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ARTICLE

The relative reinforcing value of snack food is a significant predictor of fat loss in women with overweight or obesity

Luzia Jaeger Hintze, Éric Doucet, and Gary S. Goldfield

Abstract: Reinforcing Relative Value (RRV) of food and impulsivity are associated with energy intake and obesity. This study investigated the degree to which changes in RRV and impulsivity independently or interactively predict changes in body weight and composition in women with overweight or obesity engaged in either fast or slow weight loss programs. Body weight, body composition, impulsivity (Barratt Impulsiveness Scale), and RRV snack (computerized Behavioural Choice Task) were measured at baseline and post-intervention in 30 women with obesity undergoing either slow (n = 14, −500 kcal/day, 20 weeks) or fast (n = 16, −1000 kcal/day, 10 weeks) weight reduction. No group × time effects were noted on body composition, impulsivity, or RRV, so participants from both groups were pooled for analysis. Multiple regression analyses indicated that none of the impulsivity variables predicted weight or fat mass (FM) loss. However, ΔRRV snack predicted ΔFM (r = 0.40, p = 0.046), whereby greater increases in RRV snack were associated with less FM loss. The results indicate that different rates of weight loss do not differentially affect RRV snack or impulsivity traits. However, changes in RRV snack predicted FM loss, suggesting that dietary interventions that either mitigate increases or foster reductions in the RRV snack may yield greater reductions in adiposity. Trial Registration clinicaltrials.gov identifier: NCT04866875.

Novelty:

- No differences in RRV of food were noted between fast and slow weight loss.
- Weight loss from combined fast and slow groups led to a moderate-sized reduction in total impulsivity.
- Greater diet-induced increases in RRV snacks were associated with less body fat loss.

Key words: weight loss, delay discounting, reinforcement, impulsivity.

Résumé : Le renforcement de la valeur relative (« RRV ») des aliments et l'impulsivité sont associés à l'apport énergétique et à l'obésité. L'étude examine dans quelle mesure les modifications du RRV et de l'impulsivité prédisent indépendamment ou de manière interactive les changements de composition et de poids corporel chez les femmes en surpoids ou obèses qui participent à un programme de perte de poids rapide ou lent. Le poids corporel, la composition corporelle, l'impulsivité (échelle d'impulsivité de Barratt), le RRV de la collation (tâche de choix comportemental informatisée) sont mesurés au début et après l'intervention chez 30 femmes obèses participant à un programme de perte de poids lente (n = 14, −500 kcal/jour, 20 semaines) ou rapide (n = 16, −1000 kcal/jour, 10 semaines). Aucun effet groupe × temps n'est noté concernant la composition corporelle, l'impulsivité ou le RRV de sorte que les participants des deux groupes sont regroupés pour l'analyse. Des analyses de régression multiple indiquent qu'aucune des variables d'impulsivité ne prédit la perte de poids ou de masse grasse (« FM »). Cependant, la ΔRRV de la collation prédit la ΔFM (r = 0,40, p = 0,046); des augmentations plus importantes du RRV de la collation sont associées à moins de perte de FM. Les résultats indiquent que différents taux de perte de poids n'affectent pas différemment le RRV des collations ou les traits d'impulsivité. Cependant, les changements dans les RRV des collations prédisent la perte de FM; ainsi, les interventions diététiques qui atténuent les augmentations ou favorisent les réductions du RRV de la collation peuvent entraîner des réductions plus importantes de l'adiposité. Enregistrement de l'essai identifiant clinicaltrials.gov : NCT04866875. [Traduit par la Rédaction]

Les nouveautés :

- Aucune différence du RRV des aliments n'est notée entre la perte de poids rapide et lente.
- La perte de poids rapide ou lente des groupes combinés conduit à une réduction modérée de l'impulsivité totale.
- Des augmentations plus importantes des RRV des collations induites par les régimes sont associées à une moindre perte de graisse corporelle.

Mots-clés : perte de poids, mépris des gains différés, renforcement, impulsivité.

