

## ORIGINAL ARTICLE

# Physical activity, eating traits and weight in young adulthood: a cross-sectional and longitudinal study

R. S. Falck<sup>1</sup>, C. Drenowatz<sup>2</sup>, J. E. Blundell<sup>3</sup>, R. P. Shook<sup>4</sup>, J. R. Best<sup>1</sup>, G. A. Hand<sup>5</sup> and S. N. Blair<sup>2</sup>

<sup>1</sup>Department of Physical Therapy, University of British Columbia, Vancouver, BC, Canada; <sup>2</sup>Department of Exercise Science, University of South Carolina, Columbia, SC, USA; <sup>3</sup>School of Psychology, University of Leeds, Leeds, United Kingdom; <sup>4</sup>Center for Children's Healthy Lifestyles & Nutrition, Children's Mercy Hospital, Kansas City, MI, USA; <sup>5</sup>School of Public Health, West Virginia University, Morgantown, WV, United States;

Received 15 September 2016; revised 14 October 2016; accepted 21 October 2016

Address for correspondence: R Falck, Aging, Mobility and Cognitive Neuroscience Laboratory, Faculty of Medicine, Department of Physical Therapy, 212-2177 Wesbrook Mall, Vancouver, BC V6T 1Z3, Canada. E-mail: ryan.falck@hiphealth.ca

## Summary

### Objective

To investigate the association between eating traits (e.g. dietary restraint or opportunistic eating) and weight – both cross-sectionally and longitudinally – and whether physical activity (PA) moderates these associations.

### Methods

Two-hundred seventy young adults (21–35 years; BMI: 25.40 kg/m<sup>2</sup> [SD = 3.90 kg/m<sup>2</sup>]; 48.90% female) participated in this 12-month observational cohort study. Cognitive Restraint (CR), Disinhibition (DI) and Hunger (HU) were measured using the Three-Factor Eating Questionnaire at baseline and 12 months. Participants were measured at quarterly intervals for objectively measured PA and anthropometrics. Cross-sectional and longitudinal models determined if eating traits were associated with weight or weight change, and whether these associations were moderated by PA.

### Results

At baseline, higher CR ( $B = 0.429, p < 0.01$ ) and DI ( $B = 0.942, p < 0.01$ ) were associated with higher weight. The associations of DI ( $B = -0.008, p = 0.02$ ) and HU ( $B = -0.006, p = 0.04$ ) with weight were moderated by PA at baseline. The longitudinal model for CR determined PA altered the relationship between change in CR and weight change ( $B = 0.004, p < 0.01$ ).

### Conclusions

Eating traits and PA are associated with weight and weight change. However, to elucidate how PA and eating traits directly affect weight changes, future weight loss interventions should investigate whether improving eating traits and concomitantly increasing PA amplify weight loss.

**Keywords:** Eating behaviours, epidemiology, physical activity, weight.

## Introduction

More than two thirds of US adults are living with overweight or obesity, and this number is expected to grow within the next 20 years (1). Thus, weight maintenance (i.e. preventing weight gain >2 kg per year in adults) is an important goal for obesity prevention (2). However, the factors regulating body weight are unclear, and better understanding the interactions between psycho-social risk factors for excess weight gain and actual energy balance behaviours (e.g. physical activity

[PA]) is an important step towards reducing obesity prevalence.

Increasing evidence suggests that psycho-social eating traits are strong predictors of adult weight gain (3–5). Three well-established eating traits are *cognitive restraint (CR)*, *disinhibition (DI)* and *hunger (HU)* (6). Conceptually, CR refers to behavioural and cognitive strategies used to control body weight; DI reflects a tendency towards overeating and eating opportunistically in an obesogenic environment, and HU is concerned with the extent to which craving for food is perceived and

potentially evokes food intake (7,8). The relationships between each of these traits and body weight, however, are complex and not fully understood (9). For example, short-term increases in CR may help with inducing weight loss and preventing weight gain, but successions of restrained eating may lead to a vulnerability for weight cycling because of increases in food efficiency (10,11). In addition, cross-sectional and prospective designs have found conflicting results regarding the association between CR and weight (12–15). Only DI has consistently been associated with increases in body weight – in contrast to the inconsistent findings for CR and HU (13,16). Such inconsistent findings regarding eating traits may be limiting the usefulness of these eating traits in clinical practice as a potential weight loss intervention tool. Thus, an important analysis is to directly compare cross-sectional associations to longitudinal associations within a single and reasonably sized sample of adults. Such an analysis will help determine whether the relationships seen cross-sectionally are also consistent longitudinally, thus providing stronger evidence for an association between eating traits and weight.

There is also limited knowledge about how eating traits interact with weight management behaviours – such as PA – to predict changes in weight. Preliminary evidence suggests that eating traits are independently associated with body weight and PA (17); however, these findings are predominantly based on studies with self-reported PA, which has sizable measurement error (18,19). There is an overwhelming body of literature demonstrating that regular PA aids in optimal body weight control (20), and evidence suggests that this may occur through a combination of (i) improved sensitivity to physiological feelings of satiety; (ii) adjusting food preferences; and (iii) altering the hedonic response to food (21,22). Improving the current understanding of how PA influences the relationship between eating traits and weight may thus provide valuable information for future weight loss intervention strategies (i.e. combining behaviour modification of eating traits and PA).

