




Micronutrient intakes and their food sources among Greek children and adolescents

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Abstract

Objective: To assess the usual dietary intake of twenty micronutrients and to identify their food sources in a representative sample of Greek children and adolescents.

Design: Cross-sectional data from the Hellenic National Nutrition and Health Survey (HNNHS). Vitamin and mineral intakes were estimated from two 24 h dietary recalls by sex and age groups. Estimates were calculated using the National Research Council method and the statistical software package Stata13 to account for within- and between-person variations. The prevalence of nutrients' inadequacy among sample was estimated using the estimated average requirement (EAR) cut-point method. The contribution of food groups to nutrient intake was estimated to identify micronutrients food sources.

Setting: Greece.

Participants: Children and adolescents aged 1–19 years (*n* 577) who provided sufficient and plausible 24-h recalls.

Results: A substantial percentage of children and adolescents had insufficient intakes of numerous micronutrients. Usual intake of vitamins D, K and potassium was inadequate in practically all individuals. Vitamin A, folate, Ca and Mg were also insufficient to a considerable percentage, especially in girls aged 14–18 years. Pantothenic acid was highlighted as nutrient of interest since only one out of ten boys 9–13 years and girls 14–19 years had intake above the EAR. Data demonstrated that food groups highly ranked in energy contribution were not necessarily important sources of micronutrients.

Conclusions: Results suggest that micronutrient density of Greek children and adolescents' diet should be improved. These findings might be used by public health policy-makers to help young people optimise their food choices in Greece.

Keywords
Usual intake
Nutrients
Children
Adolescents
Food groups

Childhood and adolescence are critical periods in the life course in terms of appropriate nutrition due to the increased nutritional needs for growth and development. Unhealthy dietary habits are of concern as they contribute to the epidemic of obesity, but can also contribute to inadequate micronutrient intakes. The impact of prolonged low

micronutrient intakes can have negative health effects⁽¹⁾, such as insufficient intakes of Fe and of the B vitamins and its association with different types of anaemia and with lower cognitive performances⁽²⁾; Ca and vitamin D intakes as determinants of bone mineral content and density⁽³⁾ granted that approximately 40% of total bone mass is

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accumulated during adolescence. Additionally, in the longer term, food choices and eating patterns are established early in life⁽⁴⁾. Adopting thus a healthful diet in childhood and adolescence may further help reduce the risk of non-communicable chronic diseases (NCD) in adulthood⁽⁵⁾.

Although the European food environment supplies an overabundance of energy and macronutrients, several national dietary surveys, such as the Dutch National Food Consumption Survey⁽⁶⁾, the German Health Interview and Examination Survey for Children and Adolescents and the Spanish National Dietary Survey on the Child and Adolescent Population (ENALIA)⁽⁷⁾, indicate inadequate intakes for several micronutrients. It has been suggested that this phenomenon could be explained by changes observed in many industrialised countries regarding food consumption patterns and an increase towards the consumption of foods with a low micronutrient density (i.e., fast-food, sugar-sweetened beverages, salty snacks)^(8,9). To help design effective interventions for achieving nutrient adequacy, it is valuable to know the types of foods that contribute substantially to micronutrient intakes.

In Greece, with the exception of certain studies carried out either at regional level⁽¹⁰⁾ or at national level but in limited age ranges⁽¹¹⁾, a survey examining dietary intake among representative sample of children and adolescents has not been conducted to date. The objectives of the current study were to: (i) provide updated estimates of the usual intake of twenty micronutrients – vitamins A, D, E, K, C, B₆, B₁₂, thiamin, niacin, riboflavin, pantothenic acid, folate, Ca, P, Mg, Fe, Zn, Cu, Se and potassium – for Greek children and adolescents aged 1–19 years using dietary data from the Hellenic National Nutrition and Health Survey (HNNHS); (ii) evaluate nutrient intake adequacy in the population and (iii) get insight into the main food sources of nutrients.

Methods

Study design and population

HNNHS was a population-based, nationally representative, cross-sectional study launched in Greece between September 2013 and May 2015, and it was designed to assess health and nutritional status of Greek children and adults. The survey methodology, which has been described previously, included a multistage probability sampling design based on the 2011 census data⁽¹²⁾. Briefly, stratification was made according to geographical density by country periphery, age group and sex distribution. Infants <6 months old, pregnant/lactating women, people unable to speak the national language or unable to provide informed consent due to any cause (e.g., mental impairment) and people residing outside the country or a private household (e.g., nursing homes, prisons) were excluded. Data collection included an in-person interview using the

Computer-Assisted Personal Interview (CAPI) method, which was administered by trained interviewers at the participant's residence, and a health examination appointment in the HNNHS mobile examination units performed by medical doctors and trained dietitians (approximately 1/3 of the trained interviewers). Written informed consent for inclusion was obtained from all participants or proxies before they participated in the study.

All children and adolescents aged 1–19 years who provided at least one 24 h recall were eligible for inclusion in the current study (*n* 842). From this eligible sample, recalls with extreme energy values (>25 104 kJ) were excluded from the main analyses (*n* 10). The plausibility of energy intakes (EI) for the remained recalls was assessed using the Goldberg's cut-off method updated by Black⁽¹³⁾ according to the ratio of reported EI and predicted BMR. EI was the average value of EI for each 24 h dietary recall. BMR was estimated using Schofield's age- and sex-specific equations⁽¹⁴⁾ based on body weight and height. Consequently, after the exclusion of misreporters (over-reporters = 55; under-reporters = 209), the final analytic sample consisted of 577 plausible children and adolescents.

Dietary intake

Detailed information on dietary intake was collected by trained interviewers using a computerised 24 h recall which was designed based on the validated USDA Automated Multiple-Pass Method (AMPM)⁽¹⁵⁾. Proxies, most commonly a parent, were used to collect dietary data for children aged 1–6 years and assisted with the dietary interview for children aged 7–11 years; adolescents aged 12–19 years reported their own dietary intakes. Estimations of the portion size were facilitated through the use of appropriate by age food atlases^(16,17) and of standardised household measures (e.g., cups, glasses, grids) to ensure quality. Two 24 h recalls, the first in-person and the second by telephone, were conducted approximately 10–14 d apart. HNNHS was conducted for 22 months and thus encompassed all seasons. Values for energy and micronutrients were estimated using mainly the Nutrition Data System for Research (NDSR) (developed by the University of Minnesota), as well as Greek food composition tables for traditional Greek recipes (e.g., moussakas)⁽¹⁸⁾.

