconception, 34 – 36 weeks of pregnancy and at one-year postpartum period. In the study 10 additional women served as an internal control group having the same measures assessed at baseline and 1 year later. Among the control group there were no significant differences in any of the metabolic assessments from baseline to the 1-year time point. Among the women that conceived, there were no differences in the metabolic assessments from preconception to the third trimester of pregnancy. When comparing the metabolic measures from preconception to 1 year postpartum, there were no significant differences in any of the measures, including fasting lipid oxidation rates [preconception 0.89 (0.67-1.03 IQR) mg/min/FFM versus postpartum 1.03 (0.65-1.31 IQR) mg/min/FFM); p=0.5], and carbohydrate oxidation rates [preconception 2.67(1.69-3.53 IQR) mg/min/FFM versus postpartum 2.18 (1.65-3.31 IQR) mg/min/FFM; p=0.5]. This study suggests similar metabolic profiles during preconception and one-year postpartum, however they did not assess metabolic responsiveness in response to different metabolic challenges.

Specifically, to determine the impact that the lipid oxidation may have on the weight status among women during postpartum period.

Butte, Hopkinson, Mehta, Moon and Smith (1999) conducted a study to determine the preferential use of substrates and changes in energy metabolism among women during 37-week gestation, and during three-months and six-months postpartum period. Seventy-six women aged (28.8 ± 4.2 years) were recruited and were divided into two groups based on lactation during postpartum period. A 24-hour room calorimetry was performed to measure VO_2 (L/min) and VCO_2 (L/min) along with 24-hour urine collection for nitrogen concentration. The 24-hour VO_2, VCO_2 and urine nitrogen values were used to calculate the total energy expenditure (TEE), and the lipid and carbohydrate oxidation rates. During the room calorimetry measurements, all women consumed a diet containing 50% carbohydrates, 30% fats and 20% proteins, and exercised for 30-minutes. Comparing the lipid and carbohydrate oxidation rates between 37-week gestation and six-months postpartum period in non-lactating group, there were significant differences in the lipid oxidation rates [pregnancy 30±7 (% of TEE) versus six-months postpartum 36±8 (% of TEE); p=0.008], and carbohydrate oxidation rates [pregnancy 56±6 (% of TEE) versus six-months postpartum 47±7 (% of TEE); p=0.006]. In contrast, no significant changes were observed in lactating group in lipid oxidation rates [pregnancy 30±7 (% of TEE) versus six-months postpartum 29±8 (% of TEE)] and carbohydrate oxidation rates [pregnancy 54±6 (% of TEE) versus six-months postpartum 50±8 (% of TEE)]. Therefore, an increase in the rate of lipid oxidation in non-lactating group and decrease in the rate of lipid oxidation with increased energy expenditure in lactating group specifies the role of lactation may have on lipid oxidation during the postpartum period. This study demonstrates that metabolism is altered during postpartum, and that lactation may play a further role in altered metabolic flexibility among women during the postpartum period.

Lipid oxidation in response to high-fat meals:

Schrauwen, Lichtenbelt, Saris and Westerterp (1997) have measured the rate of lipid oxidation in response to a low-fat diet and a high-fat diet subsequently for two separate weeks and assessed the time taken for the alteration of lipid oxidation rates to an increase in lipid content in the diets. Twelve healthy, non-obese males (n=6) and females (n=6) participants (age: 26±2 years; body mass index: 21.4±0.5 kg/m^2) were given a low-fat diet to consume between 1-6 days and a high-fat diet between 7-13days. In addition, all participants also performed a low- to- moderate- intensity interval exercise for 45mins/day. 24-hour whole-room indirect calorimetry was performed on days 5-9 and on 13th day, and VO_2 and VCO_2, RQ and urine nitrogen concentration values were measured and used to calculate the lipid and carbohydrate oxidation rates. The study found no significant differences in the values of lipid and carbohydrate oxidation rates (grams/day) between 5 and 6 days in response to a low-fat diet. But, in response to a high-fat diet the rate of lipid oxidation increased, and the rate of carbohydrate oxidation decreased significantly between 6 and 13 days. In addition, a significant decrease in 24-hour RQ between 7 and 13 days ($p < 0.005$). Therefore, the study is indicating a gradual adaptation of lipid oxidation to fat diets within few days, implying substrate utilization matches gradually with substrate availability.

Berk, Kovera, Boozer, Pi-Sunyer and Albu (2006) also conducted a study to examine the rate of lipid oxidation in response to a high-fat meal (50% fat, 35% carbohydrate) and a low-fat meal (30% fat, 55% carbohydrate) among pre-menopausal lean and obese women. Twenty-one Caucasian and 21 African-American aged 22-44years participated. Low-fat and high-fat meals were randomly assigned to be consume for 7-days each and with a washout period of two-weeks between diets. Indirect calorimetry was performed on sixth-day and lipid and carbohydrate oxidation rates were calculated. The main finding of the study disclosed a significantly higher rate of lipid oxidation in response to high-fat meals ($p=0.05$) and a higher rate of carbohydrate oxidation to low-fat meals ($p= 0.01$) among Caucasian women. Therefore, the study indicates the effect of race on lipid oxidation in connection with the lipid content in diets.

Blaak, Hul, Verdich, Stich, Martinez et al (2006) conducted a study to assess the rate of lipid oxidation in fasting and in response to a high-fat meal (95% of energy from fat) among obese and lean participants. Eight hundred fourteen Caucasian men and women (age range: 20-50years) were recruited and divided into an obese group (n=701; body mass index: $\geq$30 kg/m^2) and lean reference group (n=113; body mass index: $\leq$ 25 kg/m^2). The study design included the assessment of fasting lipid oxidation rate for 30-minutes followed by consumption of a high-fat meal and reassessment of lipid oxidation three hours after consuming the meal. All indirect calorimeter measurements were performed using a ventilated hood system in supine lying. Frayn equations for lipid oxidation calculation were used to assess substrate oxidation (Frayn 1983). The results demonstrated significantly higher rates of fasting lipid oxidation in males than in females ($p< 0.001$) and fasting lipid oxidation rates (mg/min) increased with increasing body mass index ($p< 0.001$). However, the rate of lipid oxidation (% of postprandial EE) in response to a high-fat meal were decreased significantly with increased body mass index ($p< 0.01$). This suggests an impaired regulation of lipid oxidation in response to a lipid overload challenge in both sexes with increasing body mass index and indicates that metabolic responsiveness to a meal challenge can be linked with weight status.

