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Evaluating current egg consumption patterns: Associations with diet quality, nutrition and health status in the UK National Diet and Nutrition Survey

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Abstract

Dietary habits are constantly evolving with changes in culture, economics and the food supply. In the UK, red meat intakes have been declining for more than a decade, while egg consumption has increased in tandem with interest in healthy, sustainable diets. To explore current dietary habits of egg consumers and non-consumers and potential implications for nutrition and health, we analysed dietary records from 647 adults participating in Year 9 (2017) of the UK *National Diet and Nutrition Survey (NDNS)*. Mean consumption of eggs and egg dishes was 29 g/day (3.5 eggs/week). Female egg consumers (n = 224; mean 46 g/day, 5 eggs/week) ate more fruit, vegetables and fish and had significantly higher dietary intakes of protein, monounsaturated fatty acids, n-3 polyunsaturated fatty acids and most micronutrients, notably vitamin D, most B vitamins, vitamin C, iron, zinc and selenium, compared with non-consumers (n = 150). They also had higher plasma levels of 25-hydroxyvitamin D, total carotenoids, selenium and ferritin and were less likely to be anaemic. Female egg consumers had a lower mean body mass index and waist circumference, despite reporting a higher mean energy intake than non-consumers. Male egg consumers (n = 159; mean 54 g/day, 6 eggs/week) had higher dietary intakes of vitamin D, biotin, iodine and selenium but similar micronutrient status and bodyweight to non-consumers (n = 114). There were no significant differences in cardiometabolic risk factors for either sex. Egg consumption appears to be associated with signs of higher dietary quality, better nutritional status, and slightly lower body mass index among women participating in the latest *NDNS*.

Keywords: eggs, diet, nutrients, bodyweight, CVD

Introduction

Dietary recommendations in relation to egg consumption have evolved over time. For many years, dietary guidelines suggested restricting dietary cholesterol intake and avoiding eggs to reduce cardiovascular

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disease (CVD) risk, but this is no longer the case (Clayton *et al.* 2017). In the UK, there is no specific recommendation or limit for egg consumption; eggs are now recognised as nutritious, and a good choice as part of a healthy, balanced diet (NHS 2018a). Specifically, eggs are a source of high-quality protein and several micronutrients of concern, such as vitamins A, D, B12, riboflavin and folate, and minerals selenium, and iodine, and *n*-3 polyunsaturated fatty acids (Benelam *et al.* 2012). Eggs are also a rich source of choline, a modest source of lutein, and contain many bioactive compounds whose potential as nutraceuticals is being actively explored (Rehault-Godbert *et al.* 2019). In several studies, egg consumption has been positively associated with dietary quality and a greater likelihood of meeting recommended intakes for vitamin and minerals (Ruxton *et al.* 2010; Papanikolaou & Fulgoni 2019; Melough *et al.* 2019).

The totality of evidence suggests no effect of eggs on CVD risk and mortality (Mah *et al.* 2019; Dehghan *et al.* 2020). This has been confirmed most recently in a systematic review and meta-analysis of prospective cohort studies by Drouin-Chartier *et al.*, with over 1.7m participants. This concluded that an average intake of up to one egg a day is not associated with CVD risk, nor with components of CVD [coronary heart disease (CHD) and stroke] (Drouin-Chartier *et al.* 2020). In analyses stratified by geographical location, there was no association between egg consumption and CVD risk in European or US cohorts but an inverse association in Asian cohorts. Some studies have reported positive associations between egg consumption and risk of type 2 diabetes (T2D) although these appear to be specific to US populations (Djousse *et al.* 2016; Mah *et al.* 2019). As noted by others (Geiker *et al.* 2018), conflicting findings in epidemiological studies may reflect clustering of risk factors or different dietary patterns accompanying egg consumption. For example, Sabate *et al.* found a significant interaction between meat and egg intake in a large US cohort study, such that meat consumption, but not egg consumption was independently associated with T2D risk (Sabate *et al.* 2018) while Shikany *et al.* identified a Southern (US) dietary pattern, characterised by high intake of fats, eggs, meat and soft drinks, which was associated with a greater hazard of incident CHD (Shikany *et al.* 2015). Among Polish adults, egg consumption was associated with an unhealthy Western or traditional diet pattern that influenced the association with fasting glucose level (Czekajlo-Kozlowska *et al.* 2019).

In reanalysing data from the UK *National Diet and Nutrition Survey (NDNS)* for 2000/2001 we previously reported that egg consumption in the UK was associated with a more traditional eating pattern, high in meat and saturated fat (Ruxton *et al.* 2010). However, observations from consumer trends have led us to hypothesise that patterns of consumption may be changing, with eggs increasingly being consumed as part of a healthy diet and lifestyle. Egg purchase volume increased by 49% between 2008 and 2019, with most of the growth coming from younger shoppers (18–44 years) (British Egg Information Service 2020). Personal consumption of eggs and egg dishes (as defined in the *NDNS* Rolling Programme) has also increased, by 23% in adults aged 19–64 years between years 1–4 (2008/2009–2011/2012) and years 5–9 (2012/2013–2016/2017) (Bates *et al.* 2014; Bates *et al.* 2019). Cultural changes over the same period include a growing emphasis on health and fitness, rather than bodyweight alone, and on low-carbohydrate/high-protein diets rather than calorie counting, as well as a growing interest in environmental sustainability and a desire to reduce intake of red meat intake for both health and ethical reasons.

Empirical evidence includes a time-trend analysis from the *NDNS* over a 9-year period (2008/2009 to 2016/2017) which reported a downward trend in red and processed meat (RPM) intake in adults (Bates *et al.* 2019). These changing patterns of consumption may have implications for the role of eggs in the diet, specifically in providing high-quality protein and key micronutrients such as vitamin D, vitamin B12, selenium, iodine and iron that may be in short supply for some groups. We used the latest available data from the *NDNS* (2016/2017 or year 9 of the Rolling Programme) to explore associations between egg consumption and nutrition (nutrient intakes and status) and CVD risk measures (blood lipids, blood pressure, glycated haemoglobin and anthropometrics) in adult men and women in the UK. Our main hypothesis was that egg consumption is now likely to be associated with a healthier dietary pattern and therefore possibly higher micronutrient intakes, in contrast to past associations with more traditional dietary patterns high in fat and processed meat. Additional hypotheses were that healthier habits (of egg consumers vs. non-consumers) would be more apparent among women, whose average red meat intake is lower than men, and that biochemical and anthropometric measurements would be consistent with the dietary findings. Finally, we expected that dietary differences between egg consumers and non-consumers would be more important among low consumers of red meat, a group potentially at risk of low intakes of key nutrients such as iron, zinc and selenium.

Methods

National Diet and Nutrition Survey

The *NDNS* is a continuous cross-sectional survey, designed to assess the diet, nutrient intake and nutritional status of the general population aged 1.5 years and over living in private households in the UK (Public Health England). Results are used by government to monitor progress towards diet and nutrition objectives of UK Health Departments and to develop policy interventions. The sample was drawn from small geographical areas or primary sampling units, based on postcode sectors, randomly selected from across the UK. A list of addresses was randomly selected from each sampling unit, and from one household an adult, or one adult and one child, randomly selected to participate. Fieldwork comprised three visits from a trained interviewer, a 4-day estimated diet diary, collection of a spot urine sample, and a subsequent nurse visit to obtain physical measurements and a fasting blood sample. Food intakes were estimated using household measures, food labels and a photographic atlas. Interviewers revisited participants once during the diary period to encourage and improve recording and collect missing detail, and finally within 3 days of the last diary day to check and collect records. At the nurse visit, body height and weight were measured using a portable stadiometer and a weight scale. Waist circumference was measured using a tape measure. Blood pressure was taken in a sitting position after a 5-minute rest using an automated validated monitor. Further details of sampling and methodology can be found, with a time trend analysis, at https://www.gov.uk/government/statistics/ndns-time-trend-and-income-analyses-for-years-1-to-9. Raw data for the latest data release (Year 9), were obtained from the UK Data Archive (https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=6533).

