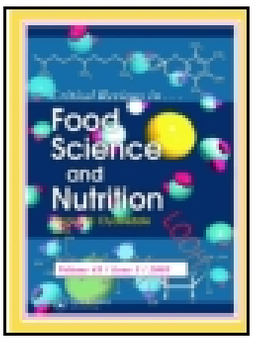

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Joris C Verster & Juergen Koenig

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Caffeine intake and its sources: a review of national representative studies

Joris C Verster[1,2], Juergen Koenig[3]

[1]Utrecht University, Division of Pharmacology, Utrecht, The Netherlands

[2]Centre for Human Psychopharmacology, Swinburne University, Melbourne, Australia

[3]Department of Nutritional Sciences, University of Vienna, Vienna, Austria

Corresponding author: Joris C Verster, Utrecht University. Division of Pharmacology, Universiteitsweg 999, 3584CG, Utrecht, The Netherlands. Tel. +31 30 253 6909, Fax. +31 30 253 7900, E-mail; j.c.verster@uu.nl

ABSTRACT

Aim of this review is to summarize current daily caffeine intake of children, adolescents and adults, and trends in caffeine intake over the past decade. A literature search was conducted (1997-2015) which yielded 18 reports on nationally representative studies, describing caffeine consumption of over 275,000 children, adolescents and adults. The data revealed that mean total daily caffeine intake in children, adolescents and adults is below caffeine intake recommendations such as those stated by Health Canada (2.5 mg/kg bw/day for children and adolescents, and 400 mg/day for adults) and the European Food Safety Authority, EFSA (3 mg/kg bw/day for children and adolescents, and 400 mg/day for adults). Total daily caffeine intake has remained stable in the last 10-15 years, and coffee, tea and soft drinks are the most important caffeine sources. Across all age groups, energy drinks contribute little to total caffeine intake. The highest potential for reducing daily caffeine intake is by limiting coffee consumption, and in some countries and age groups, by reducing tea and soft drink consumption.

Keywords

caffeine, consumption, intake, coffee, tea, cola, energy drink

 ACCEPTED MANUSCRIPT

INTRODUCTION

Despite various statements from health authorities (e.g. EFSA, Health Canada, US FDA) that the general population of healthy adults is not at risk for potential adverse effects of caffeine, there is continuous concern that caffeine intake would increase in the general population and particularly in children, adolescents and pregnant or lactating women, and that these caffeine intakes would result in adverse health effects.

Based on an extensive review of the scientific literature on caffeine (Nawrot et al., 2003), Health Canada concluded that the general population of healthy adults is not at risk for potential adverse effects from caffeine at daily consumption levels up to 400 mg caffeine (Health Canada, 2010). Regarding children, Health Canada advised that 10-12 year olds should not consume more than 85 mg caffeine per day, and not more than 2.5 mg/kg body weight (i.e., 125-175 mg caffeine for 50-70 kg) for adolescents 13-18 years old. The European Food Safety Authority (EFSA) recently also examined the safety of caffeine intake (European Food Safety Authority, 2015). They concluded that for adults habitual caffeine consumption up to 400 mg per day, and 3 mg/kg bw per day for children and adolescents, does not give rise to safety concerns. For pregnant women, maximum daily intake levels of caffeine were set at 200 mg per day.

Although the general population typically is not identified as a vulnerable group in terms of caffeine intake, some authorities consider children, adolescents and pregnant women as groups at risk for adverse effects resulting from caffeine consumption. The introduction of new caffeinated foods and beverages during the past decades has triggered these concerns, since these new sources of caffeine could be consumed in addition to the more traditional caffeine sources like coffee, tea, colas and chocolate. Whether this indeed is the case, however, has rarely been

studied in caffeine consumption surveys, as most surveys focus only on few sources of caffeine. Assessing the current caffeine intake from all sources therefore is crucial to estimate the contribution of new caffeinated foods and beverages to the total caffeine intake and to identify the potential of single categories of caffeine sources in our diet for a reduction of total caffeine consumption, if this is required from a public health point of view.

