

## Article

# Genetic and Environmental Influences of Dietary Indices in a UK Female Twin Cohort

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## Abstract

A healthy diet is associated with the improvement or maintenance of health parameters, and several indices have been proposed to assess diet quality comprehensively. Twin studies have found that some specific foods, nutrients and food patterns have a heritable component; however, the heritability of overall dietary intake has not yet been estimated. Here, we compute heritability estimates of the nine most common dietary indices utilized in nutritional epidemiology. We analyzed 2590 female twins from TwinsUK (653 monozygotic [MZ] and 642 dizygotic [DZ] pairs) who completed a 131-item food frequency questionnaire (FFQ). Heritability estimates were computed using structural equation models (SEM) adjusting for body mass index (BMI), smoking status, Index of Multiple Deprivation (IMD), physical activity, menopausal status, energy and alcohol intake. The AE model was the best-fitting model for most of the analyzed dietary scores (seven out of nine), with heritability estimates ranging from 10.1% (95% CI [.02, .18]) for the Dietary Reference Values (DRV) to 42.7% (95% CI [.36, .49]) for the Alternative Healthy Eating Index (A-HEI). The ACE model was the best-fitting model for the Healthy Diet Indicator (HDI) and Healthy Eating Index 2010 (HEI-2010) with heritability estimates of 5.4% (95% CI [-.17, .28]) and 25.4% (95% CI [.05, .46]), respectively. Here, we find that all analyzed dietary indices have a heritable component, suggesting that there is a genetic predisposition regulating what you eat. Future studies should explore genes underlying dietary indices to further understand the genetic disposition toward diet-related health parameters.

**Keywords:** Dietary index; heritability; twin study and food preference

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Diet quality is measured via dietary indices that weigh different food and nutrients to provide an overall estimate of someone's dietary intake. Via dietary indices, it is possible to compare the overall diet across individuals and populations (Gil et al., 2015).

Diet quality is associated with the development of many common disorders, including cardiovascular diseases (CVD; Neelakantan et al., 2018), mental health (Jacka, 2017) and glaucoma (Al Owaifeer & Al Taisan, 2018). Recent studies linked the increased risk of developing common diseases to a less healthy diet (Badimon et al., 2019; Tedstone et al., 2020). However, adherence to a healthy or unhealthy dietary pattern is influenced by a complex mix of socioeconomic, environmental and genetic factors. Thus, research seeking to ameliorate diet quality at an individual level to smoothen the way of disease prevention should also take into account genetic components (Berciano et al., 2017).

Previous twin studies have shown that a strong genetic component defines consumption of some specific foods such as coffee and garlic (Teucher et al., 2007), beverages including soda and alcohol (de Castro, 1993), energy and macronutrient intake (Faith et al., 1999; Hasselbalch et al., 2008; Liu et al., 2013), healthy/unhealthy pattern as well as food liking/disliking (Pallister et al., 2015; Vink

et al., 2020), eating behavior (Tholin et al., 2005) and variety in the overall diet (Scheibehenne et al., 2014). However, the full extent of the genetic impact on dietary indices has never been fully explored.

Here for the first time, we define the heritability of the nine most used dietary indices in nutritional epidemiology (Aljuraiban et al., 2020) in order to assess to which extent genetic components influence overall dietary intake.

## Materials and Methods

### Study Population

In this study, we included 2590 female twins from the UK Adult Twin Register, TwinsUK. The TwinsUK cohort is described in detail in Verdi et al. (2019). Briefly, TwinsUK is a large cohort including 14,000 twins historically developed to study the heritability and genetics of diseases with a higher prevalence among women. The study population is not enriched for any particular disease or trait and is representative of the British general population of Caucasian ethnicity (Verdi et al., 2019). Twin zygosity was determined by the 'peas in the pod' similarity questionnaire (the PPQ), genomewide genotyping or by using 16 short tandem repeat DNA markers (Jarrar et al., 2018). All participants included in this study completed a 131-item food frequency questionnaire (FFQ; Ocké et al., 1997). The TwinsUK study is approved by London-Westminster NHS Research Ethics Committee (TwinsUK, REC ref: EC04/015, November 1, 2011) and all twins have provided written informed consent.

