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Impact of COVID-19 on health behaviours and body weight: A prospective observational study in a cohort of 1.1 million UK and US individuals

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Abstract

Evidence regarding the impact of COVID-19 on health behaviours is limited. In this prospective study including 1.1 million UK and US participants we collected diet and lifestyle data 'pre- 'and 'peri- 'pandemic, and computed a bi-directional health behaviour disruption index. We show that disruption was higher in the younger, female and socioeconomically deprived ($p < 0.001$). A loss in body weight (-0.45kg) was greater in highly disrupted individuals compared to those with low disruption (-0.03kg). There were large inter-individual changes observed in all 46 health and diet behaviours measured peri-pandemic versus pre-pandemic, but no mean change in the total population. Individuals most adherent to unhealthy pre-pandemic health behaviours improved their diet quality (0.93units) and weight (-0.79kg) compared with those reporting healthy pre-pandemic behaviours (0.08units and -0.04kg respectively), irrespective of relative deprivation. For a proportion of the population, the pandemic may have provided an impetus to improve health behaviours.

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Keywords: coronavirus, physical activity, sleep, nutrition, eating behaviours, social isolation, diet

Abbreviations: ZOE COVID Symptom Study (ZCSS); United Kingdom (UK); United States of America (US); Mobile Application (app); Disruption Index (DI); Diet Quality

Score (DQS); Food Frequency Questionnaire (FFQ); Body Mass Index (BMI); (SEM)
Structural equation modelling; (IMD) Index of Multiple Deprivation

Introduction:

Mandatory public health initiatives to control and limit COVID-19 disease spread have led to dramatic changes in day-to-day routines, resulting in increased social isolation ^{1,2}, employment and financial insecurities ³, and an altered food environment ⁴. This is placing most of the world's population in a unique global experiment on a massive scale. Small European-based studies have observed exacerbation of unfavourable diet and lifestyle behaviours attributable to these changes such as increased sedentary behaviour, more snacking, less fresh food consumption and weight gain, although the published data are inconclusive ⁵⁻⁷.

At an individual level, significant life events are associated with changes in health behaviours such as alcohol intake ⁸, sleep ^{9,10}, diet ^{11,12} and physical activity ¹³. The complex interrelation of these health behaviours potentially mediates increases in body weight observed during adulthood ¹⁴⁻¹⁶, impacting the number of adults living with excess weight and consequent morbidities ¹⁷⁻²⁰, which is a significant public health threat ²¹. Therefore, understanding how health behaviours change in the context of a pro-longed pandemic is critical to understanding its long-term consequences, and to inform short- and long-term strategies to prevent excess weight gain.

In a prospective observational cohort study of 1.1 million participants from the ZOE COVID Symptom Study (ZCSS) we: i) describe the self-reported impact of the COVID-19 pandemic on diet and health behaviours using a composite disruption

index, ii) determine the association of diet and lifestyle behaviours with weight change during the pandemic, and iii) explore the relationship between pre-pandemic behavioural patterns and change in specific diet and lifestyle behaviours.

There were large inter-individual changes observed in all 46 health and diet behaviours measured peri-pandemic versus pre-pandemic, but no mean change was observed in the total population. Individuals most adherent to unhealthy pre-pandemic diet and health behaviours were more inclined to improve their overall diet quality and lose weight, irrespective of relative deprivation, whilst those most adherent to healthy pre-pandemic behaviours exhibited little change in health behaviours. Disruption of health behaviours resulting from the pandemic was higher in the younger, female, and socioeconomically deprived segment of the population. However, a greater disruption was associated with a more variable change in weight and greater weight loss compared to less disrupted individuals, suggesting that the disruption resulted in a more favourable diet and lifestyle change for a proportion of people. Structural equation modelling revealed that changes in physical activity and diet quality during the pandemic were the most relevant factors associated with weight change.

Our data provide quantitative evidence about the impact of the COVID-19 pandemic on lifestyle behaviours, and indicate that the perceived negative impact of the pandemic on health behaviours and factors that exacerbate this, may not hold true²². Indeed, the pandemic may have provided the impetus to improve many diet and lifestyle behaviours amongst a large proportion of the population.

Results

Characteristics of participants responding to the diet and lifestyle survey

A detailed dataset from 1.1 million respondents: Within the ZCSS, we launched a diet and lifestyle longitudinal, observational cohort study (United Kingdom (UK) 31/07/2020 to 25/09/2020, United States of America (US) 25/09/2020 to 30/11/2020) concurrent with other ongoing ZCSS investigations. For this study, participants were invited to complete a retrospective diet and lifestyle questionnaire (see **Methods**) assessing diet quality, diet habits, and lifestyle behaviours at two time points; (1) 'peri-pandemic', described as the previous month from participant access, and (2) 'pre-pandemic' described as the month of February 2020. Baseline participant characteristics including demographics and comorbidities were also assessed from the ZCSS ²³. For UK data, an Index of Multiple Deprivation (IMD) was assigned to participants as a surrogate measure of deprivation. IMD provides an estimate of relative deprivation across several domains (including income, employment, and education) by geographical region ²⁴.

After exclusion of pregnant women, incomplete questionnaires, and implausible data (see **Methods**), data were available for n=909,096 peri-pandemic and n=310,565 pre- and peri- pandemic participants. The characteristics of the participants who completed the diet and lifestyle survey peri-pandemic are summarised in **Table 1**, **Supplemental Table 1 and 2**. Compared to the average UK population, UK participants who completed the diet and lifestyle survey were older (mean age 52 vs 41 years respectively), had a lower BMI (25 vs 27 kg/m² respectively), resided in less deprived areas (for IMD range 8-10: 41 vs 30 % and for IMD range 1-3: 10 vs 30 %

respectively) and were less likely to smoke. The UK proportion of males and non-white UK ethnicities was also lower amongst surveyed participants versus the general population (33 vs 49 % and 4 vs 14 % respectively). The proportions of respondents across geographical regions in the UK were broadly similar to the UK population distribution. A similar pattern was observed for the US cohort (**Table 1 and Supplemental Table 1**).

Prior to data analysis, the UK cohort was divided into discovery (n=425,657) and validation (n=422,285) sets, owing to slight differences in data collection processes (see **Methods** and **Supplemental Table 2**). Data from 61,154 participants from the US were used as an independent replication cohort (see **Methods**).

Table 1. Characteristics of app users; all UK participants, and from whom pre- and peri-pandemic data are included in analyses.