To determine whether overall caffeine intake indeed is increasing, or whether new caffeine sources are substituting the more traditional sources, standardized studies on consumption of all caffeine containing foods and beverages on a nationally representative level are required. Summarizing the available data, this review therefore provides an overview of the current status on global caffeine intake from all sources.

METHODS

A literature search was conducted (October 2nd 2015) in PubMed/Medline and Embase to identify relevant literature, using the keywords "caffeine", and "consumption" or "intake" (limit: human studies). Data collected between 1997-2015 was considered, and only studies stating to be nationally representative were included in the current review. To be included, data on caffeine intake from all sources should have been reported. Studies that did not include information on caffeine consumption from all (beverage) sources were omitted (e.g., studies only reporting on one specific caffeine containing product category, but not on other sources of caffeine).

Abstracts were screened, and full text articles were obtained for papers that were likely to meet the inclusion criteria. Cross-references were checked for additional references, and the Internet was searched for other nationally representative reports on caffeine consumption. Figure 1 shows the PRISMA flow diagram of the literature search.

The literature search revealed 3883 papers (Embase: 1688, Pubmed: 2278). After removing 1059 duplicates, the initial search comprised 2824 papers. Of these papers, the abstracts were screened for relevance. As we used very general search terms in order to not omit any relevant paper on caffeine consumption and its sources, many of the papers of the search were not relevant. Of potential relevant papers full text articles were obtained. Cross references were checked for additional publications. A total of 18 articles and reports were eligible for inclusion in this review.

RESULTS

Data from nationally representative studies, summarized in 18 articles and reports, were included in the review. These studies came from different regions around the world, including the USA, Europe, Australia, and Asia.

To provide an overview on the results on caffeine intake reported in these articles and reports, table 1 lists the total mean caffeine intakes for the different age groups and years as provided. It has to be noted though that these figures are heterogeneous in respect to different factors including sampling frame, sample design, and method to measure food and/or beverage consumption. Therefore, the potential to compare caffeine intakes between different studies is limited. Some details from the different studies are presented below, but it has to be noted that there is inconsistent level of details across studies due to the varying focus of the results reported in the published data.

USA

In the USA, two large national representative surveys monitor caffeine intake from food and beverages: The Kantar Worldpanel (KWP) and the National Health and Nutrition Examination Survey (NHANES).

Mitchell et al. (2014) examined caffeine consumption in a nationally representative sample of 37,602 caffeine consumers aged 2 years and older from the Kantar Worldpanel (KWP) Beverage Consumption Panel survey. For the selection of participants, U.S. Census demographic data were used to guide the selection of the participants to form a representative "Beverage Consumption Panel". Age, gender, race, Hispanic origin, geographic region, market size, household income, household size, and presence of children in the household were included as sample selection characteristics. Data were collected 2010-2011 using a 7-day online beverage diary. Coffee, carbonated soft drinks, tea and energy drinks together comprise approximately 98% of daily caffeine intake (Mitchell et al. 2014). Energy shots were excluded altogether from the analysis due to very low frequency of consumption in the overall survey ($n < 100$). Sixty-three percent of those who consume caffeinated beverages consume carbonated soft drinks, 55% consume coffee, 53% consume tea, and 4% consume energy drinks. The overall proportion of participants that consume caffeinated beverages increased with age from about 43% of 2-5 year olds to almost 100% in those 65 years of age and older.

Also, the amount of caffeine intake increased with age and was highest among 50-64 years old consumers (on average 165 mg/day (2.2 mg/kg bw/day) across all age groups; 50-64 years old: 226 mg per day (2.9 mg/kg bw/day)). For all age groups, the average total caffeine consumption was below the levels recommended by Health Canada. There were some small differences between men and women. However, these were absent when correcting the data for body weight.

