Dietary intake of 337 polyphenols in French adults[1–3]

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ABSTRACT

Background: Epidemiologic studies have suggested an association between polyphenol intake and health. These studies have been limited to ≤40 flavonoid and lignan aglycones.

Objective: We estimated intakes of all known individual polyphenols in the French cohort SUpplémentation en VItamines et Minéraux AntioXydants (SU.VI.MAX) by using the recently developed database Phenol-Explorer, which contains content values for 502 polyphenols in 452 foods.

Design: A total of 4942 men and women, who were aged 45–60 y and who had completed at least six 24-h dietary records, participated in this study. Foods documented in 24-h dietary records and the Phenol-Explorer database were matched, and intakes of all individual polyphenols were calculated.

Results: A total of 337 polyphenols were consumed by SU.VI.MAX subjects, including 258 polyphenols consumed by at least one-half of the population and 98 polyphenols consumed in an amount >1 mg/d. Mean total polyphenol intake was estimated at 1193 ± 510 mg/d (or 820 ± 335 mg/d when expressed as aglycone equivalents), with hydroxycinnamic acid esters and proanthocyanidins being the most largely consumed polyphenols. These values may have been underestimated because of insufficient data or lack of accurate data on the content in foods for proanthocyanidins and thearubigins. Nonalcoholic beverages and fruit were the most important contributors to polyphenol intakes.

Conclusions: The current study provides intake data for all individual polyphenols known to be present in the diet of a cohort. This information will be essential to characterize the health effects of individual phenolic compounds that differ widely in their bioavailability and physiologic properties. The SU.VI.MAX study was registered at clinicaltrials.gov as NCT00272428. *Am J Clin Nutr* 2011;93:1220–8.

INTRODUCTION

A number of clinical trials and cohort studies have suggested a role of dietary polyphenols in the prevention of several major chronic diseases such as cardiovascular diseases, cancers, diabetes, neurodegenerative diseases, and osteoporosis (1, 2). In many of these studies, only a limited number of polyphenols have been considered that are far from representing the large diversity of compounds observed in the diet. Nevertheless, >500 different molecules are known in foods, from low-molecular-weight phenolic acids to highly polymerized proanthocyanidins (3, 4). Dietary polyphenols belong to 4 main classes of flavonoids, phenolic acids, stilbenes, and lignans, that are largely present in a glycosidic form (glycosides of flavonoids, lignans, and stilbenes) or as esters (phenolic acids esterified to polyols such as quinic acid) (4).

The bioavailability and biological properties of dietary polyphenols vary to a great extent and depend on their chemical structure (5, 6). The number and position of hydroxyl groups and the structure of the heterocycle in flavonoids are important variables that influence their biological properties. Glycosylation and acylation are also important variables that influence absorption in the gut and bioavailability (7, 8).

For these reasons, it is important to precisely know the intake of individual polyphenols and to relate their intakes in populations to health and disease outcomes. However, in most cohort studies, a limited number of polyphenols (eg, daidzein, genistein, secoisolariciresinol, matairesinol, and quercetin) have been considered and their intake levels determined (9–11). Other authors have used the US Department of Agriculture database that contains food-composition data for 38 flavonoid aglycones (12–14) sometimes together with specific composition data for phenolic acids (15). These data have been used to calculate intakes and unravel new associations between intakes and disease outcomes (16–19).

The new Phenol-Explorer database (www.phenol-explorer.eu) contains food-composition data for all known polyphenols (flavonoids, phenolic acids, lignans, stilbenes, and other minor polyphenols) in foods (3). Moreover, it includes data on glycosides and esters. It contains data on a total of 502 polyphenols in 452 foods. The Phenol-Explorer database is freely accessible on the Web (www.phenol-explorer.eu). We report the first application of the Phenol-Explorer data to estimate dietary intakes of these 502 polyphenols in a well-established nutritional cohort

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of French adults called the SUpplémentation en VItamines et Minéraux AntioXydants (SU.VI.MAX) study. To our knowledge, this study provides the most comprehensive data on polyphenol intake so far published.

SUBJECTS AND METHODS

Study population

Subjects were participants of the SU.VI.MAX study, which was a randomized double-blind, placebo-controlled, primary prevention trial that was undertaken to determine whether supplementation with antioxidant vitamins and minerals at nutritional doses could reduce incidences of cancers, ischemic heart disease, and overall mortality. The rationale, design, and methods of the study have been described in detail elsewhere (20, 21). In brief, 13,017 eligible subjects (women aged 35–60 y and men aged 45–60 y) were included in 1994 to be followed for 7.5 y. Participants were volunteers recruited by using mass-media campaigns and were free of chronic diseases and apparently healthy at baseline. The SU.VI.MAX study was approved by the ethical committee for studies with human subjects (CCPPRB no. 706) of Paris-Cochin and the Commission Nationale de l'Informatique et des Libertés (no. 334641), which advocated that all medical information was confidential and anonymous. The study was also registered at clinicaltrials.gov as NCT00272428.