Lipid oxidation in response to exercise:

San-Millán and Brooks (2017) have compared different metabolic measurements including lipid and carbohydrate oxidation rates in response to exercise to assess the metabolic flexibility. Fifty-two male participants categorized into three groups: professional cyclists (n=22; age: 26.8±2.8years; BMI: 21.25±2.1 kg/m^2), moderately active (n=20; age: 40.0±4.7years; BMI: 23.34±2.8) and men with metabolic syndrome (n=10; age: 55.2±5.2years; BMI: 35.05±7.1 kg/m^2) were involved in the study. The experimental protocol included a graded leg cycling protocol after an overnight fast, with increasing intensities (i.e. 35 Watts) every 10minutes. Indirect calorimetry was performed to assess substrate utilization. Lipid and carbohydrate oxidation rates were calculated using Frayn equations (Frayn 1983). The results demonstrated significantly negative correlations between mean lipid and carbohydrate oxidation rates for all the three groups [professional cyclists: r= -0.90, p< 0.01; moderately active: r= -0.99, p< 0.01, and metabolic syndrome individuals: r= -0.96, p< 0.01] with increasing exercise intensities. In addition, there was also a significantly higher maximal lipid oxidation in professional cyclists group compared to moderately active group (0.66 g/min vs 0.38 g/min; p< 0.01) and to metabolic syndrome (0.66 g/min vs 0.12 g/min; p< 0.01). Also, the upregulation of lipid oxidation among highly active individuals with low BMI values demonstrates the metabolic responsiveness to exercise demand.

Pillard, Moro, Harant, Garrigue, Lafonan, et.al (2007) have compared the rates of lipid oxidation in response to different exercise intensities (low, moderate and high) among eighteen overweight men (n=9) and women (n=9) aged (31.4±2.3 and 26.7±2.1 years). All participants performed VO_2 max test using graded cycle ergometry. The experimental design consisted of two different exercise sessions separated by one month. The first session included participants cycling at 30% VO_2 max (low-intensity) for 30-minutes followed by cycling at 50% VO_2 max (moderate-intensity) for 30 more minutes. And the second session included cycling at 30% VO_2 max (low-intensity) for 30-minutes followed by cycling at 70% VO_2 max (high-intensity) for 30-minutes. During each 30-minute exercise bout, VO_2 and VCO_2 values were measured for 6minutes at the following time segments: 14-20 and 24-30 minutes and used to calculate respiratory exchange ratio (RER) and lipid oxidation rates. A mask and computerized ergospirometer were used to collect gases. Though there were significant increases in RER values with increase in exercise intensity for both men and women with $p< 0.0001$, the RER values for women were significantly smaller than men during any time point of exercise ($p= 0.008$). There was also a significant increase in the rate of lipid oxidation for women than for men at any time point of exercise ($p= 0.03$). The highest percentage of lipid oxidation (per kg of lean mass) was observed during 50% VO_2 max (moderate-intensity) among both sexes. Therefore, the study suggests the effect of time and gender over the rate of lipid oxidation in response to different exercise intensities, and the efficacy of a shorter bout of 30-minutes and moderate-intensity exercise in delivering the best lipid oxidation rate.

Dumortier, Thoni, Brun and Mercier (2005) conducted a study on eight healthy overweight or obese women aged (57.4±2.4 years), body mass index (31.8±2.1 kg/m^2) to determine the effect of time interval between the meal and an exercise bout in inducing higher rates of lipid oxidation. The experimental protocol included four separate test sessions: 1) the incremental maximal exercise test to determine VO_2 max, 2) the standardized submaximal exercise test to determine the individualized exercise intensity, 3) and 4) two separate 30-minute exercise bouts with two different time intervals (1-hour and 3-hours). All women were given the same standardized meal containing 550 kcal with 57% carbohydrates (65g), 26% protein (30g) and 17% fat (19g) to consume before exercising on two test days. Indirect calorimetry using nose clips and mouth piece was performed to measure VO_2, VCO_2, and RER values. The data was averaged from 15-min rest, during every 5minute periods (0-5, 5-10, 10-15, 15-20, 20-25, 25-30) and from 15-minute recovery period, and used to calculate the rates of lipid and carbohydrate oxidation (mg/min). The results demonstrated lower RER and higher lipid oxidation rates in response to a 30-minute exercise that took place 3 hours after consuming the meal. Thus, the study indicates the impact of time interval (i.e. the greater the time interval the higher the lipid oxidation) and the efficacy of short duration exercise session over improving the rate of lipid oxidation in response to a meal and exercise.

METHODS

All Participants were recruited from recent pregnancy study participation at Western Kentucky University (WKU) and all the study procedures have taken place at the Department of Physical Therapy Research Laboratory in the WKU Medical Center Health Complex or at the WKU Exercise Physiology Laboratory. Participants included 17 Healthy, Caucasian postpartum women (N=17) (~ 6 months post-delivery) and the characteristics of participants were: Age: 32 ± 4.5 years, Height: 1.67 ± 0.05m, Weight: 68.74 ± 3.97 kg, BMI: 24.74 ± 3.97 kg/m^2. Prior to the commencement of the study, the signed informed consent form, and the completed International Physical Activity Questionnaire (IPAQ) (APPENDIX 1) and the Physical Activity Readiness Questionnaire (PAR-Q) (APPENDIX 2) forms were obtained from each participant. The Experimental protocol was approved by the Institutional Review Board at Western Kentucky University, Bowling Green, Kentucky.

Materials Used:

All participants were measured for Height (m) and Weight (kg) using dual reading scale (Detecto, Webb City, MO, USA), Blood Pressure (mm of Hg) and Heart Rate (bpm) using heart rate monitor (Vive Precision), Body Composition by using skinfold anthropometry (Harpenden Skinfolds Callipers, Baty International, UK).