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### Dietary Assessment

The 131-item FFQ was developed and validated against pre-established nutrient biomarkers for the European Prospective Investigation into Diet and Cancer (EPIC) Norfolk (Bingham et al., 1997; Bingham et al., 2001) as previously described (Teucher et al., 2007). All subjects included in this study completed the FFQ questionnaire in 2007, which captures the average yearly intake. Nutrient intake was determined by FETA software (Mulligan et al., 2014). We excluded from this study all twins with more than 10 food items missing in their FFQ or if the ratio between the estimate of the individual total energy intake (derived from FFQ) and the subject's estimated basal metabolic rate (determined by the Harris–Benedict equation; Frankenfield et al., 1998) was more than two standard deviations outside the mean of this ratio (<.52 or >2.58).

### Standardized Comparative Indices

FFQ items were allocated to predefined food group categories to calculate the nine most frequently reported dietary indices for studies investigating associations with cardiovascular risk (Aljuraiban et al., 2020). These include the Alternative Healthy Eating Index (A-HEI; Chiuve et al., 2012), the Amended Mediterranean Score (A-Med; Fung et al., 2005), the Dietary Approaches to Stop Hypertension (DASH; Fung et al., 2008), the Diet Quality Index International (DQI-I; Kim et al., 2003), the Dietary Reference Values (DRV; Eriksen et al., 2018), the Healthy Diet Indicator (HDI; Berentzen et al., 2013), the Healthy Eating Index 2010 (HEI-2010; Guenther et al., 2013), Nordic Diet Score (NDS; Galbete et al., 2018) and the Original Mediterranean Score (O-Med; Trichopoulou et al., 2003).

The detailed descriptions of the methods utilized to generate the different indices included in this study have been previously reported (Berentzen et al., 2013; Chiuve et al., 2012; Eriksen et al., 2018; Fung et al., 2005, 2008; Galbete et al., 2018; Guenther et al., 2013; Kim et al., 2003; Trichopoulou et al., 2003). In brief, HEI-2010 is a cumulative score ranging from 0 to 100 points that accounts for 12 dietary components (Guenther et al., 2013) that reflect recommendations based on the Food Guide Pyramid (Reedy & Krebs-Smith, 2008) and the Dietary Guidelines for Americans (McGuire, 2011). The A-HEI scoring criteria (Chiuve et al., 2012) include elements of the HEI-2010 with selected dietary components, based on their associations with chronic diseases — the score range is from 0 to 110. The DQI-I is a cumulative score ranging from 0 to 100 points based on methods by Kim et al. (2003). It accounts for 17 dietary components that measure (a) intake of several food groups and nutrients and (b) diet diversity and moderation. The O-Med is based on the intake of nine dietary components and its score ranges from 0 to 9 points, as described by Trichopoulou et al. (2003). More recently, Fung et al. (2005) modified the original Mediterranean score. The Amended Mediterranean Score (A-Med) is based on dietary patterns and eating behaviors that have been consistently associated with lower risks of chronic disease in clinical and epidemiologic studies, and more reflective of an American diet (Fung et al., 2005). The DASH is a dietary score ranging from 8 to 40 points that accounts for eight dietary components determined by a landmark randomized control trial (Appel et al., 1997). Of these eight components, five are beneficial (i.e. fruits, vegetables, legumes and nuts, whole grains, low-fat dairy) and three are detrimental (i.e. meat, sugar sweetened beverages and sodium; Fung et al., 2008).