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Introduction

Impulsivity is a complex personality construct defined as the tendency to act without premeditation, a lower ability to control inappropriate behaviours and its consequences, and higher difficulty in delaying rewards (Patton et al. 1995; Dawe and Loxton 2004). More precisely, in the body weight (BW) regulation field, this construct might provide an understanding of how different factors influence everyday food choices, which can lead to positive energy balance and potential weight gain (Epstein et al. 2007*a*, 2010; Stojek and MacKillop 2017). In fact, studies have demonstrated that adults with a greater body mass index (BMI) also have higher impulsivity (Schag et al. 2013; Price et al. 2016). Particularly in women, studies have demonstrated that compared with leaner women, women living with obesity exhibited reduced delay of gratification, as evidenced by greater discounting of larger, future rewards in favour of smaller, more immediate rewards (Weller et al. 2008; Manwaring et al. 2011; Schiff et al. 2016). Impulsivity also plays a role in food choice and energy intake (EI), as women living with obesity with higher impulsivity tend to choose and consume away-from-home foods with a higher energy density (kcal/g), and in greater quantity (Appelhans et al. 2012). Measures of impulsivity in these studies included computer tasks (such as delay discounting tasks) (Leitch et al. 2013; Meule and Kübler 2014) and multi-dimensional self-report scales (e.g., Barratt Impulsiveness Scale) (Patton et al. 1995), with results indicating consistent findings with self-report and objective measures of impulsivity.

Another factor that has been found to be a powerful determinant of food choice and energy intake is the relative reinforcement value of food (RRV) (Epstein et al. 2007*a*). Particularly in studies involving eating behaviours, the RRV characterizes how reinforcing energy-dense food items are to the individual in comparison to an alternative item available (Epstein et al. 2007*a*). Individual differences in the RRV of food exist, whereby the RRV of palatable snack food has been reliably demonstrated to be higher in adults living with obesity compared with lean individuals (Temple et al. 2009; Clark et al. 2010; Giesen et al. 2010; Epstein et al. 2011; Goldfield et al. 2011; Temple and Epstein 2012), and are positively associated with laboratory-measured energy intake (Epstein et al. 2004, 2011) and energy intake in free-living conditions (Epstein et al. 2011).

In situations where food or reinforcing alternatives are not freely available, such as fasting and dieting periods, deprivation might increase RRV, making it more difficult to resist these foods and maintain dietary adherence over time (Epstein et al. 2007*a*). In this case, the motivation to obtain food may gain strength over time, and people may allocate more resources to obtain and consume these reinforcing foods compared with lower-energy dense foods needed for weight loss. Accordingly, there is evidence suggesting that after a few hours of fasting (Raynor and Epstein 2003; Epstein et al. 2003; Polivy et al. 2005) and 16-week caloric restriction periods (Best et al. 2012), individuals have an increased RRV of palatable energy-dense foods compared with healthier food and nonfood alternatives. This evidence supports the idea that caloric restriction can increase RRV, and RRV is a potent predictive measure of food choice and short-term energy intake, which may play an important role in the dietary adherence needed for successful weight management. Accordingly, decreases in RRV for palatable snack foods were found to predict greater weight loss in children with obesity (Buscemi et al. 2014). However, little is known about how diet-induced changes in RRV predict weight loss in adults with obesity, as well as the influence of different rates of calorie restriction and rate of weight loss on food reinforcement.

The RRV of food and impulsivity may independently exert effects on BMI and weight status (Carr et al. 2014). Previous evidence indicated that individuals with obesity commonly present higher RRV of food compared with individuals with healthy weight (Epstein et al. 2007*b*; Buscemi et al. 2014). Along the same lines, impulsivity has been found to be associated with a higher BMI in women living with obesity (Appelhans et al. 2012). However, when high RRV for food and high impulsivity interact, a phenomenon recently known as reinforcement pathology, this combination of traits provides better prediction of obesity status than either construct alone (Appelhans 2009; Epstein et al. 2012*b*; Meule and Kübler 2014). Although it is still uncertain whether these variables interact to predict energy intake and potential weight loss, previous evidence has demonstrated that impulsive reactions to high-calorie food cues seem to be more pronounced when both impulsivity and food craving are high. On the other hand, in situations where levels of impulsivity are low and food cravings are high, reactions to high-calorie food cues are less obvious (Meule and Kübler 2014). Even though food cravings and RRV of food represent different constructs, they are both reward-seeking variables and, thus, are conceptually related. More precisely, in women, RRV of food was found to predict energy intake only when participants had more difficulty in delaying gratification, which is one of the traits of impulsivity (Rollins et al. 2010). Conversely, a recent study showed that food reinforcement, but not impulsivity, was independently associated with energy intake in adults, suggesting that food reinforcement might be a more powerful independent predictor of energy intake, and by extension, weight loss (Brace and Yeomans 2016).