Data analysis

Adult egg consumers (defined as persons aged 19 years and over who consumed any eggs and egg dishes) were identified from their 4-day dietary records and compared with non-consumers. Eggs and egg dishes included foods such as omelette and quiche, but not eggs used as minor ingredients (*e.g.* in cakes). Men and women were analysed separately. Egg consumers and non-consumers were compared for dietary macronutrient and micronutrient intakes (excluding contribution from supplements), and consumption of major food groups, using mean daily intakes averaged over the recording period. Macronutrients were expressed as a percentage of total energy. For assessment of micronutrient intakes, P values were adjusted for energy (as covariate). Differences were assessed using unequal-variances t-test, or Mann–Whitney test for variables with markedly non-normal distribution. Chi-square and z-tests of column proportions were used for categorical variables. General linear modelling (GLM) was used to adjust for covariates where indicated. CVD risk markers examined were body mass index (BMI; kg/m^2), waist circumference (WC; cm), systolic blood pressure (SBP; mmHg), diastolic blood pressure (DBP; mmHg), total cholesterol (TC; mmol/l), triglycerides (TAG; mmol/l), HDL-cholesterol (HDL-C; mmol/l), LDL-cholesterol (LDL-C; mmol/l), TC:HDL-C (the ratio of TC and HDL-C). All tests were conducted using SPSS version 26 (IBM) with $P < 0.05$ (2-tailed) as the criterion for statistical significance. We did not employ the Bonferroni correction, which tends to be over-conservative and is of debatable value for exploratory analyses comparing two groups (Rothman 1990). Instead, we have treated P values between 0.01 and 0.05 with greater caution.

Results

Background differences

Mean consumption of eggs across the whole sample was 32 g/day for men and 28 g/day for women, equivalent to about 3.5 eggs a week (Table 1). Approximately 58% of men and 60% of women consumed eggs during their 4-day recording period. Mean intakes among egg consumers were 54 g/day (approx. 6 eggs a week) for men and 46 g/day (approx. 5 eggs a week) for women. There were no significant differences between consumers and non-consumers in age, ethnicity, income, smoking habit, dieting, vegetarianism, or taking prescribed medication, although women who consumed eggs were more likely to record taking a supplement of some type during the survey.

Dietary intakes

Female egg consumers ate, on average, more fruit (116 vs. 75 g/day, $P < 0.001$) and vegetables (195 vs. 159 g/day, $P = 0.006$) and consumed one extra

Table 1 Background characteristics of egg consumers and non-consumers (means and column %)

			Male			Female		
			Egg non-consumer	Egg consumer	*P* value	Egg non-consumer	Egg consumer	*P* value
		N	*114*	*159*		*150*	*224*	
Eggs and egg dishes (g/day)†		Mean	0	54	<0.001	0	46	<0.001
		SE	0	3		0	3	
Age (years)		Mean	50	52	0.285	50	52	0.322
		SE	2	1		1	1	
Age group (years)					0.517			0.392
	19–39	*N* %	32%	29%		33%	29%	
	40–59	*N* %	39%	35%		38%	36%	
	60+	*N* %	30%	37%		29%	35%	
Take any type of supplement					0.735			0.009
	No	*N* %	79%	77%		79%	67%	
	Yes	*N* %	21%	23%		21%	33%	
Ethnic group					0.228			0.49
	White	*N* %	90%	91%		93%	91%	
	Non-white	*N* %	11%	9%		7%	9%	
Equivalised household income tertiles					0.423			0.106
	Lowest Tertile	*N* %	22%	24%		41%	30%	
	Middle Tertile	*N* %	33%	33%		32%	40%	
	Highest Tertile	*N* %	45%	43%		28%	31%	
Dieting to lose weight					0.423			0.202
	Yes	*N* %	12%	16%		27%	21%	
	No	*N* %	88%	84%		73%	79%	
Cigarette smoking status					0.602			0.282
	Current smoker	*N* %	13%	17%		23%	16%	
	Ex-regular smoker	*N* %	30%	31%		21%	22%	
	Never regular smoker	*N* %	57%	52%		56%	61%	
Whether taking prescribed medicines					0.59			0.81
	Yes	*N* %	52%	56%		62%	61%	
	No	*N* %	48%	44%		38%	39%	

Chi-square test for categorical variables. T-test for continuous variables. SE, standard error.
Italics indicate number of subjects.
†Mean egg consumption (g/day) for total sample including non-consumers = 32 (SE 3) for men; 28 (SE 2) for women.

portion of the recommended 5 A DAY compared with non-consumers (4.3 vs. 3.3 portions, $P < 0.001$) (Tables 2–4). They also consumed more fish (24 vs. 14 g/day, $P = 0.002$), including oil-rich fish (12 vs. 5 g/day; $P = 0.001$), but total meat consumption was not significantly different. In contrast with results for women, dietary habits of male egg consumers did not differ markedly from those of non-consumers, except for a slightly higher intake of total meat (126 vs. 107 g/day, $P = 0.021$), spirits ($P = 0.032$) and beer (mean 275 vs. 146 g/day, $P = 0.016$). Consumption of fruit and vegetables was identical between male egg consumers and non-consumers.

Female egg consumers had significantly higher mean intakes of energy (6.8 vs. 6.0 MJ/day; $P < 0.001$), and percentage energy from protein and fat, compared with non-consumers (Table 3). In terms of fatty acid profile, egg consumers had diets higher in monounsaturated fatty acids and *n*-3 polyunsaturated fatty acids but not significantly higher in saturated fatty acids (% energy). Their diets were also lower in carbohydrate and free sugars (9.3% vs. 11% of energy; $P = 0.01$). Male egg consumers had a slightly higher mean intake of energy, fat, monounsaturated fatty acids and *n*-6 polyunsaturated fatty acids and a lower intake of

Table 2 Food consumption habits of egg consumers and non-consumers (mean g/day)

	Male			Female		
Food consumption (g/day)	Egg non-consumer	Egg consumer	*P* value	Egg non-consumer	Egg consumer	*P* value
N	*114*	*159*		*150*	*224*	
Eggs and egg dishes	0	54	<0.001	0	46	<0.001
Total fish (g)†	21	22	ns	14	24	0.002
Oil-rich fish (g)†	9	8	ns	5	12	0.001
Total meat	107	126	0.021	74	81	ns
Total red meat	70	78	ns	40	48	ns
Processed red meat	16	21	ns	10	12	ns
Total white meat	37	48	0.042	34	32	ns
Total fruit and vegetables	318	318	ns	234	311	<0.001
Total fruit (not including juice)	111	111	ns	75	116	<0.001
Total vegetables	207	206	ns	159	195	0.006
5 A DAY portions (portions/day)	4.4	4.4	ns	3.3	4.3	<0.001
Milk	173	163	ns	133	141	ns
Fats and oils	10	12	ns	9	10	ns
Cheese	18	20	ns	16	20	ns
Bread	66	75	ns	52	54	ns
Pasta, rice and other cereals	84	73	ns	52	63	ns
Biscuits and cakes	30	35	ns	30	35	ns
Confectionery	11	10	ns	9	10	ns
Breakfast cereals	55	42	ns	40	42	ns
Yogurt and fromage frais	27	22	ns	27	37	ns
Puddings and ice cream	19	20	ns	14	15	ns
Sugar, preserves and sweet spreads	9	11	ns	10	7	ns
Soft drinks	265	217	ns	196	207	ns
Fruit juice	68	51	ns	36	33	ns
Tea, coffee and water	1200	1215	ns	1202	1298	ns
Beer and cider†	146	275	0.016	29	34	ns
Spirits†	1	8	0.032	2	4	0.046
Wine†	42	56	ns	36	51	ns