The 90th percentile (P90) data showed a similar trend across ages with a mean daily caffeine intake of 380 mg/day (5.0 mg/kg bw/day), of which 80% was contributed via coffee consumption.

Coffee was the primary source of caffeine in all age groups (64%; 105.4 mg/day), followed by carbonated soft drinks (17%; 27.9 mg/day) and tea (17%; 27.9 mg/day). Energy drinks contributed less than 2% to total caffeine intake (2.6 mg/day). The greatest prevalence of energy drink consumers was found among 13-24 years old (around 10% of caffeine consumers versus 4.3% across all age groups). In this age group, 5-7% of total caffeine intake was by means of consuming energy drinks (6.1/day among 13-17 year olds, and 6.2 mg/day among 18-24 year olds). Across age groups, chocolate milk, cocoa and energy shots together contributed only to 1-2% of total caffeine intake. Among children and adolescents, greatest caffeine intake came from carbonated soft drinks, followed by tea and coffee. For adults 18 years and older, coffee was by far the greatest contributor to daily caffeine intake, whereas energy drinks contributed very little to daily caffeine intake.

An earlier study (Knight et al., 2004) examined data collected via the Share of Intake Panel (SIP), a marketing research program monitoring the consumption beverages. Data from 10,712 caffeinated beverage consumers, collected in 1999, revealed a daily caffeine intake from beverages ranging from 106 to 170 mg/day (P90: 227-382 mg/day) for adults, 14 mg/day (P90: 37 mg/day) in children aged 1 to 5 years old, and 22 mg/day (P90: 45 mg/day) in children aged 6 to 9 years old. Daily caffeine intake was highest among 35 to 49 year olds (170 mg/day, P90: 382 mg/ day). Coffee was the primary source of caffeine intake in adults. In children, caffeinated soft drinks were the main source of caffeine, followed by tea.

Mitchell et al. (2014) reported that a trend over the period 1999-2010 was seen in that overall caffeine consumption increased from 120 mg/day in 1999 to 165 mg/day in 2010; i.e. an increase comparable to about half a cup of coffee. Regarding the contribution to total caffeine intake, an increase was seen for coffee (53% to 64%), a reduction for carbonated soft drinks (29% to 17%), whereas the contribution of tea remained stable. The substitution of carbonated soft drinks by coffee may possibly account for the slight increase in total daily caffeine consumption from 1999 to 2010.

The National Health and Nutrition Examination Survey (NHANES) comprises an interview at home followed by a telephone interview. Trained interviewers record all food and beverage intake of the past day (24-hour dietary recall). To obtain data from children (< 6 years old) caregivers are interviewed, children 6-12 years old have assistance to complete the dietary recall, others (>12 years old) complete the dietary recall interview unassisted. The response rate for the NHANES 24-hour dietary recall data typically is between 75-80%. NHANES surveys are held every 2 years among approximately 10.000 respondents.

Somogyi (2010) examined caffeine intake data from the national representative NHANES (1999-2000, 2001-2002, 2003-2004, 2005-2006), as well as the NPD Group's Food Consumption surveys, conducted in 2008 (Somogyi, 2010). The NHANES 2005-2006 reported data from 24-hour dietary recalls of 2 consecutive days by approximately 9,500 participants. Among all subjects 2 years and older, total daily caffeine intake remained stable from 2001-2002 (142.1 mg/day) to 2003-2004 (150.8 mg), and 2005-2006 (149.8 mg/day). The 2006 data revealed that caffeine consumption increases with age, and that men consume more caffeine (mg/day) than

women. The highest caffeine intake (295.6 mg/day) was seen in men of the 50-59 years old group.

