RESTING METABOLISM AND METABOLIC RESPONSES TO SOLID AND LIQUID MEALS IN SEDENTARY AND EXERCISING COLLEGE-AGE MALES

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# RESTING METABOLISM AND METABOLIC RESPONSES TO SOLID AND LIQUID MEALS IN SEDENTARY AND EXERCISING COLLEGE-AGE MALES

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AND LIQUID MEALS IN SEDENTARY AND EXERCISING

COLLEGE-AGE MALES

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DISSERTATION ABSTRACT

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Differences in resting metabolic rate (RMR) were measured in a total of 29 sedentary and exercising college-age males, as were their metabolic responses (diet-induced thermogenesis, DIT) to solid and liquid meals. Subject classification was based on habitual exercise. A group of 9 males was classified as sedentary, 11 males were classified as endurance (aerobic) exercisers, and 9 males were classified as weight lifters (resistance exercise). Resting metabolism was measured soon after waking; DIT for each meal was measured immediately following meal consumption, and then every 30 minutes for 3 hours. RMR and DIT were measured via indirect calorimetry, height was determined via stadiometer, and all body composition meaurements were done with bioelectrical impedance. No significant differences existed between groups for age, body mass index (BMI), percent body fat, fat-free mass (ffm), percent ffm, and hydration. Moreover, no significant differences existed in DIT based on meal form ($Eta^2 = 0.049$, $F = 1.336$, $p = 0.258$). However, there was a significant overall metabolic increase based on group ($Eta^2 = 0.271$, $F = 4.844$, $p = 0.016$). Specifically, both exercise groups had a significantly ($p < 0.05$) greater RMR when compared to the sedentary group; this increased RMR indicated that the exercise groups expended more energy expended more energy at rest than did the sedentary group. There were no significant RMR differences between the exercising groups ($p = 0.843$). RMR and DIT were negatively correlated ($r = -0.38$; $p = 0.023$). The variables positively correlated with RMR include ffm ($r = 0.59$; $p < 0.001$), and BMI ($r = 0.39$; $p = 0.020$). In conclusion, these findings give further support to the importance of exercise, specifically frequent and intense exercise, in amplifying resting metabolic rate and increasing total energy expenditure.

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

# CHAPTER I

# INTRODUCTION

Over the past few decades, obesity (Body Mass Index (BMI) $\geq$ 30.0 kg/m$^2$) rates have climbed to include almost one-third (32.9%) of U.S. adults (CDC 2008d). When the percentage of overweight (BMI 25.0-29.9) U.S. adults is included (33.4%), it becomes obvious that overweight and obesity are very common in adults (CDC 2008c); in fact, obesity has reached epidemic proportions in the United States (Dietz 2002). Many health problems are associated with being overweight or obese, including hypertension, osteoarthritis, high serum cholesterol, high serum triglycerides, type 2 diabetes, heart disease, stroke, some forms of cancer, sleep apnea, respiratory conditions, and others (CDC 2008d). Moreover, Bray (1986) points out that obesity may be frowned upon socially and carries numerous educational and employment disadvantages.

It should come as no surprise that the health problems just mentioned have a substantial economic impact. Some of this impact involves the direct medical costs for prevention, diagnosis, and treatment of overweight and obesity, and some of the economic impact involves the indirect costs – things such as decreased productivity, absenteeism, and loss of future income due to premature death. All totaled, it is estimated that at least 117 billion dollars is spent annually for medical expenses related to overweight and obesity (Dietz 2002), and approximately half of that is paid by Medicaid and Medicare (CDC 2008b).

There may be numerous pieces to the obesity puzzle, and genetic factors appear to play at least some role. Bouchard and others (1989) determined that genotype differences comprise ~40% of our resting metabolic rate (RMR). However, "except for the very rare cases of monogenic origin, obesity results from a polygenic disorder (Jequier 2002)."

Overweight and obesity can often be viewed from a practical standpoint as an energy imbalance (energy intake vs. energy output). Jequier (2002) states the energy balance equation in terms of energy storage:

Energy stored = Energy intake – Energy output in urine & feces – Energy expenditure.

Small, almost immeasurable, imbalances in the above equation over an extended period of time can account for as much as a 5 kg (11 lb.) weight gain per year (Jequier 2002). Overweight and obesity in this context are the result of excess energy (calorie) intake, inadequate energy output, or both (CDC 2008). Energy intake is simply calories ingested, but energy output has at least three components: resting metabolic rate (RMR), physical activity, and diet-induced thermogenesis (DIT), also known as the thermic effect of food (TEF). The proportions contributed to energy output from each component vary per person. RMR as a percentage of energy output tends to change as exercise increases or decreases (Weststrate and Hautvast 1990); in fact, RMR can account for as much as 80% of total energy output in a very sedentary person, or as little as 30% in someone with very high levels of exercise (Tremblay and others 1985). Physical activity may contribute only 15% of overall energy expenditure in an extremely sedentary individual, but it generally contributes somewhere around 30% (Poehlman 1989). DIT includes the energy used for digestion, absorption, and nutrient storage (Tremblay and others 1985); it is thought to account for ~10% of total energy output (Oba and others 1999; Weststrate and Hautvast 1990). This represents only a small part of total energy output, but this may be important over time and with respect to combating obesity (King and Tribble 1991; Oba and others 1999).

Some studies have shown that exercise (purposeful physical activity) can affect both RMR and DIT (Poehlman and others 1988; Poehlman and others 1989), but others (Thorne and Wahren 1989) have not reported similar findings. These studies have only focused on endurance exercise; research focused on resistance exercise (weight lifting) is limited, but it appears that resistance exercise increases RMR and DIT (Thyfault and others 2004). Meal form, composition, and content may also play an important role in DIT (Samueloff and others 1982); however, no studies to date have examined different types of habitual exercise and their effects on RMR and DIT after different forms of meals. The purpose of this study, therefore, was to determine the effects of endurance exercise and resistance exercise on RMR and DIT in college-age males after the consumption of different meal forms. The role of meal forms themselves on DIT was also examined.

CHAPTER II

LITERATURE REVIEW

## Overview

Overweight and obesity has become very common in the United States; data from the 2003-2004 NHANES indicates that over 66% of U.S. adults are overweight (Body Mass Index (BMI) 25.0-29.9 kg/m$^2$) or obese (BMI $\geq$ 30.0 kg/m$^2$) (CDC 2008d). It appears as though this trend is across all races, ethnic groups, and ages, as well as both genders (King and Tribble 1991). Obesity is one of the most serious health problems facing the U.S. at the current time because it is a risk factor for so many health disorders. Obesity is associated with heart disease, hypertension, hypercholesterolemia, hypertrigylceridemia, type 2 diabetes, stroke, gallstones, several forms of cancer, and respiratory problems (CDC 2008d). In addition to the above health issues, obesity may be frowned upon socially, and it may result in educational and employment disadvantages (Bray 1986).

Obesity is a multi-factorial condition, and researchers are trying to combat it from many angles. However, the most basic and arguably the most common cause of obesity is a problem with energy balance (energy intake vs. energy expenditure); that is to say too much energy intake, not enough energy output, or both (King and Tribble 1991). Indeed, it was noted over 40 years ago that energy output was trending downward at that time

(Reiff and others 1967), and it is difficult to make a case for society changing that trend since then.

Energy intake consists of one component, which is simply the calories we consume. Energy output, on the other hand, consists of three significant components: resting metabolic rate (RMR), exercise (or physical activity), and diet-induced thermogenesis (DIT), also known as the thermic effect of food (TEF). Adaptive thermogenesis is the change in metabolic rate as a result of environmental influences, usually from cold acclimation or responses to drugs or hormones; it is a fourth component of energy output in some individuals, but not all of us (Tremblay and others 1985; Horton 1986). The proportions contributed to energy output from each component vary per person.

An excess energy intake and/or a decreased energy output can result in weight gain and lead to obesity, but, conversely, decreased energy intake and/or increased energy output can result in weight loss and less occurrence of obesity. Decreased energy intake can result in weight loss, but decreased energy intake often results in the unfortunate decrease of RMR (Mole and others 1989; Ravussin and others 1982; Weigle and others 1988; Elliot and others 1989).

Exercise could be an important strategy in the prevention of obesity (Garrow 1987), especially if exercise can result in a larger weight loss than decreased energy intake by itself (Tremblay and others 1985). This effect is possibly due to exercise's role in maintaining RMR (Mole and others 1989; Ravussin and others 1982; Weigle and others 1988; Elliot and others 1989) and reducing the loss of fat-free mass (Pavlou and others 1985), and possibly as an impetus for increased DIT. The next section of the literature review focuses on these three primary components of energy expenditure, the factors affecting these components, and the possible interactions that these components may have with each other. Unless noted otherwise, all studies discussed deal with humans, specifically males.

**Resting Metabolic Rate (RMR)**

RMR is the largest portion of energy expenditure, often being 60-75% of the total amount of energy used on a daily basis (Poehlman 1989). Poehlman (1989) defines RMR as the energetic cost of maintaining body systems and temperature at rest, including the energy required to maintain electrolyte gradients, sustain cardiovascular and pulmonary work at rest, and carry on reactions of the central nervous system.

Numerous factors may affect RMR, including fat-free mass (FFM). Webb (1981) used a combination of both direct and indirect calorimetry to record 59 metabolic measurements on seven men (22-55 years old) and eight women (22-54 years old). Underwater weighing was utilized to determine body composition. After correcting for age and gender, Webb found a highly significant and positive correlation between RMR and FFM ($r = 0.93$; $p < 0.001$).

In a much larger study, Weyer and others (1999) used a respiratory chamber to assess the metabolic rates of 916 adults (561 males, 355 females; 31.5 ± 11.9 years old). Body composition was determined via underwater weighing or dual-energy x-ray absorptiometry (DEXA). For the entire group, FFM had a significant and positive correlation with RMR ($r = 0.80$; $p < 0.001$).

Illner and others (2000) examined RMR and body composition in 13 males (26.2 ± 2.1 years old) and 13 females (24.8 ± 2.4 years old). RMR was measured via indirect calorimetry, and body composition was measured via bioelectrical impedance analysis (BIA), DEXA, and magnetic resonance imaging (MRI). RMR was significantly and positively correlated to FFM when measured with BIA ($r = 0.92$; $p < 0.01$), DEXA ($r = 0.89$; $p < 0.01$), and MRI ($r = 0.90$; $p < 0.01$).

It is apparent that a significant and positive correlation exist between RMR and FFM. This relationship appears to exist regardless of gender. The research of Webb (1981), Weyer and others (1999), and Illner and others (2000) indicates that FFM may explain anywhere from approximately 60-80% of RMR.

A second factor affecting RMR is gender. A 5-year study by Ferraro and others (1992) compared 114 males and 121 females. RMR was measured in a respiratory chamber. For the entire group, RMR in men was significantly greater than in women (1785 ± 352 kcals/day vs. 1534 ± 314 kcals/day; $p < 0.01$). In an age-matched subset of 12 males and 24 females, RMR remained significantly greater in males by 116 ± 45 kcals/day ($p < 0.02$), even when adjusted for body composition.

Webb (1981) compared RMR in males (n = 7; 22-55 years old) and females (n = 8; 22-54 years old). RMR was measured using direct and indirect calorimetry. Webb stated that there was no significant relationship between RMR and gender, although no specific data were given.

Illner and others (2000) utilized indirect calorimetry to assess RMR in 13 males (26.2 ± 2.1 years old) and 13 females (24.8 ± 2.4 years old). RMR was significantly greater in males (7.28 ± 0.85 MJ/day vs. 5.74 ± 0.68 MJ/day; $p < 0.01$).

Meijer and others (1991) studied 32 adult subjects (16 men, 16 women) who were not habitually active (sedentary). Subjects were trained and monitored for 20 weeks in a progressive endurance exercise program; by Week 20 the subjects were running 25-40 km/week. The average daily metabolic rate for women at 0 weeks (10.0 ± 1.0 MJ/day), 8 weeks (11.5 ± 1.2 MJ/day), and 20 weeks (11.3 +/- 2.2 MJ/day) was significantly ($p < 0.05$) lower than the corresponding time measurement for men (11.6 +/- 1.5 MJ/day @ 0 weeks, 13.9 +/- 1.5 MJ/day @ 8 weeks, 14.9 +/- 2.6 MJ/day @ 20 weeks).

Hence, there appears to be a significant effect of gender on RMR. Although Webb (1981) did not find a significant relationship between RMR and gender, the research of Ferraro and other (1992), Illner and others (2000), and Meijer and others (1991) provide strong support that males have a greater RMR compared to females.

A third factor of significance for RMR is heredity, which is to say that some people simply seem to inherit a higher or lower RMR. Bouchard and others (1989) studied the genetic effect in the RMR of 21 pairs of dizygotic twins and 37 pairs of monozygotic twins. They determined that heredity (genetics) accounts for approximately 40% of the RMR variance after accounting for FFM, age, and gender.