Assessment of food intakes

Dietary data were collected by using the Minitel Telematic Network, which was widely used as an adjunct to the telephone in France at the beginning of the SU.VI.MAX study. A tiny central processing unit that contained specialized software enabled subjects to fill out the computerized dietary record. Participants were invited to provide a 24-h dietary record every 2 mo from 1995 to 1996. At enrollment, subjects received a scheduled calendar for recording of 24-h dietary data. The 24-h records were randomly distributed for 2 weekend days and 4 weekdays per year so that each day of the week and all seasons were covered to account for the individual variability in intake. An instruction manual for the codification of foods and beverages, which included photographs to facilitate the estimation of portion sizes, was mailed to each subject. This manual included validated photographs of >250 foods (which corresponded to 1000 generic foods) that were represented in 3 different portion sizes. Along with the 2 intermediate and 2 extreme quantities, there were 7 choices of amounts. Photos of portion sizes were previously validated by using 780 subjects in a pilot study (22). (*See* supplemental Table 1 under "Supplemental data" in the online issue for the average consumption of main foods that contributed to polyphenol intake.)

Correspondence between food items in dietary records and in the Phenol-Explorer database

SU.VI.MAX dietary records included 736 food items (excluding recipes). The Phenol-Explorer database contains data on the content of 502 polyphenols in 452 foods (3, 4). All animal foods that contain no or only traces of plant polyphenols were excluded. Certain food entries that may have contained polyphenols were present in SU.VI.MAX dietary records but not in the Phenol-Explorer database. These food entries included some spirits such as tequila, coconut milk, honey, some breakfast cereals, and certain minor oils such as walnut oil, maize oil, or grape seed oil. The consumption or polyphenol content of these foods was low, and therefore, the contribution of these foods to polyphenol intake was considered insignificant. In contrast, some SU.VI.MAX food entries could have corresponded to several entries in the Phenol-Explorer database. For example, the SU.VI.MAX item olive oil could have corresponded to either extra-virgin, virgin, or refined olive oil in Phenol-Explorer database. The polyphenol content in the SU.VI.MAX food was weighted according to their respective consumptions in the French population. For mixed foods made of polyphenol-containing ingredients (eg, cocoa products) and for recipes, polyphenol contents were calculated on the basis of contents of the ingredient (eg, cocoa) or food component and their polyphenol composition.

Estimation of polyphenol intakes in the SU.VI.MAX cohort

An advanced search was carried out in the Phenol-Explorer database (www.phenol-explorer.eu/contents) to retrieve mean content values for all polyphenols contained in the SU.VI.MAX foods. The total polyphenol content was considered as the sum of all individual polyphenols as determined by chromatography, except for proanthocyanidins for which content data obtained by normal phase HPLC were used (4). For foods that contained polyphenols linked to the food matrix that were only solubilized and quantified after basic or acid hydrolysis, content values obtained by chromatography after hydrolysis were used (4); in particular, this concerned lignans in several foods, ellagic acid in walnuts, and hydroxycinnamic acids in cereals, white beans, and olives. Similar advanced searches in Phenol-Explorer–retrieved total antioxidant contents were determined by the Folin assay with gallic acid, catechin, and caffeic acid used as standards (23). The polyphenol intake was also calculated as aglycone equivalents by taking into account all possible forms of glycosides and esters by removing, for each individual polyphenol, the contribution to molecular weight of the nonphenolic part of the molecule (eg, sugar from flavonoid glycosides or quinic acid from chlorogenic acids).

The following data that were missing in Phenol-Explorer were obtained by extrapolation. The hydroxycinnamic acid content in breakfast cereals was obtained from values in wheat flour. Some missing data for orange fruit were extrapolated from orange juice data. For some cooked foods consumed in the SU.VI.MAX cohort and absent in the Phenol-Explorer database (a number of vegetables, cereals, and seeds), yield factors (24) were applied to take into account the gain or loss of water during cooking.

Several products that contained refined wheat flour were included in the list of foods (eg, different kinds of breads and biscuits). Polyphenol contents in these foods were estimated from their wheat-flour contents. Although the polyphenol intake from each of these foods was calculated, they are presented together as refined wheat flour products.

