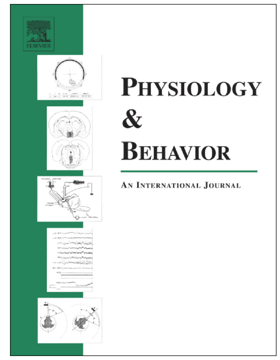
Accepted Manuscript



Reliability of hunger-related assessments during 24-hour fasts and their relationship to body composition and subsequent energy compensation

Grant M. Tinsley, M. Lane Moore, Austin J. Graybeal

PII: S0031-9384(18)30061-1
DOI: doi:10.1016/j.physbeh.2018.02.017
Reference: PHB 12077

To appear in: *Physiology & Behavior*

Received date: 17 November 2017
Revised date: 26 January 2018
Accepted date: 9 February 2018

Please cite this article as: Grant M. Tinsley, M. Lane Moore, Austin J. Graybeal , Reliability of hunger-related assessments during 24-hour fasts and their relationship to body composition and subsequent energy compensation. The address for the corresponding author was captured as affiliation for all authors. Please check if appropriate. Phb(2018), doi:10.1016/j.physbeh.2018.02.017

Reliability of Hunger-Related Assessments During 24-hour Fasts and Their Relationship to Body Composition and Subsequent Energy Compensation

Grant M. Tinsley*, M. Lane Moore, Austin J. Graybeal

Department of Kinesiology & Sport Management, Texas Tech University, Lubbock, TX.

*Corresponding author: Grant M. Tinsley, Box 43011, Department of Kinesiology & Sport Management, Texas Tech University, Lubbock, TX 79409. grant.tinsley@ttu.edu. (806) 834-5895.

Abstract

Many diets employ regular periods of fasting that extend beyond a typical overnight fast (i.e. intermittent fasting [IF]). Evaluation of acute fasting responses provides information concerning the potential theoretical rationale for IF. The purpose of the present investigation was to assess the test-retest reliability of hunger-related variables during 24-hour fasts and the relationship between these variables and body composition, as well as subsequent energy intake (EI) after fasting. Eleven participants (6 F, 5 M) completed two 24-hour fasts after being provided a 3-day standardized weight-maintenance diet. From 16 to 24 hours of fasting, participants were directly observed and provided hourly assessments of hunger, desire to eat (DTE), prospective food consumption (PFC), fullness and energy. After the fast, participants were allowed *ad libitum* food consumption, and compensation was calculated as EI relative to weight-maintenance energy needs. Test-retest reliability for hunger-related assessments at particular durations of fasting was evaluated using intraclass correlation coefficients (ICC), changes in dependent variables were evaluated using ANOVA with repeated measures, and relationships between variables were explored using bivariate correlations. At 16 hours of fasting, the ICCs for all hunger-related assessments were statistically significant ($r=0.67$ – 0.91; $p \leq 0.05$). However, as the fast progressed, reliability varied substantially. When averaged across the nine measurements, the ICCs were: 0.81 (fullness), 0.74 (PFC), 0.67 (energy), 0.44 (DTE) and 0.36 (hunger). Body fat percentage was significantly correlated with changes in PFC ($r=0.62$, $p=0.04$), hunger ($r=0.66$, $p=0.03$), DTE ($r=0.71$, $p=0.02$), and fullness ($r=-0.63$, $p=0.04$), but not energy ($r=-0.16$, $p=0.64$). Average EI compensation was only 60% of weight-maintenance needs, but substantial variability was observed (7 to 110% compensation). Compensation was significantly correlated with changes in PFC ($r=0.72$, $p=0.01$), hunger ($r=0.63$, $p=0.04$) and DTE ($r=0.60$, $p=0.05$), but not fullness (r=0.58, p=0.06) or energy (r=0.35, p=0.29). Compensation and body fat percentage were not correlated (r=0.03, p=0.94). The percent of energy intake from fat and protein increased after the fast (29.9 to 37.3% and 13.8 to 16.8%; $p < 0.05$), while the percent of energy intake from carbohydrate decreased (56.4 to 46.0%; p=0.02). These results may have implications for IF programs. It is possible that the implementation of multiple “test fasts,” in which subjective variables and subsequent energy intake are evaluated, could be used to identify candidates who may be more likely to benefit from an IF program.

Key words: intermittent fasting, energy intake, appetite, obesity, weight loss

1. Introduction

It is well known that the increasing prevalence of overweight and obesity is a significant public health concern. Recent global estimates indicate that nearly two billion adults are overweight and over 650 million are considered obese [1]. Due to the prevalence of overweight and obesity, as well the common desire for weight loss in the general population, caloric restriction (CR) diets are heavily utilized. These diets focus on reducing total energy intake (EI) each day, often by eliminating particular energy-dense foods and reducing portion sizes [2]. Additionally, although experimental support is lacking, many individuals increase eating frequency during CR diets for the purpose of enhanced weight loss [3-5]. Although CR diets can be successful, especially in the short-term, traditional CR is difficult to sustain long-term for many individuals [6-8]. This reality has led to the consideration of whether alternative methods for weight loss may be better suited to individuals who struggle with traditional daily CR. One such alternative incorporates the use of regular fasting periods that are longer than a typical overnight fast (i.e. intermittent fasting [IF]). Several variants of IF utilize periods of fasting that last 16 to 24 hours in duration [9]. While shorter fasting periods may be employed daily, longer fasting periods (i.e. 24+ hours) are often employed only once or twice per week. The main purpose of these IF programs is to reduce overall energy intake and promote weight loss and health improvement. Although limited information is available concerning the optimal duration of fasting periods, there is some evidence that 24 hours may be an appropriate length [9]. For example, it has been shown that the greatest increase in triglyceride breakdown and fat oxidation occurs between hours 18 and 24 of a 72-hour fast [10].