Food grouping

To determine food sources of nutrients, it was first important to design the appropriate food grouping scheme. Food items were classified into thirty-eight food groups (listed in online supplementary material, Supplemental Table S1), each of which included foods of similar nutrient composition and culinary use. Composite foods (e.g., sandwiches) and recipes (e.g., moussakas) were disaggregated to their ingredients, which were further allocated to their

appropriate food group; pizza, souvlaki and burger were not disaggregated, but instead they formed the 'fast-food' group due to their high EI and low micronutrient intake.

The percentage contribution made by any one food group to the intake of a given nutrient was estimated in the total sample. This was calculated by dividing the total nutrient provided by a specific food group by the total nutrient provided by all food groups and multiplying this by 100⁽¹⁹⁾.

Assessment of non-dietary variables

A general questionnaire, interview based, was used to record demographic data. Those data included sex, age and country of origin; family income was not used due to a high percentage of missing data (20.6%). Furthermore, body weight and height were reported; when the participant was unable to self-respond (i.e., young age), a parent/guardian was asked to respond.

Statistical analysis

All statistical analyses have been performed based on the nature of the study (svy: in STATA 2013), for proportions and main group comparisons. To account for the survey's complex design and to better reflect known strata in the population, a weighted average of the population (total population/sampled population) was obtained, accounting for the primary sampling unit (PSU = household). A *P* value < 0.05 was considered statistically significant.

The normality of the distribution of the continuous variables was tested using the Kolmogorov–Smirnov test. Continuous variables are expressed as the medians, 25th and 75th percentiles, whereas categorical variables are expressed as percentages (%).

Nonparametric Mann–Whitney test was used to compare sex differences for skewed variables and Student *t* test for continuous, normally distributed data. Chi square tests were conducted for categorical variables.

The National Research Council (NRC) method⁽²⁰⁾ was applied to estimate the usual intake distribution of twenty vitamins and minerals, after removing the effects of day-to-day (within subject) and subject-by-subject (between-subject) variability in dietary intakes. In brief, the NRC consists of four steps: (i) examining normality of intake distribution (log transforming if required); (ii) estimating the within- and between-person variances; (iii) adjusting individual subjects' mean intakes to estimate the distribution of usual intakes and (iv) back transforming the adjusted data (if original data were transformed in step 1). The usual (adjusted) dietary intake (step 3) was calculated by the following equation⁽²⁰⁾:

$$\text{Adjusted intake} = \left[(\text{subject's mean} - \text{group mean}) \times \frac{SD_{\text{between}}}{SD_{\text{observed}}} \right] + \text{group mean},$$

where SD_{between} is the square root of true variance of the distribution of usual intakes, and SD_{observed} is the square root of

the variance in the observed daily intakes that is not accounted for by between-subject differences, both divided by the mean number of days of intake data per participant. In case that someone had only one 24 h dietary recall (24.4% of plausible participants), the mean number of days of intake data was set to one.

The estimated average requirement (EAR) cut-off point method proposed by the Institute of Medicine (IOM) was used to assess the adequacy of vitamin and mineral intakes, except Fe, of children and adolescents⁽²¹⁾. The IOM DRIs were used since they are regularly updated and frequently used compared with reference values provided by other scientific bodies of organisations⁽¹¹⁾. The EAR is the average daily nutrient level estimated to meet the requirements of 50% of all healthy individuals in a particular life stage and group. The proportion of individuals in a group with usual intakes below the EAR provides an estimate of the prevalence of inadequate intakes in the group⁽²¹⁾. For vitamin K, pantothenic acid and K, the proportion below the adequate intake (AI) was used to assess nutrient adequacy of groups, as there are no established EAR values. The AI is defined as a recommended average daily nutrient intake level, based on experimentally derived intake levels or approximations of observed mean nutrient intake by a group (or groups) of apparently healthy people that are assumed to be adequate. Regarding Fe, the proportion of menstruating adolescent girls aged 11–19 years with suboptimal intake was estimated by probability approach. This was performed since the underlying requirement distribution for Fe after menstruation varies with blood loss, and this needs to be accounted for when estimating nutrient inadequacy⁽²²⁾. For the probability approach method, an upper limit of Fe absorption of 20% was accounted for to observed intake, since Greek children and adolescents have a diet rich in animal proteins.

Results

Characteristics of the studied sample are presented in Table 1. Participants were equally distributed to boys and girls (49.0 and 51.0%, respectively, *P* = 0.587) and had a Greek nationality (96.0%). In total, 75.6% of the plausible Greek children and adolescents provided two recall days.

The usual dietary intakes of vitamins and minerals are summarised in Tables 2 and 3, respectively.

Vitamins

In both sexes and all age groups, the percentage of the participants with a usual intake of vitamins D and K below EAR reached 100.0%. Exceptions to this conclusion were boys aged 19 years for vitamin D (85.7% inadequacy) and for vitamin K (85.7% inadequacy) and females aged 19 years for vitamin K (75.0% inadequacy). Nearly all children aged

**Table 1** Characteristics of 1- to 19-year-old Greek children and adolescents providing plausible dietary intake data in Hellenic National Nutrition and Health Survey

	Total		Boys		Girls		<i>P</i> *
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	
Age (years)	577	100.0	282	49.0	295	51.0	0.282
SD	9.8		9.5		10.1		
	5.6		5.9		5.8		
Age group							
1–3 years	92	16.0	43	15.2	49	16.6	0.859
4–8 years	178	30.8	92	32.6	86	29.1	0.617
9–13 years	131	22.7	69	24.5	62	21	0.639
14–18 years	130	22.5	64	22.7	66	22.4	0.964
19 years	46	8.0	14	5.0	32	10.9	0.522
Dietary Information							
First recall	577	100.0	282	100.0	295	100.0	–
Second recall	443	76.8	226	80.1	217	73.6	0.105
Nationality							
Nationals	553	96.0	272	96.4	281	95.2	0.480
Non Nationals	24	4.0	10	3.5	14	4.6	0.886

The symbol '–' indicates that the test could not be implemented because there were insufficient data.
**P* values are derived from *t* test to detect significant differences (*P* < 0.05) between sex groups.

