Measurement of weight change after change in frequency of a locally recognised habit. How much weight is lost while one higher-protein breakfast more is eaten per week?

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ABSTRACT

It is not known how much reduction in weight is caused by an increased frequency of breakfasts including more protein, or whether such a practice suppresses intake by subconscious post-ingestional effects or intentional reduction in frequency of consumption of other foods. Participants with low frequency of what they believed to be higher protein breakfasts (HPBs) were asked to increase HPB frequency for 4 weeks and then to decrease HPB frequency for the subsequent 4 weeks, while participants with high HPB frequency were asked to follow the opposite sequence. Participants recorded daily if they ate an HPB that morning and had eaten perceived energy-dense foods (EDFs) and/or taken exercise at any time. Greater amounts of fat and weight were lost with perceived HPBs increase than decrease. One more perceived HPB per week for 4 weeks lowered body fat by a mean of 0.05 % (95% CLs: 0.15, -0.04), and weight by 97 g (171, 24). One less perceived EDF occasion a week reduced fat 0.04 % (0.11, -0.03) and weight 81 g (134, 27). These findings show that a sustained change in the frequency of a culturally specified habit can influence weight by a measured amount. This effect could come from the delayed gluconeogenesis from dietary protein amino acids but beliefs about protein at breakfast and energy-dense foods may also play a part.

Keywords:

breakfast; protein; habit frequency; weight loss amount; hunger-suppression; energy-dense food; local practices; obesity education

1. Introduction

Efforts to lose weight, whether clinically guided or not, change multiple patterns of behaviour in diet and/or physical activity. However, the effects on weight of different patterns of ingestive and energy-spending behaviour are not separated out [1]. Measurement of the contribution to weight loss of the change in any one pattern of food choice or exercise requires the pattern to be monitored from before the start of behaviour change and throughout a period of weight change [2]. For instance, the weight loss found with raised protein content of ad libitum diet [3,4] involves diverse eating and exercise practices that were not recorded.

The experiment reported here manipulated the personal frequency of widely eaten breakfasts perceived by the participant as higher in either protein (HPBs) or carbohydrate (HCBs). Episodes of these breakfasts were recorded between monthly measurements of body weight and fat mass. Episodes perceived as energy dense food consumption (EDF) and exercise (Exer) were also recorded each day. The change in weight from a sustained change in frequency of HPBs was measured using a set of innovative methodological principles. These are now described in turn.

1.1. Active ingredients of lifestyle behaviour

Higher protein breakfasts have generated some of the clearest evidence for a single practice with the potential to reduce body weight. Raising the protein content of breakfast cuts down midmorning snacks and lunch sizes [5,6,7,8,9,10]. If this effect is not fully compensated, higher protein breakfasts could help individuals to reduce weight [11]. The mechanism of a weight reducing effect of eating protein at breakfast could be either metabolic or cognitive, or a combination of both, as follows.

In the Cahill cycle [12], amino acids absorbed from the digestion of protein are temporarily stored in muscle tissue and released as alanine and glutamine when the insulin response to absorption declines; the liver uses these amino acids to produce glucose. The hormonal and metabolic effects of this extra glucose on specialised cells in the brain could delay the usual rise of appetite for food as absorption from the last meal slows [13].

Participants in this experiment might believe that higher protein breakfasts are being evaluated as part of a weight control programme based on increasing the protein content of the whole diet [14]. At the same time, being asked to report exercise, participants might come to believe that protein reduces weight by facilitating exercise, e.g. by strengthening muscles [15]. Furthermore, when asked to monitor eating of energy dense foods, participants may eat

them less often because they believe such foods are fattening [16,17]. Similarly, the belief that lack of exercise is fattening [14,18] could encourage participants to take exercise more often throughout the study. Calling attention to such practices would be expected to reinforce action on those beliefs, even without explicit advocacy of those changes to lose weight [19,20,21].

1.2. Rates of exchange of energy between body and environment

Change in body energy content results from a difference between rates (not cumulative amounts) of energy intake and expenditure [22]. A sustained change in the frequency of episodes of a pattern of behaviour that contributes to energy exchange must therefore change the body's energy content [23]. The percentage content of fat mass was measured alongside weight in order to test the relevance of the experiment's results to reduction of obesity and overweight. A change in weight is unlikely to affect health unless the proportion of fat in the body changes in parallel. How much of the change in energy content goes into or comes from adipose tissue is a separate question [24].

1.3. Asymptotic weight change from sustained change in behaviour

The physics of weight control centres on the fact that a change in body mass produces a change in basal metabolic rate in the same direction [25,26]. Eventually the difference in rates of energy intake and expenditure will slow down and come to zero [27,28,29]. Hence change in weight from a sustained change in frequency of a habit of eating or exercise will approach an asymptote within weeks [30,31,32] and not accumulate indefinitely as has often been assumed [33,34].

This step change in weight with sustained change in frequency of an effective pattern of behaviour would explain an initial loss of weight, its slowing and then reversal into weight gain, universally seen in weight loss programmes [35]. The initial changes of frequency are not maintained and the lapses result in a return to initial weight or even beyond [35,36,37].

1.4. Culturally recognised descriptions of existing behaviour

Human nutrition usually investigates isolated foods or nutrients rather than particular food combinations familiar to the eaters. Government education in many countries has been based on nutrient-related food groups, although recommended frequencies of common food combinations that characterise eating patterns are being introduced [38]. Health education

and clinical practice should describe categories of eating and exercise in the public's words for prevalent habits in a locality [31,32,39,40]. This cultural sensitivity relates participants' reports better to their everyday practices, improving the validity of measures such as habit frequency [41].