The TrueOne Canopy Option and TrueOne Metabolic Cart (TrueOne 2400, Parvomedics, Sandy, UT) were used to measure the oxygen consumption (VO_2), Carbon dioxide production (VCO_2), RQ (VCO_2/ VO_2), REE and RER. A motorized treadmill

(Woodway (Model: Desmo 05), Waukesha, WI, USA) and a Polar Heart Rate Monitor were used to perform an acute bout of continuous moderate intensity walking and to measure heart rate for 30 minutes.

Experimental Design:

All participants were asked to consume a standardized dietary intake with approximately 50% carbohydrate, 30% fat and 20% protein on the day before the tests. Upon arrival to the laboratory on the next day at 8:00 am following a 10-hour overnight fast, all participants were measured for height (m) and weight (kg) using dual reading scale and the vital signs: blood pressure (mm of Hg) and heart rate (bpm) using heart rate monitor. Also, the skin folds at seven body sites (triceps, subscapular, chest, maxillary, supra-iliac, abdomen and thigh) were measured using a caliper and percent body fat was calculated using Jackson-Pollock equations (Jackson and Pollock, 1978). Later, the participants were asked to occupy a suitable and comfortable supine or half-lying position with pillows on a plinth. The baseline measurements: VO_2, VCO_2, RQ and REE values were collected by placing a canopy/ hood-like tool over their head for 30 minutes using the TrueOne Canopy Option and TrueOne Metabolic Cart (TrueOne 2400, Parvomedics, Sandy, UT) metabolic cart. After the baseline measurements, all participants were given a high-fat meal (975 Calories; 62% fat) to consume. The high-fat meal was a research smoothie containing almond milk, banana, apple, peanut butter, super grains, cocoa, vegan protein and almond. Later approximately after two-hour post consumption of a high-fat meal, the above- mentioned metabolic measurements were repeated for 30-minutes.

150-minutes after consumption of a high-fat meal, all participants performed an acute bout of continuous moderate-intensity (40-60% of heart rate reserve (HRR)) walking on a treadmill at their own selected speed and inclination for 30minutes. During the exercise session, the volumes of oxygen consumption (VO_2) and carbon dioxide production (VCO_2) values were collected through the mouth piece connected to the Parvo metabolic cart. RER is also collected and derived from VCO_2/VO_2. Each participant was given a nose clip to wear and a mouthpiece to insert and hold during continuously for 2-5-minute segments at three different time points (5-10min, 15-20min and 25-30min) of exercise. Heart rate and the rate of perceived exertion (APPENDIX 3) were also monitored continuously using Polar heart rate monitor and the Borg scale for every 2 minutes throughout the exercise session. Continuous heart rate was used to ensure they were performing moderate exercise (40-60% HRR) (calculations shown below).

Calculations:

Exercise Heart Rate Range = [HRR * Exercise Intensity] + Resting HR

HRR= Maximum HR- Resting HR

Maximum HR= 220 – Age

Exercise Intensity= 40 and 60%

Lipid and Carbohydrate Oxidation:

The VO_2 and VCO_2 values obtained during baseline, after two-hour post consumption of a high-fat meal and at three different time points (5-10, 15-20 and 25-30) during exercise were averaged separately and inserted in the following stoichiometric equations developed by Frayn (1983) to calculate the rates of lipid and carbohydrate oxidation.

LO (g. min⁻¹) = $1.67VO_2$ (L. min^{-1}) - $1.67VCO_2$ (L. min^{-1})

CHO (g. min⁻¹) = $4.55VO_2$ (L. min^{-1}) – $3.21VCO_2$ (L. min^{-1})

Where VO_2 and VCO_2 were expressed in liters per minute and LO and CHO in grams per minute.

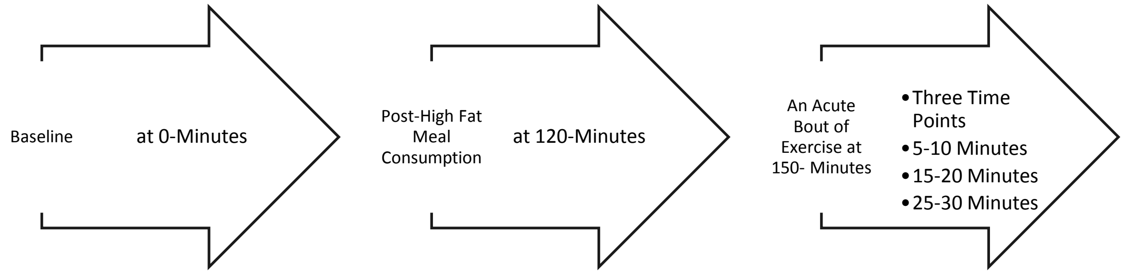

Figure 1. Representing the experimental design and the time points for LO and CHO rates.

Lipid and Carbohydrate Oxidation Fold Changes:

The LO and CHO fold changes in response to a high-fat meal and an exercise bout are calculated as follows:

Meal Fold Calculations:

LO Meal Fold Change= $\frac{\text{(Two-hour post meal LO) - (Baseline LO)}}{\text{Baseline LO}}$

CHO Meal Fold Change= $\frac{\text{(Two-hour post meal CHO) - (Baseline CHO)}}{\text{Baseline CHO}}$

Exercise Fold Calculations:

LO Exercise Fold Change= $\frac{\text{(Exercise LO) - (Baseline LO)}}{\text{Baseline LO}}$

CHO Exercise Fold Change= $\frac{\text{(Exercise CHO) - (Baseline CHO)}}{\text{Baseline CHO}}$

Post Meal Fold Calculations:

LO Post Meal Fold Change= $\frac{\text{(Exercise LO) - (Two-hour post meal LO)}}{\text{Two-hour post meal LO}}$

CHO Post Meal Fold Change= $\frac{\text{(Exercise CHO) - (Two-hour post meal CHO)}}{\text{Two-hour post meal CHO}}$

Statistical Analysis:

Redcap data analysis software was used for all data entry and cleaning. IBM SPSS software, version 24.0 was used to perform all statistical analyses. Data values are presented as means ± SD or means ± SEM (as indicated). Comparisons between the mean rates of LO and CHO were analyzed using the repeated-measures ANOVA where the time (baseline, two-hour post meal and during exercise) was the within-subjects factor. Pearson product moment correlation coefficients were performed to assess the statistical significance of associations between the LO and CHO fold change variables studied. Also, a paired sample t-test was performed to delineate the differences between LO and CHO fold changes in response to a high-fat meal and exercise. A $p \leq 0.05$ was set as a statistically significant value.