Statistical analyses

Analyses focused on the 4942 subjects who were aged 45–60 y and had completed at least six 24-h dietary records during the first 2 y of follow-up (1994–1995). The numbers of included dietary

records were chosen to be balanced between winter and summer to more precisely take into account the seasonal variability in food intake. These subjects did not differ from the total population with respect to major characteristics. Data are presented as means (±SDs) or medians for continuous variables and frequencies or percentages for categorical variables. The general characteristics of the study population are shown in **Table 1**. The mean and median intakes of all individual polyphenols, polyphenol subclasses, and total polyphenols in the SU.VI.MAX cohort were determined for the whole study population as well as according to different sociodemographic characteristics such as sex, age, occupation, and educational level. Differences in intakes between groups were tested by using Student's *t* test for independent samples or by analyses of covariance, and differences below the probability level ($P < 0.05$) were considered significant. Statistical analyses were performed with SAS software (version 9.2; SAS Institute Inc, Cary, NC).

RESULTS

Total intakes of polyphenols

Among the 736 food items considered in the SU.VI.MAX dietary records, 232 food items were shown to contain polyphenols according to the Phenol-Explorer database. A total of 337 polyphenols were shown in these foods. One hundred thirty polyphenols of the Phenol-Explorer database were absent from foods of the SU.VI.MAX dietary records (*see* supplemental Table 2 under "Supplemental data" in the online issue).

Total polyphenol intake in the SU.VI.MAX cohort was determined as the sum of the intakes of all individual polyphenols (**Table 2**). Mean and median polyphenol intakes for the whole population were 1193 and 1123 mg polyphenols/d, respectively. The majority of dietary polyphenols in foods were glycosides (80% of 277 flavonoids) and esters (50% of 108 phenolic acids) (4), and therefore, these intake values included intakes of sugars and polyols linked to aglycones. The total intake of aglycones was also determined. Mean (±SD) and median intakes of polyphenol aglycones were 820 ± 335 and 531 mg/d, respectively

Polyphenol intake was also calculated according to sex, age, educational level, and occupation. Intakes were higher in men than in women (Table 2). Higher intakes of anthocyanins, proanthocyandins, and stilbenes were observed in men than in women (70 ± 52 compared with 43 ± 36 mg/d, 260 ± 178 compared with 191 ± 136 mg/d, and 7 ± 6 compared with 2 ± 3 mg/d, respectively; all $P < 0.001$). In contrast, women had a higher intake of catechins (114 ± 133 compared with 86 ± 93 mg/d) and theaflavins (16 ± 23 compared with 8 ± 16 mg/d) than did men (all $P < 0.001$). Age, within the limited range tested, had no significant influence on polyphenol intakes. Subjects with a higher educational level (university) showed a significantly ($P = 0.001$) higher polyphenol intake (1154 ± 508 compared with 1233 ± 509 mg/d) than did subjects with a lower educational level (primary school) mainly because of higher intakes of flavonols, proanthocyandins, catechins, and theaflavins.

The contribution of different food groups to the total polyphenol intake as well as the main food contributors in each food group are shown in **Table 3**. Nonalcoholic beverages and fruit were the main polyphenol providers with respective contributions of 658 and 206 mg/d (390 and 162 mg/d as aglycones). Alcoholic beverages, cocoa products, and vegetables provided ≈100 mg/d each; cereals provided ≈50 mg/d, and seeds and oils each provided <8 mg/d. Seasonings, which included vinegar, herbs, and spices, had only a minor contribution of <1 mg/d. Within each food group, the few main food contributors were identified as coffee and tea for nonalcoholic beverages and red wine for alcoholic beverages (Table 3). For other food groups and, in particular, fruit and vegetables, polyphenols were more widely distributed over several food sources. Flavonoids and phenolic acid were the 2 main classes of polyphenols consumed with intakes of 506 and 639 mg/d, respectively (Table 3). Fruit was the main sources of flavonoids (35%), whereas nonalcoholic beverages were the main sources of phenolic acids (nearly 80%).

Polyphenol intakes were highly dependent on food preferences and, more particularly, on preferences for their main dietary sources. Consumers of coffee or red wine had systematically

TABLE 1
General characteristics of the study population ($n = 4942$)

Characteristics	Mean ± SD	Minimum	Maximum
Age (y)	51.5 ± 4.4	45	60
Weight (kg)	69.2 ± 13.1	37	146
BMI (kg/m^2)	24.5 ± 3.6	15.8	45.3
Energy intake (kcal/d)	2166 ± 608	582	5067

TABLE 2
Total polyphenol intakes in the SUpplémentation en VItamines et Minéraux AntioXydants (SU.VI.MAX) cohort according to sociodemographic characteristics[1]

		Polyphenol intake	
	n	Mean ± SD	Median
		mg/d	
Total population	4942	1193 ± 510	1123
Sex			
Male	2596	1270 ± 514	1213
Female	2346	1108 ± 491	1038
P	—	0.001	—
Age class			
45–49 y	1994	1189 ± 513	1114
50–54 y	1544	1191 ± 502	1130
55–60 y	1404	1201 ± 510	1137
P	—	0.80	—
Educational level			
Elementary school	1128	1154 ± 508	1094
Secondary school	1961	1178 ± 509	1104
University	1853	1233 ± 509	1163
P	—	0.001	—
Occupational level			
Upper management	1443	1243 ± 508	1169
Middle management, employee	2540	1175 ± 504	1101
Farmer, self-employed	234	1264 ± 580	1189
Laborer	219	1230 ± 498	1177
Unemployed	244	1087 ± 474	1016
P	—	0.001	—

[1] Comparisons across categories were performed by using Student's *t* test with equal variance for sex and ANOVA for age class, educational level, and occupational level.