The DRV dietary index is a 16-point score based on the intake of the six nutritional components (total carbohydrates, sugars, total fat, SFA, salt, dietary fiber) and two food group components (fruit and vegetables combined and total fish), as listed in the Public Health England UK dietary policy for optimal health and prevention of CVD (Levy & Tedstone, 2017). Of these eight components, four are beneficial (i.e. fruits/vegetables, fish, carbohydrates, fiber) and four are detrimental (i.e. SFA, fat, sodium, sugar; Eriksen et al., 2018). The HDI index was generated as described by Berentzen et al. (2013) and accounts for seven dietary components. For each component, a dichotomous variable is defined and the index represents the sum of all the dichotomous variables with a range between 0 and 7 points (Berentzen et al., 2013). Finally, the construction of the NDS was based on Galbete et al. (2018). The NDS ranges from 0 to 18 points and incorporates nine components. Each food component is categorized into sex-specific tertiles of intake, and each participant receives a score of 0–2 points according to the first, second and third tertile, respectively, (Galbete et al., 2018). All indices were constructed in RStudio (Rizzo, 2019) following relevant methodologies; see Table 1.

### Assessment of Covariates

The heritability estimates were adjusted for six major confounders: age, body mass index (BMI), smoking and menopause status, physical activity and the Index of Multiple Deprivation (IMD). Age, physical activity, smoking and menopause status were recorded as part of the self-report lifestyle questionnaire collected on an annual basis and during TwinsUK visits (Verdi et al., 2019). BMI was determined from weight and height measurements (weight kg/height m<sup>2</sup>) collected using harmonized protocols by trained research nurses during clinical visits (Verdi et al., 2019).

The IMD is a composite decile score measuring the area-level deprivation (lower deciles represent the most deprived areas). The IMD score is based on a total of seven domains: income, employment, health, education, barriers to services, environment and crime (Goodman & Gatward, 2008). The IMD was derived from the postcode reported by the participant at the time of data collection. Furthermore, alcohol and energy intake were included in the analysis models of those scores, which do not account for energy intake and alcohol in their score (O-Med, A-Med, DASH, A-HEI, NDS). Both alcohol (mean g/day) and energy intake (kcal) were estimated from the FFQ.

### Heritability

We used the classical twin models to define the influence of genetic and environmental factors on the variance of the nine dietary indices included in this study.

Twin studies compare the degree of similarity among monozygotic (MZ) twins, who share 100% of their genetic makeup, and dizygotic (DZ) twins, who share on average 50% of their segregating genes. Under the equal environment assumption (EEA), the variance of the trait/phenotype (P) is explained by the following latent parameters:

$$P = A + D + C + E,$$

where 'A' represents the additive genetic influence, 'D' the genetic variance explained by the relationship between the recessive/dominant alleles, 'C' the common or shared environment

**Table 1.** Summary of the food groups/dietary groups of the dietary indices included in the study

Dietary groups	Dietary indices								
	O-Med	A-Med	HEI-2010	A-HEI	HDI	DASH	DQI-I	NDS	DRV
Food groups									
Vegetables	✓	✓	✓	✓	✓	✓	✓	✓	✓
Starchy vegetables	✓			✓			✓	✓	
Fruit	✓	✓	✓	✓	✓	✓	✓		✓
Fruit juice		✓	✓	✓		✓		✓	✓
Refined grains	✓		✓				✓		
Whole grains	✓	✓	✓	✓		✓	✓	✓	
Legumes	✓	✓	✓	✓		✓	✓		
Nuts	✓	✓	✓	✓		✓			
Tofu			✓	✓		✓			
Seeds			✓						
Seafood	✓	✓	✓				✓		✓
Poultry	✓		✓				✓		
Red meat	✓	✓	✓	✓		✓	✓		
Processed meat	✓	✓	✓	✓		✓	✓		
Eggs			✓				✓		
Butter	✓							✓	
Dairy	✓		✓				✓	✓	
Low-fat dairy	✓		✓			✓	✓	✓	
Cheese	✓		✓				✓	✓	
Sugar-sweetened beverages				✓					
Low nutrient density foods			✓				✓		
Dairy alternatives								✓	
Nutrients									
Carbohydrates							✓		✓
Fiber					✓		✓		✓
Sugars					✓				✓
Protein					✓		✓		
Total fat							✓		✓
Monounsaturated	✓	✓	✓				✓		
Polyunsaturated			✓	✓	✓		✓		
Omega 3				✓					
Saturated	✓	✓	✓		✓		✓		✓
Trans fats				✓					
Cholesterol					✓		✓		
Sodium			✓	✓			✓		✓
Iron							✓		
Calcium							✓		
Vitamin C							✓		
Alcohol	✓	✓		✓					

Note: O-Med, Original Mediterranean Score; A-Med, Amended Mediterranean Score; HEI-2010, Healthy Eating Index 2010; A-HEI, Alternative Healthy Eating Index; HDI, Healthy Diet Indicator; DASH, Dietary Approaches to Stop Hypertension; DQI-I, Diet Quality Index International; NDS, Nordic Diet Score; DRV, Dietary Reference Values.

