

# Role of Eating Behavior and Stress in Maintenance of Dietary Changes During the PREVIEW Intervention

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## ABSTRACT

**Objective:** To examine whether eating behavior and perceived stress predict the maintenance of self-reported dietary change and adherence to dietary instructions during an intervention.

**Design:** A secondary analysis of the behavior maintenance stage (6–36 months) of the 3-year PREVIEW intervention (PREvention of diabetes through lifestyle Intervention and population studies in Europe and around the World).

**Participants:** Adults (n = 1,311) with overweight and prediabetes at preintervention baseline.

**Variables Measured:** Eating behavior (Three-Factor Eating Questionnaire), stress (Perceived Stress Scale), and dietary intake (4-day food records on 4 occasions) were reported.

**Analysis:** Associations between predictors and dietary outcomes were examined with linear mixed-effects models for repeated measurements.

**Results:** Eating behaviors and stress at 6 months did not predict the subsequent change in dietary outcomes, but higher cognitive restraint predicted lower energy intake, and both higher disinhibition and hunger predicted higher energy intake during the following behavior maintenance stage. In addition, higher disinhibition predicted higher saturated fat intake and lower fiber intake, and higher hunger predicted lower fiber intake. Stress was not associated with energy intake or dietary quality. Eating behaviors and stress were not consistently associated with adherence to dietary instructions.

**Conclusions and Implications:** Higher cognitive restraint predicted lower energy intake (food quantity), but disinhibition and hunger were also associated with dietary quality.

**Key Words:** Eating Inventory, eating style, behavior change, behavior maintenance, food consumption (*J Nutr Educ Behav*. 2024;000:1–10.)

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## INTRODUCTION

Behavioral interventions for the treatment of obesity target changes in diet and physical activity, but the final goal is weight loss, and the success of the intervention is also defined through weight loss. Although short/medium-term behavioral interventions may be successful in that regard,<sup>1</sup> the long-term maintenance of weight loss is notoriously difficult.<sup>2</sup> This is a consequence of decreased adherence to dietary (and physical activity) changes over time.<sup>3</sup> More information about the factors predicting maintenance of desired dietary changes is required to support individuals achieving sustained behavioral changes, which are also essential for long-lasting weight control. Furthermore, changing the focus from weight loss to behavioral changes and targeting well-being may be more motivating for participants.<sup>4</sup> The underlying reason for conducting weight loss interventions is to promote health instead of just reducing weight, and it can be at least partly achieved by changing behavior toward a healthier direction.<sup>5</sup>

Eating behavior dimensions, such as cognitive restraint of eating, disinhibition, and hunger, measured by the Three-Factor Eating Questionnaire (TFEQ),<sup>6</sup> influence choices related to food and eating.<sup>7</sup> These include decisions about the amount and type of food eaten along with eating frequency. In the context of behavioral interventions, eating behaviors have been mainly examined

as predictors of weight change. There is consistent evidence that in behavioral interventions, an increase in cognitive restraint, together with decreases in both disinhibition and hunger, are associated with greater weight loss and weight loss maintenance.<sup>8–12</sup>

The association between eating behaviors and weight changes during interventions might be explained by changes in dietary intake, but to date, this hypothesis has not been studied extensively. Cognitive restraint, by definition, refers to an intention to restrict energy intake and food consumption.<sup>6</sup> Two earlier intervention studies suggested that an increase in cognitive restraint was associated with decreased energy intake,<sup>13,14</sup> and increased contribution to energy intake from carbohydrates and protein, and decreased contribution from fat and sweets.<sup>13</sup> An association between higher cognitive restraint and lower energy intake,<sup>15,16</sup> as well as higher consumption of certain healthy food groups (eg, vegetables and fish) and lower consumption of sugar and confectionery<sup>17</sup> has also been reported in cross-sectional observational studies. Both disinhibition and hunger, by definition, refer to tendencies to overeat in response to certain stimuli (external and emotional cues and perceived hunger, respectively).<sup>6</sup> Positive cross-sectional associations between disinhibition and hunger and energy intake have been reported.<sup>15</sup>

Maintenance of behavioral changes can be considered a demanding cognitive task, at least before they have

turned into automatized habits.<sup>18,19</sup> Any factor implying additional cognitive demands on an individual may thus hinder the process of maintenance. Stress is one such factor, and we have previously shown that perceived stress was related to increased disinhibition and hunger, which in turn were associated with less successful weight loss maintenance.<sup>20</sup> Stress is also associated with food consumption in healthy adults,<sup>21</sup> but to our knowledge, less is known about the relevance of stress in the context of dietary weight loss maintenance interventions.

