

Aging, Physical Activity, and Energy Intake Regulation

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ABSTRACT

More than seventy percent of Americans over the age of sixty are classified as overweight or obese (1), and the future incidence of these conditions is expected to rise (2). Although it is unclear why older adults are predisposed to weight gain, decreased total energy expenditure may contribute to positive energy balance (3). It is also possible that age-related impairments in energy intake regulation result in the inability to appropriately adjust food intake to meet energy requirements with advancing age (4). The purpose of these investigations was to determine the influence of age and habitual physical activity on acute regulation of energy intake. Secondary objectives were to determine if there are sex differences in energy intake regulation, and to determine if pre-meal water consumption decreases meal energy intake in young and older adults. To achieve these objectives, the ability to spontaneously adjust energy intake at a meal under “preloading” conditions in which a yogurt shake or water was consumed prior to the meal was determined. We hypothesized that older adults would demonstrate less accurate energy intake regulation than younger adults, but that energy intake dysregulation would be attenuated in physically active older adults. We also expected that young men would have higher accuracy of energy intake regulation compared to young women matched for dietary cognitive restraint and cardiorespiratory fitness, and that pre-meal water consumption would decrease meal energy intake in young and older adults. Our main finding was that energy intake regulation is significantly impaired in older compared to younger adults, and that habitual physical activity improves short-term, but not acute, energy intake regulation. We also found that young men demonstrate significantly higher accuracy of energy intake regulation compared to young women. Lastly, we determined that pre-meal water consumption significantly decreases meal energy intake in older, but not young, adults. Overall, these results indicate that acute energy intake regulation is less accurate with advancing age, but that regular physical activity improves short-term energy intake regulation. Additionally, sex appears to influence energy intake regulation, and water consumption is a potential strategy to reduce energy intake in older adults.

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CHAPTER 1: INTRODUCTION

Nearly two-thirds of the United States adult population is classified as overweight or obese, and the future incidence of these conditions is expected to rise (1). While obesity affects Americans of all ages, the risk of obesity among older adults is significantly higher than that of the general population (1). Importantly, obesity in older adults is associated with a number of serious medical conditions, decreased independence and quality of life, and overall mortality (2). As both the number of Americans over the age of sixty and the prevalence of obesity among older adults is projected to increase in the coming years (3, 4), it is imperative to determine the specific age-related causes of obesity in order to develop effective prevention and treatment programs.

The purpose of these investigations was to determine if energy intake regulation is impaired with advancing age, and to determine if accuracy of short-term energy intake regulation is influenced by habitual physical activity level in healthy older adults. Additionally, the influence of sex on acute energy intake regulation in younger adults has not previously been examined, yet it is a factor that potentially contributes to sex differences in obesity prevalence in older adults and warrants study. Therefore, a secondary goal was to determine if sex affects ability to regulate energy intake in younger adults after accounting for factors that may independently influence energy intake regulation, such as dietary cognitive restraint and cardiorespiratory fitness. Finally, because there is a common belief among the lay public that water suppresses hunger and energy intake, we sought to determine if pre-meal water consumption reduces meal energy intake in young and older adults.

There is preliminary evidence that acute energy intake regulation is impaired in older men (5) and that habitual physical activity improves short-term regulation of energy intake in

young men (6). It was therefore hypothesized that older adults would demonstrate less accurate energy intake regulation than younger adults, but that acute energy intake dysregulation would be attenuated in physically active older adults. We also hypothesized that short-term energy intake regulation would be less accurate in young women compared to young men due to a potentially higher orexigenic drive in females (7). Lastly, we hypothesized that pre-meal water consumption would decrease meal energy intake, although the effect of a water preload on subsequent meal energy intake has not previously been determined.

Accuracy of energy intake regulation was assessed by measuring the ability to spontaneously adjust energy intake at an *ad libitum* meal under “preloading” conditions in which a high-energy yogurt beverage or water is consumed 30 minute prior to the meal. If energy intake in the “preload condition” (preload + meal) is equal to energy intake in a “no preload” condition, accuracy of energy intake regulation, or compensation, is 100%. Therefore, compensation values close to 100% indicate high accuracy of energy intake regulation, while compensation values lower than 100% are indicative of overeating in the preload condition relative to the no preload condition and reflect less accurate energy intake regulation. Using this method, we were able to assess differences in ability to compensate for the energy content of the yogurt preload beverage between younger and older, and physically active and sedentary adults. We also assessed sex differences in compensation for the yogurt preload beverage and meal energy intake following a high-volume water preload in young and older adults.

Overall, these investigations serve to define the degree of acute energy intake dysregulation in older adults and the influence of sex and habitual physical activity on ability to compensate. Also, pre-meal water consumption as a means to reduce meal energy is a potential intervention strategy to reduce meal energy intake and prevent weight gain, yet the efficacy of

this weight control strategy has not been previously investigated. These results contribute to the body of knowledge related to factors influencing short-term energy intake regulation. Based upon these findings, future studies may be designed to address long-term body weight management with advancing age.

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CHAPTER 2

Habitual physical activity differentially affects acute and short-term energy intake regulation in young and older adults

ABSTRACT

Background: Weight gain is common with advancing age. Previous work has demonstrated that energy intake regulation is impaired in older adults, but it is not known if habitual physical activity affects accuracy of energy intake regulation in older compared with young adults.

Objective: We tested the hypothesis that the ability to compensate for a high-energy yogurt preload beverage at a subsequent *ad libitum* meal (i.e. acute compensation) and over the course of the testing day (i.e. short-term compensation) will decrease with age, but the magnitude of the decline will be smaller in physically active compared with sedentary older adults.

Design: On two separate occasions, young active (n=15), young sedentary (n=14), older active (n=14), and older sedentary (n=11) subjects consumed either a high-energy yogurt preload beverage (500 mL, 1988 kJ, men; 375 mL, 1507 kJ, women), or no preload, 30 minutes prior to an *ad libitum* test meal. Energy intake at both *ad libitum* meals was measured, and total daily energy intake was determined on both testing days. Percent energy intake compensation for the yogurt preload beverage was calculated for the test meal and testing day to determine acute and short-term compensation, respectively. Perceptions of hunger and satiety and blood glucose concentrations were also determined during the test meals.

Results: Percent energy intake compensation at the test meal was significantly lower in the older compared with the young subjects (65 ± 4 vs. $81 \pm 4\%$, $P=0.005$). There was no effect of habitual physical activity level on acute compensation, and no age by physical activity level interaction ($P=0.60$). In contrast, short-term compensation was not different with age (87 ± 5 vs. $93 \pm 6\%$,

older vs. young, $P=0.45$), but was more accurate in active compared with sedentary subjects (100 ± 5 vs. $79\pm 6\%$, $P=0.013$). As with acute compensation, there was no age by physical activity interaction ($P=0.39$). Physical activity status did not affect ratings of hunger or fullness, or glycemic response during test meals, but glycemic response to the yogurt preload and the test meals was higher in the older compared to the young subjects (condition x age interaction, $P<0.01$).

Conclusion: Acute energy intake regulation is impaired in older adults, and physical activity status does not attenuate acute age-related energy intake dysregulation. However, energy intake regulation over the course of a day is more accurate in active compared with sedentary adults, which may facilitate long-term energy balance. Future work is needed to determine if higher energy expenditure in older active compared to older sedentary adults improves long-term accuracy of energy intake regulation.

KEY WORDS

Aging, physical activity, compensation, *ad libitum* meal, energy intake

INTRODUCTION

Recent estimates indicate that over thirty percent of the United States adult population is obese, with older adults more likely to be obese than younger adults (1). As both the number of older Americans and the prevalence of obesity in this population is projected to increase in coming years (2, 3), it is critical to identify specific age-related causes of obesity in order to develop effective prevention and treatment strategies. One factor contributing to the increased risk of obesity in older adults is a decrease in energy expenditure with advancing age, which may predispose them to positive energy balance (4). Energy intake regulation may also be impaired in older adults (5, 6), potentially preventing older individuals from appropriately decreasing energy intake to match the age-related reduction in energy requirements. This disparity between energy intake and energy expenditure could lead to positive energy balance and weight gain over time.

There is currently little information on energy intake regulation in older adults. Rolls et al. investigated the ability of healthy young (18-35 y) and older (60-85 y) men to acutely compensate for the energy content of a high-energy preload at a subsequent *ad libitum* meal (5). Younger men were found to compensate well, in that the high-energy preloads reduced meal energy intake such that overall energy intake (preload + meal) was not significantly different from energy intake in a no preload (meal only) condition. Compensation in older men was significantly less accurate, suggesting that acute energy intake regulation is impaired in this population. Perceptions of hunger and satiety were also blunted in the older compared to the younger men, indicating that age-related alterations in hunger and satiety cues may contribute to energy intake dysregulation. Insofar as other similarly designed investigations have yielded conflicting results (7-9), it is not clear if true age-related differences in energy intake regulation

exist and/or if there are other factors that modulate the relationship between aging and energy intake dysregulation.

In younger adults, habitual physical activity level may be an important factor contributing to the accuracy of energy intake regulation. Evidence suggests that young men who engage in regular physical activity (>120 min/wk) may have higher accuracy of energy intake regulation compared to their sedentary counterparts (10). Although habitual physical activity level does not appear to affect perceived hunger and satiety (10), it has been proposed that chronic physical activity may improve central responsiveness to hunger and satiety cues in young adults (11) thereby improving energy intake regulation. In older adults, it is possible that habitual physical activity may improve energy intake regulation by increasing sensitivity to hunger and satiety cues. However, the effects of physical activity on energy intake regulation in older individuals are not known. .

Thus, the purpose of this investigation is to determine the influence of age and habitual physical activity on the ability to compensate for the energy content of a yogurt preload beverage by reduction in energy intake at a subsequent *ad libitum* meal (i.e. acute compensation) and over the course of a day (i.e. short-term compensation). A secondary goal is to determine the influence of age and habitual physical activity on perceived hunger and satiety. We hypothesize that the ability to compensate for the energy content of the yogurt preload will decrease with age, but the magnitude of the decline will be smaller in physically active compared with sedentary adults.

METHODS

Subjects

Healthy, non-obese ($\text{BMI} \leq 30 \text{ kg/m}^2$) young (aged 21-35 yrs) physically active and sedentary and older (aged 60-80 yrs) physically active and sedentary adults were recruited for participation. Habitual physical activity level was determined by self-reported time (minutes/week) spent participating in moderate and vigorous physical activity (jogging, cycling, etc.). Physically active subjects spent ≥ 150 minutes per week engaged in moderate and/or vigorous physical activity for ≥ 2 yrs. Subjects were weight stable ($\pm 2 \text{ kg}$, $> 1 \text{ yr}$), nonsmokers, free from cardiovascular and other chronic disease (diabetes, thyroid disorders, cancer, heart, lung, and kidney disease), and not taking medications known to influence food intake or body weight. Individuals were excluded if they had impaired glucose tolerance (fasting plasma glucose $> 110 \text{ mg/dl}$). The older adults were screened for cardiovascular disease using resting and maximal exercise electrocardiograms prior to measurement of aerobic fitness (see below). Subjects were screened for dietary cognitive restraint (Eating Inventory (EI) cognitive restraint score < 11) (12), depression (Centers for Epidemiological Studies Depression Scale (CES-D) score < 35) (13), and eating disorders (Eating Attitudes Test (EAT-26) score < 20) (14), had no food allergies or restrictions, and did not consume alcohol in excess (≤ 2 drinks/day). Thirty-seven young and 34 older adults were initially enrolled in this investigation; eight young and four older subjects were unable to complete all study procedures due to time constraints or unwillingness to undergo certain study procedures (ie. venipuncture, maximal exercise test) and five older subjects did not receive medical clearance to participate based upon their resting/maximal exercise electrocardiograms. Our final sample included 29 young and 25 older individuals as follows: young active (YA), $n=15$; young sedentary (YS), $n=14$; older active (OA), $n=14$; older sedentary (OS), $n=11$. Subjects provided informed consent prior to their participation in the investigation,

but they were not aware of the specific purpose of the study. The protocol and consent form was approved by the Institutional Review Board at Virginia Tech.

Measurements

Height was measured in meters without shoes using a wall-mounted stadiometer. Body mass was measured to the nearest 0.1 kg using a physician's balance scale. Percentage body fat, absolute fat mass and fat-free mass (FFM) was measured using dual energy X-ray absorptiometry (DEXA) (GE Lunar Prodigy, GE Healthcare). Subjects were instructed in methods to accurately record their dietary intake; self-reported four-day food intake records were used to determine habitual dietary intake. Energy and macronutrient intake was assessed using nutritional analysis software (NDS-R 5.0, University of Minnesota). Cardiorespiratory fitness (maximal oxygen consumption; VO_2 max) was measured during a graded exercise treadmill test to exhaustion using open-circuit spirometry (Parvo Medics 2400, Parvo Medics Inc.). Resting metabolic rate (RMR) and respiratory quotient (RQ) were determined via indirect calorimetry using a ventilated hood system (Deltatrac II, Datex Ohmeda, Helsinki, Finland). To estimate habitual total daily energy expenditure (TEE), RMR was multiplied by an activity factor based upon physical activity group (active, 1.75; sedentary, 1.3) (15); TEE was used to assess the validity of self-reported food intake records. Fasting blood samples were collected by venipuncture into EDTA tubes (Fisher Scientific International Inc., Hampton, NH) and centrifuged at 2500 rpm for 15 min at 4 °C. Plasma glucose concentrations were measured immediately using an automated glucose analyzer (YSI 2300 STAT Plus Glucose & Lactate Analyzer, YSI Incorporated, Yellow Springs, OH). Plasma insulin concentrations were measured by enzyme immunoassay (Insulin Ultrasensitive EIA, ALPCO Diagnostics, Salem, NH). The homeostasis model assessment

(HOMA) score was calculated as the product of the fasting serum insulin concentration (uIU/mL) and fasting serum glucose concentration (mmol/L), divided by 22.5 (16).

Procedures

Subjects reported to the laboratory for two lunch meals in random order as follows: 1) 30-minute waiting period (no preload) followed by an *ad libitum* meal, and 2) preload consisting of 500 mL, 1988 kJ (men) or 375 mL, 1507 kJ (women) of a commercially available yogurt drink (Dannon Frusion; Dannon Company, Inc.) (77% energy from carbohydrate, 12% energy from protein, 11% energy from fat) followed 30 minutes later by an *ad libitum* meal. Because it has previously been demonstrated that the form of yogurt (i.e. semisolid vs. beverage) does not differentially affect perceptions of hunger and satiety or energy intake at a subsequent *ad libitum* meal (17), preload form was determined by palatability testing in pilot studies. The prescribed preload volume was determined from protocols of similar studies in men and adjusted for women according to gender-related differences in estimated energy requirements (~16% of daily energy requirements for young men and women) (15). In this sample, the energy content of the preload represented ~27 kJ/ kg body weight for all groups. Lunch meals for each subject were separated by a minimum of two days. The test meal was provided at lunchtime so as to replicate the experimental protocol used in other published work in this area (5, 18). A 30 minute waiting period between the preload and meal was chosen because this duration results in the most accurate compensation for the energy of a preload (19). Subjects were asked to eat their usual breakfast meal at the same time on both testing days, but to not eat or drink anything (other than water) for the three hours prior to their study visit. They recorded their food intake the day prior to and the morning of both testing days, as well as for the remainder of the day following and the day after the test meal. Upon arrival, an intravenous catheter was placed in an antecubital vein.

During the meal studies, visual analog scales (VAS) were completed by subjects to rate sensations of hunger and fullness and blood samples were obtained at 30 minutes intervals: prior to the preload or 30 minute waiting period (0 minutes), prior to the lunch meal (30 minutes), following the lunch meal (60 minutes), and at 90, 120, and 150 minutes (6 total). The catheter was removed and subjects were dismissed from the laboratory after completing the VAS scale at 150 minutes. VAS are reproducible and valid indicators of hedonics in both younger and older populations (20-22). Reading was permitted during the test meals, but food and diet-related content was screened and removed from all material.

Test Meals

All foods included in the test meal lunches were evaluated for palatability prior to initiation of the study. The lunch consisted of an individual buffet-style meal containing a variety of typical lunch items (e.g., bread, luncheon meat, cheese, lettuce, condiments, potato chips, carrots, applesauce, cookies, water) in excess of what would normally be consumed, from which the subjects were allowed to self-select over a 30 minute period. The study personnel recorded the amount of time taken to consume the preload and the *ad libitum* meal. Foods were weighed (± 0.1 g) before being served and again after the completion of the meal to determine the amount consumed. Meal energy and macronutrient intake was calculated using nutritional analysis software (NDS-R 5.0, University of Minnesota). Young women were studied in the follicular phase of their menstrual cycles for both feeding conditions to minimize the effect of cycle phase on energy intake (23).

Statistical Analyses

Percent compensation at the test meal (acute compensation) was calculated as meal energy intake in the no preload (NP) condition divided by meal energy intake in the yogurt preload (YP)

condition (preload + meal) multiplied by 100 (5). To determine if compensation occurred later in the day following test meals (short-term compensation), another calculation was made as follows: [(NP test meal energy intake + self-reported intake the remainder of the day following the NP test meal) divided by the YP total test meal energy intake (i.e., energy content of yogurt preload + YP test meal energy intake) + self-reported intake the remainder of the day following the YP test meal] multiplied by 100. In order to assess overall between group and condition differences in VAS ratings of hunger and fullness and blood glucose concentrations, VAS rating and blood glucose area under the curve (AUC) were calculated using the trapezoidal model (24).

Differences in demographic characteristics and percent compensation were analyzed univariate analysis of variance (ANOVA) (SPSS v. 12.0 for Windows). TEE was compared with self-reported habitual food intake and total daily energy intake on the NP testing day using paired samples t-tests. Differences in test meal VAS and blood glucose AUC, self-reported energy intake on the day prior to, the day of, and the day following the test meals were assessed with repeated measures ANOVA. Test meal VAS ratings of hunger and fullness, and blood glucose values were analyzed by 6x2x4 repeated measures ANOVA in order to assess differences between condition and group differences at each time point measured. Analysis of covariance (ANCOVA) was utilized to adjust for baseline differences when present. When significant interactions were detected, *t* tests were used for post-hoc analyses. The alpha level was set *a priori* at $P < 0.05$. Data are expressed as mean \pm SEM.

RESULTS

Participant characteristics

Participant demographic characteristics are listed in **Table 1**. Age, percent body fat, dietary cognitive restraint, fasting glucose and percent habitual energy intake from dietary fat were significantly higher in older compared with younger subjects, while VO_2 max, RMR and TEE were significantly lower in the older subjects. Cognitive dietary restraint, VO_2 max, exercise minutes per week, TEE, habitual energy intake and percent habitual energy intake from carbohydrates were significantly higher in the physically active compared with the sedentary subjects, while percent body fat, fasting insulin concentrations, HOMA score, and percent habitual energy intake from dietary fat were significantly lower in the physically active subjects. In this sample, TEE was not significantly different from self-reported habitual energy intake (mean difference 164 ± 315 kJ, $P=0.60$) or total daily energy intake on the NP test day (mean difference 147 ± 416 kJ, $P=0.73$).