Meat, fish and fruit and vegetables include amounts in composite dishes. Confectionery includes chocolate. ns, non-significant.
Italics indicate number of subjects.
†Mann–Whitney test

carbohydrate and fibre, while sugar intakes were similar to those of non-consumers.

Female egg consumers had significantly higher mean intakes of most micronutrients, with twice the intake of vitamin D (3.5 vs. 1.7 µg/day; $P < 0.001$) and significantly higher intakes of riboflavin, vitamin B12¸ folate biotin, vitamin C, iron, zinc and selenium compared with non-consumers (Table 4). Compared with female egg consumers, more than twice as many non-consumers had intakes below the Lower Reference Nutrient Intake (*i.e.* the level unlikely to meet the requirements of 97.5% of the population) for minerals iron, selenium, iodine, zinc and vitamins A, B12, riboflavin and folate (data not shown); however, these results are based on a small number of cases. Male egg consumers had significantly higher mean intakes of vitamin D, biotin, iodine, zinc and selenium, compared with non-consumers. Intake data are from food sources only, excluding supplements.

Nutritional status

Vitamin D status (plasma 25-hydroxyvitamin D) was on average 9 nmol/ (17%) higher among women who consumed eggs, compared with non-consumers (57 vs. 48 nmol/l, $P = 0.031$) (Table 5). This was slightly attenuated to a difference of 7 nmol/l ($P = 0.04$) after adjustment for vitamin D supplementation, season and ethnicity (Appendix 1). Female egg consumers also had higher mean plasma levels of lutein (0.28 vs. 0.23 µmol/l; $P = 0.033$), total carotenoids (composite of lutein, alpha-cryptoxanthin, beta-cryptoxanthin, lycopene, alpha-carotene and beta-carotene) (2.38 vs. 1.90 µmol/l; $P = 0.005$). They also had higher plasma

Table 3 Energy and macronutrient intakes of egg consumers and non-consumers (means)

	Male			Female		
	Egg non-consumer	Egg consumer	*P* value	Egg non-consumer	Egg consumer	*P* value
N	*114*	*159*		*150*	*224*	
Total energy (kJ)	8018	8697	0.030	5965	6775	<0.001
Total energy (kcal)	1906	2069	0.030	1417	1611	<0.001
Percentage energy from						
Protein	16.6	17.4	ns	16.3	17.6	0.006
Fat	32.6	34.5	0.009	33.2	35.5	0.003
Saturated fatty acids	12.2	12.5	ns	12.6	13.4	ns
Monounsaturated fatty acids	11.9	12.8	0.008	12	12.7	0.045
N3 polyunsaturated fatty acids	1.0	1.0	ns	1.0	1.1	0.016
N6 polyunsaturated fatty acids	4.6	5	0.023	4.6	4.9	ns
Carbohydrate	47.5	42.5	<0.001	48.2	43.9	<0.001
Free sugars	10.8	9.9	ns	11	9.3	0.010
Fibre (g) (AOAC method)	21.2	20.6	0.012	15.8	18.1	ns

P values include adjustment for energy intake, (% of energy for macronutrients, energy as covariate for fibre). ns, non-significant.
Italics indicate number of subjects.

Table 4 Micronutrient intakes of egg consumers and non-consumers means (unadjusted)

	Male			Female		
	Egg non-consumer	Egg consumer	*P* value	Egg non-consumer	Egg consumer	*P* value
N	*114*	*159*		*150*	*224*	
Vitamin A (retinol equivalents) (μg)	866	907	ns	704	1025	0.052
Vitamin D (μg)	2.2	3.7	<0.001	1.7	3.5	<0.001
Vitamin E (mg)	9.6	10.8	ns	7.5	9.4	0.013
Thiamin (mg)	1.7	1.7	ns	1.2	1.4	ns
Riboflavin (mg)	1.6	1.8	ns	1.2	1.5	<0.001
Niacin equivalent (mg)	37	42	ns	27	31	0.022
Vitamin B6 (mg)	1.9	2.1	ns	1.4	1.5	ns
Vitamin B12 (μg)	5.2	6	ns	3.3	5.5	0.004
Folate (μg)	261	278	ns	178	222	0.001
Pantothenic acid (mg)	6	7	ns	4.0	5.0	ns
Biotin (μg)	34	44	<0.001	23	36	<0.001
Vitamin C (mg)	92	88	ns	65	82	0.004
Sodium (mg)	2133	2391	ns	1573	1815	ns
Potassium (mg)	3088	3234	ns	2293	2648	0.033
Calcium (mg)	844	895	ns	665	764	ns
Magnesium (mg)	287	305	ns	208	243	ns
Phosphorus (mg)	1282	1416	ns	961	1157	<0.001
Iron (mg)	10.7	11.9	ns	7.9	9.5	0.017
Haem iron (mg)	0.7	0.8	ns	0.4	0.6	0.021
Non-haem iron (mg)	10.0	11.1	ns	7.5	8.9	0.039
Copper (mg)	1.3	1.3	ns	0.9	1.1	0.018
Zinc (mg)	9.0	9.9	ns	6.3	7.9	<0.001
Iodine (μg)	149	207	0.016	121	145	ns
Selenium (μg)	47	59	<0.001	32	49	<0.001

P values include adjustment for energy intake (as covariate). ns, non-significant.
Italics indicate number of subjects.

selenium compared with non-consumers (1.04 vs. 0.97 μmol/l, $P = 0.011$) and this remained weakly significant ($P = 0.049$) after adjustment for fish consumption and supplemental selenium (data not shown). In terms of iron status, female egg consumers had higher mean plasma ferritin (72 vs. 49 μg/l; $P = 0.003$) than non-consumers and this remained significant ($P = 0.009$) after adjustment for age, supplemental iron and total red meat consumption (data not shown). The prevalence of anaemia (haemoglobin < 120 g/l) was 5% among female egg consumers, compared with 18% among non-consumers ($P = 0.007$) and the prevalence of low iron stores was non-significantly lower at 8% versus 18% ($P = 0.074$). There was no apparent association with urinary iodine concentration (data not shown). Among men, none of the status markers were significantly different between egg consumers and non-consumers.

Subgroup analysis of low red meat consumers

To examine the potential benefit of egg consumption for adults with lower intake of RPM, nutrient intakes of egg consumers and non-consumers were compared in the subsample consuming less than median amounts of RPM (70 g/day for men; 36 g for women) (Table 6). Both male and female low RPM consumers who ate no eggs had lower intakes of vitamin D, riboflavin, vitamin B12 and selenium, compared with egg consumers (Table 6). In addition, among women consuming less than 36 g/day RPM, non-consumers of eggs had lower intakes of folate, vitamin C and zinc, compared with egg consumers. Women with low RPM intake who did not eat eggs had lower mean ferritin levels than egg consumers but differences in selenium and vitamin D status were not statistically significant. However, due to small sample sizes, especially for status markers, these results should be interpreted with caution.