**Table 2.** Characteristics of the study population

	DZ (1284 individuals)	MZ (1306 individuals)	Total (2590 individuals)
Age, Mean (SD, range)	58.6 (9.6, 35.0–82.0)	57.7 (10.6, 35.00–83.0)	58.1 (10.1, 35.0–83.0)
BMI, Mean (SD, range)	26.7 (4.9, 17.6–50.0)	26.3 (4.7, 16.16–48.1)	26.5 (4.8, 16.1–50.0)
Smokers			
No	794 (61.8%)	1018 (77.9%)	1812 (70.0%)
Yes	490 (38.2%)	288 (22.1%)	778 (30.0%)
Physical activity			
Yes	187 (14.6%)	99 (7.6%)	286 (11.0%)
No	1097 (85.4%)	1207 (92.4%)	2304 (89.0%)
IMD (decile)			
1	21 (1.6%)	28 (2.1%)	49 (1.9%)
2	35 (2.7%)	40 (3.1%)	75 (2.9%)
3	61 (4.8%)	53 (4.1%)	114 (4.4%)
4	90 (7.0%)	85 (6.5%)	175 (6.8%)
5	102 (7.9%)	94 (7.2%)	196 (7.6%)
6	124 (9.7%)	126 (9.6%)	250 (9.7%)
7	143 (11.1%)	128 (9.8%)	271 (10.5%)
8	150 (11.7%)	167 (12.8%)	317 (12.2%)
9	304 (23.7%)	319 (24.4%)	623 (24.1%)
10	254 (19.8%)	266 (20.4%)	520 (20.1%)
Menopause			
No	182 (14.2%)	218 (16.7%)	400 (15.4%)
Yes	1102 (85.8%)	1088 (83.3%)	2190 (84.6%)
Dietary indices			
O-Med, Mean (SD, range)	4.53 (1.7, 0.0–9.0)	4.53 (1.7, 0.0–9.0)	4.53 (1.7, 0.00–9.0)
A-Med, Mean (SD, range)	4.72 (1.8, 0.0–9.0)	4.70 (1.9, 0.0–9.00)	4.71 (1.8, 0.00–9.0)
DASH, Mean (SD, range)	24.15 (4.3, 11.0–37.0)	24.17 (4.1, 11.0–36.0)	24.16 (4.2, 11.0–37.0)
HEI-2010, Mean (SD, range)	61.37 (10.1, 30.0–93.0)	61.14 (10.0, 28.0–93.0)	61.25 (10.0, 28.0–93.0)
A-HEI, Mean (SD, range)	69.30 (9.7, 38.0–98.0)	69.75 (9.6, 40.5–106.0)	69.53 (9.7, 38.0–106.0)
NDS, Mean (SD, range)	9.07 (3.3, 0.0–18.0)	9.08 (3.3, 0.0–18.0)	9.08 (3.3, 0.0–18.0)
HDI, Mean (SD, range)	2.87 (1.1, 0.0–6.0)	2.87 (1.1, 0.0–6.0)	2.87 (1.1, 0.0–6.0)
DQI-I, Mean (SD, range)	61.43 (7.0, 36.0–81.0)	61.12 (6.7, 41.0–77.0)	61.27 (6.8, 36.0–81.0)
DRV, Mean (SD, range)	8.97 (1.6, 4.0–13.0)	9.07 (1.6, 2.0–14.0)	9.02 (1.6, 2.0–14.0)

Note: O-Med, Original Mediterranean Score; A-Med, Amended Mediterranean Score; DASH, Dietary Approaches to Stop Hypertension; HEI-210, Healthy Eating Index 2010; A-HEI, Alternative Healthy Eating Index; NDS, Nordic Diet Score; HDI, Healthy Diet Indicator; DQI-I, Diet Quality Index International; DRV, Dietary Reference Values.

between the twin pair and 'E' represents the nonshared environment ('E' also includes measurement error; Rijdsdijk & Sham, 2002).