Bosy-Westphal and others (2008) analyzed data from 815 subjects (4-84 years old) over a 3-year period. Some subjects were grandparents ($n = 223$; 67.4 ± 7.0 years old), some were parents ($n = 296$; 43.5 ± 6.4 years old), and some were children ($n = 296$; 13.0 ± 4.6 years old). RMR was measured via indirect calorimetry. The authors found a significant effect of heritability ($p < 0.001$); specifically, 30% of RMR was explained via heredity after adjustment for FFM, age, and gender.

Over a period of 3.5 years, Bogardus and others (1986) utilized indirect calorimetry to measure the RMR of 130 adults (74 men, 56 women, 25 ± 5 years old) from 54 families. The authors found that "family membership" (heredity) accounted for approximately 11% of RMR ($p < 0.05$).

Although research focused on the heredity effect of RMR does appear to vary somewhat, there is a general consensus that heredity plays a significant role in RMR. The studies of Bouchard and others (1989) and Bosy-Westphal and others (2008) indicated that heredity accounts for 30-40% of the variance in RMR after taking FFM, age, and gender into consideration. Meanwhile, Bogardus and others (1986) found that heredity explained approximately 11% of RMR as a whole.

Another variable that plays a role with RMR is age. Armellini and others (2000) used indirect calorimetry to evaluate RMR in a total of 130 subjects, including 82 premenopausal women (18-52 years old), 27 postmenopausal women (46-71 years old), and 21 men (18-70 years old). Premenopausal women were significantly younger than postmenopausal women (34 ± 9.8 years old vs. 58 ± 6.3 years old; $p < 0.05$), and they also had a significantly greater RMR (5.1 ± 0.76 kJ/min vs. 4.6 ± 0.66 kJ/min; $p < 0.05$). RMR was significantly and negatively correlated with age in men ($r = -0.54$; $p < 0.01$).

Jones and others (2004) also examined the effects of age on RMR. The authors used indirect calorimetry to measure RMR in 25 young (24 ± 1 years old) and 21 old (64 ± 1 years old) men. RMR was significantly greater in the young men (1830 ± 36 kcals/day) vs. the older men (1559 ± 36 kcals/day; $p < 0.001$).

The final factor involved with RMR that is discussed at this time is caloric intake, specifically how sustained changes in caloric intake affect RMR. Leibel and others (1995) used indirect calorimetry to measure RMR in 41 adults (18 women, 23 men, 19-45 years old). Subjects were then divided into groups for weight maintenance and different percentages of weight gain and loss via increase or decrease in caloric intake. A 10% weight loss in those with the lowest RMR (n = 11) resulted in a significant 15% decrease in RMR (1511 ± 304 kcals/day vs. 1290 ± 228 kcals/day; p = 0.002), while a 10% weight loss in those with a greater RMR (n = 9) resulted in a significant 14% decrease in RMR (2068 ± 359 kcals/day vs. 1778 ± 410 kcals/day; p = 0.037). A 20% weight loss in 10 subjects resulted in a significant 20% decrease in RMR (1984 ± 342 kcals/day vs. 1581 ± 348 kcals/day; p < 0.001). However, a 10% weight gain in 11 subjects resulted in an insignificant 6% increase in RMR.

Elliot and others (1989) assessed the long-term effects of weight loss on RMR in seven obese women (40 ± 10 years old; BMI 37.6 ± 6.3 $kg/m^2$). RMR was measured via indirect calorimetry before, during, and after a caloric restriction-induced weight loss. After the 4 weeks of caloric restriction, RMR had decreased by an average of 22% (p < 0.001; RMR values not given). After another 4-week period, no longer on the weight loss diet, RMR did not differ from the decreased values (p > 0.05; RMR values not given).

In summary, many factors affect RMR. Reviewed in this section was the substantial impact that body composition, specifically FFM, has on RMR per the research of Webb (1981), Weyer and others (1999), and Illner and others (2000). In addition, as Ravussin and Bogardus (1992) state, "…the major determinant of the RMR is FFM. However, there is also a significant variance in RMR independent of FFM." Therefore, also presented were the impacts of gender because males often have greater RMR than females (Ferraro and others 1992; Webb 1981; Illner and others 2000;

Meijer and others 1991) and heredity, which suggested that heredity does have a significant impact on RMR (Bouchard and others 1989; Bosy-Westphal and others 2008; Bogardus and others 1986). Finally, RMR in adults appears to decrease with age according to Armellini and others (2000) and Jones and others (2004), and RMR decreases with caloric restriction (Leibel and others 1995; Elliot and others 1989). Exercise may also affect RMR, but details of the possible relationship between RMR and exercise will be presented later.

### Exercise

The second component of energy expenditure is exercise, and it is also the most variable component. It can be as low as 15% of energy expenditure in cases of extreme inactivity (Poehlman 1989), but on the other end of the spectrum, exercise may account for a greater energy expenditure than RMR (Tremblay and others 1985). Exercise could be pivotal in reversing the recent trends of increased prevalence or severity of overweight and obesity. Researchers have stated that "…reduced total daily physical activity may well be the most important current factor contributing to the increase in body weight in Westernized countries (Weinsier and others 1998)." Recommendations to use exercise as a means of combating obesity suggest that exercise intensity is key (Poehlman 1989; Weinsier and others 1998). In other words, it is important to exercise as hard as possible in order to expend the greatest amount of energy in a given period of time.

### Diet-induced Thermogenesis (DIT)

The third and final significant portion of energy expenditure is DIT, which encompasses the energy expended for food ingestion, digestion, absorption, and storage.

Much of DIT can be calculated using known values of nutrient disposal and storage; this is referred to as obligatory thermogenesis. Especially in men, however, DIT measurement are often over and above these calculated values, and most researchers refer to this extra amount of energy expenditure as facultative thermogenesis; it is hypothesized to be at least partially controlled by the sympathetic nervous system (Poehlman 1989). This part of DIT can adapt to overfeeding and/or caloric deprivation (James and Trayhurn 1981; Tremblay and others 1985). All told, DIT is thought to account for ~10% of total energy output (Weststrate and Hautvast 1990). This is only a small part of total energy expenditure, but it may be significant over time to prevent weight gain (King and Tribble 1991; Oba and others 1999). As they concluded about a low RMR being a major risk factor for weight gain, Ravussin and Bogardus (1992) also suggest that a low DIT is a risk factor for weight gain.

Much the same as RMR, DIT is affected by many factors. The research reviewed in this section will focus on the relationship between DIT and meal size, test meal nutrient content, test meal forms, age, and gender. In addition, timing of DIT measurements is also important because DIT can begin within 10 minutes after eating (Samueloff and others 1982), and DIT may last as long as 5-8 hours after a meal (Poehlman 1989).

Samueloff and others (1982) used indirect calorimetry and combinations of meal protocols to assess the effects of different meal sizes and nutrient contents in 11 high-school males (16-17 years old). The smallest meal size (400 kcals: 15% protein, 30% carbohydrate, 55% fat) produced a significant 9.1% DIT response ($p < 0.02$). The largest meal size (1200 kcals: 15% protein, 30% carbohydrate, 55% fat) resulted in a significant 20.3% DIT response ($p < 0.001$). The DIT response of the 1200 kcal meal was significantly greater than that of the 400 kcal meal ($p < 0.001$).

Similarly, Belko and others (1986) assessed the effects of different meal sizes and nutrient contents. DIT test meals varied in nutrient content (15% protein, 49% carbohydrate, 36% fat vs. 30% protein, 34% carbohydrate, 36% fat vs. 45% protein, 17% carbohydrate, 36% fat) and in caloric content (520 kcals vs 1060 kcals vs. 1600 kcals). DIT was measured for 3 hours when meals varied only in caloric content, but for 5 hours when meals varied in nutrient content in anticipation of an increased DIT with increased percentages of protein. DIT was most affected by caloric content of the test meal; curvilinear estimation revealed the greatest DIT value at approximately 40% of total daily energy requirement, although no significance values were reported. DIT values were greatest for the 30% and 45% protein meals, although again no statistical significance values were mentioned. The authors conclude that DIT varies based on meal size (caloric content), and at least somewhat based on protein (macronutrient) content. In addition, they calculated that the additive DIT effects of 4 small meals throughout the day would be nearly 64% greater than the additive DIT effects of 2 larger meals during the day.

Kasai and others (2002) also examined differences in nutrient content;specifically, they assessed the effects that changes in triglyceride structure and content have on DIT in 16 adults (8 males, 8 females). Using liquid meals and a double-blind protocol, the authors determined that inclusion of 5 g or 10 g of medium-chain triglycerides (MCT) elicited a significantly greater overall DIT response ($p < 0.05$) than when long-chain triglycerides (LCT) were included in the meals.

Khoussousi and others (2008) studied the effects of fiber supplementation to a breakfast meal in 10 men. All subjects consumed both meals, in random order, separated by one week. Fiber supplementation consisted of 3 g vs. 15 g, but no DIT differences were found between the meals over a 6-hour period ($p > 0.05$).

Peracchi and others (2000) investigated DIT responses between different meal forms. They used a typical meal of solid foods to eat and liquids to drink compared to a homogenized meal of equal volume and calories. Eight men (21-28 years old) were given the meals in random order at 1-week intervals. The homogenized meal resulted in a significantly greater DIT response compared to the typical solid-liquid meal (237.7 kJ/300 minutes vs. 126.4 kJ/300 minutes; $p = 0.0029$).

Clemente and others (2003) looked at meal form and gastric emptying rates with three types of dairy (milk, mozzarella cheese, and butter) to represent liquid, semi-solid, and solid forms of lipid, respectively. A total of eight subjects (six males, two females) consumed each of the lipid forms as part of breakfast test meals (850 kcals: 115 g carbohydrate, 36 g protein, 30 g lipid) in which the primary difference was the physical structure of lipid. Gastric emptying rates were similar for the butter and milk ($14 \pm 2$ mL/hr vs. $13 \pm 6$ mL/hr; $p > 0.05$), but were significantly slower with mozzarella cheese ($18 \pm 5$ mL/hr; $p < 0.03$). Therefore, if comparing only solids and liquids, it appears that gastric emptying rates of dairy-containing meals are similar, which may indicate similar timing in the DIT response.

Furthermore, age has a significant effect on DIT. Jones and others (2004) used a total of 46 healthy men to determine the roles of age on DIT. Subjects were divided into 1 of 4 age- and exercise-based groups: 16 young sedentary men (19-36 years of age, no regular physical activity), 11 older sedentary men (54-75 years of age, no regular physical activity), 9 young exercising men (19-36 years of age, 30+ minutes of aerobic exercise 3+ days/week), and 10 older exercising men (54-75 years of age, 30+ minutes of aerobic exercise 3+ days/week). All subjects reported to the lab on a given morning ~12 hours since eating and ~24 hours since exercising (if in one of the exercising groups). DIT test meal was an orange-flavored glucose drink individualized at 2.5 g/kg fat-free mass; DIT was measured for 4 hours. The researchers found no significant interactions between aging and exercise, so they combined the sedentary and exercising groups per age group. However, DIT was distinctly different based on age. DIT was significantly ($p < 0.05$) lower in the older men over the 4-hour period. DIT in the young men was even more significant ($p < 0.001$) above the older men when compared for the first 2 hours after the meal.

Much like it did with RMR, gender may have a significant role in DIT, as males appear to have greater DIT. In the Meijer and others (1991) study already mentioned, the authors collected data from 32 adult subjects (16 men, 16 women) who were not habitually active (sedentary). The authors found that DIT was significantly ($p < 0.05$) greater in men than in women, even when normalized for body mass. The authors conclude that habitual exercise stimulates DIT in men, but not in women, and this is probably due to sympathetic nervous system (SNS) activity.

Therefore, many factors affect DIT. From the works of Samueloff and others (1982) and Belko and others (1986), the size and nutrient content of a meal can affect DIT, although Khoussousi and others (2008) indicate that up to 15 g of fiber supplementation to a meal does not significantly alter DIT. Peracchi and others (2000) determined that homogenization of a meal increases DIT, while Clemente and others (2003) showed that gastric emptying rate is not different between solids and liquids. As was the case with RMR, DIT in adults decreases with age (Jones and others 2004), and DIT is more pronounced in men than in women (Meijer and others 1991). Finally, exercise may also affect DIT; this possible relationship will be discussed later in further detail.

It is evident that all three of the significant components of energy expenditure may be affected separately by a number of factors. However, there is a solid body of evidence that RMR, exercise, and DIT can influence each other; specifically, exercise can affect RMR and DIT. In fact, Weststrate and Hautvast (1990) calculated that RMR may vary (as a percentage of total caloric expenditure) by ~1% per hour spent exercising each week. For instance, for 1-2 hours of exercise per week, RMR was calculated as 70% of total energy expenditure; for 3-5 hours of exercise per week, RMR was calculated as 67% of total energy expenditure; for 6-7 hours of exercise per week, RMR was calculated as 64% of total energy expenditure. The possible relationships between RMR, exercise, and DIT serve as the basis for the remainder of this literature review.