Cardiovascular risk markers

There were no differences between egg consumers and non-consumers in mean levels of blood lipids (total cholesterol, LDL-cholesterol, HDL-cholesterol, total: HDL-cholesterol, triglycerides) nor in glycated haemoglobin, systolic blood pressure or diastolic blood pressure (Appendix 2). Models were adjusted for age, lipid-lowering drugs (for blood lipids), and antihypertensive drugs and alcohol (for blood pressure).

Anthropometric indices

Despite their higher reported energy intakes, women who consumed eggs weighed on average 3.7 kg less

Table 5 Micronutrient status of egg consumers and non-consumers (means)

		Male			Female		
	N	Egg non-consumer	Egg consumer	*P* value	Egg non-consumer	Egg consumer	*P* value
N (max)	*295*	*54*	*73*		*59*	*109*	
25-hydroxy vitamin D (nmol/l)	*295*	47	50	ns	48	57	0.031
Total carotenoids[†] (μmol/l)	*290*	1.85	1.84	ns	1.9	2.38	0.005
Lutein (μmol/l)	*290*	0.25	0.25	ns	0.23	0.27	0.033
Holotranscobalamin (pmol/l)	*289*	71	72	ns	78	79	ns
Vitamin B2 Status (EGRAC)	*288*	1.37	1.33	ns	1.37	1.36	ns
Vitamin B1 Status (ETKAC)	*288*	1.12	1.12	ns	1.12	1.11	ns
Vitamin B6 Pyridoxal-5-Phosphate (PLP) (nmol/l)	*290*	51	52	ns	45	50	ns
Red cell folate (nmol/l)	*267*	579	604	ns	594	591	ns
Total serum folate (nmol/l)	*295*	18.1	17.9	ns	16.4	19.0	ns
Selenium (μmol/l)	*290*	1.0	1.03	ns	0.97	1.04	0.011
Zinc (μmol/l)	*290*	13.2	13.2	ns	12.3	12.5	ns
Haemoglobin (g/l)	*283*	147	148	ns	130	133	ns
Ferritin (μg/l)[‡]	*286*	118	130	ns	49	72	0.003
Low iron status							
Hb < 120 g/l	*283*	0%	2.7%	ns	18.2%	5.0%	0.007
Ferritin < 15 μg/l[‡]	*286*	0%	1.4%	ns	17.9%	8.4%	0.074

ns, non-significant. *P* values for T-test, except for carotenoids, lutein and ferritin (Mann–Whitney). Categorical analysis using chi-square.
Italics indicate number of subjects.
[†]Composite of lutein, alpha-cryptoxanthin, beta-cryptoxanthin, lycopene, alpha-carotene and beta-carotene.
[‡]Ferritin excludes values > 400 μg/l.

Table 6 Subgroup analysis: Micronutrient intake and status of low consumers of red and processed meat (RPM) according to egg consumption

	N	Male consuming < 70 g/day RPM			Female consuming < 36 g/day RPM		
		Egg non-consumer	Egg consumer	P value	Egg non-consumer	Egg consumer	P value
Dietary intake							
N	*324*	*54*	*83*		*83*	*104*	
Vitamin D (μg)		1.9	3.5	<0.001	1.6	3.5	<0.001
Riboflavin (mg)		1.6	1.8	0.046	1.1	1.5	0.001
Vitamin B12 (μg)		4.4	5.9	0.007	2.9	4.7	<0.001
Folate (μg)		256	267	ns	178	224	0.031
Vitamin C (mg)		88	85	ns	63	89	0.030
Iron (mg)		10.3	11.3	ns	7.7	9.1	ns
Zinc (mg)		7.8	8.7	ns	5.6	7.1	0.001
Selenium (μg)		41	59	<0.001	30	48	<0.001
Biochemical status							
N	*159*	*0*	*42*		*4*	*53*	
25-hydroxy vitamin D (nmol/l)	*159*	45	53	ns	50	53	ns
Selenium (μmol/l)	*155*	0.97	1.02	ns	0.98	1.05	ns
Ferritin† (μg/l)	*154*	100	113	ns	44	66	0.033

Low RPM consumers: adults below median RPM consumption (70 g/day men, 36 g/day women). *P* values for dietary intake include adjustment for energy intake (covariate). T-tests, except for Ferritin (Mann–Whitney test). ns, non-significant.
Italics indicate number of subjects.
†Ferritin excludes values> 400 μg/l.

than non-consumers ($P = 0.043$) and had smaller mean waist circumference (3.8cm difference, $P = 0.037$) (Table 7). Mean BMI was 27.2 vs. 28.9 kg/m^2 ($P = 0.007$) and more were in the normal healthy weight category (39.5% vs. 25.2%; $P = 0.044$). The proportion of dieters was not significantly higher among non-consumers but as a precautionary measure we conducted supplementary analyses to include dieting as a cofactor in models (Appendix 3). As a result, adjusted mean differences in weight and waist circumference were slightly attenuated to 2.7kg ($P = 0.121$), and 3.4cm ($P = 0.057$), respectively, but BMI remained significantly lower (by 1.4 kg/m^2, $P = 0.025$) among egg consumers, as did waist-to-height ratio (WHtR) ($P = 0.031$). There were no significant associations between egg consumption and anthropometrics in men.

Discussion

This analysis of recent data from a high-quality national survey is to our knowledge the first UK study to report significant beneficial differences in nutritional status and bodyweight associated with current egg consumption patterns. These associations were observed in conjunction with a more nutrient-rich and apparently more health-conscious diet, based on food choices that included more vegetables, fruit and fish among female egg consumers compared with non-consumers. This contrasted with male egg consumers, who had higher intakes of some nutrients but did not otherwise appear to have healthier dietary choices.

Micronutrient intakes and status

Egg composition was reanalysed in 2011 as part of the update programme for Composition of Foods (Roe *et al.* 2013). Levels of vitamin D and selenium had increased substantially due to changes in hen feed, while fat and cholesterol content had declined slightly, mainly due to a small decrease in the ratio of yolk to white over time (Benelam *et al.* 2012). Given that eggs are a good source of vitamin D and selenium (3.15 μg/100 g and 23 μg/100 g whole raw egg, respectively) (Benelam *et al.* 2012), it is likely that the observed enhanced nutritional status of these micronutrients among egg consumers is at least partly attributable to eggs. *NDNS* reports for 2015/2016 confirm that eggs provide 19% of the dietary vitamin D for adults; other major sources are meat (30%), fish (17%) and spreads (11%) (Roberts *et al.* 2018). However, vitamin D status is more influenced by non-dietary factors, principally sun exposure and supplementation (Macdonald *et al.* 2011). We found

Table 7 Anthropometric measurements among egg consumers and non-consumers (means and percentages)