One potential concern with IF programs is that individuals will simply negate an accumulated energy deficit from fasting due to a hyperphagic response when *ad libitum* food intake is allowed. However, several studies have indicated that this does not occur [11-13]. In one study conducted by Johnstone et al., researchers found that after a 36-hour fast, participants only increased their EI by 20% above typical intake [11]. Furthermore, Levitsky et al. found that EI was significantly lower following a ~36-hour fast compared to following a day of *ad libitum* feeding [12]. The results of these investigations are contrary to the belief that individuals will fully compensate for an energy deficit caused by fasting through drastically increasing their subsequent EI.

Although a small amount of previous research has considered the relationship between acute fasting and subsequent EI, some important questions remain unanswered. It is likely that there is a large amount of variability in the degree of EI compensation between individuals, but this has not been explicitly considered in most investigations. These differences in compensation could be related to variation in an individual's perception of hunger during fasting, as well as their subsequent desire to eat (DTE) once the fast is completed. It is common to assess subjective perceptions of hunger and related variables during a single period of food deprivation [11, 14, 15]. However, no reports of the test-retest reliability of these measures between multiple periods of acute fasting are readily available. Therefore, it is unclear whether subjective hunger assessments are reproducible from one period of fasting to the next. Due to the potential importance of these outcomes, this is a noteworthy methodological consideration for researchers. An additional limitation of some previous investigations is that the fasting period was not directly supervised by research personnel [11-13], and most investigations have not included an objective assessment of fasting compliance (e.g. evaluation of resting energy expenditure and respiratory quotient). The majority of previous studies have also utilized predominantly normal weight participants [11-13, 15]. It is possible that variation in adiposity may impact perceptions of hunger and DTE, thereby contributing to increased EI [16], although this has not been thoroughly examined in the context of compensatory EI after a period of fasting. Therefore, the purpose of the present investigation was to assess the test-retest reliability of hunger-related variables after specific durations of fasting in two separate 24-hour fasts, while also examining the relationships between these variables, body composition, and subsequent EI compensation after fasting.

2. Methods

2.1 Overview

The present investigation is a secondary analysis using data from a previous investigation of acute fasting [17]. This study included two separate 3-day periods of controlled food consumption, followed by a 24-hour fast. During both fasts, three small (net weight < 10 g) non-caloric gel packets were consumed, with the only difference between packets being the presence or absence of the supplement beta-hydroxy beta-methylbutyrate. This supplement has not been reported to influence hunger or associated constructs [18]. Therefore, this analysis was conducted solely to evaluate the effects of the 24-hour fast itself. Furthermore, the data from our study confirm no effects of the dietary supplement on hunger-related variables.

2.2 Subjects

The inclusion criteria for this study were: 18 to 50 years of age, generally healthy (no history of diabetes, cardiovascular disease, or other chronic or acute health concerns that could potentially be exacerbated by a 24 hour fast), regular breakfast consumer (i.e. consuming >200 kcal before 10 AM at least 5 days per week), weight stable (no weight changes >5 kg in the past 3 months), nonsmoker, not pregnant, and no known allergies to food items that were provided as part of the 3-day controlled diet period. This study was conducted according to the guidelines laid down in the Declaration of Helsinki and the study was approved by the Texas Tech University Institutional Review Board (IRB00000276). Study details were explained to participants, and informed consent was obtained prior to study commencement.

2.3 Baseline Session

A baseline session was conducted to evaluate resting energy expenditure (REE) and body composition. REE was measured using indirect calorimetry (ParvoMedics TrueOne 2400, Sandy, UT), and body composition was assessed via multi-frequency bioelectric impedance analysis (mBCA 514, Seca, Chino, CA). REE values for each participant were utilized to prescribe the weight-maintenance diet during the 3-day controlled dietary period.

2.4 Controlled Diet Period

In the 3 days leading up to each 24-hour fasting window, participants were prescribed a diet that was calculated to promote weight maintenance (i.e. REE times an activity factor of 1.5). Participants were provided with sufficient meals and snacks for the 3-

day controlled feeding period, but were allowed to substitute some of their own meat-free snacks as desired if the food items fit into the overall caloric requirements of the diet. To confirm energy intake, investigators utilized nutrition facts labels for the provided food items along with dietary record information provided by participants. This information was manually recorded, and the nutritional content of food items without nutrition labels was obtained from the United States Department of Agriculture SuperTracker tool [19].