TABLE 3
Contributions of different food groups to polyphenol intakes in the 4942 participants in the SUpplémentation en VItamines et Minéraux AntioXydants (SU.VI.MAX) cohort and main food sources

Food class	Polyphenol intake[1]				Main food contributors (% contribution to polyphenol intake in the food group)[2]
	Total polyphenols	Flavonoids	Phenolic acids	Total polyphenols as aglycones	
	mg/d per person				
Nonalcoholic beverages	658 ± 426	114 ± 74	524 ± 339	390 ± 258	Coffee (79), tea (17), orange juice (2), pummelo juice (0.2)
Fruit	206 ± 151	172 ± 130	32 ± 23	162 ± 119	Apples (45), strawberries (15), plums (8), cherries (8)
Alcoholic beverages	99 ± 136	73 ± 100	19 ± 26	83 ± 114	Red wine (94), white wine (2), rosé wine (2), blond beer (1)
Cocoa products	90 ± 132	90 ± 132	1 ± 1	91 ± 133	Dark chocolate (73), cocoa powder (23), milk chocolate (3)
Vegetables[3]	81 ± 42	26 ± 13	51 ± 26	52 ± 27	Potatoes (30), green chicory (19), onions (14), spinach (9)
Cereals	46 ± 18	28 ± 11	7 ± 3	32 ± 12	Refined wheat-flour products (66), whole-grain wheat-flour products (26), breakfast cereals (7), rice (2)
Seeds	8 ± 18	3 ± 7	5 ± 11	8 ± 18	Walnuts (37), hazelnuts (27), white beans (15), chestnuts (14)
Oils	4 ± 2	0.1 ± 0.05	0.02 ± 0.01	2 ± 1	Extra-virgin olive oil (99), rapeseed oil (0.7)
Seasonings	0.4 ± 0.3	0.06 ± 0.04	0.2 ± 0.1	0.4 ± 0.3	Vinegar (90), parsley (4), ginger (4), curry (1)
Total foods	1193 ± 510	506 ± 219	639 ± 273	820 ± 335	Coffee (44), tea (9), apples (6), red wine (6)

[1] Values are means ± SDs.
[2] The first 4 main food sources in each food group are given; a lower number of foods indicates the absence of other food sources that contained polyphenols in the food group considered.
[3] Including tubers.

a higher mean total polyphenol intake than did nonconsumers. Coffee drinkers (92% of the total population) had a total polyphenol intake of 1224 ± 471 mg/d, and coffee accounted for 44% of this intake. This intake was significantly higher ($P < 0.001$) than that measured in noncoffee drinkers (807 ± 343 mg/d). For red-wine consumers (75% of the total population), total polyphenol intake was 1242 ± 460 mg/d, with 11.1% of the intake coming from red wine, which was an amount that was also significantly higher ($P < 0.001$) than that observed in nonconsumers (1042 ± 474 mg/d). In contrast, no difference in total polyphenol intake was observed for tea between consumers (52% of the total population) and nonconsumers.

Intakes of different polyphenol classes

Polyphenol intake in the SU.VI.MAX cohort was also calculated for each polyphenol class (**Table 4**). Hydroxycinnamic acids were the most largely consumed polyphenols, with an intake close to 600 mg/d. Proanthocyanidins were the second most largely consumed polyphenols (227 mg/d), and this intake could have actually been higher if more data on the content of proanthocyanidin oligomers were available (4). Catechins and anthocyanins were the 2 next classes for polyphenol intake (99 and 57 mg/d, respectively) and were followed in decreasing order by flavonols, hydroxybenzoic acids, flavones, flavanones, theaflavins, and dihydroflavonol. The other polyphenols included

TABLE 4
Intakes of main polyphenol classes and subclasses in the 4942 participants in the SUpplémentation en VItamines et Minéraux AntioXydants (SU.VI.MAX) cohort and main food sources