This study focused on the long-term maintenance of changed dietary behavior. To explore this issue, we used the data from the 3-year PREVIEW intervention (PREvention of diabetes through lifestyle Intervention and population studies in Europe and around the World), which was originally designed to test the effects of 2 diets differing in protein and carbohydrate intake and glycemic index (GI) and 2 physical activity programs with differing intensities on type 2 diabetes prevention and weight loss maintenance.<sup>22</sup> In intervention studies, the greatest behavioral and weight changes have been reported at 6 months,<sup>23</sup> and this was also the case in the PREVIEW intervention.<sup>24</sup> Hence, in this study, we focused on the maintenance of dietary changes from 6 months to 3 years.

Specifically, this study examined whether eating behaviors and perceived stress at 6 months predicted subsequent maintenance of selected dietary outcomes. We hypothesized

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*Conflict of Interest Disclosure:* Jennie Brand-Miller is President and Director of the Glycemic Index Foundation, oversees a glycemic index testing service at the University of Sydney and is a co-author of books about diet and diabetes. She is also on the Scientific Advisory Board of Novo Foundation and of Zoe Global P/L and consults to China National Research Institute of Food and Fermentation Industries. During this project Sally Poppit was the Fonterra Chair in Human Nutrition and Principle Investigator for NZ National Science Challenge High Value Nutrition. Anne Raben has received honorariums from Nestlé A/S, the International Sweeteners Association, and Unilever. All other authors declare no conflicts of interest.

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that higher cognitive restraint would predict better maintenance of lower energy intake and improved quality of the diet, whereas higher disinhibition, hunger, and perceived stress would predict relapse of these factors. Furthermore, we analyzed whether eating behavior and perceived stress predicted protein and carbohydrate intakes differently depending on the prescribed study diet. In other words, whether eating behaviors and stress were associated with adherence to the dietary instructions. For example, we hypothesized that higher cognitive restraint would be associated with higher protein intake in the high-protein diet and lower protein intake in the moderate-protein diet.

## METHODS

### Study Design, Participants, and Recruitment

The methods<sup>22</sup> and main results<sup>24</sup> of the PREVIEW Intervention (ClinicalTrials.gov, NCT01777893) have been reported in detail previously. Participants were recruited using media advertising and through health care providers. The main inclusion criteria were participants aged 25–70 years, with a body mass index (BMI)  $\geq 25$  kg/m<sup>2</sup>, and prediabetes according to the criteria of the American Diabetes Association.<sup>25</sup> Potentially eligible volunteers were prescreened via telephone and invited to a laboratory screening visit to confirm eligibility on the basis of a full list of inclusion and exclusion criteria published previously.<sup>22</sup> Out of a total of 2,326 individuals confirmed eligible for inclusion during the screening visit, 2,223 individuals participated in the baseline visit and started the study between June 2013 and April 2015 (Supplementary Figure 1). Furthermore, 1,857 participants (84% of those who started the intervention) completed the weight loss phase and were eligible to proceed to the weight maintenance phase. Because the focus of this study was on long-term weight maintenance, the analytical sample included 1,311 participants (59%) who attended at least 1 study visit after 6 months. Data collection methods were consistent in all 8 participating countries: Denmark, Finland, the Netherlands, the United

Kingdom, Spain, Bulgaria, Australia, and New Zealand. At each of the intervention centers, the local Human Ethics Committee approved the study protocol, and participants provided written informed consent before the screening visit.

The total duration of the intervention was 3 years, divided into 2 phases (Supplementary Figure 2)—a 2-month low-energy–diet period aiming for at least 8% weight loss and a subsequent weight maintenance period for those participants who succeeded in the weight loss aim. The intervention diets were (1) moderate-protein, moderate-GI diet (MP) aiming at 15% energy from protein, 55% energy from carbohydrate, and GI  $> 56$ ; and (2) high-protein, low-GI diet (HP) aiming at 25% energy from protein, 45% energy from carbohydrate, and GI  $< 50$ . Both diets were moderate in fat (30% of energy). Both diets were consumed ad libitum with respect to energy, but participants received guidance in controlling portion sizes of specific food types to achieve the macronutrient and GI targets. In addition, the aim was to maintain the reduced body weight while also permitting further weight loss. The 2 physical activity programs targeted a similar weekly energy expenditure, but 1 group was prescribed 75 minutes of high-intensity exercise and the other 150 minutes of moderate-intensity exercise weekly. However, according to accelerometer data, there was no difference in total physical activity (assessed as counts per minute) between the groups.<sup>24</sup> Therefore, physical activity grouping was not considered in this analysis.

To support the behavior change, a theory- and evidence-based PREVIEW Behavior Modification Intervention Toolbox was designed.<sup>26</sup> The behavioral program as part of the intervention consisted of 2 phases: a 6-month active behavior change followed by a 2.5-year behavior maintenance stage (Supplementary Figure 2). The behavioral intervention was group-based and delivered as group sessions (17 visits in total). It was assumed that the biggest changes in behavior would be achieved during the first 6 months when learning new skills was supported with frequent group visits.

Toward the end of the study, the frequency of the visits decreased, resulting in 7 group visits during the behavior maintenance stage.