The inconsistency in evidence existing in the scant number of studies demonstrates the need for further investigations to gain a better understanding of the independent and combined effects that impulsivity and food reinforcement have on energy intake and potentially on the treatment response to weight loss interventions. No previous studies have investigated the role of the rate of weight loss induced by varying degrees of RRV and impulsivity. Given the potential role that RRV of snack food and impulsivity has on energy intake, this evaluation would be critical for informing individualized dietary prescriptions to obtain a better treatment outcome.

Accordingly, the purpose of this study was first to investigate the changes in RRV of food and impulsivity in premenopausal women engaged in either fast (–1000 kcal/day, 10 weeks) or slow weight loss (–500 kcal/day, 20 weeks) programs. Second, we examined whether changes in RRV for snack and impulsivity independently or interactively predict BW and fat loss. We hypothesized that (1) no differences in RRV of food or impulsivity between groups would be noted, given that the study was designed to promote similar weight losses and both groups would be in a state of energy deprivation; (2) greater increases in RRV and impulsivity would be associated with poorer BW and fat mass (FM) losses, and (3) the interaction between impulsivity and RRV for snack food would predict final weight and fat loss better than either variable alone.

Materials and methods

Participants

A total of 36 premenopausal women with overweight or obesity were enrolled in the program; however, only 30 completed the intervention. During the intervention period, 6 participants (16.7%) quit the study. The reasons included lack of motivation ($n = 3$), lack of time ($n = 2$), and personal/health problems unrelated to the trial ($n = 1$). As such, 30 participants were included in the analyses (slow, $n = 14$; fast, $n = 16$). The inclusion criteria were as follows: $27 \leq \text{BMI} \leq 40$ kg/m^2; age, 18 years and older; waist circumference >88 cm; weight-stable (±2 kg in the previous 6 months); not meeting the current physical activity guidelines for adults (i.e., less than 150 minutes per week of moderate to vigorous physical activity); no history of alcohol or drug abuse; no food allergies; non-smoker; premenopausal with a regular menstrual cycle; not pregnant; not taking any medication that can

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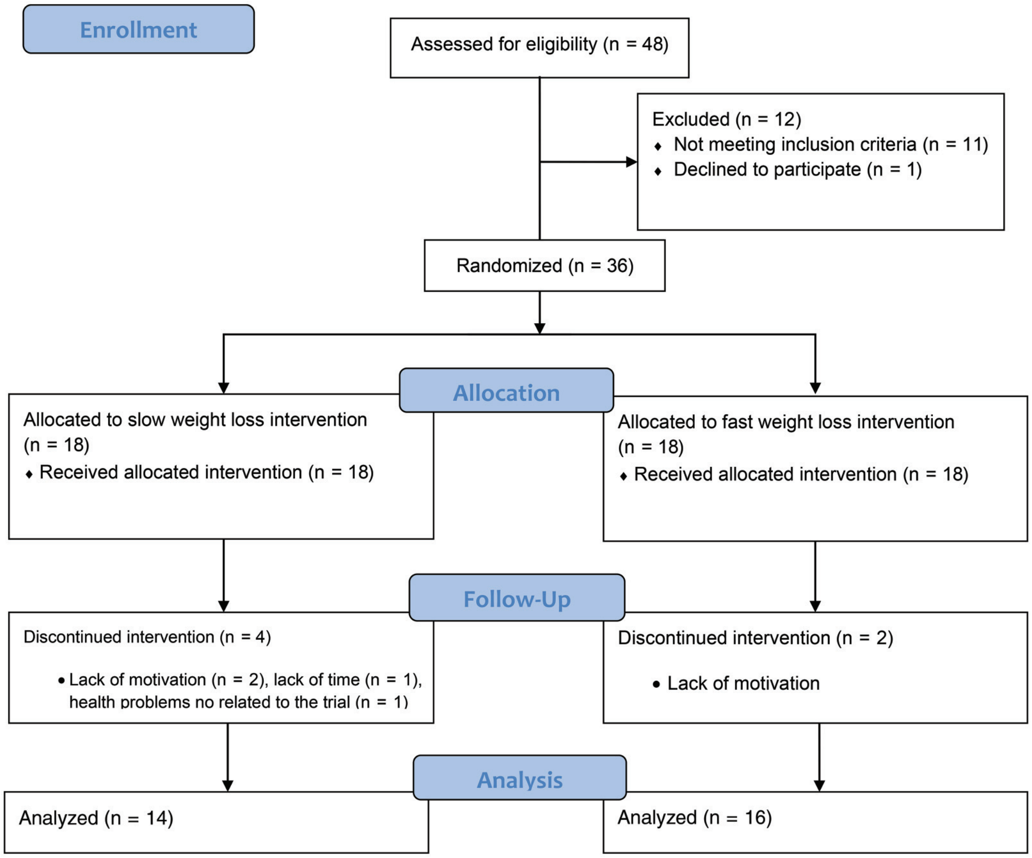
Fig. 1. Study design. [Colour online.]