RESULTS

The participant characteristics are presented in Table 1.

Table 1. Descriptive Statistics (Mean +/- SD):

Characteristic	**N**	**Mean±SD**
Age (years)	N=17	32.0 ± 4.5
Height (m)	N=17	1.67 ± 0.05
Weight (kg)	N=17	68.7±12.2
BMI (kg/m²)	N=17	24.7±3.9
Heart Rate (bpm)	N=17	68.4±10.9

Note: N= Number of Participants, SD= Standard Deviation.

In response to the high-fat meal, participants significantly increased ($p<0.05$) both lipid and carbohydrate oxidation. Additionally, both lipid and carbohydrate oxidation increased significantly in response to the acute bout of 30-minute moderate-intensity exercise (Figure 4). The average scores of lipid oxidation at baseline, in response to a high-fat meal and during exercise are 0.06 g/min, 0.08 g/min and 0.26 g/min and carbohydrate oxidation are 0.41g/min, 0.51 g/min and 2.06 g/min respectively (Figure 4). Consequently, the mean RQ values at baseline and in response to a high-fat meal are (0.83±0.05; 0.81±0.06) respectively and the mean REE values at baseline (1497.87±240.63 kcals/d) and post meal (1851.87±334.51 kcals/d).

Lipid and Carbohydrate Oxidation Mean Fold Changes:

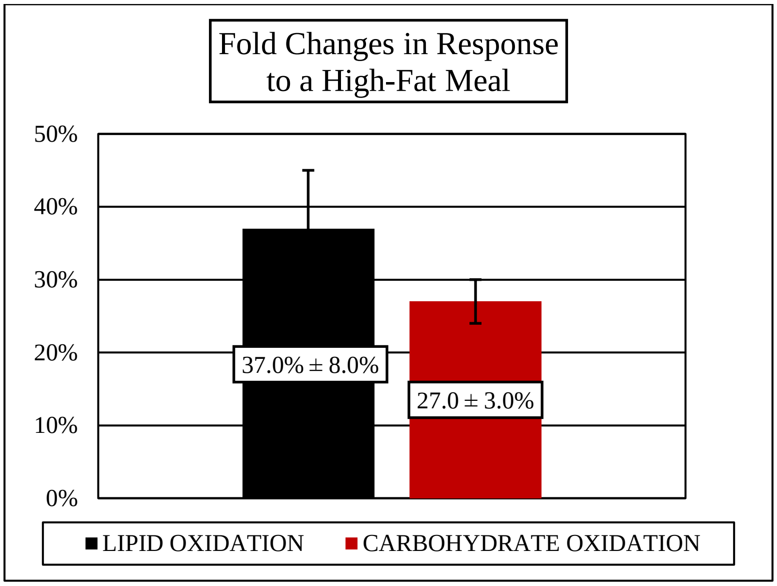

Figure 2. Increased lipid oxidation by 37.0% +/- 8.0% (SEM) and carbohydrate oxidation by 27.0% +/- 3.0% (SEM) in respone to a high-fat meal.

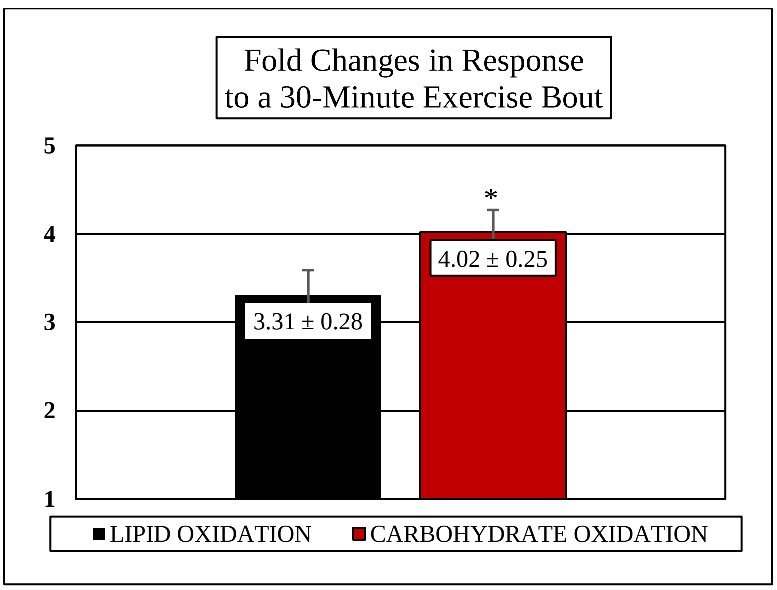

Figure 3. Increased lipid oxidation by 3.31 +/- 0.28- fold and carbohydrate oxidation by 4.02 +/- 0.25- fold in response to a 30-minute moderate-intensity exercise.

*Significant difference (p=0.008) between lipid and carbohydrate oxidation fold changes.

Lipid and Carbohydrate Oxidation Rates:

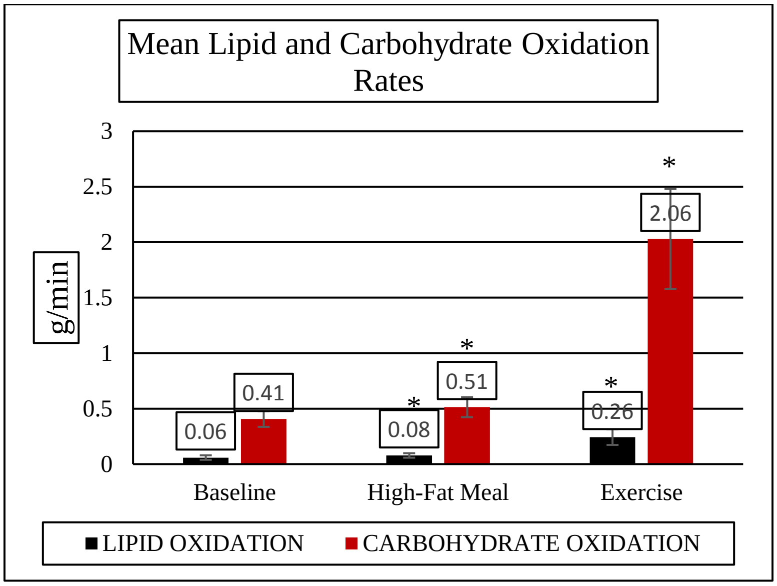

Figure 4. Representing the mean values of lipid and carbohydrate rates at baseline, in response to a high-fat meal and during a 30-minute exercise bout.