## Measures

*Eating behavior and perceived stress.* Eating behavior dimensions and perceived stress were assessed at baseline and the beginning of the behavior maintenance stage (at 6 months) with widely used and validated psychometric questionnaires. The self-administered questionnaires were completed through a computer platform during the study clinic visit.

The 51-item TFEQ was used to measure the 3 dimensions of eating behavior: cognitive restraint of eating, disinhibition, and hunger.<sup>6</sup> The total score for each dimension was calculated. Higher scores for all scales indicated a higher tendency toward each of the eating behaviors. Cronbach  $\alpha$  was 0.74, 0.78, and 0.81 for cognitive restraint, disinhibition, and hunger, respectively.

The 10-item Perceived Stress Scale was used to measure perceived stress.<sup>27</sup> Summary scores (higher scores indicating higher perceived stress) for items rated from 0 (never) to 4 (very often) were calculated. Cronbach  $\alpha$  was 0.84.

*Dietary intake and selected outcomes.* Dietary intake was assessed using 4-day food records covering 4 consecutive days, including 1 weekend day. All foods and drinks consumed during those 4 days were recorded in detail using weighing scales or conventional household measures. Records were completed before study clinic visits at baseline, 6, 12, 24, and 36 months. During the study clinic visit, a trained researcher checked the records together with the participants to ensure completeness.

Food record data was coded at each study site using local nutrient analysis software (ie, Dankost Pro [Denmark], AivoDiet [Finland], Mijn Eetmeter [the Netherlands], Nutritics [UK], Dial [Spain], Nutrition Calculation [Bulgaria], and Foodworks [Australia and New Zealand]), and nutrient and energy intakes were calculated using national food

composition databases. The mean of 4 days was calculated to achieve an average daily intake at each time point.

To limit the number of dietary outcomes, we selected those that were potentially associated with eating behaviors and weight control, served as indicators of overall dietary quality, or were related to adherence to dietary instructions. Selected nutrient intake outcomes were as follows: energy intake (MJ/d) as an indicator of the amount of food eaten, thus related to energy balance and weight control. Saturated fat as a proportion of total fat ([intake of saturated fat/total intake of fat]  $\times$  100%) and intake of fiber (g/MJ) as indicators of the quality of the diet. Intake of protein and carbohydrates (as percentages of total energy) as markers of adherence to dietary instructions. Finally, total fat intake (% of total energy) was also included because of completeness regarding macronutrients.

In addition to nutrient intake, the consumption of vegetables and sugary products (g/MJ) was included, as eating behaviors may be more strongly linked with food choice than nutrient intake.<sup>28</sup> Vegetable consumption was selected as an indicator of the quality of the diet, and sugary products were chosen because they were hypothesized on the basis of earlier studies to be associated with eating behavior.<sup>13,17</sup> Because of constraints related to nutrient analysis software used across sites, food consumption data (grams per day) was only available from a subset of study centers (Finland, the United Kingdom, Spain, and Bulgaria;  $n = 655$ ). Consumption of vegetables included leafy vegetables, dried vegetables, mushrooms, pickles/chutney, roots/tubers/bulbs, sea vegetables/algae, vegetable dishes, other vegetables, avocado, pulses, beans, peas, lentils, and soy foods. Consumption of sugary products included table sugar, sweets (candy), honey, sugar products, chocolate, chocolate confectionery, nonchocolate confectionery, ice creams, added sugars, sweet pastries, sweet cakes, and other simple-sugar-rich products.

Adherence to dietary instruction was estimated on the basis of protein

and carbohydrate intakes. Both diets had specific intake targets, but the protein intake target in the HP group and both protein and carbohydrate intake targets in the MP group were generally not achieved during the intervention.<sup>24</sup> Hence, no cutoffs were applied for too high protein intake and too low carbohydrate intake in the HP group or too low protein intake and too high carbohydrate intake in the MP group. Adherence to dietary instructions was thus estimated on the basis of associations with continuous variables, and lower or higher intakes indicated better adherence depending on the variable and diet group in question.

The self-reported intake of energy and macronutrients, as well as changes during the intervention, have been previously reported along with the main results.<sup>24</sup> However, for the sake of comprehension, the changes in all selected dietary outcomes are included ([Supplementary Figure 3](#)). The study diets were aimed to be similar with respect to all selected dietary outcomes, except protein and carbohydrate intakes. We wanted to confirm the success of this aim and explore the differences in dietary changes between the study diets. The changes in energy, macronutrients, and fiber during the whole intervention period (baseline to 36 months) differed between the diets (significant diet  $\times$  time interactions in mixed models), but during the behavior maintenance stage (6–36 months), only changes in intakes of protein and carbohydrate differed as intended. Hence, analyses of other dietary outcomes were performed using the whole sample (diet groups merged).