Test meals

Percent compensation

Ability to compensate at the test meal for the energy in the yogurt preload was lower in older compared with young subjects (65 ± 4 vs. $81 \pm 4\%$, $P=0.005$). However, there was no effect of habitual physical activity level on acute ability to compensate (73 ± 4 vs. $72 \pm 4\%$, active vs. sedentary, $P=0.84$), and no age by physical activity level interaction ($P=0.60$). In contrast, short-term compensation (i.e., over the course of the testing day) was not different with age (87 ± 5 vs. $93 \pm 6\%$, older vs. young, $P=0.45$), but was significantly more accurate in active compared with sedentary subjects (100 ± 5 vs. $79 \pm 6\%$, $P=0.013$) (**Figure 1**). As with acute compensation, there was no age by physical activity interaction ($P=0.39$).

Test meal energy intake

There were no significant differences in energy intake during the *ad libitum* meal in the YP condition by age or activity group (**Table 2**). However, energy intake in the NP condition during the *ad libitum* meal was lower in the older subjects compared with the young subjects (2227±280 vs. 3702±258 kJ, P=0.02), but there was no effect of physical activity on *ad libitum* meal energy intake. There were no significant age by activity group interactions in either test meal condition, and no significant differences between conditions or across groups in percent of energy consumed at the *ad libitum* meals from carbohydrates, protein, or fat (data not shown).

There was no difference between groups in time taken to consume the yogurt preload (YA: 11.9±2.0, YS: 11.5±1.5, OA: 14.8±1.8, OS: 12.4±1.8 min, P=0.49). Time to consume the *ad libitum* meal was reduced in the YP condition compared with the NP (21.2±0.9 vs. 23.5±0.7 min, P=0.01), but there were no condition by group interactions.

Energy intake prior to and following test meals

Energy intake the day prior to the test meals, breakfast energy intake on the morning of the test meals, for the remainder of the day following the test meals and the day after the test meals is listed in Table 2. There were no significant differences between conditions on self-reported energy intake the day prior to the test meals, or the morning of the test meals and there were no group interactions. There was no differences between conditions in energy intake for the remainder of the day following the tests meals, but there was a condition by physical activity interaction (P=0.02). Active subjects ate more than sedentary subjects the remainder of the day in the NP condition (P=0.01). Total energy intake the day of the test meals (self-reported breakfast energy intake + measured test meal energy intake + self-reported energy intake the remainder of the day) was different between conditions (P<0.01); subjects consumed significantly less over the entire day in the NP condition compared to the YP condition, however there were no group

interactions. The day after the test meals, there was no effect of condition or group on self-reported energy intake.

Test meal VAS ratings

Hunger

Baseline hunger (rating at time 0) was lower in the YP condition compared to the NP condition (42 ± 3 vs. 50 ± 4 , $P=0.04$), but there were no age or physical activity group differences in baseline hunger ratings. Hunger changed significantly with time in response to meal ingestion (**Figure 2**). In the pooled sample, hunger ratings were higher in the NP condition as determined by analysis of both mean adjusted for baseline differences and AUC values (mean: 24 ± 2 vs. 29 ± 1 mm, $P<0.01$; AUC: 3213 ± 304 vs. 4124 ± 226 mm·min, YP and NP, respectively, $P<0.01$) (Figure 2). There was also a condition by time interaction ($P<0.01$) that is attributed to lower hunger in the YP vs. NP condition at 30 minutes (34 ± 3 vs. 63 ± 3 mm, YP and NP, respectively, $P<0.01$). There were no significant effects of age or physical activity group on hunger ratings at any time point measured or on hunger AUC.

Fullness

Baseline fullness (rating at time 0) was not different between conditions ($P=0.20$) and there were no condition by group interactions. As shown in **Figure 3**, fullness changed significantly with time in response to meal ingestion. Fullness ratings in the pooled sample were higher in the YP condition as determined by analysis of both mean and AUC values (mean: 60 ± 2 vs. 53 ± 2 mm, $P<0.01$; AUC: 9338 ± 300 vs. 8160 ± 298 mm·min, YP and NP, respectively, $P<0.01$) (Figure 3). There was a significant condition by time interaction, attributed to higher fullness ratings in the YP condition at 30 minutes (47 ± 3 vs. 21 ± 3 mm, YP and NP, respectively, $P<0.01$).

There were no significant effects of physical activity on ratings of fullness, but there was a significant condition by age interaction on fullness ratings by both mean and AUC analysis, which can be attributed to a higher mean fullness in older compared to young subjects in the YP condition (64 ± 4 vs. 55 ± 2 mm, $P=0.04$).

Blood glucose concentrations

Baseline blood glucose concentrations (values at time 0) were not different in the YP compared to the NP condition (4.8 ± 0.1 vs. 4.7 ± 0.1 mmol/L, $P=0.42$) (**Figure 4**). Blood glucose concentrations changed over time during both test meal conditions ($P<0.01$). The change in blood glucose concentrations over time was different between conditions ($P<0.01$); blood glucose concentrations were higher in the YP condition at 30 min (6.4 ± 0.2 vs. 4.8 ± 0.1 mmol/L, $P<0.01$) and lower in the YP condition at 90 minutes (5.2 ± 0.3 vs. 6.0 ± 0.2 mmol/L, $P<0.01$).

There were time by age ($P<0.01$), and time by condition by age interactions ($P<0.01$), in blood glucose concentrations, but no differences between activity groups. In the YP condition there were blood glucose concentrations were higher in older compared to young subjects at 30, 60, 90, 120, and 150 minutes, while in the NP condition, blood glucose concentrations were higher in the older subjects at 90, 120, and 150 minutes (Figure 4). There was no significant difference in blood glucose AUC between meal conditions in the pooled sample and no significant condition by group interactions.

DISCUSSION

The first major finding of the present study is that the age-related reduction in the ability to acutely regulate energy intake is independent of habitual physical activity level. Consistent with previous observations (5), compensation to a test meal was ~15% lower in older compared

with younger subjects in the present study. Our findings extend previous observations (5) by demonstrating that habitual physical activity does not appear to influence the age-related reduction in energy intake regulation during an acute meal setting.

Our second major finding is that in contrast to what is observed during an individual meal, energy intake regulation viewed in the context of an entire day (i.e. short-term compensation) was more accurate in active compared with sedentary individuals. Short-term compensation was not different in young and older individuals. This increased accuracy of short-term energy intake regulation among active adults may facilitate long-term energy balance.

While energy intake dysregulation has the potential to cause both negative and positive energy balance resulting in either weight loss or weight gain (4), the risk of obesity among older adults in the United States is currently higher than that of younger adults (1), and the number of obese older Americans is projected to increase in the coming years (2). Importantly, obesity in older adults is associated with a number of medical complications, functional limitations, decreased health related quality of life, and overall mortality (25). It has recently been demonstrated that frailty and decreased quality of life can be reversed in obese older adults with weight loss and exercise (26) and current recommendations encourage regular physical exercise for older adults to decrease disease risk factors and improve functional capacity (27). Physical activity as a means to improve acute energy intake dysregulation in older individuals, however, has not previously been investigated.

It has been suggested that habitual physical activity may increase sensitivity to hunger and fullness cues in younger adults, thereby improving energy intake regulation (10, 11). We found that perceptions of hunger and fullness over the course of a meal were similar among physically active and sedentary subjects, and did not find that physical activity improves acute

energy intake regulation in younger adults, nor did it attenuate age-related acute energy intake dysregulation in older adults. These results indicate that habitual physical activity does not improve sensitivity to hunger and fullness cues in young or older adults. However, our finding of more accurate energy intake regulation over the course of a day in active compared with sedentary adults suggests that habitual physical activity does confer benefits to short-term energy intake regulation. This finding supports the value of habitual physical activity for both young and older adults in the context of long-term energy balance.

In our sample of healthy older adults, the sedentary and active subjects were similar in body weight and BMI, and RMR was not different between the two groups. Habitual energy intake, however, was significantly higher in the active subjects. As all subjects were weight stable, it may be surmised that higher energy expenditure of physical activity enabled the active subjects to regulate energy balance at a higher level. That is, higher energy intake and higher energy expenditure in the older active subjects resulted in increased energy flux relative to the sedentary subjects, despite similar basal energy requirements. It has previously been demonstrated that younger women successful in body weight maintenance over one year had significantly higher free living activity energy expenditure than women who gained weight over the same time period (28). It has also been shown that improvements in fitness reduce the risk of age-related weight gain in middle-aged adults (29). In older adults, increased physical activity energy expenditure may be important for body weight maintenance by counteracting both an age-related decrease in total energy expenditure as well as a predisposition toward positive energy balance as a consequence of acute age-related energy intake dysregulation. Future research is necessary to determine if increased physical activity energy expenditure in older adults can improve long-term accuracy of energy intake regulation.

There are several limitations to the present study that should be addressed. First, our results are only applicable to acute (meal) and short-term (daily) situations. It is therefore unknown if the age-related decline in ability to appropriately regulate acute energy intake would be evident over a period of several days/weeks, or if physical activity would improve acute age-related energy intake dysregulation over longer periods of time (i.e. beyond a single day). Also, we did not control food intake on the morning of our lunch meals and relied on self-reports to document breakfast intake, as well as energy intake following test meals. However, reported breakfast energy intake was not different between conditions, and we believe that our dietary intake data are reasonably accurate for several reasons. First, daily TEE calculated using RMR multiplied by an activity factor based upon habitual activity level (15) was not significantly different from self-reported habitual energy intake or total daily energy intake on the NP test day (mean difference <164 kJ, or ~39 kcal). Secondly, our TEE and habitual energy intake data are comparable to that reported for nonobese active and sedentary adults using doubly labeled water (15, 30). Nonetheless, we acknowledge the limitations of self-reported dietary intake data, and recognize this as a limitation of our investigation. Future studies using monitored *ad libitum* meal conditions over the course of one or more days (i.e. those utilizing an inpatient metabolic unit) are necessary to confirm our findings. Finally, despite clear differences in aerobic fitness in the active compared to sedentary groups, as well as lower body fat, fasting insulin, and HOMA scores in the active group expected with higher cardiorespiratory fitness, our sedentary subjects may have been healthier than typical sedentary older adults, thus potentially narrowing any differences between activity groups in ability to compensate.

In summary, we found that ability to acutely regulate energy intake is influenced by age, but not by habitual physical activity. However, energy intake regulation over the course of a day

is significantly more accurate in physically active compared with sedentary adults, regardless of age. This improved accuracy of short-term energy intake regulation may facilitate longer term body weight regulation among physically active individuals. In older adults, greater energy requirements may offset an inappropriately high energy intake as a consequence of acute energy intake dysregulation. Future studies are needed to confirm our findings using longer term controlled feeding situations, and to determine the specific mechanisms by which short-term energy intake regulation is improved with physical activity.

TABLES

Table 1. Subject Characteristics

| | Sedentary | | Physically Active | |
|-----------------------------------|--|------------------------------|---------------------------|---------------------------|
| | <u>Young</u> <u>Sedentary</u> (n=14) | Older Sedentary (n=11) | Young Active (n=15) | Older Active (n=14) |
| Age (y) | 26±1 | 69±2 | 23±1 | 68±2 ¹ |
| Height (cm) | 170.2±1.8 | 168.2±3.5 | 170.0±2.3 | 170.7±2.0 |
| Weight (kg) | 68.1±2.5 | 70.7±4.1 | 67.1±3.2 | 71.5±2.6 |
| BMI (kg/m ²) | 23.5±0.8 | 24.8±0.7 | 23.1±0.7 | 24.5±0.8 |
| Body Fat (%) | 27.2±1.5 | 34.0±2.6 | 18.2±2.2 | 27.6±2.2 ^{1,2} |
| FFM (kg) | 49.9±2.6 | 46.8±3.2 | 55.1±3.5 | 51.5±2.6 |
| VO ₂ max (ml/kg/min) | 37.9±1.9 | 21.7±1.0 | 55.6±2.7 | 32.8±2.3 ^{1,2} |
| Physical activity (min/wk) | 16±10 | 23±14 | 592±104 | 594±127 ² |
| Dietary cognitive restraint score | 4.9±0.9 | 6.4±1.1 | 6.2±0.7 | 8.7±0.81 ^{1,2} |
| RMR (kJ/d) | 6308±293 | 5363±287 | 6114±329 | 5725±170 ¹ |
| RMR per kg FFM (kJ/kg/d) | 122±3 | 117±6 | 114±4 | 111±4 |
| Respiratory Quotient | 0.89±0.01 | 0.89±0.02 | 0.89±0.01 | 0.89±0.01 |
| TEE (kJ/d) | 8035±403 | 6993±504 | 10865±403 | 10055±437 ^{1,2} |
| Fasting glucose (mmol/L) | 4.9±0.1 | 5.1±0.1 | 4.7±0.1 | 5.0±0.1 ¹ |
| Fasting insulin (uIU/mL) | 3.9±0.4 | 3.1±0.4 | 2.6±0.4 | 2.1±0.3 ² |
| HOMA score | 0.9±0.1 | 0.7±0.1 | 0.6±0.1 | 0.5±0.1 ² |
| Habitual energy intake (kJ/d) | 7958±640 | 7635±480 | 10063±818 | 9107±600 ² |

| | | | | |
|----------------------------|------------|------------|------------|---------------------------|
| % Energy from fat | 32 \pm 1 | 35 \pm 1 | 27 \pm 3 | 31 \pm 2 ^{1,2} |
| % Energy from carbohydrate | 51 \pm 1 | 48 \pm 2 | 56 \pm 3 | 53 \pm 2 ² |
| % Energy from protein | 15 \pm 1 | 16 \pm 1 | 15 \pm 1 | 16 \pm 1 |

Data are mean \pm SEM. FFM, fat-free mass; RMR, resting metabolic rate; TEE, estimated habitual daily energy expenditure. ¹ Age effect (P<0.05). ² Physical activity effect (P<0.05).

Table 2. Energy Intake on the Day Prior to Test Meal Days, Test Meal Days, and the Day Following Test Meal Days in the Yogurt Preload and No Preload Conditions

| | <u>Sedentary</u> | | <u>Physically Active</u> | |
|--------------------------------------|------------------------|-------------------------------|----------------------------|----------------------------|
| | Young Sedentary (n=14) | <u>Older Sedentary</u> (n=11) | <u>Young Active</u> (n=14) | <u>Older Active</u> (n=14) |
| Yogurt Preload (YP) Condition | | | | |
| Day Prior | 7221±878 | 7483±784 | 10104±1009 | 8176±770 |
| Test Meal Day | | | | |
| Breakfast | 332±279 | 1473±234 | 1476±262 | 1865±245 |
| Test Meal (Including YP) | 4535±452 | 3853±318 | 4667±323 | 4381±411 |
| Remainder of Day | 4813±823 | 4162±509 | 6157±724 | 3609±333 ¹ |
| Total Day (Including Test Meal) | 10252±1187 | 9489±731 | 12255±1497 | 9876±560 ² |
| Day Following | 7556±684 | 6857±592 | 9829±1253 | 7626±955 |
| No Preload (NP) Condition | | | | |
| Day Prior | 7557±708 | 8413±708 | 8989±811 | 8700±635 |
| Test Meal Day | | | | |
| Breakfast | 509±253 | 1219±189 | 1630±351 | 1657±225 |

| | | | | |
|------------------------------------|----------------|----------------|------------------|----------------|
| Test Meal | 3608 \pm 401 | 2478 \pm 294 | 3796 \pm 369 | 3069 \pm 399 |
| Remainder of Day | 3812 \pm 555 | 3537 \pm 658 | 6997 \pm 819 | 4816 \pm 694 |
| Total Day (Including Test Meal) | 7962 \pm 574 | 6862 \pm 698 | 11223 \pm 1254 | 9432 \pm 721 |
| Day Following | 6605 \pm 586 | 7494 \pm 678 | 10283 \pm 1211 | 8466 \pm 708 |

Data are mean \pm SEM. ¹ Condition by physical activity group interaction (P<0.05). ² Effect of condition (P<0.05).

FIGURE LEGEND

Figure 1.

Short-term energy intake (EI) compensation in sedentary young and older and active young and older subjects.

* Significant difference in energy intake percent compensation in active compared to sedentary subjects ($P < 0.05$).

Figure 2.

Subjective hunger ratings and hunger area under the curve (AUC, inset) during yogurt preload (YP) test meal (Figure 2a) and the no preload (NP) test meal (Figure 2b).

The yogurt preload was given immediately following completion of the 0 min VAS scale (**a**).

Subjects completed a second VAS scale at 30 min (**b**), and were immediately provided with the *ad libitum* meal. Following completion of the *ad libitum* meal at 60 minutes, subjects completed a third VAS scale (**c**). The VAS scales were again completed at 90, 120, and 150 min.

Figure 3.

Subjective fullness ratings and fullness area under the curve (AUC, inset) during yogurt preload (YP) test meal (Figure 3a) and during the no preload (NP) test meal (Figure 3b).

The yogurt preload was given immediately following completion of the 0 min VAS scale (**a**).

Subjects completed a second VAS scale at 30 min (**b**), and were immediately provided with the *ad libitum* meal. Following completion of the *ad libitum* meal at 60 minutes, subjects completed a third VAS scale (**c**). The VAS scales were again completed at 90, 120, and 150 min.

Figure 4.

Blood glucose concentrations during yogurt preload (YP) test meal (Figure 4a) and during the no preload (NP) test meal (Figure 4b).

Blood glucose concentrations were measured at baseline (time 0), immediately prior to the yogurt preload (YP condition) or waiting period (NP condition) (**a**). Blood glucose concentrations were measured again at 30 minutes, immediately prior to the *ad-libitum* meal (**b**). Blood glucose concentrations were measured again after completion of the *ad-libitum* meal at 60 min (**c**), and at 90, 120, and 150 min. * Significant difference between older and young subjects ($P < 0.05$).

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Figure 1.

