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AUTHOR
King, Alexandra; Mavrommatis, Yiannis; Pilic, Leta; et al.

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A randomised controlled trial to determine the effect of genotype-based personalised diet and physical activity advice for *FTO* genotype (rs9939609) delivered via email on healthy eating motivation in young adults

Alexandra King[1] | **Mark Glaister**[1] | **Kate Lawrence**[1] | **Jonathan Nixon**[1] | **Leta Pilic**[2] | **Yiannis Mavrommatis**[3]

[1]Faculty of Sport, Technology and Health Sciences, St Mary's University, Twickenham, UK

[2]Optimyse Nutrition LTD, Twickenham, UK

[3]Lake Lucerne Institute, Vitznau, Switzerland

Correspondence
Alexandra King, Faculty of Sport, Technology and Health Sciences, St Mary's University, Waldegrave Road, Twickenham TW1 4SX, UK.
Email: alexandra.king@stmarys.ac.uk

Abstract

The prevalence of obesity continues to rise, and public health dietary recommendations are not being adhered to. The transition to higher education is a period of risk for weight gain in young adults and has been demonstrated as a good time to initiate behaviour change. A genotype-based personalised approach to dietary recommendations may motivate young adults to maintain or adopt positive dietary behaviours. The aim of the present study was to determine the efficacy of genotype-based personalised dietary and physical activity advice on healthy eating motivation in young adults. Participants were young adults ($n = 153$), aged 18–25 years. Baseline measures (participant characteristics, height, weight, body mass index [BMI], body fat percentage [BF%], healthy eating motivation and physical activity) were collected. Participants were genotyped for a SNP in the *FTO* gene (rs99396090) and randomly allocated (stratified for genotype) to three different groups (1. Genotype-based personalised advice: dietary and physical activity advice based on genotype, BMI and reported physical activity; 2. Non-genotype-based personalised advice: dietary and physical activity advice based on BMI and reported physical activity; 3. Control: no advice). A week after receipt of advice delivered via email, participants completed the healthy eating motivation questionnaire for a second time. Genotype-based personalised dietary advice did not affect healthy eating motivation: when participants were analysed across the whole group ($p = 0.417$), when analysed according to those informed of a risk or non-risk-associated genotype ($p = 0.287$), or when analysed according to those with a BMI (>25 kg/m^2; $p = 0.336$) or BF% (male >18%, female >31%; $p = 0.387$) outside the healthy range. There was also no significant difference in healthy eating motivation at 1-week in the control or non-genotype-based advice groups. Genotype-based personalised advice for the prevention of obesity did not affect healthy eating motivation in this group of healthy, young adults.

KEYWORDS
behaviour change, diet, genotype, healthy, motivation, personalised nutrition

INTRODUCTION

The prevalence of obesity has risen sharply since the 1990s due to environmental factors such as reduced physical activity and increased availability of highly palatable energy-dense foods (Speakman, 2007). However, overfeeding studies in twins suggest that there is a genetic component to the risk of obesity (Bouchard et al., 1990). It is likely that genetic and environmental risk factors interact, resulting in an increased likelihood of individuals developing obesity based on their genetics if they have unfavourable lifestyle behaviours (van der Klaauw & Farooqi, 2015). A single-nucleotide polymorphism (SNP) in the first intron of the fat mass and obesity-associated (*FTO)* gene was the first common variant identified that could affect the risk of obesity in the general population, and *FTO* is consistently identified in genome-wide association studies (GWAS) to explain the largest proportion of inter-individual genetic variation in body mass index (BMI) (Yeo, 2014). There is strong evidence from large trials and meta-analyses that the risk associated with *FTO* rs9939609 can be moderated by modification of both saturated fat intake (Corella et al., 2011; Phillips et al., 2012; Sonestedt et al., 2009) and physical activity (Celis-Morales et al., 2016; Kilpeläinen et al., 2011) to affect BMI.

Since 80%–90% of individuals who successfully lose weight return to their previous weight; prevention rather than treatment of obesity is a more favourable approach (Rosenbaum & Leibel, 2010). The prevalence of obesity increases with age; in England, 36% of adults aged 65–74 years are obese compared to 13% of those aged 16–24 years (Moody, 2020). Therefore, young adults are an important population to target to prevent this trend from continuing. The transition to higher education and subsequent years at university is a period of risk for weight gain (Deforche et al., 2015; Fedewa et al., 2014), and transition points, such as leaving school in young people, have been demonstrated as a good time to initiate behaviour change (NICE, 2007).

Dietary intake and physical activity have long been identified as modifiable risk factors that can reduce the risk of becoming obese, yet recommendations are not met and worldwide the prevalence of obesity continues to increase (Health Survey for England, 2017; Roberts et al., 2018; The GBD 2015 Obesity Collaborators, 2017). Current public health interventions appear to raise population awareness but fail to translate into modification of behaviour (Croker et al., 2012). Interventions designed to change health-related behaviours are more likely to be successful when theoretical links between the intervention and the behaviour have been considered in the design (Davis et al., 2015; Horne et al., 2017; NICE, 2007; Timlin et al., 2020).

One of the most frequently cited behaviour change theories incorporated in health-related interventions is the Theory of Planned Behaviour (TPB) (Ajzen, 1991; Davis et al., 2015). The theory states that motivation to perform a behaviour (intention) can be predicted from three independent factors: (1) The extent to which an individual has a favourable appraisal of that behaviour (attitude towards the behaviour), (2) An individual's perceived social pressure to perform or not perform the behaviour (subjective norm) and (3) An individual's perception of how easy or difficult it is to perform the behaviour (perceived behavioural control [PBC]). Attitude towards the behaviour is affected by an individual's 'behavioural beliefs'; subjective norms are affected by 'normative beliefs'; and PBC is affected by 'control beliefs'. The 'intention' and 'PBC' have been demonstrated to account for a considerable amount of variation in the behaviour (correlations from 0.20 to 0.78) (Ajzen, 1991). Therefore, to elicit behaviour change, an intervention should aim to address one or more of these factors to increase the motivation of individuals to perform the behaviour.

A genotype-based personalised approach to dietary recommendations has been proposed as a way of motivating individuals to make positive changes in their dietary and physical activity behaviour (Celis-Morales et al., 2015). Genotype-based advice is delivered in combination with other levels of personalisation (phenotypic, clinical and dietary), with the aim to provide more precise and effective advice as well as to encourage behaviour change (Grimaldi et al., 2017). In the context of the TPB, personalisation of behaviour change advice should affect 'behavioural beliefs' which will create a more favourable 'attitude towards the behaviour'. The provision of this advice from a healthcare provider may affect 'normative beliefs' which will have a positive effect on 'subjective norms' (Horne et al., 2017). 'Control beliefs' may be affected if instructions are provided on how to meet the advice, which will increase 'PBC' (Ajzen, 1991). Each of these factors should then increase motivation or 'intention' to perform the behaviour and subsequently change the actual behaviour.