2.5 Fasting Period

During each condition, the 24-hour fasting period was initiated in the evening on the 3rd day of the weight-maintenance diet. Fasting periods were required to start between 4 and 7 PM and were terminated at the same time the following day. On the 3rd day of the weight-maintenance diet, participants were required to consume all food items prior to the initiation of the 24-hour fasting period in the evening. Participants were also asked to minimize the amount of physical activity that they engaged in, as well as to perform no exercise, on the 3rd day of the diet and during the 24-hour fasting period. Participants were allowed to sleep in their own homes the night following initiation of the fast and were unsupervised from 0 to 16 hours of the fasting period (i.e. the evening after beginning the fast and overnight). Upon waking, participants were required to report to the laboratory and remain under the direct supervision of research personnel during the final 8 hours of the fast (i.e. from hours 16 to 24). Upon arrival at the laboratory, REE and respiratory quotient (RQ) were evaluated to confirm fasting. Participants were instructed not to consume any water or other fluids before reporting to the lab. The volume of water provided to each participant was strictly controlled. Males were provided up to 1.5 L of water during the period corresponding to 16 to 20 hours of fasting, and an additional up to 1.5 L during 20 to 24 hours. Females were provided with up to 1.0 L during each of these periods. For the first 24-hour fasting period, the exact amount of water consumed during each 4-hour interval was measured and recorded. For the second 24-hour fasting period, each participant received the same amount of water that they ingested during the first fast.

2.6 Visual Analog Scales

Visual analog scales (VAS) have previously been validated and extensively used in appetite research [20]. A commercially-available iPad application was used for VAS measurements (VasQ Clinical). iPad-based VAS measurements of appetite have previously been validated [21]. The software displayed each question with anchor words at the ends of a 100-mm line. The participant touched the tablet to drag a marker to the point on the line corresponding to his or her response. Five questions were utilized for the assessment of DTE, hunger, fullness, prospective food consumption (PFC) and energy. The questions, with corresponding left and right anchors shown in parentheses, were: "How strong is your desire to eat?" (Very weak - Very strong), "How hungry do you feel?" (Not hungry at all - As hungry as I have ever felt), "How full do you feel? (Not full at all - Very full), "How much food do you think you could eat?" (Nothing at all - A large amount), and "What is your current level of energy?" (No energy - Very high energy). VAS were completed hourly from 16 to 24 hours of fasting for a total of 9 measurements (Figure 1).

2.7 Ad Libitum Energy Intake

Following each of the 24-hour fasts, participants were provided with a dietary record form and were asked to record all of their energy intake between the end of their fast and when they went to sleep that night. The study investigators informed the participants that they were free to eat and drink whatever they desired, but were required to record their food intake as accurately and completely as possible. This dietary record was analyzed in the same manner as the records for the 3 days leading up to the fast.

2.8 Washout Period

After completing the first condition, the participants entered a washout period of 3 to 10 days prior to completing the second condition. Between the two fasts, participants were instructed to maintain their normal nutrition and exercise patterns, while not engaging in any attempts to gain or lose weight.

2.9 Statistical Analysis

Changes in VAS variables were examined via 2-way ANOVA with repeated measures to confirm no condition by time interactions or condition main effects. Statistically significant time main effects were followed up with pairwise comparisons. Energy and macronutrient intake after the fast were compared to weight-maintenance intakes during the controlled feeding period via 2-way ANOVA with repeated measures to confirm no condition by time interactions or condition main effects. Statistically significant time main effects were followed up with pairwise comparisons. Energy intake compensation was defined as the percent of daily weight maintenance calories that were consumed in the evening after the completion of the 24-hour fast. Once the absence of condition effects was confirmed, the data from both fasts were averaged for each individual participant and used to examine the relationship between body composition, VAS variables, and compensation via bivariate correlations. For the correlation analysis, the change in VAS variables were calculated as the 24-hour measurement minus the 16-hour measurement. The test-retest reliability of VAS variables during the fast and energy intake after the fast were examined through calculation of the intraclass correlation coefficient (ICC). The two-way random model with absolute agreement was utilized [22]. Bonferroni corrections for multiple comparisons were utilized for ANOVA analysis, and statistical significance was set at $p \leq 0.05$. Statistical analysis was completed in SPSS (v. 22).

3. Results

Eleven participants were included in this analysis (6 F, 5 M; age: 26.4 ± 6.3 y; BMI: 26.8 ± 6.4 kg/m^2; BF%: 26.6 ± 11.9; REE: 1852 ± 316 kcal). Upon reporting to the lab for each condition (i.e. at 16 hours of fasting), assessment of REE and respiratory quotient indicated compliance with the assigned fasting protocol [17]. As expected, there were no differences between fasts due to the dietary supplement ($p > 0.05$ for condition main effects and condition by time interactions for all dependent variables). Perceptions of energy and fullness decreased progressively from 16 to 24 hours of fasting (-32% and -52%, respectively), while PFC, DTE and hunger increased (+79%, +122% and +195%) (Figure 2). Body fat percentage was significantly correlated with changes in PFC ($r=0.62$, $p=0.04$), hunger ($r=0.66$, $p=0.03$), DTE ($r=0.71$, $p=0.02$), and fullness ($r=-0.63$, $p=0.04$), but not changes in energy ($r=-0.16$, $p=0.64$).