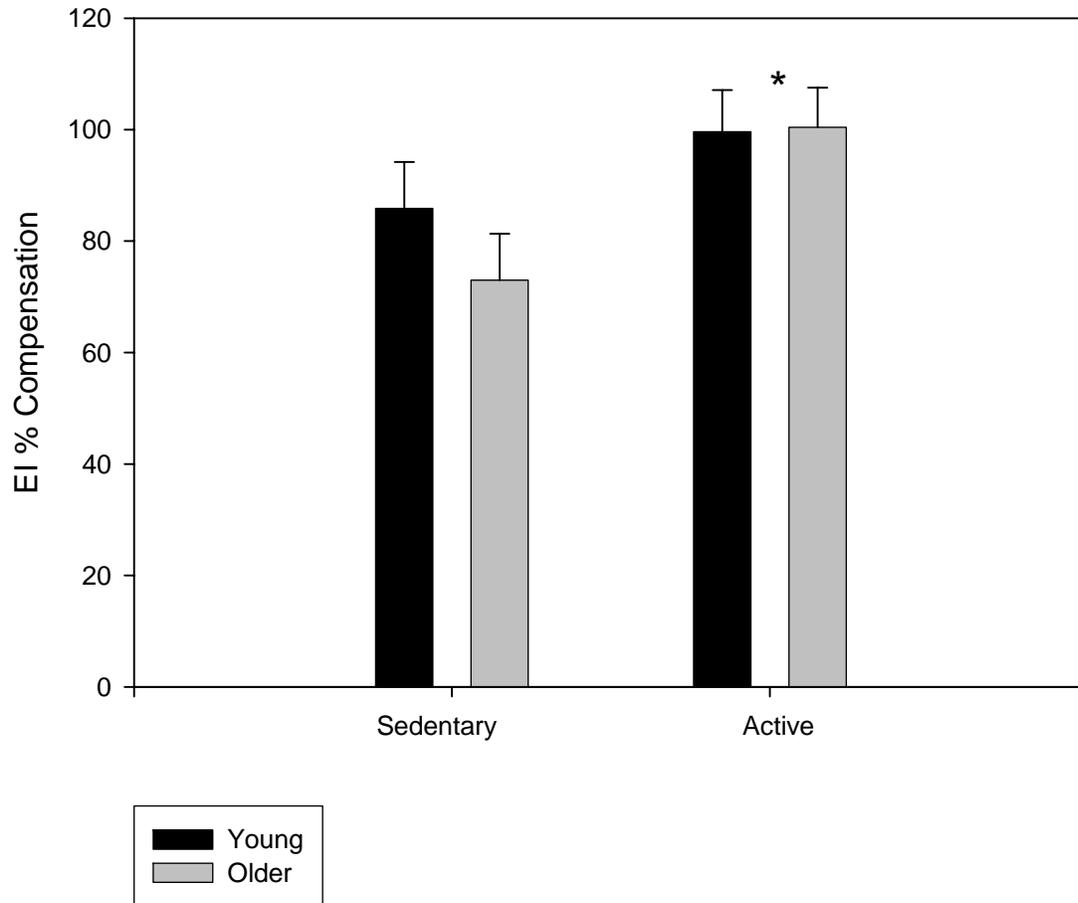


Figure 1.

Short-term energy intake (EI) compensation in sedentary young and older and active young and older subjects.

* Significant difference in energy intake percent compensation in active compared to sedentary subjects ($P < 0.05$).

Figure 2a.

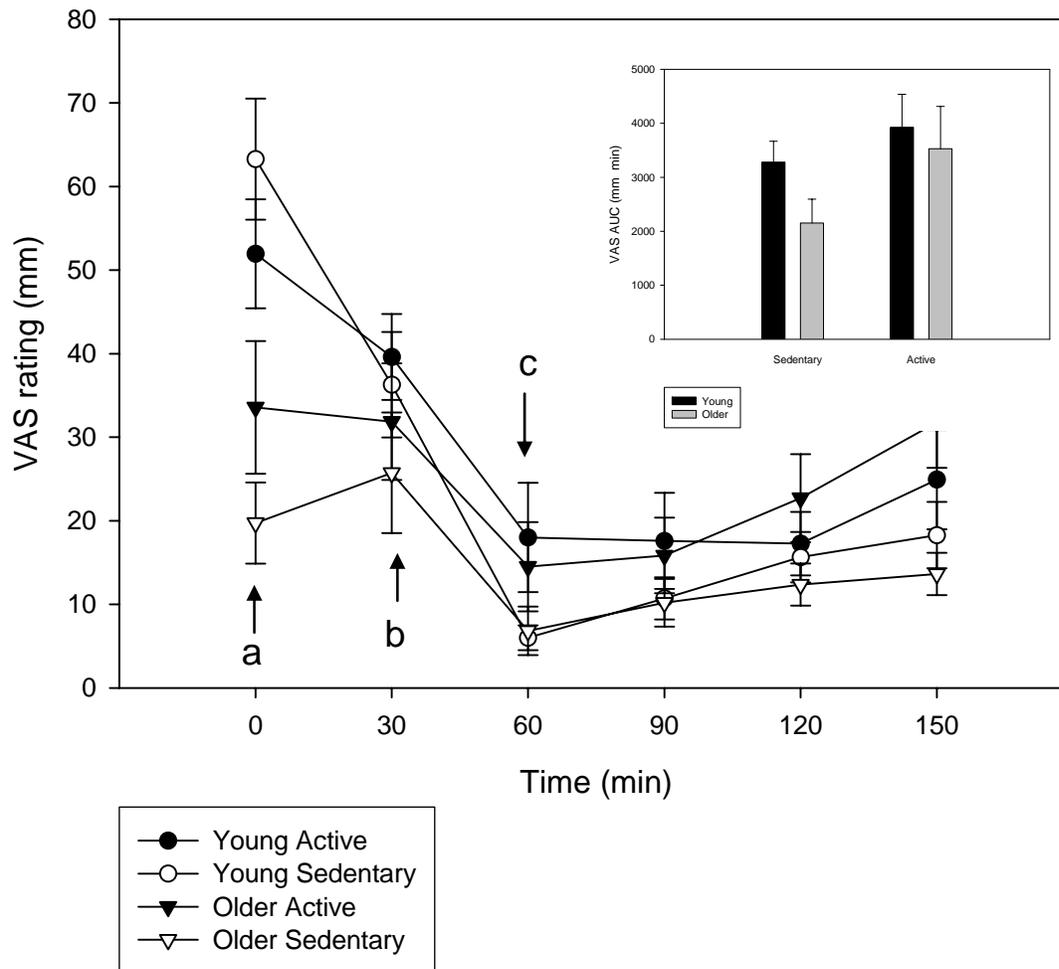


Figure 2a.

Subjective hunger ratings and hunger area under the curve (AUC, inset) during yogurt preload (YP) test meal.

The yogurt preload was given immediately following completion of the 0 min VAS scale (**a**).

Subjects completed a second VAS scale at 30 min (**b**), and were immediately provided with the *ad libitum* meal. Following completion of the *ad libitum* meal at 60 minutes, subjects completed a third VAS scale (**c**). The VAS scales were again completed at 90, 120, and 150 min.

Figure 2b.

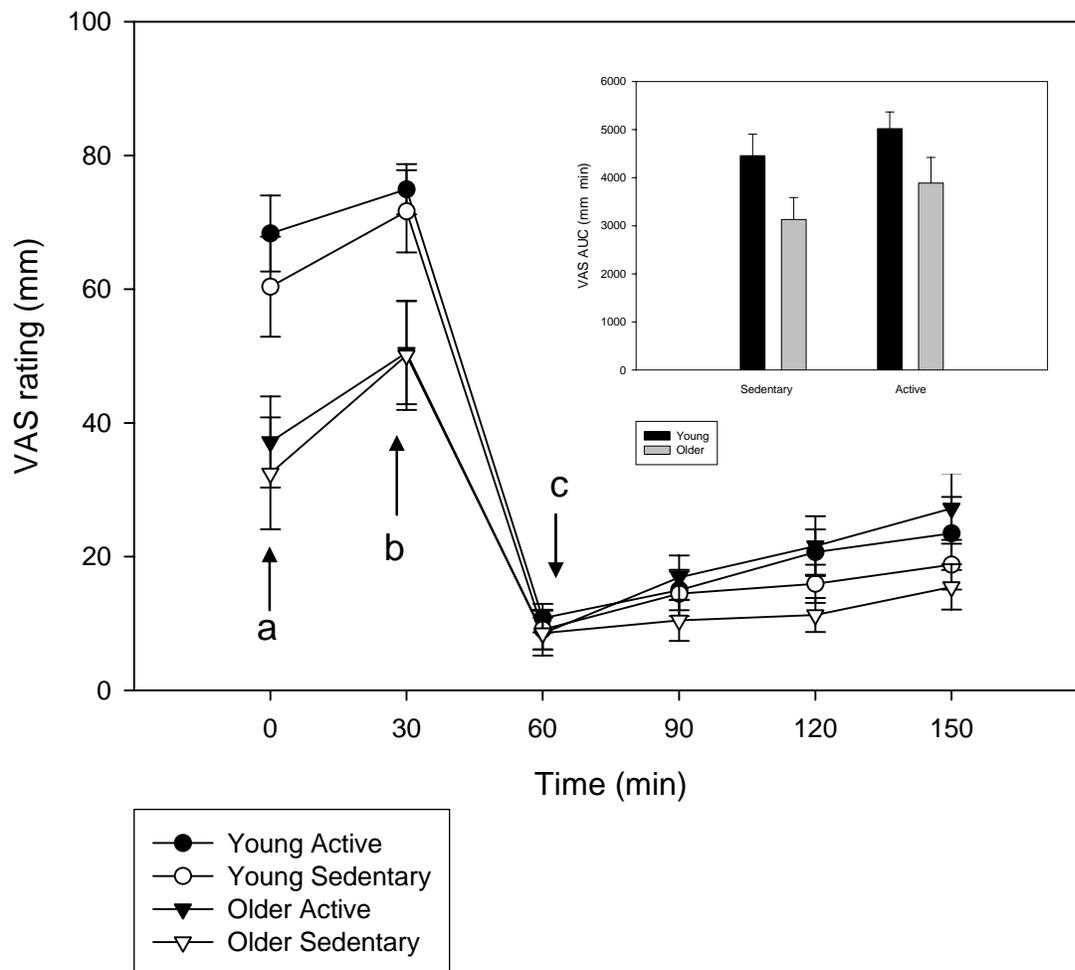


Figure 2b.

Subjective hunger ratings and hunger area under the curve (AUC, inset) during the no preload (NP) test meal.

The yogurt preload was given immediately following completion of the 0 min VAS scale (**a**).

Subjects completed a second VAS scale at 30 min (**b**), and were immediately provided with the *ad libitum* meal. Following completion of the *ad libitum* meal at 60 minutes, subjects completed a third VAS scale (**c**). The VAS scales were again completed at 90, 120, and 150 min.

Figure 3a.

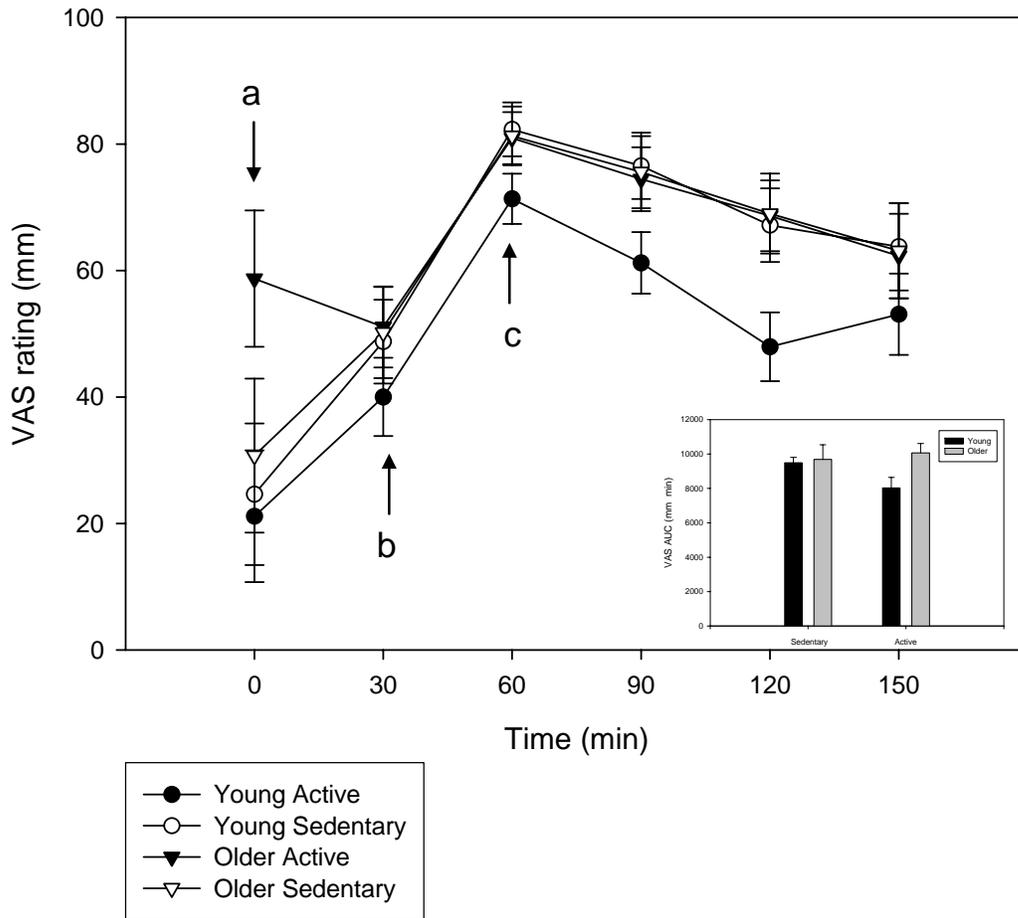


Figure 3a.

Subjective fullness ratings and fullness area under the curve (AUC, inset) during yogurt preload (YP) test meal.

The yogurt preload was given immediately following completion of the 0 min VAS scale (**a**).

Subjects completed a second VAS scale at 30 min (**b**), and were immediately provided with the *ad libitum* meal. Following completion of the *ad libitum* meal at 60 minutes, subjects completed a third VAS scale (**c**). The VAS scales were again completed at 90, 120, and 150 min.

Figure 3b.

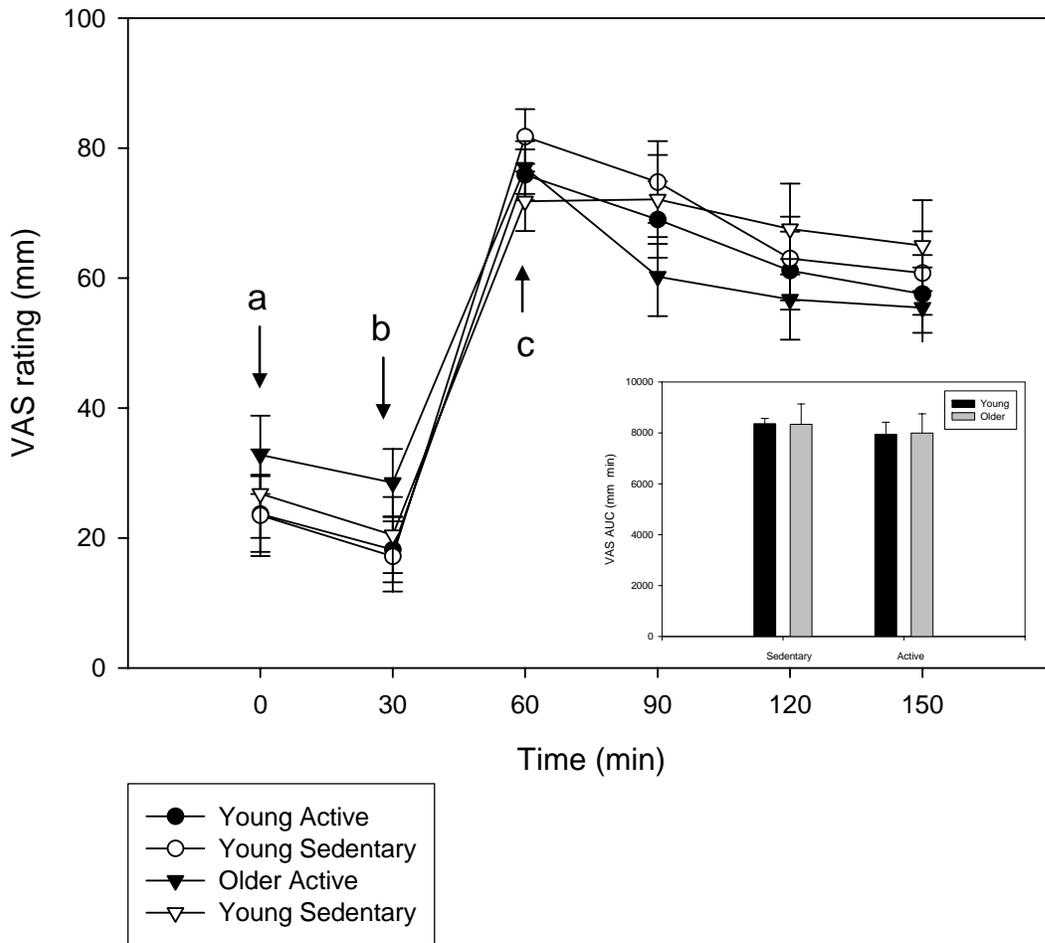


Figure 3b.

Subjective fullness ratings and fullness area under the curve (AUC, inset) during the no preload (NP) test meal.

The yogurt preload was given immediately following completion of the 0 min VAS scale (**a**).

Subjects completed a second VAS scale at 30 min (**b**), and were immediately provided with the *ad libitum* meal. Following completion of the *ad libitum* meal at 60 minutes, subjects completed a third VAS scale (**c**). The VAS scales were again completed at 90, 120, and 150 min.

Figure 4a.