interfere with energy intake and energy expenditure (e.g., psychiatric medications, appetite suppressants); normal scores in the Binge Eating Scale (Gormally et al. 1982); and depression symptoms (Beck et al. 1961). Furthermore, participants who self-reported having any history or evidence of (1) cardiovascular disease, peripheral vascular disease, or stroke; (2) diabetes (75 g oral glucose tolerance test); (3) known renal and liver disease; (4) asthma requiring therapy, plasma cholesterol > 8 mmol/L; (5) systolic blood pressure > 140 mm Hg or diastolic blood pressure > 90 mm Hg; (6) previous history of inflammatory disease or cancer; (7) untreated thyroid or pituitary disease; (8) medications that could affect cardiovascular function and/or metabolism; and (9) food allergies, could not be included in the study ($n = 12$). All participants provided written informed consent to participate in this study, which was approved by the Research Ethics Board of the University of Ottawa (#H08-15-27).

Study design and procedures

Participants who met all inclusion criteria and completed all measures of the preliminary session and baseline were then randomized into 2 distinct groups: fast weight loss (–1000 kcal/day) and slow weight loss (–500 kcal/day) (Fig. 1). Randomization was performed using a random number generator sequence in the Statistical Package for the Social Sciences (SPSS) version 15.0 (SPSS Inc., Chicago, IL, USA). Once the participant's eligibility to participate in the study was confirmed, a block of 6 participants was randomized at a time, ensuring that 3 patients were allocated to the fast weight group and 3 patients to slow weight loss. The total duration of the program was thus 10 and 20 weeks for the fast and slow groups, respectively, since we wanted to match the total weight loss between groups. Both groups were assessed at baseline and post-intervention for body composition, impulsivity, and RRV. More details of the study design can be found elsewhere (Hintze et al. 2019, 2021).

Nutritional intervention

The nutritional interventions consisted of caloric restrictions of –500 kcal/day and –1000 kcal/day for slow and fast weight loss, respectively. These restrictions were calculated based on individual daily energy requirements. Total energy expenditure was estimated using indirect calorimetry and a biaxial accelerometer placed around the upper arm (mid-distance between the acromion and the olecranon). The SenseWear Professional software (version 7.0, Bodymedia, Pittsburgh, PA, USA) was used to retrieve the data once the accelerometer was returned to the laboratory as previously described (McNeil et al. 2016). The diet macronutrient composition was personalized for each participant based on the results of the 2-day energy intake during the preliminary session, as previously described (Hintze et al. 2019). To achieve and maintain their respective degrees of energy restriction, each participant received an explanation of the Food Exchange System–Canadian Diabetes Association (Lawton 2004). This method allows participants to select foods that they enjoy during weight loss, but in smaller quantities. Weekly counselling was provided to help with potential difficulties with dietary compliance throughout the dietary intervention. Although no compliance measures were taken during this period, a previous study from our group noted that the degree of energy compensation was approximately 50% in both groups (Hintze et al. 2019).

Measures

Body composition

BW was measured to the nearest 0.1 kg on a calibrated balance scale (HR-100; BWB-800AS, Tanita Corporation, Arlington Heights, IL, USA) and standing height was measured using a wall stadiometer (Tanita HR-100, Tanita Corporation). Fat free mass (FFM) and FM were measured using dual-energy X-ray absorptiometry (DXA; Lunar Prodigy, General Electric, Madison, WI, USA). In our laboratory, the coefficient of variation and correlation for body fat percentage measured by DXA scanner in 12 healthy participants were 1.8% and $r = 0.99$, respectively.