1.5. Frequency of episodes of a habit

Research approaches to energy balance continue to be limited by a demand for precise measurement of energy intake and expenditure in all the diet and physical activity of the individual participant [42,43]. Hence there is a dearth of evidence for effectiveness of components of the lifestyle changes recommended to reduce overweight or obesity [1].

It has been proposed that body weight can be controlled by altering how often a conventional pattern of eating or exercise is habitually carried out, with attention only secondarily to variation in the amount of energy taken in and put out on each occasion [31,32]. Present frequency is calculated from reports of the most recent episodes of a pattern of behaviour. Memory for the eating occasions on the same day or recent previous days is very accurate [44,45,46,47]. Conventional food frequency questionnaires allow numerical responses without requiring recall of any actual occasion, as well as attempting to recall foods over several weeks [48].

1.6. Design for causal evidence

To gain evidence that change in a habit is causing a change in weight, the weight change must not start before the change in behaviour and also behaviour change must not stop before the next measurement of weight. Otherwise any number of other influences could change weight after the last score of the hypothesised influence. Previous studies have related diet evaluations only at times before the end of the trial [49,50]. In the experiment reported here, the occurrence or not of each habit each day was recorded every day between measurements of weight.

1.7. Estimation of the dose-response function

The response in weight change to the dose of behaviour change can be estimated by linear regression across individuals, if the frequencies of the habit can be extrapolated to zero (e.g., never that week) and to maximum attainable (e.g. each day that week) and are distributed normally (with outliers excluded). If the amount of change in weight does not

differ between rise and fall in habit frequency, then all the data can be put together to measure the slope of the relationship. The regression slope has been called a “dose-response” [49], although for indirect dietary scores in that study, not specific patterns of behaviour.

Such estimation of the amount by which the outcome has been affected by the manipulation is a scientific measure of the size of an effect. This is entirely different from the statistical “effect size” given by a regression coefficient or the partial eta squared, which contain no specific mechanistic or practical information.

1.8. Expected outcomes

The aim of the present work was to measure for the first time the step change in body weight and fat mass caused by a sustained change in frequency of a locally recognised habit. If the slope of the dose-response regression line is reliably different from zero, this supports the qualitative hypothesis that there is an effect on weight of protein in breakfasts.

Neither beliefs nor metabolic processes were measured in this experiment but the pattern of habit frequencies could turn out to indicate cognitive mediation of an effect of perceived HPBs on weight. For example, an increased frequency of exercise is unlikely to arise from metabolic consequences of eating higher protein breakfasts, given the lack of evidence for such an effect outside sport, and so could indicate a belief that protein facilitates exercise.

2. Methods

2.1. Participants

Members of the public were invited to take part in weight loss programme by a notice at the gate of the Multidisciplinary Health Clinic of the Autonomous University of the State of Mexico, Toluca city. Male and female volunteers were eligible if they were 18 y or older, had no chronic disease, could lose 3 kg for a healthier weight, and their baseline frequency of a tested breakfast (believed to be high in protein or carbohydrate) could be increased to most days of the week, while the frequency of the other tested breakfast was decreased at the same time. Monitoring of a person’s body weight, diet and/or physical activity is not ethical without consent to collection and use of the data. Hence volunteers were told that the study tested if weight is reduced by a single habit of eating and that the results might be used for advice on weight control. The institutional ethics committee reviewed and approved the study

protocol (record number 2013/12). Written informed consent was obtained from each participant.

2.2. Design

Participants visited the Multidisciplinary Health Clinic for three sessions of physical measurements and both oral and written reporting of the occasions of each monitored habit. Participants with low baseline frequency of HPBs were asked to increase frequency of HPBs (i.e. consume on most days of the week) for 4 weeks and then to increase frequency of HCBs for the subsequent 4 weeks, while participants with high HPBs baseline frequency were asked to follow the opposite sequence.

Two written examples were provided of each tested breakfast type, approximately equivalent in content of energy and dietary fat. The participants were also instructed how to exchange the foods of the assigned type of breakfast with others having similar culinary role and macronutrient contents.

2.3. Monitoring of behaviour

Wordings for each habit to be reported were formulated using a database of reports of eating and exercising episodes by people from the same locality in their usual vocabulary (Table 1).

During session 1, participants recalled the number of times in a week that they usually carried out each of the tracked habits, taking as reference the previous four weeks. In addition, at each session the participant received a dated sheet on which to mark at the end of each day whether or not s/he had carried out each investigated habit, i.e. the tested breakfasts, energy-dense foods consumption at every period of the day, and exercise. Note that this procedure monitors each occurrence of the manipulated eating habit, unlike most dietary assessments and feeding studies.

The mean weekly frequency of each pattern over each 4-week period was estimated from the daily records. The baseline frequency of each habit was the usual number of times per week reported at session 1.

Table 1

Habitual patterns of behaviour monitored during the experiment.