Experimental analogue study designs have been utilised to determine the effect of disclosure of a hypothetical increased genetic risk of obesity on affective outcome measures including motivation to change behaviour. Analogue studies suggest that participants informed of an increased risk of obesity are more motivated to make healthy changes to lifestyle behaviours in comparison to when informed of an average risk (Ahn & Lebowitz, 2018; Frosch et al., 2005; Meisel et al., 2012; Sanderson et al., 2010). However, the studies that have measured motivation to change lifestyle behaviour following actual genotype-based advice have not shown an effect. In the context of risk related to type 2 diabetes (T2D), most studies have demonstrated that communication of genetic risk did not significantly increase intention or motivation to make changes to diet or physical activity behaviour (Godino et al., 2016; Grant et al., 2013), or affect stages of change (Grant et al., 2013; Knowles et al., 2017). Since these studies have not been carried out in the context of obesity prevention and only one

of them was in a healthy population, further research is required to determine whether the findings from analogue studies can be replicated in a study where the actual genetic risk of obesity is communicated to a young adult population. Therefore, the aim of the present study was to determine the efficacy of genotype-based personalised dietary and physical activity advice on healthy eating motivation in a young adult population.

METHODS

Participants

Undergraduate students aged 18–25 years enrolled at a University in September 2019 were recruited to participate in the study. Students aged above 25 years, those who were pregnant or lactating, and those who had a chronic disease, a history of disordered eating or were following a restricted diet, were excluded. The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the St Mary's University Research Ethics Sub-Committee (SMEC_2018-19_052). Written informed consent was obtained from all participants. This study is registered with ClinicalTrials.gov: NCT04096404. All data were collected and stored according to the Data Protection Act 1998 and the Human Tissue Authority.

Experimental design

Baseline measures were collected in person at the University and included participants' height, weight, BF% and waist circumference (WC). A saliva sample was obtained for genotyping. Participants were asked to complete an online questionnaire to measure physical activity and healthy eating motivation. Following the collection of baseline measures from all participants, participants were randomly allocated using the randomisation function in MS Excel by AK (stratified by *FTO* risk and non-risk genotype) to one of three parallel groups: (1) Genotype-based personalised advice; (2) Non-genotype-based personalised advice; (3) Control: no advice. Following allocation to groups, participants in groups 1 and 2 received appropriate dietary and physical activity advice via email and 1 week later all participants were asked to complete the healthy eating motivation questionnaire for a second time (Figure 1). The study was originally designed to measure change in bodyweight over 3 years as the primary outcome; however, due to issues with data collection during the COVID-19 pandemic, healthy eating motivation score (a secondary outcome) was the only planned outcome that could be utilised. Participants were initially asked to report dietary data; however, adherence was very low so it was removed from the study.

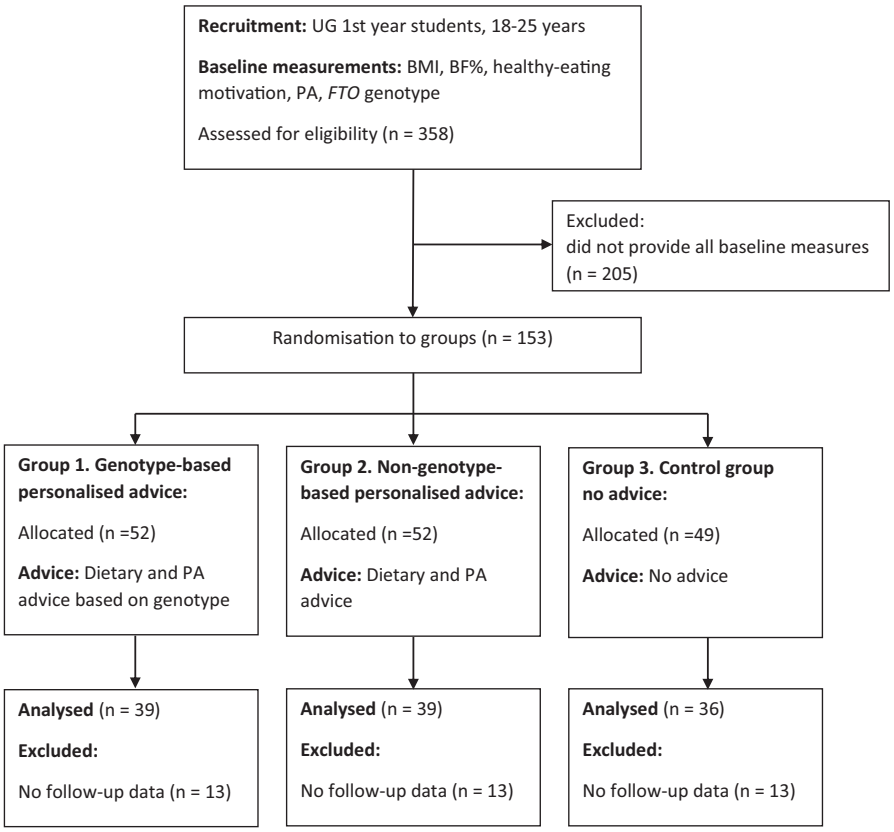

FIGURE 1 Study design flow chart. BF%, body fat percentage; BMI, body mass index; PA, physical activity; UG, undergraduate.

Experimental protocol

Participant characteristics and adiposity indices

Participants were asked to report their age, ethnicity, programme of study, who they lived with and smoking status. Height was measured to the nearest centimetre using a free-standing height measure (Seca UK, Birmingham). Weight was measured to the nearest 0.1 kg and BF% to the nearest 0.1% using a bioelectrical impedance analysis system and scales (Tanita BC-418 Foot-to-FootMPMS-230, Tanita Corporation of America, Inc., IL, USA). Participants' weight was measured clothed without shoes or overgarments. BMI was calculated by dividing participants' weight (kg) by their height (m) squared. Participants with a BMI in the overweight or obese category (>25 kg/m^2) were informed that they were not meeting the BMI recommendation (World Health Organization, 2000). Recommendations for BF% are not provided by the World Health Organization or NICE, and the cut-offs provided by different research papers (Flegal et al., 2009; Gallagher et al., 2000) and manufacturers (MARSDEN; TANITA) vary. In this study, male participants with a BF% >18% and female participants with a BF% >31% were informed that they were not meeting the recommendation for BF%, reported to correspond to a BMI of 25 kg/m^2 (WHO Expert Consultation, 2004).