However, in studies including only MZ and DZ correlations, it is not possible to estimate the phenotypic variance including all four sources of variation, and either 'C' or 'D' needs to be excluded from the model. Twin correlations are utilized to define which parameter to include in the model. The common environmental effect 'C' is included in the model when the correlation of MZ twins is less than half the correlation of DZ twins, whereas the dominance genetic effects 'D' is analyzed when the MZ twin correlation is more than half the correlation of DZ twins. Based on the correlation values reported in the results section, either the ACE or ADE model was fitted in the heritability analyses.

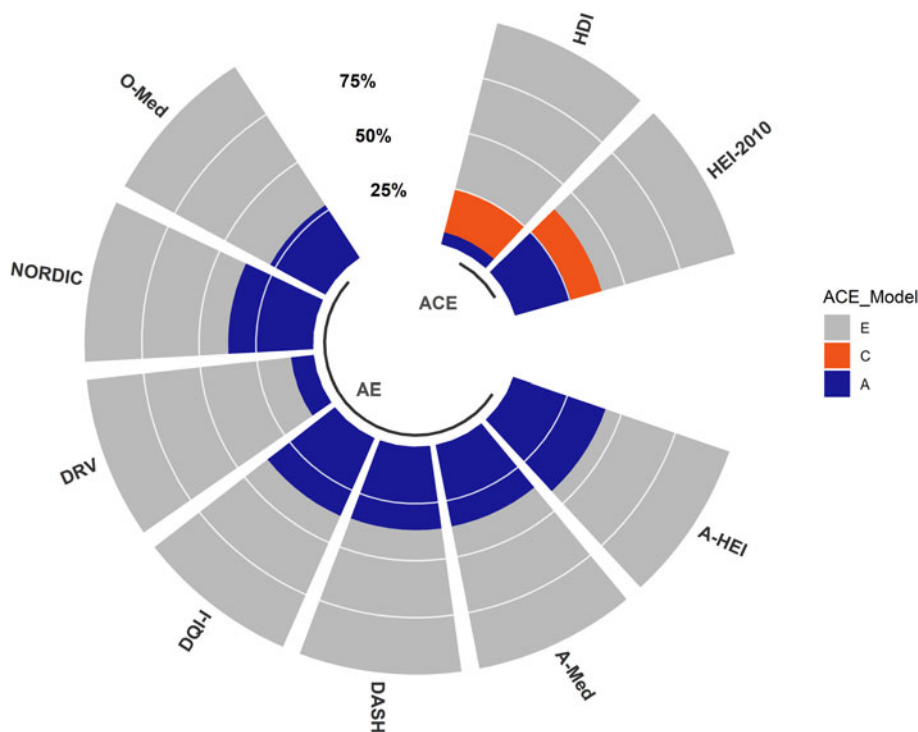
To estimate the heritability, we take advantage of structural equation models (SEM), which utilize observed covariances from both MZ and DZ pairs to establish a causal relationship among the covariances and the latent parameters.

We investigated ACE, ADE, AE and E models, and the Akaike's information criterion (AIC) was used to select the best-fitting model. The model (ACE, ADE, AE or E) with the minimum AIC reflects the best balance between explanatory power and parsimony and was the preferred model. In all the models, the marginal (individual) effect of each twin was adjusted for age, BMI, smoking status, physical activity, menopause status and IMD. Heritability analyses were performed using the package METs (version 1.2.7.1; Scheike et al., 2014) in R (version 4.0.2).