	All UK participants (n = 847,942)*	UK Discovery cohort (n = 207,722)*#	UK Validation cohort (n = 76,868)*#	US Replication cohort (n = 14,366) #
Basic characteristics				
Male/Female	33.4/66.5%	31.0/68.9%	24.0/76.0%	17.5/82.4%
Age (Y)	52 (40, 62)	58 (48, 66)	50 (39, 59)	61 (47, 68)
Weight (kg)	73.4 (63.9, 85)	72.0 (63.0, 84.3)	74.3 (64.8, 87.0)	74.7 (64.3, 88.3)
BMI (kg/m ²)	25.3 (22.8, 28.7)	25.1 (22.7, 28.5)	26.1 (23.3, 30.0)	26.6 (23.5, 31.0)
Smokers	3.0%	2.1%	2.9%	3.0%
Ethnicity				
Asian	1.4%	0.8%	1.6%	3.8%
Black	0.3%	0.2%	0.4%	3.2%
Chinese	0.3%	0.2%	0.4%	Native American 1.3%
Middle Eastern	0.3%	0.2%	0.4%	Native Hawaiian 0.4%
White	95.8%	97.1%	95.1%	88.4
Mixed other	1.0%	0.8%	1.2%	-
Mixed white/black	0.4%	0.3%	0.4%	-
Other	0.3%	0.4%	0.5%	1.6
Preconditions				
Diabetes	3.1%	3.8%	2.9%	5.2%
Heart disease	2.9%	3.8%	2.5%	6.0%
Kidney disease	0.8%	0.9%	0.7%	1.8%
UK location				
England	80.7%	80.8%	81.2%	-
Scotland	5.4%	5.3%	5.5%	-
Wales	4.7%	4.5%	4.6%	-
Northern Ireland	0.6%	0.5%	0.6%	-
Index of multiple deprivation				
1-3	10.2%	8.7%	10.9%	-
4-7	34.6%	34.2%	35.5%	-
8-10	40.5%	42.4%	39.4%	-

Data are percentages, unless units are not given, whereby data are median (25th, 75th percentile).

*Some questions were not answered, data here is a percentage of those that answered. #Those who completed pre- and peri-pandemic, those who completed peri-pandemic only are not included. Full dataset can be found in Supplemental Table 1.

Application of a novel lifestyle Disruption Index

A novel disruption index revealed that lifestyle disruption resulting from the pandemic varied according to sex, age and level of deprivation: To quantify

lifestyle disruption attributable to the pandemic, we computed a novel disruption index (DI) including 5 metrics; Diet Quality Score ²⁵, alcohol frequency, physical activity, snacking frequency (food consumed outside of main meals) and weekday sleep duration (see **Methods**). These domains were selected to capture the primary diet and lifestyle behaviours associated with multiple health outcomes including obesity ^{26–31}. The DI was independent of direction of change, ranged from 0 (no disruption) to 5 (change in all five health behaviour domains) and approximated a normal distribution (**Figure 1a**). In the UK discovery cohort, most participants experienced a moderate level of disruption (65.5%; $DI \geq 2$), while 15% had a high level of disruption ($DI \geq 4$). The DI (Figure 1a) was different (chi-squared) according to sex ($P < 0.001$, effect size: 0.119), age category ($P < 0.001$, effect size: 0.274), assigned level of deprivation ($P < 0.001$, effect size: 0.066), and geographical location ($P < 0.001$, effect size=0.018); with a greater DI among younger individuals, females and people living in more deprived areas. Similar patterns for age and sex was observed for the US replication cohort. Participant characteristics according to the DI scores, for the UK and US are detailed in **Supplementary Table 3**.

A greater disruption is associated with a larger bi-directional change in weight:

The mean overall change in body weight was small in the UK discovery cohort; mean change (10th, 90th percentile) was -0.1 (-4.1, 3.6) kg. However, weight change was highly variable among individuals, with 32% of participants losing a mean body weight of -4.0kg (10th centile; -8.2, 90th centile; -0.9) and 34% gaining a mean body weight of 3.5kg (10th centile; 0.9, 90th centile; 6.3) during the pandemic (**Supplemental Table 4**). A similar pattern and magnitude of change was also observed for the US replication cohort (**Supplemental Table 4**). Owing to the

marked bi-directional weight change in the study population, we separately examined associations according to weight change, loss and gain.

When we analysed the association between the DI and body weight change, we observed a more pronounced and variable weight change (both loss and gain) among individuals with a high DI (CV; UK discovery cohort; 1355%, US; 1750%) compared with those with a low DI (CV; UK discovery cohort; 1142%, US; 1531%); **Figure 1b, Supplemental Table 3**. Weight loss and gain in the high DI group (mean (10th, 90th percentile)) was -5.2 (-10.9, -1.0) kg and 4.0 (1.0, 8.0) kg respectively, compared with -3.2 (-6.3, -0.6) kg and 3.1 (0.5, 5.4) kg respectively in the low DI group (all $p < 0.001$). A similar pattern and magnitude of weight loss and gain was observed in the US according to DI (**Supplemental Table 3**).

In the UK, we showed that the DI was associated with weight changes after adjusting for potential confounders (age and sex) in which the association was similar but of greater magnitude among individuals living in areas with low deprivation (IMD; 8-10, β -0.041, 95%CI: -0.194, -0.137) compared with high deprivation (IMD; 1-3, β -0.024, 95%CI: 0.-13, - 0.057). When stratified according to DI groups and deprivation index, there was a similar magnitude of weight loss between levels of deprivation, but a moderately higher weight gain in the UK group residing in more deprived areas (4.4kg) versus the group in less deprived areas (3.8kg) within the highly disrupted group (**Supplemental Table 3**). This observation suggests that community-level deprivation factors may not impair the potential positive behavioural effects of disruption, but may also exacerbate the negative effects to a small extent, with individuals living in more deprived areas being more susceptible to weight gain.

167

168 **Figure 1. Disruption Index population distribution and weight change.**

169 **a.** Community-level disruption Index on a scale of 0-5 including 5 domains (Diet Quality
170 Score, snacking frequency, alcohol intake frequency, physical activity and weekday sleep
171 duration), stratified according to sex, age and multiple deprivation index based on residence

(IMD) in the UK cohort. **b.** Change in body weight during the pandemic (pre minus pandemic values) stratified according to low (≤ 1) or high (≥ 4) disruption index in the UK discovery and US replication cohort. **c.** Geographical distribution of disruption index and change in weight in the UK discovery cohort.

Physical activity and diet quality are important determinants of weight gain

during the pandemic: We next examined the association of changes in the 5 lifestyle behaviour domains captured by the DI and age³², with body weight change (bi-directional) using structural equation modelling (**Figure 4a and d**). For individuals who gained weight during the pandemic, a reduction in physical activity, diet quality, and an increase in alcohol intake and snacking were moderately associated with weight gain. Among individuals who lost weight during the pandemic, contrasting associations were observed. This trend remained when examined within strata of community level deprivation (**Supplemental Table 5**), **Figure 4b, c, e and f**; although the effect size was slightly greater in individuals residing in more deprived areas. Therefore, in accordance with most population based strategies, our results show that diet quality and physical activity are the most promising targets to prevent weight gain across all socioeconomic classes during a global pandemic.