Behaviour pattern	Descriptions given to participants^a
Breakfast with protein-rich food e.g. 1.58 MJ (378 kcal), 48% carbohydrate (46 g), 29% protein (27 g) and 24% fat (10 g)	<i>Two tortillas filled with egg or meat</i> <i>or</i> <i>Ham and cheese sandwich</i> <i>Dos tacos de huevo o carne</i> <i>o</i> <i>Sándwich de jamón con queso</i> <i>and coffee or tea with two spoonfuls of sugar</i> <i>y café o té con dos cucharadas de azúcar</i>
Breakfast without protein-rich food e.g. 1.57 MJ (374 kcal), 61% carbohydrate (57 g), 15% protein (14 g) and 24% fat (10 g)	<i>Fruit milkshake and bread</i> <i>or</i> <i>Yogurt with apple and granola</i> <i>Licuada de fruta y pan</i> <i>o</i> <i>Yogurt con manzana y granola</i> <i>and coffee or tea with two spoonfuls of sugar</i> <i>y café o té con dos cucharadas de azúcar</i>
Energy-dense foods at or between meals	<i>e.g. burger, pizza, hot dog, fries, fatty meat or typical preparations high in fat</i> <i>(i.e. tacos filled with carnitas, tamales, pambazos), empanadas, desserts, crisps,</i> <i>chocolate, sweets, pastry, biscuits, cake, ice-cream, sugary drinks, bottled juice, alcohol</i> <i>e.g. hamburguesa, pizza, hot dog, papas fritas, carne grasosa o antojitos mexicanos altos en grasa</i> <i>(i.e. tacos de carnitas, tamales, pambazos), empanadas, postres, papitas,</i> <i>chocolate, dulces, pan dulce, galletas, pastel, helado, refrescos, jugo embotellado, alcohol</i>
Exercise	<i>e.g. go to the gym, go for a jog or walk, dance or fitness class, exercise routine at home</i> <i>e.g. ir al gimnasio, salir a correr o caminar, clase de baile o aerobics, rutina de ejercicio en casa</i>

^a English wordings are translations of Spanish terms used in the experiment (presented above and below respectively for each habit).

2.4. Weighing

Body weight and fat mass were measured at 4-week intervals. This is sufficient time for weight change to reach asymptote (see 1.3). It also avoids fluctuations from water loss/gain over the initial days of diet change [27,32]. Each participant's weight in kilograms and percentage of fat mass in the body were measured at each session on the same weighing monitor fitted with bioimpedance (BF541, Tanita Corp., Tokyo, Japan; measures of body fat by bioimpedance analysis are claimed to correlate satisfactorily with dual energy x-ray absorptiometry [24,51,52,53]). The participant wore light clothes, was barefoot, and had recently evacuated bladder and rectum. To calculate baseline BMI, height was measured during session 1 with shoes off, using a wall stadiometer (Seca 1013522, Seca North America, Hanover, MD). $\text{BMI} \leq 27 \text{ kg.m}^{-2}$ was used to distinguish healthier from unhealthier BMI, in accordance with cut-off points for adults in Mexico [54].

2.5. Analysis of data

Measurement of the weight-changing effect of a sustained change in the frequency of a tested habit required the data from all three sessions. Measurement of effects of breakfast change also required its frequency to be different from previously throughout the experiment in either of the sequences of frequency increase and decrease. Participants in the two sequences did not differ reliably in mean age or percentages in the categories of gender, occupation or BMI (Table 2).

The amounts of weight and fat mass lost for a unit change in frequency of a habit were estimated as the slope of the regression from change in frequency of the behaviour pattern to the change in weight [31,32]. The statistical reliability of the slope value was indicated by its 95% confidence limits (CLs) being on the same side of zero. Non-overlap between these CLs of two slopes corresponds to $P < 0.05$.

Mixed and factorial analysis of variance showed no reliable differences in means of changes in fat mass, weight and frequencies of consumption of perceived energy-dense food items or bouts of exercise between the requested directions of change, baseline-sequences, first and second phases or BMI ranges (Supplementary Information Table S1 lines 7-30, columns 21-24; Table S2 lines 4-15, columns 5-7). There were no reliable differences in the slopes between sequences or direction of requested change in frequency of higher protein breakfasts (Table S3; Figures S1-S4). Hence data on one direction from each sequence were combined. Four participants were excluded from regression analyses of combined data

because of one outlier in frequency change of HPBs, two outliers in frequency change of exercise and one outlier in fat mass change (outlier criterion: $P < 0.001$ from the rest of the group). In consequence, each regression included 84 cases of 4-week periods (Table S4; Figure S5).

Table 2

Characteristics of complying participants in each sequence of requested changes in frequency of higher protein breakfasts (%).

	Raise protein initially Lower protein crossover n = 31	Lower protein initially Raise protein crossover n = 15	Between groups	
			χ^2	P
Age (Mdn split)				
< 38 y	68	53	0.90	0.34
≤ 38 y	32	47		
Gender				
<i>Women</i>	90	80	0.26	0.61
<i>Men</i>	10	20		
Occupation				
<i>Non-students</i>	65	80	0.53	0.47
<i>Students</i>	35	20		
Body mass index				
< 27 kg.m ⁻²	39	40	0.01	0.93
≥ 27 kg.m ⁻²	61	60		

3. Results

3.1. Manipulation check

The directional effect of requested changes on the frequencies of higher protein and higher carbohydrate breakfasts was reliable (Figure 1 chart a; Table S2 lines 1-3, columns 1-5). As asked of participants with low baseline frequency of HPBs, reported frequency was high in the first four weeks and lower in the second four weeks (respective mean changes: 3.6, -4.0 per week; Figure 2 upper charts; Table S1 lines 1-6, columns 4-14). Participants with high baseline frequency showed the opposite (-2.9, 4.3 per week), as requested.