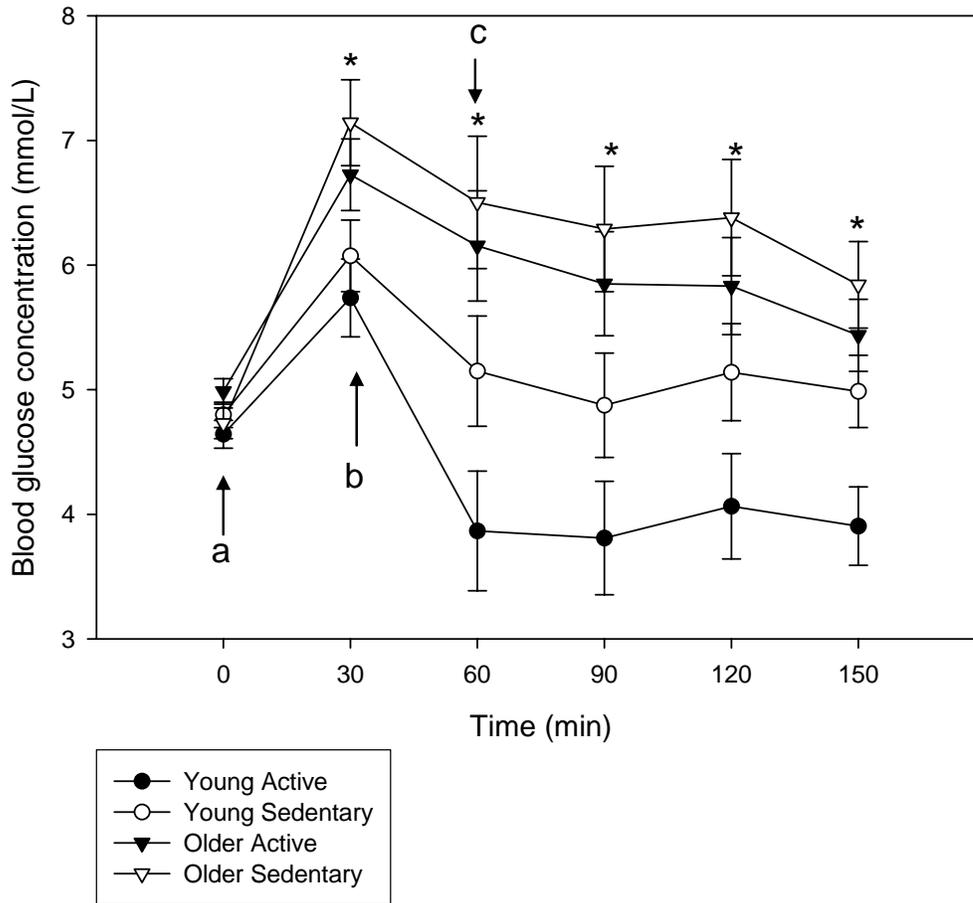


Figure 4a.

Blood glucose concentrations during yogurt preload (YP) test meal.

Blood glucose concentrations were measured at baseline (time 0), immediately prior to the yogurt preload (YP condition) or waiting period (NP condition) (a). Blood glucose concentrations were measured again at 30 minutes, immediately prior to the *ad-libitum* meal (b). Blood glucose concentrations were measured again after completion of the *ad-libitum* meal at 60 min (c), and at 90, 120, and 150 min. * Significant difference between older and young subjects ($P < 0.05$).

Figure 4b.

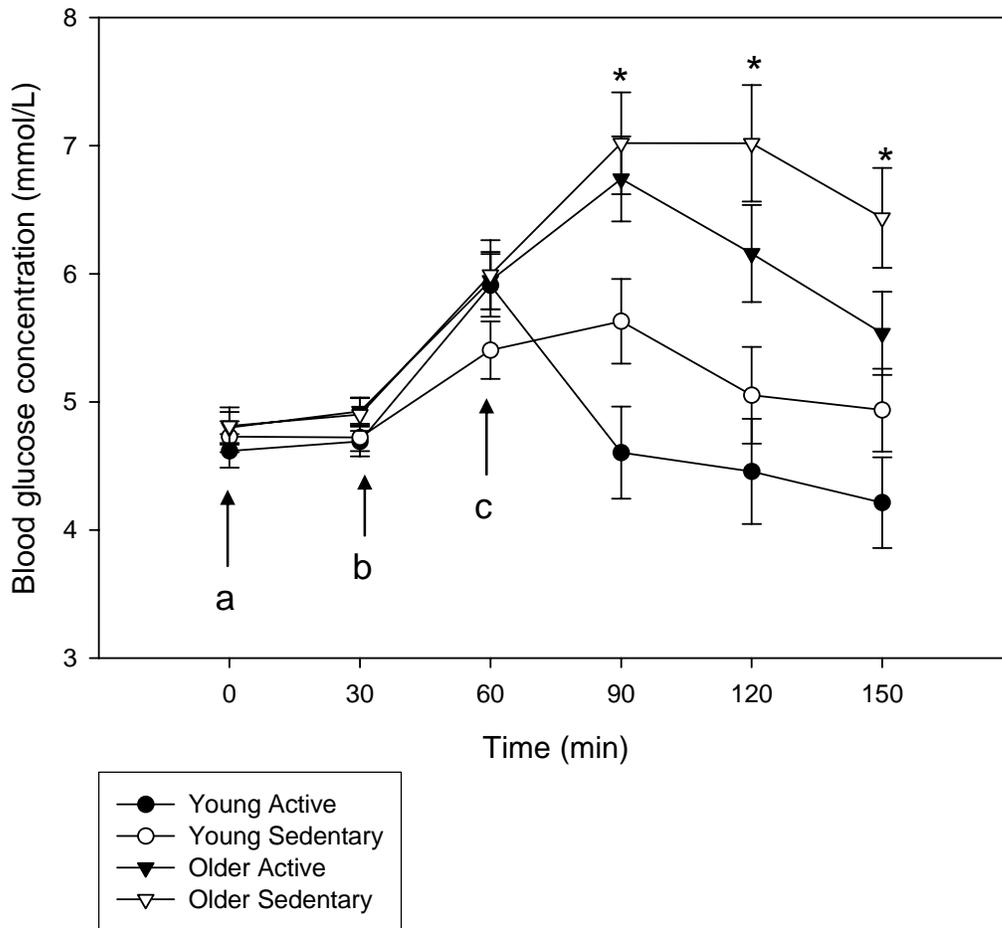


Figure 4b.

Blood glucose concentrations during the no preload (NP) test meal.

Blood glucose concentrations were measured at baseline (time 0), immediately prior to the yogurt preload (YP condition) or waiting period (NP condition) (a). Blood glucose concentrations were measured again at 30 minutes, immediately prior to the *ad-libitum* meal (b). Blood glucose concentrations were measured again after completion of the *ad-libitum* meal at 60 min (c), and at 90, 120, and 150 min. * Significant difference between older and young subjects ($P < 0.05$).

CHAPTER 3

Sex differences in acute energy intake regulation

ABSTRACT

Background: Sex differences in acute energy intake regulation have not previously been explored in humans.

Objective: The purpose of this investigation was to determine if energy intake compensation is more accurate in males compared to females matched for age, habitual physical activity, cardiorespiratory fitness, and dietary cognitive restraint. We also sought to determine if there are sex differences in sensations of hunger and satiety.

Design: Healthy, non-obese young men (n=12) and women (n=12) were provided with an *ad libitum* lunch meal on two occasions. Thirty minutes prior to the lunch meals, subjects were given either a yogurt preload (YP) (500 mL, 1988 kJ, men; 375 mL, 1507 kJ, women) or no-preload (NP). Energy intake at the two lunch meals was measured. Visual analog scales (VAS) were used to assess changes in hunger and fullness. Blood glucose concentrations were also determined.

Results: Energy intake compensation for the yogurt preload was significantly higher in the male compared to the female subjects (86.2±5.0 vs. 73.6±4.8 % compensation, P=0.04). There were no sex differences in perceptions of hunger and satiety. In the pooled sample, hunger ratings were significantly higher in the NP condition (P<0.01), but there were no significant differences in fullness ratings between test meals. In the YP condition, glycemic response to the preload and the *ad libitum* meal was significantly higher in males compared to females.

Conclusion: These results suggest that under acute test meal conditions, energy intake regulation is more accurate in males. Relative inability to regulate energy intake may predispose females to weight gain over time.

KEYWORDS

sex, compensation, preload, *ad libitum* meal, energy intake

INTRODUCTION

The factors contributing to the increasing prevalence of overweight and obesity among younger men and women in the United States (1) are multifaceted and complex, and it is therefore not clear if energy over-consumption is a consequence of physiologic dysregulation of energy intake *per se*, or a combination of cognitive and environmental factors leading to weight gain. Young normal weight men, however, are able to accurately regulate acute energy intake in a controlled environment (2). This ability has been assessed by measuring differences in compensation for the energy content of a high-energy preload at a subsequent *ad libitum* meal. In young men with low levels of dietary cognitive restraint, the high-energy preloads reduce meal energy intake such that overall energy intake (preload + meal) is not significantly different than energy intake in a no preload (meal only) condition (2).

While young men compensate well in response to a high-energy preload by decreasing their energy intake at a subsequent *ad libitum* meal, acute regulation of energy intake in men is influenced by age and habitual physical activity. Rolls et al. reported that older men (aged 64-84 y) compensate significantly less well for the energy in a yogurt preload and have blunted perceptions of hunger and satiety compared to younger men (aged 18-35 y) (2). In a similarly designed investigation, sedentary young men were shown to compensate less well than physically active young men, yet subjective appetite sensations (i.e. hunger, satiety) were not different between groups in response to a preload or a meal (3). These investigations suggest that the cause of energy intake dysregulation in older men may be due to age-related alterations in physiologic mechanisms controlling appetite, while physically inactive men may be less sensitive to hunger and satiety cues.

Although sex differences in ability to regulate acute energy intake have not previously been explored in humans, it has been proposed that physiologic control of energy homeostasis differs in men compared to women (4, 5). In order to isolate sex-specific differences in energy intake regulation, however, it is important to control other factors that may influence food intake and/or perceptions of hunger and satiety, including age and physical activity level. Women also have higher levels of dietary cognitive restraint than men, which may affect food intake in a controlled environment (6, 7).

Thus, the purpose of this investigation is to determine the influence of sex on the ability to compensate for a high-energy yogurt preload beverage consumed immediately prior to an *ad libitum* meal in young, non-obese men and women matched for age, habitual physical activity, cardiorespiratory fitness, and dietary cognitive restraint. A secondary goal is to investigate sex related differences in perceptions of hunger and satiety. Because work in animals suggests that “orexigenic drive” is greater in females than males (8), thus potentially predisposing females to overeating, we hypothesized that energy intake compensation for a high-energy preload beverage consumed immediately prior to an *ad libitum* meal would be lower in females (i.e., less accurate energy intake regulation) compared to males.

METHODS

Subjects

Healthy, non-obese ($BMI \leq 30 \text{ kg/m}^2$) young ($n = 24$, aged 21-35 yrs) adults were recruited for participation. Subjects were weight stable ($\pm 2 \text{ kg}$, $> 1 \text{ yr}$), nonsmokers, free from cardiovascular and other chronic disease (diabetes, thyroid disorders, cancer, heart, lung, and kidney disease), and not taking medications known to influence food intake or body weight. Individuals were

excluded if they had impaired glucose tolerance (fasting plasma glucose >6.1 mmol/L). Subjects were screened for dietary restraint (Eating Inventory (EI) cognitive restraint score <11) (9), depression (Centers for Epidemiological Studies Depression Scale (CES-D) score <35) (10), and eating disorders (Eating Attitudes Test (EAT-26) score <20) (11), had no food allergies or restrictions, and did not consume alcohol in excess (≤ 2 drinks/day). Subjects provided informed consent prior to participation in the investigation, but they were not aware of the specific purpose of the study. The protocol and consent form was approved by the Institutional Review Board at Virginia Tech.

Measurements

Height was measured in meters without shoes using a wall-mounted stadiometer. Body mass was measured to the nearest 0.1 kg using a digital scale. Body mass index was calculated as weight (kg)/height (m)². Percentage body fat, absolute fat mass and fat-free mass were measured using dual energy X-ray absorptiometry (DEXA) (GE Lunar Prodigy, GE Healthcare). Subjects were instructed in methods to accurately record their dietary intake; self-reported four-day food intake records were used to determine habitual dietary intake. Energy and macronutrient intake was assessed using nutritional analysis software (NDS-R 5.0, University of Minnesota). Habitual physical activity level was determined by self-reported time (minutes/week) spent participating in moderate and vigorous physical activity. Cardiorespiratory fitness (maximal oxygen consumption, i.e., VO₂ max) was determined by a graded exercise treadmill test to exhaustion using open-circuit spirometry (Parvo Medics 2400, Parvo Medics Inc.). VO₂ max percentile was assigned according to American College of Sports Medicine sex- and age- specific normative values (12). Fasting blood samples were collected by venipuncture into EDTA tubes (Fisher Scientific International Inc., Hampton, NH) and centrifuged at 2500 rpm for 15 min at 4 °C.

Plasma glucose concentrations were measured immediately using an automated glucose analyzer (YSI 2300 STAT Plus Glucose & Lactate Analyzer, YSI Incorporated, Yellow Springs, OH).

Procedures

Each subject reported to the laboratory for two lunch meals in random order, separated by at least two days, as follows: 1) 30-minute waiting period (no preload) followed by an *ad libitum* meal, and 2) preload consisting of 500 mL, 1988 kJ (men) or 375 mL, 1507 kJ (women) of a commercially available yogurt drink (Dannon Frusion; Dannon Company, Inc.) (77% energy from carbohydrate, 12% energy from protein, 11% energy from fat) followed 30 minutes later by an *ad libitum* meal. The prescribed preload volume was determined by protocols of similar studies in men (2, 13) and adjusted for women accord to sex-related differences in estimated energy requirements (~16% of daily energy requirements for young men and women) (14). In this sample, the energy content of the preload represented ~28 kJ/ kg body weight for both men and women. The test meal was provided at lunchtime so as to replicate the experimental protocol used in other published work in this area (2, 13). Because individuals compensate most accurately for the energy content of a preload when the preload is given 30 minutes prior to the lunch meal, the 30 minute waiting period between water preload and meal was chosen(15). Subjects were asked to eat their usual breakfast meal at the same time on both testing days, but to not eat anything for the three hours prior to their study visit. They recorded their food intake on the morning of both testing days, as well as for the remainder of the day following the test meal. Upon arrival, an intravenous catheter was placed in an antecubital vein. During the meal studies, visual analog scales (VAS) were completed by subjects to rate sensations of hunger and fullness and blood samples were obtained at 30 minutes intervals: prior to the preload or 30 minute waiting period (0 minutes), prior to the lunch meal (30 minutes), following the lunch meal (60

minutes), and at 90, 120, and 150 minutes (6 total). VAS, which are reproducible and valid indicators of hedonics (16, 17), consist of a query (“How hungry are you right now?”) and a 100 mm line that is anchored with descriptors that are polar opposites (“not at all hungry” to “extremely hungry”). Individuals are asked to make a mark on a line corresponding to their feelings. The catheter was removed and subjects were dismissed from the laboratory after completing the VAS scale at 150 minutes. Reading was permitted during the meal studies, but food and diet-related content was screened and removed from all material.

Test Meals

All foods included in the test meal lunches were evaluated for palatability prior to initiation of the study. The lunch consisted of an individual buffet-style meal containing a variety of typical lunch items (e.g., bread, luncheon meat, cheese, lettuce, condiments, potato chips, carrots, applesauce, cookies, water) in excess of what would normally be consumed, from which the subjects were allowed to self-select over a 30 minute period. Foods were weighed (± 0.1 g) before being served and again after the completion of the meal to determine the amount consumed. Meal energy and macronutrient intake was calculated using nutritional analysis software (NDS-R 5.0, University of Minnesota). Young women were studied in the follicular phase of their menstrual cycles for both feeding conditions to minimize the effect of cycle phase on energy intake (5).

Statistical Analysis

Male and female subjects were pair-matched according to age, minutes of moderate to high intensity physical activity per week, VO_2 max percentile, and dietary cognitive restraint score. Percent compensation was calculated as energy intake in the no preload (NP) condition divided by energy intake in the yogurt preload (YP) condition (preload + meal) multiplied by 100. VAS

scale and blood glucose area under the curve (AUC) were calculated using the trapezoid formula to determine overall between group and condition differences in ratings of hunger and fullness and blood glucose concentrations (18). Differences in demographic characteristics and percent compensation by sex were assessed using independent samples t-tests (SPSS v. 12.0 for Windows). Self-reported energy intake on the morning of/remainder of the day following the test meals was assessed with repeated measures analysis of variance (ANOVA). In order to assess between group and condition differences in perceptions of hunger and fullness and blood glucose at each time point, VAS ratings and glucose concentrations were analyzed with 6x2x2 repeated measures ANOVA. When significant interactions were detected, paired *t* tests were used as post-hoc tests. Associations among variables were assessed by simple correlational analyses (Pearson's *r*). The alpha level was set *a priori* at $P < 0.05$. Data are expressed as mean \pm SEM.

RESULTS

Participant demographic characteristics are listed in **Table 1**. Age, dietary cognitive restraint scores, habitual exercise minutes per week, VO_2 max percentile, and fasting blood glucose were not significantly different in male compared with female subjects, but BMI was significantly higher in male subjects. As expected, there were also sex differences in VO_2 max when expressed relative to body weight, and percent body fat. There were no differences in habitual dietary intake (energy; % kJ from fat, carbohydrates, protein or alcohol) between male and female subjects (Table 1).

Energy intake and percent compensation in male and female subjects is shown in **Figure 1**. Ability to compensate for the energy in the yogurt preload was significantly higher in males compared to females (86.2 ± 5.0 vs. 73.6 ± 4.8 % compensation, $P = 0.04$). Energy intake was

significantly higher in males compared to females in both conditions ($P<0.01$), but there were no significant sex differences in macronutrient intake as percent of total energy (data not shown).

There were also no significant differences in percent of energy consumed at the *ad libitum* meals from carbohydrates, protein, or fat in the YP compared to the NP condition.

Self-reported breakfast energy intake on the morning of the test meals and for the remainder of the day following the test meals is listed in **Table 2**. There were no significant effects of condition on self-reported breakfast energy intake or self-reported energy intake for the remainder of the test meal days following the meal studies ($P=0.06$ and $P=0.53$, respectively) and there were no condition by sex interactions on breakfast or remainder of the day energy intakes ($P=0.89$ and $P=0.35$, respectively). Total energy intake the day of the test meals (self-reported breakfast energy intake + measured test meal energy intake + self-reported energy intake the remainder of the day) was also not different in the YP compared to the NP condition ($P=0.26$) and there was no condition by sex interaction ($P=0.92$) (Table 2).

Baseline hunger and fullness (ratings at time 0) were not significantly different in the YP compared to the NP condition and there was no condition by sex interaction (YP condition hunger: 59 ± 7 vs. 51 ± 9 mm, males and females; NP condition hunger: 73 ± 5 vs. 54 ± 8 mm, males and females; YP condition fullness: 25 ± 6 vs. 21 ± 7 mm, males and females; NP condition fullness: 29 ± 4 vs. 27 ± 7 mm, males and females). As expected, hunger and fullness changed significantly with time in response to meal ingestion (**Figures 2-3**). Hunger ratings were significantly higher in the NP condition as determined by analysis of both mean and AUC values (mean: 27 ± 3 vs. 34 ± 2 mm, YP and NP, respectively, $P=0.02$; AUC: 3430 ± 343 vs. 4860 ± 332 mm·min, YP and NP, respectively, $P<0.01$) (Figure 2). There was no significant difference in average fullness ratings between test meals determined by mean or AUC (mean: 55 ± 3 vs. 53 ± 3

mm, YP and NP, respectively, $P=0.22$; AUC: 8737 ± 469 vs. 8109 ± 328 mm·min, YP and NP, respectively, $P=0.16$) (Figure 3).