The NPD Group Survey consists of a national representative sample of 2,000 US households (about 5,000 people). For 14 days in 2008, a daily food and beverage diary was completed. Overall, on a typical day, caffeine consumption of participants aged 2 years and older was 131.9 mg/day. In adults, 22 years and older, daily caffeine intake was highest (161.9 mg/day). In children 2-13 years old caffeine intake was 28.7 mg/day. In adolescents (14-21 years old), caffeine intake was slightly higher among men (74.9 mg/day) when compared to women (62.0 mg/day). Most caffeine came from beverages (92.3% in children and 98.6% in adults). For children and adolescents, carbonated soft drinks (about 38%) and tea (25 -31%) were major sources of caffeine; in adults, coffee (55.8%) was the major source of caffeine, followed by tea (16.9%) and carbonated soft drinks (16.1%).

Taking into account the NHANES data, NPD Group Survey data and trade information, Somogyi calculated that the mean daily caffeine intake of adults aged 22 and older in 2008 was 300.7 mg. Children had a daily caffeine intake of 43.5 mg/day, which increased in adolescence (14-22 years old) to 110.5 mg/day for men and 103.4 mg/day for women. For females in childbearing age (16-45 years old) daily caffeine intake was 208.2 mg/day. Total daily caffeine remained unchanged between 2003 and 2008. Most caffeine came from beverages (94.9% in children and 99.2% in adults). For children, carbonated soft drinks (39.1%), other beverages (32.0%) and tea (18.2%) were major sources of caffeine; in adolescent men and women, carbonated soft drinks (41.0% and 35.1%, respectively) and coffee (22.9% and 32.6%,

respectively) were major caffeine sources. In adults, coffee (68.7%) was the major source of caffeine, followed by carbonated soft drinks (13.5%) and tea (9.5%).

Fulgoni III presented caffeine intake data from NHANES 2007-2010 (N=17,387), and trend data from 2001 to 2010 (N=42,154) at the Caffeine in Food and Dietary Supplements Workshop of the Institute of Medicine (Institute of Medicine, 2014). Among caffeine consumers (N=13,923), daily caffeine intake increased with age from approximately 25 mg/day (P90: 90 mg/day) in 2-11 year olds, 75 mg (P90: 180 mg/day) in 12-17 year olds, to over 250 mg/day (P90: 515 mg/day) in 50-59 year olds. For single consumption sessions, the average caffeine intake was 65 mg (15 mg among children (P90: 25 mg), 35 mg among adolescents (P90: 60 mg), and 70-80 mg among adults (P90: 140 mg)). From 2001-2010 caffeine intake remained stable, although small but significant decreases in caffeine intake were found for 2-11 year olds (-2.5 mg) and 35-39 year olds (-19 mg). Regarding sources of caffeine, among 2-11 year olds carbonated soft drinks are the major contributor to caffeine intake. However, over the period 2001-2010 a significant reduction in carbonated soft drink consumption was seen for this age group, whereas consumption of coffee, tea and energy drinks remained stable. Among adolescents (12-17 years old), carbonated soft drinks were the main source of caffeine, and also in this age group a significant decline in consumption was seen from 2001 to 2010. Coffee was the greatest source of caffeine in adults. Among 18-35 year olds, a significant decrease in carbonated soft drink consumption and a small but significant increase in energy drink consumption was seen. Fulgoni concluded that overall caffeine intake remained stable from 2001 to 2010, but that new caffeine sources (e.g. RTD coffees, energy drinks) may be replacing traditional ones (e.g. carbonated soft drinks).

Fulgoni et al. further examined NHANES data covering 2001 to 2010 of N=24,808 adults (≥ 19 years old) (Fulgoni et al., 2015). Of them, 89% reported regular caffeine consumption. Among caffeine users, usual daily intake was 211±3 mg (P90 = 436 mg/day). Men (240±4 mg/day) had a significant higher usual caffeine intake than women (183±3 mg/day). About half of the caffeine intake (46%, 85 mg) was consumed in a single session.