Food records are prone to certain reporting errors, such as underreporting and reactivity, which means that the process of keeping the records affects eating.<sup>29</sup> Reporting errors may also be related to eating behaviors, especially cognitive restraint.<sup>30</sup> Hence, we also included protein intake, which was objectively estimated via 24-hour urinary nitrogen or urea. Urine samples were collected during the day before each study clinic visit at baseline, 6, 12, 24, and 36 months. The total volume of the 24-hour urine was recorded, and the

collection of  $< 0.5$  L was regarded as incomplete. Estimated protein intake (grams per day) was calculated with the following formula:  $6.25 \times 24$ -hour urinary nitrogen (grams per day)  $\times 1.1$ .<sup>24,25</sup> A multiplication factor of 1.1 was applied to correct for nitrogen loss in feces. The conversion factor of 0.4664 was used to convert measured urea to nitrogen.

## Data Analysis

The changes in selected dietary outcomes were analyzed using linear mixed-effects models with maximum likelihood estimation. Main effects were used to analyze whether the eating behaviors and perceived stress (predictors) at 6 months predicted overall levels of dietary outcomes during the maintenance stage (6–36 months). The interaction term for predictor  $\times$  time was added to analyze whether each predictor was associated with subsequent changes in dietary intake. Nonsignificant interaction terms were omitted from the final reported models. The models were adjusted for potential confounding factors, age at the time of enrollment (in years), sex, intervention diet, time-varying BMI (measured at 6, 12, 24, and 36 months), and baseline (0 months) predictor and outcome as fixed effects and participant ID and intervention center as random effects.

The mixed-effects models included all available data from all participants present at each time point, regardless of later dropout, which is an effective way of handling the missing data.<sup>31</sup> The number of valid observations for each variable and time point was reported in [Supplementary Table 1](#). When protein and carbohydrate intakes were analyzed as outcomes, models were additionally adjusted for three-way predictor  $\times$  time  $\times$  diet interaction (including also all two-way interactions). The results of mixed models are reported as unstandardized  $\beta$  estimates (B) and 95% confidence interval (CI).

Statistical analyses were conducted using the R software (version 4.0.3, R Core Team, 2022) with R Studio. Package lme4 was used to perform linear mixed-effects analyses,<sup>32</sup> and package lmerTest was used to obtain  $P$  values for fixed effects.<sup>33</sup> The threshold for

**Table 1.** Basic Characteristics and Eating Behaviors of the PREVIEW Sample<sup>a</sup> (n = 1,311)

Variables	Mean ± SD or n (%)	Missing Information, n (%)
Baseline		
Sex		0
Women	857 (65)	
Men	454 (35)	
Age (y)	54 ± 10	0
BMI (kg/m <sup>2</sup> )	34.4 ± 5.7	0
Ethnic minorities <sup>b</sup>	98 (7)	33 (3)
Education		33 (3)
Up to secondary	199 (15)	
Secondary vocational	224 (17)	
Higher vocational	244 (19)	
University	496 (38)	
Other	115 (9)	
Employment status		29 (2)
In paid work	802 (61)	
Retired	260 (20)	
Other <sup>c</sup>	220 (17)	
6 mo		
Cognitive restraint <sup>d</sup>	13.8 ± 3.6	152 (12)
Disinhibition <sup>d</sup>	7.2 ± 3.4	137 (10)
Hunger <sup>d</sup>	4.9 ± 3.5	145 (11)
Perceived stress <sup>e</sup>	13.3 ± 6.3	102 (8)

BMI indicates body mass index; PREVIEW, PREvention of diabetes through lifestyle Intervention and population studies in Europe and around the World.

<sup>a</sup>Participants included in the present sample attended at least 1 follow-up visit after 6 mo; <sup>b</sup>Participant self-reported belonging to a minority ethnic group in their resident country (Denmark, Finland, Netherlands, United Kingdom, Spain, Bulgaria, Australia, or New Zealand); <sup>c</sup>Includes for example full-time students, unemployed, permanently sick or disabled, and participants caring for home/family; <sup>d</sup>Measured with Three-Factor Eating Questionnaire; <sup>e</sup>Measured with Perceived Stress Scale.

statistical significance was set at  $P < 0.05$ . This threshold was corrected for multiple comparisons according to the Bonferroni method by dividing it by the number of tests. Nutrient intake and food consumption outcomes were considered as different sets of tests because of different measurement levels and sample sizes. This resulted in adjusted significance levels,  $P < 0.002$  for nutrient intake outcomes (24 tests) and  $P < 0.006$  for food consumption (8 tests). Additional analyses stratified by diet group and considering absolute protein intake measured with different methods were also considered as different sets of tests.

## RESULTS

The participants (65% women) included in the present sample (n = 1,311) were, on average, aged 54 ± 10 years and had a mean BMI of 34.4 ± 5.7 kg/m<sup>2</sup> (Table 1). As expected, the mean change in all selected dietary

behaviors was greatest during the first 6 months (Supplementary Figure 3). During the behavior maintenance stage (after 6 months), on average, the achieved changes were maintained in many parameters, or there were gradual relapses toward baseline levels.