Relative reinforcing value of food

RRV is defined and measured as the amount of work (button presses) performed to obtain palatable snack foods relative to the amount of work performed to obtain the alternative reinforcer, which in this study was fruit and vegetables, with the greater number of points earned (or button presses) reflecting greater RRV. A validated computerized task (Epstein et al. 2012*a*) assessed the RRV of snack food vs fruits/vegetables (Epstein et al. 2012*b*) at 180 minutes after a standard breakfast, just prior to lunch. In our trial, the reinforcement schedule for fruits/vegetables remained constant at variable ratio (VR2), whereby participants earned points for this alternative every second button press (on average). The work requirements to obtain snack food remained constant at VR5, whereby participants had to press the button 5 times (on average) to obtain snack food points. Food points were earned by selectively working for the food item of choice, and this was accomplished by activating a slot-machine-like program with a simple 2-button joystick. Button 2 allowed the user to freely switch between the snack or fruit/vegetable screen, and button 1 started the slot game. Participants were asked to perform a taste test and rate the palatability of a 10 g sample of their favourite snack and fruit/vegetable served before starting the computer task, and their highest rated snack food and fruit/vegetables were used in the reinforcement computer task. They were also informed that every 5 points earned in the game, 25 g of the item chosen would be served to them during lunchtime.

Impulsivity

The Barratt Impulsiveness Scale-11 (BIS-11) (Patton et al. 1995) was used to assess impulsivity. The BIS-11 consists of a 30 item self-report instrument designed to assess the personality/behavioural construct of impulsivity on attentional (e.g., I do not 'pay attention'; I have 'racing thoughts'), motor (e.g., I do things without thinking; I act on the spur of the moment) and planning (e.g., I am more interested in the present than the future; I concentrate easily) sub-scales. Participants were instructed to rate the frequency in which items applied on a Likert-type scale (1 = rarely, 2 = occasionally, 3 = often, 4 = almost always). The scale was computed and scored according to the authors' previous instructions and this measure has been found to have sound psychometric properties (Patton et al. 1995). The measure was administered at baseline and post-weight loss, at 30 minutes after a standard breakfast. Higher scores indicated higher levels of impulsivity in all domains.

Statistical analysis

All data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 15.0 (SPSS Inc., Chicago, IL, USA). Normality of the data was assessed using the Shapiro–Wilk test, and the results showed that transformations were not required. Variables with a parametric distribution are presented as mean ± standard deviation. Two-way repeated-measures ANOVA was performed for changes in BW, FM, RRV of snack food, and impulsivity at baseline and post-weight loss intervention within each group and between groups (time × group interaction). Effects were considered significant at $p < 0.05$. Moreover, in order to assess the magnitude of observed differences, the effect size was computed (eta squared, η^2). The values of 0.0099, 0.0588, and 0.1379 were considered mid-range benchmarks for small, medium, and large effect sizes, respectively (Richardson 2011).

Table 1. Baseline characteristics of the slow and fast weight loss groups.

	Slow ($n = 17$)	Fast ($n = 19$)	p
Age (years)	30.18 (9.31)	33.05 (9.3)	0.361
BW (kg)	85.25 (12.45)	92.64 (16.2)	0.137
BMI (kg/m^2)	32.12 (3.12)	33.99 (4.38)	0.076
WC (cm)	93.8 (6.5)	96.7 (9.39)	0.295
%BF	45.99 (4.46)	47.39 (2.63)	0.256
Attempts to lose weight	3.82 (3.07)	4.16 (2.4)	0.714
Highest BW lifetime (kg)	89.62 (12.22)	95.42 (16.15)	0.238
REE (kcal/day)	1404.81 (396.51)	1558.52 (190.17)	0.141
Estimated TEE (kcal)	1872.47 (413.71)	2103.26 (264.16)	0.06
EI breakfast (kcal)	467.73 (188.04)	481.51 (173.61)	0.82
Ethnicity (*n*, %)			
White	11 (30.6%)	13 (36.1%)	
Black	3 (8.3%)	1 (2.8%)	
Other	3 (8.3%)	5 (13.9%)	0.458
Education (*n*, %)			
High school	4 (11.1%)	3 (8.3%)	
Some college, no degree	3 (8.3%)	2 (5.6%)	
Associate's degree	2 (5.6%)	1 (2.8%)	
Bachelor's degree	2 (5.6%)	7 (19.4%)	
Master's degree	6 (16.7%)	5 (13.9%)	
Professional degree	0	1 (2.8%)	0.487

Note: Data are presented as mean (±SD); categorical variables are presented as frequency (%). BF, body fat; BMI, body mass index; BW, body weight; EI, energy intake; REE, resting energy expenditure; TEE, total energy expenditure; WC, waist circumference. (From Hintze et al. 2019, reproduced with permission of Physiol. Behav., Vol. 199, p. 317, © 2019 Elsevier.)