DNA isolation and genotyping

Genotyping was performed according to a method described elsewhere (Pilic & Mavrommatis, 2018). In brief, genotyping for *FTO* genotype rs9939609 was carried out using the TaqMan® method using qPCR (StepOnePlus Real-time, LifeSciences, Applied Biosystems, CA, USA) with two technical replicates for each sample. The polymerase chain reaction amplification was performed under the conditions specified by the manufacturer. Genotypes were inferred by Thermofisher Connect™ platform. The call rate for rs9939609 was above 95%. Genotype frequencies for *FTO* genotype rs9939609 were within Hardy Weinberg Equilibrium ($p = 0.998$). Individuals with an A allele (A+) were considered the 'risk-associated' genotype, and those without (A–) were considered the 'non-risk-associated' genotype.

Physical activity

Physical activity was measured using the Epic Physical Activity Questionnaire (EPAQ2) (Wareham et al., 2002). The self-reported questionnaire measured participants' physical activity in the previous year. Energy expenditure was estimated by multiplying the time spent on each moderate or vigorous intensity activity (min/week) by the metabolic equivalent (MET) for that activity. Current guidelines for physical activity in the UK are to accumulate at least 150 min of moderate-intensity activity and/or 75 min of vigorous-intensity activity each week (Department of Health and Social Care, 2019), which equates to 500 MET minutes/week (Kaminsky & Montoye, 2014). Participants reporting <500 MET minutes/week of moderate or vigorous intensity physical activity were informed that they were not meeting the recommendation for physical activity.

Healthy-eating motivation

Participants' motivation to eat healthily was measured using the healthy-eating motivation score (Naughton et al., 2015). The healthy eating motivation score was calculated by recording participants' mean score from seven items (response: 1: strongly disagree to 7: strongly agree) (Table 1). Cronbach's alpha (α) for the healthy-eating motivation score items was 0.82; this value is similar to the alpha score of 0.81 reported by Naughton et al. (2015). An $\alpha > 0.7$ has been suggested to indicate adequate internal consistency (Tavakol & Dennick, 2011).

Personalised advice

Behaviour change techniques (BCT) were utilised in the design and implementation of advice provided to groups 1 and 2 to align with constructs of the TPB, and are indicated in Table 2. Incorporated BCTs included: 'fear arousal', 'consequences of their behaviour to them as an individual', 'goal setting', and 'how to perform the behaviour' (Michie et al., 2013). With reference to the TPB, 'fear arousal' and 'consequences of their behaviour to them as an individual'

TABLE 1 Healthy-eating motivation items (Naughton et al., 2015).

Items
1. It is important that the food I eat contains vitamins and minerals
2. It is important that the food I eat keeps me healthy
3. It is important that the food I eat is nutritious
4. I always follow a healthy and balanced diet
5. I eat what I like and I do not worry about healthiness of food *R*
6. The healthiness of food has little impact on my food choices *R*
7. It is important that the food I eat helps me control my weight

Note: *R* Items reverse scored for analysis.

TABLE 2 Personalised advice provided to participants in groups 1, 2 and 3; behaviour change techniques utilised are indicated.

Advice	Group 1: Genotype-based (risk)	Group 1: Genotype-based (non-risk)	Group 2: Non-genotype-based	Group 3
Importance	'Obesity is a risk factor for numerous chronic diseases including diabetes, cardiovascular disease and cancer. The risk of individuals to develop obesity is highly variable. Some of this variation may be explained by the interaction between an individual's DNA variation (genotype) and their diet and physical activity. You can reduce your risk of becoming obese by adhering to the diet and physical activity advice below' *BCT*: fear arousal; consequences of their behaviour to them as an individual		'Obesity is a risk factor for numerous chronic diseases including diabetes, cardiovascular disease and cancer. You can reduce your risk of becoming obese by adhering to the diet and physical activity advice below' *BCT*: fear arousal; consequences of their behaviour to them as an individual	No advice
BMI	Informed of their current BMI, recommendation, and if they were meeting the recommendation; *BCT*: goal setting			No advice
Body fat percentage	Informed of their current BF%, recommendation, and if they were meeting the recommendation; *BCT*: goal setting			No advice
Physical activity	Informed of their current physical activity, recommendation, and if they were meeting the recommendation; *BCT*: goal setting			No advice
Genotype-based	'You have a genetic variation in the *FTO* gene that is associated with a higher risk of obesity; consequently, it is important for you to meet recommendations for physical activity and dietary intake of energy, saturated fat and sugar' 'Research suggests that individuals with your genotype are more likely to become obese. Obesity is linked to numerous chronic diseases such as cardiovascular disease, diabetes and cancer. Individuals with your genotype that are more physically active are less likely to become obese. Individuals with your genotype that eat less saturated fat are less likely to become obese.' *BCT*: fear arousal; consequences of their behaviour to them as an individual	'You do not have a genetic variation in the *FTO* gene that is associated with a higher risk of obesity; you should follow healthy eating and physical activity guidelines'	No advice	No advice
Practical	Provided with information about what to do to reduce their risk of weight gain which included practical tips on the basics of physical activity and healthy eating to help make healthier choices *BCT*: goal setting and how to perform the behaviour			No advice

Abbreviations: BCT, behaviour change technique; BF%, body fat percentage; BMI, body mass index.

were incorporated to target their 'behavioural beliefs'. 'Goal setting' and 'how to perform the behaviour' were incorporated to target 'control beliefs'. The provision of this advice by a university lecturer who is also a registered nutritionist was aimed to target their 'normative beliefs'.

Participants in groups 1 and 2 were informed of their current BMI, BF%, physical activity status, the recommendation for each measure and if they were meeting the recommendation. Participants in group 1 were also provided with personalised advice based on their *FTO* genotype. Both groups 1 and 2 were provided with information about what to do to reduce their risk of weight gain, which included practical tips on the basics of physical activity, based on UK physical activity guidelines for adults and older adults from the Chief Medical Officers (Department of Health and Social Care, 2019), and healthy eating based on the UK Eatwell Guide (Public Health England, 2016). Participants in group 3 were not provided with any advice (Table 2 and Appendix S1).

Statistical methods

According to a sample size calculation, to identify a medium effect size (Cohen's $d = 0.5$), for a two-tailed test, with a power of 0.8 and probability of 0.05, 34 participants per group were required. The power calculation was conducted using the statistical power analyses software G*Power version 3.1.9.2 (Faul et al., 2007). Statistical analysis was carried

out using IBM SPSS Statistics 26 for Windows (IBM Corp, New York, USA). Internal consistency of the healthy-eating motivation score was assessed using α. Measures of centrality and spread are presented as mean ± SD; categorical data are presented as frequencies and percentages. The normality of data was assessed using the Shapiro–Wilk test. Baseline continuous measures were compared between groups using a one-way ANOVA for normally distributed data or an Independent-Sample Kruskal–Wallis test for data that was not normally distributed. Categorical variables were compared between groups using a Chi-squared Test. Two-way mixed ANOVA was used to determine the effect of different levels of personalised advice (control, non-genotype-based advice, genotype-based advice) and time (pre- vs. post-advice) on healthy eating motivation scores. A three-way mixed ANOVA was carried out to assess differences between groups (control, non-genotype-based advice, genotype-based advice), compliance with recommendations (met vs. not met at baseline) and time (baseline vs. 1-week post advice) on healthy eating motivation score. All tests were two-tailed and considered statistically significant when $p < 0.05$.