Figure 2. Association between diet and lifestyle and change in weight pre- to peri-pandemic. Structural equation modelling (SEM) showing the associations between exposures identified by machine learning and outcome (body weight increase/decrease). **a.** overall increase, **b.** body weight increase in the high IMD (IMD8-10) sub-population, **c.** body weight increase in the low IMD (IMD1-3) sub-population, **d.** overall decreased body weight, **e.** body weight decrease in high IMD (IMD8-10) sub-population, **f.** body weight decrease in low IMD (IMD1-3) sub-population. Blue arrows represent indirect effects on body weight. Red arrows represent direct effects on body weight. Dashed arrows represent inverse

effects on body weight. Numbers represent strength of association (standardised β coefficients). *significant at $P < 0.05$. Full dataset seen in **Supplementary Table 5**.

Changes in separate lifestyle, dietary habits and diet quality pre- and peri-pandemic

There was no mean change in the total population, but large individual level changes in lifestyle, diet habits and diet quality:

To assess the changes in individual exposure variables that contribute to the disruption and weight change caused by the pandemic, we next explored the direction of change in the different health behaviours measured, pre- and peri-pandemic (**Table 2** and **Figure 3a** and **b**, **Supplemental Table 4, 6 and 7**). In accordance with the negligible average change in weight across the population, there was minimal average change in all diet and lifestyle variables in response to the pandemic (in the UK and US). However, when assessed according to the proportion of individuals who increased or decreased specific lifestyle behaviour, the magnitude of the change was larger. For example, in the UK discovery cohort, although there was overall minimal mean change in the Diet Quality Score (mean (10th and 90th percentile)) (0.3 (-2.0, 2.0)), more participants increased their score (39% by a mean of 1.8 (1.0, 3.0) than decreased (26% by a mean of -1.7 (-3.0, -1.0)). Likewise, a higher proportion of participants (32.5%) increased daily fruit and vegetable portions (by mean 2.1 (1.0, 5.0), from 3.5 (0.0, 6.0) to 5.6 (3.0, 8.0) portions/d) than decreased (22.7%) (by mean -1.7 (-3.0, -1.0), from 5.6 (3.0, 8.0) to 3.8 (1.0, 7.0) portions/d), consistent with a level that would confer significant health effects^{27,33}. There was also only a minimal mean change in the number of snacks consumed per day (by mean -0.1 (-1.0, 1.0), but a large number of individuals increased (18%) (by mean 1.4 snacks/d (1.0, 2.0) (from

1.0/d)) and decreased (22%) (by mean -1.3 snacks/d (-2.0, -1.0) (from 2.5/d)). More people increased their weekday sleep (15%) than decreased (9%) although the magnitude of change was similar (mean +/- 1.2 hrs). Interestingly, for frequency of alcohol intake, the proportion of people increasing (18.4%) was greater than the proportion decreasing (11.2%), whilst the inverse was the case for the amount at each drinking event (10.7% increasing vs 13.5% decreasing units); suggesting that total amount of alcohol (frequency x units) consumption may have been unchanged. Notably, most participants reported no change (92.8%) in food access, likely a reflection of the survey demographic, although more participants reported a decrease in food access (5.8%) versus an increase (1.4%).

A similar pattern of change in the individual variables was observed in the UK validation cohort and US replication cohort, with the exception of physical activity levels. In the UK the proportion of participants increasing and decreasing their physical activity was similar (in both cohorts) yet in the US the proportion of participants decreasing their physical activity (35.6%) was greater than those increasing (24.1%) (**Table 2 and Figure 3**). The moderately greater magnitude of change in the UK validation and US replication cohorts versus the UK discovery cohort is likely a consequence of the different data collection methods (see **Methods**). All other variables from the questionnaire, including full FFQ data, are reported for pre- and peri-pandemic, as well as the change, in **Supplementary Tables 4, 6 and 7**.

Table 2. Pre- and peri-pandemic data, percentage increase/decrease, and size of change