The purpose of this study was therefore to determine the association between eating traits and weight – both cross-sectionally and longitudinally – and whether these associations were moderated by PA. It was hypothesized that (i) CR and DI would be associated with both weight and weight change; and (ii) the association of CR and DI with weight and weight change would be moderated by PA.

## Methods

This was an observational cohort sub-analysis from the Energy Balance Study which was designed to examine

potential contributing aspects of weight change in young adults (23). Briefly, the Energy Balance Study is a 3-year observational study of 430 healthy young adults to identify determinants of weight changes. Measurements of energy intake and multiple objective measures of energy expenditure, as well as other physiological, anthropomorphic and psychosocial measurements, were made quarterly. Resting metabolic rate and blood chemistry were measured at baseline, 6 and 12 months (24). Eating traits were measured at baseline and 12-month follow-up. This study was approved by the University of South Carolina Institutional Review Board, and detailed descriptions of the study protocol can be found elsewhere (24).

## Participants

In this open cohort study, participants were 21–35 years of age. Participants were required to: (i) have no plans to move from the area within the next 15 months; (ii) not have used medications to lose weight; (iii) not have changed smoking status in the previous 6 months; and (iv) not have planned weight loss surgery. In addition, participants were also excluded for: exceedingly high blood pressure (>150/90 mmHg), glucose >145 mg/dl, diagnosis with a major chronic health condition, having been pregnant or given birth in the previous 12 months or any other reason which might influence body weight status (e.g. use of selective serotonin reuptake inhibitors).

For the analyses in this manuscript, participants were included if they: (i) completed eating trait questionnaires at both baseline and 12-month follow-up; and (ii) provided  $\geq 3$  time points of PA and anthropometric data – including baseline and 12-month follow-up. Thus, of the 430 participants at study entry, the final sample consisted of 270 males and females (males:  $N = 138$ ; females:  $N = 132$ ).

## Measures

Demographic information regarding personal health, health habits, educational attainment, race and socioeconomic status were assessed via questionnaires at baseline. Psychometric information – including eating traits – was assessed at baseline and 12 months. Measurements of anthropometrics and PA were taken at baseline and then at quarterly intervals.

## Eating traits

Eating traits were assessed via the Three-Factor Eating Questionnaire at baseline and 12-month follow-up. The Three-Factor Eating Questionnaire is a reliable and

validated questionnaire containing 51 items which cover three domains of human eating: (i) CR ( $\alpha=0.90$ ;  $r=.20$ ); (ii) DI ( $\alpha=0.87$ ;  $r=0.53$ ) and (iii) HU ( $\alpha=0.82$ ;  $r=0.21$ ) (6). The 21-item domain CR is characterized by a permanent cognitive control of food intake in order to maintain or to reduce body weight. The 16-item DI domain describes a loss of control in food intake by various external or internal circumstances such as socially or emotionally triggered eating. The HU domain includes 14-items which describe the exceeding sense of food craving.

All Three-Factor Eating Questionnaire items were coded with either 0 or 1 point, leading to maximum sum scores of 21 points for the domain of CR, 16 points for DI and 14 points for HU. Higher scores for a given trait indicate stronger characteristic values of the eating trait.

### *Anthropometrics*

Participants' height and weight were measured while wearing surgical scrubs and in bare feet. Height and weight were calculated from the average of three trials using a wall-mounted stadiometer (Model S100, Ayrton Corp., Prior Lake, MN, USA) and electronic scale (Healthometer® model 500KL, McCook, IL, USA), and recorded to the nearest 0.1 cm and 0.1 kg, respectively.

### *Physical activity*

Time spent in PA was measured using the SenseWear Mini Armband (Body Media, Pittsburgh, PA, USA), a valid and reliable measure of PA (25). Descriptions of the device and procedures used to track PA can be found elsewhere (24). Briefly, this portable, multi-sensor device, worn on the upper arm, incorporates tri-axial accelerometry, heat flux, galvanic skin response, skin temperature and near-body ambient temperature. Participants were monitored for 10 days of measurement and were instructed to only remove the monitor when it might get wet. These measures were entered in combination with demographic information into an algorithm to activity. Compliance criteria for adequate wear time were set at 7 days, with at least 23 h of daily wear time. Time spent in PA was classified as all activity  $\geq 3.0$  metabolic equivalents (METs).

### *Statistical analyses*

Descriptive characteristics of the study sample are reported as mean (SD), or percentage. Associations between eating traits were determined using Pearson bivariate correlation analysis. For participants to be included in the analyses, a minimum of three measurement time points of anthropometrics and PA – including

baseline and 12-months follow-up – was required. Participants included in the analyses also had baseline and 12-month follow-up Three-Factor Eating Questionnaire scores. From the 430 participants at study entry, those retained and those excluded from the analyses were compared in order to assess potential selection bias.