*Significant difference (p<0.001) between baseline LO and CHO and in response to a high-fat meal and exercise

A repeated measures ANOVA was conducted to compare the effect of time on the LO and CHO at baseline, in response to a high-fat meal and during exercise conditions. There was a significant effect of time on LO rate, Wilks' Lambda = 0.06, F (2, 13) = 95.44, p < 0.001 and on CHO rate, Wilks' Lambda = 0.05, F (2, 13) = 123.57, p < 0.001 (Figure 4). There were statistically significant mean differences between all pairwise comparisons (p <0.001).

Lipid and Carbohydrate Oxidation Fold Change Correlations:

There was a moderately significant correlation between LO fold changes in response to a high-fat meal and an acute exercise bout ($r = 0.45$, $n = 16$, $p = 0.08$) (Figure: 5). And, there wasn't a statistically significant correlation between CHO fold changes in response to a high-fat meal and an acute exercise bout ($r = 0.30$, $n = 16$, $p = 0.26$) (Figure: 6). However, there were statistically significant and positive correlations between the following: the LO fold change and CHO fold change in response to a high-fat meal ($r = 0.87$, $n = 17$, $p < 0.001$); the LO fold change and CHO fold change in response to an acute exercise bout ($r = 0.63$, $n = 16$, $p = 0.009$); the LO post meal fold change and CHO post meal fold change ($r = 0.73$, $n = 16$, $p = 0.001$); the LO post meal fold change and LO fold change in response to an acute exercise bout ($r = 0.67$, $n = 16$, $p = 0.005$); and the CHO post meal fold change and CHO fold change in response to an acute exercise bout ($r = 0.85$, $n = 16$, $P < 0.001$). These significant correlations are not unexpected, since we used the same VO2 (L/min) and VCO2 (L/min) values to calculate both the lipid oxidation and carbohydrate oxidation rates.

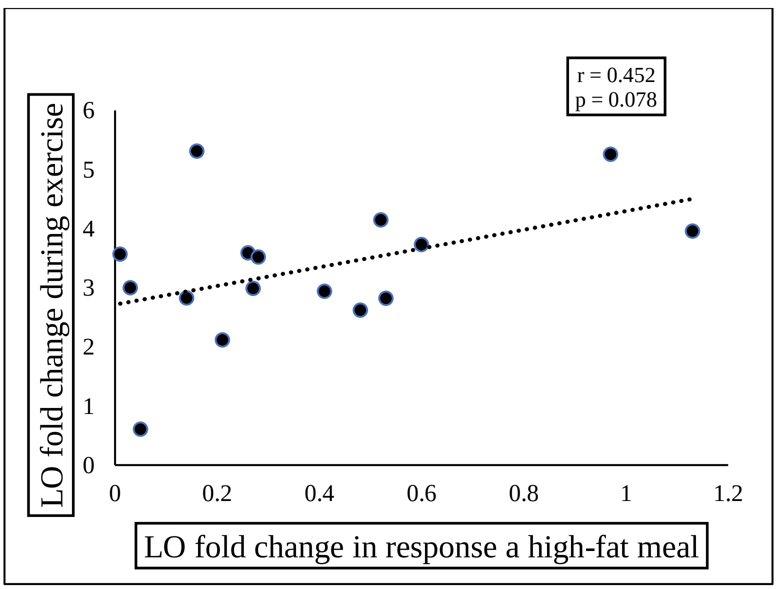

Figure 5. Representing the association between the LO fold change in response to a high-fat meal and exercise.

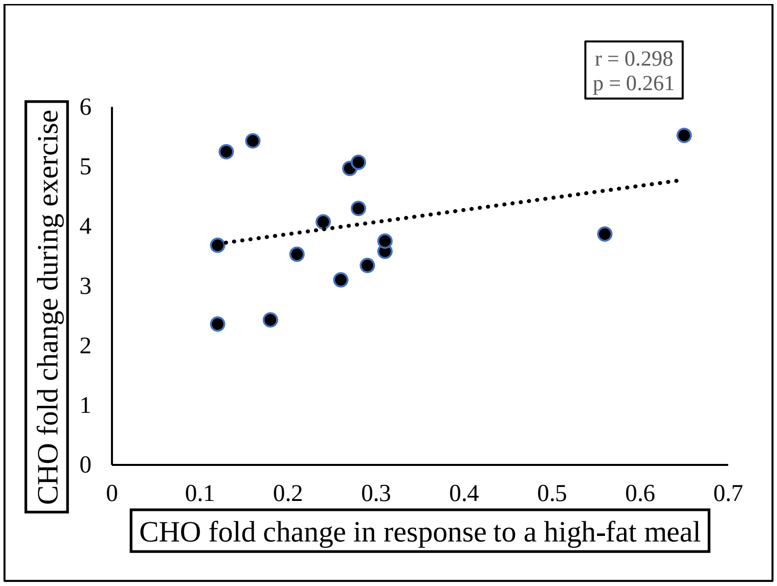

Figure 6. Representing the association between the CHO fold change in response to a high-fat meal and exercise.

Table 2. RER, Heart Rate and RPE during Exercise (Mean +/- SD):

Variable	N	Mean±SD
RER	N=16	0.86±0.05
Heart Rate (HR)	N=15	119.72±17.27
RPE	N=15	9.9±2.45

Note: N= Number of Participants, SD= Standard Deviation.

Table 2 and Figure 7 represents the average scores of RER, HR, RPE, lipid, and carbohydrate oxidation rates during a 30-minute exercise bout. Also, the Mean RER (0.86) during a 30-minute continuous moderate-intensity exercise indicates the decreased contribution of lipids for the energy expenditure.