	Averaged data			Increase		Decrease	
	Pre-pandemic	Peri-pandemic	Change (10 th , 90 th)	Participants (%)	Change (10 th , 90 th)	Participants (%)	Change (10 th , 90 th)
UK Discovery cohort							
Anthropometrics							
Weight (kg)	74.9 (15.8)	74.8 (15.6)	-0.1 (-4.1, 3.6)	34.0	3.5 (0.9, 6.3)	32.0	-4.0 (-8.2, -0.9)
BMI (kg/m ²)	26.0 (4.3)	25.9 (4.3)	-0.04 (-1.5, 1.2)	34.0	1.1 (0.3, 2.3)	32.0	-1.3 (-2.9, -0.3)
LSFFFQ Diet questionnaire							
Diet quality score	10.8 (1.8)	11.1 (1.8)	0.3 (-2.0, 2.0)	39.0	1.8 (1.0, 3.0)	26.0	-1.7 (-3.0, -1.0)
Fruit Portions	2.0 (1.3)	2.1 (1.3)	0.2 (-1.0, 1.0)	24.0	1.5 (1.0, 3.0)	15.0	-1.3 (-2.0, -1.0)
Vegetable portions	2.5 (1.3)	2.7 (1.3)	0.1 (-1.0, 1.0)	23.0	1.6 (1.0, 3.0)	17.0	-1.4 (-2.0, -1.0)
Glasses of juice	0.3 (0.6)	0.3 (0.6)	0.02 (0.0, 0.0)	8.0	1.3 (0.5, 3.0)	6.0	-1.3 (-3.0, -1.0)
Activity behaviours							
Weekdays sleep (h)	7.0 (1.0)	7.0 (0.9)	0.1 (0.0-1.0)	15.0	1.2 (1.0, 2.0)	9.0	-1.2 (-2.0, -1.0)
Weekends sleep (h)	7.4 (1.1)	7.3 (1.0)	-0.04 (-1.0-0.0)	8.0	1.2 (1.0, 2.0)	11.0	-1.2 (-2.0, -1.0)
Eating behaviour							
Number of main meals [#]	1.9 (0.7)	1.9 (0.6)	0.04 (0.0, 0.0)	7.0	1.4 (1.0, 2.0)	6.0	-1.1 (-2.0, -1.0)
Numbers of snacks	1.6 (1.1)	1.5 (1.0)	-0.1 (-0.1, 1.0)	18.0	1.4 (1.0, 2.0)	22.0	-1.3 (-2.0, -1.0)
Eats breakfast (%)	80.6	83.4	2.8	-	-	-	-
Worried about control (%) [†]	15.2	18.4	3.3	-	-	-	-
UK Validation cohort							
Anthropometrics							
Weight (kg)	77.1 (16.5)	77.2 (16.2)	0.1 (-6.3, 5.9)	49.0	4.1 (1.0, 7.7)	36.0	-5.2 (-10.4, -1.0)
BMI (kg/m ²)	27.1 (5.4)	27.2 (5.4)	0.1 (-2.2, 2.0)	49.0	1.5 (0.4, 2.7)	36.0	-1.8 (-3.7, -0.4)
LSFFFQ Diet questionnaire							
Diet quality score	10.5 (1.9)	10.9 (1.9)	0.4 (-2.2, 3.0)	44.0	2.2 (1.0, 4.0)	30.0	-1.9 (-3.0, -1.0)
Fruit Portions	1.8 (1.3)	2.0 (1.2)	0.2 (-1.0, 2.0)	32.0	1.5 (1.0, 3.0)	21.0	-1.3 (-2.0, -1.0)
Vegetable portions	2.4 (1.4)	2.7 (1.3)	0.3 (-1.0, 2.0)	31.0	1.7 (1.0, 3.0)	19.0	-1.3 (-2.0, -1.0)
Glasses of juice	0.3 (0.6)	0.3 (0.6)	0.02 (0.0, 0.5)	11.0	1.2 (0.5, 2.0)	8.0	-1.3 (-2.0, -0.5)
Activity behaviours							
Weekdays sleep (h)	6.9 (1.0)	7.0 (1.0)	0.1 (-1.0, 1.0)	33.0	1.2 (1.0, 2.0)	14.0	-1.3 (-2.0, -1.0)
Weekends sleep (h)	7.5 (1.2)	7.4 (1.1)	-0.1 (-1.0, 1.0)	24.0	1.3 (1.0, 2.0)	18.0	-1.3 (-2.0, -1.0)
Eating behaviour							
Number of main meals [#]	1.9 (0.7)	2.0 (0.6)	0.1 (0.0, 1.0)	12.0	1.4 (1.0, 2.0)	9.0	-1.0 (-1.0, -1.0)
Numbers of snacks	1.8 (1.2)	1.8 (1.1)	0.0 (-2.0, 2.0)	30.0	1.5 (1.0, 2.0)	31.0	-1.5 (-2.0, -1.0)
Eats breakfast (%)	73.9	78.3	4.4	-	-	-	-
Worried about control (%) [†]	26.6	36.3	9.7	-	-	-	-
US Replication cohort							
Anthropometrics							
Weight (kg)	77.8 (17.5)	77.5 (17.2)	-0.3 (-6.8, 5.0)	44.0	3.8 (0.9, 7.7)	39.0	-5.0 (-10.4, -0.9)
BMI (kg/m ²)	27.8 (5.9)	27.8 (5.8)	-0.1 (-2.3, 1.8)	44.0	1.4 (0.3, 2.7)	39.0	-1.8 (-3.7, -0.4)
LSFFFQ Diet questionnaire							
Diet quality score	10.8 (1.7)	10.5 (1.7)	0.3 (-0.2, 3.0)	41.0	2.0 (1.0, 4.0)	29.0	-1.7 (-3.0, -1.0)
Fruit Portions	1.5 (1.1)	1.7 (1.1)	0.2 (-1.0, 1.0)	29.0	1.4 (1.0, 2.0)	18.0	-1.2 (-2.0, -1.0)
Vegetable portions	2.0 (1.4)	2.3 (1.3)	0.3 (-1.0, 2.0)	30.0	1.7 (1.0, 3.0)	20.0	-1.3 (-2.0, -1.0)
Glasses of juice	0.2 (0.6)	0.3 (0.6)	0.02 (0.0, 0.0)	9.0	1.3 (0.5, 3.0)	8.0	-1.2 (-2.0, -0.5)
Activity behaviours							
Weekdays sleep (h)	7.0 (1.0)	7.0 (1.0)	0.1 (-1.0, 1.0)	20.0	1.2 (1.0, 2.0)	15.0	-1.3 (-2.0, -1.0)
Weekends sleep (h)	7.6 (1.2)	7.5 (1.1)	-0.05 (-1.0, 1.0)	13.0	1.3 (1.0, 2.0)	16.0	-1.3 (-2.0, -1.0)
Eating behaviour							
Number of main meals [#]	2.0 (0.8)	1.8 (1.0)	0.03 (-1.0, 1.0)	11.0	1.6 (1.0, 3.0)	14.0	-1.1 (-1.0, -1.0)
Numbers of snacks	1.8 (1.2)	2.0 (0.6)	0.1 (-1.0, 1.0)	27.0	1.4 (1.0, 2.0)	25.0	-1.3 (-2.0, -1.0)
Eats breakfast (%)	73.0	76.9	3.9	-	-	-	-
Worried about control (%) [†]	20.5	33.7	13.2	-	-	-	-

Data are presented as means (SD) unless otherwise stated. [#]Not including breakfast. [†]Worried about losing control of eating.

Figure 3. Proportion of the population changing frequency of intake of food groups and behaviours. Percentage of cohort that changed (increase/decreased) the frequency of dietary intake and lifestyle behaviours from pre- to peri-pandemic, obtained from the amended Leeds Short Form Food Frequency Questionnaire and others, in the **a)** UK discovery **b)** UK validation and **c)** US replication cohorts.

257 ***An unfavourable pre-pandemic diet and lifestyle behaviour is associated with***
258 ***improved changes to diet and lifestyle:*** To explore the impact of pre-pandemic
259 diet and lifestyle behaviours on the variable response to the pandemic reported
260 above, we undertook a factor analysis (see **Methods**). Two distinct diet and lifestyle
261 patterns were identified and labelled as a 'healthy 'and an 'unhealthy 'pattern based
262 on items and loadings summarised in **Figure 4** and **Supplementary Table 8**. The
263 'healthy 'pattern was characterised by lower intakes of alcohol, fast food and
264 processed meats, a higher intake of cheese and fibre-rich cereals and higher levels
265 of physical activity. The 'unhealthy 'pattern differed, with a lower Diet Quality Score,
266 lower intakes of fruit and vegetable portions, higher intakes of crisps, savoury
267 snacks, sweets, biscuits and processed meats, and lower levels of physical activity
268 generally observed. A broadly similar pattern was displayed in the US replication
269 cohort, albeit with increased emphasis on salad and oily fish for the 'healthy 'pattern
270 and fast food for the 'unhealthy 'pattern.

Figure 4. Loadings of diet and health behaviour variables to ‘healthy ’and ‘unhealthy ’ clusters. Loadings (≥ 0.1) for ‘healthy ’(a) and ‘unhealthy ’(b) patterns in the UK discovery and ‘healthy ’(c) and ‘unhealthy ’(d) patterns in the US replication cohort. Full breakdown of the loading of each dietary and health behaviour variable for the ‘healthy ’and ‘unhealthy ’ pattern can be seen in **Supplementary Table 8**.