1–13 years met the EAR for the fat-soluble vitamin A. Inadequate intake in vitamin A (>60.0%) was recorded in the oldest age groups, with the subset of female adolescents 14–18 being far below the acceptable range (100.0%). Similarly, the prevalence of vitamin E and pantothenic acid inadequacy was quite high among the sample. Greek children and adolescents met intake recommendations for the remaining water-soluble vitamins (thiamin, riboflavin, niacin and vitamins B₆ and B₁₂) in general. However, more than 50.0% of the participants aged 9–18 years had folate intakes below the specific sex and age EAR. Additionally, more than 70.0% of girls aged 14–18 years and boys aged 19 years had low vitamin C intake.

Minerals

The prevalence of inadequacy was extremely high for potassium in every subset of the population ranging from 85.7 to 100.0%. Dietary inadequacy was also high for Ca and Mg, in the subset of adolescents aged 14–18 years. Also, approximately one out of ten girls aged 14–18 years reported intakes of Ca and Mg below the EAR (88.6 and 87.1%, respectively). Regarding Zn, the prevalence of inadequacy was in general low, except the subset of male adolescents aged 14–18 years (51.6%).

Dietary intake of P was sufficient for most age groups other than 9- to 18-year-old female participants and for 9- to 13-year-old males. Similarly, only the subset of females aged 14–18 years showed a slight inadequacy of Cu intake. Finally, the inadequacy percentages for Fe and Se were small ranging from 0.0 to 1.6% in boys and 0.0 to 6.3% in girls, and 0.0 to 14.3% in boys and 0.0 to 10.6% in girls, respectively.

The food sources of energy and the studied vitamins and minerals were ranked, and top ten sources are presented in Tables 4 and 5 for all Greek children and adolescents.

Energy and vitamins

Processed cereals were the major source of energy (17.9%) for 1- to 19-year-olds, followed by milk (9.3%) and fast-food (8.7%). In general, processed cereals together with milk were the two highest ranked dietary sources of many vitamins. More specifically, processed cereals were found to be the prevailing source of folate (44%), reporting the highest contribution of a food group to a vitamin, of vitamin A (21.9%), thiamin (36.9%), riboflavin (23.5%), niacin (34.2%) and vitamin B₆ (23%). Processed cereals were also among the top three sources of vitamins D (18.2%), E (12.2%), K (6.8%), B₁₂ (22.6%) and pantothenic acid (12.2%). Milk had the highest contribution to vitamin D (28.2%), pantothenic acid (26.3%) and vitamin B₁₂ (26.4%). Furthermore, the dairy products, milk and cheese, were important contributors to riboflavin (23.2 and 6.9%, respectively). Cheese was also ranked as the third food source for vitamin A (8.4%).

As far as wholegrain cereals are concerned, the specific food group was ranked as the second or third highest contributor of certain vitamins: thiamin (6.6%), pantothenic acid (7.1%), folate (16.3%), vitamins B₆ (10.6%) and B₁₂ (12.7%). Non-starchy vegetables provided less than half of vitamin K intake (40.5%); this group also provided 14.9% of vitamin C. Fruit and fruit juices predominated as dietary sources of vitamin C (17.6 and 16.8%, respectively). Lastly, salty snacks were the main food source of vitamin E (12.5%).

Table 2 Usual intakes of vitamins stratified by sex and age group in 1- to 19-year-old Greek children and adolescents and percentage of the population having usual micronutrient intakes below the estimated average requirement: data from Hellenic National Nutrition and Health Survey