3.2. Observed behaviour changes and effects of request to eat more or fewer HPBs

Participants in both sequences lost body weight and fat mass across the three sessions (Figure 2 bottom charts; Table S1 lines 7-18). They also decreased frequency of consumption of energy dense foods over all 8 weeks (Figure 2 middle charts; Table S1 lines 19-24). The frequency of exercise did not differ reliably between 4-week periods (Figure 2 middle charts; Table S1 lines 25-30).

Requested changes in frequency of HPBs sustained in one direction for 4 weeks had additional effects on body weight and fat (Figure 1 charts b and c; Table S2 lines 4-9, columns 1-5). Regression through increases and decreases in HPBs showed that raising the number of HPBs by one per week for 4 weeks accelerated decreases in fat mass by a mean (CLs) of 0.05 % (0.15, -0.04) and in weight of 97 g (171, 24) (Figure S5 charts a and b; Table S4 lines 1 and 2, columns 4-6).

3.3. Potential mediators of effect on weight

There was evidence that reduction in EDF consumption played a role in the body energy loss induced by increased frequency of HPBs. A rise by one HPB a week occurred with a decrease per week of 0.32 (0.61, 0.02) EDFs over the whole day (Figure S5 chart c; Table S4 line 3, columns 4-6). This effect could come from a belief that HPBs keep hunger at bay, i.e. help to prevent eating during the morning, and lessen eating at lunch and perhaps later in the day [14]. This cognitive mediation could account for all the HPB-specific decrease in EDF frequency. Yet delayed metabolic satiation [12,13] could occur as well or instead.

Figure 1

Effects of requesting fewer or more perceived higher protein breakfasts (pHPBs), in groups with initially low ($n = 31$; continuous line) or high ($n = 15$; broken line) number of pHPBs per week in both sequences together (P value: Table S2 line, column). (a) Number of pHPBs recorded each week (frequency), averaged over 4-week phase (< 0.0001 : 1, 5). (b) Body fat change (0.12: 4, 5). (c) Weight change (0.06: 7, 5), (d) Recorded frequency of perceived energy-dense foods: pEDFs (0.38: 10, 5). (e) Recorded frequency of perceived exercise: pExer (< 0.07 : 13, 5). Data are expressed as mean $\pm$ standard error.

Figure 2

Mean frequency of habits in times per week (tpw) and mean weight (kg) and fat mass (%) in two groups differing in proportion of perceived higher-protein or -carbohydrate breakfasts (pHPB, pHCB) at baseline (Week 0): left side - more baseline pHCBs ($n = 31$), asked to eat pHPBs more often first; right side - more baseline pHPBs ($n = 15$), asked to eat fewer HPBs first.

Decreasing the consumption of EDFs over the whole day by one episode a week was characterised by a mean decrease in fat mass of 0.04 % (0.11, -0.03) and in weight of 81 g (134, 27) (Figure S5 charts e and f; Table S4 line 3, columns 11-13 and 18-20).

Exercise was not predicted to change with frequency of HPBs, and indeed no reliable difference between phases was observed (Figure 1 chart e; Table S2 lines 13-15, columns 1-5). Hence, there was no support for either social or physiological signals from HPBs to exercise. However, any change in exercise might affect weight [55]. A rise in bouts of exercise by once a week went with a mean decrease in weight of 194 g (376, 1) (Figure S5 charts g and h; Table S4 line 4, columns 11-13 and 18-20) but no appreciable change in fat mass.

4. Discussion

4.1 Effect on weight of education about prevalent behaviour

Participants in the present study were asked to test a potential component of a weight control programme by varying the frequency of higher versus lower protein breakfasts and also to report at the end of each day which sort of breakfast they had eaten that morning. Breakfasts common in their culture that were higher or lower in protein content were described in terms provided by others from the same locality. Following this explicit nutrition education, the self-monitoring indicated strong effects on such behaviour of the requests to change breakfast protein content in either direction. This supports the widely made assumption that education in change in a dietary practice has an effect on action, not just on knowledge.

Participants were also asked to report each day's consumption of energy dense foods and occasions of taking exercise, again understood in their own terms. Evidence for an indirect educational effect of such requests was observed in a decrease in frequency of EDF consumption and an increase in frequency of exercise bouts throughout the study, regardless of direction of change in frequency of breakfasts perceived as higher in protein.

Nevertheless, there was a greater decrease in frequency of EDFs when HPB frequency was increased. This evidence extends previous research on patterns of eating and exercise that reduce weight [23,31,32,39] and provides for the first time a measurement of effect on body energy content of a piece of dietary behaviour [namely, HPB] with known influence on appetite [5,6,7,8,9,10].

4.2. Implications for research and practice

This study demonstrates the methodology required for a dose-response measure of effectiveness of a specified component of a therapy programme. Such quantitative scientific evidence -- not just statistical effect size -- should be obtained for each active component to be included in dietetic and medical interventions or public health messages. Imposing treatment not known to succeed is not only a waste of resource but also arguably unethical [56].

A package of those validated changes in habits can be selected for fully operationalised personal tailoring in accord with the individual's scope for moving the habit's frequencies in a weight-reducing direction. Changes in a limited number of habits having known impact could be at least as effective as implementing an entire dietetic and exercising regime [57,58,59]. From the results presented here, a weight loss programme might start with a decrease in consumption of EDFs from 12 to 6 times per week which extrapolates to a step loss of about 0.5-1.0 kg, plus an increase in exercise, say, from 2 to 3-5 times per week, producing a loss of 0.2-0.6 kg. That would add up to a clinically meaningful weight loss of 0.7-1.6 kg as a first stage.