RESULTS

Baseline characteristics of all participants are presented in Table 3. The mean BMI of all participants was within the healthy category (23.5 ± 3.7 kg/m^2) and 25% of participants were classified as overweight or obese (BMI >25 kg/m^2). The mean BF% of both male (14.2 ± 6.1%) and female (28.2 ± 7.3%) participants was within the healthy range. 23% of male and 27% of female participants had a BF% above the

TABLE 3 Participant baseline characteristics ($n = 153$), presented as frequency (percentage) or mean ± standard deviation.

Characteristic		Group 1 ($n = 52$)	Group 2 ($n = 52$)	Group 3 ($n = 49$)
Gender	Men	24 (46)	22 (42)	22 (45)
	Women	28 (54)	30 (58)	27 (55)
Age (years)		19 ± 2	19 ± 2	19 ± 2
Ethnicity	White	40 (77)	42 (81)	38 (78)
	Asian or Asian British	5 (10)	3 (6)	4 (8)
	Black or Black British	4 (8)	2 (4)	3 (6)
	Other ethnic group	3 (6)	5 (10)	4 (8)
Living situation	At home with parent	14 (27)	17 (33)	18 (37)
	Student accommodation	33 (64)	30 (58)	24 (49)
	Other	5 (10)	5 (10)	7 (14)
Undergraduate programme	Science-based	35 (67)	38 (73)	33 (67)
	Non-science based	17 (33)	16 (31)	16 (33)
Smoking status	Non-smoker	45 (87)	46 (89)	42 (86)
	Light smoker	2 (4)	6 (12)	5 (10)
	Moderate	1 (2)	0 (0)	1 (2)
	Ex-smoker	4 (8)	0 (0)	1 (2)
FTO genotype	TT	23 (44)	23 (44)	21 (43)
BMI (kg/m^2)	AT	20 (39)	20 (39)	20 (41)
	AA	9 (17)	9 (17)	8 (16)
	Men and women	23.7 ± 4.3	23.4 ± 3.6	23.3 ± 3.2
Body fat (%)	Meeting recommendation	40 (77)	38 (73)	37 (76)
	Men	14.3 ± 6.4	15.1 ± 7.0	13.2 ± 4.9
	Meeting recommendation	19 (79)	16 (73)	17 (77)
	Women	29.2 ± 6.8	27.2 ± 6.9	28.2 ± 8.2
Physical activity (MET min/week)	Meeting recommendation	19 (68)	24 (80)	19 (70)
		6191 ± 4051	6622 ± 5182	5497 ± 3771
Healthy eating motivation score	Meeting recommendation	51 (98)	51 (98)	47 (96)
		5.0 ± 0.9	5.0 ± 1.0	5.1 ± 1.1

Abbreviations: BMI, body mass index; MET, metabolic equivalent; FTO, fat mass and obesity-associated genotype (TT: non-risk homozygous, AT: heterozygous; AA: risk homozygous).

recommendation for BF%. Mean reported physical activity levels (6116 ± 4384 MET min/week) were above recommended levels for physical activity and 97% of participants were meeting the recommendation for physical activity. There were no significant differences in any of the baseline characteristics between groups ($p \geq 0.05$; Table 3). Thirty-nine participants did not complete the study (Figure 2). There were no significant differences in age, BMI, BF%, physical activity level or baseline healthy-eating motivation score between participants included in the analysis and those who did not complete the second healthy eating motivation questionnaire ($p \geq 0.05$). There were no significant differences in BMI, BF% or physical activity level between *FTO* genotype groups ($p \geq 0.05$) (data not shown).

The effect of levels of advice on healthy eating motivation

All participants

A two-way ANOVA was used to assess the effect of the level of advice provided on healthy eating motivation before and after the intervention. There was no significant effect of time ($F = 0.025$, $p = 0.875$), group ($F = 0.176$, $p = 0.839$) or time × group interaction on healthy-eating motivation score ($F = 0.881$, $p = 0.417$) (Figure 2).

Participants informed of a risk versus non-risk-associated genotype

Within the genotype-based personalised advice group, a two-way ANOVA was used to assess the effect of being informed of a risk versus a non-risk-associated genotype on healthy eating motivation before and after the intervention. There was a significant effect of risk on healthy eating motivation score ($F = 4.955$, $p = 0.032$). Participants with a risk-associated genotype had a significantly higher healthy eating motivation score than participants with a non-risk-associated genotype at baseline and post-advice. However, there was no significant effect of time ($F = 0.054$, $p = 0.818$), or time × risk interaction on healthy-eating motivation score ($F = 1.383$, $p = 0.287$). Therefore, healthy eating motivation score was unchanged in either group following the disclosure of genotype-based advice (Figure 3).

BMI recommendations

Healthy eating motivation score was compared before and after advice, between participants meeting and not meeting the BMI recommendation and also between groups. There was no significant time × compliance × group interaction on healthy eating motivation ($F = 1.101$, $p = 0.336$).