Polyphenol subclass[1]	Polyphenol intake[2]		Main food contributors (% contribution to intake of the polyphenol subclass)[3]
	Total in the subclass	Total as aglycones	
	mg/d per person		
Hydroxycinnamic acids	599 ± 426	316 ± 225	Coffee (83), potatoes (4), apples (2), green chicory (2)
Proanthocyanidins	227 ± 162	227 ± 162	Apples (31), cocoa products (18), red wine (12), strawberries (8)
Catechins	99 ± 116	87 ± 102	Tea (71), red wine (10), apples (6), cocoa products (5)
Anthocyanins	57 ± 47	35 ± 29	Red wine (41), cherries (23), strawberries (20), black grapes (6)
Flavonols	51 ± 28	34 ± 19	Tea (23), onions (23), spinach (13), red wine (12)
Hydroxybenzoic acids	41 ± 39	40 ± 38	Tea (49), red wine (15), green chicory (9), walnuts (8)
Flavones	33 ± 17	18 ± 9	Refined wheat-flour products (64), whole-grain wheat-flour products (20), oranges (6), orange juice (5)
Flavanones	26 ± 29	13 ± 14	Oranges (50), orange juice (44), red wine (3), pummelo juice (2)
Theaflavins	12 ± 21	9 ± 16	Tea (100)
Dihydroflavonols	7 ± 9	5 ± 5	Red wine (96), white wine (2), rosé wine (1)
Other polyphenols	41 ± 20	28 ± 14	Coffee (21), refined wheat-flour products (18), whole-grain wheat-flour products (16), extra-virgin olive oil (14)

[1] Only polyphenol classes or subclasses with a daily mean intake >5 mg/d per person.
[2] Values are means ± SDs.
[3] Four main food sources for each polyphenol; a lower number indicates the absence of other food sources.

tyrosols (14.7 ± 5.9 mg/d), alkylphenols (11.3 ± 15.4 mg/d), stilbenes (4.8 ± 5.2 mg/d), dihydrochalcones (3.7 ± 3.6 mg/d), alkylmethoxyphenols (2.8 ± 2.2 mg/d), methoxybenzaldehydes (0.89 ± 1.06 mg/d), methoxyphenols (0.37 ± 0.32 mg/d), lignans (0.4 ± 0.2 mg/d), hydroxycoumarins (0.1 ± 0.16 mg/d), hydroxybenzaldehydes (0.09 ± 0.09 mg/d), furanocoumarins (0.04 ± 0.13 mg/d), methoxyphenylpropenes (0.01 ± 0.07 mg/d), isoflavonoids (0.01 ± 0.247 mg/d), and curcuminoids (0.003 ± 0.029 mg/d). When expressed as aglycone equivalents, the relative contribution of hydroxycinnamic acids was reduced from 50% to 40% and that of proanthocyanidins increased from 19% to 29%, whereas the relative contributions of the other polyphenol subclasses remained similar.

The main food contributors to the intake of each polyphenol class or subclass are also shown in Table 4. Hydroxycinnamic acids arose mainly from coffee but also from potatoes, apples, and green chicory. Potatoes, vegetables, and fruit together provide ≈100 mg/d. Tea and red wine were the main sources of hydroxybenzoic acids, with contributions of 20 and 6 mg/d, respectively, mainly as gallic acid. Sources of proanthocyanidins were fruit, cocoa products, and red wine. Apart from these same sources, the major source of catechins was tea. Anthocyanins arose from red wine and red fruit; flavonols arose from tea, onions, some green vegetables, and wine; and flavanones arose from citrus fruit. Main sources for other polyphenols were red wine and olive oil for tyrosols and cereals for alkylphenols.

Intakes of individual polyphenols

A total of 337 polyphenols that corresponded to 155 different polyphenol aglycones were found in the various foods consumed by the SU.VI.MAX cohort (**Table 5**). The larger groups were hydroxycinnamic acids (55 compounds), flavonols (54 compounds), and anthocyanins (45 compounds), which all showed a large diversity of hydroxylation, methylation, glycosylation, or esterification patterns. The number of aglycones was also high for proanthocyanidins (because of their polymeric nature) and for hydroxybenzoic acids, hydroxycinnamic acids, flavanones, and flavones. The distribution of some of these polyphenols may have been limited to only one food consumed by a minor fraction of the cohort (eg, the [6]-gingerol characteristic of ginger).

The numbers of more commonly consumed polyphenols are also shown in Table 5. A total of 258 compounds (76%) out of the 337 consumed polyphenols had median intake values higher than zero and corresponded to polyphenols consumed by at least one-half of cohort members. These commonly consumed polyphenols again included large numbers of hydroxycinnamic acids, flavonols, and anthocyanins.

The intake of all individual polyphenols consumed in the SU.VI.MAX cohort was determined (*see* supplemental Tables 3 and 4 under "Supplemental data" in the online issue). Ninety-eight polyphenols were consumed in amounts >1 mg/d The 25 first compounds in the list were all consumed in amounts greater than 8 mg/d (**Table 6**). Nine of the 25 most ingested polyphenols in the SU.VI.MAX cohort were phenolic acids, including 7 hydroxycinnamic acids that largely originated from coffee. This list also included 6 catechins that principally originated from tea, red wine, and cocoa products. The remaining compounds among these 25 polyphenols were 5 proanthocyanidins that came from tea, fruit, wine, and cocoa products, 2 anthocyanins that came from red wine, red fruit, and black olives, 2 flavones that mainly came from wheat products, and one flavanone, hesperidin, that mainly came from oranges and orange juice.