	Boys				Girls			
	Median	P25, P75	EAR	<EAR (%)	Median	P25, P75	EAR	<EAR (%)
Vitamin A (mcg)								
1–3 years	388	326, 544	210	4.7	407	325, 462	210	4.1
4–8 years	460	360, 593	275	6.5	451	439, 469	275	0.0
9–13 years	525	383, 750	445	33.3	563	420, 756	420	24.2
14–18 years	539	416, 683	630	70.3	447	434, 454	485	100.0
19 years	503	411, 1008	625	64.3	475	272, 785	500	53.1
Vitamin D (mcg)								
1–3 years	2.1	1.7, 2.4	10.0	100.0	1.6	1.4, 2.3	10.0	98.0
4–8 years	1.9	1.1, 3.5	10.0	98.9	2.0	1.6, 2.8	10.0	100.0
9–13 years	2.3	1.5, 3.4	10.0	100.0	2.0	1.6, 3.0	10.0	98.4
14–18 years	2.2	1.9, 2.5	10.0	100.0	2.0	1.8, 2.2	10.0	100
19 years	3.6	1.9, 5.6	10.0	85.7	2.2	1.8, 2.5	10.0	100
Vitamin E (mg)								
1–3 years	5.0	4.6, 5.3	5.0	51.2	4.5	3.4, 5.6	5.0	63.3
4–8 years	5.5	5.1, 5.9	6.0	76.1	5.1	4.1, 7.4	6.0	61.6
9–13 years	6.1	4.9, 7.8	9.0	88.4	6.8	5.2, 8.1	9.0	83.9
14–18 years	7.7	6.0, 9.3	12.0	96.9	6.0	4.8, 7.3	12.0	98.5
19 years	7.4	6.2, 10.1	12.0	92.9	7.6	5.3, 9.2	12.0	93.8
Vitamin K (mcg)								
1–3 years	16	12, 21	30*	93.0	14	12, 22	30*	89.8
4–8 years	18	15, 20	55*	100.0	19	14, 23	55*	100.0
9–13 years	21	13, 29	60*	92.8	21	10, 27	60*	96.8
14–18 years	26	17, 46	75*	95.3	20	16, 28	75*	100.0
19 years	33	9, 50	120*	85.7	36	18, 78	90*	75.0
Vitamin C (mg)								
1–3 years	52	24, 77	13	7.0	43	3, 50	13	0.0
4–8 years	52	35, 67	22	13.0	52	34, 72	22	9.3
9–13 years	47	40, 54	39	18.8	56	36, 87	39	27.4
14–18 years	68	46, 97	63	42.2	48	41, 52	56	83.3
19 years	60	44, 78	75	71.4	87	41, 108	60	37.5
Thiamin (mg)								
1–3 years	1.2	1.1, 1.4	0.4	0.0	1.2	1.1, 1.3	0.4	0.0
4–8 years	1.4	1.3, 1.5	0.5	0.0	1.3	1.2, 1.5	0.5	0.0
9–13 years	1.5	1.3, 1.6	0.7	0.0	1.5	1.3, 1.7	0.7	0.0
14–18 years	1.5	1.4, 1.5	1.0	0.0	1.4	1.3, 1.6	0.9	1.5
19 years	1.8	1.3, 2.0	1.0	0.0	1.7	1.4, 2.1	1.0	3.1
Riboflavin (mg)								
1–3 years	1.5	1.4, 1.9	0.4	0.0	1.5	1.3, 1.7	0.4	0.0
4–8 years	1.7	1.5, 2.0	0.5	0.0	1.6	1.3, 2.1	0.5	0.0
9–13 years	1.8	1.6, 1.9	0.8	0.0	1.8	1.5, 2.1	0.8	0.0
14–18 years	1.8	1.7, 1.9	1.1	0.0	1.7	1.5, 1.9	0.9	1.5
19 years	2.0	1.7, 2.6	1.1	0.0	2.0	1.6, 2.4	0.9	0.0
Niacin (mg)								
–3 years	10	8, 12	5	2.3	11	10, 12	5	0.0
4–8 years	12	10, 16	6	3.3	12	11, 13	6	2.3
9–13 years	13	11, 19	9	14.5	13	11, 15	9	3.2
14–18 years	20	14, 25	12	14.1	14	12, 17	11	16.7
19 years	20	15, 34	12	14.3	15	14, 18	11	3.1
Pantothenic acid (mg)†								
1–3 years	3.0	2.6, 3.5	2.0*	0.0	3.1	2.9, 3.5	2.0*	0.0
4–8 year	3.3	2.5, 4.1	3.0*	37.0	3.1	2.8, 3.4	3.0*	39.5
9–13 years	3.2	3.0, 3.3	4.0*	98.6	3.3	2.6, 4.1	4.0*	67.7
14–18 years	3.9	3.2, 4.7	5.0*	81.3	3.1	2.4, 3.9	5.0*	90.9
19 years	4.2	2.7, 5.4	5.0*	71.4	3.4	2.6, 3.9	5.0*	93.8
Vitamin B₆ (mg)								
1–3 years	1.3	1.1, 1.4	0.4	0.0	1.1	0.9, 1.3	0.4	0.0
4–8 years	1.4	1.2, 1.6	0.5	0.0	1.3	1.0, 1.7	0.5	0.0
9–13 years	1.5	1.3, 1.7	0.8	0.0	1.6	1.3, 2.0	0.8	3.2
14–18 years	1.8	1.6, 2.1	1.1	3.1	1.4	1.2, 1.7	1.0	6.1
19 years	2.1	1.6, 2.6	1.1	7.1	1.5	1.4, 2.1	1.1	3.1
Folate (mcg)								
1–3 year	202	173, 219	120	0.0	191	162, 213	120	8.2
4–8 year	213	172, 303	160	17.4	218	162, 264	160	24.4
9–13 year	242	209, 286	250	63.8	247	196, 295	250	53.2

Table 2 *Continued*

	Boys				Girls			
	Median	P25, P75	EAR	<EAR (%)	Median	P25, P75	EAR	<EAR (%)
14–18 year	256	223, 335	330	73.4	234	200, 259	330	98.5
19 year	411	178, 618	320	35.7	322	252, 461	320	50.0
Vitamin B ₁₂ (mcg)								
1–3 years	2.7	2.3, 3.2	0.7	0.0	2.8	2.5, 1.3	0.7	0.0
4–8 years	2.9	2.2, 4.1	1.0	1.1	2.8	2.1, 3.7	1.0	1.2
9–13 years	3.1	2.6, 3.8	1.5	0.0	3.4	2.3, 4.4	1.5	9.7
14–18 years	3.5	2.7, 4.4	2.0	9.4	2.6	2.4, 3.2	2.0	6.1
19 years	4.3	2.4, 9.0	2.0	21.4	3.4	1.7, 5.5	2.0	28.1

EAR, estimated average requirement; AI, adequate intake.

*AI and therefore the percentages of subjects below AI have been calculated.

†Data on pantothenic acid are subject to potential underestimation since values for this nutrient for specific Greek foods are lacking to date.

Minerals

Processed cereals were the highest ranked dietary source of Mg, Fe, Zn, Cu and Se (15.5, 41.2, 20.7, 18.3 and 31.0 %, respectively). This food group was also ranked as second major source of P (12.5 %) and third major source of Ca (11.5 %). Milk was the first contributor to Ca, P and potassium (30.7, 20.9 and 16.4 %, respectively) and was also the second highest food source of Mg and Se (11.9 and 11.0 %, respectively). In addition, the dairy product cheese was placed among the top three contributors of Ca and P (13.3 and 9.1 %, respectively). Wholegrain cereals, red meat, water and fruits were recorded as the second higher food source of Fe (11.4 %), Zn (11.8 %), Cu (11.3 %) and potassium (11.4 %), respectively.

Discussion

Intake of twenty micronutrients among children and adolescents in Greece consumed from food and beverages were assessed in the present study. This was performed to estimate inadequacies that can possibly affect their growth and development. Excluding vitamin D, for which the major source is exposure to sunlight, a well-balanced and healthy diet should cover the needs of all vitamins and minerals assessed. The current study showed a high prevalence of inadequate micronutrient intake, as more than half of the population studied intakes were below the EAR reference values. Additionally, the current study provides insight in the major dietary sources of those nutrients. The intake of micronutrients was estimated by other studies in Greece, but this information either came from limited areas of the country, hence was not representative⁽²³⁾, or information provided include mostly vitamins and is limited in minerals⁽²⁴⁾.