		Male			Female		
	N	Egg non-consumer	Egg consumer	*P* value	Egg non-consumer	Egg consumer	*P* value
N (max)	*586*	*103*	*145*		*133*	*205*	
Age (years)	*586*	49	51	ns	49	50	ns
Weight (kg)	*586*	84.9	84.4	ns	75.3	71.6	0.043
Height (cm)	*583*	175.5	175.3	ns	161.1	162.5	ns
BMI (kg/m^2)	*576*	27.7	27.4	ns	28.9	27.2	0.007
Waist measurement (cm)	*441*	99.5	97.8	ns	91.6	87.8	0.037
WHtR	*416*	0.57	0.56	ns	0.57	0.54	0.019
WHtR category†	*416*			ns			ns
<0.5		22%	26%		25%	36%	
0.5 +		78%	74%		75%	64 %	
BMI groups†	*576*			ns			0.044
Underweight (<18.5)		1%	1%		2%	1%	
Normal (18.5–25)		33%	26%		25%	40%	
Overweight (25–30)		37%	50%		37%	34%	
Obese (30–40)		26%	22%		28%	23%	
Very obese (over 40)		3%	1%		8%	3%	
Dieting (%)†	*586*	10.5%	17.4%	ns	29.3%	22.2%	ns

BMI, body mass index; ns, non-significant; WHtR, waist-to-height ratio.
Italics indicate number of subjects.
†Chi-square test.

that female egg consumers had higher levels of plasma 25-(OH)D even after adjusting for ethnicity, season and vitamin D supplement use. In view of the high prevalence of suboptimal vitamin D status among British adults with almost one in five having plasma 25-(OH)D concentration below 25 nmol/l in 2014-2016 (Roberts *et al*. 2018), Public Health England advises supplementation of 10 μg/day in the wintertime, and supplementation all year round for vulnerable groups, including people with dark skin, older people and those not spending much time outdoors (Public Health England 2016). In 2020, given the current restriction measures to contain coronavirus, PHE reinforced this advice, stating that all consider taking a 10 μg/day vitamin D supplement throughout spring and summer while the lockdown continues (NHS 2020). However, since supplementation advice rarely guarantees compliance, food sources of vitamin D (such as eggs, meat and fish) remain important, while fortification may be an option if population status does not improve (Buttriss & Lanham-New 2020).

Selenium is a shortfall nutrient in the UK diet and suboptimal selenium status is reported to be widespread throughout Europe, the UK and the Middle East (Stoffaneller & Morse 2015). British vegetarians have been found to have lower selenium intakes and status compared with non-vegetarians (Sobiecki 2017), consistent with their avoidance of meat and fish, which are major sources. Two medium eggs (100 g) provide 23 μg, more than a third of the reference nutrient intake (RNI) for adult women (60 μg/day), and hence are a valuable source of selenium for those reducing their meat consumption. Our results showed that selenium status was significantly higher among female egg consumers (vs. non-consumers), and in separate analysis of low RPM consumers, egg consumption was associated with better selenium intakes in both sexes.

It has been suggested that iodine status may be insufficient among women of childbearing age in the UK (Jiang *et al*. 2018) and iodine deficiency and thyroid disease can be exacerbated by selenium deprivation. In 2014 the Scientific Advisory Committee on Nutrition stated the need for better data from population groups thought to be at greatest risk of iodine deficiency; namely girls of reproductive age, pregnant and lactating women, and dairy and fish avoiders (The Scientific Advisory Committee on Nutrition 2014). In Years 7 and 8 of the *NDNS* 27% of girls aged 11–18 years and 15% of adult women had iodine intakes below the Lower Reference Nutrient Intake (LRNI) and 17% of women aged 16–49 years had urinary iodine concentration below 50 μg/l (Roberts *et al*. 2018). Milk and milk products are the major source of iodine (https://www.bda.uk.com/resource/iodine.html.) contributing 34% of the total intake among adults aged 19–64 years, while fish and eggs contribute 10% and 7%, respectively (Roberts *et al.* 2018); two medium eggs (100 g) provide approximately 50 mg iodine or one third of the RNI for a non-pregnant woman. In the present study, iodine intakes were higher in male egg consumers, but just failed to reach significance in female egg consumers after adjustment for energy ($P = 0.07$). Milk intakes were very similar for egg consumers and non-consumers. We did not identify any differences in iodine status associated with egg consumption but in *NDNS* this is estimated from urinary iodine concentration in spot samples, which has well-recognised methodological limitations (The Scientific Advisory Committee on Nutrition 2014; Chen *et al.* 2020).

There is evidence that the carotenoids lutein and zeaxanthin may reduce the risk of age-related macular degeneration (Kelly *et al.* 2017) as well as emerging research to suggest that higher blood levels of these carotenoids are associated with improved cognition (Wallace 2018). Mean levels of total carotenoids were 25% higher among female egg consumers compared with non-consumers ($P = 0.008$); lutein levels were also higher. Some trials using non-UK eggs, or enriched eggs, have reported that adding one egg a day to the diet increased plasma levels of lutein and zeaxanthin (Goodrow *et al.* 2006; Kishimoto *et al.* 2017). In an Irish study, Kelly *et al.* found that consumption of both enriched and non-enriched eggs increased serum carotenoids, although to a greater extent with enriched eggs (Kelly *et al.* 2017). Eggs in the UK contain around 94 μg lutein per 100 g (Roe *et al.* 2013) and negligible amounts of zeaxanthin (Handelman *et al.* 1999; Roe *et al.* 2013), while corn and green vegetables such as kale and spinach are richer sources (Maiani *et al.* 2009). Although the lutein in eggs is highly bioavailable, greater consumption of vegetables among female egg consumers in this study may more likely explain their higher lutein and carotenoid status.

Iron status may be suboptimal among women of reproductive age, particularly among low-income groups (The Scientific Advisory Committee on Nutrition 2010) and those who are vegetarian or cutting down on red meat (Pawlak *et al.* 2018). In years 7 and 8 of the *NDNS*, more than a quarter of adult women and half of girls aged 11–18 years had iron intakes below LRNI, and 12% and 24% of women and girls, respectively, had ferritin levels below 15 μg/l (Roberts *et al.* 2018). We found evidence of lower iron intakes and lower iron status among adult female non-consumers of eggs, compared with consumers. Moreover, the subsample of women with below-median RPM intakes and who did not consume eggs had lower intakes of a number of key nutrients, including riboflavin, vitamin B12, folate, vitamin C, iron, zinc and selenium, compared to egg consumers with below-median RPM intakes. Further research is warranted to assess the impact of egg consumption on nutritional status and health markers in low red meat consumers, especially those with a restricted diet.

Cardiometabolic risk factors

Although egg consumers reported higher energy intakes than non-consumers, indices of body weight or obesity were either similar for consumers and non-consumers, or significantly lower in the case of women. Of BMI and waist-to-height ratio (WHtR), the latter is a better indicator of cardiometabolic risk (Ashwell *et al.* 2012; Gibson & Ashwell 2019) as it measures central obesity. Data from other populations on associations with egg consumption are conflicting. In a rural Chinese population, Liu *et al.* recently reported that female egg consumers had lower risk of excessive body fat and central obesity than non-consumers (Liu *et al.* 2020), while in the US NHANES (2003–2012), egg consumption was positively associated with BMI and waist circumference (Melough *et al.* 2019). Another study using the US NHANES (2001–2008) found that the positive association with BMI disappeared after adjustment for other food habits and medication (Nicklas *et al.* 2015). One possible explanation for lower BMI despite higher energy intake is that female egg consumers participating in the *NDNS* had a more active lifestyle, complementary to the healthier eating practices observed. Further analyses could explore the *NDNS* physical activity data to test this hypothesis.