TABLE 5
Number of individual polyphenols consumed by the 4942 participants in the SUpplémentation en VItamines et Minéraux AntioXydants (SU.VI.MAX) cohort

	All polyphenols consumed		Polyphenols commonly consumed[1]	
	Aglycones, glycosides, and esters	Aglycones[2]	Aglycones, glycosides, and esters	Aglycones[2]
Flavonoids				
Anthocyanins	45	9	36	9
Chalcones	1	1	0	0
Dihydrochalcones	3	1	3	1
Dihydroflavonols	2	2	2	2
Catechins	9	4	8	4
Theaflavins	4	1	4	1
Proanthocyanidins	16	16	12	12
Flavanones	15	8	11	4
Flavones	19	7	15	7
Flavonols	54	13	38	7
Isoflavonoids	13	4	0	0
Phenolic acids				
Hydroxybenzoic acids	28	17	22	12
Hydroxycinnamic acids	55	12	50	8
Hydroxyphenylacetic acids	7	7	4	2
Stilbenes	7	4	7	4
Lignans	7	7	5	4
Other polyphenols	52	42	41	30
Total	337	155	258	107

[1] Median intake value >0.
[2] The number of aglycones consumed as such or in the form of glycosides and esters.

Together, the 25 most-consumed polyphenols accounted for 68% of the total polyphenol intake.

Many other polyphenols were consumed in amounts less than 8 mg polyphenols/d (*see* supplemental Table 3 under "Supplemental data" in the online issue). The most largely consumed flavonol, tyrosol, theaflavin, alkylresorcinol, and stilbene were quercetin 3,4′-*O*-diglucoside, tyrosol, theaflavin 3′-*O*-gallate, 5-heneicosylresorcinol, piceatannol 3-*O*-glucoside, and isolariciresinol, respectively.

Intakes of all polyphenol aglycones were also determined (*see* supplemental Table 4 under "Supplemental data" in the online issue). Fifty-five polyphenol aglycones were consumed in amounts greater than 1 mg /d. The 10 aglycones with the highest mean intakes were caffeic acid (264 ± 108 mg /d), ferulic acid (39 ± 16 mg/d), gallic acid (35 ± 21 mg/d), (−)-epicatechin (30 ± 18 mg/d), (−)-epigallocatechin (23 ± 29 mg/d), procyanidin dimer B2 (22 ± 13 mg/d), quercetin (20 ± 5 mg/d), (+)-catechin (20 ± 13 mg/d), apigenin (17 ± 6 mg/d), and procyanidin dimer B1 (15 ± 12 mg/d).

DISCUSSION

Intakes of 337 phenolic compounds out of the 502 polyphenols documented in the Phenol-Explorer database have been determined in the French SU.VI.MAX cohort. The remaining compounds were either not consumed (eg, anethole in fennel tea or star anise) or present in foods that were not documented in the dietary questionnaires (eg, eugenol in cloves). Most of these polyphenols were observed in minor foods, were not consumed, or were consumed in very low amounts (*see* supplemental Table 2 under "Supplemental data" in the online issue).

Most previous studies on polyphenol intake were focused on specific classes of polyphenols, flavonoids (16, 28–38), lignans (10), or stilbenes (39). The most comprehensive data were obtained in a Finnish cohort (15), which included intake values for flavonoids, phenolic acids, and lignans. However, only aglycones were considered in these studies because of the lack of data on the content of glycosides and esters in common food-composition databases.

Intake values for the different classes of polyphenols varied widely between studies (eg, 4–121 mg/d for catechin monomers, 3–47 mg/d for anthocyanins, 20–78 mg/d for flavonones, and 5–25 mg/d for flavonols) (9, 40). Such large differences could be explained by various dietary habits in the different populations. However, a number of technical issues could also explain these differences. First, the presence or absence of data for a given polyphenol in food-composition tables may have introduced a bias in the comparison of intakes between studies. For example,

TABLE 6
List of the 25 most-consumed individual polyphenols in the 4942 participants of the SUpplémentation en VItamines et Minéraux AntioXydants (SU.VI.MAX) cohort and their main food sources