Intakes of kcal ($p<0.001$), fat ($p=0.049$), carbohydrate ($p<0.001$), and protein ($p=0.006$) were lower after the fast as compared to the average daily intakes during controlled feeding period (Table 1). As compared to the average intake during the 3-day controlled diet, participants consumed approximately 60% of weight maintenance needs in the evening after completion of fasting. Average compensation after the fast did not differ between the first and second fast ($p=0.47$) or between supplement and placebo conditions ($p=0.53$). For both of these comparisons, compensation was between 56 and 65% of weight maintenance needs, on average. As compared to the controlled feeding period, the percent of energy intake from fat ($p=0.04$) and protein ($p=0.03$) increased after the fast (29.9% to 37.3%; 13.8 to 16.8%), while the percent of energy intake from carbohydrate decreased ($p=0.02$; 56.4 to 46.0%).

Substantial individual variability in compensation was observed, with participants consuming between 7 and 110% of energy needs (Figure 3). Additionally, the energy intake responses after the two fasts were dissimilar in many individuals (ICC for compensation = 0.49; $p=0.16$). Average compensation (i.e. EI relative to weight-maintenance intake) was significantly correlated with changes in PFC ($r=0.72$, $p=0.01$), hunger ($r=0.63$, $p=0.04$) and DTE ($r=0.60$, $p=0.05$), but not fullness ($r=0.58$, $p=0.06$) or energy ($r=0.35$, $p=0.29$). However, compensation and body fat percentage were not correlated ($r=0.03$, $p=0.94$).

Test-retest reliability analysis indicated that all subjective variables (i.e. PFC, DTE, hunger, fullness and energy) were significantly correlated between fasting days at 16 hours of fasting, but varied in their reliability thereafter (Table 2). When averaged across the nine measurements, the ICCs were: 0.81 (fullness), 0.74 (PFC), 0.67 (energy), 0.44 (DTE) and 0.36 (hunger).

4. Discussion

The purpose of the present analysis was to examine the test-retest reliability of subjective hunger-related assessments, as well as the relationship of these assessments to body composition and energy intake compensation after acute 24-hour fasts. Unsurprisingly, subjective evaluations of energy and fullness decreased between 16 and 24 hours of fasting, while DTE, PFC, and hunger increased appreciably. It is tempting to speculate that an individual's response in these variables during an acute fast could predict the long-term ease of adherence and feasibility of an IF program for that individual. However, in the present study, the test-retest reliability of the subjective variables during acute fasting was shown to vary considerably between 16 and 24 hours of fasting. All five variables were significantly correlated between the two fasts at the start of the 8-hour observation window (i.e. 16 hours of fasting), but the test-retest reliability of these measures varied as the fast progressed. Fullness, PFC, and energy were significantly correlated at 5 to 8 out of the 9 assessments. Conversely, although hunger and DTE exhibited significant correlations earlier in the observation window (i.e. 16 and 17 hours of fasting), the test-retest reliability was very poor thereafter. These findings are noteworthy because they suggest that subjective ratings during a single acute fast may not accurately predict how an individual will perceive future fasts, particularly in regards to hunger and DTE. This finding may also suggest that it would be inappropriate to make conclusions concerning an individual's subjective responses to IF programs based on evaluation of responses during a single period of fasting. Nonetheless, future research should consider whether assessments during acute fasting periods are able to predict long-term success of IF, although it may be necessary to utilize multiple "test fasts" at the outset of an IF program in order to obtain this information.

In the present investigation, we observed that body fat percentage was significantly correlated with changes in PFC, DTE, hunger and fullness. Individuals with higher relative body fat experienced greater increases in PFC, DTE and hunger, while also experiencing the greater declines in fullness. This may suggest that acute fasting was better tolerated by individuals with a lower body fat percentage as compared to those with greater adiposity. The cause of this finding cannot be definitively provided based on the present analysis, but may result from psychological or psychophysiological influences. Individuals with greater quantities of fat mass may exhibit altered eating behaviors and perceptions of appetite as compared to individuals with lower quantities of fat mass [23, 24], which could have produced the significantly greater increases in DTE, PFC, and hunger observed in the present analysis. If short periods of fasting are indeed more difficult for those with greater adiposity (i.e. those who may benefit most from fasting programs designed to promote weight loss), this may call into question the long-term utility of IF programs using these durations of fasting due to potential adherence concerns. However, due to the acute nature of our study, as well as the small sample size, these preliminary results should not be over-interpreted. Furthermore, many IF programs utilize fasts which are shorter than the 24-hour period employed in the present investigation (e.g. 16 to 20 hours [25, 26]).