Baseline blood glucose concentrations (values at time 0) were not significantly different in the YP compared to the NP condition (4.7 ± 0.1 vs. 4.7 ± 0.1 mmol/L, $P=0.80$) and there was no condition by sex interaction in baseline blood glucose concentration ($P=0.09$) (**Figure 4**). As expected, there was a significant effect of time on blood glucose concentrations during the test meals ($P<0.01$). There were significant time by sex, time by condition, and condition by sex interactions ($P=0.02$, $P<0.01$, and $P=0.01$, respectively). In the NP condition, there were no significant differences in blood glucose concentrations at any time point measured. However, in the YP condition, blood glucose concentrations were significantly higher in males than females at 30 min (post-preload) ($P<0.01$), 60 min (post-meal) ($P=0.05$), and 120 min ($P=0.03$). There was no significant difference in blood glucose AUC between meal conditions in the pooled sample. However, there was a significant sex difference in blood glucose AUC between meal conditions (i.e., sex by condition interaction) ($P=0.01$). This difference is attributed to a significantly higher glucose AUC in the males as compared to females in the YP condition (785 ± 36 vs. 641 ± 40 mmol·min/L, $P=0.02$).

In the pooled sample, there were no significant associations between energy intake percent compensation and BMI, age, habitual exercise minutes per week, percent body fat, VO_2 max, VO_2 max percentile, or habitual energy intake. However, a significant inverse association between percent compensation and dietary cognitive restraint score was noted ($r=-0.496$, $P=0.01$).

DISCUSSION

In this study, our main finding is that acute energy intake regulation is significantly less accurate in females compared with males, resulting in a ~12.5 % difference in ability to compensate for an energy-containing preload. Importantly, this sex difference in ability to compensate could not be attributed to group differences in age, habitual physical activity, cardiorespiratory fitness or dietary cognitive restraint. In spite of the significant sex difference in compensation, subjective ratings of hunger and fullness did not differ among men and women. The finding that young men compensated relatively well for the yogurt preload is in agreement with previous observations (2). These results suggest that more accurate energy intake regulation in men compared to women may be the result of sex differences in sensitivity to hunger and satiety cues.

Del Parigi et al. demonstrated sex-specific central processing of hunger and satiety cues, which may explain our finding of differences between men and women in energy intake regulation despite similar perceptions of hunger and satiety (19). These investigators reported no sex differences in subjective ratings of hunger and satiety in response to controlled administration of an energy load, yet they detected sex differences in neuronal activity in response to hunger and satiety. In agreement with these findings, other investigators have found increased cortical activity in response to food-related stimuli in women compared to men, and have suggested sex differences in central processing of satiation may be an important factor predisposing women to weight gain (20, 21). Additional potential explanations for sex differences in ability to compensate include sex-specific secretion of, or sensitivity to, hormones regulating food intake, interactions between sex hormones and peptides involved in energy intake regulation, or glycemic response to the preload.

Animal studies have noted sex-specific responses to a short-term fast, with female rodents exhibiting significant hyperphagia, as well as higher ghrelin and lower leptin

concentrations relative to male rodents(8). While research in humans is inconsistent, there is preliminary evidence of sexual dimorphism in secretion of gastrointestinal (GI) hormones, specifically, that ghrelin concentrations are significantly higher in females compared to males both in a fasting state and in response to oral glucose and lipid loads (22). Sex hormones, which independently influence food intake in women (5), may also interact with GI hormones (23), thereby attenuating hypothalamic sensitivity to peripheral satiety signals and ultimately resulting in overeating and weight gain. Finally, it is also possible that sex differences in glycemic response to the preload may have also affected ability to compensate. Anderson et al. reported that blood glucose AUC in response to a preload given one hour prior to an *ad libitum* meal was inversely related to meal energy intake. That is, preloads that initiated a higher blood glucose response resulted in more accurate compensation for the preload at the *ad libitum* meal (24). We found that following the yogurt preload, but immediately prior to the *ad libitum* meal (Figure 4); blood glucose concentrations were significantly higher in males compared to females, which may have contributed to sex differences in compensation. It is clear that future research is necessary to determine the mechanisms responsible for the disparity in ability to acutely regulate energy intake in men compared to women.

Despite our finding that young men regulate energy intake more accurately than women and should therefore have a superior ability to maintain an appropriate body weight, the prevalence of obesity in the United States is not different in younger men compared to women (1). Although the reasons for this apparent discrepancy are not clear, it is possible that sex-related differences in environmental or cognitive factors related to body weight homeostasis that lead to energy restriction in women may offset more accurate energy intake regulation in men. Environmental factors, including social pressure for women to be thin or to achieve a culturally

ideal body shape may override internal cues regulating energy intake (25). Interestingly, we found that in our sample of unrestrained eaters, dietary cognitive restraint was significantly inversely associated with percent compensation. A relatively high level of cognitive control over food intake may interfere with the ability to appropriately regulate energy intake in response to physiologic signals of hunger and satiety, potentially leading to energy over-consumption. De Castro et al. reported that in men and women with comparable levels of restraint, the effect of restraint on energy intake is equivalent (6). According to our results, both men and women exhibiting higher levels of dietary cognitive restraint may be prone to weight gain over time.

In older adults, however, the incidence of obesity is significantly higher in women compared to men (1). It is possible that the decline in the physiologic ability to regulate energy intake is greater in females than in males, ultimately resulting in relatively more weight gain in females with advancing age. An alternative possibility is that the degree of physiologic energy intake dysregulation is not different in older men and women, but social-cultural pressure to maintain a normal body weight is reduced in older women compared to younger women. Further investigation is required to determine if energy intake compensation is different in older men compared to older women.

There are several limitations in the present study that should be acknowledged. First, our results are only applicable to an acute meal setting. It is, therefore, not clear if long-term energy intake compensation is different in men compared to women. Also, we did not control food intake on the morning of the lunch meals. However, we found that there were no differences in breakfast energy intake between conditions or in males compared to females. Due to our relatively small sample size, additional studies with a greater number of subjects are needed to confirm our findings. Finally, our results cannot be extrapolated beyond the age range studied.

In conclusion, our results suggest that under acute meal conditions, energy intake regulation is more accurate in men compared to women matched for age, habitual physical activity, cardiorespiratory fitness, and dietary cognitive restraint. These differences may be due to sex-related differences in central integration of hunger and satiety cues, sex specific interactions of sex hormones with hunger and satiety signals, or glycemic response to food intake. Our data also suggest that environmental and/or cognitive factors that influence energy intake may differ between young men and women, thereby mediating sex differences in energy intake regulation such that the prevalence of obese younger men and women in the United States is not different. Future studies are warranted to investigate the physiologic and/or behavioral mechanisms responsible for differences in energy intake compensation between men and women.

TABLES

Table 1. Subject Characteristics

| | Males (n=12) | Females (n=12) | P |
|---------------------------------------|-----------------|-------------------|-------|
| Age, yrs | 26 \pm 1 | 23 \pm 1 | 0.16 |
| Dietary Restraint Score | 4.4 \pm 0.7 | 6.1 \pm 0.8 | 0.14 |
| BMI, kg/m ² | 24.4 \pm 0.8 | 21.7 \pm 0.6 | 0.01 |
| Body Fat, % | 15.8 \pm 2.5 | 26.2 \pm 1.8 | <0.01 |
| Habitual Dietary Intake: | | | |
| Energy, MJ | 10.5 \pm 0.9 | 8.2 \pm 0.7 | 0.06 |
| Fat, % energy | 29.6 \pm 2.7 | 28.0 \pm 2.4 | 0.66 |
| Carbohydrate, % energy | 51.4 \pm 2.0 | 58.3 \pm 2.9 | 0.06 |
| Protein, % energy | 16.0 \pm 1.3 | 13.6 \pm 0.8 | 0.13 |
| Alcohol, % energy | 1.6 \pm 0.6 | 2.3 \pm 0.9 | 0.49 |
| Habitual Physical Activity, min/wk | 390 \pm 140 | 346 \pm 106 | 0.80 |
| VO ₂ max, ml/kg/min | 56.0 \pm 3.6 | 43.3 \pm 2.4 | 0.01 |
| VO ₂ max percentile | 71.7 \pm 7.5 | 67.9 \pm 7.4 | 0.72 |
| Fasting glucose, mmol/L | 4.8 \pm 0.1 | 4.7 \pm 0.1 | 0.26 |

Data are expressed as Mean \pm SEM.

Table 2. Self-reported Energy Intake on Test Meal Days in the Yogurt Preload (YP) and No Preload (NP) Conditions

| | Males | Females | P |
|-------------------------------------|------------------|------------------|------|
| Breakfast, YP Condition (kJ) | 858 \pm 419 | 833 \pm 381 | 0.64 |
| Remainder of Day, YP Condition (kJ) | 6057 \pm 879 | 5287 \pm 942 | 0.70 |
| Total Day, YP Condition (kJ)* | 12001 \pm 2248 | 10168 \pm 1109 | 0.30 |
| Breakfast, NP Condition (kJ) | 1047 \pm 452 | 996 \pm 385 | 0.65 |
| Remainder of Day, NP Condition (kJ) | 7158 \pm 1038 | 5065 \pm 1109 | 0.12 |
| Total Day, NP Condition (kJ)* | 11378 \pm 1817 | 9071 \pm 1055 | 0.09 |

Data are expressed as Mean \pm SEM.

*Includes test meal total energy intake (kJ)

FIGURE LEGEND

Figure 1. Lunch meal energy intake in the yogurt preload (YP) and no preload (NP) conditions in males and females. * Significant difference in energy intake percent compensation in males compared to females (P=0.04).

Figure 2. Subjective hunger ratings during yogurt preload (YP) and no preload (NP) test meals in males and females. The yogurt preload was given immediately following completion of the 0 min VAS scale (**a**). Subjects completed a second VAS scale at 30 min (**b**), and were immediately provided with the *ad libitum* meal. Following completion of the *ad libitum* meal at 60 minutes, subjects completed a third VAS scale (**c**). The VAS scales were again completed at 90, 120, and 150 min.

Figure 3. Subjective fullness ratings during yogurt preload (YP) and no preload (NP) test meals in males and females. The yogurt preload was given immediately following completion of the 0 min VAS scale (**a**). Subjects completed a second VAS scale at 30 min (**b**), and were immediately provided with the *ad libitum* meal. Following completion of the *ad libitum* meal at 60 minutes, subjects completed a third VAS scale (**c**). The VAS scales were again completed at 90, 120, and 150 min.

Figure 4. Blood glucose concentrations during yogurt preload (YP) and no preload (NP) test meals in males and females. Blood glucose concentration was measured at baseline (time 0), immediately prior to the yogurt preload (YP condition) or waiting period (NP condition) (**a**). Blood glucose concentration was measured again at 30 minutes, immediately prior to the *ad*

libitum meal (**b**), and after completion of the *ad libitum* meal at 60 min (**c**), and at 90, 120, and 150 min. * Significant sex difference in YP condition ($P < 0.05$).

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Figure 1.

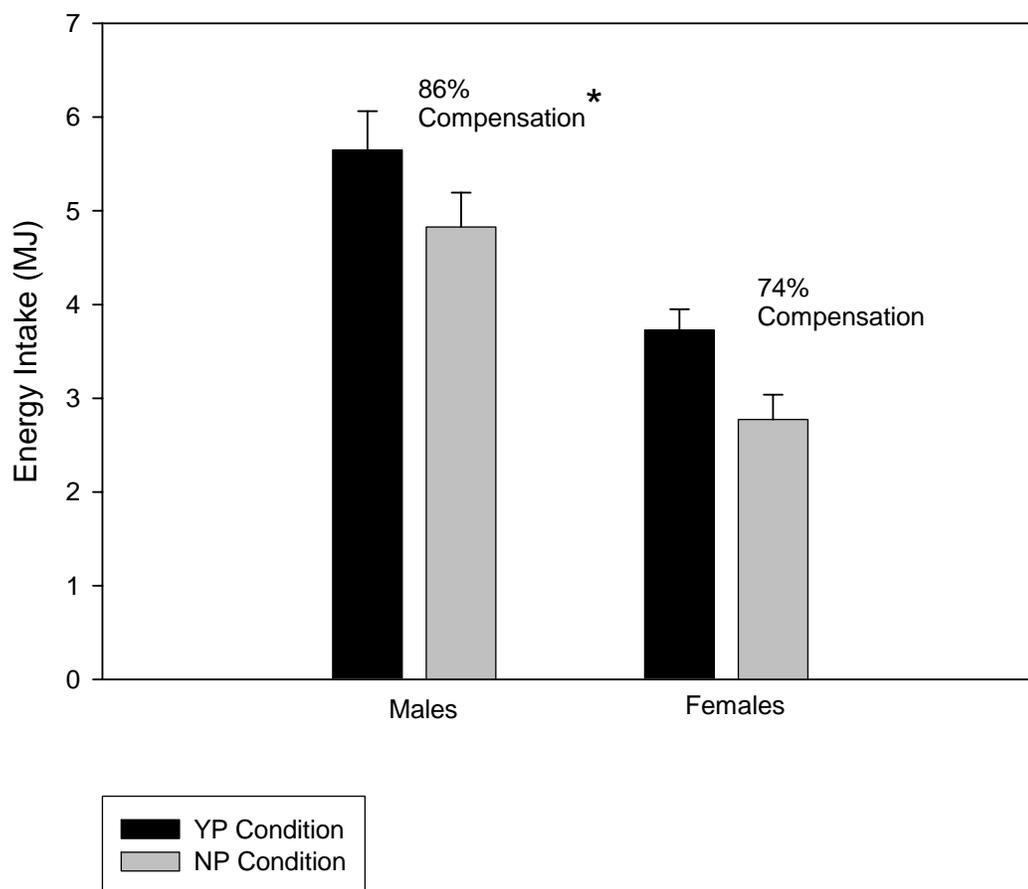


Figure 1. Lunch meal energy intake in the yogurt preload (YP) and no preload (NP) conditions in males and females. * Significant difference in energy intake percent compensation in males compared to females (P=0.04).

Figure 2.

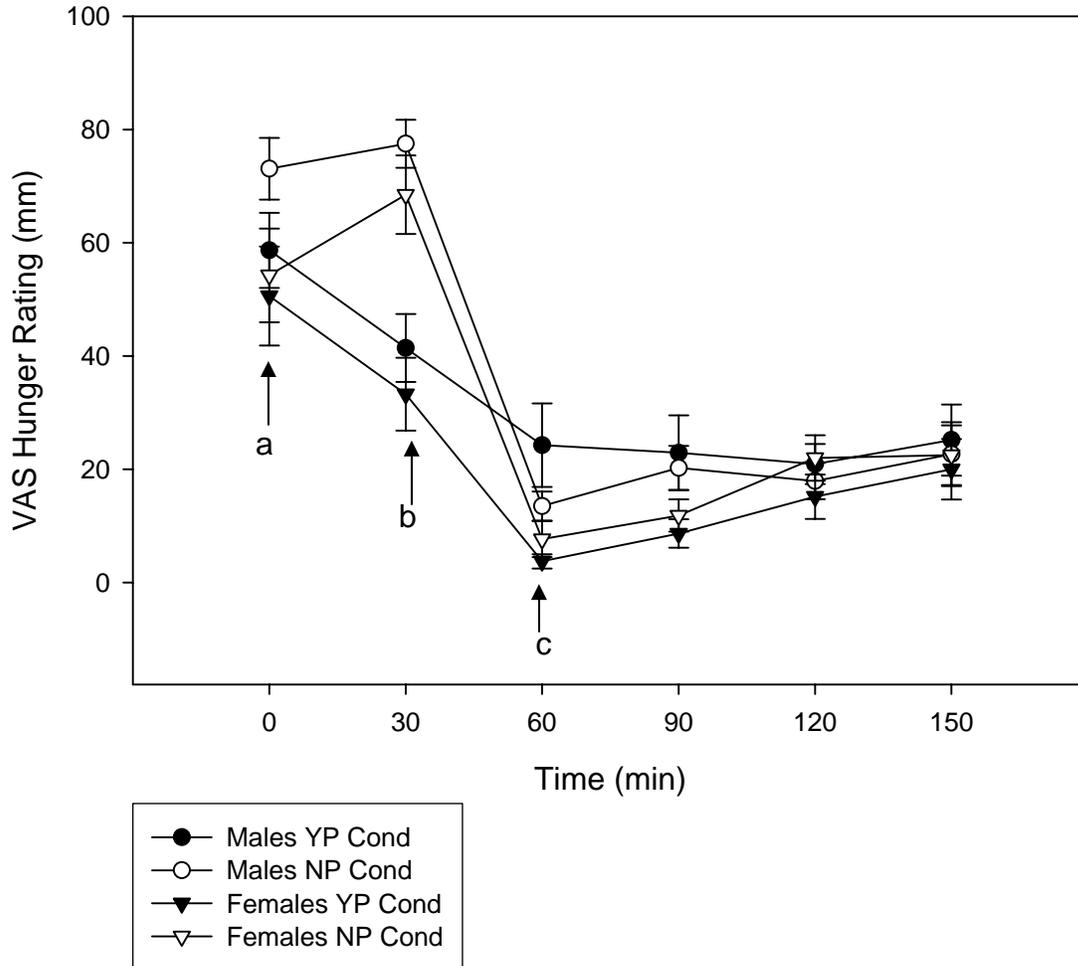


Figure 2. Subjective hunger ratings during yogurt preload (YP) and no preload (NP) test meals in males and females. The yogurt preload was given immediately following completion of the 0 min VAS scale (a). Subjects completed a second VAS scale at 30 min (b), and were immediately provided with the *ad libitum* meal. Following completion of the *ad libitum* meal at 60 minutes, subjects completed a third VAS scale (c). The VAS scales were again completed at 90, 120, and 150 min.

Figure 3.