Polyphenol	Polyphenol subclass	Polyphenol intake[1]	Main food contributors (% contribution to intake of the polyphenol)[2]
		mg/d per person	
5-Caffeoylquinic acid	Hydroxycinnamic acids	216 ± 142	Coffee (76), potatoes (10), apples (4), artichokes (3)
3-Caffeoylquinic acid	Hydroxycinnamic acids	141 ± 117	Coffee (90), plums (3), cherries (2), prunes (1)
4-Caffeoylquinic acid	Hydroxycinnamic acids	131 ± 104	Coffee (97), tea (0.8), prunes (0.3), tomatoes (0.2)
5-Feruloylquinic acid	Hydroxycinnamic acids	27 ± 23	Coffee (99), carrots (0.3)
(−)-Epicatechin	Catechins	24 ± 15	Tea (28), apples (24), cocoa products (17), red wine (15)
Procyanidin dimer B2	Proanthocyanidins	22 ± 13	Apples (48), red wine (23), tea (14), cocoa products (10)
4-Feruloylquinic acid	Hydroxycinnamic acids	20 ± 17	Coffee (99), carrots (0.1)
(+)-Catechin	Catechins	17 ± 12	Red wine (41), tea (15), cocoa products (10), peaches (6)
Hesperidin	Flavanones	17 ± 20	Oranges (53), orange juice (46), lemon juice (0.6)
(−)-Epigallocatechin 3-*O*-gallate	Catechins	16 ± 29	Tea (100)
Apigenin galactoside-arabinoside	Flavone	16 ± 10	Refined wheat flour products (75), whole-grain wheat flour products (25)
Procyanidin dimer B1	Proanthocyanidins	15 ± 12	Peaches (30), tea (29), red wine (26), cocoa products (5)
Malvidin 3-*O*-glucoside	Anthocyanins	14 ± 16	Red wine (85), black grapes (14), red raspberries (0.06)
Procyanidin dimer B3	Proanthocyanidins	14 ± 15	Red wine (85), tea (6), peaches (4), strawberries (1)
(+)-Gallocatechin	Catechins	14 ± 24	Tea (99), red wine (0.4), strawberries (0.04), lentils (0.01)
5-*O*-Galloylquinic acid	Hydroxybenzoic acids	13 ± 24	Tea (100)
Gallic acid	Hydroxybenzoic acids	12 ± 11	Tea (44), red wine (29), green chicory (17), chestnuts (4)
(−)-Epigallocatechin	Catechins	12 ± 22	Tea (99), red wine (0.3), almonds (0.2), broad bean seeds (0.1)
Procyanidin dimer B4	Proanthocyanidins	12 ± 12	Red wine (72), tea (25), plums (0.07), strawberries (0.029)
Cyanidin 3-*O*-rutinoside	Anthocyanins	11 ± 21	Cherries (82), plums (15), black currants (1), black olives (1)
Apigenin arabinoside-glucoside	Flavones	11 ± 6	Refined wheat-flour products (78), whole-grain wheat-flour products (22)
3-Feruloylquinic acid	Hydroxycinnamic acids	9.9 ± 8.3	Coffee (98), plums (0.8), carrots (0.5), cherries (0.3)
(−)-Epicatechin 3-*O*-gallate	Catechins	9.9 ± 15.7	Tea (92), red wine (6), black grapes (0.6), strawberries (0.4)
Procyanidin trimer T2	Proanthocyanidins	8.8 ± 10.7	Red wine (100)
Ferulic acid	Hydroxycinnamic acids	8.3 ± 4.1	Refined wheat-flour products (78), cocoa products (11), white beans (4), red wine (0.8)

[1] Values are means ± SDs.
[2] Four main food sources for each polyphenol; a lower number indicates the absence of other food sources.

thearubigins, which are oxidation products of catechins, were not included in the Phenol-Explorer database because of their ill-defined structure and the lack of accurate methods for their estimation, whereas thearubigins were included in an Australian study (41). Thearubigin content values used in the Australian study (41) were extracted from the US Department of Agriculture database and were obtained by an unspecific spectrophotometric method (13). These values were not included in the Phenol-Explorer database, which resulted in a much lower flavanol intake in the current study (87 mg/d) than in the Australian study (454 mg flavanols/d). Second, content values may differ from one food-composition table to another (23). Proanthocyanidin intake estimated in the Finnish cohort (116 mg/d) was lower than that in the SU.VI.MAX cohort (227 mg/d), and this may have been because of the much lower proanthocyanidin content value in dark chocolate used in the first study (<500 mg/100 g) than the value used in the present study (1490 mg/100 g) (3, 15).

Thus, the comparison of polyphenol intakes in different populations appeared to be difficult because of the large heterogeneity of food-composition data. The use of the same food-composition database or of harmonized food-composition data is highly desirable. The systematic publication of the polyphenol food-composition data used in epidemiologic studies should also be encouraged to facilitate the comparison of polyphenol intake data between studies. All food-composition data used in the current work were available on the Phenol-Explorer website (www.phenol-explorer.eu) together with all original data used to build the database (3).