Cross-sectional analyses involved linear-regression via SPSS 22.0 using separate models for each of the three eating traits (i.e. CR, DI and HU). These determined whether baseline weight was associated with higher scores for each eating trait while controlling for sex, race, education and income. In order to determine if PA moderated the relationship between eating traits and weight, average time spent in PA was included along with an interaction term of eating trait  $\times$  PA. Significant interactions were decomposed using model-based estimates of simple slopes, in which the relation between eating traits on change in the dependent variable was estimated separately for participants with high PA (+1 SD above mean PA), low PA (–1 SD below the mean PA), high eating trait score (+1 SD above mean eating trait score) and low eating trait score (–1 SD below the mean eating trait score). Beta estimates, confidence intervals and  $p$  values are presented. To illustrate significant interactions, predicted baseline weight for participants with PA and eating trait scores above/below 1 SD of the mean were plotted.

For longitudinal analyses, individual slope scores for weight change over 12 months (i.e. weight slope) (26) and PA change over 12 months (i.e. PA slope) were computed using up to five quarterly assessments. Linear regression models were calculated to examine if changes in PA slope moderated the relationship between change in eating traits and weight slope. A separate model was constructed for CR, DI and HU, wherein weight slope was regressed on the change score for each eating trait (i.e.  $\Delta$ eating trait). Each model included the main effects of  $\Delta$ eating trait over 12 months, PA slope over 12 months and the interaction of the two terms (i.e.  $\Delta$ eating trait  $\times$  PA slope). The models also included baseline weight, baseline PA and baseline eating trait score as covariates of interest to control for baseline scores. Sex, race, education and income were also included in the models as covariates. Significant interactions were decomposed using model-based estimates of simple slopes, in which the relation between eating traits on change in the dependent variable was estimated separately for participants with high PA (+1 SD above mean PA change), low PA (–1 SD below the mean PA change), high  $\Delta$ eating trait (+1 SD above mean  $\Delta$ eating trait) and low  $\Delta$ eating trait (–1 SD below the mean  $\Delta$ eating trait). Beta estimates, confidence intervals and  $p$  values are presented. To illustrate significant interactions from the previously described linear regression models, predicted 12-month

weight change for participants with PA and eating trait changes above/below 1 SD of mean change were plotted. In seeking the most secure explanation for the findings, separate analyses for each of the cross-sectional and longitudinal models were run – adjusted for body fat percentage within each eating trait score (27). However, the results of these analyses were not substantially different and did not change the interpretation of the data, and are therefore not presented.

## Results

### Preliminary analyses

Participant characteristics are described in Table 1. Of the 430 participants at baseline, the study sample consisted of 270 participants with sufficient data. In comparison to those excluded, the participants included in this analysis were more likely to be Caucasian ( $\chi^2=6.45$ ,  $p=0.04$ ) and had significantly lower baseline HU scores ( $t=-2.34$ ,  $p=0.02$ ). Participants with complete data did not differ from participants with incomplete data for other measured eating traits, PA or body composition.

Mean age was 27.83 years (SD=3.70 years) and 48.90% were female. The average BMI was 25.40 kg/m<sup>2</sup>

(SD=3.89 kg/m<sup>2</sup>), and participants engaged in an average of 131.50 min/day of PA (SD=78.09 min/day). For eating trait scores, participants scored an average CR of 10.43 (SD=4.78), 4.94 (SD=2.81) for DI and 4.79 (SD=3.05) for HU. In addition, baseline DI score was significantly associated with both CR ( $r=0.221$ ,  $p<0.01$ ) and HU ( $r=0.465$ ,  $p<0.01$ ); however, there was no relationship between CR and HU ( $r=-0.021$ ,  $p=0.67$ ).

Means and number of observations for repeatedly measured outcome variables are reported in Table 2. After 12 months, participant weight increased by an average of 1.24 kg (SD=3.83 kg) and PA decreased by an average of 4.93 min/day (SD=50.82 min/day). Following 12-month observation, mean CR, DI and HU scores decreased by 0.53 (SD=3.36), 0.21 (SD=1.86) and 0.29 (SD=2.29), respectively. Participant weight ( $t=5.32$ ,  $p<0.01$ ), CR ( $t=-2.59$ ,  $p=0.01$ ) and HU ( $t=-2.05$ ,  $p=0.04$ ) all changed significantly from baseline, and there was a trend towards significantly lower PA following 12 months ( $t=-1.60$ ,  $p=0.11$ ).

### Cross-sectional analyses

Table 3 describes cross-sectional models estimating the interaction between eating traits and PA on weight.