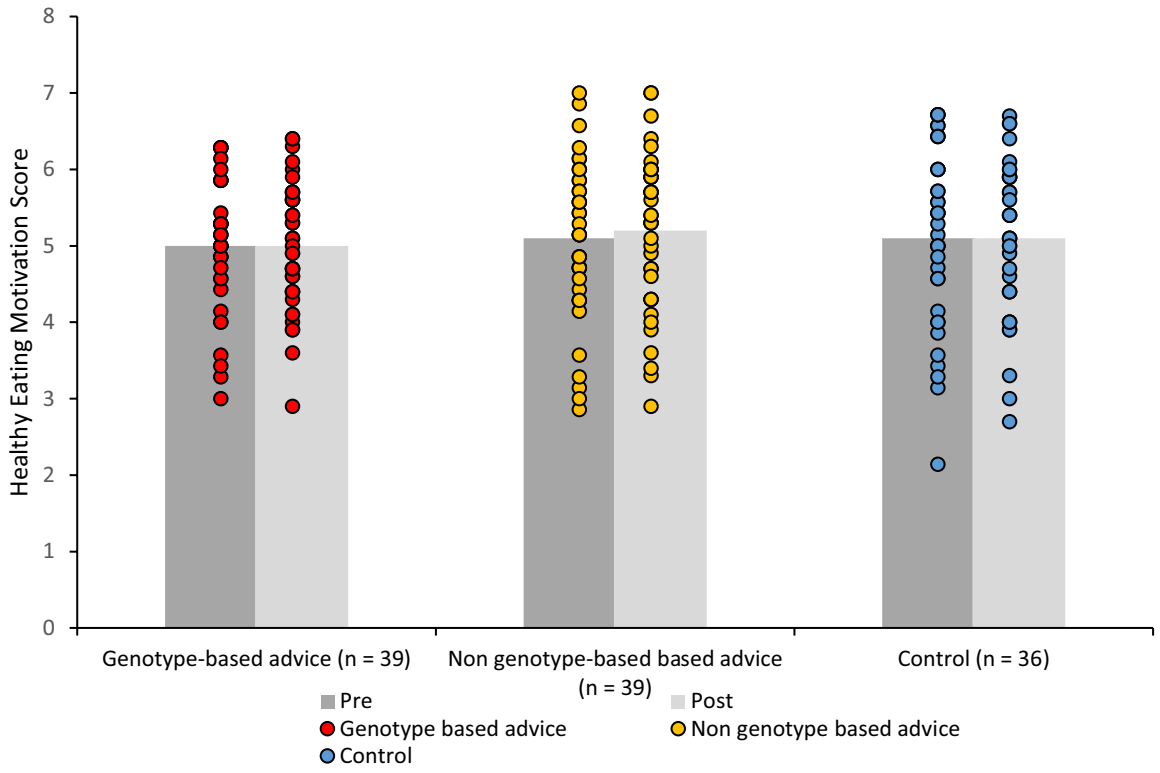

FIGURE 2 Mean healthy eating motivation score pre- and post-advice for participants provided with genotype-based personalised advice, non-genotype-based personal advice or no advice. Dots represent individual scores within each group and time point.

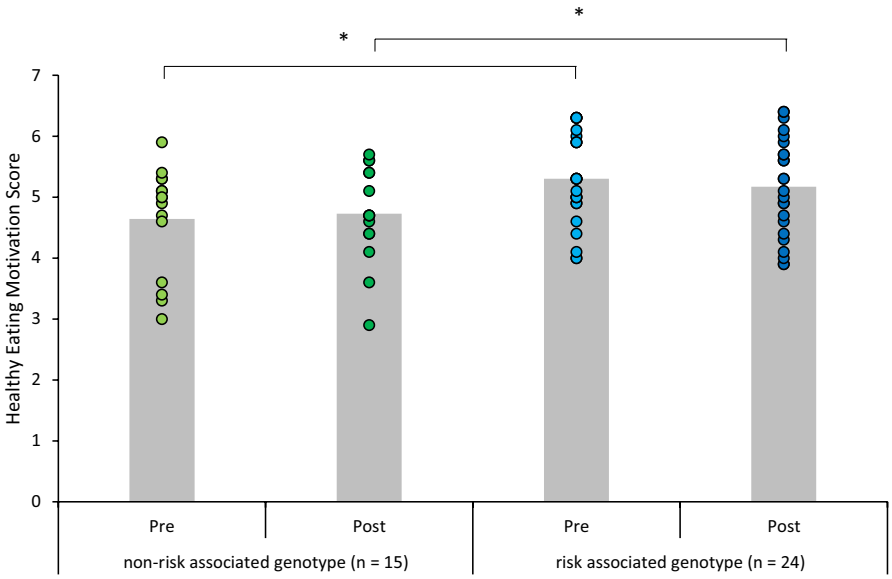

FIGURE 3 Mean healthy eating motivation score pre- and post-advice for participants within the genotype-based personalised advice group for those informed of a risk-associated genotype or a non-risk-associated genotype. Dots represent individual scores within each group and time point. * Significant effect of risk on healthy-eating motivation score ($F = 4.955$, $p = 0.032$).

There were no significant two-way interactions ($p \geq 0.05$) or main effects of time, compliance or group ($p \geq 0.05$).

Body fat percentage recommendation

Healthy eating motivation score was also compared before and after advice, between participants meeting and not meeting the BF% recommendation and between groups. There was no significant interaction between time, compliance and group ($F = 0.958$, $p = 0.387$). There were no significant two-way interactions ($p \geq 0.05$) or main effects of time, compliance or group ($p \geq 0.05$).

DISCUSSION

The aim of the present study was to determine the efficacy of genotype-based personalised dietary and physical activity advice on healthy eating motivation in young adults. The findings suggest that genotype-based personalised dietary advice did not affect healthy eating motivation 1 week later: when participants were analysed as a whole, when analysed in those informed of a risk or non-risk-associated genotype or when analysed in those meeting or not meeting the BMI or BF% recommendation. Healthy eating motivation was also unaffected by non-genotype-based personalised advice or no advice.

Genotype-based personalised advice to motivate healthy eating

The null findings of this study agree with previous studies that have measured motivation or intention to eat a healthy diet following actual genotype-based advice (Godino et al., 2016; Grant et al., 2013; Knowles et al., 2017). Although these studies were carried out in the context of T2D rather than obesity, the lifestyle behaviours they were aiming to motivate were comparable. It was hypothesised that the inclusion of genetic risk within personalised dietary advice would increase the personal salience of recommendations, positively influencing behavioural beliefs and subsequently motivate healthy eating behaviour (Horne et al., 2017). Previously, vignette studies which had asked participants to imagine they had received results of genetic testing for obesity, suggested that their motivation to eat healthily would increase following a high genetic risk result (Ahn & Lebowitz, 2018; Frosch et al., 2005; Meisel et al., 2012; Sanderson et al., 2010). However, in the present study, although healthy -eating motivation score was significantly higher in participants with a risk-associated genotype compared to those with a non-risk-associated genotype, healthy-eating motivation did not change significantly in either group following genotype-based advice. The significant difference in healthy-eating motivation score between the risk-associated genotype group and the non-risk-associated genotype group was apparent prior to disclosure of genotype-based advice. This difference is likely a chance finding since these participants were not aware of their genotype at this time point; furthermore, there was no significant difference in healthy-eating motivation between the risk and non-risk-associated genotype participants within groups 2 or 3.