Egg consumption was not associated with adverse levels of cardiovascular risk markers such as LDL-cholesterol, total:HDL-cholesterol, triglycerides, blood pressure and glycated haemoglobin (HbA1c). For blood lipids, this is in accordance with a major systematic review of randomised controlled trials (RCT) that found no effect of eggs on total:HDL-cholesterol or triglycerides (Rouhani *et al.* 2018). Another recent meta-analysis also found no significant effects of eggs on systolic or diastolic blood pressure in adults (Kolahdouz-Mohammadi *et al.* 2020), while population studies have found no association or inverse associations (Shin *et al.* 2017; Abdollahi *et al.* 2019). Our null finding for HbA1c is in contrast to a meta-analysis of prospective studies (Mazidi *et al.* 2019) and one cross-sectional study based on earlier *NDNS* data (2008–2012) that reported positive associations between egg consumption and HbA1c (Guo *et al.* 2018). The authors of this UK study remarked that residual confounding factors may have influenced the associations between egg consumption and health and recommended that dietary patterns of high and low egg consumers should be explored (Guo *et al.* 2018). When we investigated this in earlier *NDNS* data (2000/2001), egg consumption was highly correlated with a "traditional" dietary pattern characterised by a high intake of RPM, although we did not examine men and women separately (Ruxton *et al.* 2010). Our new results from *NDNS* Year 9 (2017) suggest that the change in dietary patterns may be comparatively recent. Women especially appear to be consuming eggs as part of a healthier modern dietary pattern, with significantly higher amounts of fruit, vegetables and fish and a higher dietary quality as measured by intake of micronutrients, protein, *n*-3 polyunsaturated fatty acids and free sugars. Further work may be warranted to confirm how dietary patterns in men and women have changed over the course of the *NDNS* and especially in the last few years.

Healthy dietary patterns and sustainability issues

It is becoming increasingly recognised that a reductionist, pharma-model approach that seeks to elucidate relationships between single nutrients or foods and specific outcomes is insufficient to understand their complexity and interactions. Hence the evolution of research into dietary patterns and the development of food-based dietary guidelines. Furthermore, the food matrix, nutrient bioavailability and synergistic effects of various components are at least as important as the nutritional composition and amount consumed. Eggs contain a package of nutrients including various minerals, vitamins and fatty acids that may be lacking in diets low in animal products. They are also versatile and relatively inexpensive. In many parts of the world, they are a valuable source of scarce high-quality protein (Willett *et al.* 2019), which is also important for older adults in all societies, who may be at risk of sarcopenia (Smith & Gray 2016). Protein also contributes to the management of obesity and the metabolic syndrome, by acting on the relevant metabolic targets of satiety and energy expenditure in negative energy balance, thereby preventing a weight cycling effect (Westerterp-Plantenga *et al.* 2012). While meat is a particularly rich source of both protein and micronutrients of concern in the UK diet, there is an undeniable trend in Western societies towards reducing consumption of red and processed meat in particular. Global health organisations have advocated reducing consumption of RPM to reduce risk of non-communicable diseases (NCD) for some years, although not all experts agree that this would have a significant effect on cardiometabolic outcomes or cancer (Johnston *et al.* 2019). In the UK, government advice is 'on average, eat no more than 70 g red and processed meat a day' (Public Health England 2018; NHS 2018b). In the last published data from *NDNS* (years 7 and 8), average consumption among adult men aged 19–64 years exceeded the recommendation (mean 77 g/day RPM), while women met the recommendation (mean 47 g/day RPM) (Roberts *et al.* 2018). More recently, enhanced awareness of the environmental impact of meat production is driving behaviour change towards diets that are, arguably, more sustainable (Willett *et al.* 2019). However, the concept of sustainability is highly complex in definition and quantification. It depends on the efficiency of agriculture, processing, transport and consumer use and applies across the whole diet. Eggs have a lower carbon footprint (kg greenhouse gas emissions per serving) than meat, poultry or fish (Poore & Nemecek 2018; *BBC News* 2019) and approximately 65% of the eggs purchased in the UK are free-range (British Egg Information Service 2020). It has been argued that replacing meat with eggs just once a week would be a 'win-win diet' (Willett *et al.* 2019), with both environmental and health benefits. With regard to CVD, *EPIC* investigators using substitution modelling across nine European populations recently estimated that replacement of 100 kcal/day from red and processed meat with 100 kcal/day from eggs was associated with approximately 20% lower risk of ischaemic heart disease (Key *et al.* 2019).

Strengths and limitations

This study used government data (*NDNS*) of recognised quality and reliability, employed for dietary monitoring and planning purposes. These files are accessible to researchers via the UK Data Archive to verify our findings and conduct further analyses. We used only the most recent data from year 9 (2017) to capture current dietary habits of egg consumers and non-consumers. Although this limited the statistical power, we identified some differences that are both statistically and biologically meaningful. As egg sales appear to be continuing to rise, new studies of accumulated data may be warranted, including more sophisticated analysis of dietary patterns and modelling of the impact of egg consumption on status. The usual caveats apply to self-reported dietary records, which may be prone to misreporting and changes in eating habits as a result of participation in the survey. There is no satisfactory way of dealing with misreporting and most solutions involve excluding certain participants, potentially creating bias as well as reducing numbers for analysis. Finally, causal inferences cannot be drawn about the effects of egg consumption on nutrition and health, as the data are observational.

Conclusion

Epidemiological studies need to follow recent trends in dietary intakes for their conclusions on diet/health relationships to be valid today. In this analysis of *NDNS* data from 2017, egg consumption appeared to be associated with higher intakes of fruit, vegetables and fish, higher nutrient status in respect of plasma levels of vitamin D, selenium, iron and carotenoids, and slightly lower BMI among British women. There was no evidence of adverse associations with CVD risk markers in either sex. Results may reflect changing eating patterns among current egg consumers, led by women. Further research into how people are incorporating eggs into healthier eating practices would help inform food-based dietary guidelines and dietary advice for different groups.

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Conflict of Interest

The article reflects the views of the authors alone, and the funding source, BEIC, had no role in the preparation or submission of the article. SG received research funding from BEIC for the present study. JG is a scientific adviser to the BEIC. There are no other conflicts of interest to declare.

References

Abdollahi AM, Virtanen HEK, Voutilainen S *et al.* (2019) Egg consumption, cholesterol intake, and risk of incident stroke in men: the Kuopio Ischaemic Heart Disease Risk Factor Study. *The American Journal of Clinical Nutrition* **110**: 169–76.

Ashwell M, Gunn P & Gibson S (2012) Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis. *Obesity Reviews* **13**: 275–86.

Bates B, Lennox A, Prentice A*et al.* (2014) *National Diet and Nutrition Survey: Results from Years 1, 2, 3 and 4 (combined) of the Rolling Programme (2008/2009 – 2011/2012)*, Public Health England, Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/594361/NDNS_Y1_to_4_UK_report_full_text_revised_February_2017.pdf. (accessed 31 July 2020).

Bates B, Collins D, Cox L*et al.* (2019) *National Diet and Nutrition Survey: Years 1 to 9 of the Rolling Programme (2008/2009–2016/2017): Time Trend and Income Analyses*. Public Health England, Available at: https://www.gov.uk/government/statistics/ndns-time-trend-and-income-analyses-for-years-1-to-9. (accessed 31 July 2020).