**Table 1** Baseline means (standard deviations) or percentages for completers and non-completers

Variable	All participants (N = 430)	Complete-data cohort (N = 270)	Partial-data cohort (N = 160)	p-Value
Age	27.66 (3.78)	27.86 (3.69)	27.33 (3.91)	0.16
Weight (kg)	75.07 (13.96)	75.54 (14.04)	74.28 (13.84)	0.37
BMI (kg/m <sup>2</sup> )	25.39 (3.83)	25.40 (3.90)	25.36 (3.71)	0.90
Sex				
Female	50.70%	48.90%	53.80%	0.33
Race				
White	66.50%	66.30%	66.90%	<b>0.04</b>
African American	12.60%	10.00%	16.90%	
Other	20.90%	23.70%	16.30%	
Education				
University diploma or higher	16.00%	17.80%	13.10%	0.12
Less than university Diploma	84.00%	82.20%	86.60%	
Income				
Unknown	0.50%	0.70%	0.00%	0.80
<\$20,000	16.50%	16.30%	16.90%	
\$20,000–\$39,999	34.90%	35.90%	33.10%	
\$40,000–\$59,000	20.00%	19.30%	21.30%	
\$60,000–\$79,000	12.30%	13.00%	11.30%	
>\$80,000	15.80%	14.80%	17.50%	
Three-Factor Eating Questionnaire				
Cognitive restraint	10.30 (4.90)	10.43 (4.78)	10.09 (5.10)	0.48
Disinhibition	5.11 (2.89)	4.94 (2.81)	5.41 (3.00)	0.10
Hunger	5.07 (3.16)	4.79 (3.05)	5.53 (3.28)	<b>0.02</b>
Physical activity (min/day)	135.71 (77.28)	131.50 (78.09)	142.87 (75.59)	0.14

Bold indicates significance at  $p < 0.05$ .

**Table 2** Means (standard Deviations) and number of observations for the repeatedly measured outcome variables for complete cases

Variable	Baseline	3 months	6 months	9 months	12 months	12-month difference <sup>a</sup>
Weight (kg)	75.54 (14.03) N = 270	75.93 (13.96) N = 270	75.75 (14.17) N = 267	76.55 (14.53) N = 266	76.78 (14.54) N = 270	1.24 (3.83)* N = 270
Physical activity (min/day)	131.50 (78.09) N = 270	128.41 (72.91) N = 269	131.03 (78.88) N = 265	124.85 (72.09) N = 266	126.56 (72.27) N = 270	-4.93 (50.82) N = 270
Eating traits (Three-Factor Eating Questionnaire)						
Cognitive restraint	10.43 (4.78) N = 270	—	—	—	9.90 (4.59) N = 270	-0.53 (3.36)* N = 270
Disinhibition	4.94 (2.81) N = 270	—	—	—	4.73 (2.98) N = 270	-0.21 (1.86) N = 270
Hunger	4.79 (3.05) N = 270	—	—	—	4.51 (3.04) N = 274	-0.29 (2.29)* N = 270

<sup>a</sup>12 months - baseline.

\*12-month values significantly different than baseline ( $p < 0.05$ ).

Across all three models, higher PA was associated with lower weight (CR:  $B = -0.087$ ,  $p < 0.01$ ; DI:  $B = -0.083$ ,  $p < 0.01$ ; HU:  $B = -0.089$ ,  $p < 0.001$ ). For the CR model, higher CR was associated with higher weight at baseline ( $B = 0.406$ ,  $p < 0.01$ ); however, PA did not moderate the association between CR and weight.

For the DI model, higher DI was associated with higher weight at baseline ( $B = 0.998$ ,  $p < 0.01$ ), and PA moderated the association between DI and weight ( $B = -0.007$ ,  $p = 0.03$ ). Simple slope analyses revealed that higher baseline DI was associated with higher weight when PA levels were low ( $B = 1.531$ , 95% CI[0.906, 2.155],  $p < 0.01$ ) but not when PA levels were high ( $B = 0.466$ , 95% CI[-0.267, 1.199],  $p = 0.21$ ). This interaction is displayed in Figure 1, which shows that PA attenuates the association between DI and higher baseline weight. Specifically, participants with DI 1 SD above the mean and PA 1 SD below the mean had higher predicted weight (86.03 kg; SE = 1.20); however, participants with DI 1 SD above the mean and PA 1 SD above the mean had lower predicted weight (70.01 kg; SE = 1.58). Finally, HU was not associated with baseline weight; however, there was a marginally significant moderation effect of PA on the relationship of HU and weight such that greater PA attenuated the association between HU and weight ( $B = -0.005$ ,  $p = 0.07$ ).