**Interaction of RMR, exercise, and DIT**

The overall effect of exercise on RMR may vary depending on the study. RMR remains elevated for an extended amount of time after activity due to a number of factors: continued oxidation of metabolic substrates (i.e. lactate, free fatty acids), replenishment of glycogen stores, increased levels of hormones (i.e. catecholamines), and increased body temperature. One's metabolic rate can remain as high as 23%

above pre-exercise levels up to 13 hours after completion of exercise; elevations of 8-10% have been measured 48 and 72 hours after the completion of very intense exercise (Horton 1986), although Poehlman (1989) contends that increased RMR > 24 hours post-exercise is likely due to a chronic adaptation of exercise.

Most of the literature describing aspects of the interactions between RMR, exercise, and DIT can be divided into four categories based on the timing (related to test meal) and mode of exercise; the four categories include: acute endurance exercise, habitual endurance exercise, acute resistance exercise, and habitual resistance exercise. A brief description of the possible mechanisms (i.e. biochemical changes) behind the interaction of exercise's effects on RMR and DIT is also included.

### Acute Endurance Exercise

Weststrate and Hautvast (1990) examined the effects of short-term carbohydrate overfeeding and prior exercise on RMR and DIT on 10 subjects (5 men, 5 women) who were moderately active (1-7 hours/week of exercise). They found that glycogen-depleting exercise (2 15-minute cycling bouts at 70-80% of maximum work capacity separated by a 15-minute rest period) the night prior to metabolic measurements significantly ($p = 0.02$) increased RMR, and it tended to increase DIT ($p = 0.08$). Carbohydrate overfeeding significantly ($p = 0.008$) increased DIT by an average of 39%, but the authors found no interaction effect of carbohydrate overfeeding and exercise on DIT. Peak DIT values were observed 30-120 minutes after feeding.

In a study of 11 males (16-17 years of age), Samueloff and others (1982) used combinations of meal sizes (400 kcals, 1200 kcals) and meal content (15% protein, 30% carbohydrate, 55% fat; 33% protein, 15% carbohydrate, 52% fat), along with and without brief (10-minute) post-meal cycling at 50% $VO_2max$, to determine possible changes in DIT. The brief post-meal exercise produced a four- to fivefold increase in oxygen consumption, but this effect was gone within 30 minutes. There was no significant effect of exercise after consuming a 400 kcal meal, but post-meal exercise did create a significantly ($p < 0.05$) greater response after consuming the 1200 kcal meal.

Belko and others (1986) studied the effects of varied intensities of acute aerobic exercise in 8 healthy males (23-30 years of age) of similar body composition (181.6 ± 3.0 cm, 78.0 ± 4.8 kg, 17.1 ± 2.8% body fat) and fitness level (48.7 ± 3.0 mL $O_2$/kg/min). Exercise varied in intensity (35% vs. 50% vs. 65% of $VO_2max$). Each subject took part in a number of tests. On the day of each test, subjects reported to the lab after a 12-hour fast and were given one of the test meals, which may or may not have been consumed in conjunction with performing acute exercise. Acute aerobic exercise increased DIT, but simply in an additive manner.

Ohnaka and others (1998) studied 6 healthy adult males (36 ± 16 years of age) who exercised regularly to observe the effects of acute aerobic exercise on DIT. Unlike other acute exercise and DIT investigations, Ohnaka and others (1998) required the subjects to exercise for a longer overall period of time (three 20-minute cycling bouts at ~58% VO2max; bouts separated by 5-minute rest intervals), and the researchers fed the subjects 2 meals while observing them for a total of 10 hours. Subjects were asked to refrain from exercise the day prior to each lab trial, as well as to refrain from alcohol and caffeine for 12 hours before each visit. Regardless of the protocol (exercise or rest), all subjects reported to the lab after an overnight fast and consumed the first test meal (~422 kcals: 68% carbohydrate, 12% protein, 20% fat). Subjects then exercised or rested (according to the protocol) for 1 hour, and were then observed at rest for 8 hours and given a second meal (~675 kcals: 72% carbohydrate, 11% protein, 17% fat) approximately halfway through this period. All totaled, the researchers found no significant effect of the aerobic exercise on DIT measured during the 4 hours. The researchers concluded that DIT may also be related to differences in meals, physical conditions, and exercise intensity, as well as other factors.

From the results of these studies, a single bout (acute) of endurance exercise appears to increase DIT. Although Ohnaka and others (1998) saw no significant effect on DIT, Weststrate and Hautvast (1990) found a tendency ($p = 0.08$) for increased DIT after subjects had performed two 15-minute cycling bouts the previous evening. Samueloff and others (1982) found a significant ($p < 0.05$) DIT increase with post-meal exercise; Belko and others (1986) also found increased DIT with exercise.

Habitual Endurance Exercise

Poehlman and others (1989) performed a study of 28 healthy, nonobese men (19-36 years of age). Of these 28 subjects, 8 were considered highly-trained because they were competitive endurance runners who exercised 6-7 times per week and ran 80-120 km/week; 11 were considered moderately-trained because they ran 3-4 times per week; 9 were considered untrained because they reported no regular participation in exercise. Subjects reported to the lab on a given morning at least 24 hours post-exercise, RMR was measured, and then subjects were given a liquid test meal consisting of 55% carbohydrate, 24% protein, and 21% fat; DIT was then measured for 3 hours. RMR was significantly ($p < 0.05$) higher in the highly-trained group when compared to the moderately-trained group and when compared to the untrained group, and this finding held consistent even when RMR was normalized for body mass and fat-free mass. The greatest total DIT values occurred in the moderately-trained group: these subjects had a significantly ($p < 0.05$) greater DIT when compared to the untrained group, and they had a significantly ($p < 0.01$) greater DIT when compared to the highly-trained group.

Fourteen males (18-30 years of age), 7 well-trained and 7 sedentary, were studied by Thorne and Wahren (1989) to determine possible DIT differences if fed a specific test meal proportioned to basal energy expenditure estimation. All exercising subjects were at least 36 hours post-exercise, and all baseline metabolic measurements were 12 hours after the previous evening's meal. All subjects consumed a liquid test meal (55% carbohydrate, 28% fat, 17% protein) that correspond to 60% of estimated basal energy expenditure. RMR was significantly ($p < 0.001$) greater in well-trained subjects when it was expressed relative to body mass. The authors found no significant differences in DIT between the groups when expressed in absolute terms or in terms relative to caloric ingestion. There was also no significant relationship between DIT and aerobic capacity.

Tremblay and others (1983) studied 8 trained men (25.9 ± 1.4 years of age, 64.1 ± 1.9 kg, all ran 100-160 km/week) and 8 untrained men (21.9 ± 0.4 years of age, 69.2 ± 2.5 kg, only occasional leisure activity) to record possible differences in RMR or DIT based on training status. The DIT test meal was quite large (1636 kcals) and contained 15% protein, 38% carbohydrate, and 47% lipid. DIT measurements were obtained every 15 minutes for 2 hours. RMR was not significantly different between the two groups. However, DIT was significantly ($p < 0.01$) greater in the untrained group. The DIT response in the trained group returned to baseline by the 1.5 hour post-meal mark, while the DIT response in the untrained group still remained above baseline at the 2 hour post-meal mark; this suggests that DIT could have been even more significantly greater in the untrained group had the measurements continued. The greater DIT response in the untrained group holds true when expressed in absolute terms (kJ) or relative terms (kJ/kg, kJ/lean kg).

LeBlanc and others (1984) studied RMR and DIT in 30 healthy females (averaging 26 years of age, 53.5 kg) divided in 3 groups of 10 each based on exercise habits. Group 1 was highly-trained endurance exercisers, Group 2 was moderately-trained endurance exercisers, and Group 3 was nontrained subjects. RMR and DIT measurements occurred on a given morning at least 10 hours since the previous evening's meal. DIT test meal consisted of 818 kcals (15% protein, 39% carbohydrate, 46% lipid), and DIT was then measured for 2 hours. RMR was not significantly different based on group. DIT was significantly ($p < 0.05$) lower in the highly-trained subjects (Group 1) than in the nontrained subjects (Group 3). No significant DIT differences were found between Groups 1 and 2 or between Groups 2 and 3.

Poehlman and others (1988) performed a study on 18 men (18-37 years of age) to determine possible differences in RMR and DIT based on habitual endurance exercise. One-half (n=9) of the subjects were considered highly-trained (approximately 100-160 km of distance running per week for at least 4 years), and one-half (n=9) of the subjects were considered untrained (no regular exercise). RMR was measured after an overnight fast (~12 hours) and at least 24 hours since recent exercise session. The DIT test meal was in liquid form, and it provided 10 kcals/kg fat-free mass (although fat-free mass was not significantly different between groups); its proportions were 24% protein, 55% carbohydrate, and 21% fat. DIT was measured for 3 hours. Absolute RMR values tended ($p = 0.07$) to be greater in trained subjects, and this difference became significant ($p < 0.05$) when RMR was standardized per kg fat-free mass. DIT values were significantly ($p < 0.01$) greater in the untrained subjects, and this held true even when DIT values were standardized per kg fat-free mass or expressed as a percentage (DIT divided by caloric load of meal). The authors also subdivided both groups to get 5 trained and 5 untrained subjects who were very similar in weight, BMI, percent body fat, and fat-free mass. All RMR and DIT observations remain unchanged: RMR was still greater ($p < 0.05$) in trained subjects, while DIT values remained greater ($p < 0.01$) in untrained subjects. "…suggests that high levels of endurance training promote an economy of energy utilization of ingested nutrients."

It is apparent that habitual endurance exercise can have significant effects on both RMR and DIT, but research suggests that these effects may be independent of each other, or possibly even inversely related. Poehlman and others (1989), Thorne and Wahren (1989), and Poehlman and others (1988) all found significant increases in RMR, but only Poehlman and others (1989) found any increase in DIT with habitual endurance exercise. In fact, Tremblay and others (1983), LeBlanc and others (1984), and Poehlman and others (1988) found increased DIT in non-exercising subjects. This negative relation between RMR and DIT is pointed to as an indication of energy efficiency in exercising subjects so that ingested glucose is being stored as glycogen to provide energy for the next exercise session.

## Acute Resistance Exercise

Denzer and others (2003) examined the effects of an acute bout of weight lifting on DIT. Nine subjects (3 males, 6 females; 22 ± 1 years of age) participated; all were habitual exercisers of both aerobic and weight-lifting exercise. Prior to each DIT test, subjects were asked to refrain from alcohol and tobacco for 24 hours and from exercise for 36 hours. Subjects reported to the lab on a given morning after an overnight fast. When required by the protocol, subjects performed approximately 20 minutes of standardized weight lifting prior to meal consumption. Exercises included bench press, biceps curl, triceps extension, lunges, twisted trunk curl, pullover, rowing, leg press, and seated press. All test meals were pudding-based, and each contained 660 kcals (80% carbohydrate, 13% protein, 7% fat). The researchers recorded DIT for 2 hours. Subjects were not separated by gender (probably due to small sample size). DIT for the 2-hour period was 73% greater ($p < 0.02$) when subjects performed an acute bout of weight lifting prior to meal ingestion compared to no exercise before the test meal.

Oba and others (1999) simulated microgravity conditions in 14 males, each of whom was randomly assigned to 1 of 3 groups: control (n = 4; 20 ± 1.7 years old), isometric resistance training (n = 5; 24 ± 4.7 years old; static maximal leg contractions), and isotonic resistance training (n = 5; 23 ± 3.7 years old; squats and leg extensions). Subjects in the isometric and isotonic resistance training groups exercised every day. RMR and DIT were assessed via indirect calorimetry on Day 0, 1, 4, 10, and 20. After 20 days, all groups showed a similar decrease in RMR compared to Day 0 ($p < 0.05$); however, DIT was maintained in both resistance exercise groups and was significantly greater than in the control group (significance level not reported).

Therefore, it appears that resistance training (weight lifting) significantly increases DIT. The research of Denzer and others (2003) supports this DIT increase in both genders for at least 2 hours after meal ingestion. The work of Oba and others (1999) indicated that resistance training can increase DIT independently of changes in RMR.

Habitual Resistance Exercise

In what became a two-part study, Thyfault and others (2004) first examined 12 resistance-trained males (22.0 ± 0.8 years of age; consistent training for at least 5 years) and 12 sedentary males (24.8 ± 1.4 years of age; no regular exercise for at least 1 year) in an effort to record any RMR and/or DIT differences that may have existed. Subjects consumed two different liquid meals (moderate fat: 37% carbohydrate, 18% protein, 45% fat; high carbohydrate: 79% carbohydrate, 20% protein, 1% fat) in a counterbalanced design with a 7-day separation. Calorie content was standardized to 40% of RMR. All subjects reported to the lab after an overnight fast, and all subjects had been asked to refrain from exercise, caffeine, or alcohol for 48 hours. DIT was measured for 4 hours. Absolute RMR was significantly ($p = 0.005$) greater in the resistance-trained group, but relative RMR (per kg fat-free mass) was significantly ($p = 0.008$) greater in the sedentary group. Absolute DIT and relative DIT (per kg fat-free mass) were significantly ($p = 0.001$; $p = 0.009$, respectively) greater in the resistance-trained group for the high carbohydrate test meal, but not for the moderate fat test meal.