In agreement with previous investigations of 19 to 36-hour periods of fasting [11-13], we observed that an acute period of fasting is not fully compensated for by a hyperphagic response at the first opportunity for *ad libitum* food intake. In the present analysis, average caloric compensation was only 60% of weight-maintenance needs. However, there was also a substantial amount of variation in the degree of compensation (i.e. 7% to 110% compensation), and two individual participants consumed greater than 100% of weight-maintenance energy needs after one of the fasts. Johnstone et al. [11] reported that, following an acute fast of 36 hours, normal weight men and women failed to fully compensate for the fasting period over a day of *ad libitum* eating, but rather only increased their daily EI by approximately 20% compared to the non-fasting condition. Unlike this protocol, subjects were not required to fast for an entire calendar day in the present study. Rather, on the day the fast started, adequate food for weight maintenance was provided for consumption prior to the commencement of the fasting period (i.e. the evening). Participants then fasted until the same evening time the following day, when *ad libitum* food intake was allowed. During this period of unrestricted food intake, participants consumed, on average, 60% of their weight-maintenance needs. It could be contended that participants increased EI on subsequent days in order to restore energy balance and negate the energy deficit induced by fasting. However, Levitsky et al. [12] demonstrated that normal weight women do not compensate for a day of complete fasting over the following four days of *ad libitum* eating. Cameron et al. [15] employed a 24-hour fasting period similar to the present investigation, although the timing of the fast differed (i.e. midday to midday rather than evening to evening). During the non-fasting condition, participants were fed standardized breakfast and lunch meals prior to being presented with an *ad libitum* dessert buffet. In the fasting condition, participants were not provided with breakfast, but were provided with a standardized lunch at the conclusion of the 24-hour fast. This was followed with the same *ad libitum* dessert buffet that was presented during the non-fasting condition. EI from the buffet was 74% higher after the 24-hour fast as compared to the non-fasting condition (855 vs. 491 kcal). Although not explicitly reported, it is highly unlikely that this 364-kcal difference was sufficient to negate the negative energy balance produced by skipping breakfast, as well as dinner the previous evening. Interestingly, we also observed that the percent of energy intake from fat and protein increased after the fast, while the percent of energy intake from carbohydrate decreased. This is in agreement with the results of Johnstone et al. [11], who observed preferential selection of high-fat foods after acute fasting. Similarly, Cameron et al. [15] reported fat intake of 12.2% of energy after fasting, as compared to 6.5% in the control condition, when participants were given access to a dessert buffet. However, this difference was not statistically significant.

Based on the results of the present investigation, it appears that there is substantial variability in the degree of compensation that occurs after fasting, both within and between individuals. Although these acute data may not necessarily reflect energy compensation during long-term IF programs, the large amount of inter-individual variation indicates that short-term fasting does not lead to predictable energy intake responses. Furthermore, unlike previous investigations, we specifically examined the within-subject variability in energy compensation following multiple acute periods of fasting. While some individuals exhibited nearly identical EI following both fasting periods, others demonstrated noticeably disparate responses. The latter group indicates that a single acute fast may not be sufficient to predict energy compensation behaviors in a habitual IF diet. However, it is possible that the evaluation of energy compensation after several "test fasts" may help determine which individuals could respond favorably to this style of eating (i.e. those who do not fully compensate).

Previous studies of acute fasting and subsequent EI have primarily utilized normal weight participants [11, 12, 15], and the results of these investigations may not be applicable to individuals with obesity (i.e. those who could experience the greatest benefit from IF programs [9]). In the present analysis, the full spectrum of body compositions was utilized. Although this potentially allowed for our interesting findings concerning the correlation of body fat percentage to subjective responses during the fast, it also meant that each individual participant had a large influence on our results due to our small sample size. There were some additional limitations in the current analysis. For example, research participants were only directly observed for the final 8 hours of the 24-hour fast. While we believe this was the most critical time for direct observation, it is possible that participants demonstrated noncompliance during the first 16 hours of fasting. However, results of indirect calorimetry measurements during this fasting period provided objective evidence of compliance. Additionally, the direct supervision during the later stages of the fast are a strength of our study, as some previous studies did not incorporate any form of supervision throughout the entire duration of the fast. Finally, although food items were provided to participants in the days leading up to the fast, participants were responsible for accurately self-reporting their consumption of these items, and it is possible that errors in reporting may have occurred.

5. Conclusions

The present investigation provides preliminary evidence concerning the test-retest reliability of hunger-related assessments during 24-hour fasts, as well as reporting relationships between these assessments, body composition and energy intake after fasting. While all subjective variables exhibited potentially acceptable reliability at 16 hours of fasting, the reliability over the following 8 hours varied substantially. Overall, the test-retest reliabilities of fullness, PFC and energy were superior to hunger and DTE. These results have important methodological implications for researchers using these measures during a single acute period of food deprivation. Additionally, in our small sample of varying adiposity, we observed that body fat percentage was positively correlated with changes in PFC, hunger and DTE and negatively correlated with fullness. On average, participants did not fully compensate for the energy deficit induced by fasting, but rather consumed approximately 60% of daily weight-maintenance energy needs when allowed *ad libitum*

consumption following the 24-hour fasts. However, substantial variation between and within individuals was observed. EI compensation was positively correlated with changes in PFC, hunger and DTE, but was not correlated with body composition. The information gained in this study may have implications for dietary programs employing periods of fasting, such as intermittent fasting. It is possible that the implementation of multiple "test fasts," in which PFC and subsequent energy intake are evaluated, could be used to identify candidates who may be more likely to find success with an intermittent fasting protocol.

Acknowledgements

The authors would like to thank Amy Givan, Michael Villarreal, Austin Cross, Danielle Hardin, Victor Uribe, Austin Martin and Tyler Cook for their assistance with the original data collection.

Funding

The original data collection was supported by Texas Tech University and Metabolic Technologies Inc. These entities did not have a role in the collection, analysis or interpretation of data, writing of the report or decision to publish, and did not have a role in study design relevant to the present analysis.

Declaration of interest

Conflicts of interest: none.