The communications by professionals should be in locally identified language for common existing patterns of eating, exercise and keeping warm or cool [60]. Recalls of each occasion of each habit should be written at the end of each day, or each week at most, for valid use as data in constructing dose-response regressions onto weight (and fatness, or waist circumference) or indeed any outcome. Those reports also provide data on scope for intensifying a frequency change and any need for lapse correction or substitution by a better maintained habit. Finally, to maximise accuracy, a person's weight readings should be taken on the same machine under the same bodily conditions each time.

4.3. Methodological considerations

In the present study, both breakfast conditions were run in each participant. Measurement of the effects of the two breakfast conditions in both sequences removes confounding with direction of behavioural change.

The usual weight loss and regain during and after a dietary intervention on obesity is attributable to initial compliance and subsequent lapsing [e.g. 35,61]. This pattern is modelled

by the sequence of raised frequency of higher protein breakfast followed by lowered frequency of higher protein breakfast.

The tailoring added to this example of the design confounded baseline habit frequency range with sequence of conditions. Future studies should randomise assignments of the sequences and check for effects of baseline during analysis of data.

The record of the timing of a habit made at the end of the day, or even some days after its occurrence, provides accurate and reliable information because of the high precision of recent episodic memories [43,44,45,46]. Data for calculation of actual frequency from physical records of occasions of a habit could be provided in real time by mobile technology, after consent.

4.5. Conclusions

A sustained increase in the frequency of higher protein breakfast reduced body weight. Monitoring common habits between weight measurements also induced changes in frequency that influenced weight. Our innovative measurement of the effect on weight of a change in frequency of a particular habit can be readily applied in research and clinical practice. Moreover, incorporation of this approach into a mobile interface would enable any member of the public to self-experiment on how much weight changes with changes in frequency of locally recognised habits, as well as to contribute to a pooled research database [30,31].

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Conflict of interest

The authors declare no conflicts of interest.

Online supplementary information accompanies this paper (Tables S1-S4 and Figures S1-S5).

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ONLINE SUPPLEMENTARY INFORMATION

Table S1. Frequencies of perceived eating patterns and exercise in times per week (tpw), and measured body fat percentage and weight kilograms, with statistical analyses below. *n*: number of participants. *M ± SD*: mean ± standard deviation.

			Phase of initially requested change							Phase of reversal towards initial habit					
			<i>n</i>	Baseline	<i>M±SD</i>				Week 1 to 4	<i>M±SD</i>					Week 5 to 8
					Week 1	Week 2	Week 3	Week 4		Week 5	Week 6	Week 7	Week 8		
1	pHPBs, tpw	Healthy BMI													
2		Baseline pHCB	12	2.0±1.1	5.6±1.2	6.3±0.9	5.8±1.1	5.7±1.1	5.8±0.9	1.1±1.2	1.2±1.1	0.9±0.9	1.1±1.0	1.1±0.9	
3		Baseline pHPB	6	4.7±2.0	0.7±0.8	1.2±1.5	0.8±0.8	1.0±0.9	1.0±0.6	5.7±0.9	4.8±1.7	5.7±0.8	5.0±1.6	5.3±1.0	
4		Unhealthy BMI													
5		Baseline pHCB	19	1.9±1.3	5.1±1.6	5.3±1.2	5.4±1.4	5.4±1.5	5.3±1.1	2.2±1.8	1.6±1.4	1.6±1.5	1.9±1.6	1.8±1.3	
6		Baseline pHPB	9	3.9±2.3	1.4±1.0	1.3±1.2	1.6±1.7	1.7±1.9	1.5±1.3	5.8±1.0	5.7±1.3	6.0±1.0	5.4±1.5	5.8±0.9	
7	Body fat, %	Healthy BMI													
8		Baseline pHCB	12	30.4±5.9	-	-	-	-	28.5±5.9	-	-	-	-	28.3±6.0	
9		Baseline pHPB	6	28.4±9.6	-	-	-	-	27.8±9.8	-	-	-	-	27.6±9.3	
10		Unhealthy BMI													
11		Baseline pHCB	19	39.6±6.1	-	-	-	-	38.7±6.6	-	-	-	-	38.2±6.4	
12		Baseline pHPB	9	38.4±7.2	-	-	-	-	38.3±7.0	-	-	-	-	37.9±7.4	
13	Weight, kg	Healthy BMI													
14		Baseline pHCB	12	62.0±7.2	-	-	-	-	60.6±7.1	-	-	-	-	60.8±7.1	
15		Baseline pHPB	6	66.4±7.0	-	-	-	-	66.1±6.4	-	-	-	-	65.3±7.2	
16		Unhealthy BMI													
17		Baseline pHCB	19	77.8±13.4	-	-	-	-	77.1±13.4	-	-	-	-	76.9±13.6	
18		Baseline pHPB	9	77.9±7.9	-	-	-	-	76.6±9.1	-	-	-	-	76.1±8.8	
19	pEDFs, tpw	Healthy BMI													
20		Baseline pHCB	12	10.6±4.4	5.9±2.2	5.7±3.5	4.6±2.5	6.2±2.5	5.6±2.2	6.1±3.3	6.4±4.9	4.6±3.0	6.4±3.7	5.9±3.4	
21		Baseline pHPB	6	5.8±2.8	5.5±2.8	5.0±4.3	6.2±3.3	4.0±2.5	5.2±2.2	3.7±1.4	4.8±3.1	6.0±3.6	4.8±4.3	4.9±1.2	
22		Unhealthy BMI													
23		Baseline pHCB	19	10.0±5.4	7.9±5.9	6.8±6.1	7.8±6.1	6.5±4.2	7.3±4.7	7.1±5.2	6.8±5.3	5.8±4.8	5.1±4.1	6.2±4.2	
24		Baseline pHPB	9	10.7±4.9	6.2±5.6	5.5±6.7	6.0±6.2	5.1±5.7	5.7±5.9	6.1±7.4	6.9±7.9	8.1±6.7	5.2±5.3	6.6±6.7	
25	pExer, tpw	Healthy BMI													
26		Baseline pHCB	12	1.1±1.4	2.3±2.1	2.6±1.9	1.8±2.0	2.2±1.8	2.2±1.7	1.8±2.0	1.9±1.8	2.0±2.2	1.3±1.5	1.8±1.5	
27		Baseline pHPB	6	3.3±2.1	2.3±1.9	2.7±2.1	2.5±2.0	2.2±2.0	2.5±1.9	3.0±2.5	2.2±2.1	3.5±2.4	2.7±2.3	2.9±2.2	
28		Unhealthy BMI													
29		Baseline pHCB	19	2.5±2.3	2.2±1.5	1.8±2.1	2.3±2.6	1.8±2.4	2.1±1.9	1.4±1.6	1.6±1.6	1.2±1.4	1.6±1.9	1.5±1.4	
30		Baseline pHPB	9	1.1±1.6	1.4±1.4	1.8±2.3	1.9±2.0	1.4±1.8	1.7±1.7	1.4±1.8	1.7±1.7	2.2±2.2	1.7±2.1	1.8±1.8	
1	2	3	4	5	6	7	8	9	10	11	12	13	14		