BBC News (2019) *Climate change food calculator: What's your diet's carbon footprint?* By Nassos Stylianou, Clara Guibourg and Helen Briggs, 9 August 2019. Available at: https://www.bbc.co.uk/news/science-environment-46459714 (accessed 31 July 2020).

Benelam B, Rowe M, Pinchen H *et al.* (2012) New data on the nutritional composition of UK hens' eggs. *Nutrition Bulletin* **37**: 344–49.

British Egg Information Service (2020) *Industry data*. Available at: https://www.egginfo.co.uk/egg-facts-and-figures/industry-information/data (accessed 31 July 2020).

Buttriss JL & Lanham-New SA (2020) Is a vitamin D fortification strategy needed? *Nutrition Bulletin* **45**: 115–22.

Chen W, Gao S, Guo W *et al.* (2020) Intra-individual and inter-individual variations in iodine intake and excretion in adult women: implications for sampling. *British Journal of Nutrition* **123**: 987–93.

Clayton ZS, Fusco E & Kern M (2017) Egg consumption and heart health: A review. *Nutrition* **37**: 79–85.

Czekajlo-Kozlowska A, Rozanska D, Zatonska K *et al.* (2019) Association between egg consumption and elevated fasting glucose prevalence in relation to dietary patterns in selected group of Polish adults. *Nutrition Journal* **18**: 90.

Dehghan M, Mente A, Rangarajan S *et al.* (2020) Association of egg intake with blood lipids, cardiovascular disease, and mortality in 177,000 people in 50 countries. *The American Journal of Clinical Nutrition* **111**: 795–803.

Djousse L, Khawaja OA & Gaziano JM (2016) Egg consumption and risk of type 2 diabetes: a meta-analysis of prospective studies. *American Journal of Clinical Nutrition* **103**: 474–80.

Drouin-Chartier JP, Chen S, Li Y *et al.* (2020) Egg consumption and risk of cardiovascular disease: three large prospective US cohort

studies, systematic review and updated meta-analysis. *British Medical Journal* **368**: m513.
Geiker NRW, Larsen ML, Dyerberg J *et al.* (2018) Egg consumption, cardiovascular diseases and type 2 diabetes. *European Journa of Clinical Nutrition* **72**: 44–56.
Gibson S & Ashwell M (2019) A simple cut-off for waist-to-height ratio (0.5) can act as an indicator for cardiometabolic risk: recent data from adults in the Health Survey for England. *British Journal of Nutrition* **123**: 1–26.
Goodrow EF, Wilson TA, Houde SC *et al.* (2006) Consumption of one egg per day increases serum lutein and zeaxanthin concentrations in older adults without altering serum lipid and lipoprotein cholesterol concentrations. *Journal of Nutrition* **136**: 2519–24.
Guo J, Hobbs DA, Cockcroft JR *et al.* (2018) Association between egg consumption and cardiovascular disease events, diabetes and all-cause mortality. *European Journal of Nutrition* **57**: 2943–52.
Handelman GJ, Nightingale ZD, Lichtenstein AH *et al.* (1999) Lutein and zeaxanthin concentrations in plasma after dietary supplementation with egg yolk. *American Journal of Clinical Nutrition* **70**: 247–51.
Jiang H, Powers HJ & Rossetto GS (2018) A systematic review of iodine deficiency among women in the UK. *Public Health Nutrition* **31**: 1–10.
Johnston BC, Zeraatkar D, Han MA *et al.* (2019) Unprocessed Red Meat and Processed Meat Consumption: Dietary Guideline Recommendations From the Nutritional Recommendations (NutriRECS) Consortium. *Annals of Internal Medicine* **171**: 756–64.
Kelly D, Nolan JM, Howard AN *et al.* (2017) Serum and macular response to carotenoid-enriched egg supplementation in human subjects: the Egg Xanthophyll Intervention clinical Trial (EXIT). *British Journal of Nutrition* **117**: 108–23.
Key TJ, Appleby PN, Bradbury KE *et al.* (2019) Consumption of Meat, Fish, Dairy Products, and Eggs and Risk of Ischemic Heart Disease. *Circulation* **139**: 2835–45.
Kishimoto Y, Taguchi C, Saita E *et al.* (2017) Additional consumption of one egg per day increases serum lutein plus zeaxanthin concentration and lowers oxidized low-density lipoprotein in moderately hypercholesterolemic males. *Food Research International* **99**: 944–49.
Kolahdouz-Mohammadi R, Malekahmadi M, Clayton ZS *et al.* (2020) Effect of Egg Consumption on Blood Pressure: a Systematic Review and Meta-analysis of Randomized Clinical Trials. *Current Hypertension Reports* **22**: 24.
Liu R, Zhao Y, Li Q *et al.* (2020) Body Fat Mass, Fat Distribution and Egg Consumption: a Population-Based Study in Chinese Adults. *Journal of the American College of Nutrition* **36**: 1–9.
Macdonald HM, Mavroeidi A, Fraser WD *et al.* (2011) Sunlight and dietary contributions to the seasonal vitamin D status of cohorts of healthy postmenopausal women living at northerly latitudes: a major cause for concern? *Osteoporosis International* **22**: 2461–72.
Mah E, Chen CO & Liska DJ (2019) The effect of egg consumption on cardiometabolic health outcomes: an umbrella review. *Public Health Nutrition* **23**: 1–21.
Maiani G, Caston MJ, Catasta G *et al.* (2009) Carotenoids: actual knowledge on food sources, intakes, stability and bioavailability and their protective role in humans. *Molecular Nutrition and Food Research* **53**(Suppl 2): S194–218.
Mazidi M, Katsiki N, Mikhailidis DP *et al.* (2019) Egg Consumption and Risk of Total and Cause-Specific Mortality: An Individual-Based Cohort Study and Pooling Prospective Studies on Behalf of the Lipid and Blood Pressure Meta-analysis Collaboration (LBPMC) Group. *Journal of the American College of Nutrition* **38**: 552–63.
Melough MM, Chung SJ, Fernandez ML *et al.* (2019) Association of eggs with dietary nutrient adequacy and cardiovascular risk factors in US adults. *Public Health Nutrition* **22**: 2033–42.
Public Health England (2020) National diet and nutrition survey. https://www.gov.uk/government/collections/national-diet-and-nutrition-survey (accessed 31 July 2020).
NHS (2018a) *The healthy way to eat eggs*. Available at: https://www.nhs.uk/live-well/eat-well/eggs-nutrition/ (accessed 31 July 2020).
NHS (2018b) *Meat in your diet*. Available at: https://www.nhs.uk/live-well/eat-well/meat-nutrition/ (accessed 31 July 2020).
NHS (2020) *Vitamin D*. Available at: https://www.nhs.uk/conditions/vitamins-and-minerals/vitamin-d/ (accessed 31 July 2020).
Nicklas TA, O'Neil CE & Fulgoni VL 3rd (2015) Differing statistical approaches affect the relation between egg consumption, adiposity, and cardiovascular risk factors in adults. *Journal of Nutrition* **145**: 170S–6S.
Papanikolaou Y & Fulgoni VL (2019) Egg Consumption in U.S. Children is Associated with Greater Daily Nutrient Intakes, including Protein, Lutein + Zeaxanthin, Choline, alpha-Linolenic Acid, and Docosahexanoic Acid. *Nutrients* **11**: pii:E1137.
Pawlak R, Berger J & Hines I (2018) Iron Status of Vegetarian Adults: A Review of Literature. *American Journal of Lifestyle Medicine* **12**: 486–98.
Poore J & Nemecek T (2018) Reducing food's environmental impacts through producers and consumers. *Science* **360**: 987–92.
Public Health England (2016) PHE publishes new advice on vitamin D. Ref: PHE publications gateway number 2016188, PHE bulletin: 28 July 2016.
Public Health England (2018) *A Quick Guide to the Government's Healthy Eating Recommendations*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/742746/A_quick_guide_to_govt_healthy_eating_update.pdf (accessed 31 July 2020).
Rehault-Godbert S, Guyot N & Nys Y (2019) The Golden Egg: Nutritional Value, Bioactivities, and Emerging Benefits for Human Health. *Nutrients* **11**: 684.
Roberts C, Steer T & Maplethorpe N. (2018) *National Diet and Nutrition Survey Results from Years 7 and 8 (combined) of the Rolling Programme (2014/2015 to 2015/2016) . PHE publications*. Available at: https://www.gov.uk/government/statistics/ndns-results-from-years-7-and-8-combined (accessed 31 July 2020).
Roe M, Pinchen H, Church S*et al.* (2013) Nutrient analysis of eggs: analytical report (revised version). Vol. accessed March 2020) Department of Health, Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/167973/Nutrient_analysis_of_eggs_Analytical_Report.pdf (accessed 31 July 2020).
Rothman KJ (1990) No adjustments are needed for multiple comparisons. *Epidemiology* **1**: 43–46.
Rouhani MH, Rashidi-Pourfard N, Salehi-Abargouei A *et al.* (2018) Effects of Egg Consumption on Blood Lipids: A Systematic Review and Meta-Analysis of Randomized Clinical Trials. *Journal of American College of Nutrition* **37**: 99–110.