References

[1] WHO | Obesity and overweight. World Health Organization; 2017.
[2] Rolls, B. J. What is the role of portion control in weight management? Int J Obes (Lond). 2014,38 Suppl 1:S1-8.
[3] Kulovitz, M. G., Kravitz, L. R., Mermier, C., Gibson, A. L., Conn, C. A., Kolkmeyer, D., et al. Potential role of meal frequency as a strategy for weight loss and health in overweight or obese adults. Nutrition. 2014,30:386-92.
[4] Schoenfeld, B. J., Aragon, A. A., Krieger, J. W. Effects of meal frequency on weight loss and body composition: a meta-analysis. Nutrition Reviews. 2015,73:69-82.
[5] St-Onge, M.-P., Ard, J., Baskin, M. L., Chiuve, S. E., Johnson, H. M., Kris-Etherton, P., et al. Meal Timing and Frequency: Implications for Cardiovascular Disease Prevention: A Scientific Statement From the American Heart Association. Circulation. 2017.
[6] Sumithran, P., Proietto, J. The defence of body weight: a physiological basis for weight regain after weight loss. Clinical Science. 2012,124:231.
[7] Ochner, C. N., Barrios, D. M., Lee, C. D., Pi-Sunyer, F. X. Biological Mechanisms that Promote Weight Regain Following Weight Loss in Obese Humans. Physiology & behavior. 2013,0:106-13.
[8] Greenway, F. L. Physiological adaptations to weight loss and factors favouring weight regain. International Journal of Obesity (2005). 2015,39:1188-96.
[9] Tinsley, G. M., Bounty, P. M. L. Effects of intermittent fasting on body composition and clinical health markers in humans. Nutrition Reviews. 2015,73:661-74.
[10] Klein, S., Sakurai, Y., Romijn, J. A., Carroll, R. M. Progressive alterations in lipid and glucose metabolism during short-term fasting in young adult men. Am J Physiol. 1993,265:E801-E6.
[11] Johnstone, A., Faber, P., Gibney, E., Elia, M., Horgan, G., Golden, B., et al. Effect of an acute fast on energy compensation and feeding behaviour in lean men and women. International journal of obesity and related metabolic disorders : journal of the International Association for the Study of Obesity. 2002,26.
[12] Levitsky, D. A., DeRosimo, L. One day of food restriction does not result in an increase in subsequent daily food intake in humans. Physiology & Behavior. 2010,99:495-9.
[13] Hetherington, M. M., Stoner, S. A., Andersen, A. E., Rolls, B. J. Effects of acute food deprivation on eating behavior in eating disorders. International Journal of Eating Disorders. 2000,28:272-83.
[14] O'Connor, K. L., Scisco, J. L., Smith, T. J., Young, A. J., Montain, S. J., Price, L. L., et al. Altered Appetite-Mediating Hormone Concentrations Precede Compensatory Overeating After Severe, Short-Term Energy Deprivation in Healthy Adults. The Journal of Nutrition. 2016,146:209-17.
[15] Cameron, J. D., Goldfield, G. S., Finlayson, G., Blundell, J. E., Doucet, E. Fasting for 24 hours heightens reward from food and food-related cues. PLoS One. 2014,9:e85970.
[16] Ludwig, D. S., Friedman, M. I. Increasing adiposity: Consequence or cause of overeating? JAMA. 2014,311:2167-8.
[17] Tinsley, G., Givan, A., Graybeal, A., Villarreal, M., Cross, A. Beta-hydroxy Beta-methylbutyrate free acid alters hormonal responses, but not myofibrillar protein breakdown, during a 24-hour fast. British Journal of Nutrition. 2018.

[18] Wilson, J. M., Fitschen, P. J., Campbell, B., Wilson, G. J., Zanchi, N., Taylor, L., et al. International Society of Sports Nutrition Position Stand: beta-hydroxy-beta-methylbutyrate (HMB). Journal of the International Society of Sports Nutrition. 2013,10:6.
[19] SuperTracker. United States Department of Agriculture; 2016.
[20] Parker, B. A., Sturm, K., MacIntosh, C. G., Feinle, C., Horowitz, M., Chapman, I. M. Relation between food intake and visual analogue scale ratings of appetite and other sensations in healthy older and young subjects. European Journal of Clinical Nutrition. 2004,58:212-8.
[21] Brunger, L., Smith, A., Re, R., Wickham, M., Philippides, A., Watten, P., et al. Validation of an iPad visual analogue rating system for assessing appetite and satiety. Appetite. 2015,84:259-63.
[22] Weir, J. P. Quantifying the Test-Retest Reliability Using the Intraclass Correlation Coefficient and the SEM. Journal of Strength & Conditioning Research. 2005,19:231-40.
[23] van den Akker, K., Schyns, G., Jansen, A. Altered appetitive conditioning in overweight and obese women. Behaviour research and therapy. 2017,99:78-88.
[24] Bourdier, L., Orri, M., Carre, A., Gearhardt, A. N., Romo, L., Dantzer, C., et al. Are emotionally driven and addictive-like eating behaviors the missing links between psychological distress and greater body weight? Appetite. 2017,120:536-46.
[25] Tinsley, G., Forsse, J., Butler, N., Paoli, A., Bane, A., Bounty, P. Time-restricted feeding in young men performing resistance training: A randomized controlled trial. Eur J Sport Sci. 2017,17.
[26] Moro, T., Tinsley, G., Bianco, A., Marcolin, G., Pacelli, Q. F., Battaglia, G., et al. Effects of eight weeks of time-restricted feeding (16/8) on basal metabolism, maximal strength, body composition, inflammation, and cardiovascular risk factors in resistance-trained males. J Transl Med. 2016,14:290.