We observed differences in participant’s demographic and behavioural characteristics between quartiles of the diet and lifestyle patterns (**Supplementary Table 9 and 10**).

280 For example, in the UK, those with the highest adherence to the 'healthy 'pattern (Q4
281 vs Q1) were on average older (61 vs 56 years), more likely to be female (73 vs 62
282 %), less likely to smoke (0.8 vs 4.1 %) and more likely to reside in an area with a
283 lower level of deprivation (44.6 vs 40.5 with IMD 8-10) than those with the least
284 adherence (all $p < 0.001$) (**Table 3**). The reverse pattern was observed for those most
285 and least adherent to the 'unhealthy 'pattern. A broadly similar pattern was observed
286 in the US replication cohort (**Supplementary Table 9**).

287
288 We next examined the association between pre-pandemic diet and lifestyle
289 behaviours with the peri-pandemic change in health behaviours. We found that
290 individuals most adherent to the 'unhealthy 'pre-pandemic lifestyle pattern lost more
291 weight than those reporting higher adherence to the 'healthy 'lifestyle pattern (by
292 1.1kg) (**Table 3**). The same trends of association were also observed in other diet
293 and lifestyle measures; with a larger increase in Diet Quality Score, fruit and
294 vegetable consumption and a larger decrease in the number of snacks among those
295 most adherent to the 'unhealthy 'pattern compared with the 'healthy 'lifestyle pattern.
296 These findings suggest that participants with unhealthy behaviours in the pre-
297 pandemic phase were more likely to implement healthy changes. This may be a
298 consequence of a greater scope for improvement in the 'unhealthy 'group, whilst
299 those classified as having a healthy pre-pandemic lifestyle pattern, tended to retain
300 their 'beneficial 'health behaviours and experienced minimal change. This
301 observation was also reflected in the lower DI in those highly adherent to the
302 'healthy 'pattern and the higher DI in those adherent to the 'unhealthy 'pattern (both
303 $p < 0.001$). A similar pattern of response was observed in the US replication cohort,
304 but with a greater magnitude of favourable change in those most adherent to the

unhealthy lifestyle, possibly due to minimal differences in data collection (see **Methods**).

To assess if the population demographics were driving this finding, in the UK, we stratified individuals most adherent to the 'unhealthy' pattern according to their community-level deprivation, age, sex and geographical location. When stratified according to deprivation (IMD 1-3 vs 8-10), the improvement in diet quality (0.91 vs 0.92 units respectively) and reduction in body weight (-0.5 vs. -0.8 kg respectively) remained, although attenuated. Age, sex and country also had only a small impact on the change in weight (aged 18-25 yrs; -1.1 vs. aged >65 yrs; -0.6 kg; male -1.1 vs. female -0.6 kg; England -0.8 vs. Wales -0.8 vs. Scotland -0.7 vs. Northern Ireland -0.9 all kg) and minimal impact on diet quality score (aged 18-25 yrs; 0.8 vs. aged >65 yrs; 0.8, England 0.9 vs. Wales 1.0 vs. Scotland 0.9 vs. Northern Ireland 0.7, all units). Therefore, irrespective of community-level deprivation, age, sex and location, individuals most adherent to an 'unhealthy' pre-pandemic pattern experienced beneficial changes in diet quality and weight.

Taken together, our data suggest that the perceived negative impact of the pandemic on diet and lifestyle behaviours may not hold true for all.

Table 3. Characteristics and outcomes for upper and lower quartiles within 'Unhealthy' and 'Healthy' patterns, clustered using principal component analysis (PCA).

UK Discovery cohort				
	Unhealthy pattern		Healthy pattern	
	Q1	Q4	Q1	Q4
Descriptives				
Basic characteristics				
Male/Female (%)	21.2/78.7	39.8/60.1	37.7/62.3	27.5/72.5
Age (Y)	61 (53, 68)	53 (43, 62)	56 (46, 64)	61 (52, 67)
Race: white	97.5	97.3	97.0	97.7
Smokers	1.2	2.8	4.1	0.8
Preconditions				
Diabetes	2.8	3.9	4.6	2.2
Heart disease	3.4	3.1	3.8	3.4
Kidney disease	0.7	0.9	0.9	0.7
UK location				
England	83.2	79.1	81	81
Scotland	4.4	6.3	5.0	5.7
Wales	3.7	5.1	5.1	4.1
Northern Ireland	0.4	0.7	0.6	0.5
Index of multiple deprivation				
1-3	7.2	9.8	10.6	6.5
4-7	35.0	34.1	34.9	33.8
8-10	44.7	40.4	40.5	44.6
Disruption Index				
0	13.3	5.7	8.4	11.1
1	28.3	18.7	22	27.7
4	8.8	17.2	14.2	10
5	2.2	6	4.7	2.5
Changes				
Anthropometrics				
Weight (kg)	0.32 (-3.0, 3.6)	-0.79 (-6.2, 3.6)	-0.24 (-5.2, 4.1)	-0.04 (-3.2, 3.0)
Diet				
Diet quality score	-0.32 (-2.0, 1.0)	0.93 (-1.0, 3.0)	0.37 (-1.0, 2.0)	0.08 (-2.0, 2.0)
Fruit Portions	-0.03 (-1.0, 1.0)	0.13 (-1.0, 1.0)	0.07 (-1.0, 1.0)	0.01 (-1.0, 1.0)
Vegetable portions	-0.09 (-1.0, 1.0)	0.11 (-1.0, 1.0)	0.04 (-1.0, 1.0)	-0.03 (-1.0, 1.0)
Eating behaviour				
Number of snacks	0.04 (-1.0, 1.0)	-0.34 (-2.0, 1.0)	-0.13 (-1.0, 1.0)	-0.11 (-1.0, 1.0)
US replication cohort				
	Unhealthy pattern		Healthy pattern	
	Q1	Q4	Q1	Q4
Basic characteristics				
Male/Female (%)	12.1/87.9	23.2/76.7	18.5/81.4	18.6/81.3
Age (Y)	63 (53, 69)	43 (57, 67)	54 (40, 66)	63 (54, 69)
Race: white	91.6	89.9	90.1	90.0
Smokers	1.7	4.3	4.4	1.6
Preconditions				
Diabetes	3.0	5.8	5.0	3.1
Heart disease	5.4	5.8	5.0	5.5
Kidney disease	0.9	1.5	1.7	1.5
Changes				
Anthropometrics				
Weight (kg)	1.0 (-3.6, 5.4)	-2.0 (-9.5, 4.5)	-0.7 (-8.2, 5.0)	-0.1 (-5.4, 4.5)
Diet				
Diet quality score	-0.53 (-2.0, 1.0)	1.16 (-1.0, 4.0)	0.54 (-1.0, 3.0)	-0.12 (-2.0, 2.0)
Fruit Portions	-0.07 (-1.0, 1.0)	0.22 (-1.0, 1.0)	0.15 (-1.0, 1.0)	-0.03 (-1.0, 1.0)
Vegetable portions	-0.19 (-1.0, 1.0)	0.27 (-1.0, 2.0)	0.18 (-1.0, 1.0)	-0.07 (-1.0, 1.0)
Eating behaviour				
Number of snacks	0.21 (-1.0, 1.0)	-0.43 (-2.0, 1.0)	-0.12 (-1.0, 1.0)	-0.04 (-1.0, 1.0)

*Worried about losing control of eating.