Thus, only a crude comparison of intakes of polyphenol aglycones with values previously published was possible. The total polyphenol aglycone intake of 820 mg/d observed in the present study was close to the intake obtained in the Finnish cohort (752 mg/d) (15). Phenolic acids were the main polyphenols consumed in both studies, and their intake was 2 times higher in the Finnish cohort than in the French cohort (608 compared with 356 ± 228 mg/d, respectively, expressed as aglycone equivalents), which was a difference that was consistent with the twice higher consumption of coffee in Finland (42). Proanthocyanidins were the second most abundant polyphenols in both cohorts (116 and 227 mg /d in the Finnish and French cohorts, respectively). Other flavonoid classes were consumed in amounts that varied between 5 and 87 mg/d, depending on the class and cohort. Some polyphenol classes were hardly consumed, with intakes <1 mg polyphenols/d, because of their low contents in foods (lignans and stilbenes) or to the low consumption of their main dietary sources (isoflavones). Although these particular polyphenols exhibit some interesting biological properties, their low daily intakes in the French and other Western populations raises questions about their significance in terms of health and disease prevention.

Total polyphenol intake was influenced by sex with a higher intake of polyphenols in men than in women. A similar difference according to sex was previously reported (15, 34) and was largely explained by higher consumptions of coffee and red wine in men. Age within the limited range studied (45–60 y) had no significant influence on intakes.

Total polyphenol intake was calculated in several studies by using the Folin colorimetric assay (43–45). This assay has often been used to estimate total polyphenol content in foods (25–27), and Folin values were collated for a large number of foods in the Phenol-Explorer database (3) and were used to calculate the total polyphenol intake in the SU.VI.MAX. cohort. An intake of 1998 mg polyphenols/d was obtained (data not shown), which was a value that was much higher than the sum of individual polyphenols (820 ± 335 mg/d) expressed as aglycone equivalents (the aglycone is the phenolic fraction of the polyphenol molecule that reduces the Folin reagent) (23). This difference was explained by the presence in foods of nonphenolic food constituents such as ascorbic acid that also responded to the Folin assay and led to an overestimation of the polyphenol content in foods (23). The difference could also be explained by the lack of suitable methods to estimate complex phenolic compounds, such as thearubigins and proanthocyanidins, that resulted in an underestimation of the total polyphenol content in the current work. Due to interference with nonphenolic reducing compounds, the Folin assay cannot be considered as a suitable method for the total polyphenol estimation.

The main food contributors to polyphenol intakes were determined in the SU.VI.MAX. cohort, and the data largely confirmed those obtained in other Western populations (15, 34). Three beverages (coffee, tea, and red wine) accounted for 44%, 9%, and 6%, respectively, of the total polyphenol intake, and fruit, cocoa products, vegetables, and cereals accounted for 17%, 8%, 7%, and 4%, respectively, of the total polyphenol intake (Table 3). Oils and seasonings provided only a minor fraction of the total polyphenols consumed.

In conclusion, for the first time to our knowledge, the current study provided information on intakes in a cohort of 337 individual polyphenols with a level of detail that was not achieved before. However, the study also had certain limitations. As mentioned, food-content data for some relatively abundant phenolic compounds were missing (thearubigins) or insufficient (proanthocyanidins) (4, 46). For some major polyphenol dietary sources, composition data are still scarce and intake values might be revised as more data become available. This was particularly evident for coffee for which only 4 literature sources have been used to calculate intakes of phenolic acids and these calculations did not take into account the different brewing recipes. Data on cooked foods were also lacking in the Phenol-Explorer database (a new module is under construction). Taking into account losses in polyphenol content during cooking will be particularly important for vegetables and may result in lower estimates of their contribution to polyphenol intakes.

The level of detail on dietary intakes of polyphenols achieved in the present study will be essential to study associations between the intake of individual polyphenols with health and disease outcomes. Focus should clearly be given on individual polyphenol compounds rather that polyphenol classes or subclasses to take into account subtle structural differences between individual compounds within a class or subclass that can result in major differences in the bioavailability and biological effects (8, 47). With the development of omics approaches in human biology, the complexity of human organism has been commonly described and integrated into complex models. In contrast, the chemical complexity of foods and the human diet have rarely been considered (48, 49). An appraisal of the diet in all its chemical complexity should be essential to understand the complex interactions that link foods to human health. This work illustrates how the food complexity could be characterized to

better define the exposure to food bioactives and, ultimately, the effects on health.

The authors' responsibilities were as follows—AS, PG, and SH: designed, planned, and monitored the study; JP-J and NA: matched the foods in the food-frequency questionnaire to the foods in the Phenol-Explorer database; MT, NA, and LF: performed statistical analyses; JP-J, LF, and AS: interpreted data; JP-J and AS: wrote the first draft of the manuscript; and all authors: contributed to the writing of the manuscript and approved the final version of the manuscript. The funders of the study did not participate in the design and implementation of the study or the data analyses and interpretation. None of the authors had a personal or financial conflict of interest.

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