Linear multiple regression analysis was used to examine the independent and combined impact of delta changes in RRV and impulsivity scales (motor, attentional, planning, and total score) as predictors of weight loss and fat loss. Regression analyses were based on the pooled sample, given that there were no differences in changes in weight loss or body composition between the groups. All variables were centred before entering the linear regression model. The centred values were obtained by subtracting the mean from the measured value of the median of the variable. We calculated the delta change scores observed in the trial by subtracting the final measures from the baseline measures. The probability of entering the model was set at 0.05 (2-tailed).

Results

At baseline, no differences were noted between the groups for any of the physical and demographic characteristics of the participants, as reported in Table 1. As previously reported, total weight loss after both interventions were –6.23 (3.06) % ($p = 0.001$) and –4.46 (3.99) % of body weight ($p < 0.001$) in the fast and slow groups, respectively (Hintze et al. 2019). The rate of weight loss was –0.52 (0.25) kg/week and –0.21 (0.18) vs. ($p < 0.001$) in the fast and slow groups, respectively. Overall, a significant time effect with a large effect size was observed for reductions in body weight ($p < 0.01$; $\eta^2 = 0.73$) and fat mass ($p = 0.008$, $\eta^2 = 0.213$), but no time × group interaction effects were observed ($p = 0.169$; $\eta^2 = 0.067$ and $p = 0.801$; $\eta^2 = 0.002$, respectively), indicating that the changes between groups were not significantly different. BW and body composition results have been reported elsewhere (Hintze et al. 2019).

Table 2 presents the changes in impulsivity and RRV in the completers of the slow and fast weight loss groups. As shown in Table 2, no changes over time ($p = 0.428$; $\eta^2 = 0.023$) or group × time interaction ($p = 0.978$) were noted in the RRV of snack food.

Table 2. Changes in Impulsivity, RRV of snack at baseline and post dietary intervention by group.

	Slow (n = 14)		Fast (n = 16)		Changes within group, p	η^2	Changes between group, p	η^2
	Baseline	Post intervention	Baseline	Post intervention				
Body weight (kg)	87.29 (11.65)	83.36 (11.16)	92.18 (16.54)	86.69 (17.26)	**<0.01**	0.73	0.169	0.067
Fat mass (kg)	41.72 (7.83)	37.81 (12.86)	42.75 (7.57)	38.0 (12.84)	**0.008**	0.213	0.801	0.002
BIS								
Attentional facet	15.73 (2.05)	14 (4.94)	14.82 (3.02)	14.29 (4.71)	0.154	0.066	0.443	0.02
Motor facet	20.93 (3.63)	21.57 (3.52)	20.50 (3.81)	19.06 (2.91)	0.494	0.017	0.081	0.105
Planning facet	22.14 (3.08)	21.50 (2.90)	22.81 (2.86)	21.50 (3.33)	**0.05**	0.128	0.493	0.017
Total score	58.79 (5.34)	58.07 (7.47)	58.69 (6.35)	55.69 (6.78)	0.079	0.106	0.271	0.043
RRV snack	12.14 (11.13)	9.71 (9.09)	13.56 (9.89)	11.13 (22.57)	0.45	0.021	0.999	0

Note: Data are presented as mean ± SD; significant differences are in bold. BIS, Barratt Impulsiveness Scale; RVV, Reinforcing Relative Value.

Table 3. Summary of hierarchical regression analysis for delta variables predicting changes in fat mass in both groups (n = 30).

	ΔFM			
	R	R^2	B	p
Model 1				
ΔRRV snack	0.468	0.219	0.278	0.142
ΔBIS-11 motor scale			0.841	0.060
ΔRRV snack × ΔBIS-11 motor scale			0.599	0.175
Model 2				
ΔRRV snack	0.400	0.160	0.525	**0.046**
ΔBIS-11 planning scale			0.497	0.146
ΔRRV snack × ΔBIS-11 planning scale			0.556	0.119
Model 3*				
ΔRRV snack	0.255	0.065	0.255	0.191
ΔRRV snack	0.255	0.065	0.255	0.199
ΔBIS-11 attentional scale			–0.015	0.939
Model 4				
ΔRRV snack	0.352	0.124	0.243	0.221
ΔBIS-11 total score			0.542	0.277
ΔRRV snack × ΔBIS-11 total score			0.381	0.443

Note: BIS, Barratt Impulsiveness Scale; BW, body weight; RRV, Relative Reinforcing Value.