### Longitudinal analyses

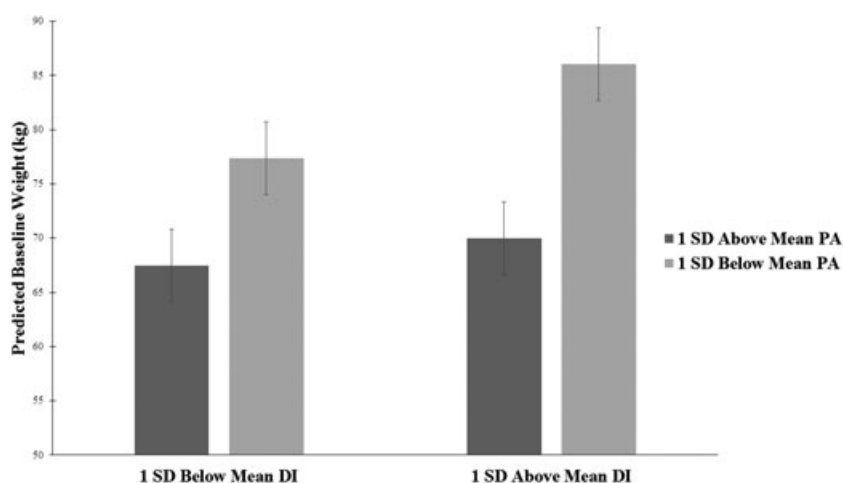
Table 4 describes the longitudinal models estimating the interaction of  $\Delta$ eating traits  $\times$  PA slope on weight change. Across all three models, increases in PA were associated with better maintenance in weight over the 12-month observational period (CR:  $B = -0.027$ ,  $p < 0.01$ ; DI:  $B = -0.023$ ,  $p < 0.01$ ; HU:  $B = -0.026$ ,  $p < 0.01$ ). The model investigating the interaction of  $\Delta$ CR  $\times$  PA slope on weight change found PA slope moderated the relationship between  $\Delta$ CR and weight slope ( $B = 0.004$ ,  $p < 0.01$ ). Simple slope analyses revealed that increased CR was associated with weight maintenance (i.e. preventing weight gain  $>2$  kg per year) when PA levels also increased ( $B = -0.055$ , 95% CI[-0.108, -0.003],  $p = 0.04$ ) but not when PA levels decreased ( $B = 0.04$ , 95% CI[-0.013, 0.095],  $p = 0.14$ ). This interaction effect is illustrated in Figure 2, which shows that the effects of increased CR on weight maintenance were strongest for those individuals who concomitantly increased PA. Specifically, individuals who increased 1 SD above mean PA change and increased 1 SD above mean CR change had predicted weight maintenance (-0.65 kg; SE = 0.50 kg); however, for individuals who decreased 1 SD below mean PA change and increased 1 SD above mean CR change, there was a predicted increase in weight (3.09 kg; SE = 0.50 kg).



**Table 3** Estimates for cross-sectional models on the interaction between eating traits and MVPA on weight

Independent variable	Eating trait								
	Cognitive restraint			Disinhibition			Hunger		
	Estimate	S.E.	Pr  t <	Estimate	S.E.	Pr  t <	Estimate	S.E.	Pr  t <
Intercept	70.558	3.450	< <b>0.01</b>	67.846	3.352	< <b>0.01</b>	69.518	3.470	< <b>0.01</b>
Physical activity (min/day)	-0.087	0.009	< <b>0.01</b>	-0.083	0.009	< <b>0.01</b>	-0.089	0.009	< <b>0.01</b>
Eating trait	0.406	0.143	< <b>0.01</b>	0.998	0.241	< <b>0.01</b>	0.230	0.222	0.30
Interaction of eating trait × physical activity	-0.002	0.002	0.31	-0.007	0.003	<b>0.03</b>	-0.005	0.003	0.07

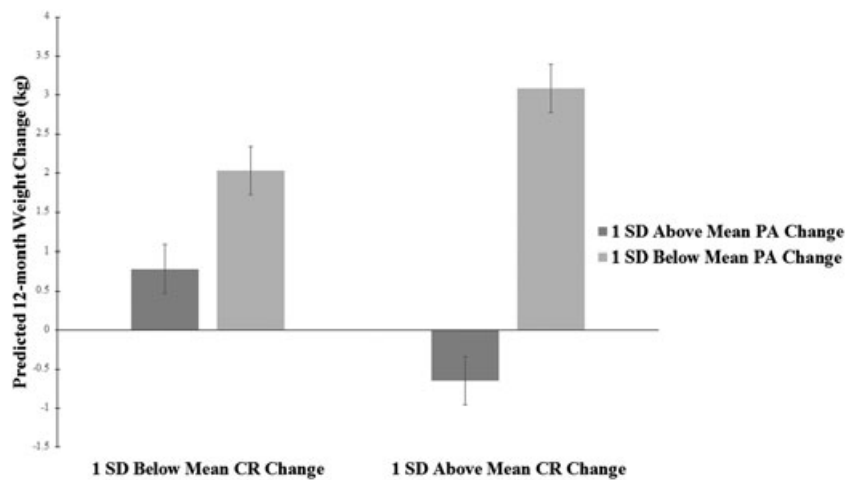
Covariates included: sex, race, education and income.

Bold indicates significance at  $p < 0.05$ .**Figure 1** Graphical display of the interaction between disinhibition (DI) and physical activity (PA) on baseline weight. Predicted baseline weight for participants with PA and disinhibition (DI) above/below 1 SD of mean. Error bars represent standard error. Predicted weight calculated using beta estimates from cross-sectional model.**Table 4** Estimates for longitudinal models on the interaction between  $\Delta$ eating traits × PA slope on weight slope

Independent variable	Changes in eating traits over 12 months								
	Cognitive restraint			Disinhibition			Hunger		
	Estimate	S.E.	Pr  t <	Estimate	S.E.	Pr  t <	Estimate	S.E.	Pr  t <
<i>Model for PA</i>									
Intercept	0.513	0.308	0.10	0.572	0.307	0.06	0.460	0.307	0.14
Physical activity slope (min/day)	-0.027	0.006	< <b>0.01</b>	-0.023	0.006	< <b>0.01</b>	-0.026	0.006	< <b>0.01</b>
$\Delta$ Eating trait**	0.007	0.019	0.70	-0.071	0.032	<b>0.03</b>	-0.030	0.028	0.28
Interaction of $\delta$ eating trait × physical activity slope	0.004	0.002	<b>0.01</b>	-0.004	0.003	0.15	0.002	0.003	0.55

Covariates included: sex, race, education, income, baseline physical activity, baseline weight and baseline eating trait score.