Figure Captions

Figure 1. Study Protocol.

Arrows indicate assessments of subjective variables (energy, prospective food consumption, fullness, hunger, and desire to eat). The asterisk indicates the beginning of the ad libitum feeding period and diet record completion.

Figure 2. Change in Hunger-Related Assessments During Fasting.

DTE = desire to eat; PFC = prospective food consumption; VAS = visual analog scale

Figure 3. Individual Variability in Energy Intake Compensation After Fasting. Compensation was calculated as: (energy intake after acute fasting)/(weight-maintenance energy needs) x 100. Average compensation was approximately 60%, and there were no differences between fasting conditions.

Table 1. Energy and Macronutrient Intake Before and After 24-h Fasts

	Weight-maintenance diet	Ad libitum feeding after fast	p-value[a]
Energy (kcal)	2,248 ± 587	1,349 ± 646	< 0.001*
Carbohydrate	316 ± 80 g 56 ± 7%	148 ± 84 g 46 ± 13%	< 0.001*
Fat	75 ± 28 g 30 ± 7 %	54 ± 35 g 37 ± 11%	0.049*
Protein	79 ± 31 g 14 ± 3%	51 ± 24 g 17 ± 6%	0.006*

[a]p-values represent comparisons of absolute quantities (i.e. grams) rather than relative quantities (%). *statistically significant difference.

Table 2. Intraclass Correlation Coefficients for Subjective Measures

	Duration of Fasting (h)								
Variable	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Energy	0.91*	0.61	0.78*	0.69*	0.85*	0.43	0.76*	0.70*	0.27
PFC	0.90*	0.93*	0.80*	0.86*	0.62	0.6	0.68*	0.63	0.63
Fullness	0.76*	0.61	0.74*	0.86*	0.92*	0.87*	0.95*	0.76*	0.84*
Hunger	0.67*	0.78*	0.35	0.33	0.18	0.08	0.39	0.19	0.28
DTE	0.77*	0.75*	0.61	0.15	0.01	0.18	0.69*	0.16	0.62