The authors also wanted to investigate the type of resistance training on RMR and DIT, so they carried out a second part of the study, very similar to the first, in 8 bodybuilders (26.9 ± 0.9 years of age; consistent upper- and lower-body training for at least 5 years) and 8 powerlifters (22.6 ± 1.3 years of age; consistent upper- and lower-body training for at least 5 years). Neither absolute nor relative RMR values were significantly different between the two groups. Similarly, there were no statistical differences in absolute DIT or relative DIT.

Byrne and Wilmore (2001) performed a 20-week study on a total of 28 sedentary moderately obese women (18-45 years of age; 37.5 ± 0.8 % body fat) were randomly assigned to one of three groups: control (sedentary; n = 9), resistance exercise (4 days/week; n = 10), or resistance + endurance exercise (same resistance exercise as resistance group, but also 3 days/week of endurance exercise (n = 9). Resistance exercise sessions were monitored, but endurance training was not. Resistance exercise sessions were performed on Mondays and Thursdays (chest press, rowing, overhead press, lateral raises, and tricep kick backs) and Tuesdays and Fridays (leg press, leg extension, leg curl, lat pulldowns, and arm curls). Endurance training was simply 20-40 minutes of walking. The only significant body composition changes over the 20 weeks were in the two exercising groups; each gained a significant ($p < 0.05$) amount of fat-free mass, but did not significantly increase overall body mass or decrease percent body fat. RMR significantly ($p < 0.05$) increased in the resistance exercising group (compared to control), but decreased in the resistance + endurance exercise group ($p < 0.05$, compared to control).

In reviewing the work of Thyfault and others (2004) and Byrne and Wilmore (2001), it is apparent that habitual resistance training can have significant effects on both RMR and DIT. Thyfault and others (2004) found increased RMR with habitual resistance training, and it did not matter if that training was bodybuilding or powerlifting. This finding was also seen in the research of Byrne and Wilmore (2001) who found significantly increased RMR with 20 weeks of resistance training. Thyfault and others (2004) also saw significant increases in DIT in resistance-trained subjects.

<u>Possible Mechanisms</u>

Some of the literature reviewed provides correlative data as to the possible mechanism(s) or reason(s) for the metabolic changes with exercise. It appears that exercise intensity may play a significant part in some of these changes. Weststrate and Hautvast (1990) exercised their subjects at 70-80% of maximum work capacity, an intensity level that the authors contend was enough to deplete some glycogen stores and therefore increase DIT as the body replenished these stores. This is contrary to Belko and others (1986) who found a significant effect of acute endurance exercise on DIT, but no effect of intensity at 35%, 50%, and 65% of $VO_2$max. Poehlman and others (1988) and Poehlman and others (1989) provide evidence that increasing the intensity of habitual endurance exercise increases RMR.

It is plausible to suggest a relationship between biochemical factors and metabolic changes. Poehlman and others (1989) found that highly-trained endurance exercisers have decreased insulin concentrations and thus a likely increase in insulin sensitivity. Thyfault and others (2004) showed similar results with resistance training. However, Thorne and Wahren (1989) and Poehlman and others (1988) did not find differences in insulin concentrations. Thorne and Wahren (1989) found increased adrenaline levels in endurance exercisers, but other studies (Poehlman and others 1988; Poehlman and others 1989; Thyfault and others 2004) did not concur.

## Literature Review Summary

In summary, many factors affect RMR. Specifically, RMR is positively correlated to FFM (Webb 1981; Weyer and others 1999; Illner and others 2000), and RMR is greater in men than in women (Ferraro and others 1992; Illner and others 2000; Meijer and others 1991). In addition, RMR appears to be affected by heredity (Bouchard and others 1989; Bosy-Westphal and others 2008; Bogardus and others 1986), age (Armellini and others 2000; Jones and others 2004), and caloric intake (Leibel and others 1995; Elliot and others 1989). Similarly, DIT is affected by many factors, including relationships to meal size (kcal) and content (Samueloff and others 1982; Belko and others 1986; Kasai and others 2002; Khoussousi and others 2008), meal form (Peracchi and others 2000; Clemente and others 2003), age (Jones and others 2004), and gender (Meijer and others 1991).

There is solid evidence for endurance exercise and resistance exercise, both on an acute and habitual level, each having significant effects on RMR and DIT. Acute endurance exercise increases DIT (Weststrate and Hautvast 1990; Samueloff and others 1982; Belko and others 1986). Research pertaining to the effects of habitual endurance exercise on RMR and DIT is not as clear. Habitual endurance exercise may increase RMR (Poehlman and others 1989; Thorne and Wahren 1989; Poehlman and others 1988), but it may actually decrease DIT (Tremblay and others 1983; LeBlanc and others 1984; Poehlman and others 1988). Acute resistance exercise, however, does appear to increase DIT (Denzer and others 2003; Oba and others 1999), while habitual resistance exercise increases both RMR and DIT (Thyfault and others 2004; Byrne and Wilmore 2001).

The metabolic changes appear to be especially true when either mode of exercise is performed at a high intensity (Weststrate and Hautvast 1990; Poehlman and others 1989; Thorne and Wahren 1989; Poehlman and others 1988). A portion of these changes may be due to fat-free mass (Meijer and others 1991; Thyfault and others 2004; Ballor and others 1996), while there is not sufficient evidence for any hormonal variations, with the possible exception of insulin (Poehlman and others 1989; Jones and others 2004; Thyfault and others 2004).

## Justification & Purpose

RMR and DIT comprise a large portion of total energy expenditure, which is important in terms of weight gain, weight loss, and energy balance. The other part of total energy expenditure, exercise, is suggested to be the key to fighting obesity, and this battle may require special attention for adults in their early-20's (Williamson and others 1990). Some studies have examined the effects of exercise on RMR and DIT, but only a few have looked at different types of exercise on both RMR and DIT. Moreover, a review of the literature at this time did not yield any direct comparisons of solid vs. liquid meals, and the effects of each on DIT. Also, DIT appears to be more pronounced in men (Meijer and others 1991), so DIT research should probably focus on men at the present time. Therefore, the purpose of the current study was to investigate possible differences in RMR and DIT in college-age males depending on type of habitual exercise and what form (physical structure) of meal they recently consumed.

## Limitations

There exist some limitations to the current study. First, only college-age (19-27 years of age) males participated, so conclusions to the general population may be inaccurate. Also, all subjects were currently residing in the Auburn area, so conclusions to males of similar ages in other geographical regions may be inaccurate. Another limitation is the relatively small sample size. Lack of control over each subject's usual diet, seasonal variations (some subjects participated in August or September, others were much later in the fall), and the fact that biochemical analyses were not performed to measure specific hormonal differences are all limitations. Finally, the researchers relied on all subjects to be honest and comply with requests to refrain from exercise, caffeine, alcohol, and tobacco prior to each visit.

**Null Hypotheses**

1. There will be no significant differences in RMR between groups.
2. There will be no significant differences in DIT between groups.
3. There will be no significant relationship between RMR and DIT
4. There will be no significant differences in DIT between meal forms.
5. There will be no significant difference in the peak DIT time between meal forms.
6. There will not be a significant DIT in any group.
7. There will not be any significant interactions between meal form and group.

CHAPTER III

# RESTING METABOLISM AND METABOLIC RESPONSES TO SOLID AND LIQUID MEALS IN SEDENTARY AND EXERCISING COLLEGE-AGE MALES

**ABSTRACT**

Differences in resting metabolic rate (RMR) were measured in a total of 29 sedentary and exercising college-age males, as were their metabolic responses (diet-induced thermogenesis, DIT) to solid and liquid meals. Subject classification was based on habitual exercise. A group of 9 males was classified as sedentary, 11 males were classified as endurance (aerobic) exercisers, and 9 males were classified as weight lifters (resistance exercise). Resting metabolism was measured soon after waking; DIT for each meal was measured immediately following meal consumption, and then every 30 minutes for 3 hours. All metabolic measurements were via indirect calorimetry, height was determined via stadiometer, and all body composition measurements were done with bioelectrical impedance. No significant differences existed between groups for age, body mass index (BMI), percent body fat, fat-free mass (ffm), percent ffm, and hydration. Moreover, no significant differences existed in DIT based on meal form ($Eta^2 = 0.049$, $F = 1.336$, $p = 0.258$), nor on exercise group ($p = 0.416$). However, there was a significant overall metabolic increase based on group ($Eta^2 = 0.271$, $F = 4.844$, p

= 0.016). Specifically, both exercise groups had a significantly ($p < 0.05$) greater RMR when compared to the sedentary group; this increased RMR indicated that the exercise groups expended more energy at rest than did the sedentary group. There were no significant RMR differences between the exercising groups ($p = 0.843$). RMR and DIT were negatively correlated ($r = -0.38$; $p = 0.023$). The variables positively correlated with RMR include ffm ($r = 0.59$; $p < 0.001$) and BMI ($r = 0.39$; $p = 0.020$). In conclusion, these findings give further support to the importance of exercise, and specifically intense exercise, in amplifying resting metabolic rate and increasing total energy expenditure.

## INTRODUCTION

Over the past few decades, obesity (Body Mass Index (BMI) $\geq 30.0$ kg/m$^2$) rates have climbed to include almost one-third (32.9%) of U.S. adults (CDC 2008d). When the percentage of overweight (BMI 25.0-29.9) U.S. adults is included (33.4%), it becomes obvious that overweight and obesity are very common in adults (CDC 2008c); in fact, obesity has reached epidemic proportions in the United States (Dietz 2002). Many health problems are associated with being overweight or obese, including hypertension, osteoarthritis, high serum cholesterol, high serum triglycerides, Type 2 diabetes, heart disease, stroke, some forms of cancer, sleep apnea, respiratory conditions, and others (CDC 2008d). Moreover, Bray (1986) points out that obesity may be frowned upon socially and carry numerous educational and employment disadvantages with it.

It should come as no surprise that the aforementioned health problems have a substantial economic impact. Some of this impact involves the direct medical costs for prevention, diagnosis, and treatment of overweight and obesity, and some of the economic impact involves the indirect costs – things such as decreased productivity, absenteeism, and loss of future income due to premature death. All totaled, it is estimated that at least 117 billion dollars is spent annually for medical expenses related to overweight and obesity (Dietz 2002), and approximately half of that is paid by Medicaid and Medicare (CDC 2008b).

There may be numerous pieces to the obesity puzzle, and genetic factors appear to play at least some role. Bouchard and others (1989) determined that genotype differences comprise ~40% of our resting metabolic rate (RMR). However, "except for the very rare cases of monogenic origin, obesity results from a polygenic disorder (Jequier 2002)."

Overweight and obesity can often be viewed from a practical standpoint as an energy imbalance (energy intake vs. energy output). Jequier (2002) states the energy balance equation in terms of energy storage:

Energy stored = Energy intake – Energy output in urine & feces – Energy expenditure.

Small, almost immeasurable, imbalances in the above equation over an extended period of time can account for as much as a 5 kg (11 lb.) weight gain per year (Jequier 2002). Overweight and obesity in this context are the result of excess energy (calorie) intake, inadequate energy output, or both (CDC 2008). Energy intake is simply calories ingested, but energy output has at least three components: resting metabolic rate (RMR), physical activity, and diet-induced thermogenesis (DIT), also known as the thermic effect of food (TEF). The proportions contributed to energy output from each component vary per person. RMR as a percentage of energy output tends to change as exercise increases or decreases (Weststrate and Hautvast 1990); in fact, RMR can account for as much as 80% of total energy output in a very sedentary person, or as little as 30% in someone with very high levels of exercise (Tremblay and others 1985). Physical activity may contribute only 15% of overall energy expenditure in an extremely sedentary individual, but it generally contributes somewhere around 30% (Poehlman 1989). DIT includes the energy used for digestion, absorption, and nutrient storage (Tremblay and others 1985); it is thought to account for ~10% of total energy output (Oba and others 1999; Weststrate and Hautvast 1990). This represents only a small part of total energy output, but this may be important over time and with respect to combating obesity (King and Tribble 1991; Oba and others 1999).

Some studies have shown that exercise (purposeful physical activity) can affect both RMR and DIT (Poehlman and others 1988; Poehlman and others 1989), but others (Tremblay and others 1983; LeBlanc and others 1984) have not reported similar findings. These studies have only focused on endurance exercise; research focused on resistance exercise (weight lifting) and DIT is limited, but it appears that resistance exercise increases RMR and DIT (Thyfault and others 2004; Byrne and Wilmore 2001). Meal form, composition, and content may also play an important role in DIT (Thorne and Wahren 1989); however, no studies to date have examined different types of habitual exercise and their effects on RMR and DIT after different forms of meals. The purpose of this study, therefore, was to determine the effects of endurance exercise and resistance exercise on RMR and DIT in college-age males after the consumption of different meal forms. The role of meal forms themselves on DIT was also examined.