Our study highlights the poor mean vitamin D intake, and the fact that the prevalence of inadequacy was over 97.0 % across all age and sex groups, with the exception of the 19-year-old boys. Such high prevalence of vitamin D along with the recommendations to avoid sun exposure needs to

be further evaluated, since historically hypovitaminosis D has been associated with an increased risk of skeletal disease, including rickets in children, while increasing evidence supports an association between low intake of vitamin D and CVD, cancer and diabetes⁽²⁵⁾. Our results are in line with other European epidemiologic surveys conducted in Spanish children and adolescents⁽⁷⁾ and in European adolescents⁽²⁶⁾. This is due to the fact that vitamin D occurs naturally in a limited number of foods, specifically egg yolks and oily fish, such as salmon, cod liver oil⁽²⁷⁾ and these foods are consumed scarcely making it unrealistic to achieve the recommended dietary intake. Food fortification and the use of supplements have been reported to impact the % <EAR for vitamin D in Northern European countries⁽²⁸⁾ and USA⁽²⁹⁾ and could set the basis for improving vitamin D status in Greece.

Vitamins K and E were also identified as nutrients of public health concern from the current analysis with inadequate prevalence rates ranging from 51.2 to 100 %. Regarding vitamin K, almost all individuals had intakes that were at risk. This prevalence is quite high relative to the HELENA study⁽²⁶⁾, although differences may be due to different eating patterns. More specifically, Manios *et al.*⁽¹¹⁾ concluded that 86.0–93.0 % of boys and girls in Greece aged 9–13 years did not meet the recommended portions for vegetables, which are the primary food source of vitamin K⁽³⁰⁾. This fat-soluble vitamin is important for the prevention of CVD and of osteoporosis, but to have a clear estimate of the problem blood pro-thrombin levels are required. Low vitamin K intake among Greek children and adolescents needs to be accounted for and programs focusing on higher consumption of greens are recommended. Regarding vitamin E, the findings of the current study are consistent with those reported by NHANES 2003–2006, which showed that 83.0 % of children and adolescents failed to meet the recommendations, except for those taking supplements⁽²⁹⁾. Similar data were observed in Spanish adolescents⁽⁷⁾. The importance of vitamin E is underlined by its antioxidant activity and its potential protective role against CVD, certain types of cancer and neurological disease⁽³¹⁾. Deficiency symptoms include a

**Table 3** Usual intakes of minerals stratified by sex and age group in 1- to 19-year-old Greek children and adolescents and percentage of the population having usual micronutrient intakes below the estimated average requirement: data from Hellenic National Nutrition and Health Survey

	Boys				Girls			
	Median	P25, P75	EAR	<EAR (%)	Median	P25, P75	EAR	<EAR (%)
Ca (mg)								
1–3 years	889	660, 1025	500	4.7	821	667, 1011	500	10.2
4–8 years	964	792, 1098	800	26.1	894	855, 940	800	1.2
9–13 years	1062	795, 1337	1100	52.2	988	768, 1207	1100	62.9
14–18 years	1016	909, 1167	1100	64.1	894	857, 927	1100	100.0
19 years	1069	905, 1334	800	21.4	884	773, 988	800	34.4
P (mg)								
1–3 years	996	897, 1062	380	0.0	927	831, 1027	380	0.0
4–8 years	1042	970, 1114	405	0.0	979	868, 1143	405	0.0
9–13 years	1097	1007, 1195	1055	37.9	1112	963, 1218	1055	41.9
14–18 years	1387	1184, 1682	1055	9.4	1062	863, 1284	1055	50.0
19 years	1141	1075, 1172	580	0.0	1146	1009, 1313	580	0.0
Mg (mg)								
1–3 years	188	160, 216	65	0.0	189	172, 202	65	0.0
4–8 years	210	204, 216	110	0.0	199	178, 220	110	0.0
9–13 years	207	198, 236	200	31.9	214	186, 238	200	40.3
14–18 years	277	241, 328	340	81.3	216	201, 230	300	98.5
19 years	333	240, 423	330	50.0	237	212, 290	255	62.5
Fe (mg)								
1–3 years	9.0	8.1, 10.7	3.0	0.0	8.3	7.5, 9.7	3.0	0.0
4–8 years	9.8	8.0, 13.2	4.1	0.0	10.3	9.2, 11.6	4.1	0.0
9–13 years	11.3	10.6, 12.2	5.9	0.0	12.4	10.2, 15.2	5.7	1.0, 0.8*
14–18 years	13.5	11.9, 16.9	7.7	1.6	11.2	10.2, 12.3		8.7*
19 years	17.6	12.5, 20.3	6.0	0.0	13.6	10.6, 18.6		2.2*
Zn (mg)								
1–3 years	7.7	7.1, 8.2	2.5	0.0	6.8	5.7, 8.2	2.5	0.0
4–8 years	7.8	7.1, 9.5	4.0	0.0	7.4	6.4, 9.2	4.0	1.2
9–13 years	8.2	8.0, 8.5	7.0	0.0	8.8	7.5, 10.0	7.0	14.5
14–18 years	8.5	8.3, 8.7	8.5	51.6	8.1	6.5, 9.7	7.3	40.9
19 years	10.8	8.4, 14.5	9.4	35.7	8.7	7.4, 10.6	6.8	15.6
Cu (mcg)								
1–3 years	611	491, 693	260	0.0	655	614, 697	260	0.0
4–8 years	697	662, 752	340	0.0	702	599, 782	340	1.2
9–13 years	757	628, 899	540	11.6	714	647, 826	540	3.2
14–18 years	861	747, 1089	685	10.9	719	642, 803	685	40.9
19 years	1027	795, 1233	700	21.4	725	698, 735	700	28.1
Se (mcg)								
1–3 years	61	52, 70	17	0.0	55	45, 68	17	2.0
4–8 years	65	60, 72	23	0.0	63	52, 74	23	2.3
9–13 years	72	60, 80	35	0.0	66	64, 68	35	0.0
14–18 years	82	72, 96	45	3.1	77	57, 90	45	10.6
19 years	96	62, 129	45	14.3	74	61, 84	45	6.3
Potassium (mg)								
1–3 years	1823	1572, 2138	3000†	97.7	1867	1687, 1979	3000†	98.0
4–8 years	1910	1742, 2149	3800†	98.9	1939	1673, 2226	3800†	98.8
9–13 years	2037	1829, 2149	4500†	100.0	2051	1731, 2289	4500†	100.0
14–18 year	2719	2174, 3160	4700†	93.8	1981	1843, 2096	4700†	100.0
19 years	3046	1978, 3851	4700†	85.7	2076	1846, 2339	4700†	93.8

EAR, estimated average requirement; AI, adequate intake.