Discussion

The COVID-19 pandemic could be viewed as a unique natural experiment with a major lifestyle disruptor impacting key health behaviours associated with longer-term health outcomes, both at individual-level and for populations as a whole. In this study, using data collected through the largest survey of diet and lifestyle during the pandemic to date, we have described the impact of the pandemic on lifestyle behaviour changes in large samples of the UK and US populations. Through the application of a novel Disruption Index, this study highlights the disruptive nature of the pandemic on health behaviours, which was associated with a higher and more variable bi-directional change in body weight. The magnitude of weight loss (-5.2kg) was greater than the weight gain (4.0kg) in more disrupted individuals, whilst less disrupted individuals experienced no difference in the magnitude of weight loss (-3.2kg) or gain (3.1kg). The health behaviours of females, younger participants and those residing in more deprived areas were the most disrupted during this time period of the pandemic. This observation is a likely consequence of unpaid care and family responsibilities falling disproportionately to women, particularly younger females (26-35 years), with women over-represented in lower-income households³⁴. Although we observed no mean changes in diet and lifestyle behaviours in the total population, upon stratifying the data, considerable inter-individual variation exists. This variability in the response of individual health behaviours to COVID-19 is in agreement with studies exploring the impact of comparable mandatory public health interventions across Europe. The EHLC-COVID19 project in Italy (3,533 participants) observed no mean change in diet or lifestyle habits due to lockdown in 46.1% of respondents, but a perceived weight gain reported by 58.6% and a slight increase in physical activity reported by 38.3% of study participants⁶. Findings from the NutriNet-

Sante cohort in France (37,252 participants, surveyed over 2-months) showed a weight gain in a comparable percentage of the population sample (35%) with an average weight gain of +1.8kg. However, this study observed a lower incidence of weight loss (23% of respondents), with a -2kg average loss compared to our findings³⁵.

Most surprisingly, those participants who were identified to have an ‘unhealthy’ pattern pre-pandemic were more likely to experience improvements in diet quality and greater weight loss peri-pandemic, irrespective of deprivation status. Whilst this may reflect some bias due to the users of the app being self-selected and typically of a higher socio-economic demographic than the UK and US average citizen, the NutriNet-Sante study also observed that positive health behaviour changes were associated with less healthy pre-pandemic behaviours³⁶. These findings suggest that the pandemic may not have had the detrimental impact on diet and lifestyle behaviours for a significant proportion of the population, as had previously been speculated and reported in the media^{37,38}.

Excess body weight has been linked with an increase of COVID-19 severity^{39,40} and chronic disease mortality⁴¹, and is known to be interrelated with social determinants of health, including systematic racism⁴², and disparities in food security and socio-economic status^{43,44}. Bi-directional weight changes were observed between groups stratified by levels of deprivation, with those reporting unhealthy behaviours residing in more deprived areas experiencing more weight gain than for those residing in less deprived areas. However, irrespective of deprivation, physical activity and diet quality were identified as key determinants of both short-term weight gain and loss. Mean change in body weight for those who experienced an increase (3.5kg, SD 5.1kg) or

decrease (-4.0kg, SD 4.8kg) in weight was significant and greater than typical daily body weight fluctuations of 1-2kg⁴⁵. While definitions of clinically significant weight change are not consistent within the literature, >5% decrease in body weight has been associated with improved metabolic function⁴⁶. Follow-up investigations are required to determine if body weight changes are maintained in the long-term and associated with corresponding improvements in metabolic health.

Whilst this study had multiple strengths including sample size, an independent replication cohort, and longitudinal data, we note several limitations. Firstly, the self-reported nature of the data collected with the potential of recall bias with retrospective data collection. Data collection methods were modified part way through the study to minimise participant burden and decrease attrition (see **Methods**). Although we observed no significant difference in baseline characteristics of individuals who had their information collected prior to and after the change, a sensitivity analysis displayed minimal population characteristic differences. Therefore, the UK sample population was divided into a discovery and validation cohort to reduce possible error.

Other limitations include the absence of data on change in smoking behaviour. Additionally, the DI is a crude index designed to determine positive or negative changes in each health behaviour domain, further work is needed to determine how direction of change in the individual components may contribute to health outcomes. Further, only 5 domains were included in the DI and 6 in the SEM, and therefore other health behaviours associated with the pandemic disruption and subsequent weight change are not accounted for. For example, we did not include level of isolation, mental health or comorbidities due to time restraints on participant

questionnaire completion. Other considerations such as job role and furlough status may also be relevant. This should be a consideration for future studies to assist in interpretation of lifestyle behaviour change in response to COVID-19.

Regression to the mean can also be problematic in studies that focus on assessing change in behaviours in subgroups of the population, such as ours, where only a single follow-up assessment is made. This is because the assessment of health behaviours is prone to error, and error tends to be greatest at the extremes of the distribution of the variable being assessed, such as the most and least healthy participants. Thus, to some extent, the improvements in health behaviours seen in people recording the most unhealthy behaviours at baseline could be artificial improvements. Nevertheless, the same degree of change was not observed in people who reported the most healthy baseline behaviours, which reinforces the argument that changes in health seen in either group are likely to be real.

In conclusion, rare and extreme events, such as the COVID-19 pandemic, could be viewed as a major disruptor impacting key health behaviours associated with longer-term health outcomes for populations. However, what becomes clear from this large population-based study is that the pandemic has impacted individuals differently, with those most disrupted being more susceptible to greater weight change.

Targeted approaches towards population groups more susceptible to unhealthy diet and lifestyle behaviours as a result of future disruption may increase the effectiveness of public health initiatives and minimise national and local expenditure. Similarly, focused public health approaches that can support and expand on positive health behaviour changes may be of value.