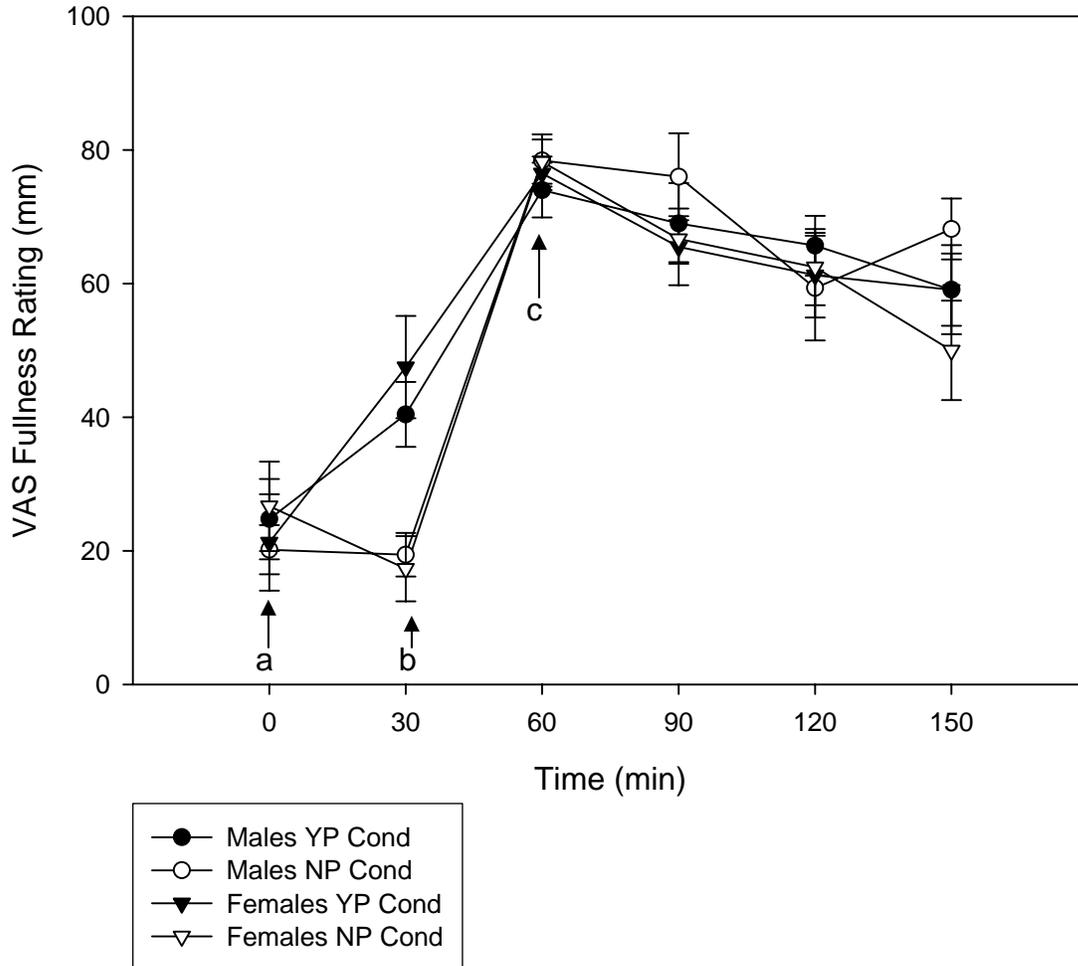


Figure 3. Subjective fullness ratings during yogurt preload (YP) and no preload (NP) test meals in males and females. The yogurt preload was given immediately following completion of the 0 min VAS scale (a). Subjects completed a second VAS scale at 30 min (b), and were immediately provided with the *ad libitum* meal. Following completion of the *ad libitum* meal at 60 minutes, subjects completed a third VAS scale (c). The VAS scales were again completed at 90, 120, and 150 min.

Figure 4.

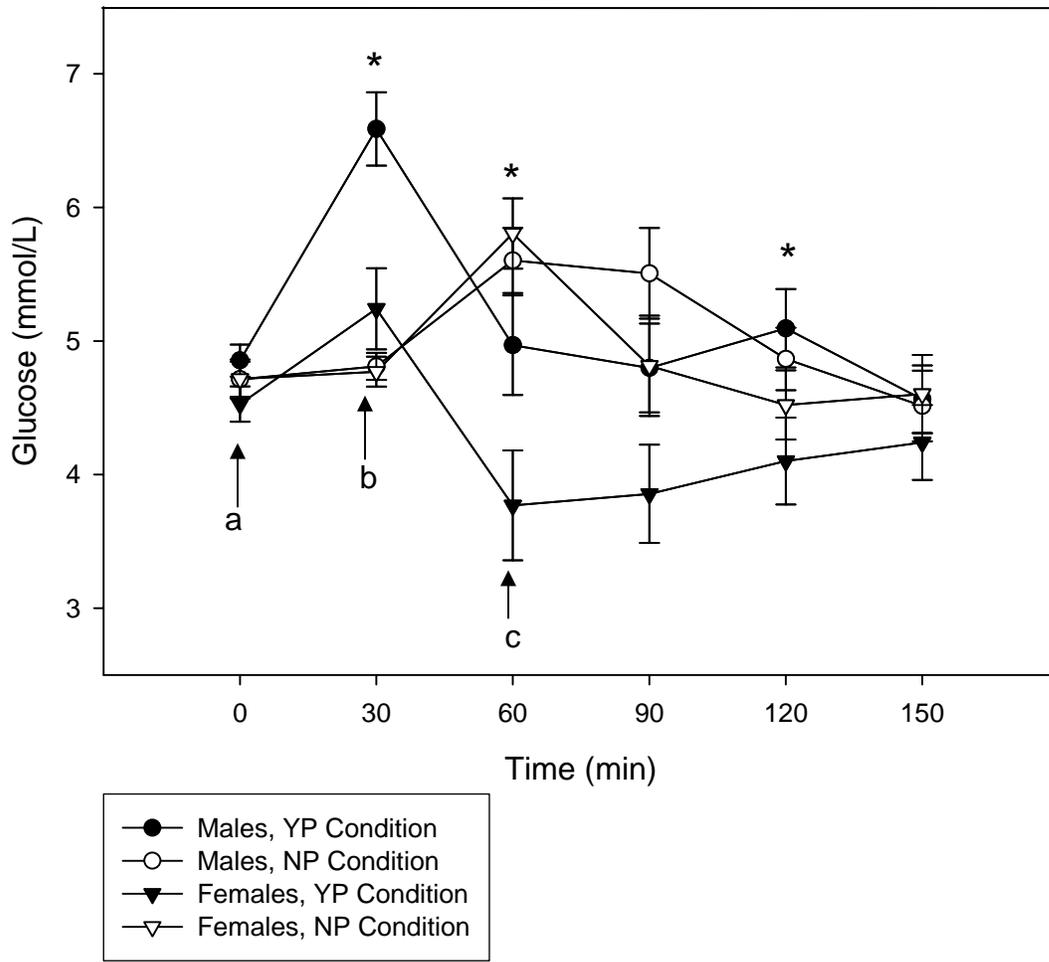


Figure 4. Blood glucose concentrations during yogurt preload (YP) and no preload (NP) test meals in males and females. Blood glucose concentration was measured at baseline (time 0), immediately prior to the yogurt preload (YP condition) or waiting period (NP condition) (a). Blood glucose concentration was measured again at 30 minutes, immediately prior to the *ad libitum* meal (b), and after completion of the *ad libitum* meal at 60 min (c), and at 90, 120, and 150 min. * Significant sex difference in YP condition ($P < 0.05$).

CHAPTER 4

Pre-meal water consumption reduces meal energy intake in older but not younger adults

ABSTRACT

Background: Despite the common belief that water ingestion suppresses hunger and reduces energy intake, few studies have been conducted which directly address this issue.

Objective: The purpose of this investigation was to determine if the consumption of water 30 minutes prior to an *ad libitum* meal reduces meal energy intake. Since aging is accompanied by changes in sensations of hunger and satiety, as well as body weight, we also sought to determine if aging influences the effect of water consumption on meal energy intake.

Design: Healthy, non-obese young (n= 32, aged 21-35 yrs) and older (n=25, aged 60-80 yrs) individuals were provided with an *ad libitum* lunch meal on two occasions. Thirty minutes prior to the lunch meals, subjects were given either a water preload (WP: 375 ml, women; 500 ml, men) or no-preload (NP). Energy intake at the two lunch meals was measured. Visual analog scales (VAS) were used to assess changes in hunger, fullness, and thirst during the meal studies.

Results: There was no significant difference in meal energy intake between conditions in the young subjects (892±51 vs. 913±54 kcal at NP and WP, respectively; P=0.65). However, meal energy intake after the water preload was significantly reduced relative to the no-preload condition in the older subjects (682±53 vs. 624±56 kcal, NP and WP, respectively; P=0.02). This effect was primarily due to the reduction in meal energy intake following water consumption in older men. Hunger ratings were lower and fullness ratings

were higher in older compared with younger adults ($P < 0.01$). Fullness ratings were higher in the water preload condition compared with the no-preload condition for all subjects ($P = 0.01$). No age differences in thirst were detected during the test meals. **Discussion:** **Conclusion:** These results suggest that under acute test meal conditions, pre-meal water consumption reduces meal energy intake in older but not younger adults. Since older adults are at increased risk for overweight and obesity, intervention studies are needed to determine if pre-meal water consumption is an effective long-term weight management strategy for the aging population.

Key Words: water consumption, energy intake regulation, aging

INTRODUCTION

Recent estimates indicate that two-thirds of the United States adult population is classified as either overweight or obese, and the prevalence of these conditions is higher in middle-aged and older adults (i.e., 71-73%) compared with the general population (1). In an effort to curtail progression of the obesity epidemic, much research has focused on identifying strategies to reduce meal energy intake, thereby preventing energy over-consumption and subsequent weight gain. One such strategy is to modify perceptions of hunger and fullness prior to a meal by consumption of a “preload” food or beverage. Low-energy, high-volume preloads, including specific formulations of soup and salad, reduce hunger and increase fullness prior to a meal and reduce overall energy intake (preload + *ad libitum* meal) when compared with a no-preload condition (*ad libitum* meal alone) (2-4). The effect of beverage consumption on *ad libitum* energy intake has also been of interest, as it has been suggested that liquids are less satiating than solids (5). Energy intake is higher under *ad libitum* meal conditions when energy-containing beverages (ie. wine, beer, juice, milk, cola) are given prior to a meal, or consumed with a meal, compared with identical conditions when no beverage or water is provided (6-8).

There is a common belief among the lay public that water ingestion will suppress hunger and reduce energy intake, thereby facilitating weight reduction. However, to our knowledge there are no studies which directly address this issue. Water consumed with a meal reduces subjective ratings of hunger and increases ratings of satiety during a meal (9), but its effect on meal energy intake is not clear. Studies of beverage preloads and meal energy intake often use a water preload as the control condition; thus, a no-preload condition is not available for comparison (10-17). Only one study is available which

included both a water preload and no-preload condition so that the effect of pre-meal water consumption on meal energy intake can be surmised. Rolls et al. (18) reported that young, normal weight men consume the same amount of energy at an *ad libitum* meal when given a water preload (8 and 16 fl. oz) as compared to no beverage 30 minutes prior to the meal (18). Given that changes in energy intake regulation have been reported with advancing age in both men and women (10, 19, 20) and that increased water consumption is frequently recommended to facilitate weight control, there is surprisingly little data addressing the effect of pre-meal water consumption on meal energy intake in healthy young and older adults.

Thus, the purpose of this investigation is to determine if the consumption of water 30 minutes prior to an *ad libitum* meal affects perceptions of hunger and fullness and reduces meal energy intake in healthy men and women. Because aging is accompanied by changes in sensations of hunger and satiety (17, 19) and body weight (20-22), we also sought to determine if aging influences the effect of water consumption on meal energy intake.

METHODS

Subjects

Healthy, non-obese ($BMI \leq 30 \text{ kg/m}^2$) young (aged 21-35 yrs) and older (aged 60-80 yrs) adults were recruited for this investigation. Subjects were weight stable ($\pm 2 \text{ kg}$, $>1 \text{ yr}$), nonsmokers, free from cardiovascular and other chronic disease (diabetes, thyroid disorders, cancer, heart, lung, and kidney disease), and not taking medications known to influence food intake or body weight. Individuals were excluded if they had impaired

glucose tolerance (fasting plasma glucose >110 mg/dl). The older adults were screened for cardiovascular disease using resting and maximal exercise electrocardiograms prior to measurement of aerobic fitness (see below). Subjects were screened for dietary restraint (Eating Inventory (EI) cognitive restraint score <11) (23), depression (Centers for Epidemiological Studies Depression Scale (CES-D) score <35) (24), and eating disorders (Eating Attitudes Test (EAT-26) score <20) (25), had no food allergies or restrictions, and did not consume alcohol in excess (≤ 2 drinks/day). Thirty-seven young and 30 older adults were initially enrolled in this investigation; eight young and four older subjects were unable to complete all study procedures due to time constraints or unwillingness to undergo certain study procedures (ie. venipuncture, maximal exercise test) and five older subjects did not receive medical clearance to participate based upon their resting/maximal exercise electrocardiograms. Our final sample included 29 young and 21 older individuals. All subjects provided informed consent prior to their participation in the investigation, but they were not aware of the specific purpose of the study. This protocol and consent form was approved by the Institutional Review Board at Virginia Tech.

Measurements

Height was measured in meters without shoes using a wall-mounted stadiometer. Body mass was measured to the nearest 0.1 kg using a physician's balance scale. Body mass index was calculated as weight (kg)/height(m)². Percentage body fat, absolute fat mass and fat-free mass was measured using dual energy X-ray absorptiometry (DEXA) (GE Lunar Prodigy, GE Healthcare). Subjects were instructed in methods to accurately record their dietary intake; self-reported four-day food intake records were used to determine habitual

dietary intake. Energy and macronutrient intake were assessed using nutritional analysis software (NDS-R 5.0, University of Minnesota). Habitual physical activity level was determined by self-reported time (minutes/week) spent participating in moderate and vigorous physical activity. Cardiorespiratory fitness (maximal oxygen consumption; VO_2 max) was determined by a graded exercise treadmill test to exhaustion using open-circuit spirometry (Parvo Medics 2400, Parvo Medics Inc.).

Procedures

Subjects reported to the laboratory for two lunch meals in random order as follows: 1) 30-minute waiting period (no preload) followed by an *ad libitum* meal, and 2) preload consisting of 375mL (women) or 500mL (men) of water followed 30 minutes later by an *ad libitum* meal. Lunch meals for each subject were separated by a minimum of two days. The test meal was provided at lunchtime so as to replicate the experimental protocol used in other published work in this area (19, 26). The 30 minute waiting period between water preload and meal was chosen because individuals compensate most accurately for the energy content of a preload when the preload is given 30 minutes prior to the lunch meal (26). Subjects were instructed to consume the water preload as quickly as they comfortably could, within a maximum time period of 30 minutes. The amount of time taken to drink the preload was recorded by the study personnel. Subjects were asked to eat their usual breakfast meal at the same time on both testing days (3, 19), but to not eat anything for the three hours prior to their study visit. They recorded their food intake on the morning of both testing days, as well as for the remainder of the day following the test meal. During the meal studies, visual analog scales (VAS) were completed by subjects at 30 minutes

intervals to rate sensations of fullness, hunger, and thirst: prior to the preload or 30 minute waiting period (0 minutes), prior to the lunch meal (30 minutes), following the lunch meal (60 minutes) and at 90, 120, and 150 minutes (6 total). Subjects were dismissed from the laboratory after completing the VAS scale at 150 minutes. VAS consist of a query (“How hungry are you right now?”) and a 100-mm line that is anchored with descriptors that are polar opposites (“not at all hungry” to “extremely hungry”). Individuals are asked to make a mark on a line corresponding to their feelings. VAS are reproducible and valid indicators of hedonics in young and older populations (27-29). Reading was permitted during test meal sessions, but food and diet-related content was screened and removed from all material.

Test Meals

All foods included in the test meal lunches were evaluated for palatability prior to initiation of the study. The lunch consisted of an individual buffet-style meal containing a variety of typical lunch items (e.g., bread, luncheon meat, cheese, lettuce, condiments, potato chips, carrots, applesauce, cookies, water) in excess of what would normally be consumed, from which the subjects were allowed to self-select over a 30 minute period. The water preloads consisted of chilled tap water served at a constant temperature (5-7°C). Foods were weighed (± 0.1 g) before being served and again after the completion of the meal to determine the amount consumed. Meal energy and macronutrient intake were calculated using nutritional analysis software (NDS-R 5.0, University of Minnesota). Young women were studied in the follicular phase of their menstrual cycles for both feeding conditions to minimize the effect of cycle phase on energy intake (30).

Statistical Analysis

Differences in demographic characteristics by age and gender were assessed using independent samples t-tests (SPSS v. 12.0 for Windows). Differences in energy intake, VAS ratings, and self-reported food intake on the morning of/remainder of the day following the test meals were assessed by repeated measures analysis of variance (ANOVA). Analysis of covariance (ANCOVA) was utilized to adjust for baseline differences between age groups in VAS data. Associations among variables were assessed by simple correlational analyses (Pearson's *r*). The alpha level was set *a priori* at $P < 0.05$.

RESULTS

Participant demographic characteristics are listed in **Table 1**. BMI was not significantly different in the older compared with younger subjects (23.3 ± 0.5 vs. 24.7 ± 0.6 kg/m², $P > 0.05$), but body fat was higher in the older subjects (30.5 ± 1.8 vs. 22.6 ± 1.6 %, $P < 0.01$). Restraint scores were higher in older subjects relative to their younger counterparts (7.7 ± 0.7 vs. 5.3 ± 0.6 , $P < 0.01$). There were no significant differences in habitual dietary intake (energy; % kcal from fat, carbohydrate, protein or alcohol) between older and younger subjects in our sample, but young women reported a lower energy and protein intake than younger men (Table 1). Self-reported water consumption was lower in older than younger subjects (469 ± 118 vs. 905 ± 155 g, $P = 0.03$), but habitual total beverage consumption (all beverages, including water) was not significantly different between age groups (1713 ± 151 vs. 1771 ± 147 g, $P = 0.79$). Habitual water consumption did not differ among men and women within age groups (ie. young males vs. young females, older males

vs. older females; both $P > 0.05$), but gender differences in self-reported beverage consumption within age groups were noted. In both the young and older groups, mean beverage consumption was ~600g higher in males as compared to females (Older: 1995 ± 256 vs. 1406 ± 93 g, $P = 0.05$; Young: 2131 ± 241 vs. 1433 ± 130 g, $P = 0.02$). Habitual physical activity level did not differ by age or gender group. As would be expected with advancing age, maximal oxygen consumption (VO_2 max) was lower in older compared with younger subjects (28.2 ± 1.8 vs. 46.2 ± 2.2 ml/kg/min, $P < 0.01$).

Energy intake during the two test meals in young and older subjects are shown in **Figure 1**. Neither the condition effect ($P = 0.47$) nor the condition by age group interaction effect ($P = 0.16$) were significant, but meal energy intake was lower in older compared with younger adults ($P = 0.02$). When the younger subjects were considered in a separate analysis, there was no significant condition effect (Figure 1; 892 ± 51 vs. 913 ± 54 at NP and WP, respectively; $P = 0.65$) or gender by condition interaction effect ($P = 0.57$). In contrast, meal energy intake after the water preload was significantly reduced relative to the no-preload condition in the older subjects by ~60 kcal (Figure 1; 682 ± 53 vs. 624 ± 56 kcal, NP and WP, respectively; $P = 0.02$). The reduction in meal energy intake following water consumption in older adults was due primarily to a significantly greater reduction in older men compared with women (111 ± 37 vs. 4 ± 25 kcal, $P = 0.03$). The difference in energy intake between the two meal conditions was not associated with either habitual water ($P = 0.11$) or beverage ($P = 0.10$) consumption. There were no significant differences in meal macronutrient composition (% total energy) or in water consumption (excluding the water preload) by age or condition (data not shown, all $P > 0.05$). The time taken to consume the

water preload was also not significantly different between older and younger subjects (13 ± 2 vs. 12 ± 2 min, $P=0.65$).