*EAR cut-off point method was used to estimate Fe inadequacy in 9–10 years girls, and probability approach in 11–19 years menstruating girls.

†AI and therefore the percentages of subjects below AI have been calculated.

progressive neurologic disorder resulting in ataxia⁽³²⁾. Vitamin E deficiency is more frequently found in children compared with adults due to low body reserves and intense growth and development, making low vitamin E intake reported in the current study a major concern. Dietary consumption of nuts and seeds and vegetable oils is positively associated with increasing alpha-tocopherol concentrations. It must be emphasised that the present study assessed

low intakes and not deficiencies; therefore, clinically relevant assessments cannot be made.

A substantial portion of adolescents had usual intakes below the EAR also for vitamins A and C. While the adequacy in the intake of those two vitamins has been reported from several European studies^(6,7), data from the current analysis are comparable with the percentages reported for children and adolescents in the USA⁽³³⁾.



Table 4 Dietary sources of energy and vitamins among 1- to 19-year-old Greek children and adolescents: Hellenic National Nutrition and Health Survey

Ranking	Food group	% Total	% Cumulative
Energy			
1	Processed cereals	17.9	17.9
2	Milk	9.3	27.2
3	Fast-food	8.7	35.9
4	Desserts and sweets	6.5	42.4
5	Cheese	5.5	47.9
6	Baked products	5.5	53.4
7	Red meat	4.8	58.2
8	Olive oil and olives	4.5	62.7
9	Fruits	4.1	66.8
10	Non-starchy vegetables	4.1	70.9
Vitamin A			
1	Processed cereals	21.9	21.9
2	Milk	21.6	43.5
3	Cheese	8.4	51.9
4	Fast-food	6.8	58.7
5	Non-starchy vegetables	5.9	64.6
6	Wholegrain cereals	5.0	69.6
7	Desserts and sweets	4.2	73.8
8	Baked products	3.3	77.1
9	Processed red meat	3.1	80.2
10	Animal fat	3.1	83.3
Vitamin D			
1	Milk	28.2	28.2
2	Processed cereals	18.2	46.4
3	Fish and shellfish	16.9	63.3
4	Red meat	8.0	71.3
5	Desserts and sweets	4.8	76.1
6	Eggs	4.3	80.4
7	Baked products	3.6	84.0
8	Cheese	3.4	87.4
9	Wholegrain cereals	2.1	89.5
10	Processed red meat	2.0	91.5
Vitamin E			
1	Salty snacks	12.5	12.5
2	Processed cereals	12.2	24.7
3	Olive oil and olives	9.8	34.5
4	Non-starchy vegetables	8.4	42.9
5	Wholegrain cereals	7.5	50.4
6	Fast-food	5.3	55.7
7	Desserts and sweets	5.2	60.9
8	Potato	4.2	65.1
9	Fruits	3.8	68.9
10	Red meat	3.1	72.0
Vitamin K			
1	Non-starchy vegetables	40.5	40.5
2	Fruits	7.6	48.1
3	Processed cereals	6.8	54.9
4	Potato	5.6	60.5
5	Baked products	5.5	66.0
6	Olive oil and olives	3.7	69.7
7	Salty snacks	3.7	73.4
8	Desserts and sweets	3.4	76.8
9	Fast-food	3.1	79.9
10	Red meat	2.7	82.6
Vitamin C			
1	Fruits	17.6	17.6
2	Fruit juice	16.8	34.4
3	Non-starchy vegetables	14.9	49.3
4	Processed cereals	10.6	59.9
5	Sugar-sweetened beverages	10.0	69.9
6	Olive oil and olives	8.2	78.1
7	Potato	5.6	83.7
8	Wholegrain cereals	3.3	87.0

Table 4 Continued

Ranking	Food group	% Total	% Cumulative
9	Starchy vegetables	1.4	88.4
10	Red meat	1.4	89.8
Thiamin			
1	Processed cereals	36.9	36.9
2	Fast-food	7.2	44.1
3	Milk	7.0	51.1
4	Wholegrain cereals	6.6	57.7
5	Red meat	5.5	63.2
6	Baked products	4.5	67.7
7	Non-starchy vegetables	3.7	71.4
8	Cheese	3.2	74.6
9	Processed red meat	2.9	77.5
10	Olive oil and olives	2.6	80.1
Riboflavin			
1	Processed cereals	23.5	23.5
2	Milk	23.2	46.7
3	Cheese	6.9	53.6
4	Wholegrain cereals	5.6	59.2
5	Fast-food	5.1	64.3
6	Red meat	4.3	68.6
7	Desserts and sweets	3.8	72.4
8	Baked products	3.4	75.8
9	Eggs	2.6	78.4
10	Fruits	2.4	80.8
Niacin			
1	Processed cereals	34.2	34.2
2	Coffee	9.4	43.6
3	Red meat	9.0	52.6
4	White meat	9.0	61.6
5	Wholegrain cereals	7.3	68.9
6	Baked products	3.2	72.1
7	Fish and shellfish	3.2	75.3
8	Fast-food	3.0	78.3
9	Fruits	2.8	81.1
10	Potato	2.8	83.9
Pantothenic acid			
1	Milk	26.3	26.3
2	Processed cereals	12.2	38.5
3	Wholegrain cereals	7.1	45.6
4	Fruits	6.4	52.0
5	White meat	5.7	57.7
6	Red meat	5.6	63.3
7	Potato	5.3	68.6
8	Cheese	4.3	72.9
9	Desserts and sweets	4.1	77.0
10	Baked products	2.7	79.7
Vitamin B₆			
1	Processed cereals	23.0	23.0
2	Wholegrain cereals	10.6	33.6
3	Fruits	8.6	42.2
4	Potato	6.3	48.5
5	Non-starchy vegetables	6.0	54.5
6	Red meat	6.0	60.5
7	Milk	5.5	66.0
8	White meat	4.9	70.9
9	Fast-food	4.3	75.2
10	Olive oil and olives	4.2	79.4
Folate			
1	Processed cereals	44.0	44.0
2	Wholegrain cereals	16.3	60.3
3	Baked products	5.0	65.3
4	Fruits	4.7	70.0
5	Milk	4.1	74.1
6	Non-starchy vegetables	3.4	77.5
7	Cheese	2.9	80.4
8	Fruit juice	2.2	82.6
9	Salty snacks	2.2	84.8