\*\*Baseline – 12 months.



**Figure 2** Graphical display of the interaction between changes in cognitive restraint (CR) and changes in physical activity ( $\Delta$ PA) on weight change over 12 months. Predicted 12-month weight change (12 months – baseline) for participants with PA and CR changes above/below 1 SD of mean change. Error bars represent standard error. Predicted weight change calculated using beta estimates from longitudinal model.

For the model examining the interaction of  $\Delta$ DI  $\times$  PA slope on weight change, decreased DI ( $B = -0.071$ ,  $p = 0.03$ ) was associated with decreased weight slope; however, PA slope did not moderate the relationship between  $\Delta$ DI and weight change. The model investigating the interaction of  $\Delta$ HU  $\times$  PA slope on weight change found no interaction between  $\Delta$ HU and PA slope.

## Discussion

These findings indicate that eating traits – specifically CR and DI – are associated with weight and weight change, and PA moderates the relationships between eating traits and weight. However, the relationships between eating traits, PA and weight appear to be complex and dynamic. The cross-sectional analyses indicate that lower levels of CR and higher levels of DI are associated with higher weight, but the relationship of DI with weight is attenuated by engaging in high levels of PA. Longitudinal analyses indicate that PA amplifies the association of CR with weight change; increases in CR and concomitant increases in PA are associated with better weight maintenance, and decreases in CR and simultaneous decreases in PA are associated with weight gain. In addition, increases in PA and decreases in DI are both associated with weight loss over time, but are independently associated with weight change.

To date, there is limited evidence on whether eating traits and PA might have synergistic effects on weight. Moreover, much of the current literature is composed of either (i) subjectively measured PA data (16,17) or (ii) exercise interventions where exercise dose was controlled, and thus PA was not an outcome of interest (28,29). The current study's use of objective methods to track

changes in body mass and PA, as well as the inclusion of cross-sectional and longitudinal analyses, has helped fill the current literature gap by providing the most complete description of physiological, behavioural and eating trait changes to date.

While this paper adds to the substantial body of evidence detailing the relationship of eating traits with weight change (30,31), it is still unclear how CR, DI and HU affect weight. For instance, recent research paradoxically suggests that dieting significantly predicts future weight gain while CR does not (30). One plausible explanation for this is CR represents a more effective means of preventing weight gain because dieting strategies are often short-lived attempts to prevent future weight gain (10,11). While results on the effectiveness of CR as a predictor of weight maintenance are inconclusive (32–34), the results suggest that PA has a complex and dynamic role in moderating the relationship between CR and weight. Specifically, the cross-sectional analysis suggests that CR is associated with increased weight, but greater PA may attenuate this relationship. In addition, increased CR over time by itself does not significantly impact weight gain, but increasing PA may amplify the impact of CR on weight over time.

A number of studies have also investigated the association of DI with weight loss; however, the effect of DI on weight loss is still unclear (7). Further complicating the matter, it is unclear how the relationship of DI and weight is affected by PA. Some evidence suggests that women with high DI who exercise respond with increased energy intake (28,29); however, few studies have examined this phenomena. Strong evidence also suggests that increasing PA has the potential to improve appetite control by (i) improving the sensitivity of the physiological satiety

signalling system; (ii) adjusting macronutrient preferences and (iii) altering the hedonic response to food (21). As such, PA may aid in weight control by improving the matching of food intake to energy expenditure (22).

Some studies also suggest that PA has a positive influence on high DI score. For example, an acute bout of exercise decreases the motivation to eat and increases preference for low fat foods (35,36). These findings support both independent and interactive effects, depending on the type of analysis in question. Specifically, the cross-sectional results indicate that PA attenuates the association of DI on weight; however, the longitudinal data suggests that DI and PA are independently associated with weight change. Therefore, the evidence suggests that both PA and DI are related to weight management, but PA may have modest impact on the relationship of DI with weight change.

There is some evidence to suggest that HU is associated with weight change – although PA may not affect this relationship. Weight loss intervention studies have shown that losing weight is related to decreases in HU scores (37,38). However, exercise does not significantly alter HU scores, regardless of exercise dose (39). These results further suggest that HU scores are not strongly associated with weight or weight change, and PA does not appear to moderate this relationship.

Collectively, these results suggest that eating traits and PA are dynamically related to weight and weight maintenance. Nothing more can be achieved by an observational design, and thus this is the maximum which can be deduced about a complex situation. The way to untangle these interactions would be a research design in which an identical PA intervention was made in groups of individuals characterized by high, medium or low levels of the traits. There is an urgent need for such a project in order to determine those individuals in whom PA can bring about optimal control of eating (21).

While these results suggest a dynamic relationship of eating traits and PA with weight and weight maintenance, there are several limitations to this study. Importantly, while the present study used a rigorous measure of PA (i.e. the SenseWear Armband) (25), the study population was highly active engaging in an average of 131.50 min/day of PA at baseline. Given that the general population is less active (40), future research should investigate the relationship of eating traits and PA with weight maintenance among individuals with lower PA.