Methods

Study design and participants

The ZOE COVID Symptom Study mobile application (ZCSS app) was developed by the technology company ZOE in collaboration with King's College London, UK and Massachusetts General Hospital, US. It was made available for free download for Apple and Android users (UK 24/03/2020, US 29/03/2020). The application offers a guided interface developed using Expo and ReactNative (JavaScript). Participants were requested to report information including baseline demographics, comorbidities, daily symptoms, and COVID-19 testing outcomes.

Using the ZCSS app, a longitudinal, observational cohort study investigating diet quality, diet habits and lifestyle changes before and during the pandemic was launched (UK 31/07/2020 to 25/09/2020, US 25/09/2020 to 30/11/2020). Participants were recruited via the app interface. At enrolment, participants consented to the use of their information for research investigations related to COVID-19, diet and lifestyle, and to applicable privacy policies and terms of use. The study was approved by Partners Human Research Committee (protocol 2020P000909) and King's College London ethics committee (REMAS ID 18210; LRS-19/20-18210). The ZCSS app is registered with ClinicalTrials.gov, NCT04331509. Data collected in the app are being shared with other health researchers through the NHS-funded Health Data Research UK (HDRUK)/SAIL Consortium, housed in the UK Secure e-Research Platform (UKSeRP) in Swansea, Wales. Anonymized data are available to be shared with bona fide researchers through HDRUK according to their protocols in the public interest. U.S. investigators are encouraged to coordinate data requests through the COPE Consortium (www.monganinstitute.org/cope-consortium).

Procedures

Information obtained through the ZCSS mobile application has been described in detail previously^{23,47}. Participants were requested to complete a retrospective questionnaire investigating diet quality, diet habits and lifestyle at two time points; (1) 'peri-pandemic', described as the previous month (from user access), (2) 'pre-pandemic' described as the month of February 2020. The sections contained identical sets of questions collated by the research team and included the validated Leeds Short Form Food Frequency Questionnaire (FFQ)²⁵ developed by Cleghorn and listed in the Nutritools (www.nutritools.org) library (**Supplementary Document App Flow**).

Questionnaire Userface: The user experience was drafted in a requirements document by the engineering and product team at ZOE. A designer laid out a format optimised for mobile and tablet devices. The format and the requirements document were reviewed by the researchers. Answer options were developed using a library of standard form components, these included a dropdown list, multi-select checkboxes and user input validation. Interstitial pages provided guidance to the users on how to answer these questions. A prominent callout label displayed the time period at the top of every screen to remind users to '*Answer for the last 4 weeks*' or '*Answer for the month of February 2020*'.

Prior to launching, the release candidate of the app (including the questionnaire) was circulated to internal quality assurance (QA) testers and nutrition researchers to check the delivered software matched the requirements document. Sample data collected from the QA sessions were reviewed and checked to be in an analysable

format. The questionnaire was launched via controlled roll-out to a smaller cohort of users before wider dissemination. Existing users were invited to complete the questionnaire using a feature flag, which allows targeting of specific users before roll-out to wider user base. 199,230 UK users, and 19,079 US users declined the diet study invite in the app.

Participants were prompted to complete an additional consent form to allow processing for data for purposes outside of COVID-19 research, to allow for further investigations into diet and lifestyle aspects independent of COVID-19. As users submit questionnaires to the application, data is submitted in JSON format to REST APIs / WebServers that store the questionnaire response in a Postgres Database that is hosted in Google Cloud Platform operated by ZOE. This data is anonymised and exported daily into Comma Separated Value files that are delivered via Secure FTP from ZOE to the researchers partners for further analysis.

The LSF-FFQ interface was developed by the engineering team in conjunction with the designer using a 4x2 grid of the 8 FFQ 'frequency of consumption' options. Effort was made to retain the original structure and layout of the paper-based validated LSF-FFQ ²⁵. The questionnaire was designed for participants to complete the first section in reference to the previous four weeks (peri-pandemic), and then guided to complete an identical section for the month of February 2020 (pre-pandemic). Additional food items were included in the LSF-FFQ under general consensus by two dietitians and a nutritionist. These food items included fast food, eggs and egg dishes, refined carbohydrates such as white rice, white pasta and white bread, live

probiotic or fermented foods such as kimchi, live yogurt and kefir (**Supplementary Document App Flow**).

Data collection: Data was collected via two similar app flows in the UK (over an 8 week period), and via one app flow in the US (over a 9 week period). In the UK, the questionnaire was released to 1% on 31/07/2020, 2% 04/08/2020, and 100% of users on 06/08/2020. In this first app flow 425,657 participants completed the questionnaire. After reviewing feedback from UK users, the app flow was altered to limit participant burden and to reduce attrition. On 07/08/2020 a new question was added after the participants had completed the first '*peri-pandemic*' section asking '*Has your diet changed?*' [Yes, No or Unsure]. If users answered '*yes*' or '*unsure*' they were invited to complete the '*pre-pandemic*' section. If users answered '*no*' the app flow ended (**Figure 5**). 422,285 participants participated in the second flow. In the US, the questionnaire was launched to 20% of users on 03/09/2020, and 100% on 28/09/2020 (n = 80,306) via the second flow only. Mode completion time for both sections was 14-16 minutes. Within the app, individuals reported their height and weight in response to the questions "About how much do you weigh without shoes?" and "About how tall are you without shoes?". These were converted (if necessary) to kilograms and meters before calculating the BMI (kg/m²). Participant characteristics are described in **Supplementary Table 1**.

Exclusions and cohort interaction analysis: Participants were excluded based on the primary outcome (BMI) if: (1) <2 or > 98th percentile (excluding 0) for weight (kg) and height (cm); (2) pregnant; (3) > 98 percentile for free text options sleep, fruit and vegetable portions, number of meals and number of snacks (excluding 0); (4) both

questionnaire sections left incomplete (**Supplementary Table 7**). Participants were divided into cohorts relative to the flow of the app (**Figure 5**), and by country. The discovery cohort (n=425,657) from the first flow, the UK validation cohort (n=422,285) from the second flow (*'Has your diet changed'*), and the US replication cohort (n=14,366). A sensitivity analysis was performed to assess significant population differences between the discovery and validation cohort. Researchers defined 'change 'and 'no change 'groups within both cohorts relative to a >1 point multi-directional change in diet quality score (no change; ≤ 1 and ≥ -1). Demographic characteristics were compared between the 'change 'and 'no change 'groups (**Supplementary Table 2**). The interaction was plotted between the primary outcome (BMI) and the primary exposure (DQS). To minimise bias, all analyses in this study were performed using the discovery cohort. Disruption index as well as diet and lifestyle pattern analyses were replicated in the UK validation and the US replication cohorts.

Figure 5. Consort Diagram

Disruption Index: A novel diet and lifestyle disruption index (DI) was developed.