# SUBJECTS AND METHODS

## Subjects

Subjects were recruited via flyers (Appendix A) posted within the Auburn University campus, specifically the Student Activities Center, the Poultry Science Building, and Spidle Hall, after Auburn University Institutional Review Board approval was granted (# 07-125EP0705). Approximately 45 males were recruited, all of whom needed to be 19-28 years old, healthy, and free of milk, peanut, and chocolate allergies. It was desired to have at least eight subjects in each of the three groups, and it was desired that these groups did not differ in BMI and body composition measurements in order to eliminate confounding variables.

Each subject was initially screened over the phone or e-mail to ensure he qualified. Exclusion criteria included, but was not limited to: subjects being too young or too old, or not meeting the definition for resistance training, endurance training, or sedentary; a recent change in exercise patterns; use of stimulant or depressant medications; currently following a strict fad or medically-prescribed diet; presence of nut, chocolate, or milk allergy. Subjects were not excluded if currently using or consuming alcohol, tobacco, caffeine, and/or dietary supplements; however, subjects were asked to refrain from using caffeine, alcohol, and dietary supplements for 24 hours prior to visits during which metabolism was measured. In addition, subjects were asked to refrain from tobacco products the morning of these visits.

If subjects answered "YES" to any of the allergy questions on the questionnaire (Appendix C), they were excluded because both experimental conditions (liquid and solid meal of equal caloric content) contained nuts, chocolate, and/or milk. Subjects were also excluded if they had an illness or infection within the last 7 days because illness or infection often increases resting metabolic rate. Exclusion was also due to answering "YES" to current usage of a prescription medication if that medication, when checked in the Physicians' Desk Reference, was known to affect metabolic rate. Finally, subjects were excluded if their exercise habits (based on questionnaire, Appendix C) fell somewhere between the definitions of sedentary, resistance trained, or endurance trained, as well as if subjects had been following a strict fad or medically-prescribed diet since an abrupt change may alter metabolism.

Study Design and Methods

Subjects reported 2 times for a total of about 8 hours. Visit 1 included completion of the medical and exercise history questionnaires (Appendix C), as well as the Informed Consent documentation (Appendix D) and Demographic Information page (Appendix B). This visit also included height measurement with a measuring tape in addition to body weight, hydration, and body composition via scale and bioelectrical impedance (Tanita; Arlington Heights, IL). These measurements took place privately in Room 204, Auburn University Student Activities Center.

Each subject was classified into 1 of 3 groups (resistance trained, endurance trained, or sedentary) based on their answers to the exercise history questionnaire (Appendix C). Resistance training was defined as 3 or more 1-hour weight lifting sessions per week (Treuth and others 1995); endurance training was defined as regular running or jogging for greater than 1 hour per week (Meijer and others 1991); sedentary was defined as no more than 2 half-hour exercise sessions per week (Treuth and others 1995).

Subjects were randomly assigned to Meal Group 1 or Meal Group 2. The principal investigator was blinded as to which subjects were assigned to which group. Meal Group 1 received a solid meal on their first trial and a liquid meal on their second trial. Meal Group 2 received a liquid meal on their first trial and a solid meal on their second trial. Each meal consisted of 570 calories and varied in form (solid vs. liquid); solid meals were Slim Fast High-Protein bars, while liquid meals were Slim Fast High-Protein shakes. The meals varied slightly in macronutrient composition. The solid meal (bars) was 42% carbohydrate, 31% protein, and 27% fat; the liquid meal (shakes) was 46% carbohydrate, 31% protein, and 23% fat.

After anthropometric measurement and questionnaire completion, subjects were transported by the principal investigator to Room 116, Auburn University Poultry Science Building. Each subject sat quietly for 5-10 minutes prior to his resting metabolism measurement. Resting metabolism of subjects was measured between 6:00 and 9:00 a.m., depending on each subject's daily schedule. Resting metabolism and DIT were both measured using MedGem (Healthetech; Golden, CO), a handheld, FDA-approved, indirect calorimeter that has been validated to measure resting metabolism (Stewart and others 2005) and DIT (St-Onge and others 2004). Measurements were recorded on a specified sheet for that subject (Appendix E). Each subject had his own mouthpiece and noseclip to minimize risk of contamination. Subjects then had 15-20 minutes to consume the meal, after which DIT was measured every 30 minutes for the next 3.5 hours. During the periods when DIT was not being measured, subjects were allowed to read or study, and were given water and bathroom breaks as desired.

Visit 2 lasted about the same length of time; it included very similar procedures with the exception being meal form. There was a minimum of 4 days between visits.

This was a crossover design where the experimental conditions (liquid or solid meal of equal caloric content) were initially made by random assignment. Thus, in a counterbalanced manner, each subject performed the experiment on two different occasions, separated by a minimum of 4 days.

**Statistical Analysis**

Statistical analyses were performed using SPSS (Statistical Package for the Social Sciences, Inc., Version 16.0, 2007, Chicago, IL) and SigmaPlot (Statistical Package for the Social Sciences, Inc., Version 8.0, 2002, Chicago, IL). Regression analysis was utilized in order to determine relationships between age, BMI, FFM, percent FFM, percent body fat, hydration, RMR, relative RMR, DIT, and relative DIT. Relative RMR and relative DIT were calculated as RMR and DIT, respectively, divided by FFM (Thyfault and others 2004; Poehlman and others 1988; Tremblay and others 1983). Analysis of variance (ANOVA) was used to detect possible significant ($p < 0.05$) differences in the above variables when compared by group. Repeated measures analysis was used to determine the effects of time, meal form, overall group differences, and combinations thereof. Paired-samples t-tests were applied to compare values at each time point. ANOVA also served as the means by which RMR and DIT were compared based on group; when a significant ($p < 0.05$) difference was found, post-hoc multiple comparisons were made via LSD, Bonferroni, and Tukey tests.

# RESULTS

Included in this section are the findings of the current study, beginning with an overview of those who participated. The information then progresses into more detail for the study's two independent variables, meal form and exercise group. Specific attention is paid to the effects of the independent variables on RMR and DIT.

A total of 32 participants (10 sedentary, 12 endurance exercisers, 10 resistance exercisers) completed all forms and took part in the study. However, one participant in the resistance training group did not return for the second visit, so he was excluded. Two participants, one each from the sedentary and endurance exercise groups, had markedly inconsistent values at different measurement times, so they were excluded. The final tally included 29 participants (9 sedentary, 11 endurance exercisers, and 9 resistance exercisers) who completed the entire study. All participants reported being free from milk, peanut, and chocolate allergies; all were male; all were between the ages of 19-27 years old. Of the 9 sedentary subjects, 4 of them reported having no regular physical activity for at least the past year, and the remaining 5 each reported 1 cardiovascular (endurance) exercise session per week as part of a group activity such as ultimate frisbee or flag football. The endurance exercisers averaged approximately 4.5 cardiovascular (endurance) exercise sessions per week. The resistance exercisers averaged approximately 3.8 weight-lifting sessions per week.

## Group Characteristics & Differences

The primary independent variable in the current study was exercise group. Table 1 includes the variables measured in the current study, as well as their means and ranges. These variables were analyzed to determine differences based on group.

Across the three groups, RMR is the only variable that is significantly different (Table 1: F = 3.489; p = 0.045). In other words, the groups showed no significant differences in BMI, age, body fat, FFM, percent FFM, hydration, total DIT (area-under-the-curve), relative DIT, and relative RMR.

Effect of Meal Form

The second independent variable in the current study was meal form (SlimFast High-Protein bars and SlimFast High-Protein shakes). No significant differences existed in DIT between meal forms (Figure 1; Table 2: $Eta^2 = 0.049$, F = 1.336, p = 0.258). When participants consumed shakes, metabolic rate peaked at post-meal + 60 minutes (2548 calories/24 hrs); with the bars, DIT peaked at post-meal + 30 minutes (2471 calories/24 hrs). At post-meal + 60 minutes, DIT was significantly greater for the shakes than for the bars (2548 calories/24 hrs vs. 2458 calories/24 hrs; p = 0.031). However, for the entire 3-hour DIT period, there was no significant effect of meal form over time (Table 2: $Eta^2 = 0.042$, F = 1.148, p = 0.335). Also seen in Table 2, there was no significant effect of the meal form based on exercise group ($Eta^2 = 0.017$, F = 0.228, p = 0.797), nor was there a significant relationship when comparing the meal effects of the groups over time ($Eta^2 = 0.089$, F = 1.271, p = 0.229). Because these findings indicate a lack of significance pertaining to meal form (SlimFast High-Protein bars and shakes), each participant's respective measurements for the different meal forms were averaged at each time point.

Group Effects on RMR and DIT

Table 3 displays the mean group values for RMR and DIT at each time point. Also included is the absolute and percent change from RMR at each time point. RMR

(Table 3 and Fig. 2) was significantly greater in the endurance exercisers compared to the sedentary group (2100 calories/24 hrs vs. 1894calories/24 hrs; $p = 0.032$), and RMR was significantly greater in the resistance exercisers than in the sedentary group (2118 calories/24 hrs vs. 1894 calories/24 hrs; $p = 0.027$). There was no significant difference in RMR between the endurance and resistance exercise groups. The resistance group had a slightly higher RMR than the endurance group (2118 calories/24 hrs vs. 2100 calories/24 hrs), but this was not significant ($p = 0.843$).

Metabolic measurements (Table 3 and Fig. 2) were significantly ($p < 0.05$) greater at each time point for the resistance exercise group when compared to the sedentary group. When comparing the endurance exercise group to the sedentary group, DIT values were significantly greater in the endurance exercisers at post-meal + 30 minutes ($p = 0.040$), post-meal + 60 minutes ($p = 0.044$), and post-meal + 120 minutes ($p = 0.049$). DIT values between the resistance and endurance exercise groups were not significantly different at any time point ($p > 0.05$).

When expressed as a percentage above RMR, DIT values (Table 3 and Fig. 3) were not significantly different between groups at any time point ($p > 0.05$). The values were highest for the resistance exercise group. When examining average DIT values per group (AUC: area under the curve; the total DIT area above RMR for each group; Fig. 4), the resistance exercise group had the greatest value, but again, the group effect was not significant (Table 1: $F = 0.908$, $p = 0.416$).

The DIT peak for the sedentary group occurred at post-meal + 60 minutes (2308 calories/24 hrs); for the endurance exercise group, the DIT peak also occurred at post-meal + 60 minutes (2528 calories/24 hrs). However, for the resistance exercise group, the DIT peak did not occur until post-meal + 90 minutes (2670 calories/24 hrs). Still in all, neither the average DIT nor the average relative DIT was significantly different by group (Table 1).

Effects of Group and Time

From Table 2, it is evident that a significant effect exists based on group ($Eta^2$ = 0.271, F = 4.844, p = 0.016), and a significant effect exists based on time ($Eta^2$ = 0.670, F = 52.903, p < 0.001). However, there was not a significant interaction in the groups over time ($Eta^2$ = .070, F = 0.986, p = 0.470). These data can be interpreted as saying that the energy expended by the subjects depended on what group they were in, but the response to either meal over time did not depend on group.

Correlates with RMR and DIT

The current study examined two primary outcomes, RMR and DIT. Variables measured and their relationships with RMR and DIT are in Table 4. These two outcomes correlated negatively with each other (r = -0.38, p = 0.023). The variables positively correlated with RMR include relative RMR (r = 1.00, p < 0.001), FFM (r = 0.59, p < 0.001), and BMI (r = 0.39, p = 0.020). In addition to the negative correlation for DIT with RMR (noted above), relative DIT correlated negatively with RMR (r = -0.47, p = 0.005). Percent body fat tended to correlate positively with RMR (r = 0.30, p = 0.058); percent FFM (r = -0.30, p = 0.058) and hydration (r = -0.28, p = 0.068) tended to correlate negatively with RMR. Age was not correlated to RMR (r = 0.12; p = 0.264).

Table 4 also displays the relationships between DIT and the study's variables. Unlike the number of variables correlated to RMR, only relative DIT displays a significant positive correlation with DIT ($r = 0.98$; $p < 0.001$), and only RMR displays a significant negative correlation with DIT (noted above). No significant relationship exists between DIT and BMI ($r = 0.02$; $p = 0.456$), age ($r = -0.11$; $p = 0.280$), percent body fat ($r = -0.03$; $p = 0.434$), percent FFM ($r = 0.03$; $p = 0.435$), FFM ($r = -0.24$; $p = 0.109$), hydration ($r = 0.02$; $p = 0.454$), and relative RMR ($r = -0.21$; $p = 0.142$).

## DISCUSSION

### Resting Metabolic Rate

It was hypothesized that there would be no significant differences in RMR between groups. However, the RMR of both exercise groups (endurance exerciser, weight lifters) was significantly greater than that of the sedentary group (Table 1; Table 3; Figure 2). This does not appear to be the result of any physical or body composition measurement recorded (age, BMI, % body fat, fat-free mass, % fat-free mass, or hydration) because there were no between-group differences in any of these measurements (Table 1). This finding is in line with that of Poehlman and others (1988), Poehlman and others (1989), Thorne and Wahren (1989), Byrne and Wilmore (2001), and Thyfault and others (2004) who found an increased RMR in exercising subjects, although none of these studies directly compared RMR for endurance and resistance exercisers.