**Table 3.** Twin correlations (maximum likelihood estimates) for each dietary index for MZ (618 pairs and 70 individuals and DZ female twins (608 pairs and 68 individuals)

	MZ	95% CI	DZ	95% CI
A-HEI	.44	[.37, .51]	.18	[.09, .26]
A-Med	.37	[.29, .44]	.22	[.14, .30]
DASH	.36	[.28, .43]	.18	[.09, .26]
DQI-I	.37	[.29, .44]	.18	[.09, .26]
DRV	.12	[.03, .20]	.5	[−.04, .13]
HDI	.24	[.15, .32]	.24	[.15, .32]
HEI-2010	.40	[.32, .47]	.27	[.18, .34]
NDS	.38	[.30, .45]	.22	[.13, .30]
O-Med	.31	[.22, .38]	.1	[.01, .18]

Note: MZ, monozygotic; DZ, dizygotic; A-HEI, Alternative Healthy Eating Index; A-Med, Amended Mediterranean Score; DASH, Dietary Approaches to Stop Hypertension; DQI-I, Diet Quality Index International; DRV, Dietary Reference Values; HDI, Healthy Diet Indicator; HEI, Healthy Eating Index; NDS, Nordic Diet Score; O-Med, Original Mediterranean Score.

**Fig. 1.** Heritability of nine dietary indices TwinsUK. The total variance of each dietary index is decomposed into variance components attributed to additive genetics (A), common environment (C) and unique environment (E). The figure represents the best-fitting model for each dietary index determined by the lowest AIC. The full summary report of the heritability estimates is presented in Table 4.

## Results

We included 2590 female twins (1284 DZ and 1306 MZ) from TwinsUK. The full descriptive characteristics of the study population are presented in Table 2. The average age of the participants was 58.1 years ( $\pm 10.2$  years). The mean BMI was 26.5 ( $\pm 4.9$ ) and 55.7% of the subjects were classified as overweight/obese (BMI > 25). The majority of the participants were postmenopausal (85%), nonsmokers (70%), not engaged in high physical activity (89%) and had a good socioeconomic status (67% of the participants at the time of sample collection lived in the least deprived areas of the country; IMD  $\geq 7$ ).

The correlations between MZ twins was higher than the DZ twin correlation for all the analyzed dietary indices (Table 3). The MZ correlation was more than double the DZ correlation

for five indices (DRV, O-Med, DASH, DQI-I, A-HEI). For these indices, we fitted an ADE full model. For the remaining four indices (HEI-2010, HDI, A-Med, NDS), as the DZ correlations were more than half of the MZ correlations, we fitted an ACE model (Table 3).

Heritability estimates for the nine dietary scores are presented in Figure 1 and Table 4.

The ACE model was the best-fitting model for both HDI and HEI-2010. For the remaining seven dietary indices, the AE model was the best-fitting model. We observed a strong genetic effect ( $A \geq 20\%$ ) for seven out of the nine dietary indices, with the contribution of genetic factors ranging from 47.2% (95% CI [0.36, 0.49]) for A-HEI to 25.4% (95% CI [0.05, 0.46]) for HEI-2010 (Figure 1 and Table 4). We observed a less strong additive genetic