Ruxton CHS, Derbyshire E & Gibson S (2010) The nutritional properties and health benefits of eggs. *Nutrition and Food Science* **40**: 263–79.
Sabate J, Burkholder-Cooley NM, Segovia-Siapco G *et al.* (2018) Unscrambling the relations of egg and meat consumption with type 2 diabetes risk. *American Journal of Clinical Nutrition* **108**: 1121–28.
Shikany JM, Safford MM, Newby PK *et al.* (2015) Southern Dietary Pattern is Associated With Hazard of Acute Coronary Heart Disease in the Reasons for Geographic and Racial Differences in Stroke (REGARDS) Study. *Circulation* **132**: 804–14.
Shin S, Lee H-W, Kim CE *et al.* (2017) Egg Consumption and Risk of Metabolic Syndrome in Korean Adults: Results from the Health Examinees Study. *Nutrients* **9**: 687.
Smith A & Gray J (2016) Considering the benefits of egg consumption for older people at risk of sarcopenia. *British Journal of Community Nursing* **21**: 305–9.
Sobiecki JG (2017) Vegetarianism and colorectal cancer risk in a low-selenium environment: effect modification by selenium status? A possible factor contributing to the null results in British vegetarians. *European Journal of Nutrition* **56**: 1819–32.
Stoffaneller R & Morse NL (2015) A review of dietary selenium intake and selenium status in Europe and the Middle East. *Nutrients* **7**: 1494–537.
The Scientific Advisory Committee on Nutrition (2010) Iron and Health. (TSO ed. London, UK.
The Scientific Advisory Committee on Nutrition (2014) Statement on Iodine and Health. (Public Health England, P. ed. London, UK.
Wallace TC (2018) A Comprehensive Review of Eggs, Choline, and Lutein on Cognition Across the Life-span. *Journal of the American College of Nutrition* **37**: 269–85.
Westerterp-Plantenga MS, Lemmens SG & Westerterp KR (2012) Dietary protein - its role in satiety, energetics, weight loss and health. *British Journal of Nutrition* **108**(Suppl 2): S105–12.
Willett W, Rockstrom J, Loken B *et al.* (2019) Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *Lancet* **393**: 447–92.

Appendix 1

Plasma 25-hydroxy Vitamin D (nmol/l) adjusted models

	B	SE	t	*P* value
Females				
Egg consumer [a]	7.2	3.5	2.1	0.040
Ethnic group – white [b]	24.1	5.8	4.2	<0.001
Vitamin D supplement [c]	14.9	3.7	4.1	<0.001
Summer vs. winter [d]	12.4	3.4	3.7	<0.001
Males				
Egg consumer [a]	0.9	3.2	0.3	0.8
Ethnic group – white [b]	25.1	5.6	4.5	<0.001
Vitamin D supplement [c]	17.1	4.2	4.1	<0.001
Summer vs. winter [d]	14.3	3.2	4.5	<0.001

[a]Egg consumer vs. non-consumer.
[b]White vs. other ethnic group.
[c]Supplement containing vitamin D vs. no supplement containing vitamin D.
[d]April to September vs. October to March.

Appendix 2

Cardiometabolic risk factors among egg consumers and non-consumers (means)

		Male			Female		
	N	Egg non-consumer	Egg consumer	*P* value	Egg non-consumer	Egg consumer	*P* value
Total cholesterol (mmol/l)	294	4.4	4.4	ns	4.6	4.6	ns
Triglycerides (mmol/l)	293	1.3	1.5	ns	1.1	1.1	ns
High-density lipoproteins (mmol/l)	294	1.2	1.2	ns	1.4	1.5	ns
Low-density lipoproteins (mmol/l)	291	2.7	2.6	ns	2.6	2.6	ns
Total: HDL-cholesterol ratio	294	4.1	3.9	ns	3.4	3.2	ns
Haemoglobin A1c (mmol/mol)	253	37.8	37.7	ns	37.4	37.6	ns
Systolic blood pressure	396	127	129	ns	125	124	ns
Diastolic blood pressure	396	75	73	ns	71	71	ns

All risk factors adjusted for age. Lipids adjusted for lipid-lowering drugs. Blood pressure adjusted for antihypertensive drugs and alcohol. N = 294 for lipids. N = 396 for blood pressure.

Appendix 3

Anthropometric models adjusted for dieting

	B	SE	*t*	*P* value
Females				
Weight (kg)				
Egg consumer [a]	−2.68	1.72	−1.56	0.121
Dieting to lose weight [b]	12.92	1.95	6.62	0.000
BMI (kg/m^2)				
Egg consumer [a]	−1.43	0.64	−2.25	0.025
Dieting to lose weight [b]	3.95	0.72	5.47	0.000
Waist (cm)				
Egg consumer [a]	−3.38	1.77	−1.92	0.057
Dieting to lose weight [b]	8.05	2.01	4.00	0.000
WHtR				
Egg consumer [a]	−0.026	0.012	−2.167	0.031
Dieting to lose weight [b]	0.042	0.013	3.129	0.002
Males				
Weight (kg)				
Egg consumer [a]	−1.35	1.89	−0.71	0.477
Dieting to lose weight [b]	12.32	2.65	4.65	0.000
BMI (kg/m^2)				
Egg consumer [a]	−0.55	0.61	−0.91	0.362
Dieting to lose weight [b]	4.26	0.84	5.05	0.000
Waist (cm)				
Egg consumer [a]	−1.89	1.87	−1.01	0.312
Dieting to lose weight [b]	12.38	2.67	4.63	0.000
WHtR				
Egg consumer [a]	−0.009	0.011	−0.8	0.425
Dieting to lose weight [b]	0.066	0.016	4.084	0.000

[a]Egg consumer vs. non-consumer.

[b]Dieting to lose weight vs. not dieting.