Poehlman and others (1988) contend that exercise has a role in RMR separate from body composition, and specifically apart from adiposity. They speculate some sort of increase in metabolic activity, possibly with an increased synthesis of proteins in muscle that is not connected with specific body composition measurements, but they are not certain.  Thorne and Wahren (1989) concur with increased RMR in well-trained subjects, but they also are unsure of an exact explanation.

The most likely explanation for the current finding of both exercising groups having increased RMR is that subjects in these groups frequently worked at high levels of intensity.  Weststrate and Hautvast (1990), Poehlman and others (1988), and Poehlman and others (1989) all concluded that intense exercise can increase RMR. Subjects in both Poehlman and others (1988; 1989) studies were highly-trained, competitive endurance athletes, as were those in the Thorne and Wahren (1989) study. Exercising subjects in the current investigation were not necessarily competitive athletes on a collegiate team (although some endurance exercisers were members of a cycling club), but all were frequent exercisers, often at an intense level.

A second possible explanation is that habitual exercise (either endurance or resistance) induces a hormonal change that in turn increases RMR.  An obvious hormonal explanation for RMR differences could be accounted for by thyroid hormones, specifically $T_3$ and $T_4$.  However, that does not appear to be the case (Poehlman and others 1988; Poehlman and others 1989; Thorne and Wahren 1989). Poehlman and others (1989) reported that insulin levels were consistently lower during RMR measurements in their highly-trained group, and Thyfault and others (2004) showed similar findings with resistance exercise.  Specific to the current study, one can surmise that an analysis of various hormones would reveal concentrations at least somewhat similar to the above studies, but the current study did not examine any biochemical markers.

One further possibility accounting for the increased RMR in both exercising groups is the residual effect of recent exercise. In other words, if subjects in both exercising groups had not followed protocol (no exercise within 24 hours of each visit), then that could be an explanation for increased RMR in those groups because exercise can increase metabolic rate by as much as 23% for up to 13 hours after exercise. This is a possibility, but with the significance of each exercising group's RMR above that of the sedentary group, coupled with the proximity of within-groups RMR measurements, this explanation is unlikely. It is more likely that exercise, regardless of the type, at a habitually-moderate or greater level of intensity, common to both the endurance-trained and resistance-trained subjects in this study, confers increased metabolic activity in the tissues of the body. The current study occurred at least 24 hours post-exercise, a time frame that appears to minimize the residual effects of exercise (Poehlman 1989), as well as one that was seen in all publications reviewed.

Diet-induced Thermogenesis

It was also hypothesized that there would be no significant differences in DIT between groups; this is true. DIT (area-under-the-metabolic-curve, RMR serving as a baseline) is not significantly different between the 3 groups (Tables 1 & 3; Figs. 3 & 4). While the initial appearance of DIT is greatest in the resistance-training group (Fig. 2), that is only because RMR is greatest in this group. When DIT is expressed as a percent change from RMR at each time point (Fig. 3), these DIT values are not significantly different at any point post-meal based on group. This trend of similar DIT holds true when all DIT per each group are averaged together for a total area-under-the-metabolic-curve (Fig. 4). Another way of stating all this is to say that the overall shapes of the metabolic curves are very similar. The energy expenditure from RMR and DIT is greatest in the exercising groups, and specifically greatest in the resistance training group, but this is primarily the effect of RMR. Simply put exercise has no significant effect on DIT in this population.

Thorne and Wahren (1989) showed results much like those of the current study with no significant differences in DIT between their highly-trained and sedentary groups of men. If the majority of exercisers in the current study are also highly-trained, then a finding of no significant DIT differences would be similar, especially since this is also what Samueloff et al (1982) found. Further evidence of the possibility that DIT is not really influenced by exercise is provided by Ohnaka and others (1998). They measured DIT for 4 hours and were unable to find any significant differences; they conclude that DIT may be more related to meal size and content than it is to fitness levels.

On the other hand, Tremblay and others (1983) found DIT to be significantly higher in untrained, sedentary subjects. Poehlman and others (1988) showed a similar finding of increased DIT in their sedentary group. Both investigations were in males and revolved around endurance training. LeBlanc and others (1984) also revealed a greater DIT in untrained female subjects. The authors propose that the untrained, sedentary subjects have a much greater percentage of ingested macronutrients, particularly glucose, going towards fat storage rather than glycogen storage (Tremblay and others 1985). Because the conversion of glucose to fat requires a greater energy cost than that of glucose to glycogen (LeBlanc and others 1984), DIT in untrained, sedentary subjects is higher.

Resistance training appears to have a consistent effect of increasing DIT. Denzer and Young (2003) found a significantly greater DIT after an acute bout of resistance training (weight lifting), and Thyfault and others (2004) found increased DIT in those who habitually performed resistance training. The current study examined habitual weight lifters (much the same as Thyfault and others 2004), but there were no significant differences in the DIT of any group (Fig. 4).

There are a number of possibilities as to why a discrepancy exists in the literature of exercise's effects on DIT. The most probable reason is that different studies have used different designs. Some studies included acute bouts of exercise before or after the DIT test meal (Weststrate and Hautvast 1990; Samueloff and others 1982; Belko and others 1986; Ohnaka and others 1998; Denzer and Young 2003; Oba and others 1999). Other studies simply took a cross-sectional view of DIT in habitual exercisers (Meijer and others 1991; Poehlman and others 1988; Poehlman and others 1989; Thorne and Wahren 1989; Tremblay and others 1983; LeBlanc and others 1984; Thyfault and others 2004; Ballor and others 1996; Bryner and others 1999; Byrne and Wilmore 2001); this was the case for the current study.

Another suggestion for the different findings with respect to DIT lies in the intensity of exercise. If the study involves an acute bout of post-meal exercise, then intensity may need to be somewhat low to prevent gastrointestinal discomfort. If the study involves habitual exercise, then the same issues arise as were the case for RMR; namely, it may be difficult to find a sufficient sample of subjects who exercise at a similar intensity and frequency (Poehlman 1989). The current study includes groups of subjects who perform similar modes of exercise within each group, and they appear to exercise at somewhat similar, if not very similar, levels of intensity and frequency.

Three other items to consider with respect to varied DIT findings in exercisers are heredity, nutritional status, and hormonal variations. Samueloff and others (1982) suggest that certain DIT differences have a genetic basis; that is to say that some people simply have a greater DIT, or they have a greater sensitivity to the factors which may affect DIT. These authors also believe that one's underlying nutritional status can affect how he/she metabolizes a meal and, therefore, his/her DIT. It has been suggested that hormone levels may also have some bearing on DIT. No DIT differences in thyroid hormone concentrations were noted in any of the literature reviewed. However, Poehlman and others (1989) and Thyfault and others (2004) found significantly decreased DIT levels of insulin in exercising subjects compared to sedentary subjects. Meanwhile, Thorne and Wahren (1989) showed a significant increase in plasma adrenaline (epinephrine) during DIT in well-trained subjects. As was the case with RMR and hormone levels, one can only surmise what could be the relationship between DIT and hormone levels because the current study did not examine any biochemical markers.

Finally, it may be of interest to note that the DIT values had not returned to baseline (resting) metabolic values by 180 minutes post-meal (Table 2; Figs. 2 & 3). It was hypothesized that there would not be a significant DIT response in any of the groups, but there was a significant DIT response in all the groups (Table 3, effect of time: $Eta^2 = 0.670$; $p < 0.001$). This finding is consistent with almost every other study, the two exceptions being Tremblay and others (1983) and LeBlanc and others (1984) because DIT values in exercising groups during those studies returned to normal within 2 hours, but the authors do not suggest a reason. This 2-hour DIT period seems abnormal; in fact, Poehlman (1989) suggests that it may take as long as 5-8 hours for DIT values to return to baseline (resting).

RMR, DIT, and Energy Balance

The relationship between RMR and DIT may need further study. Some studies (Tremblay and others 1983; Poehlman and others 1988; LeBlanc and others 1984) noted greater DIT in sedentary subjects; other studies (Poehlman and others 1989; Thyfault and others 2004) showed increased DIT in exercising subjects. It was hypothesized in the current study that there would not be a significant relationship between RMR and DIT. In the current study, there existed a significant inverse relationship ($r = -0.38$; $p = 0.02$) between RMR and DIT (Table 4). Tremblay and others (1983) contend that those who exercise frequently have conditioned their bodies to conserve energy during DIT, and they suggest that carbohydrates are therefore simply being converted to glycogen.

It may also be possible that the body tries to maintain a physiological energy balance, and thereby maintain a consistent body weight. In other words, it may be possible that the body expends additional energy via DIT if one has a rather low RMR. If this is true, and if it is true that DIT decreases with age (Jones and others 2004), then DIT does play a critical role in adult obesity and long-term energy balance (de Jonge and Bray 1997). In the current study, RMR and DIT had a significant negative correlation, but DIT did not differ by exercise group.

Meal Form

Finally, it was hypothesized that there would be no significant differences in DIT between meal forms or in peak DIT time, as well as no significant interactions between meal form and group. While much of the above discussion focused on exercise group and how components of energy expenditure may vary based on this, the effects of meal form (solids vs. liquids) do not appear to play a significant role in DIT and overall energy expenditure (Table 2; Fig. 1), provided that components and contents of those solid and liquid meals are similar.

Prior to Visit 1, subjects were randomly assigned to consume either three (3) SlimFast High-Protein bars or shakes; subjects consumed the alternate meal form during Visit 2. Limited, if any, research has been done specifically to investigate how changing the form of a meal (solid vs. liquid) may alter DIT. Related research has shown that protein induces the greatest thermogenic response (Jequier 2002), although using medium-chain triglycerides instead of long-chain triglycerides can significantly increase the DIT of lipids (Kasai and others 2002). Alternatively, changes in fiber content of a mixed meal do not appear to play a significant role in DIT (Khoussousi and others 2008). However, Peracchi and others (2000) found an increase in DIT over a 5-hour period when a mixed meal was homogenized.

The current study can be considered as using two unique forms (solid vs. liquid) of a homogenized mixed meal, and no significant DIT differences existed between the two forms. This is highlighted in Table 2 and again in Figure 1. The shakes did induce a significantly greater DIT peak at 60 minutes post-meal (2548 kcals/24 hrs vs. 2458 kcals/24 hrs; $p = 0.031$), which may be somewhat contrary to the findings of Clemente and others (2003), who showed no difference in gastric emptying rate between solids and liquids. However, there was not a significant effect of meal form in the entire sample of subjects over the 3-hour DIT period. Furthermore, there was no significant interaction of meal form by group, meal form by time, or meal form by group by time (Table 2).

Therefore, provided that differences in lipid form, protein content, and homogenization of meals are negligible, it does not appear that the form (solid vs. liquid) of a meal has a substantial effect on DIT. As previously mentioned with the shapes of the DIT curves for each group (Fig. 2), the overall shapes of the DIT curves for each meal (Fig. 1) are pretty similar. The current study made certain to keep the caloric load of the meals equal (570 kcals), so these findings may provide additional support to the suggestion that caloric load is of primary importance with respect to DIT (Samueloff and others 1982).

In conclusion, a number of factors may affect the components of energy expenditure. The current study examined the three significant components of energy expenditure in college-age males, and it was determined that resting metabolic rate, but not diet-induced thermogenesis, was significantly greater in groups of habitual exercisers. Also, provided that caloric load and nutrient content are kept constant, it does not appear that meal form (solid vs. liquid) plays a substantial role in diet-induced thermogenesis in college-age males. The sum of these findings give further support to the importance of exercise, specifically frequent and intense exercise, in amplifying resting metabolic rate and increasing total energy expenditure.