Domains sleep (weekdays), physical activity, diet (DQS and snacking frequency), and alcohol intake frequency were selected based on commonality in previous published healthy lifestyle scores^{48,49}. A bi-directional ‘change’ was determined as one point for any change (either +/-) for each variable, with maximum disruption score as 5, and the minimum as 0 (**Supplementary Table 3**).

Pre and peri-pandemic comparisons: In the discovery cohort, and validated in the UK validation cohort, the mean, SD, and 10th and 90th percentiles for ‘pre-pandemic’ and ‘peri-pandemic’, percentage change (between the two time-points), and the number of participants who increased/decreased was applied to the continuous and categorical variables (**Supplementary Tables 4, 5, and 6**). For

continuous variables, the quantity of increase/decrease was also described. Change in body weight, BMI, disruption index, physical activity, alcohol intake (units), snacking, fruit and vegetable intake (combined) and diet quality was visualised across UK geographical regions using python package geopandas v. 0.7.0. IMD was estimated according to small geographical location, or neighbourhood, ranking areas according to multiple deprivation parameters (least deprived = 32844, most deprived = 1). Further reference to deprivation throughout is related to IMD status ²⁴. Deciles for England, Wales and Northern Ireland were pre generated by the official data source ²⁴. For Scotland, the same deciles were applied by the research team.

Factor analysis: Factor analysis with orthogonal transformation (varimax procedure) was used to construct a distinct 'healthy' diet and lifestyle pattern and an 'unhealthy' dietary pattern (loadings and input variables depicted in **Supplementary Table 8**). The dietary patterns were stratified into quartiles to compare demographic characteristics and body weight changes (**Supplementary Table 9 and 10**).

Structural equation modelling (SEM): SEM was used to describe the relationship of exposures of a change in sleep (weekends and weekdays), physical activity, diet (DQS and snacking frequency), and alcohol intake (frequency and quantity) (**Supplementary Table 11**). Age was included in the model owing to its established relationship with BMI ³². Change in body weight was categorised as; (1) an absolute bi-directional change, (2) an increase in body weight, and (3) a decrease in body weight from 'pre-pandemic' to 'peri-pandemic' weight status. Further, stratified models were also developed based on a low and high IMD. The model was fitted under a maximum likelihood framework using covariance matrices. Relative model fit

was assessed using the comparative fit index (0 no fit; 1 perfect fit) ⁵⁰, and the absolute fit by the root mean square error of approximation. Statistical analysis was performed using SPSS (IBM Corp, Armonk, NY, USA), R (v 3.5.1), AMOS and ExeTera.

Ethics

The King's College London Ethics Committee approved the ethics for the app, and all users provided consent for non-commercial use. An informal consultation with TwinsUK members over email and social media before the app was launched found that they were overwhelmingly supportive of the project. The US protocol was approved by the Partners Human Research Committee.

Data availability

Data collected in the app are being shared with other health researchers through the NHS-funded Health Data Research UK (HDRUK)/SAIL consortium, housed in the UK Secure e-Research Platform (UKSeRP) in Swansea. Data from the Diet and Lifestyle Questionnaire can be made available by application to TREC at the Department of Twins Research and Epidemiology at King's College London. US investigators are encouraged to coordinate data requests through the COPE Consortium (www.monganinstitute.org/cope-consortium). Data updates can be found at <https://covid.joinzoe.com>.

Code availability

The app code is publicly available from <https://github.com/zoe/covid-tracker-react-native>.

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Author contributions

Conceptualization: SEB, TDS, JW, SO, CS; Data Curation: BM, MM; Formal Analysis: BM, MM, PF, LN, JM, RG, ERL, AC, MG; Investigation: SS, CH, ERL, SEB, RG, MM, PF, AC, JM, LM, CG; Supervision: SEB; Writing of the Manuscript: MM, ERL, JM, LN, SS, KK, BM, TM, MG, CS, JW, CH, DD, CS, SO, CG, TDS, AC, PF, RG, SEB.

Competing interests

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 635 CH and KK are or have been employees of Zoe. Other authors have no conflict of
 636 interest to declare. The study sponsors (Zoe Global Ltd; JW and GH) contributed as
 637 part of the Scientific Advisory Board in the study design and collection.

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Supplements:

Supplementary tables:

<https://drive.google.com/file/d/1cvWjMW3IDYM4qtUbZfv8rvXYkR35J-cb/view?usp=sharing>

App flow:

https://docs.google.com/document/d/1kgNHjCXUD16cKn8zMRAngHXk_sSE_b_eH4T26s5Cly0/edit?usp=sharing

Figures

Figure 1

Disruption Index population distribution and weight change. a. Community-level disruption Index on a scale of 0-5 including 5 domains (Diet Quality Score, snacking frequency, alcohol intake frequency, physical activity and weekday sleep duration), stratified according to sex, age and multiple deprivation

index based on residence (IMD) in the UK cohort. b. Change in body weight during the pandemic (pre minus peri-pandemic values) stratified according to low (≤ 1) or high (≥ 4) deprivation index in the UK discovery and US replication cohort. c. Geographical distribution of deprivation index and change in weight in the UK discovery cohort.

Figure 2

Association between diet and lifestyle and change in weight pre- to peri-pandemic. Structural equation modelling (SEM) showing the associations between exposures identified by machine learning and outcome (body weight increase/decrease). a. overall increase, b. body weight increase in the high IMD (IMD8-10) sub-population, c. body weight increase in the low IMD (IMD1-3) sub-population, d. overall decreased body weight, e. body weight decrease in high IMD (IMD8-10) sub-population, f. body weight decrease in low IMD (IMD1-3) sub-population. Blue arrows represent indirect effects on body weight. Red arrows represent direct effects on body weight. Dashed arrows represent inverse 2 effects on body weight. Numbers represent strength of association (standardised β coefficients). *significant at $P < 0.05$. Full dataset seen in Supplementary Table 5.

Figure 3

Proportion of the population changing frequency of intake of food groups and behaviours. Percentage of cohort that changed (increase/decreased) the frequency of dietary intake and lifestyle behaviours from pre- to peri-pandemic, obtained from the amended Leeds Short Form Food Frequency Questionnaire and others, in the a) UK discovery b) UK validation and c) US replication cohorts.

Figure 4

Loadings of diet and health behaviour variables to 'healthy' and 'unhealthy' clusters. Loadings (≥ 0.1) for 'healthy' (a) and 'unhealthy' (b) patterns in the UK discovery and 'healthy' (c) and 'unhealthy' (d) patterns in the US replication cohort. Full breakdown of the loading of each dietary and health behaviour variable for the 'healthy' and 'unhealthy' pattern can be seen in Supplementary Table 8.

Figure 5

Consort Diagram

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [BerryDietCovidsupplementarytablesNatureFood2ndFeb.xlsx](#)
- [DietStudyFlow2.pdf](#)