Almost all caffeine (98%) came from beverages. Most important caffeine sources were coffee (64%), soft drinks (18%), and tea (16%). Caffeine intake was stable from 2001 to 2010. There was however a small but significant decrease in soft drink consumption (-3 mg for each subsequent 2 years), and a small but significant increase in energy drink consumption (+0.5 mg per 2 years) between 2001 and 2010. To put this into perspective, it should be noted that energy drinks contribute less than 1% to daily caffeine intake.

Ahluwalia et al. also used the NHANES database (2009-2010) to examine trends in caffeine intake of a national representative sample of N=18,530 US children during the years 2001–2010 (Ahluwalia et al., 2014). A small but significant decline in caffeine intake was found for children aged 2–5 years (–3.0 mg/day) and 6–11 years (-4.6 mg/day). Also caffeine intake among 12-19 years old adolescents remained stable over the 10-year study period. In 2009-2010, 71% of US children and adolescents consumed caffeine. Average daily caffeine intake increased with age from 4.7 mg/day (2–5 years old), to 9.1 mg/day (6–11 years old) and 40.6 mg/day (12-19 years old). The analyses revealed that 90–95% of children 12 years old or younger and 75-90% of 12-19 years old have daily caffeine intakes below the levels recommended by Health Canada. The 90th percentile of caffeine consumers among 12-19 years old had an average daily caffeine

intake of 2.45 mg/kg body weight and day (186.3 mg/d), equal to the recommended consumption limit of Health Canada for this age group.

Branum et al. examined trends in caffeine intake among US children, using NHANES data from 1999 to 2010 (Branum et al., 2014). Dietary recall data (Day 1 of NHANES) were analyzed for different age categories (2-5, 6-11, 12-16, 17-18 and 19-22 year olds), and the authors further looked at race/ethnicity and poverty status. About 73% of children reported caffeine intake. A clear effect of age was seen: among 2-5 year olds 63% consumed caffeine which increased to around 75% of older children and adolescents. Caffeine consumers were more frequently found among non-Hispanic white children, when compared to non-Hispanic black or Mexican-American children. Males consumed significantly more caffeine than females.

Over the years 1999-2010, a significant decline in total daily caffeine intake was seen for 2-5 year olds, 6-11 year olds, and Mexican-American children. For other groups, total daily caffeine intake (mg/day) remained stable.

Overall, carbonated soft drinks accounted for the majority of caffeine intake in children. However, a significant decline was seen from 62% in 1999-2000 to 38% in 2009-2010. Tea consumption remained stable over the years and was the second greatest contributor to daily caffeine intake. On the other hand, a significant increase in coffee consumption was seen from 1999 to 2010. Coffee contributed 10% to daily caffeine intake in 1999-2000 and 24% in 2009-2010. Regarding different age groups, tea was the greatest caffeine source in children 2-5 years old, and coffee was the greatest caffeine contributor among 19-22 year olds. Energy drinks were absent in 1999-2000, and in 2009-2010 energy drinks contributed to 6% to daily caffeine intake. The number of children reporting energy drink consumption in 2009-2010 was however small

(N=111, 0.7%). The highest contribution to daily caffeine intake was found among 19-22 year olds (10%).

CANADA

Knight et al. compared caffeine intake of children 1 to 5 years old from Canada and USA (Knight et al., 2006). Data from two nationally representative household surveys, the 2001 Canadian Facts Study (N=658) and the 1999 United States Share of Intake Panel Study (N=619) were compared. Of 1 to 5 years old children, 36% in Canada and 58% in USA consume caffeinated beverages. Daily caffeine consumption of Canadian children was on average 7 mg/day (0.42 mg/kg/day) versus 14 mg/day (0.82 mg/kg/day) in US children. The 90th percentile of daily caffeine consumption of Canadian children was 26.7 mg/day (1.71 mg/kg/day) versus 37.3 mg/day (2.32 mg/kg/day) in US children. Most common source of caffeine was carbonated soft drinks followed by tea. The higher daily intake of caffeinated beverages among US children is due to a higher consumption of carbonated soft drinks. Caffeine intake of both Canadian and US children was well within the Health Canada safety limits for children.