Lipid and Carbohydrate Oxidation Changes during a 30-Minute Exercise Bout:

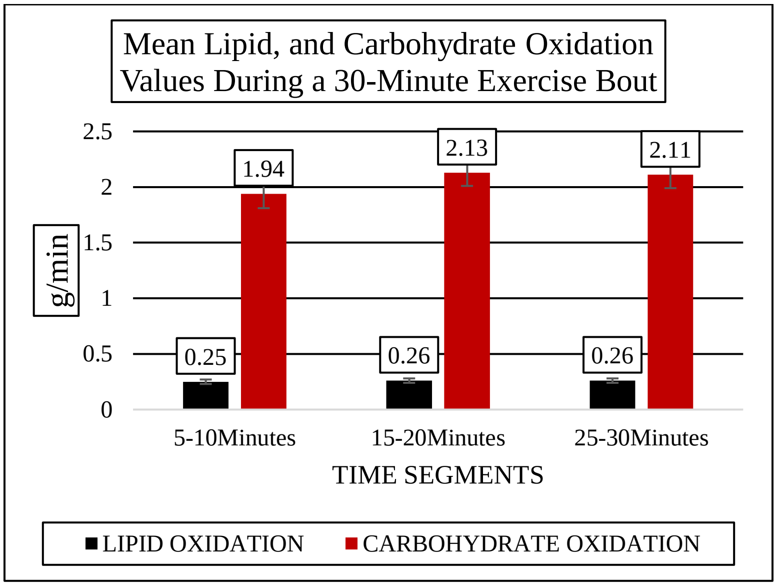

Figure 7. Representing the mean LO and CHO values at three-time segments in g/min during a 30-minute exercise bout.

Conversion of grams into kcals and Expression of lipid, and carbohydrate oxidation rates in kcals:

The lipid oxidation and carbohydrate oxidation rates in g/min during three-time segments during a 30-minute exercise bout (Figure 7) are converted into kcals (Figure 8) as follows:

1 gram of lipid = 9 kcals and

1 gram of carbohydrate = 4 kcals.

Therefore, Number of kcals from fat = (9) * (fat grams)

Number of kcals from carbohydrates = (4) * (carbohydrate grams)

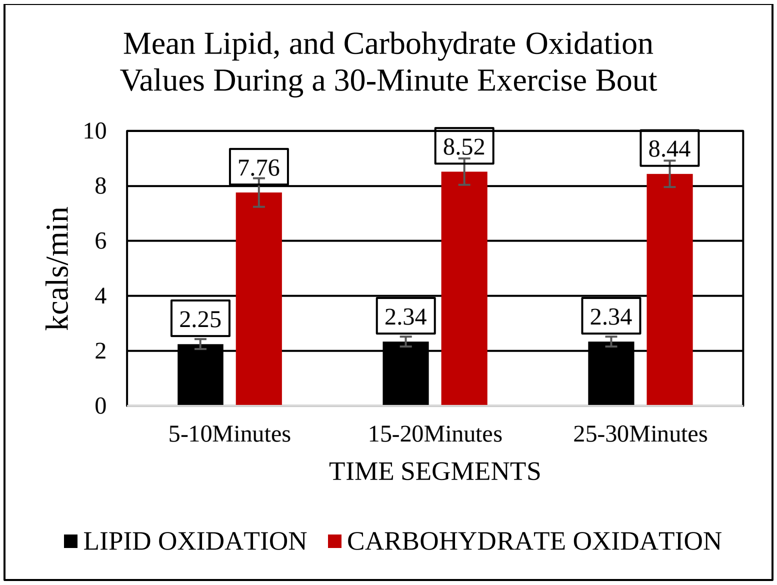

Figure 8. Representing the mean LO and CHO values at three-time segments in kcals/min during a 30-minute exercise bout.

DISCUSSION

Our novel study examined the relationship between the metabolic responsiveness in response to two different metabolic challenges: a high-fat meal and a 30-minute moderate-intensity exercise among six-month postpartum women. The results demonstrated statistically non-significant correlations between the lipid and carbohydrate oxidation fold changes in response to a high-fat meal and a 30-minute exercise bout. In other words, the metabolic response to a high-fat meal challenge and to an acute bout of exercise (in terms of upregulating lipid and carbohydrate oxidation) were not related. However, the correlation between LO fold change in response to a high-fat meal and LO in response to an acute bout of exercise did trend towards significance. A larger sample size may reveal a statistically significant correlation. Also, as anticipated, the rate of lipid oxidation and the rate of carbohydrate oxidation were significantly increased from baseline in response to both the high-fat meal and the 30-minute moderate-intensity exercise.

Previous pregnancy and postpartum studies conducted to assess the rates of lipid and carbohydrate oxidation during fasting have demonstrated higher carbohydrate oxidation rates during postpartum period compared to preconception (Berggren et al 2015). Further, a study conducted in response to a meal with a concurrent physical activity (Butte et al 1999) also found higher rates of carbohydrate oxidation particularly among postpartum lactating women compared to non-lactating postpartum women. Though the lactation has a beneficial effect on weight loss and lipid mobilization during postpartum period, on contrary the study conducted by Butte et al. (1999) to determine the rate of substrate utilization during a 24-hour period among pregnant and postpartum women evidenced a higher rate of lipid oxidation in non-lactating group than in lactating group. Although lactating categorical data was currently unavailable in the present study, we suspect lactation may contribute to the unanticipated higher rates of carbohydrate oxidation in response to a high-fat meal and a moderate-intensity exercise in our study (Figure 4).

Previous studies have suggested that substrate utilization in response to substrate availability shifts more dramatically among healthy weight individuals, compared to overweight and/or obese individuals (classified by body mass index). For example, in response to a high-fat diet, there was a greater increase in the upregulation of lipid oxidation observed among both men and women with a lower body mass index compared to individuals with a higher body mass index (Schrauwen et al 1997; Blaak et al 2006). In our study, the average rate of lipid oxidation (Figure 4) in response to a high-fat meal (0.08 g/min) was significantly higher compared to baseline (0.06 g/min) among postpartum women, and thus, the RQ value in response to a high-fat meal (0.81±0.06) was decreased from baseline (0.83±0.05), which suggests an upregulation in lipid metabolism. However, we were not able to make weight status comparisons due to the small sample of women who were all at a healthy body weight.