[continued over]

Table S1. [*continued*]

			Baseline, Week 1 to 4 and Week 5 to 8									Mixed ANOVA											
			rm ANOVA			Linear trend			Quadratic trend			Phase			Phase * Baseline-sequence			Phase * BMI range			Phase * Baseline-sequence * BMI range		
			r^2	F	P	r^2	F	P	r^2	F	P	r^2	F	P	r^2	F	P	r^2	F	P	r^2	F	P
1	pHPBs, tpw	Healthy BMI																					
2		Baseline pHCB	0.908	108.77	0.0001	0.340	5.66	0.036	0.957	242.37	0.0001												
3		Baseline pHPB	0.818	22.49	0.003	0.144	0.84	0.40	0.904	47.09	0.001												
4		Unhealthy BMI										0.004	0.16	0.69	0.866	271.76	0.0001	0.0001	0.01	0.92	0.070	3.15	0.083
5		Baseline pHCB	0.750	54.05	0.0001	0.005	0.09	0.77	0.844	97.02	0.0001												
6		Baseline pHPB	0.646	14.60	0.0001	0.369	4.47	0.067	0.798	31.68	0.0001												
7	Body fat, %	Healthy BMI																					
8		Baseline pHCB	0.506	11.26	0.001	0.569	14.51	0.003	0.328	5.36	0.041												
9		Baseline pHPB	0.134	0.78	0.44	0.199	1.24	0.32	0.037	0.19	0.68	0.032	1.38	0.25	0.022	0.95	0.34	0.027	1.15	0.29	0.002	0.08	0.78
10		Unhealthy BMI																					
11		Baseline pHCB	0.207	4.70	0.019	0.330	8.87	0.008	0.009	0.17	0.69												
12		Baseline pHPB	0.060	0.51	0.54	0.071	0.61	0.46	0.026	0.22	0.66												
13	Weight, kg	Healthy BMI																					
14		Baseline pHCB	0.399	7.31	0.004	0.469	9.71	0.01	0.316	5.09	0.045												
15		Baseline pHPB	0.407	3.44	0.075	0.601	7.53	0.041	0.072	0.39	0.56	0.088	4.06	0.05	0.046	2.04	0.16	0.002	0.09	0.77	0.079	3.60	0.065
16		Unhealthy BMI																					
17		Baseline pHCB	0.266	6.53	0.006	0.314	8.25	0.01	0.128	2.65	0.121												
18		Baseline pHPB	0.458	6.76	0.012	0.520	8.68	0.019	0.174	1.69	0.23												
19	pEDFs, tpw	Healthy BMI																					
20		Baseline pHCB	0.397	7.24	0.008	0.440	8.65	0.013	0.320	5.17	0.044												
21		Baseline pHPB	0.107	0.60	0.51	0.117	0.66	0.45	0.029	0.15	0.71	0.180	9.22	0.004	0.001	0.02	0.89	0.004	0.19	0.67	0.099	4.62	0.037
22		Unhealthy BMI																					
23		Baseline pHCB	0.200	4.50	0.027	0.241	5.71	0.028	0.053	1.01	0.33												
24		Baseline pHPB	0.428	5.98	0.027	0.388	8.14	0.021	0.504	8.14	0.021												
25	pExer, tpw	Healthy BMI																					
26		Baseline pHCB	0.249	3.64	0.051	0.164	2.15	0.17	0.355	6.04	0.032												
27		Baseline pHPB	0.280	1.95	0.21	0.137	0.79	0.41	0.505	5.11	0.073	0.006	0.23	0.63	0.044	1.95	0.17	0.001	0.06	0.81	0.070	3.15	0.083
28		Unhealthy BMI																					
29		Baseline pHCB	0.089	1.76	0.20	0.137	2.86	0.108	0.002	0.04	0.108												
30		Baseline pHPB	0.165	1.58	0.24	0.253	2.71	0.14	0.054	0.46	0.52												
15	16	17	18	19	20	21	22	23	24														

Table S2. Effects of requested change on frequencies of eating patterns and exercise in times per week (tpw), body fat percentage and weight kilograms. *n*: number of participants (See Figure 1). *M ± SD*: mean ± standard deviation.