*Model 3: the interaction between ΔRRV snack and ΔBIS-11 attentional scale was not entered as independent variable as it did not follow the collinearity criteria adopted in the models.

Moreover, no effects of time were noted for any component of the impulsivity data, except for a trend toward improvements in the planning scale (p = 0.05; η^2 = 0.128). A similar trend was observed for the BIS-11 total score (p = 0.079; η^2 = 0.106). No group × time interactions were observed for any of the impulsivity variables; however, for the motor scale of BIS-11, the interaction trended toward significance and a large effect size was noted (p = 0.081; η^2 = 0.105). More precisely, the slow weight loss group showed increases over time in motor impulsivity, whereas values decreased over time in the fast weight loss group.

Table 3 displays the results of the regression models for changes in RRV, each impulsivity scale, and their interaction as independent variables. The results demonstrated that only the ΔRRV snack was found to predict ΔFM. However, the model that also included changes in impulsivity planning predicted 16% of the variance in FM loss. As shown in Table 3, greater increases in RRV snack were associated with poorer fat loss.

None of the changes in impulsivity-related variables either entered independently or with RRV snack were found to predict FM losses. Changes in impulsivity motor scale showed a trend toward predicting FM loss; however, the results were not statistically significant (B = 0.841, p = 0.060). Also, the interaction between impulsivity scales and RRV did not predict fat loss. Of note, model 3 did not include the interaction between ΔRRV snack and ΔBIS-11 attentional scale given the high collinearity (variance inflation factor = 7.51) observed in this variable when included in the model.

Discussion

This study is the first to examine the effects of different rates of weight loss on impulsivity and RRV food, as well as to examine whether the interaction between these 2 constructs would predict treatment response (changes in BW and FM) in women living with obesity. The findings of the present study support our initial hypothesis that no differences in RRV of food or impulsivity between groups would be noted, given that the study was designed to promote similar weight losses and both groups would be in a state of energy deprivation. On the other hand, weight loss from combined fast and slow groups led to a moderate-sized reduction in the total impulsivity score, but this trend was not significant. Additionally, participants in the fast weight loss group reported a reduction in motor-related impulsivity scores, whereas participants in the slow weight loss group exhibited a slight increase in motor scale, whereby a large effect size for this interaction was observed. We partially confirmed our second hypothesis that greater increases in RRV of snack food were associated with poorer fat loss; however, none of the impulsivity scales were predictive of BW or FM loss in the regression models. We did not confirm our third hypothesis, as the interaction between impulsivity and RRV for snack food did not predict final weight and fat loss better than either variable alone.

Impulsive characteristics were previously found to be greater in energy- and water-deprived participants (Kirk and Logue 1997; Manasse et al. 2017), and these traits were associated with worse weight management (Best et al. 2012; Kishinevsky et al. 2012; Weygandt et al. 2015; Brockmeyer et al. 2017). In fact, previous evidence has shown that when participants were more energy- and water-deprived (approximately 16 hours of deprivation), they exhibited lower self-control and were less able to wait for food reinforcers compared with individuals that consumed a preload meal (approximately 200 kcal) (Kirk and Logue 1997). Along the same lines, a recent study suggested that 2 constructs of impulsivity, namely inhibitory control and delay discounting, may play a role in predicting weight loss outcomes (Manasse et al. 2017). Specifically, poorer general inhibitory control was associated with reduced weight loss after 12 months. Moreover, in a clinical context, greater inhibitory control promotes better adherence to the diet and makes it less difficult to resist palatable, high-calorie food items (Manasse et al. 2017). Our data are not consistent with previous findings, as only one of the impulsive indicators (planning) was impacted by caloric deprivation and none were found to predict weight or fat loss. The discrepant findings could be partially due to baseline scores of impulsivity values in our study being lower than normative samples, and/or the fact that we did not measure delay discounting or inhibitory control directly through behavioural tasks; rather, we used subjective (self-perception) measures of impulsivity sub-traits, which may be less sensitive in detecting changes from bioenergetic challenges. Nevertheless, our findings are novel in that different levels of food deprivation inherent in the different rates of weight loss led to comparable reductions in future thinking relative to immediate thinking, which is a construct that is conceptually similar to delay discounting. Although no significant associations were observed between BIS-11 planning and FM losses in our study, the literature still considers the planning facet as an important contributor to weight loss maintenance, given that those with cognitive styles that focus more on the future rather than immediate rewards are more likely to purchase healthier foods and make healthier food choices (Epstein et al. 2011). In fact, improving the delay of gratification through a method known as episodic future thinking demonstrates the importance of shifting time horizons and its impact on energy intake (Epstein et al. 2011, 2012*a*). In looking at potential mechanisms for our novel findings, it is possible that the improved self-regulation required for the conscious effort of selecting and consuming lower energy-dense foods over high-calorie foods on a regular basis to meet the longer-term goal of weight loss translated to a shift towards future thinking of non-eating related behaviours, goals, or outcomes. It is also possible that caloric restriction itself had some direct effects on the BIS-11 Planning subscale, given that animal and human data show that caloric restriction and intermittent fasting enhance various aspects of cognition and executive functioning (Anton et al. 2018; Mattson 2019). Future research is needed to better understand how dietary prescriptions that vary in caloric restriction and macronutrient intake impact both cognitive and behavioural indicators of impulsivity and how these changes predict long-term weight maintenance/relapse in individuals living with obesity.