Our novel experimental design with simultaneous meal and exercise, focused on the impact that a 30-minute moderate-intensity exercise bout on lipid oxidation rates among postpartum women. Though there were no specific physical activity recommendations for postpartum women to be healthy, they can be advised to do a 20-60-minute moderate-intensity exercise for 3-5 days/week (Davenport et al, 2011); thus, the 30-minutes chosen would fall within recommendations. Also, many previous studies have already studied and postulated that exercising at a low- to - moderate intensity results in higher lipid oxidation rates (Achten et al, 2004). Accordingly, in our study, there was a significant increase from the baseline lipid oxidation to lipid oxidation during exercise [(0.06 g/min); (0.25 g/min); $p<0.001$], and from lipid oxidation in response to a high-fat meal to lipid oxidation in response to exercise [(0.08 g/min); (0.25 g/min); $p<0.001$)] Figure 4. However, the long-term impact of an acute bout or multiple acute bouts of exercise among postpartum women is still unknown and an important future direction.

The present study also examined the rate of lipid and carbohydrate oxidation at three different exercise segments (5-10 minutes, 15-20minutes and 25-30minutes) during a 30-minute exercise bout. However, there were no significant differences between the mean scores of lipid and carbohydrate oxidation during the three-time segments (Figure 7). The increase in the mean score of lipid oxidation during 5-10minute segment (0.25 g/min) compared to the lipid oxidation rate in response to a high-fat meal (0.08 g/min) was appreciable. In addition, the carbohydrate oxidation rate also increased during 5-10minute segment (1.94 g/min) and during 15-20minute segment (2.13 g/min) and remained almost same during rest of the time segment. The increase in lipid oxidation by 3.31-fold was achieved in response to a 30-minute moderate intensity exercise (40-60% HRR) bout two hours after high-fat meal consumption. Our findings are consistent with a previous study observed a larger increase in lipid oxidation during a 30-minute moderate-intensity (50% VO2 max) exercise session when compared to a 30-minute low-intensity (30% VO2max) and a 30-minute high-intensity (70% VO2 max) exercise session (Pillard et al, 2007). The other findings of our study such as RQ during baseline (0.83) and in response to a high-fat meal (0.81), and RER (0.86) (Table 2) during a 30-minute exercise bout were appropriately corresponded with the rates of lipid and carbohydrate oxidation (g/min).

There were certain limitations in the present study. The main limitation includes a small sample size. However, a moderate correlation between LO fold change in response to a high-fat meal and LO fold change in response to an acute bout of moderate- intensity exercise trended towards significance. A larger sample size may exhibit a statistically strong correlation. Other limitations in the study include race, lactation, and weight status. All participants in the current study were Caucasian and relatively lean, therefore we could not assess the impact that race and/or weight status has on metabolic flexibility. Additionally, we did not robustly measure lactation and therefore, we cannot determine the impact that lactation has on metabolic flexibility in this study. This novel study also indicates several future directions. Breastfeeding status and weight status are linked to weight retention (or weight loss) and both warrant further investigation. In addition, describing metabolic responsiveness in response to different metabolic challenges in different races is recommended.

CONCLUSION

In summary, there was an expected increase in the rate of lipid oxidation in response to a high-fat meal challenge and in response to a 30-minute moderate-intensity exercise bout. However, the study denoted no significantly strong correlations between them metabolic responsiveness to a high-fat meal and an acute bout of exercise; however, data are trending and a larger sample size may confirm a relationship between metabolic responsiveness to an acute bout of exercise and a high-fat meal among postpartum women. Another notable finding is that even just moderate exercise lasting for 30minutes may be enough of a stimulus to increase lipid metabolism; however, longer-term exercise studies are needed to confirm. If this is the case, postpartum women, who often struggle with weight loss and increase body fat storage, should be encouraged to participate in easy exercise activities (such as walking) to upregulate fat metabolism and potentially improve weight management during this critical time.

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APPENDIX-1

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (October 2002)

LONG LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation Translation from English is encouraged to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ International collaboration on IPAQ is on-going and an International Physical Activity Prevalence Study is in progress. For further information see the IPAQ website.

More Information More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). Assessment of Physical Activity: An International Perspective. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

LONG LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised October 2002.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the last 7 days. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the vigorous and moderate activities that you did in the last 7 days. Vigorous physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Moderate activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

Yes

No Skip to PART 2: TRANSPORTATION

The next questions are about all the physical activity you did in the last 7 days as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, heavy construction, or climbing up stairs as part of your work? Think about only those physical activities that you did for at least 10 minutes at a time.

_____ days per week

No vigorous job-related physical activity Skip to question 4

3. How much time did you usually spend on one of those days doing vigorous physical activities as part of your work?

_____ hours per day _____ minutes per day

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate physical activities like carrying light loads as part of your work? Please do not include walking.

_____ days per week

No moderate job-related physical activity Skip to question 6

LONG LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised October 2002.

5. How much time did you usually spend on one of those days doing moderate physical activities as part of your work?

_____ hours per day _____ minutes per day

6. During the last 7 days, on how many days did you walk for at least 10 minutes at a time as part of your work? Please do not count any walking you did to travel to or from work.

_____ days per week

No job-related walking Skip to PART 2: TRANSPORTATION

7. How much time did you usually spend on one of those days walking as part of your work?

_____ hours per day _____ minutes per day

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the last 7 days, on how many days did you travel in a motor vehicle like a train, bus, car, or tram?

_____ days per week

No traveling in a motor vehicle Skip to question 10

9. How much time did you usually spend on one of those days traveling in a train, bus, car, tram, or other kind of motor vehicle?

_____ hours per day _____ minutes per day

Now think only about the bicycling and walking you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the last 7 days, on how many days did you bicycle for at least 10 minutes at a time to go from place to place?

_____ days per week

No bicycling from place to place Skip to question 12

LONG LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised October 2002.