The personalised advice provided to both the genotype-based and non-genotype-based groups was delivered using BCT to target constructs of the TPB that could subsequently increase participants' intention or motivation to eat a healthy diet (Ajzen, 1991; Horne et al., 2017; Michie et al., 2013). There are several possible explanations why genotype-based advice did not translate to increased healthy eating motivation. Vignette

studies overestimate predicted behaviours in response to genetic testing scenarios (Lerman et al., 2002; Persky et al., 2007). This may explain the contradictory findings between vignette and actual studies of participants' intentions following disclosure of genotype-based advice. Additionally, participants may have viewed genetic risk as deterministic and consequently developed a fatalistic attitude in response to disclosure of a high genetic risk for obesity (Ehrlinger et al., 2017). Compared to phenotypic health outcomes, such as high blood cholesterol that can be changed through lifestyle modification, genes are not modifiable and therefore changes in behaviours to address outcomes linked to genetics may be inaccurately assessed by participants to be beyond their control (Marteau & Weinman, 2006). In the current study, participants were clearly told that genes can interact with lifestyle behaviours: '*Individuals with your genotype that eat less saturated fat are less likely to become* obese'; therefore, it should be unlikely that this would explain the lack of an effect on healthy eating motivation. The expectation was that participants informed that they were meeting recommendations were less likely to report an increase in healthy eating motivation in response to advice. Indeed, the concern in this group was that advice may reduce their motivation to eat a healthy diet. Therefore, it was also important to observe the effect on healthy eating motivation in participants that were meeting the recommendation; nevertheless, a detrimental effect in this group was not observed. However, the lack of a change in healthy eating motivation in response to advice in the present study may be explained by the majority of participants meeting recommendations for BMI, BF% and physical activity; furthermore, based on their baseline healthy eating motivation score they were positively oriented to healthy eating (Naughton et al., 2015). The study population of undergraduate young adults was deliberately targeted with a view to prevent rather than treat overweight and obesity. Therefore, in this young, educated, physically active and relatively healthy population, with a baseline positive orientation towards motivation for healthy eating, maintenance of their current behaviour was what was required. Consequently, an unchanged motivation score in response to disclosure of a risk-associated genotype should be considered a positive outcome. Furthermore, the response of individuals informed of a non-risk-associated genotype should be considered; these individuals may inaccurately conceive that they are unaffected by poor lifestyle behaviours that increase the risk of obesity, the so-called genetic invincibility effect (Ahn & Lebowitz, 2018). Previous research reported that participants who received imagined feedback from a non-risk-associated genotype reported reduced worth of the importance of diet and exercise and an increased likelihood of selecting unhealthy food (Ahn & Lebowitz, 2018). In the present study, participants informed of a non-risk-associated genotype were also advised of the influence that diet and physical activity behaviours have on the risk of obesity. As such, the disclosure of a non-risk-associated genotype in the present study did not affect the healthy eating motivation score, which is in line with other studies that disclosed actual genetic risk (Grant et al., 2013).

Strengths and limitations

The provision of actual rather than imagined genotype-based advice was provided to participants in the present study; therefore, the subsequently reported motivation of participants to eat a healthy diet provides stronger evidence than that reported from vignette studies (Lerman et al., 2002; Persky et al., 2007). The present study adds to a small number of previous studies that have investigated the response to genotype-based personalised advice on healthy eating motivation. A limitation of these studies, as in the present study, is that healthy eating motivation, intention to perform the behaviour or stages of change were secondary outcomes (Godino et al., 2016; Grant et al., 2013; Knowles et al., 2017). It is a limitation of the study that within the group that received genotype-based advice there was a significant difference in baseline healthy-eating motivation score between participants with a risk versus a non-risk-associated genotype. As discussed above this is likely a chance finding since there was no significant difference in healthy eating motivation score between risk and non-risk-associated genotype participants in groups 2 and 3. The present study measured motivation to eat healthily; although the TPB has demonstrated that intention to perform a behaviour is strongly linked to the actual behaviour (Ajzen, 1991), participants' eating behaviour in response to the advice was not assessed. The present study assessed motivation to eat healthily 1 week after the receipt of advice. It is possible that motivation to eat healthily would have differed if measured earlier or later and would likely reduce with duration of follow-up (Samdal et al., 2022). Furthermore, due to the advice provided, which was specifically focused on healthy weight, all items of the healthy eating motivation questionnaire may not have been impacted by advice. The most applicable item 'It is important that the food I eat helps me control my weight' may have changed in response to advice but may not have resulted in a statistically meaningful effect on overall healthy eating motivation score. BMI cut-offs were used consistently across participants and participants were not requested to be fasted or hydrated prior to BF% measures, in future research it may be more appropriate to use cut-offs based on participants' ethnicity and have a standardised protocol for BF% measurement (Caleyachetty et al., 2021). As mentioned above, the high proportion of participants that were meeting the recommendation for body fat percentage and BMI may have reduced the effect of

advice on healthy eating motivation. The provision of advice via email enables greater scalability of personalised advice and has been used in previous research (Celis-Morales et al., 2016; Godino et al., 2016; Nielsen & El-Sohemy, 2014); however, in-person delivery of genetic information has been shown to result in a greater understanding and more accurate interpretation of results (Haga et al., 2014). Consequently, the mode of delivery of genotype-based advice may have influenced participants understanding and therefore their response to the advice. Finally, there was a high rate of dropout (25%) which was consistent across the three groups. Although the baseline data was collected in September 2019, there was some delay in genotyping which meant that advice was delivered to participants in early 2020 and some participants may have lost interest in the study; furthermore, this timing coincided with the start of the COVID-19 pandemic.

Recommendations for further research

In the present study, we did not observe an effect of BMI or BF% on motivation to eat a healthy diet; however, previous research suggests that compared to normal weight, overweight individuals are more interested in genotype-based advice (Bayer et al., 2021; Stewart-Knox et al., 2009; Vallée Marcotte et al., 2018) and more motivated to eat a healthy diet following disclosure of a high genetic risk (Frosch et al., 2005). Further research should be conducted to determine the effect of genotype-based personalised advice in populations that are healthy compared to those that are already 'at-risk' of developing non-communicable diseases such as T2D and cardiovascular disease.

Although genotype-based personalisation of advice provides a tool to increase the personal salience of healthy lifestyle advice in preventative interventions delivered earlier in the lifespan, the findings from this study suggest that healthy eating motivation in relatively healthy young adults is not influenced by that advice. A deeper understanding of additional psychological factors that may interact with how genotype-based advice is perceived by young adults is required to target and develop interventions in this population appropriately.

CONCLUSION

The findings of the present study suggest that genotype-based personalised advice for the prevention of obesity did not affect healthy eating motivation in this group of healthy, young adults. Further research is needed to understand perceptions of genotype-based personalised nutrition in different population groups including healthy versus 'at-risk', and young adults, if it is to be used within interventions for the prevention of obesity.

AUTHOR CONTRIBUTIONS

Alexandra King: Conceptualisation, methodology, formal analysis, investigation, data curation, writing – original draft. **Mark Glaister:** Conceptualisation, methodology, writing – review and editing, supervision. **Kate Lawrence:** Conceptualisation, methodology, writing – review and editing. **Jonathan Nixon:** Investigation, data curation. **Leta Pilic:** Conceptualisation, methodology, writing – review and editing, supervision. **Yiannis Mavrommatis:** Conceptualisation, methodology, writing – review and editing, supervision. All authors read and approved the final manuscript. The authors thank Eleanora Mauro for her technical support during the data collection phase.