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**Table 1:** Study variables, means, ranges, and differences between groups

| Variable | Mean | Range | Sedentary (± SD) | Endurance (± SD) | Resistance (± SD) | F-value | Sig. |
|---|---|---|---|---|---|---|---|
| BMI ($kg/m^2$) | 24.3 | 19.8-29.5 | 23.8 ± 3.0 | 24.6 ± 2.5 | 24.4 ± 2.4 | 0.212 | 0.810 |
| Age (years) | 22.2 | 19-27 | 22.1 ± 1.5 | 22.7 ± 1.9 | 21.8 ± 2.5 | 0.605 | 0.554 |
| Body Fat (%) | 14.8 | 6.0-23.9 | 15.3 ± 6.4 | 14.8 ± 4.5 | 14.2 ± 4.0 | 0.114 | 0.893 |
| Fat-Free Mass (lbs.) | 146.9 | 123.8-168.1 | 142.8 ± 12.6 | 149.8 ± 15.2 | 147.5 ± 11.0 | 0.718 | 0.497 |
| Fat-Free Mass (%) | 85.2 | 76.1-94.1 | 84.7 ± 6.5 | 85.3 ± 4.5 | 85.8 ± 4.0 | 0.113 | 0.894 |
| Hydration (%) | 62.4 | 55.7-68.8 | 61.9 ± 4.7 | 62.5 ± 3.3 | 62.8± 2.9 | 0.123 | 0.885 |
| DIT (area-under-the-curve; kcals x 180 min) | 3599 | 495-5660 | 3615 ± 1319 | 3198 ± 1539 | 4072 ± 1442 | 0.908 | 0.416 |
| Relative DIT (DIT/ffm) | 25 | 3.2-40.9 | 26 ± 10 | 22 ±11 | 28 ± 10 | 0.786 | 0.466 |
| RMR (kcals/24 hrs) | 2041 | 1650-2475 | 1894 ± 226 | 2100 ± 204 | 2118 ± 173 | 3.489 | 0.045 |
| Relative RMR (RMR/ffm) | 14 | 11.9-18.1 | 13 | 14 | 14 | 2.149 | 0.137 |

**Table 2:** Effects of group, meal, and time

| **Between-Subjects** | **df** | **MS** | **F-value** | **$Eta^2$** | **Significance** |
|---|---|---|---|---|---|
| Group | 2 | 3315744.392 | 4.844 | 0.271 | p = 0.016 |
| Error (group) | 26 | 684545.591 | | | |
| **Within-Subjects** | | | | | |
| Meal | 1 | 165249.397 | 1.336 | 0.049 | p = 0.258 |
| Meal x Group | 2 | 28260.850 | 0.228 | 0.017 | p = 0.797 |
| Error (meal) | 26 | 123705.730 | | | |
| Time | 7 | 1332262.831 | 52.903 | 0.670 | p < 0.001 |
| Time x Group | 14 | 24823.705 | 0.986 | 0.070 | p = 0.470 |
| Error (time) | 182 | 25183.275 | | | |
| Meal x Time | 7 | 15255.542 | 1.148 | 0.042 | p = 0.335 |
| Meal x Time x Group | 14 | 16890.160 | 1.271 | 0.089 | p = 0.229 |
| Error (meal x time) | 182 | 13293.642 | | | |

**Table 3:** Mean (± SD) values for RMR and DIT based on group

| Time | Average | Sedentary | Endurance | Resistance | F-value; Sig. |
|---|---|---|---|---|---|
| RMR (kcals/24 hrs) | 2041 ± 220 | 1894 ± 226 | 2100 ± 204 | 2118 ± 173 | F = 3.489; p = 0.045 |
| Post-meal (PM) (kcals/24 hrs) | 2286 ± 278 | 2109 ± 227 | 2316 ± 249 | 2426 ± 288 | F = 3.568; p = 0.043 |
| Change from RMR at PM | 245 (12%) | 215 (11%) | 216 (10%) | 308 (15%) | F = 0.858; p = 0.436 |
| PM +30 (kcals/24 hrs) | 2477 ± 270 | 2289 ± 302 | 2526 ± 222 | 2603 ± 203 | F = 4.090; p = 0.029 |
| Change from RMR at PM +30 | 436 (21%) | 395 (21%) | 426 (20%) | 485 (23%) | F = 0.597; p = 0.558 |
| PM +60 (kcals/24 hrs) | 2503 ± 266 | 2308 ± 289 | 2528 ± 213 | 2668 ± 182 | F = 5.558; p = 0.010 |
| Change from RMR at PM +60 | 462 (23%) | 414 (22%) | 428 (20%) | 550 (26%) | F = 1.757; p = 0.192 |
| PM +90 (kcals/24 hrs) | 2472 ± 294 | 2282 ± 299 | 2465 ± 269 | 2670 ± 195 | F = 5.050; p = 0.014 |
| Change from RMR at PM +90 | 431 (21%) | 388 (20%) | 365 (17%) | 552 (26%) | F = 2.380; p = 0.112 |
| PM +120 (kcals/24 hrs) | 2438 ± 249 | 2263 ± 278 | 2468 ± 224 | 2577 ± 139 | F = 4.709; p = 0.018 |
| Change from RMR at PM +120 | 397 (19%) | 369 (19%) | 368 (18%) | 459 (22%) | F = 0.978; p = 0.389 |
| PM +150 (kcals/24 hrs) | 2384 ± 232 | 2244 ± 229 | 2420 ± 227 | 2478 ± 194 | F = 2.824; p = 0.078 |
| Change from RMR at PM +150 | 343 (17%) | 350 (18%) | 320 (15%) | 360 (17%) | F = 0.150; p = 0.861 |
| PM +180 (kcals/24 hrs) | 2332 ± 231 | 2211 ± 265 | 2336 ± 206 | 2449 ± 177 | F = 2.685; p = 0.087 |
| Change from RMR at PM +180 | 291 (14%) | 317 (17%) | 236 (11%) | 331 (16%) | F = 1.201; p = 0.317 |
| Average (kcals/24 hrs) | | 2225 | 2403 | 2498 | |

**Table 4:** Study variables and their relationships to RMR and DIT

| Variable | RMR | DIT |
|---|---|---|
| RMR (kcals/24 hrs) | --- | r = -0.38; p = 0.023 |
| DIT (area-under-the-curve) | r = -0.38; p = 0.23 | --- |
| Relative RMR (RMR/FFM) | r = 1.00; p < 0.001 | r = -0.21; p = 0.142 |
| Relative DIT (DIT/FFM) | r = -0.47; p = 0.005 | r = 0.98; p < 0.001 |
| Fat-Free Mass (FFM) (lbs.) | r = 0.59; p < 0.001 | r = -0.24; p = 0.109 |
| BMI (kg/m$^2$) | r = 0.39; p = 0.020 | r = 0.02; p = 0.456 |
| Body Fat (%) | r = 0.30; p = 0.058 | r = -0.03; p = 0.434 |
| Fat-Free Mass (FFM) (%) | r = -0.30; p = 0.058 | r = 0.03; p = 0.435 |
| Hydration (%) | r = -0.28; p = 0.068 | r = 0.02; p = 0.454 |
| Age (years) | r = 0.12; p = 0.264 | r = -0.11; p = 0.280 |

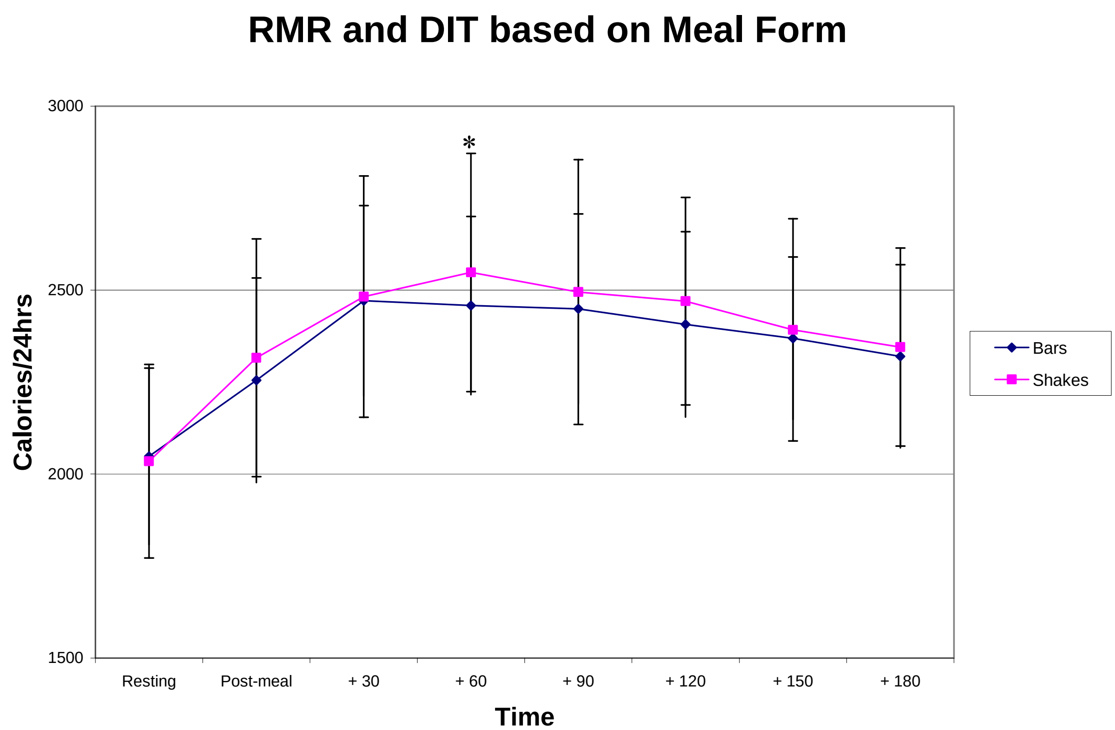


Figure 1: DIT based on meal form. Figure includes means +/- SD for all subjects combined at each time point and representing data for consumption of bars (●) and shakes (■). * indicates statistical significance ($p < 0.05$) between bars and shakes at a given time point. There was no overall DIT difference in meal forms over 180 min.

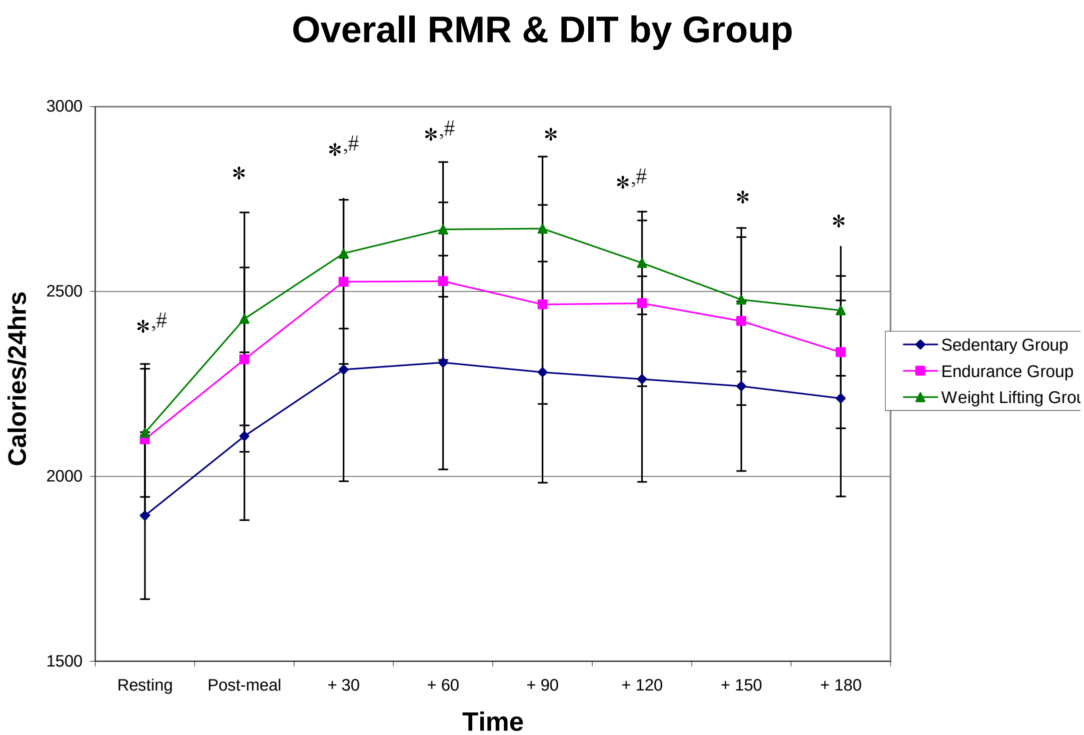


Figure 2: RMR and DIT measurements based on group. Figure includes means +/- SD at each time point for the average measurements of meal forms for sedentary (♦), endurance (■), and weight lifting (▲). * indicates statistical significance ($p < 0.05$) for weight lifting vs. corresponding sedentary group value; # indicates statistical significance ($p < 0.05$) for endurance vs. corresponding sedentary group value. No significant differences existed between the two exercising groups for values at any corresponding time points.