Table 4 *Continued*

Ranking	Food group	% Total	% Cumulative
10	Desserts and sweets	2.1	86.9
Vitamin B₁₂			
1	Milk	26.5	26.5
2	Processed cereals	22.6	49.1
3	Wholegrain cereals	12.7	61.8
4	Cheese	7.6	69.4
5	Red meat	7.1	76.5
6	Fish and shellfish	6.2	82.7
7	Desserts and sweets	3.1	85.8
8	Processed red meat	2.4	88.2
9	White meat	2.0	90.2
10	Yogurt	1.8	92.0

Table 5 Dietary sources of minerals among 1- to 19-year-old Greek children and adolescents: Hellenic National Nutrition and Health Survey

Ranking	Food group	% Total	% Cumulative
Ca			
1	Milk	30.7	30.7
2	Cheese	13.3	44.0
3	Processed cereals	11.5	55.5
4	Fast-food	11.4	66.9
5	Water	5.0	71.9
6	Desserts and sweets	3.8	75.7
7	Processed red meat	3.0	78.7
8	Animal fat	2.8	81.5
9	Yogurt	2.7	84.2
10	Non-starchy vegetables	2.4	86.6
P			
1	Milk	20.9	20.9
2	Processed cereals	12.5	33.4
3	Cheese	9.1	42.5
4	Fast-food	9.0	51.5
5	Red meat	6.1	57.6
6	Desserts and sweets	3.9	61.5
7	Non-starchy vegetables	3.5	65.0
8	White meat	3.5	68.5
9	Baked products	3.2	71.7
10	Processed red meat	2.8	74.5
Mg			
1	Processed cereals	15.5	15.5
2	Milk	11.9	27.4
3	Coffee	8.8	36.2
4	Fruits	6.8	43.0
5	Water	6.2	49.2
6	Fast-food	5.0	54.2
7	Desserts and sweets	5.0	59.2
8	Non-starchy vegetables	4.7	63.9
9	Potato	4.1	68.0
10	Cheese	3.6	71.6
Fe			
1	Processed cereals	41.2	41.2
2	Wholegrain cereals	11.4	52.6
3	Non-starchy vegetables	4.3	56.9
4	Fast-food	4.0	60.9
5	Baked products	3.7	64.6
6	Olive oil and olives	3.2	67.8
7	Red meat	3.1	70.9
8	Desserts and sweets	2.9	73.8
9	Potato	2.6	76.4
10	Cheese	2.4	78.8

Table 5 *Continued*

Ranking	Food group	% Total	% Cumulative
Zn			
1	Processed cereals	20.7	20.7
2	Red meat	11.8	32.5
3	Milk	10.9	43.4
4	Cheese	8.0	51.4
5	Fast-food	5.7	57.1
6	White meat	4.9	62.0
7	Wholegrain cereals	4.6	66.6
8	Non-starchy vegetables	4.2	70.8
9	Desserts and sweets	3.8	74.6
10	Olive oil and olives	3.3	77.9
Cu			
1	Processed cereals	18.3	18.3
2	Water	11.3	29.6
3	Desserts and sweets	9.4	39.0
4	Fruits	9.1	48.1
5	Potato	8.0	56.1
6	Milk	7.5	63.6
7	Baked products	4.3	67.9
8	Wholegrain cereals	3.3	71.2
9	Red meat	3.0	74.2
10	Fast-food	2.5	76.7
Se			
1	Processed cereals	31.0	31.0
2	Milk	11.0	42.0
3	Red meat	8.6	50.6
4	White meat	6.7	57.3
5	Fish and shellfish	6.0	63.3
6	Cheese	5.7	69.0
7	Baked products	4.6	73.6
8	Wholegrain cereals	3.6	77.2
9	Desserts and sweets	3.4	80.6
10	Processed red meat	3.3	83.9
Potassium			
1	Milk	16.4	16.4
2	Fruits	11.4	27.8
3	Coffee	8.4	36.2
4	Processed cereals	7.7	43.9
5	Potato	7.7	51.6
6	Non-starchy vegetables	7.4	59.0
7	Red meat	5.0	64.0
8	Olive oil and olives	4.5	68.5
9	Fast-food	4.3	72.8
10	Desserts and sweets	3.3	76.1

Vitamin A is required in a wide array of physiologic processes, including vision, immune function, cell differentiation, intercellular communication and reproduction⁽³⁴⁾. Vitamin A deficiency has been associated with increased rates of infectious diseases and of visual defects. As for vitamin C, in addition to its antioxidant properties, it is required in the normal functioning of immune system and improves the absorption of Fe⁽³⁵⁾. Severe deficiency of this water-soluble vitamin can result in scurvy and should thus be prevented. The observed low intakes of vitamins A and C among Greek adolescents could be related to the lower adherence to the Mediterranean diet⁽⁸⁾, as reported also in a more recent study among young Greeks and Cypriots⁽³⁶⁾. Increasing fruit and vegetable consumption may improve the intake of those micronutrients⁽³⁷⁾.

Low folate intake among children and adolescents over 9 years raises concerns, especially for female adolescents



of whom only 1.5% had intakes above the EAR. Other nutritional studies have also reported problematic folate dietary intake by adolescents^(7,26). Adequate intake among women of reproductive age is essential only for prevention of fetal neural tube defects during pregnancy, for nucleic acids (DNA and RNA) synthesis, for essential functions of cell metabolism and for the prevention of hyperhomocysteinemia and megaloblastic anaemia⁽³⁸⁾. Recently, Martiniak *et al.*⁽³⁹⁾ investigated the potential population dietary folate intake, based on the German National Dietary Survey II data, considering different food fortification levels and evaluated the percentage of the population meeting the recommended intake. The consumption of foods with a high fortification level led to a substantial decrease in the prevalence of inadequacy.

Children and adolescents aged over 9 years did not meet the recommendations for the water-soluble vitamin pantothenic acid, with boys aged 9–13 years and girls aged over 14 years showing the lowest adequacy. Surveys providing data on pantothenic acid are scarce in Europe⁽⁴⁰⁾. Foods rich in this nutrient include meat products, eggs, nuts and vegetables⁽⁴¹⁾, and the low consumption of those foods by Greek children and adolescents could explain the low intakes of this vitamin. Pantothenic acid's primary function is the synthesis of coenzyme A and acyl carrier protein, which are involved in carbohydrate, protein and fat metabolisms.