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CONFLICT OF INTEREST STATEMENT

YM is a scientific consultant for MyHealthChecked, a wellness company that uses genetic testing. LP is founder of Optimyse Nutrition, a nutritional advice company that offers genetic testing. KL previously held a paid role as Research Editor for Foodsmatter. She is an Editorial Board Member for the British Association of Nutritional and Lifestyle Medicine, Nutritional Evidence Database (NED) and a Scientific Advisory Board Member for Chuckling Goat, both in an unpaid capacity. She is occasionally paid, or receives hospitality, to deliver talks on her research and infrequently receives sample products related to health and nutrition.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Alexandra King https://orcid.org/0000-0002-1788-5402
Leta Pilic https://orcid.org/0000-0001-8046-1269
Mark Glaister https://orcid.org/0000-0003-4454-4854
Kate Lawrence https://orcid.org/0000-0002-0284-9804
Yiannis Mavrommatis https://orcid.org/0000-0003-2717-6324

REFERENCES

Ahn, W.-K. & Lebowitz, M.S. (2018) An experiment assessing effects of personalized feedback about genetic susceptibility to obesity on attitudes towards diet and exercise. *Appetite*, 120, 23–31.

Ajzen, I. (1991) The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50(2), 179–211.

Bayer, S., Drabsch, T., Schauberger, G., Hauner, H. & Holzapfel, C. (2021) Knowledge, opinions and expectations of adults concerning personalised genotype-based dietary recommendations: a German survey. *Public Health Nutrition*, 24(7), 1916–1926.

Bouchard, C., Tremblay, A., Després, J.P., Nadeau, A., Lupien, P.J., Thériault, G. et al. (1990) The response to long-term overfeeding in identical twins. *The New England Journal of Medicine*, 322(21), 1477–1482.

Caleyachetty, R., Barber, T.M., Mohammed, N.I., Cappuccio, F. P., Hardy, R., Mathur, R. et al. (2021) Ethnicity-specific BMI cutoffs for obesity based on type 2 diabetes risk in England: a population-based cohort study. *The Lancet Diabetes & Endocrinology*, 9(7), 419–426.

Celis-Morales, C., Lara, J. & Mathers, J.C. (2015) Personalising nutritional guidance for more effective behaviour change. *Proceedings of the Nutrition Society*, 74(2), 130–138.

Celis-Morales, C., Marsaux, C.F.M., Livingstone, K.M., Navas-Carretero, S., San-Cristobal, R., O'donovan, C.B. et al. (2016) Physical activity attenuates the effect of the FTO genotype on obesity traits in European adults: The Food4Me study. *Obesity (Silver Spring, Md.)*, 24(4), 962–969.

Corella, D., Arnett, D.K., Tucker, K.L., Kabagambe, E.K., Tsai, M., Parnell, L.D. et al. (2011) A high intake of saturated fatty acids strengthens the association between the fat mass and obesity-associated gene and BMI. *The Journal of Nutrition*, 141(12), 2219–2225.

Croker, H., Lucas, R. & Wardle, J. (2012) Cluster-randomised trial to evaluate the 'Change for Life' mass media/ social marketing campaign in the UK. *BMC Public Health*, 12(1), 404.

Davis, R., Campbell, R., Hildon, Z., Hobbs, L. & Michie, S. (2015) Theories of behaviour and behaviour change across the social and behavioural sciences: a scoping review. *Health Psychology Review*, 9(3), 323–344.

Deforche, B., Van Dyck, D., Deliens, T. & De Bourdeaudhuij, I. (2015) Changes in weight, physical activity, sedentary behaviour and dietary intake during the transition to higher education: a prospective study. *The*. *International Journal of Behavioral Nutrition and Physical Activity*, 12, 16.

Department of Health and Social Care (2019) *UK chief medical Officers' physical activity guidelines*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/832868/ukchief-medical-officers-physical-activity-guidelines.pdf

Ehrlinger, J., Burnette, J.L., Park, J., Harrold, M.L. & Orvidas, K. (2017) Incremental theories of weight and healthy eating behavior. *Journal of Applied Social Psychology*, 47(6), 320–330.

Fedewa, M.V., Das, B.M., Evans, E.M. & Dishman, R.K. (2014) Change in weight and adiposity in college students: a systematic review and meta-analysis. *American Journal of Preventive Medicine*, 47(5), 641–652.

Flegal, K.M., Shepherd, J.A., Looker, A.C., Graubard, B.I., Borrud, L.G., Ogden, C.L. et al. (2009) Comparisons of percentage body fat, body mass index, waist circumference, and waist-stature ratio in adults. *The American Journal of Clinical Nutrition*, 89(2), 500–508.

Frosch, D.L., Mello, P. & Lerman, C. (2005) Behavioral consequences of testing for obesity risk. *Cancer Epidemiology, Biomarkers & Prevention: A Publication of the American Association for Cancer Research, Cosponsored by the American Society of Preventive Oncology*, 14(6), 1485–1489.

Gallagher, D., Heymsfield, S.B., Heo, M., Jebb, S.A., Murgatroyd, P.R. & Sakamoto, Y. (2000) Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index. *The American Journal of Clinical Nutrition*, 72(3), 694–701.

Godino, J.G., van Sluijs, E.M.F., Marteau, T.M., Sutton, S., Sharp, S.J. & Griffin, S.J. (2016) Lifestyle advice combined with personalized estimates of genetic or phenotypic risk of type 2 diabetes, and objectively measured physical activity: a randomized controlled trial. *PLoS Medicine*, 13(11), e1002185.

Grant, R.W., O'Brien, K.E., Waxler, J.L., Vassy, J.L., Delahanty, L.M., Bissett, L.G. et al. (2013) Personalized genetic risk counseling to motivate diabetes prevention: a randomized trial. *Diabetes Care*, 36(1), 13–19.

Grimaldi, K.A., van Ommen, B., Ordovas, J.M., Parnell, L.D., Mathers, J.C., Bendik, I. et al. (2017) Proposed guidelines to evaluate scientific validity and evidence for genotype-based dietary advice. *Genes & Nutrition*, 12, 35.

Haga, S.B., Barry, W.T., Mills, R., Svetkey, L., Suchindran, S., Willard, H.F. et al. (2014) Impact of delivery models on understanding genomic risk for type 2 diabetes. *Public Health Genomics*, 17(2), 95–104.

Health Survey for England. (2017) Health Survey for England, 2016. Available from: https://digital.nhs.uk/data-and-information/publications/statistical/health-survey-for-england/health-survey-for-england-2016 [Accessed 3rd July 2021].

Horne, J., Madill, J. & Gilliland, J. (2017) Incorporating the 'theory of planned behavior' into personalized healthcare behavior change research: a call to action. *Personalized Medicine*, 14(6), 521–529.

Kaminsky, L.A. & Montoye, A.H.K. (2014) Physical activity and health: what is the best dose? *Journal of the American Heart Association*, 3(5), e001430.