Other limitations to the study bear mentioning. Eating traits were measured at baseline and 12-month follow-up, and therefore this study is unable to determine how eating traits change over shorter periods of time, or whether early changes in eating traits predict later changes in weight or energy-balance behaviours. The

analyses presented did not adjust eating trait scores based on body composition or weight (27); however, when these analyses were performed, there were not any important differences in outcomes, and thus a more parsimonious model is presented. Finally, energy intake data is not included within the analyses because previous research shows that underreporting of dietary intake is a common phenomenon which often makes the values reported biologically implausible (18).

## Conclusion

The results highlight the association of eating traits – most importantly CR and DI – with weight and weight change, and illustrate the dynamic and complex relationships between eating traits, PA and weight. Importantly, the results from the cross-sectional analyses differed from those of the longitudinal analyses in important ways; therefore, it is unclear whether the results of cross-sectional studies extend to longitudinal analysis of change. As such, increases in PA may improve weight maintenance among those who increase CR over time; however, it may also amplify weight gain among individuals who decrease their CR. Furthermore, improved DI and increased PA are independently associated with weight loss over time, but do not interact with one another. The results suggest that optimal weight loss interventions should be designed to concomitantly improve eating traits and PA.

## Conflict of interest statement

RSF has nothing to disclose. CD reports grants from The Coca-Cola Company during the conduct of this study. JEB reports grants from Novo Nordisk and the Almond Board of California, and consultancy fees from General Mills. RPS reports grants from The Coca-Cola Company outside the submitted work. JRB has nothing to disclose. GAH reports grants from The Coca-Cola Company during the conduct of the study and non-financial support from The Coca-Cola Company outside the submitted work. SNB reports grants from The Coca-Cola Company, during the conduct of this study; and gives many lectures each year at scientific meetings, academic institutions and other organizations, outside the submitted work.

## Author contributions

RSF wrote the first draft of the manuscript and performed the statistical analyses. JEB, GAH and SNB conceived the study concept and design. CD, JEB, RPS, JRB,



GAH and SNB all wrote portions of the manuscript and provided critical review.

## Funding

Funding for this project was provided through a grant from The Coca-Cola Company. The sponsor played no role in the study design, collection, analysis and interpretation of data, or preparation and submission of this manuscript.