Neither eating behaviors nor perceived stress at 6 months predicted the subsequent changes in dietary outcomes (nonsignificant predictor × time interactions in mixed models, Table 2). However, eating behaviors were associated with overall levels of nutrient intake during the behavior maintenance stage (significant main effects in the mixed models, Table 2). Higher cognitive restraint predicted lower energy intake, whereas higher disinhibition and higher hunger predicted higher energy intake (all  $P < 0.001$ ). In addition, higher disinhibition was associated with higher total fat intake and saturated fat as a proportion of total fat and lower fiber intake (all  $P < 0.001$ ). Higher hunger was associated with

higher total fat intake and lower fiber intake (both  $P < 0.001$ ). Although the associations between total restraint and indicators of the quality of the diet were not significant after correcting for multiple testing, there was still a clear pattern toward an association between higher cognitive restraint and better dietary quality (lower saturated fat as a proportion of total fat and higher fiber intake). At a food group level, there were no associations between eating behaviors or perceived stress and the outcomes (vegetable or sugary products consumption).

Eating behavior or perceived stress were not clearly associated with adherence to dietary instructions, as measured by protein and carbohydrate intakes. In the whole sample, cognitive restraint predicted overall higher protein intake during the behavior maintenance stage (Table 3). In contrast, higher disinhibition and higher perceived stress predicted lower protein intake (both  $P < 0.001$ ). The

**Table 2.** Eating Behaviors and Stress at 6 Months as Predictors of Dietary Outcomes During the Behavior Maintenance Stage of the PREVIEW Intervention

Variables	Energy Intake <sup>a</sup> (MJ/day)		Fat Intake <sup>a</sup> (% of Total Energy)		Saturated Fat Intake (% of Total Fat) <sup>a</sup>		Fiber Intake <sup>a</sup> (g/MJ)		Vegetable Consumption <sup>b</sup> (g/MJ)		Sugary Products Consumption <sup>b</sup> (g/MJ)	
	B (95% CI)	P	B (95% CI)	P	B (95% CI)	P	B (95% CI)	P	B (95% CI)	P	B (95% CI)	P
Cognitive restraint	-0.10 (-0.13 to -0.07)	< 0.001*	-0.10 (-0.19 to -0.005)	0.04	-0.12 (-0.21 to -0.03)	0.01	0.02 (0.01-0.04)	0.002	0.75 (0.19-1.31)	0.01	0.10 (-0.12 to 0.32)	0.37
Predictor × time		0.59		0.03		0.15		0.63		0.76		0.50
Disinhibition	0.10 (0.07-0.14)	< 0.001*	0.21 (0.09-0.33)	< 0.001*	0.19 (0.08-0.30)	< 0.001*	-0.04 (-0.06 to -0.02)	< 0.001*	-0.30 (-1.01 to 0.41)	0.41	0.001 (-0.28 to 0.28)	0.99
Predictor × time		0.42		0.38		0.03		0.50		0.17		0.14
Hunger	0.09 (0.06-0.12)	< 0.001*	0.21 (0.10-0.32)	< 0.001*	0.12 (0.01-0.22)	0.03	-0.03 (-0.04 to -0.01)	< 0.001*	-0.43 (-1.08 to 0.22)	0.20	0.09 (-0.17 to 0.35)	0.49
Predictor × time		0.10		0.31		0.39		0.35		0.35		0.73
Perceived stress	0.03 (0.01-0.04)	0.01	0.02 (-0.04 to 0.08)	0.46	0.06 (-0.0004 to 0.11)	0.05	-0.01 (-0.02 to 0.001)	0.07	-0.10 (-0.49 to 0.29)	0.62	0.09 (-0.05 to 0.23)	0.23
Predictor × time		0.17		0.13		0.37		0.68		0.67		0.73

B indicates unstandardized  $\beta$  estimates; BMI, body mass index; CI, confidence interval; MJ, megajoule; PREVIEW, PREvention of diabetes through lifestyle Intervention and population studies in Europe and around the World.

<sup>a</sup>Number of participants included in the model varies between 939 and 1,011, depending on the availability of the data; <sup>b</sup>Food consumption was available from a subset of participants (4 study centers included Finland, United Kingdom, Spain, and Bulgaria). The number of participants included in the model varies between 421 and 479, depending on the availability of the data. Consumption of vegetables included leafy vegetables, dried vegetables, mushrooms, pickles/chutney, roots/tubers/bulbs, sea vegetables/algae, vegetable dishes, other vegetables, avocado, pulses, beans, peas, lentils, and soy foods. Consumption of sugary products included table sugar, sweets (candy), honey, sugar products, chocolate, chocolate confectionery, nonchocolate confectionery, ice creams, added sugars, sweet pastries, sweet cakes, and other simple-sugar-rich products.