**Table 4.** Results of model fitting for twin correlations (see Table 3) for all nine analyzed dietary indexes

Trait	Model	Parameter estimates [95% CI]				Goodness-of-fit indices			
		A	C	D	E	$\chi^2$	df	p-value	AIC
A-HEI	ADE	0.26 [-0.07, 0.59]	–	.18 [-0.17, 0.52]	0.56 [0.49, 0.63]	68.71	51	4.97 E-02	6088.07
	AE	0.43 [0.36, 0.49]	–	–	0.57 [0.51, 0.64]	69.75	52	5.07 E-02	6087.10
	E	–	–	–	1.00 [1.00, 1.00]	192.99	53	8.56 E-18	6208.35
A-Med	ACE	0.28 [0.06, 0.49]	0.77 [-0.10, 0.26]	–	0.65 [0.57, 0.72]	57.07	51	2.60 E-01	5845.28
	AE	0.36 [0.30, 0.43]	–	–	0.63 [0.57, 0.70]	57.75	52	2.71 E-01	5843.97
	E	–	–	–	1.00 [1.00, 1.00]	155.24	53	5.72 E-12	5939.45
DASH	ADE	0.31 [-0.01, 0.64]	–	.50 [-0.29, 0.40]	0.63 [0.55, 0.71]	62.55	57	2.86 E-01	6060.96
	AE	0.37 [0.29, 0.44]	–	–	0.63 [0.56, 0.71]	62.65	58	3.15 E-01	6059.06
	E	–	–	–	1.00 [1.00, 1.00]	143.76	59	4.96 E-09	6138.17
DQI-I	ADE	0.23 [-0.09, 0.56]	–	.15 [-0.20, 0.50]	0.61 [0.54, 0.69]	52.16	51	4.29 E-01	5891.59
	AE	0.37 [0.30, 0.44]	–	–	0.63 [0.56, 0.70]	52.88	52	4.40 E-01	5890.31
	E	–	–	–	1.00 [1.00, 1.00]	140.33	53	7.91 E-10	5975.77
DRV	ADE	0.2 [-0.32, 0.36]	–	.9 [-0.28, 0.46]	0.89 [0.80, 0.98]	52.59	51	4.12 E-01	5596.36
	AE	0.10 [0.02, 0.18]	–	–	0.90 [0.82, 0.98]	52.79	52	4.43 E-01	5594.56
	E	–	–	–	1.00 [1.00, 1.00]	59.13	53	2.62 E-01	5598.90
HDI	ACE	0.5 [-0.17, 0.28]	0.19 [0.02, 0.37]	–	0.75 [0.67, 0.83]	61.93	54	2.14 E-01	5801.24
	AE	0.28 [0.21, 0.36]	–	–	0.72 [0.64, 0.79]	66.39	55	1.40 E-01	5803.70
	E	–	–	–	1.00 [1.00, 1.00]	120.20	56	1.38 E-06	5855.51
HEI	ACE	0.25 [0.05, 0.46]	0.14 [-0.03, 0.31]	–	0.60 [0.53, 0.68]	38.06	51	9.10 E-01	6045.99
	AE	0.41 [0.35, 0.48]	–	–	0.58 [0.52, 0.65]	40.58	52	8.74 E-01	6046.51
	E	–	–	–	1.00 [1.00, 1.00]	161.61	53	6.49 E-13	6165.54
NDS	ACE	0.32 [0.10, 0.54]	0.40 [-0.14, 0.22]	–	0.63 [0.56, 0.71]	72.42	63	1.95 E-01	5466.83
	AE	0.37 [0.30, 0.44]	–	–	0.63 [0.56, 0.70]	72.64	64	2.15 E-01	5465.05
	E	–	–	–	1.00 [1.00, 1.00]	168.07	65	4.55 E-11	5558.48
O-Med	ADE	0.11 [-0.25, 0.47]	–	0.18 [-0.20, 0.55]	0.71 [0.64, 0.79]	50.30	51	5.01 E-01	5950.33
	AE	0.27 [0.20, 0.35]	–	–	0.72 [0.65, 0.80]	51.14	52	5.08 E-01	5949.16
	E	–	–	–	1.00 [1.00, 1.00]	104.15	53	3.48 E-05	6000.17

Note: A-HEI, Alternative Healthy Eating Index; A-Med, Amended Mediterranean Score; DASH, Dietary Approaches to Stop Hypertension; DQI-I, Diet Quality Index International; DRV, Dietary Reference Values; HDI, Healthy Diet Indicator; HEI, Healthy Eating Index; NDS, Nordic Diet Score; O-Med, Original Mediterranean Score.

effect ( $A \leq 10\%$ ) for DRV (10%; 95% CI [0.02, 0.18]) and HDI (5.4%; 95% CI [-0.17, 0.28]); see Figure 1 and Table 4.

## Discussion

The present study established for the first time to which extent variations in dietary indices in adults are influenced by genetic and environmental factors. We found that variations in overall diet quality measured by diet scores are heritable, with estimates varying between 42% (A-HEI) and 5% (HDI). These estimates are comparable with the results reported in previous studies investigating the heritability of food preference in adults (Pallister et al., 2015; Smith et al., 2016; Törnwall et al., 2014; Vink et al., 2020).