*$p \leq 0.05$

DTE = desire to eat; PFC = prospective food consumption

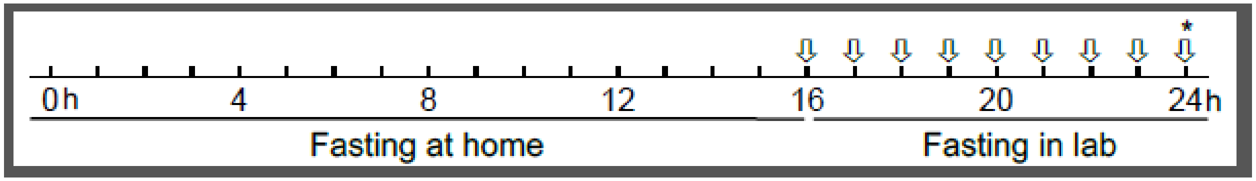


Fig. 1

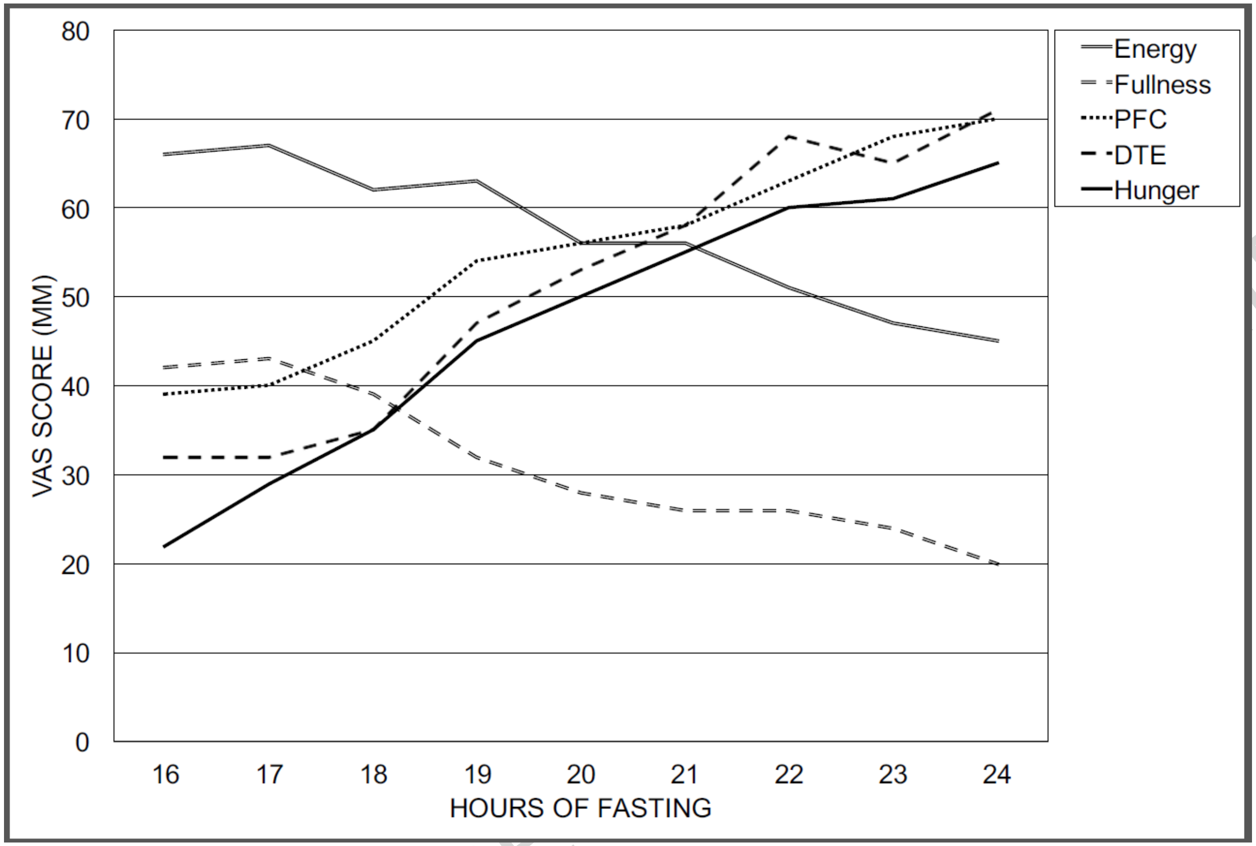

80
70
60
50
40
30
20
10
0
VAS SCORE (MM)
16
17
18
19
20
21
22
23
24
HOURS OF FASTING
Energy
Fullness
PFC
DTE
Hunger

Fig. 2

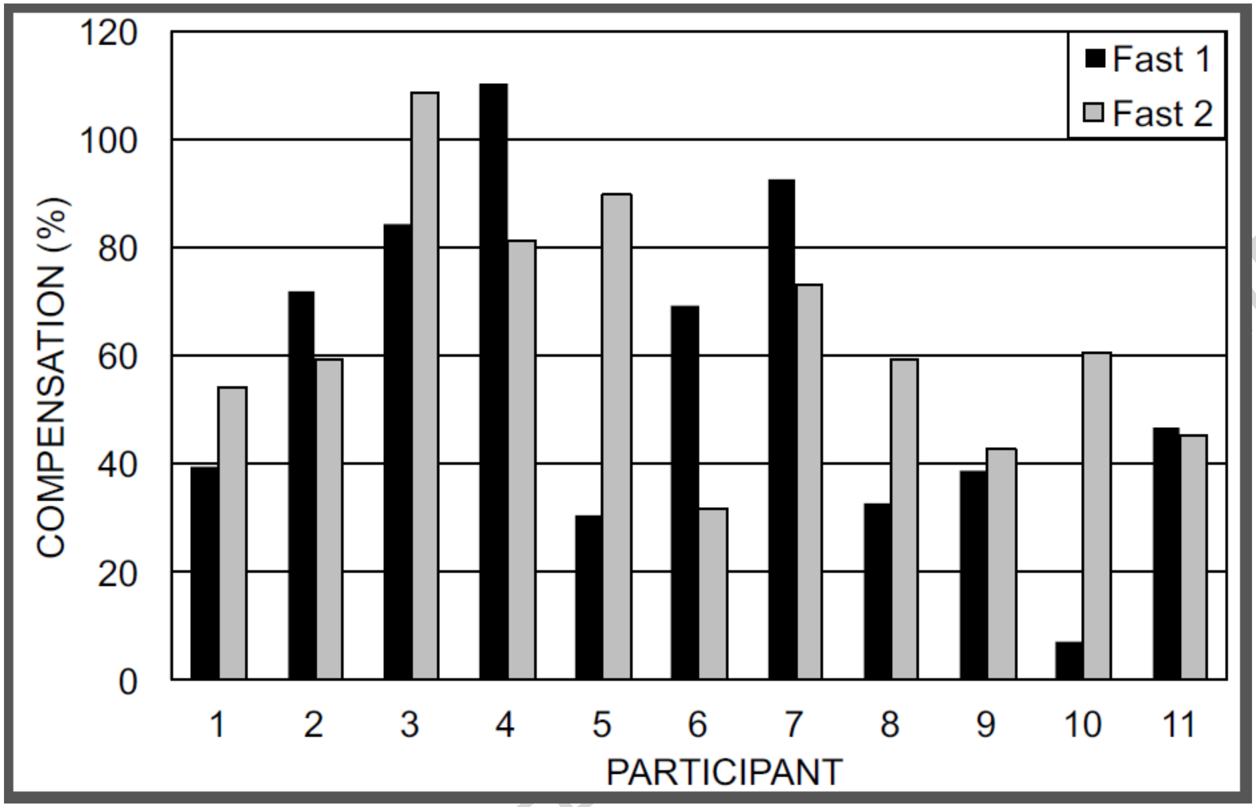

120
100
80
60
40
20
0
COMPENSATION (%)
Fast 1
Fast 2
1
2
3
4
5
6
7
8
9
10
11
PARTICIPANT

Fig. 3

Highlights

- Hunger-related variables exhibit varying test-retest reliability during fasting
- Energy intake compensation after fasting was ~60% of weight-maintenance needs
- Compensation after fasting was correlated with changes in hunger-related variables
- There is substantial variability in energy intake after fasting
- Body composition was correlated with changes in hunger-related variables