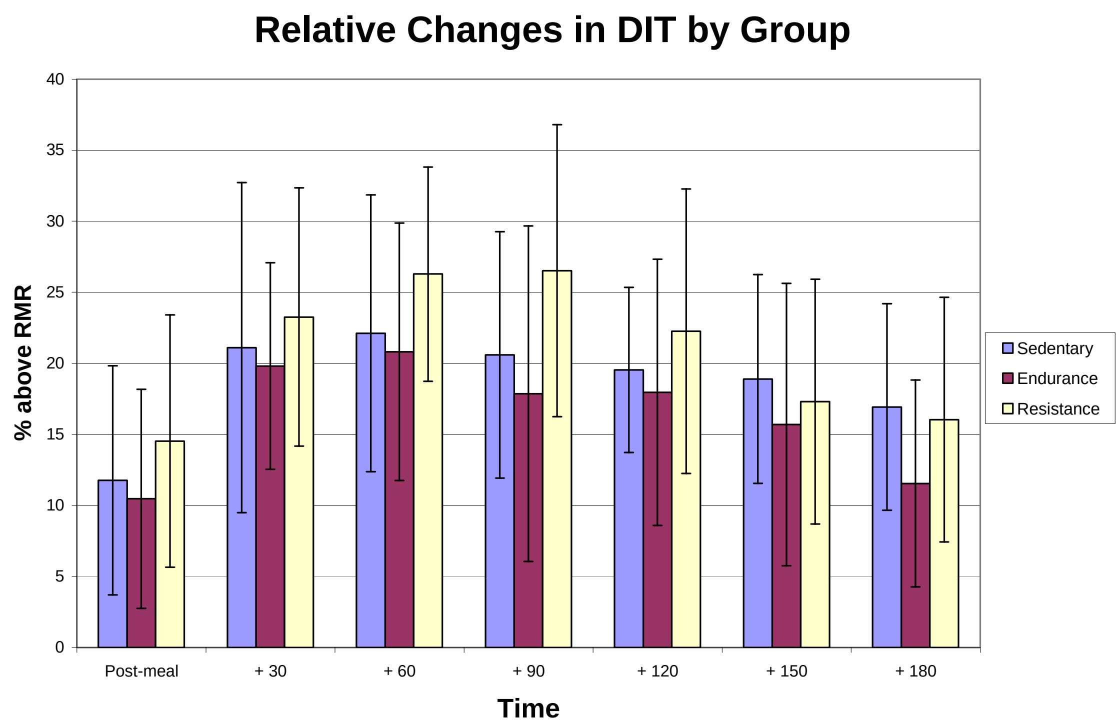


Figure 3: Relative changes in DIT by group. Figure includes means +/- SD of DIT values, expressed as a percentage above baseline (RMR) at each post-meal time point, for the average measurements of meal forms. No statistical significant differences were present.

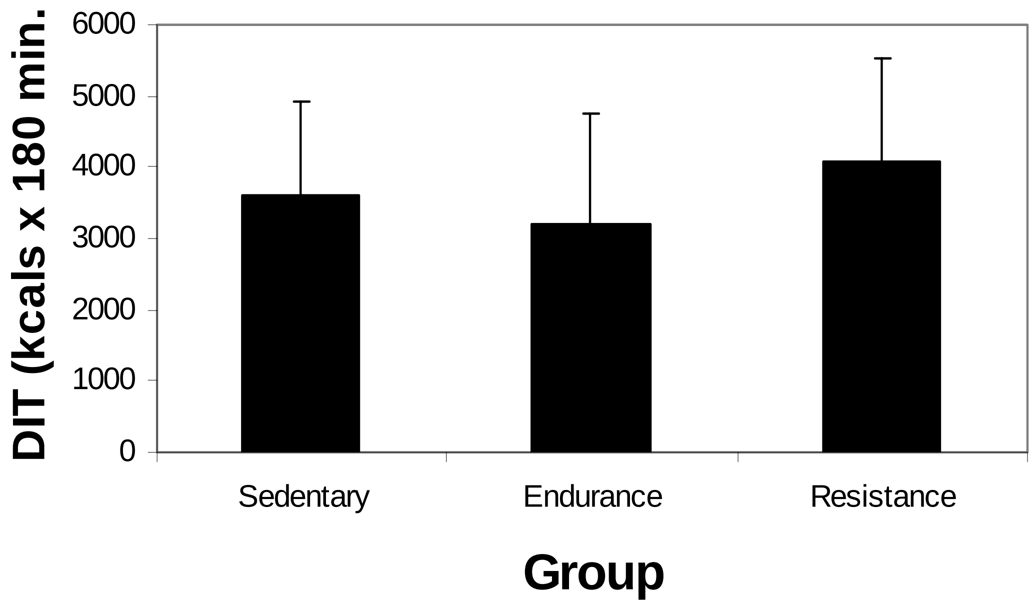


Figure 4: Total area-under-the-curve DIT by group. Figure includes means ± SD of DIT values for the average measurements of meal forms for each group. No statistical significant differences were present.

## CHAPTER IV

## SUMMARY OF FINDINGS

1. There were significant differences in RMR between groups. Specifically, RMR was greater in both exercising groups. This finding rejects null hypotheses one.

2. There were no significant differences in DIT between groups. This finding supports null hypothesis two.

3. There was a significant relationship between RMR and DIT. This finding rejects null hypothesis three.

4. There were no significant differences in DIT between meal forms. This finding supports null hypothesis four.

5. There was no significant difference in the peak DIT time between meal forms. This finding supports null hypothesis five.

6. There was a significant DIT in each group. This finding rejects null hypothesis six.

7. There were no significant interactions between meal form and group. This finding supports null hypothesis seven.

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APPENDICES

Appendix A
Recruitment Flyer

RESEARCH STUDY

# EVER WONDER HOW HIGH YOUR METABOLISM IS?

# EVER WONDER HOW EXERCISE AND FOOD AFFECT YOUR METABOLISM?

The Department of Nutrition & Food Science is conducting a research study for males 19-28 years of age in which your metabolism will be measured before and after a meal.

Information: contact Dr. Huggins (844-3296; huggikw@auburn.edu) or Lance Ratcliff (844-8074; ratclla@auburn.edu).

Appendix B
Demographic Information

CODE # _________

**DEMOGRAPHIC INFORMATION**

NAME:_____________________________________________________

E-MAIL:____________________________________________________

PHONE NUMBER:___________________________________________

DATE OF BIRTH:___________________________________________

Appendix C
Health and Exercise Questionnaire

CODE #_________

**GENERAL EXERCISE HISTORY AND MEDICAL QUESTIONNAIRE**

Have you been diagnosed or suspect you have an allergy to nuts? ___YES ___NO

Have you been diagnosed or suspect you have an allergy to chocolate? __YES __NO

Have you been diagnosed or suspect you have an allergy to milk? ___YES ___NO

Have you had a recent illness (cold, flu, sore throat, infection, etc.)? ___YES ___NO
If YES, when?________________________

Are you taking any medications? ___YES ___NO
If YES, please tell the researcher the medications you are taking.

Do you exercise regularly? ___YES ___NO

If YES, what type of exercise and how many times per week?

_____________________

_____________________

If YES, how many minutes of exercise per session, and how long have you been doing this type of exercise (weeks? months? years?)

_____________________

_____________________

Are you currently following any special type of diet? ___YES ___NO

If YES, please describe this diet and how long you have been following it:

______________________________________________________________________

______________________________________________________________________

Appendix D
Informed Consent

**INFORMED CONSENT**

Research Study: “Diet-induced Thermogenesis in Differing College-Age Male Populations”

You are invited to participate in a research study looking at changes in metabolism after eating different forms (liquid, solid) of food. This study is being conducted by Lance Ratcliff, MS, RD, under the supervision of Dr. Kevin Huggins, Assistant Professor in the Department of Nutrition and Food Science. We hope to learn about differences in metabolism after food intake based on the form of food you eat and/or the type of exercise you might do. You were selected as a possible participant because you are a healthy male, 19-28 years of age, and free from nut, chocolate, and milk allergies.

If you choose to participate, we will ask you to report on three separate visits; this will be a time commitment of about 9 hours total. The first visit will be in the Student Activities Center, Room 204, where you will complete the consent form, as well as the medical and exercise history questionnaire. At this time, your height will be measured using a measuring tape, and your weight, hydration status, and body composition will be determined via Tanita Body Composition Analyzer (Tanita; Arlington Heights, IL).

The researchers will arrange 2 occasions, based on your convenience and separated by at least 4 days, for you to come to Room 102B in the Poultry Science Building to consume a meal and have your metabolism measurements. These visits will be in the morning so that each meal will be your first of the day, and we ask that you don’t eat for 12 hours prior to these two visits. We also ask that you refrain from caffeine, alcohol, and exercise for 24 hours prior to each visit, as well as refrain from all tobacco products the morning of each visit. Upon arriving at the Poultry Science Building, you will be asked to sit comfortably and relax for 10 minutes, at which time your resting metabolism will be measured. This will be done using a small, lightweight, handheld device known as MedGem. The MedGem is FDA-approved and has been used in numerous other metabolism research studies. It measures metabolism based on your resting oxygen intake and carbon dioxide output. You will be given your own noseclip and mouthpiece. You will connect the mouthpiece to the MedGem, and, once you place the clip on your nose, you will only breathe through the mouthpiece. In 5-10 minutes the MedGem will “beep” to signal the end of the test.

____________________

Participant’s Initials

You will then be given your meal and allowed 15 minutes to consume it. You will receive either a solid meal (Zone Perfect bars or Slim Fast High-Protein bars) or a liquid meal (Zone Perfect shakes or Slim Fast High-Protein shakes). Each meal will contain 500 calories. After finishing your meal, your metabolism will be measured with MedGem every 30 minutes for 3 ½ hours in order to examine how your metabolism changes after that meal. During those 3 ½ hours you will be sitting comfortably and relaxing, studying, or reading whenever you aren't using the MedGem. Bottled water will be provided for you, and you will be allowed one bathroom break per hour. The next visit will be very similar except you will consume the alternate meal (bars or shakes).

To minimize the risk of breach of confidentiality, all data will be coded and your name will not be revealed. Occasional dry mouth has been reported using the MedGem, so water will be provided as desired. You will be free to withdraw from the study at any time.

There are benefits for you in this study. Upon completion of ally your measurements, you will be provided with information about your metabolism and how it changes based on different types of meals and different types of exercise. You will also be given free nutrition counseling from a registered dietitian if you so choose. This study also benefits the researchers and the general population. Metabolism affects body weight and composition. It is important to learn how different types of meals or exercise can alter metabolism because of the possible impact with weight gain, weight loss, obesity, and public health.

Any information obtained in this study that can be identified with you will remain confidential; data will be coded to help ensure confidentiality. An e-mail address and a phone number are being requested so that the researchers can contact you to verify appointment times and give you your results at the conclusion of the study. You will be assigned a code using the first two letters of your last name, followed by the first two letters of your first name and a date based on when you enrolled in the study. Information collected through your participation may be used to fulfill educational requirements, for publication in a professional journal, and/or for presentation at a professional meeting. If so, none of your identifying information will be used.

A master list of names and codes will be kept in a locked file in the office of Dr. Huggins, 102D Poultry Science Building. Only he and Lance Ratcliff (graduate student associated with the study) will have access to this information. Shredding will ultimately destroy all identifying information.

____________________

Participant's Initials

You may withdraw from participation at any time, without penalty, and you may withdraw any identifiable data that has been collected about you.

Your decision whether or not to participate will not jeopardize your future relations with Auburn University or the Department of Nutrition and Food Science.

If you have any questions, we invite you to ask them now. If you have questions later, please contact Dr. Huggins (huggikw@auburn.edu; 844-3296) or Lance Ratcliff (ratclla@auburn.edu; 844-8074). You will be provided a copy of this form to keep.

For more information regarding your rights as a research participant you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

**HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.**

________________________________
Participant's signature Date

________________________________
Print Name

________________________________
Investigator's signature Date

________________________________
Print Name

________________________________
Co-investigator's signature Date
(if appropriate)

________________________________
Print Name

Appendix E
Form for recording Metabolic Measurements

Visit 1

Subject Code:_______
Date:______________

RMR:_________
$VO_2$:_________
Time:_________

Meal Group:_______

Time of meal completion:___________
Post-meal metabolic rate:___________
Post-meal $VO_2$:____________

Time:__________
+ 30 minutes metabolic rate:__________
+ 30 minutes $VO_2$:__________

Time:__________
+ 60 minutes metabolic rate:___________
+ 60 minutes $VO_2$:__________

Time:__________
+ 90 minutes metabolic rate:___________
+ 90 minutes $VO_2$:__________

Time:__________
+ 120 minutes metabolic rate:____________
+ 120 minutes $VO_2$:___________

Time:__________
+ 150 minutes metabolic rate:____________
+ 150 minutes $VO_2$:___________

Time:__________
+ 180 minutes metabolic rate:____________
+ 180 minutes $VO_2$:___________

Time:__________
+ 210 minutes metabolic rate:____________
+ 210 minutes $VO_2$:___________

Visit 2

Subject Code:_______
Date:_______________

RMR:_________
$VO_2$:__________
Time:_________

Meal Group:______

Time of meal completion:___________
Post-meal metabolic rate:___________
Post-meal $VO_2$:____________

Time:__________
+ 30 minutes metabolic rate:__________
+ 30 minutes $VO_2$:__________

Time:__________
+ 60 minutes metabolic rate:___________
+ 60 minutes $VO_2$:__________

Time:__________
+ 90 minutes metabolic rate:___________
+ 90 minutes $VO_2$:__________

Time:__________
+ 120 minutes metabolic rate:____________
+ 120 minutes $VO_2$:___________

Time:__________
+ 150 minutes metabolic rate:____________
+ 150 minutes $VO_2$:___________

Time:__________
+ 180 minutes metabolic rate:____________
+ 180 minutes $VO_2$:___________

Time:__________
+ 210 minutes metabolic rate:____________
+ 210 minutes $VO_2$:___________