Kilpeläinen, T.O., Qi, L., Brage, S., Sharp, S.J., Sonestedt, E., Demerath, E. et al. (2011) Physical activity attenuates the influence of FTO variants on obesity risk: a meta-analysis of 218,166 adults and 19,268 children. *PLoS Medicine*, 8(11), e1001116.

Knowles, J., Zarafshar, S., Pavlovic, A., Goldstein, B.A., Tsai, S., Li, J., McConnell, M.V. et al. (2017) Impact of a genetic risk score for coronary artery disease on reducing cardiovascular risk: a pilot randomized controlled study. *Frontiers in Cardiovascular Medicine*, 4, 53.

Lerman, C., Croyle, R.T., Tercyak, K.P. & Hamann, H. (2002) Genetic testing: psychological aspects and implications. *Journal of Consulting and Clinical Psychology*, 70(3), 784–797.

Marteau, T.M. & Weinman, J. (2006) Self-regulation and the behavioural response to DNA risk information: a theoretical analysis and framework for future research. *Social Science & Medicine (1982)*, 62(6), 1360–1368.

Meisel, S.F., Walker, C. & Wardle, J. (2012) Psychological responses to genetic testing for weight gain: a vignette study. *Obesity (Silver Spring, Md.)*, 20(3), 540–546.

Michie, S., Richardson, M., Johnston, M., Abraham, C., Francis, J., Hardeman, W. et al. (2013) The behavior change technique taxonomy (v1) of 93 hierarchically clustered techniques: building an international consensus for the reporting of behavior change interventions. *Annals of Behavioral Medicine*, 46(1), 81–95.

Moody, A. (2020) Health survey for England 2019: overweight and obesity in adults and children. London. Available from: https://digital.nhs.uk/data-and-information/publications/statistical/health-survey-for-england/2019 [Accessed 15th January 2021].

Naughton, P., McCarthy, S.N. & McCarthy, M.B. (2015) The creation of a healthy eating motivation score and its association with food choice and physical activity in a cross sectional sample of Irish adults. *The International Journal of Behavioral Nutrition and Physical Activity*, 12, 74.

NICE. (2007) Overview | Behaviour change: general approaches | Guidance | NICE. Available from: https://www.nice.org.uk/Guidance/PH6 [accessed 10th July 2019].

Nielsen, D.E. & El-Sohemy, A. (2014) Disclosure of genetic information and change in dietary intake: a randomized controlled trial. *PLoS One*, 9(11), e112665.

Persky, S., Kaphingst, K.A., Condit, C.M. & McBride, C.M. (2007) Assessing hypothetical scenario methodology in genetic susceptibility testing analog studies: a quantitative review. *Genetics in Medicine*, 9(11), 727–738.

Phillips, C.M., Kesse-Guyot, E., McManus, R., Hercberg, S., Lairon, D., Planells, R. et al. (2012) High dietary saturated fat intake accentuates obesity risk associated with the fat mass and obesity-associated gene in adults. *The Journal of Nutrition*, 142(5), 824–831.

Pilic, L. & Mavrommatis, Y. (2018) Genetic predisposition to salt-sensitive normotension and its effects on salt taste perception and intake. *The British Journal of Nutrition*, 120(7), 721–731.
Public Health England. (2016) From Plate to Guide: What, why and how for the eatwell model. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/579388/eatwell_model_guide_report.pdf [accessed 14th March 2023].
Roberts, C., Steer, T., Maplethorpe, L., Meadows, S., Nicholson, S., Polly, P. et al. (2018) National Diet and nutrition survey results from years 7 and 8 (combined) of the rolling Programme (2014/2015 to 2015/2016).
Rosenbaum, M. & Leibel, R.L. (2010) Adaptive thermogenesis in humans. *International Journal of Obesity (2005)*, 34(Suppl 1), S47–S55.
Samdal, G.B., Furset, O.J., Nysæther, M.B., Abildsnes, E., Mildestvedt, T. & Meland, E. (2022) Healthy and unhealthy eating after a behaviour change intervention in primary care. *Primary Health Care Research & Development*, 23, e23.
Sanderson, S.C., Persky, S. & Michie, S. (2010) Psychological and behavioral responses to genetic test results indicating increased risk of obesity: does the causal pathway from gene to obesity matter? *Public Health Genomics*, 13(1), 34–47.
Sonestedt, E., Roos, C., Gullberg, B., Ericson, U., Wirfält, E. & Orho-Melander, M. (2009) Fat and carbohydrate intake modify the association between genetic variation in the FTO genotype and obesity. *The American Journal of Clinical Nutrition*, 90(5), 1418–1425.
Speakman, J.R. (2007) A nonadaptive scenario explaining the genetic predisposition to obesity: the 'predation release' hypothesis. *Cell Metabolism*, 6(1), 5–12.
Stewart-Knox, B.J., Bunting, B.P., Gilpin, S., Parr, H.J., Pinhão, S., Strain, J.J. et al. (2009) Attitudes toward genetic testing and personalised nutrition in a representative sample of European consumers. *The British Journal of Nutrition*, 101(7), 982–989.
Tavakol, M. & Dennick, R. (2011) Making sense of Cronbach's alpha. *International Journal of Medical Education*, 2, 53–55.
The GBD 2015 Obesity Collaborators. (2017) Health effects of overweight and obesity in 195 countries over 25 years. *New England Journal of Medicine*, 377(1), 13–27.
Timlin, D., McCormack, J.M., Kerr, M., Keaver, L. & Simpson, E.E.A. (2020) Are dietary interventions with a behaviour change theoretical framework effective in changing dietary patterns? A systematic review. *BMC Public Health*, 20(1), 1857.
Vallée Marcotte, B., Cormier, H., Garneau, V., Robitaille, J., Desroches, S. & Vohl, M.C. (2018) Nutrigenetic testing for personalized nutrition: an evaluation of public perceptions, attitudes, and concerns in a population of French Canadians. *Lifestyle Genomics*, 11(3–6), 155–162.
van der Klaauw, A.A. & Farooqi, I.S. (2015) The hunger genes: pathways to obesity. *Cell*, 161(1), 119–132.
Wareham, N.J., Jakes, R.W., Rennie, K.L., Mitchell, J., Hennings, S. & Day, N.E. (2002) Validity and repeatability of the EPIC-Norfolk physical activity questionnaire. *International Journal of Epidemiology*, 31(1), 168–174.
WHO Expert Consultation. (2004) Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet (London, England)*, 363(9403), 157–163.
World Health Organization. (2000) Obesity: preventing and managing the global epidemic. Report of a WHO consultation. *World Health Organization Technical Report Series*, 894, i–xii, 1–253.
Yeo, G.S.H. (2014) The role of the FTO (Fat Mass and Obesity Related) locus in regulating body size and composition. *Molecular and Cellular Endocrinology*, 397(1–2), 34–41.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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