		Effect of requested change			Factorial ANOVA								
		<i>k</i>	<i>M±SD</i>		Requested change			Baseline-sequence			Requested change *Baseline-sequence		
			Fewer HPB	More HPB	<i>pη</i> ²	<i>F</i>	<i>P</i>	<i>pη</i> ²	<i>F</i>	<i>P</i>	<i>pη</i> ²	<i>F</i>	<i>P</i>
1	pHPBs, tpw												
2	Baseline pHCB	124	1.5±1.4	5.5±1.4	0.678	765.15	0.0001	0.001	0.46	0.50	0.003	1.03	0.31
3	Baseline pHPB	60	1.3±1.3	5.6±1.2									
4	Body fat change, %												
5	Baseline pHCB	124	-0.3±1.5	-1.2±1.6	0.012	2.51	0.12	0.012	1.09	0.30	0.018	1.61	0.21
6	Baseline pHPB	60	-0.4±1.4	-0.5±0.7									
7	Weight change, kg												
8	Baseline pHCB	124	0.0±1.3	-1.0±1.1	0.041	3.79	0.06	0.011	0.99	0.32	0.028	2.56	0.11
9	Baseline pHPB	60	-0.7±1.5	-0.8±1.3									
10	pEDFs all occasions, tpw												
11	Baseline pHCB	124	6.1±4.5	5.5±4.9	0.002	0.78	0.38	0.004	1.51	0.22	0.000	0.02	0.90
12	Baseline pHPB	60	6.6±4.7	5.9±5.6									
13	pExer, tpw												
14	Baseline pHCB	124	1.6±1.7	2.0±1.9	0.009	3.43	0.07	0.004	1.35	0.25	0.001	0.45	0.50
15	Baseline pHPB	60	2.1±2.1	2.2±2.1									
	1	2	3	4		5			6			7	

Table S3. Regressions from change in number of perceived higher protein breakfasts (pHPBs) per week to number per week of behaviour later in the day, or from change in number of episodes of each behaviour pattern per week to grams of weight or fat mass change over four weeks (see Figures S1-S4). Change: times per week (tpw) for behaviour, percent for body fat or grams for body weight at the end *minus* at the beginning of four weeks. *k*: number of cases across sequences. *r*: correlation coefficient. *b*: slope. *CLs*: 95% confidence limits.

		Change in number of pHPBs per week							Change in body fat							Change in weight						
		(predictor)							(outcome)							(outcome)						
		CLs of <i>b</i>					CLs of <i>b</i>					CLs of <i>b</i>										
<i>k</i>	<i>r</i>	<i>b</i>	<i>lower</i>	<i>upper</i>	<i>t</i>	<i>P</i>		<i>r</i>	<i>b</i>	<i>lower</i>	<i>upper</i>	<i>t</i>	<i>P</i>		<i>r</i>	<i>b</i>	<i>lower</i>	<i>upper</i>	<i>t</i>	<i>P</i>		
1	Habitually lower-protein breakfast																					
2	<i>Eat more pHPBs and fewer pHCBs Phase 1</i>																					
3	Change in body fat	27	-0.11	-0.13	-0.62	0.35	-0.56	0.58	-	-	-	-	-	-	0.34	234	-37	505	1.78	0.087		
4	Change in weight	27	-0.30	-251	-577	76	-1.58	0.13	0.34	0.48	-0.08	1.04	1.78	0.09	-	-	-	-	-	-		
5	Change in episodes of pEDFs per week	27	-0.09	-0.33	-1.93	1.27	-0.43	0.67	0.09	0.03	-0.10	0.15	0.47	0.64	0.31	66	-18	149	1.62	0.12		
6	Change in episodes of pExer per week	27	-0.16	-0.24	-0.85	0.37	-0.81	0.43	-0.02	-0.02	-0.35	0.31	-0.11	0.91	-0.24	-133	-355	89	-1.24	0.23		
7	<i>Eat more pHCBs and fewer pHPBs Phase 2</i>																					
8	Change in body fat	27	-0.01	-0.01	-0.74	0.73	-0.02	0.98	-	-	-	-	-	-	0.60	426	194	659	3.78	0.001		
9	Change in weight	27	-0.23	-283	-788	222	-1.15	0.26	0.60	0.85	0.39	1.32	3.78	0.001	-	-	-	-	-	-		
10	Change in episodes of pEDFs per week	27	0.02	0.04	-1.16	1.25	0.07	0.94	-0.23	-0.14	-0.38	0.11	-1.17	0.25	0.05	22	-155	199	0.25	0.80		
11	Change in episodes of pExer per week	27	-0.23	-0.28	-0.78	0.22	-1.17	0.26	0.29	0.42	-0.14	0.99	1.54	0.14	-0.01	-8	-427	411	-0.04	0.97		
12	Habitually higher-protein breakfast																					
13	<i>Eat more pHCBs and fewer pHPBs Phase 1</i>																					
14	Change in body fat	15	-0.12	-0.13	-0.78	0.51	-0.45	0.66	-	-	-	-	-	-	0.16	124	-331	580	0.59	0.57		
15	Change in weight	15	-0.19	-161	-650	328	-0.71	0.49	0.16	0.21	-0.56	0.98	0.59	0.57	-	-	-	-	-	-		
16	Change in episodes of pEDFs per week	15	-0.20	-0.49	-1.93	0.96	-0.73	0.48	0.33	0.14	-0.11	0.39	1.25	0.23	0.46	157	-23	337	1.89	0.081		
17	Change in episodes of pExer per week	15	0.43	0.31	-0.07	0.69	1.74	0.11	0.07	0.07	-0.55	0.69	0.24	0.82	-0.32	-253	-709	202	1.20	0.25		
18	<i>Eat more pHPBs and fewer pHCBs Phase 2</i>																					
19	Change in body fat	15	0.31	0.18	-0.16	0.51	1.16	0.27	-	-	-	-	-	-	0.03	45	-860	950	0.11	0.92		
20	Change in weight	15	-0.25	-224	-738	290	-0.94	0.36	0.03	0.02	-0.38	0.42	0.11	0.92	-	-	-	-	-	-		
21	Change in episodes of pEDFs per week	15	-0.61	-1.26	-2.25	-0.27	-2.75	0.02	-0.09	-0.03	-0.20	0.14	-0.34	0.73	0.03	12	-243	267	0.10	0.92		
22	Change in episodes of pExer per week	15	0.08	0.05	-0.36	0.47	0.28	0.79	-0.04	-0.03	-0.54	0.47	-0.14	0.89	-0.51	-646	-1301	8	-2.14	0.05		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	