Self-reported breakfast intake on the day of the test meals (298 ± 41 vs. 330 ± 35 kcal for NP and WP, respectively; $P=0.24$), and in the remainder of the day following the test meals (1160 ± 103 vs. 1064 ± 67 kcal for NP and WP, respectively; $P=0.39$) was not significantly different between meal conditions or age groups.

Baseline hunger and thirst (average of both conditions, time 0) were significantly lower in the older compared with younger adults (hunger: 24 ± 4 vs. 40 ± 3 , $P=0.003$; thirst: 31 ± 5 vs. 45 ± 4 , $P=0.02$), but there was no difference in baseline fullness (50 ± 3 vs. 46 ± 2 , $P=0.38$). As expected, hunger, fullness and thirst changed significantly with time in response to meal ingestion (**Figures 2-4**). There was no significant difference in hunger ratings between test meals (Figure 2), but hunger ratings during both test meals were significantly lower in the older compared with younger subjects ($P=0.006$) and there was a significant condition by time by age group interaction ($P=0.03$). There was a significant difference in fullness between meal conditions (Figure 3); subjects reported more fullness in the WP than NP condition (57 ± 2 vs 51 ± 2 mm, $P=0.01$). In addition, older subjects reported more fullness than younger subjects during the WP condition (63 ± 3 vs. 51 ± 2 mm, $P=0.002$), and more fullness overall (56 ± 3 vs. 52 ± 2 mm, $P=0.002$). In response to the water preload, older adults reported significantly more fullness than younger adults (change in VAS rating from 0-30 min: 9 ± 6 vs. 1 ± 2 mm, $P=0.001$). After adjustment of baseline thirst, there was no significant difference in ratings of thirst between conditions, but there was a significant condition by time interaction ($P=0.002$; Figure 4). No significant age difference

in thirst was noted during the test meals, and there were no significant gender differences in ratings of hunger, fullness, or thirst (data not shown).

No significant associations were noted between dietary cognitive restraint, BMI, % body fat, habitual physical activity level and aerobic fitness and difference in energy intake between test meal conditions (data not shown).

DISCUSSION

The major finding of this study is that pre-meal water consumption significantly reduced meal energy intake in older, but not younger adults. This effect was particularly pronounced among the older men, who consumed ~111 fewer kcal at the *ad libitum* meal following the water preload relative to a no-preload condition. In the group as a whole, subjective ratings of fullness were significantly higher in the water preload condition relative to the no-preload condition, but only in the older adults did this correspond with a reduction in meal energy intake. Our finding that pre-meal water does not reduce meal energy intake in young adults is consistent with observations by Rolls et al (18). Our results extend these findings by suggesting that pre-meal water does not influence meal energy intake in young women. Despite the common belief that increased water consumption facilitates weight control by reducing meal energy intake, our observations in young adults are not consistent with this postulate.

High water consumption has been linked to a lower energy intake and healthier dietary patterns in population-based studies (31). Popkin et al. (31) recently reported that the daily energy intake of water consumers (mean water intake of 51.9 fl oz per day) was 194 kcal lower than that of non-consumers of water, and that older adults were more likely

to have a high water consumption. Our finding that pre-meal water consumption significantly reduced meal energy intake in older adults suggests that this may be an effective weight control strategy for this segment of the population. If the reduction in energy intake in this sample of older adults were extrapolated to three meals per day, this would represent ~180 kcal, which is similar to the reduction in energy intake reported by Popkin et al. (30) in water consumers. However, long-term intervention studies must be conducted to address this possibility. Since recent data indicate that adults aged 60 years and older have a higher prevalence of overweight and obesity (71%) than the general population (1), such studies in older adults are warranted.

There are several possible reasons why pre-meal water consumption reduced meal energy intake in older adults. Previous work has demonstrated that aging is associated with reductions in the gastric emptying time of both solids and liquids (32). Clarkston et al (32) reported that the gastric emptying time (time for 50% of the stomach contents to empty) for a 150 ml low-nutrient (67 kcal) liquid was ~34% longer in older as compared to younger adults (47 ± 4 vs 35 ± 3 min in older and younger, respectively; $P < 0.05$). Other investigators have shown age-related differences in antral area and plasma cholecystikinin (CCK) after the ingestion of liquid preloads (17). Sensory changes are also known to occur with advancing age (33). Consistent with previous observations in older adults (17, 19, 34), our results indicate that healthy older adults report less hunger and more fullness in response to a meal. Thus, changes in gastrointestinal physiology and sensations of hunger/fullness with aging may explain the reduction in meal energy intake following water consumption.

It is not likely that differences in habitual fluid intake in young and older adults explain our findings. While older adults may be more likely to be water consumers than

young adults (31), previous reports do not suggest that overall habitual fluid intake differs with advancing age (35). We also did not find age-related differences in habitual beverage intake in our sample of healthy older adults, and our mean beverage intake data are comparable to what has been previously reported in young and older adults (35). Furthermore, the difference in energy intake between test meal conditions was not associated with either habitual water or beverage consumption. It is possible that beverage temperature could influence meal energy intake and/or subjective sensations of hunger and satiety in older adults, but we are not aware of any data addressing this issue. However, beverage temperature does not significantly affect gastric emptying rate in middle-aged adults (36).

Alterations in thirst regulatory mechanisms have been reported in response to water deprivation in older adults (37). The older adults in our sample reported less thirst at baseline than the young adults, but after accounting for these baseline differences, no age-related differences in thirst were noted in response to the test meals. De Castro (35) did not detect impairments in subjective thirst sensations in healthy, free-living older adults, thus it does not seem likely that differences in thirst sensitivity with age explain our findings.

There are some limitations of the present study that should be acknowledged. Our results are limited to an acute meal setting. Thus, it is uncertain if the reduction in meal energy intake following water consumption in older adults would be sustained over time. Long term intervention studies are needed to address this issue. Also, we did not control food intake on the morning of our lunch meals. However, reported breakfast energy intake was not different between conditions. Our sample size was relatively small; future studies

with greater subject numbers are needed to confirm our findings. Finally, our findings should not be extrapolated beyond the age ranges studied.

In conclusion, our results suggest that under acute test meal conditions, pre-meal water consumption reduces meal energy intake in older but not younger adults. These differences may be due to age-related changes in gastrointestinal physiology and perceptions of hunger and fullness. Our data also suggest that a water preload may not be an appropriate “control” condition for food intake studies using a preloading paradigm, at least in older adults, because a water preload may alter food intake despite being noncaloric. Additionally, older adults who are at nutritional risk (i.e. anorexia of aging) should refrain from consuming significant amounts of water prior to meal consumption. Since older adults are at increased risk for overweight and obesity (1), future intervention studies should be conducted to determine if pre-meal water consumption is an effective long-term weight management strategy for the aging population.

Table 1. Subject Characteristics^A

| | Young Men (n=14) | Young Women (n=15) | Older Men (n=11) | Older Women (n=10) |
|---------------------------------------|------------------------|------------------------------|-----------------------------|------------------------------|
| Age, yrs | 26 \pm 1 | 23 \pm 1 ^B | 68 \pm 2 ^B | 69 \pm 2 ^D |
| Height, cm | 176 \pm 2 | 165 \pm 2 ^B | 175 \pm 2 | 163 \pm 2 ^C |
| Weight, kg | 76.5 \pm 2.1 | 59.8 \pm 1.4 ^B | 75.4 \pm 2.9 | 65.7 \pm 2.8 ^{CD} |
| BMI, kg/m ² | 24.8 \pm 0.7 | 21.9 \pm 0.5 ^B | 24.6 \pm 0.7 | 24.7 \pm 0.9 ^D |
| Body Fat, % | 16.6 \pm 2.2 | 27.5 \pm 1.5 ^B | 24.9 \pm 1.9 ^B | 37.2 \pm 1.8 ^{CD} |
| Dietary Restraint Score | 4.4 \pm 0.7 | 6.1 \pm 0.8 | 6.7 \pm 0.9 ^B | 8.9 \pm 1.0 ^D |
| Habitual Dietary Intake: | | | | |
| Energy, kcal | 2503 \pm 201 | 1901 \pm 140 ^B | 2203 \pm 170 | 1819 \pm 108 |
| Fat, % energy | 30 \pm 2 | 29 \pm 2 | 33 \pm 2 | 33 \pm 2 |
| Carbohydrate, % energy | 51 \pm 2 | 56 \pm 2 | 51 \pm 2 | 51 \pm 3 |
| Protein, % energy | 17 \pm 1 | 14 \pm 1 ^B | 15 \pm 1 | 16 \pm 1 ^D |
| Alcohol, % energy | 1 \pm 1 | 3 \pm 1 | 3 \pm 1 | 1 \pm 1 |
| Water consumption, g | 1214 \pm 276 | 616 \pm 122 | 519 \pm 197 | 414 \pm 132 ^B |
| Total beverage consumption, g | 2131 \pm 241 | 1433 \pm 130 ^{BC} | 1995 \pm 256 | 1406 \pm 93 ^{BC} |
| Habitual Physical Activity, min/wk | 382 \pm 121 | 249 \pm 83 | 401 \pm 131 | 281 \pm 138 |
| VO ₂ max, ml/kg/min | 52.9 \pm 3.5 | 40.3 \pm 2.0 ^B | 33.0 \pm 2.3 ^B | 22.5 \pm 1.7 ^{CD} |

^AData are expressed as Mean \pm SEM.

^BSignificantly different from young men, $P < 0.05$.

^CSignificantly different from older men, $P < 0.05$.

^DSignificantly different from young women, $P < 0.05$.

FIGURE LEGEND

Figure 1. Energy intake at *ad libitum* test meals after a water preload vs. no-preload.

*Significant reduction in meal energy intake after the water preload as compared to no-preload condition in older adults ($P=0.02$).

Figure 2. Mean (\pm SEM) ratings of hunger in the no-preload and water preload condition in young and older adults. The water preload was given immediately following completion of the 0 minute VAS scale (a). Subjects completed a second VAS scale at 30 min (b), and were immediately provided with the *ad libitum* meal. Following completion of the meal at 60 minutes, subjects completed a third VAS scale (c). There was a significant difference in hunger between age groups ($P=0.006$), in all subjects over time ($P<0.001$), and a condition by time by age group interaction ($P=0.03$), which persisted after adjusting for baseline differences in hunger. *Significant condition by age group difference.

Figure 3. Mean (\pm SEM) ratings of fullness in the no-preload and water preload condition in young and older adults. The water preload was given immediately following completion of the 0 minute VAS scale (a). Subjects completed a second VAS scale at 30 min (b), and were immediately provided with the *ad libitum* meal. Following completion of the meal at 60 minutes, subjects completed a third VAS scale (c). There was a significant difference in fullness between conditions ($P=0.01$), and in all subjects over time ($P<0.001$). Older adults reported significantly more fullness than younger adults overall ($P=0.002$) and in the water preload condition ($P=0.002$). *Significant condition by age group difference.

Figure 4. Mean (\pm SEM) ratings of thirst in the no-preload and water preload condition in young and older adults. The water preload was given immediately following completion of the 0 minute VAS scale (a). Subjects completed a second VAS scale at 30 min (b), and were immediately provided with the *ad libitum* meal. Following completion of the meal at 60 minutes, subjects completed a third VAS scale (c). After adjusting for baseline age-group differences in thirst (*), there were no significant differences in thirst between older and young adults. **Significant difference in conditions.

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Figure 1.

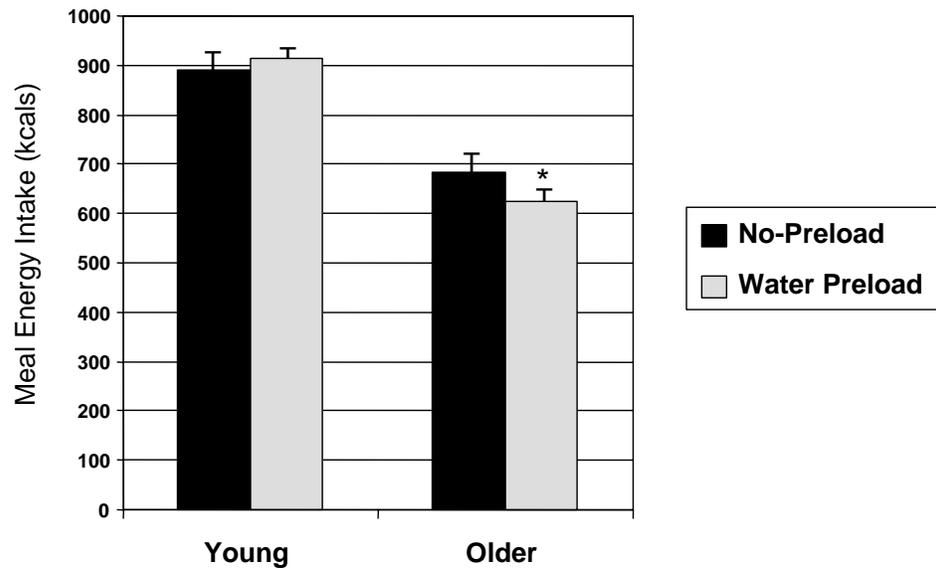


Figure 1. Energy intake at *ad libitum* test meals after a water preload vs. no-preload.

*Significant reduction in meal energy intake after the water preload as compared to no-preload condition in older adults (P=0.02).

Figure 2.

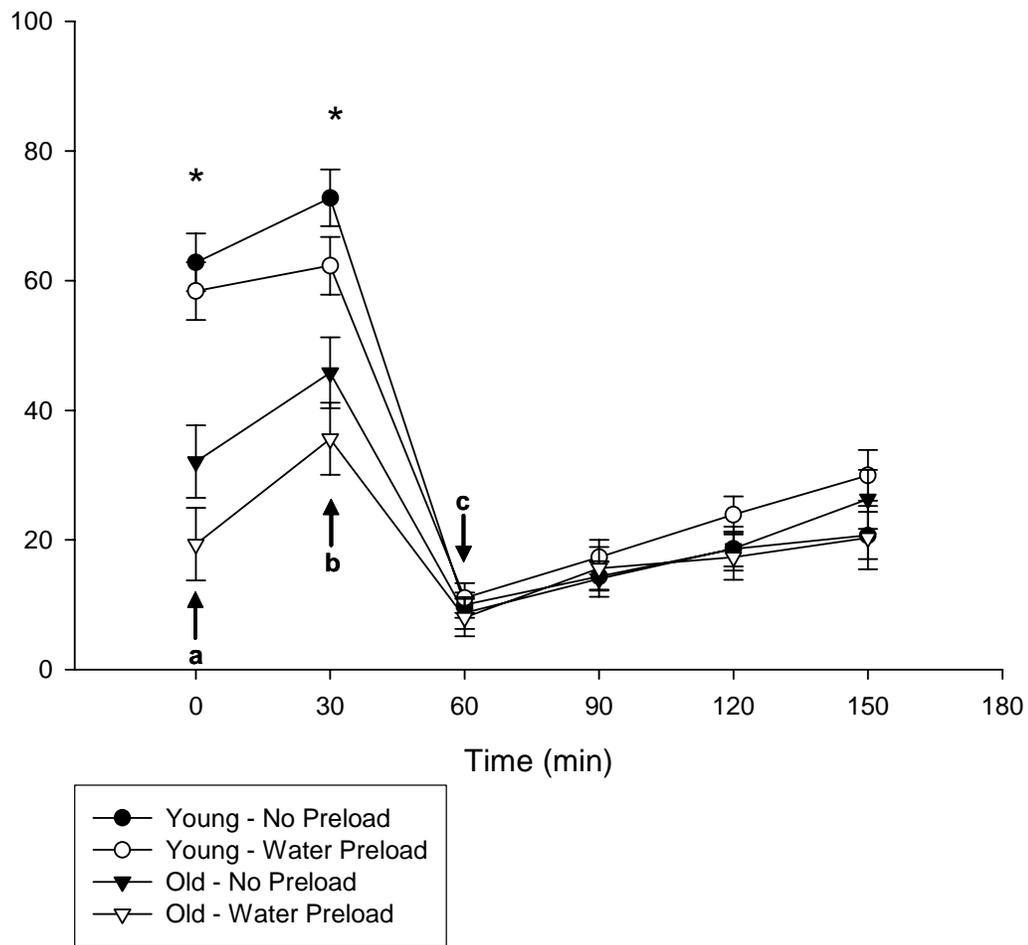


Figure 2. Mean (\pm SEM) ratings of hunger in the no-preload and water preload condition in young and older adults. The water preload was given immediately following completion of the 0 minute VAS scale (a). Subjects completed a second VAS scale at 30 min (b), and were immediately provided with the *ad libitum* meal. Following completion of the meal at 60 minutes, subjects completed a third VAS scale (c). There was a significant difference in hunger between age groups ($P=0.006$), in all subjects over time ($P<0.001$), and a condition by time by age group interaction ($P=0.03$), which persisted after adjusting for baseline differences in hunger. *Significant condition by age group difference.

Figure 3.