Regarding minerals, potassium intake was found to be below the EAR in almost the whole population regardless of age and sex. Some studies have reported an inverse relationship of potassium intake with blood pressure which is a risk factor for several cardiovascular outcomes⁽⁴²⁾. Considering that dietary patterns established in childhood can set the scene for future food choices, it is important to encourage a diet for children that is high in potassium-rich foods. Similar results have been observed in other European children and adolescents^(7,26).

The proportion of inadequate Ca and Mg intakes increased by age with the highest proportion (lowest intakes) observed in adolescents, especially among girls. Several published studies^(7,33) have also shown underconsumption of these micronutrients by adolescents compared with the EAR. Adequate intake of Ca and Mg, the two most important minerals for skeletal development during adolescence, is crucial for decreasing the incidence of osteoporosis in adult life^(3,43). Furthermore, it has been reported that one-quarter of female children and adolescents aged 9–18 years and male children aged 9–13 years follow a low P diet⁽⁴³⁾, increasing the concern of the bone health for this population.

The EAR for many minerals was met by almost all children and adolescents, excluding Zn and Cu. Our data showed that approximately one-third of adolescent males had low usual Zn intake in agreement with similar median daily Zn intakes reported in the NDNS⁽⁴⁴⁾. This mineral is primarily found in animal products and seafood⁽⁴⁵⁾, and

the low consumption of those food groups could explain the low intakes. Zn has a number of physiologic roles, and it is critical for immune function and normal growth⁽⁴⁶⁾. Mild Zn deficiency (clinical features not easily identifiable) is of great importance since it increases the risk for infection and poor growth. As for Cu, findings indicated that girls over 14 years were less likely to reach the recommendations. Cu is known to be important for the proper functioning of organs and several metabolic processes, and associations have been found between low Cu intake and bone malformation during development, risk of osteoporosis development in later life, increased frequency of infections, impaired development of cardiovascular system and alterations in cholesterol metabolism⁽⁴⁷⁾. Although Fe in most groups was adequate, Fe in adolescent girls was evaluated separately to account for blood losses. Intakes in approximately 10% of adolescent girls were inadequate to meet their needs in comparison with 40% of Australian counterparts⁽⁴⁸⁾. Other comparisons cannot be easily made, since the probability method has, unfortunately, not been extensively used. Of course, inadequate intake is not suggestive of deficiency; however, information from the current study suggests a need for nutritional intervention programs, to decrease potential deficiency risks in children and adolescents at the lower intake.

Faced with this high prevalence of inadequate nutrient intakes among children and adolescents, it was important to identify principal food consumption sources contributing to energy and micronutrient intakes. The current analysis showed that major sources of energy in young people's diet are not necessarily the same food groups that provide rich sources of nutrients. Five food groups including fast-food, desserts and sweets, baked products, salty snacks and sugar-sweetened beverages provided cumulatively 25.3% of EI, with no noticeable contribution to other nutrients. In contrast, dairy products (milk, yogurt and cheese) accounted for 15.9% of EI and provided a variety of nutrients, such as vitamin D, Ca and pantothenic acid. The conclusion that foods providing empty calories are highly ranked as sources of energy are consistent with reports that many children and adolescents do not follow dietary recommendations⁽⁹⁾. Another important issue highlighted in the current study is the high and consistent consumption of processed cereals, processed and ultra-processed food (e.g., fast-food, salty snacks, desserts and sweets) when identifying the main sources of each nutrient. Although these foods provide limited amount of nutrients, their high intake along with the low consumption of fruits, vegetables and other healthy foods make them primary contributors for many vitamins and minerals in children residing in Greece. The dietary nutrient profiles of these food items (high amounts of salt, added sugars, fat and/or additives) raise concerns as they lead in increased EI and weight gain, and they have been associated with increased risk of NCD across many industrialised countries⁽⁴⁹⁾.



One of the main strengths of the current analysis is that HNNHS is the first nationally representative survey in Greece, to our knowledge, and therefore its dataset can provide a robust basal analysis of the nutritional status of the Greek population. Adjustments for within- and between-subject variability to estimate usual intakes using the NRC method also strengthen this report. Also, with regard to the above, the assessment period of HNNHS covered all months of the year and all days of the week were included, thus the effects of intakes' variability by season and of day-to day variability could be removed. Since 24 h recalls are prone to under- and over-reporting, misreporters were identified and excluded from the analysis. The age- and sex-groups differed significantly in their adherence to the EAR recommendations in nearly all nutrients (data not shown). Moreover, the use of standardised and validated procedures to record data (dietary intake, anthropometric and demographic characteristics) could be considered as another asset of the survey.

Some limitations of the study should also be noted. First, the small HNNHS sample size in young ages could be listed as one of the main limitations, despite the stratified sampling. Further, self-reporting of food intake data via 24-h recall introduces bias (e.g., such as misreporting because of respondent memory lapses, or miss-estimation of portion size consumed) to the dietary intake data⁽⁵⁰⁾, even though misreporters were excluded. Another important issue is the lack of detailed Greek food consumption tables and the use of NDSR food and nutrient database for the current analysis, a database that includes nutrient composition for enriched/fortified foods available in Greece and specific brands that are consumed in both the USA and Europe. This was performed since validated Greek databases are not available. Lastly contraceptive use was not included in the survey's questionnaires and no further analysis regarding Fe status among adolescent girls could be performed.

Conclusion

The present paper provides a detailed analysis of the current dietary intake of vitamins and minerals and their food sources among Greek children and adolescents. Identification of micronutrients of concern and major food contributors can help public health policy makers design and promote effective population-based strategies to increase nutrient density of the diet and decrease ultra-processed food consumption. Overall, nutrition professionals, in collaboration with teachers and parents, can educate children and adolescents on the Mediterranean pattern, taking into account regional and cultural differences, including lessons from MEDIS Study and from grandparents with family role recognised by 'WHO action plan'. Additionally, the addition of fortification policy or supplements for some

crucial nutrients would seem advisable but more in-depth evaluation is needed.

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Supplementary material

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