\*Indicates significant results when corrected for multiple testing according to the Bonferroni method ( $P < 0.002$  for nutrient intakes and  $P < 0.006$  for food consumption).

Note: B and 95% CI determined from linear mixed-effects models with maximum likelihood estimation adjusted for age, sex, diet (high-protein, low-glycemic index vs medium-protein, medium-glycemic index), time-varying BMI, and baseline (0 mo) predictor and outcome as fixed effects; participant ID and intervention center as random effects; and predictor × time interaction. Because all interactions were nonsignificant, the reported main effects are from the models without an interaction term. Outcomes were measured 4 times during the behavior maintenance stage (6-36 mo) using 4-d food records.

**Table 3.** Eating Behaviors and Perceived Stress at 6 Months as Predictors of Protein and Carbohydrate Intakes During the Behavior Maintenance Stage of the PREVIEW Intervention

Variables	Protein Intake (% of Total Energy)		Carbohydrate Intake (% of Total Energy)	
	B (95% CI)	P	B (95% CI)	P
Cognitive restraint	0.12 (0.06–0.18)	< 0.001*	0.02 (–0.09 to 0.12)	0.75
Predictor × time		0.13		0.07
Predictor × diet		0.94		0.86
Predictor × time × diet		0.68		0.14
Disinhibition	–0.16 (–0.24 to –0.08)	< 0.001*	–0.10 (–0.23 to 0.03)	0.12
Predictor × time		0.59		0.18
Predictor × diet		0.89		0.84
Predictor × time × diet		0.12		0.04
Hunger	–0.11 (–0.18 to –0.03)	0.01	–0.07 (–0.19 to 0.05)	0.25
Predictor × time		0.64		0.45
Predictor × diet		0.42		0.81
Predictor × time × diet		0.09		0.15
Perceived stress	–0.07 (–0.11 to –0.03)	< 0.001*	0.02 (–0.05 to 0.09)	0.57
Predictor × time		0.15		0.49
Predictor × diet		0.44		0.61
Predictor × time × diet		0.32		0.54

B indicates unstandardized  $\beta$  estimates; CI, confidence interval; PREVIEW, PREvention of diabetes through lifestyle Intervention and population studies in Europe and around the World.

\*Indicates significant results when corrected for multiple testing according to the Bonferroni method ( $P < 0.002$ ).

Note: B and 95% CI are from linear mixed-effects models with maximum likelihood estimation adjusted for age, sex, diet (high-protein, low-glycemic index vs medium-protein, medium-glycemic index), time-varying BMI, and baseline (0 mo) predictor and outcome as fixed effects; participant ID and intervention center as random effects; and predictor × diet × time interaction. Because all 3-way interaction terms were nonsignificant, 2-way interactions ([predictor × time]/[predictor × diet]) are from the models including only the interaction term in question. Similarly, because all 2-way interaction terms were nonsignificant, the reported main effects are from the models without interaction terms. Outcomes were measured 4 times during the behavior maintenance stage (6–36 mo) using 4-d food records. The number of participants included in the models varies between 939 and 1,011, depending on the availability of the data.

3-way (predictor × diet × time) and 2-way ([predictor × diet] and [predictor × time]) interactions were nonsignificant, indicating no differences in these associations between the diet groups. However, to answer our research question, we proceeded to diet-stratified analyses, which confirmed no notable differences between the diet groups (Supplementary Table 2).

In contrast to protein intake, eating behaviors or stress were not associated with carbohydrate intake in the whole sample (Table 3). Similar to protein intake, the interactions were not significant, but we proceeded to stratified analyses, which indicated some differences between the diet groups (Table 4). Cognitive restraint or perceived stress did not predict carbohydrate intake in either of the groups. However, results for disinhibition and hunger showed some differences. In the HP group, disinhibition and hunger did not predict

carbohydrate intake, but in the MP group, they were associated with lower carbohydrate intake, though these associations were not significant after correcting for multiple testing.

Results comparing self-reported and objectively estimated protein intake (grams per day) are presented in Supplementary Table 3. Higher cognitive restraint at 6 months was associated with overall lower self-reported protein intake as grams per day during the behavior maintenance stage ( $P < 0.001$ ). Higher hunger, in contrast, was associated with overall higher protein intake ( $P < 0.001$ ). When objectively estimated protein intake was analyzed as an outcome, there were no significant associations with eating behaviors. Stress was not associated with either of the protein intake variables. Additional adjustments for height to control for different energy/protein

requirements did not affect the results.