In this study, the interclass correlations were always higher in MZ pairs than in DZ pairs (which suggested a strong genetic component). Indeed, in some cases, MZ correlations were more than double than those observed for the DZ pairs. These gaps were particularly evident for those indices that represent a development of previous scores (O-Med vs. A-Med and HEI-2010 vs. A-HEI). Our

hypothesis is that these differences are likely attributable to the amount of the dietary component captured within each index. For example, the food groups included in both O-Med and A-Med are mostly overlapping (Table 1). However, four food groups (poultry, starchy vegetables, refined grains and all the dairy products) are measured in O-Med but not in A-Med (Fung et al., 2005; Trichopoulou et al., 2003). Therefore, dissimilar patterns of consumption for these food groups in the DZ pairs will be captured by O-Med but not by the A-Med. This hypothesis is supported by previous studies (Smith et al., 2016; Teucher et al., 2007) where, in line with our observations, MZ interclass correlation estimates for poultry, refined grains and potato preferences were always more than double than those observed in DZ pairs (Smith et al., 2016; Teucher et al., 2007).

Similarly, A-HEI scoring criteria (Chiuve et al., 2012) differs from the original HEI-2010 as it includes more specific items and a different score range (Table 1). These differences are likely to be responsible for the different results reported for these indices in this study. These dissimilarities were also detected when

HEI-2010 and A-HEI were associated with the risk of mortality for both cardiovascular and cancer (Harmon et al., 2015).

To date, four studies have investigated the heritability of food preference in adults using either ACE or ADE models (Pallister et al., 2015; Smith et al., 2016; Törnwall et al., 2014; Vink et al., 2020).

None of the studies found evidence of the effects of common environmental component (C) (Pallister et al., 2015; Smith et al., 2016). A dominant genetic effect (D) was only identified for some food preferences (fruit and fish in females; Smith et al., 2016; Vink et al., 2020), but for most of the food preferences, the dominant genetic component was not detected (Smith et al., 2016; Vink et al., 2020). These results are in line with our findings. Indeed, we did not detect either common environmental or dominant genetic effects for most of the dietary indices included in this study. These observations may provide additional evidence that in adults, early familial experiences have no impact on both food preferences and on overall dietary intake.

This study has some limitations that are worth mentioning. First, our results were derived from middle-aged female twins, and it may be difficult to generalize these findings to men or younger individuals. Indeed, previous studies reported differences in food consumptions in both gender and young generations (Breen et al., 2006; Pallister et al., 2015; Prättälä et al., 2006; Smith et al., 2016). Second, most of the samples included in this study are from a wealthy socioeconomic background. It has been observed that BMI heritability estimates are higher in more deprived areas and lower in less deprived areas (Owen et al., 2017). Although this relationship was statistically significant, the authors could not establish a mechanism behind this relationship (Owen et al., 2017). To take account of this possible gene–environment interaction and following the authors' suggestions, we included the socioeconomic factor as a confounder in our model.

The final limitation applies to the twin model in general. The heritability models adopted in this study work under the assumption that common environmental influences are equal in both MZ and DZ pairs (EEA). Indeed, if this assumption is violated, then the heritability estimates would be inflated while the shared environmental values would be underestimated (Felson, 2014). However, several studies have shown that bias due to violation of the EEA is negligible in traits such as food preference, eating disorders, weight and BMI (Felson, 2014). Therefore, it is likely that this bias is also negligible for the dietary indices.

## Conclusions

In conclusion, the present study represents the first comprehensive investigation of the relative contributions of genetic and environmental factors to the variation in dietary indices. We found that all investigated dietary indices are heritable. Future research needs to validate the results reported in this study and explore the heritability patterns of the dietary indices in males and in different countries and/or different ethnicity. However, our results not only reinforce the notion of heredity in the eating behavior, but also define the role of nonshared environmental influences, which may be modifiable. These findings highlight the complex genetic and environmental relationship of eating behavior and may have future implications for public health nutrition programs and nutritional epidemiology.

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**Conflict of Interest.** T.D.S. is co-founder of Zoe Global Ltd. S.E.B. is a consultant for Zoe Global Ltd. All other authors declare no competing financial interests.

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