11. How much time did you usually spend on one of those days to bicycle from place to place?

_____ hours per day _____ minutes per day

12. During the last 7 days, on how many days did you walk for at least 10 minutes at a time to go from place to place?

_____ days per week

No walking from place to place Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

13. How much time did you usually spend on one of those days walking from place to place?

_____ hours per day _____ minutes per day

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the last 7 days in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, chopping wood, shoveling snow, or digging in the garden or yard?

_____ days per week

No vigorous activity in garden or yard Skip to question 16

15. How much time did you usually spend on one of those days doing vigorous physical activities in the garden or yard?

_____ hours per day _____ minutes per day

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate activities like carrying light loads, sweeping, washing windows, and raking in the garden or yard?

_____ days per week

No moderate activity in garden or yard Skip to question 18

LONG LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised October 2002.

17. How much time did you usually spend on one of those days doing moderate physical activities in the garden or yard?

_____ hours per day _____ minutes per day

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate activities like carrying light loads, washing windows, scrubbing floors and sweeping inside your home?

_____ days per week

No moderate activity inside home Skip to PART 4: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY

19. How much time did you usually spend on one of those days doing moderate physical activities inside your home?

_____ hours per day _____ minutes per day

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the last 7 days solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the last 7 days, on how many days did you walk for at least 10 minutes at a time in your leisure time?

_____ days per week

No walking in leisure time Skip to question 22

21. How much time did you usually spend on one of those days walking in your leisure time?

_____ hours per day _____ minutes per day

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do vigorous physical activities like aerobics, running, fast bicycling, or fast swimming in your leisure time?

_____ days per week

No vigorous activity in leisure time Skip to question 24

LONG LAST 7 DAYS SELF-ADMINISTERED version of the IPAQ. Revised October 2002.

23. How much time did you usually spend on one of those days doing vigorous physical activities in your leisure time?

_____ hours per day _____ minutes per day

24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis in your leisure time?

_____ days per week

No moderate activity in leisure time Skip to PART 5: TIME SPENT SITTING

25. How much time did you usually spend on one of those days doing moderate physical activities in your leisure time? _____ hours per day _____ minutes per day

PART 5: TIME SPENT SITTING

The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the last 7 days, how much time did you usually spend sitting on a weekday?

_____ hours per day _____ minutes per day

27. During the last 7 days, how much time did you usually spend sitting on a weekend day?

_____ hours per day _____ minutes per day

This is the end of the questionnaire, thank you for participating.

APPENDIX-2

Physical Activity Readiness Questionnaire (PAR-Q)

Now I am going to ask you a few questions to determine if you are eligible to participate in the study.

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

   No ___ Yes ___ If yes, specify: ______________________________

2. Do you feel pain in your chest when you do physical activity?

   No ___ Yes ___ If yes, specify: ______________________________

3. In the past month, have you had chest pain when you were not doing physical activity?

   No ___ Yes ___ If yes, specify: ______________________________

4. Do you lose your balance because of dizziness or do you ever lose consciousness?

   No ___ Yes ___ If yes, specify: ______________________________

5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?

   No ___ Yes ___ If yes, specify: ______________________________

6. Is your doctor currently prescribing drugs (for example, water pills) for a blood pressure or heart condition?

   No ___ Yes ___ If yes, specify: ______________________________

7. Do you know of any other reason why you should not do physical activity?

No ___ Yes ___ If yes, specify: ______________________________

Please provide accurate information for all requested items. Ask a staff member to assist you if you need clarification of any item.

Write a **Y** for all statements that are true, write a **N** for all statements that are false, and write a **U** for all statements that are unknown.

Cardiovascular Risk Factors

_____ You have a first-degree relative who had a heart attack or coronary revascularization **or** sudden death before age 55 (father or brother) **or** age 65 (mother or sister).

_____ You smoke cigarettes **or** you quit smoking cigarettes within the last 6 months.

_____ Your systolic blood pressure is $\geq$ 140 **or** your diastolic blood pressure is $\geq$ 90 mmHg **or** you take blood pressure medication.

_____ Your LDL-cholesterol is $\geq$ 130 mg/dl (if LDL not known: your total cholesterol is $\geq$ 200 mg/dl) **or** your HDL-cholesterol is < 40 mg/dl **or** you take lipid lowering medication.

_____ You are sedentary (i.e. you get less than 30 minutes/day of moderate intensity physical activity on most days and you do not participate in a regular exercise program).

_____ Your HDL-cholesterol is $\geq$ 60 mg/dl

Symptoms

_____ You experience pain or discomfort in the chest, neck, or arms.

_____ You experience shortness of breath at rest or with mild exertion.

_____ You experience dizziness or have had episodes of blackouts.

_____ You have swelling of the ankles

_____ You experience shortness of breath with change of posture or while sleeping

_____ You experience episodes of rapid heart beats or skipped heart beats.

_____ You experience pain or cramping sensations in your legs when walking.

_____ You experience fatigue or shortness of breath with unusual activities.

Medical History

You have or have had:

_____ Heart murmur _____ heart attack

_____ heart surgery _____ a lung disease

_____ a metabolic disease (diabetes, thyroid disorder, kidney or liver disease)

List all other notable health problems, injuries, or conditions

____

List names/doses/frequency of all medications taken (if not taking any medications, write "NONE")

____

Staff Comments

____

APPENDIX-3

The Borg Scale of Rating Perceived Exertion (Borg, 1970)

RATING	PERCEIVED EXERTION
6	No Exertion
7	Extremely Light
8	
9	Very Light
10	
11	Light
12	
13	Somewhat Hard
14	
15	Hard
16	
17	Very Hard
18	
19	Extremely Hard
20	Maximal Exertion

ABBREVATIONS

BMI- Body Mass Index

BMR- Basal Metabolic Rate

CHO- Carbohydrate Oxidation

FFM- Fat Free Mass

HFM- High- Fat Meal

HR- Heart Rate

LO- Lipid Oxidation

REE- Resting Energy Expenditure

RER- Respiratory Exchange Ratio

RPE- Rate of Perceived Exertion

RQ- Respiratory Quotient

TEE- Total Energy Expenditure

VCO2- Carbon Dioxide Production

VO2- Oxygen Consumption