Conversely, no group differences were noted over time for the RRV of snack food, which is in agreement with previous results (8 week caloric restriction; −700 kcal/day) (Cameron et al. 2008). On the other hand, other studies suggested that caloric restriction increases the RRV of snack food after short (Epstein et al. 2003; Raynor and Epstein 2003; Polivy et al. 2005) and long caloric restriction periods (Best et al. 2012), which might lead to increases in EI, an effect that could compromise weight loss and maintenance. Indeed, our results also demonstrated that the RRV of snack food changes was positively associated with changes in FM. In other words, increases in RRV were associated with poorer fat loss at the end of the study. In accordance with our results, previous evidence demonstrated that RRV predicts BMI increases after 12 months of follow-up in both adults (Carr et al. 2014) and children (Hill et al. 2009; Feda et al. 2015), while decreases in RRV food were found to predict greater weight loss at 6 months of weight loss in adults with obesity (Buscemi et al. 2014). Along the same lines, several studies show an association between greater RRV of snack food with increased EI (Epstein et al. 2004, 2007*b*, 2011; Brace and Yeomans 2016). A recent study has shown that food reinforcement, but not impulsivity, is independently associated with EI in adults, suggesting that food reinforcement might be a more powerful independent predictor of EI (Brace and Yeomans 2016). In the long term, the change in food reinforcement could complicate the achievement and maintenance of negative energy balance, thus compromising weight loss and weight loss maintenance.

The present study has some limitations. First, our sample size was limited to 30 premenopausal women, which might not provide sufficient power to detect all associations and effects of interest. Second, we measured impulsivity using a questionnaire that was not specifically developed to measure impulsivity toward food. Accordingly, the use of more specific food-related impulsivity measures, behavioural inhibition, or delay discounting as indicators of impulsivity could have led to different results. Third, given that this is a sub-study of a larger study, we included a brief protocol to measure food reinforcement in our participants, which may have influenced some of the null associations. Finally, we did not include compliance measures during the dietary intervention. However, our previous study showed that the weight and energy compensation data showed good compliance based on indirect estimates. On the other hand, our results are strengthened by its experimental design (i.e., randomized controlled trial), as well as by the novelty of the study. Other methodological strengths of our study include the use of gold-standard techniques in the measurement of body composition and control for the phase of the menstrual cycle, which strengthens the internal validity of our results.

Conclusions

Our results suggest that different rates of weight loss by varying levels of caloric restriction do not adversely affect RRV for snack foods or impulsivity traits in women. However, greater changes in RRV for snacks were predictive of poorer FM loss. Neither RRV nor impulsivity was associated with weight loss, highlighting the need to include body composition assessments rather than solely relying on weight loss as outcomes. The results highlight the need to address increases in RRV for snack foods during weight loss in order to optimize the outcome of weight loss interventions. Further studies including larger sample sizes and more intensive food reinforcement schedules are recommended to confirm and extend the findings of the present study.

Conflict of interest statement

The authors declare there are no competing interests.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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