## References

- Kelly T, Yang W, Chen C-S, et al. Global burden of obesity in 2005 and projections to 2030. *Int J Obes* 2008; **32**(9): 1431–1437.
- Atkinson RL, Dietz WH, Foreyt JP, et al. Towards prevention of obesity: research directions. *Obes Res* 1994; **2**(6): 571–584.
- Falck RS, Best JR, Drenowatz C, et al. Psychosocial Determinants of Weight Loss among Young Adults with Overweight and Obesity: How Does Drive for Thinness Affect Weight Loss? *J Cardiopulm Rehabil Prev*. DOI:10.1097/HCR.0000000000000202
- Hays NP, Bathalon GP, McCrory MA, et al. Eating behavior correlates of adult weight gain and obesity in healthy women aged 55–65 y. *Am J Clin Nutr* 2002; **75**(3): 476–483.
- Drapeau V, Provencher V, Lemieux S, et al. Do 6-y changes in eating behaviors predict changes in body weight? Results from the Quebec Family Study. *Int J Obes* 2003; **27**(7): 808–814.
- Stunkard AJ, Messick S. The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *J Psychosom Res* 1985; **29**(1): 71–83.
- Bryant EJ, King N, Blundell JE. Disinhibition: its effects on appetite and weight regulation. *Obes Rev* 2008; **9**(5): 409–419.
- Lowe MR. The effects of dieting on eating behavior: a three-factor model. *Psychol Bull* 1993; **114**(1): 100–121.
- Bond M, McDowell A, Wilkinson J. The measurement of dietary restraint, disinhibition and hunger: an examination of the factor structure of the Three Factor Eating Questionnaire (TFEQ). *Int J Obes Relat Metab Disord* 2001; **25**(6): 900–906.
- Brownell KD, Greenwood M, Stellar E, et al. The effects of repeated cycles of weight loss and regain in rats. *Physiol Behav* 1986; **38**(4): 459–464.
- Blackburn GL, Wilson GT, Kanders BS, et al. Weight cycling: the experience of human dieters. *Am J Clin Nutr* 1989; **49**(5): 1105–1109.
- Foster G, Wadden T, Swain R, et al. The Eating Inventory in obese women: clinical correlates and relationship to weight loss. *Int J Obes* 1998; **22**(8): 778–785.
- Lindroos AK, Lissner L, Mathiassen ME, et al. Dietary intake in relation to restrained eating, disinhibition, and hunger in obese and nonobese Swedish women. *Obes Res* 1997; **5**(3): 175–182.
- Lluch A, Herbeth B, Mejean L, et al. Dietary intakes, eating style and overweight in the Stanislas Family Study. *Int J Obes* 2000; **24**(11): 1493–1499.
- Beiseigel JM, Nickols-Richardson SM. Cognitive eating restraint scores are associated with body fatness but not with other measures of dieting in women. *Appetite* 2004; **43**(1): 47–53.
- Provencher V, Drapeau V, Tremblay A, et al. Eating behaviors and indexes of body composition in men and women from the Quebec family study. *Obes Res* 2003; **11**(6): 783–792.
- McGuire M, Jeffery R, French S, et al. The relationship between restraint and weight and weight-related behaviors among individuals in a community weight gain prevention trial. *Int J Obes Relat Metab Disord* 2001; **25**: 574–580.
- Archer E, Hand GA, Blair SN. Validity of US nutritional surveillance: National Health and Nutrition Examination Survey caloric energy intake data, 1971–2010. *PLoS ONE* 2013; **8**(10): e76632.
- Warren JM, Ekelund U, Besson H, et al. Assessment of physical activity - a review of methodologies with reference to epidemiological research: a report of the exercise physiology section of the European Association of Cardiovascular Prevention and Rehabilitation. *Eur J Cardiovasc Prev Rehabil* 2010; **17**(2): 127–139.
- Physical Activity Guidelines Advisory Committee: *Physical Activity Guidelines Advisory Committee Report* p. Washington, DC: U.S. Department of Health and Human Services, 2008.
- Blundell JE, Stubbs RJ, Hughes DA, et al. Cross talk between physical activity and appetite control: does physical activity stimulate appetite? *Proc Nutr Soc* 2003; **62**(3): 651–661.
- Blundell JE, King NA. Physical activity and regulation of food intake: current evidence. *Med Sci Sports Exerc* 1999; **31**(11 Suppl): S573–S583.
- Falck RS, Shook RP, Hand GA, Lavie CJ, Blair SN. Extremes of weight gain and weight loss with detailed assessments of energy balance: Illustrative case studies and clinical recommendations. *Postgrad Med* 2014; **127**(3): 282–288.
- Hand GA, Shook RP, Paluch AE, et al. The energy balance study: the design and baseline results for a longitudinal study of energy balance. *Res Q Exerc Sport* 2013; **84**(3): 275–286.
- Welk GJ, McClain JJ, Eisenmann JC, et al. Field validation of the MTI Actigraph and BodyMedia armband monitor using the IDEEA monitor. *Obesity* 2007; **15**(4): 918–928.
- Rogosa D, Saner H. Longitudinal data analysis examples with random coefficient models. *J Educ Behav Stat* 1995; **20**(2): 149–170.
- Kruger R, De Bray JG, Beck KL, et al. Exploring the Relationship between Body Composition and Eating Behavior Using the Three Factor Eating Questionnaire (TFEQ) in Young New Zealand Women. *Nutrients* 2016; **8**(7): 386.
- Visona C, George VA. Impact of dieting status and dietary restraint on postexercise energy intake in overweight women. *Obes Res* 2002; **10**(12): 1251–1258.
- Keim NL, Cauty DJ, Barbieri TF, et al. Effect of exercise and dietary restraint on energy intake of reduced-obese women. *Appetite* 1996; **26**(1): 55–70.
- Lowe MR, Doshi SD, Katterman SN, et al. Dieting and restrained eating as prospective predictors of weight gain. *Front Psychol* 2013; **4**(557.10): 3398.
- Kral TV. Eating Behaviors and Weight Development in Obesity-Prone Children and the Importance of the Research of Albert J. Stunkard. *Curr Obes Rep* 2016; **5**(1): 126–131.
- de Lauzon-Guillain B, Basdevant A, Romon M, et al. Is restrained eating a risk factor for weight gain in a general population? *Am J Clin Nutr* 2006; **83**(1): 132–138.
- Carr KA, Lin H, Fletcher KD, et al. Food reinforcement, dietary disinhibition and weight gain in nonobese adults. *Obesity* 2014; **22**(1): 254–259.
- McGuire M, Jeffery R, French S, et al. The relationship between restraint and weight and weight-related behaviors among individuals in a community weight gain prevention trial. *Int J Obes Relat Metab Disord* 2001; **25**(4): 574–580.
- Bryant E, King N, Blundell J. Effect of exercise on appetite control in women with high trait disinhibition. *Appetite* 2005; **45**: 363.

36. Bryant E, Finlayson G, King N, et al. The influence of acute exercise on liking and preference for food on high trait Disinhibition women. *Obes Rev* 2006; **7**(Suppl 2): 343.
37. Cuntz U, Leibbrand R, Ehrig C, et al. Predictors of post-treatment weight reduction after in-patient behavioral therapy. *Int J Obes Relat Metab Disord* 2001; **25**: S99–S101.
38. Clark MM, Marcus BH, Pera V, et al. Changes in eating inventory scores following obesity treatment. *Int J Eat Disord* 1994; **15**(4): 401–405.
39. Fogelholm M, Kukkonen-Harjula K, Oja P. Eating control and physical activity as determinants of short-term weight maintenance after a very-low-calorie diet among obese women. *Int J Obes Relat Metab Disord* 1999; **23**(2): 203–210.
40. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc* 2008; **40**(1): 181–188.