## DISCUSSION

This analysis within a large multinational intervention study revealed that eating behaviors measured at the beginning of a behavior maintenance stage predicted the overall levels of selected dietary outcomes during the following 2.5 years. Higher cognitive restraint predicted lower self-reported energy intake, whereas higher disinhibition and higher hunger both predicted higher energy intake. In addition, higher disinhibition and higher hunger predicted lower quality of the diet as measured by saturated fat as a proportion of total fat (associated with disinhibition only) and fiber intake. Perceived stress was not associated with self-reported energy intake or

**Table 4.** Eating Behaviors and Perceived Stress at 6 Months as Predictors of Carbohydrate Intake by Study Diet During the Behavior Maintenance Stage of the PREVIEW Intervention

Variables	Carbohydrate Intake (% of Total Energy)			
	High-Protein Diet <sup>a</sup>		Moderate-Protein Diet <sup>b</sup>	
	B (95% CI)	P	B (95% CI)	P
Cognitive restraint	−0.02 (−0.16 to 0.13)	0.81	0.06 (−0.10 to 0.21)	0.47
Predictor × time		0.91		0.02
Disinhibition	−0.03 (−0.20 to 0.14)	0.73	−0.22 (−0.41 to −0.02)	0.03
Predictor × time		0.56		0.02
Hunger	0.01 (−0.15 to 0.18)	0.87	−0.21 (−0.39 to −0.03)	0.02
Predictor × time		0.54		0.15
Perceived stress	0.02 (−0.07 to 0.11)	0.71	0.02 (−0.08 to 0.12)	0.66
Predictor × time		0.32		0.85

B indicates unstandardized  $\beta$  estimates; CI, confidence interval; PREVIEW, PREvention of diabetes through lifestyle Intervention and population studies in Europe and around the World.

\* Indicates significant results when corrected for multiple testing according to the Bonferroni method ( $P < 0.006$ ).

<sup>a</sup>Number of participants included in the models varies between 472 and 507, depending on the availability of the data; <sup>b</sup>Number of participants included in the models varies between 461 and 504, depending on the availability of the data.

Note: B and 95% CI are from linear mixed-effects models with maximum likelihood estimation adjusted for age, sex, time-varying body mass index, and baseline (0 mo) predictor and outcome as fixed effects; participant ID and intervention center as random effects; and predictor × time interaction. Because interactions were nonsignificant, the reported main effects are from the models without an interaction term. Outcome was measured 4 times during the behavior maintenance stage (6–36 mo).

dietary quality. Eating behaviors and stress did not clearly predict adherence to dietary instructions. Despite different protein and carbohydrate intake targets in the diet groups, the associations between eating behaviors and stress and these outcomes were similar in both groups, especially regarding protein intake.

The observed association between increased cognitive restraint and lower energy intake is consistent with earlier findings from both intervention<sup>13,14</sup> and cross-sectional studies.<sup>15,16</sup> The positive associations between disinhibition, hunger, and energy intake were also consistent with earlier cross-sectional findings.<sup>15</sup> These associations between eating behaviors and energy intake were expected because we have previously shown that eating behaviors were associated with BMI<sup>12</sup> and weight reduction success<sup>20</sup> in the PREVIEW sample.

In addition to energy intake (food quantity), eating behaviors were also associated with indicators of dietary quality (fiber intake and saturated fat as a proportion of total fat). This is relevant because diet also has health effects independent of weight change.<sup>5</sup> Higher disinhibition predicted higher saturated fat as a proportion of total

fat, and both higher disinhibition and higher hunger predicted lower fiber intake. In the case of cognitive restraint, we found no significant associations between indicators of the quality of the diet. However, there was a consistent pattern toward associations with favorable dietary outcomes, but it should be interpreted very cautiously.

There are likely to be several factors that explain the lack of association between cognitive restraint (as measured by TFEQ) and diet quality. First, the scale was originally been created to capture dietary restraint aiming for weight loss and not necessarily a healthy diet.<sup>6</sup> Second, it is probable that cognitive restraint is not a unidimensional construct, and various ways of dietary restraint are potentially differently associated with dietary and weight-related outcomes. For example, Westenhoefer et al<sup>34</sup> have developed subscales for rigid and flexible dietary restraint, but their later work demonstrated that the original TFEQ does not differentiate these constructs well enough, and additional items are needed to better capture the distinctive characteristics of these dimensions.<sup>35</sup> However, the benefit of behavioral flexibility in weight

management is well established,<sup>36–38</sup> but it may be that better instruments for measuring different forms of restraint are needed to capture associations with dietary quality.

In contrast to our hypothesis, eating behaviors did not predict dietary changes during the behavior maintenance stage. This may be related to the fact that, on average, the reported changes in dietary outcomes during the behavior maintenance stage were small. That is, the reported dietary changes were well maintained.