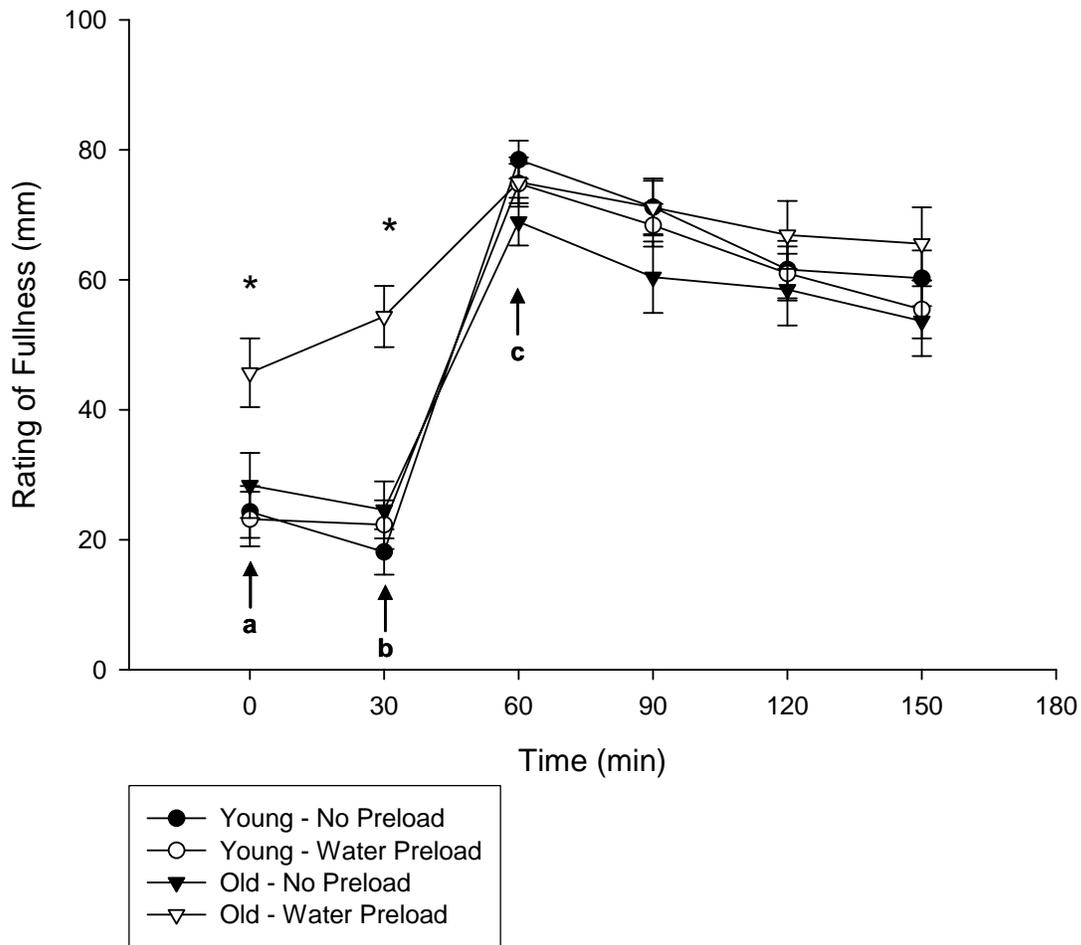


Figure 3. Mean (\pm SEM) ratings of fullness in the no-preload and water preload condition in young and older adults. The water preload was given immediately following completion of the 0 minute VAS scale (a). Subjects completed a second VAS scale at 30 min (b), and were immediately provided with the *ad libitum* meal. Following completion of the meal at 60 minutes, subjects completed a third VAS scale (c). There was a significant difference in fullness between conditions ($P=0.01$), and in all subjects over time ($P<0.001$). Older adults reported significantly more fullness than younger adults overall ($P=0.002$) and in the water preload condition ($P=0.002$). *Significant condition by age group difference.

Figure 4.

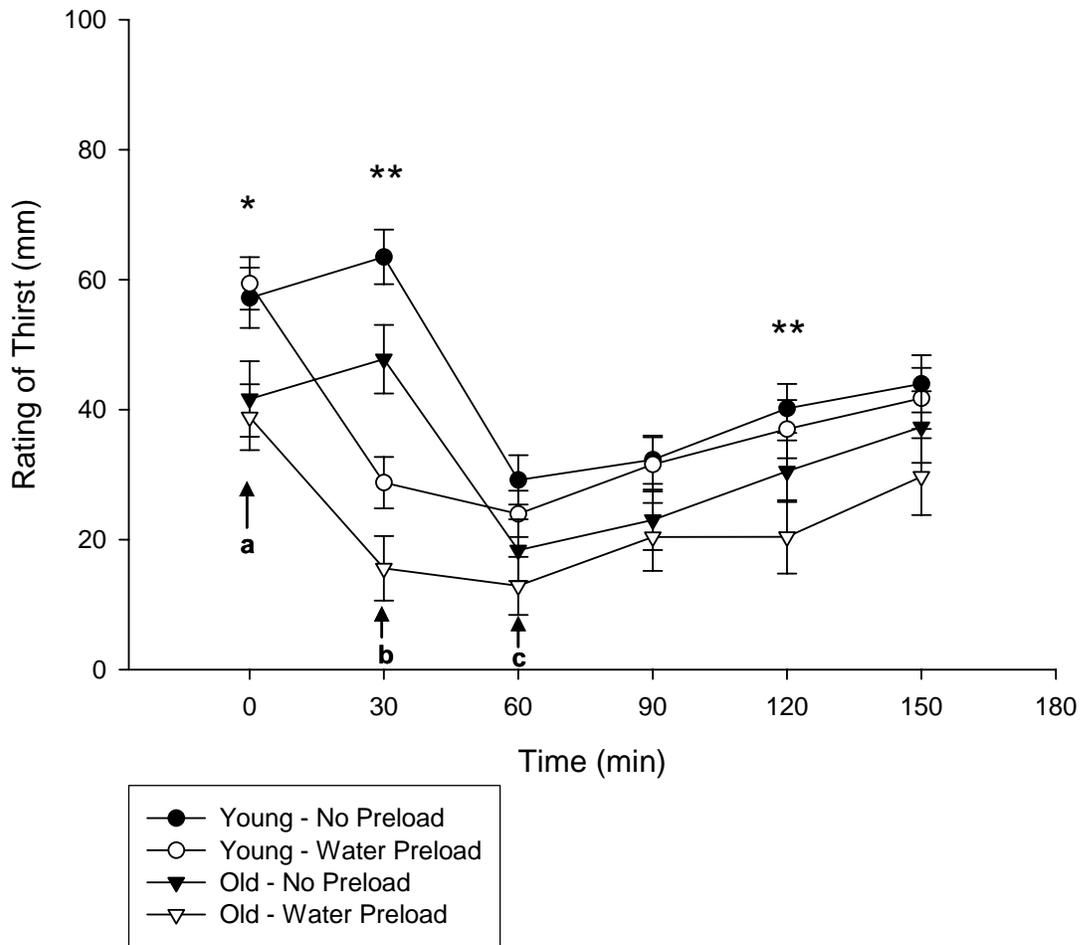


Figure 4. Mean (\pm SEM) ratings of thirst in the no-preload and water preload condition in young and older adults. The water preload was given immediately following completion of the 0 minute VAS scale (a). Subjects completed a second VAS scale at 30 min (b), and were immediately provided with the *ad libitum* meal. Following completion of the meal at 60 minutes, subjects completed a third VAS scale (c). After adjusting for baseline age-group differences in thirst (*), there were no significant differences in thirst between older and young adults. **Significant difference in conditions.

CHAPTER 5: CONCLUSIONS

Research concerning short-term energy intake regulation in older adults is limited. The previous investigations demonstrate age-related energy intake dysregulation in older adults, and identify both factors that may influence short-term energy intake regulation with advancing age and possible intervention strategies for the prevention of weight gain in older adults. We determined that acute energy intake is dysregulated with advancing age regardless of habitual physical activity level. Physical activity, however, improves short-term energy intake regulation and may serve as a means to increase total energy expenditure and therefore offset weight gain induced by energy intake dysregulation. We also determined that younger women have a reduced ability to accurately regulate energy intake compared to younger men, independently of dietary cognitive restraint, perceptions of hunger and fullness, or environmental factors. It is therefore possible that sex differences in acute energy intake regulation contribute to relatively greater weight gain in women over time, resulting in a higher prevalence of obesity in older women compared to older men. Finally, we identified pre-meal water consumption as a possible intervention strategy to decrease meal energy intake in older adults, as we found that water consumption suppresses subsequent energy intake in older adults. We also demonstrated that using water, rather than no preload, as a “control” condition in future studies may confound the results, as we found pre-meal water affects meal energy intake in older individuals.

Based on the outcome of these investigations, several future studies can be suggested. We found that habitual physical activity does not affect energy intake regulation

in an acute meal setting, nor does it appear to increase sensitivity to hunger and fullness cues. In contrast, habitual physical activity does improve short-term energy intake regulation over the course of an entire day. It is also possible that the increase in total daily energy expenditure resulting from habitual physical activity could improve long-term energy intake regulation by increasing energy flux and allowing older adults to regulate energy balance at a higher level. Future studies are needed to determine if habitual physical activity affects energy intake regulation in older adults over periods of weeks or months. Studies are also needed to determine the mechanisms by which acute energy intake regulation is impaired in older adults. Differences between young and older adults in secretion of peripheral hormones that influence food intake and ability to regulate energy intake in the acutely and in the short-term should be explored.

We also found that acute energy intake regulation is reduced in younger women compared to younger men. Future investigations in younger adults should explore possible sex differences in gastrointestinal and other peripheral hormones that affect short-term energy intake regulation as well as the influence of sex hormones on food intake. Similarly designed investigations are needed to determine the influence of sex on energy intake regulation in older adults, as it is currently not known if sex differences in short-term energy intake regulation in younger adults become more pronounced with advancing age. Such studies should also investigate the relationship between age-related changes in sex hormones in post-menopausal women and ability to regulate energy intake in older women compared to older men.

Finally, we found that pre-meal water consumption suppresses meal energy intake in older adults. Further investigation is therefore warranted to examine differences in

gastrointestinal physiology between younger and older adults that might account for differences in the effectiveness of water consumption as a means to suppress subsequent energy intake. It is also necessary to examine the effectiveness of pre-meal water consumption as an intervention strategy to prevent or reverse weight gain in older adults. These future studies will further define factors that influence energy intake regulation and identify possible weight gain prevention strategies for older adults.

APPENDIX

Institutional Review Board Approval



Institutional Review Board

Dr. David M. Moore
IRB (Human Subjects) Chair
Assistant Vice President for Research Compliance
CVM Phase II- Duckpond Dr., Blacksburg, VA 24061-0442
Office: 540/231-4991; FAX: 540/231-6033
email: moored@vt.edu

DATE: July 30, 2004

MEMORANDUM

TO: Brenda M. Davy Human Nutrition, Foods, & Exercise 0430
Kevin P. Davy Human Nutrition, Foods, & Exercise 0351

FROM: David Moore 

SUBJECT: **IRB Full Review Approval:** "Aging, activity and eating habits" IRB # 04-344
FR

The above referenced protocol was submitted to the Virginia Tech IRB for full review and approval at its July 12, 2004 meeting. The IRB, at that meeting, voted approval for this protocol for a period of (12) months, effective as of July 12, 2004.

Approval of your research by the IRB provides the appropriate review as required by federal and state laws regarding human subject research. It is your responsibility to report to the IRB any adverse reactions that can be attributed to this study.

To continue the project past the 12-month approval period, a continuing review application must be submitted (30) days prior to the anniversary of the original approval date and a summary of the project to date must be provided. Our office will send you a reminder of this (60) days prior to the anniversary date.

cc: File

Department Reviewer W. G. Herbert HNFE 0351



Institutional Review Board

Dr. David M. Moore
IRB (Human Subjects) Chair
Assistant Vice President for Research Compliance
CVM Phase II- Duckpond Dr., Blacksburg, VA 24061-0442
Office: 540/231-4991; FAX: 540/231-6033
email: moored@vt.edu

DATE: December 7, 2004

MEMORANDUM

TO: Brenda M. Davy Human Nutrition, Foods, & Exercise 0430
Kevin P. Davy Human Nutrition, Foods, & Exercise 0351

FROM: David Moore 

SUBJECT: **IRB Amendment Approval:** "Aging, activity and eating habits" IRB # 04-344
FR

This memo is regarding the above referenced protocol which was previously granted approval by the IRB on July 12, 2004. You subsequently requested permission to amend your approved protocol to include the addition of the listed changes. Since the requested amendment is nonsubstantive in nature, I, as Chair of the Virginia Tech Institutional Review Board, have granted approval for requested protocol amendment, effective as of December 7, 2004. The anniversary date will remain the same as the original approval date.

Virginia Tech has an approved Federal Wide Assurance (FWA00000572, exp. 7/20/07) on file with OHRP, and its IRB Registration Number is IRB00000667.

cc: File
Department Reviewer W. G. Herbert HNFE 0351



Institutional Review Board

Dr. David M. Moore
IRB (Human Subjects) Chair
Assistant Vice President for Research Compliance
CVM Phase II- Duckpond Dr., Blacksburg, VA 24061-0442
Office: 540/231-4991; FAX: 540/231-6033
email: moored@vt.edu

DATE: July 11, 2005

MEMORANDUM

TO: Brenda M. Davy Human Nutrition, Foods, & Exercise 0430
Kevin P. Davy

FROM: David Moore 

SUBJECT: **IRB Full Review Continuation:** "Aging, activity and eating habits" IRB #
05-377FR ref 04-344FR

This memo is regarding the above referenced protocol which was previously granted expedited approval by the IRB on July 12, 2004. The proposed research, having been previously approved at a convened IRB meeting, required full IRB review prior to granting an extension of approval, according to the specifications authorized by 45 CFR 46.110 and 21 CFR 56.110. The above referenced protocol was submitted for full review continuation and approval by the IRB at the July 11, 2005 meeting. Pursuant to your request, I, as Chair of the Virginia Tech Institutional Review Board, have, at the direction of the IRB, granted approval for this study for a period of 12 months, effective July 12, 2005.

Approval of your research by the IRB provides the appropriate review as required by federal and state laws regarding human subject research. It is your responsibility to report to the IRB any adverse reactions that can be attributed to this study.

To continue the project past the 12 month approval period, a continuing review application must be submitted (30) days prior to the anniversary of the original approval date and a summary of the project to date must be provided. Our office will send you a reminder of this (60) days prior to the anniversary date.

Virginia Tech has an approved Federal Wide Assurance (FWA00000572, exp. 7/20/07) on file with OHRP, and its IRB Registration Number is IRB00000667.

cc: File

Department Reviewer: William G. Herbert



Institutional Review Board

Dr. David M. Moore
IRB (Human Subjects) Chair
Assistant Vice President for Research Compliance
CVM Phase II- Duckpond Dr., Blacksburg, VA 24061-0442
Office: 540/231-4991; FAX: 540/231-6033
email: moored@vt.edu

DATE: July 22, 2005

MEMORANDUM

TO: Brenda M. Davy Human Nutrition, Foods, & Exercise 0430
Kevin P. Davy Human Nutrition, Foods, & Exercise 0351

FROM: David Moore 

SUBJECT: **IRB Amendment Approval:** "Aging, activity and eating habits" IRB #
05-377FR ref 04-344FR

This memo is regarding the above referenced protocol which was previously granted approval by the IRB on July 12, 2005. You subsequently requested permission to amend your approved protocol to include the addition of the listed changes. Since the requested amendment is nonsubstantive in nature, I, as Chair of the Virginia Tech Institutional Review Board, have granted approval for requested protocol amendment, effective as of July 22, 2005. The anniversary date will remain the same as the original approval date.

Virginia Tech has an approved Federal Wide Assurance (FWA00000572, exp. 7/20/07) on file with OHRP, and its IRB Registration Number is IRB00000667.

cc: File

Department Reviewer: William G. Herbert

CURRICULUM VITA

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Education

| <u>Degree</u> | <u>Major</u> | <u>Institution</u> | <u>Date</u> |
|-----------------|---|---------------------------------|----------------------------------|
| Ph.D. candidate | Human Nutrition, Foods, and Exercise | Virginia Tech Blacksburg, VA | degree expected: August, 2006 |

Dissertation Title: Aging, Physical Activity, and Energy Intake Regulation
 Advisor: Brenda Davy, PhD, RD

| | | | |
|------|---------------------|-------------------------------------|------|
| M.S. | Nutritional Science | University of Arizona Tucson, AZ | 2002 |
|------|---------------------|-------------------------------------|------|

Thesis Title: Long-Term Nutrient Associations with Bone Mineral Density in a Longitudinal Sample of Healthy Post-Menopausal Women
 Advisor: Scott Going, PhD

| | | | |
|------|------------------------------------|--------------------------------------|------|
| B.S. | Human Nutrition Chemistry Minor | University of Illinois Urbana, IL | 2000 |
|------|------------------------------------|--------------------------------------|------|

Experience

| <u>Position and Dates</u> | <u>Institution</u> |
|---|---|
| Graduate Teaching Assistant 2003-present | Department of Human Nutrition, Foods, and Exercise Virginia Polytechnic Institute and State University Blacksburg, Virginia Courses: HNFE 1214 Weight Training HNFE 3025 Metabolic Nutrition HNFE 3026 Metabolic Nutrition HNFE 3824 Kinesiology HNFE 4004 Seminar in HNFE HNFE 4174 Nutrition and Physical Performance |
| Graduate Teaching Assistant 2001-2003 | Department of Nutritional Sciences University of Arizona Tucson, Arizona Courses: N SC 104 Nutrition, Food, and You NATS 104 Nutrition, Food, and You N SC 301 Nutrition and the Life Cycle N SC 444 Community Nutrition |

Research

Publications

Van Walleghen EL, Orr JS, Gentile CL, Davy BM. Pre-meal water consumption reduces meal energy intake in older but not younger adults. Accepted, *Obesity*.

Van Walleghen EL, Orr JS, Davy BM. Sex differences in acute energy intake regulation. In Review, July 2006.

Van Walleghen EL, Orr JS, Gentile CL, Davy KP, Davy BM. Habitual physical activity differentially affects acute and short-term energy intake regulation in young and older adults. In Review, July 2006.

Abstracts

Van Walleghen E, Orr J, Morrill J, Gentile C, Johnson S, Davy B. Is Water Consumption an Effective Strategy to Reduce Meal Energy Intake? Presented at the 2005 North American Association for the Study of Obesity Annual Scientific Meeting in Vancouver, B.C., October, 2005.

Van Walleghen E, Orr J, Davy B. Gender Differences in Energy Intake Regulation. Presented at the 22nd Annual SCAN Symposium in Nashville, TN, March 24-26, 2006.

Gilmour K, Van Walleghen E, Kealey E, Von Kaenel S, Bessesen D, Johnson S, Davy B. Influence of Age, Gender and Physical Activity Habits on Eating Behavior in Nonobese Adults. Presented at the 22nd Annual Research Symposium, Graduate Student Assembly, Virginia Tech, March 29, 2006.

Dennis E, Van Walleghen E, Orr J, Gentile C, Davy K, Davy B. Aging, Physical Activity and Resting Metabolic Rate. Presented at the 22nd Annual Research Symposium, Graduate Student Assembly, Virginia Tech, March 29, 2006.

Davy B, Orr S, Van Walleghen E. Gender Differences in Energy Intake Regulation Among Healthy Older Adults. To be presented at the 2006 North American Association for the Study of Obesity Annual Scientific Meeting in Boston, MA, October, 2006.

Awards and Honors

Virginia Polytechnic Institute and State University

Outstanding Graduate Student, Department of Human Nutrition, Foods, and Exercise, 2006
Graduate Research Development Project Grant, Graduate Student Assembly, 2005

University of Illinois

Outstanding Senior in Human Nutrition, Department of Food Science and Human Nutrition, 2000