Table S4. All data ($k = 84$), regressions from change in number of perceived higher protein breakfasts (pHPBs) per week to number per week of behaviour later in the day, or from change in number of episodes of each behaviour pattern per week to grams of weight or fat mass change over four weeks (see Figure S5). Change: times per week (tpw) for behaviour, percent for body fat or grams for body weight at the end *minus* at the beginning of four weeks. k : number of cases across sequences. r : correlation coefficient. b : slope. CLs : 95% confidence limits.

		Change in number of pHPBs per week							Change in body fat							Change in weight								
		(predictor)							(outcome)							(outcome)								
		<i>CLs of b</i>							<i>CLs of b</i>							<i>CLs of b</i>								
		<i>k</i>	<i>r</i>	<i>b</i>	<i>lower</i>	<i>upper</i>	<i>t</i>	<i>P</i>			<i>r</i>	<i>b</i>	<i>lower</i>	<i>upper</i>	<i>t</i>	<i>P</i>			<i>r</i>	<i>b</i>	<i>lower</i>	<i>upper</i>	<i>t</i>	<i>P</i>
1	Change in body fat	84	-0.12	-0.05	-0.15	0.04	-1.08	0.28			-	-	-	-	-	-			0.37	295	133	457	3.63	0.0001
2	Change in weight	84	-0.28	-97	-171	-24	-2.63	0.01			0.37	0.47	0.21	0.73	3.63	0.0001			-	-	-	-	-	-
3	Change in episodes of pEDFs per week	84	-0.20	-0.32	-0.61	-0.02	-1.07	0.07			0.12	0.04	-0.03	0.11	1.08	0.28			0.32	81	27	134	3.01	0.003
4	Change in episodes of pExer per week	84	0.18	0.07	-0.02	0.16	1.64	0.11			0.06	0.07	-0.17	0.30	0.58	0.30			-0.19	-194	-376	-1	-2.12	0.04
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22		

Figure S1. Regression lines on changes in frequency of perceived higher protein breakfasts (pHPBs) in times per week (tpw) with changes in weight and changes in body fat percent. See Table S3 for statistical reliabilities of regressions.

Figure S2. Regression lines on changes in frequency of perceived higher protein breakfasts (pHPBs) in times per week (tpw) with changes in frequency of perceived energy-dense food consumption (pEDFs) in tpw and changes in frequency of perceived exercise (pExer) in tpw. See Table S3 for statistical reliabilities of regressions.

Figure S3. Regression lines on changes in frequency of perceived energy-dense food consumption (pEDFs) in times per week (tpw) with changes in weight and changes in body fat percent. See Table S3 for statistical reliabilities of regressions.

Figure S4. Regression lines on changes in frequency of perceived exercise (pExer) in times per week (tpw) with changes in weight and changes in body fat percent. See Table S3 for statistical reliabilities of regressions.

Figure S5. All data ($k = 84$), with regression lines on changes in frequency of perceived higher protein breakfasts (pHPBs) in times per week (tpw) with (a) changes in weight, (b) changes in body fat percent, (c) changes in frequency of perceived energy-dense food consumption (pEDFs) in tpw and (d) changes in frequency of perceived exercise (pExer) in tpw; and with regression lines on changes in frequency of perceived energy-dense foods (pEDFs) consumption in times per week (tpw) and changes in frequency of perceived exercise (pExer) in tpw with changes in weight (e) (g) and changes in body fat percent (f) (h). See Table S4 for statistical reliabilities.