On the basis of earlier findings,<sup>28</sup> it was assumed that eating behaviors would be more strongly associated with food consumption than nutrient intake. However, this assumption was not confirmed. Neither eating behavior nor stress was associated with the consumption of vegetables or sugary products. The lack of association with sugary products was somewhat surprising because stress, in particular, has been associated with increased consumption of palatable foods with high fat and sugar content (ie, comfort foods).<sup>21</sup> This finding may be related to characteristics of our sample (ie, participants in a behavioral intervention aiming for weight loss and maintenance and type 2 diabetes prevention). The



reported consumption of sugary products was overall quite low (< 3.5 g/MJ or < 25 g/d). It may be that PREVIEW participants avoided the consumption of such products, restricted consumption, especially when completing the food records, or even consciously or unconsciously did not report all consumption. In addition, the definition of sugary products in our sample was very broad. A more detailed grouping may have given different results. However, this was not possible because harmonization across the 8 PREVIEW study sites was challenging because of the use of different nutrient analysis software packages and food consumption databases. Consequently, we only achieved rather crudely harmonized groupings.

In this study, stress was negatively associated with protein intake but not other dietary outcomes. On average, the participants of the PREVIEW study did not have high levels of stress, and we have previously shown that higher stress levels predicted withdrawal from the intervention.<sup>12</sup> It may be that individuals having most problems in changing their diet and maintaining those changes because of a stressful life situation were also more likely to discontinue the study.

Because higher cognitive restraint and lower disinhibition and hunger are generally associated with better performance and goal achievement in terms of weight loss and maintenance,<sup>8–11</sup> we hypothesized that they would be associated with better adherence to the dietary instruction. This assumption only partially applied to carbohydrate intake in the MP group. Eating behaviors and stress were similarly associated with protein intake in both diet groups: cognitive restraint predicted higher, and disinhibition and perceived stress predicted lower protein intake. This may be explained by an overall attitude toward protein intake among dieters or even the general public. Higher intake of protein is known to be associated with satiety,<sup>39</sup> and during recent years, the relevance of protein intake for weight loss and maintenance may have been overemphasized. This is a potential reason why participants in the MP group may have been reluctant to

lower their protein intake and that the intake target of 15% of total energy was not achieved. In contrast, the HP group did not increase their protein intake sufficiently to reach the target (25% of total energy). It needs to be noted that despite the target for protein intake being different for the diet groups, the recommended protein sources were similar and aimed to be as healthy as possible (eg, the HP group was not encouraged to eat more red meat).

The main limitation of this investigation was that we assessed dietary intake using food records, which are prone to underreporting.<sup>29</sup> Although our sample was likely to be quite homogenous in terms of known factors affecting underreporting, all participants had overweight/obesity and aimed at active weight loss or weight loss maintenance; we have previously demonstrated in the PREVIEW sample that eating behaviors were associated with misreporting.<sup>40</sup> Cognitive restraint was positively, whereas disinhibition and hunger were negatively associated with underreporting of energy intake and overreporting of protein intake. Similar findings, especially regarding cognitive restraint, have been reported by previous studies.<sup>30</sup> To explore this issue, we compared self-reported protein intake and objectively estimated protein intake expressed as grams per day and found out that eating behaviors were associated only with self-reported protein intake. Hence, our results may be partly explained by the fact that eating behaviors affect the reporting of dietary intake. However, self-reported and estimated protein intakes were not directly comparable because estimated protein intake is based on a 1-day urine collection only, which does not capture the day-to-day variation like 4-day food records. Moreover, in this sample<sup>12</sup> as well as in others,<sup>8–11</sup> cognitive restraint has been linked consistently to better weight loss and maintenance. It is thus possible that individuals with high restraint may actually be successful in reducing their dietary intake, which leads to periods of negative energy balance. This could at least partly explain the underreporting of energy intake in individuals with high restraint,

especially when reported energy intake is compared with estimates of energy expenditure assuming energy balance. However, it has to be noted that despite their limitations, food records and multiple 24-hour recalls are currently considered the best dietary assessment methods to capture usual individual intake and analyze the change in an individual's dietary intake over time.<sup>29</sup>

Some additional limitations also need to be mentioned. The present analysis was a secondary analysis of a randomized intervention, and although potential confounders were taken into consideration in the analyses, unmeasured confounding may still exist. The intervention was burdensome for the participants, and thus, it is likely that the individuals enrolled were more interested in health than the general population, which may affect the generalizability of the results. The dropout during the intervention was larger than expected, and most of it happened during the early stages of the study (during the first year). This analysis only included participants who continued the study after the 6-month-time point; this may have led to even more selected samples, causing additional bias.

## IMPLICATIONS FOR RESEARCH AND PRACTICE

In this study, eating behaviors were associated with self-reported energy intake, quality of the diet based on selected indicators, and, to some extent, adherence to dietary instructions during a 2.5-year behavior maintenance stage of an intervention. This information may be used to develop even more effective interventions. For example, eating behaviors could be used to identify individuals with the greatest challenges in achieving healthy dietary habits and provide them with extra support and counseling to facilitate successful behavior change and maintenance. However, whether tailoring the intervention on the basis of eating behavior leads to improved effectiveness remains to be tested in well-designed interventions.

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## SUPPLEMENTARY DATA

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.jneb.2024.01.001>.

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