EUROPE

The EFSA Scientific Opinion on the Safety of Caffeine combined data from 39 European surveys conducted between 1997 and 2012 (European Food Safety Authority, 2015). The surveys were conducted in 22 different European countries and included a total of 66,531 participants. Combined data were presented for toddlers (12-<36 months, N=4,103), other children (3-<10 years old, N=8,755), adolescents (10-<18 years old, N=8,709), adults (10-<65 year olds, N=31,818), elderly (65-<75 years old, N=5,119), and very elderly (≥75 years old, N=2,381). Minimum and maximum total daily caffeine intake was 0.3-30.3 mg (0.0-2.1 mg/kg

bw) for toddlers, 3.5-47.1 mg (0.2-2.0 mg/kg bw) for other children, 17.6-69.5 mg (0.4-1.4 mg/kg bw) for adolescents, 36.5-319.4 mg (0.5-4.3 mg/kg bw) for adults, 22.6-362.1 mg (0.3-4.8 mg/kg bw) for elderly, and 21.8-416.8 mg (0.3-6.0 mg/kg bw) for very elderly. The minimum and maximum P95 of total daily caffeine intake was 0.8-45.4 mg (0.1-3.5 mg/kg bw) for toddlers, 19.8-102.6 mg (1.2-4.6 mg/kg bw) for other children, 60.5-211.6 mg (1.5-4.1 mg/kg bw) for adolescents, 108.6-742.4 mg (1.5-10.0 mg/kg bw) for adults, 96.3-715.7 mg (1.5-10.4 mg/kg bw) for elderly, and 174.0-454.5 mg (2.3-6.1 mg/kg bw) for very elderly.

In adults, elderly and very elderly, coffee was the most important source of caffeine, accounting for 40-94% of daily caffeine intake. In Ireland (59%) and UK (57%), tea was the major source of caffeine intake. Cola beverages, energy drinks and chocolate drinks were negligible sources of caffeine among adults and elderly.

Among adolescents, main contributors of caffeine varied between countries, and included cola beverages, coffee, tea and chocolate. The contribution of energy drinks to daily caffeine intake was minor across the EU, with highest values in the UK (11%), the Netherlands (8.1%) and Belgium (5.3%). For toddlers, chocolate and tea were the main contributors to daily caffeine intake (except for Belgium where cola beverages were the main contributing caffeine source). For children aged 3-10 years, chocolate was the main caffeine source, followed by tea and cola beverages. Energy drinks were a negligible source of caffeine among toddlers and other children.

Zucconi et al. conducted a study commissioned by EFSA on the prevalence of energy drink consumption (Zucconi et al., 2013). Data was collected between February and November 2012 in 16 EU member states. A total of N=50,587 participants were interviewed, of which N=14,557 were adults (18-65 years old, N=31,070 were adolescents (10-18 years old), and N=4,960 were

children (3-10 years old). It has to be noted, that of the total sample about 19% were from Italian origin (N=9,609). Adults were interviewed using computer assisted web interviews (CAWI [80%]) or computer assisted telephone interviews (CATI [20%]), adolescents completed a web based questionnaire, and children completed a questionnaire at school with help of teachers or parents.

Among all adults (N=14,557), total daily caffeine consumption from all sources was not recorded. Adult energy drink consumers (N=4,180) had a daily caffeine intake of 271.7 mg/day (3.87 mg/kg bw/day), of which 22.4 mg/day (0.32 mg/kg bw/day) comes from energy drinks (about 8%). Among the P90 of adult energy drink consumers (N=486), daily caffeine intake was 381.91 mg/day (5.78 mg/kg bw/day), of which 48.32 mg/day (0.70 mg/kg bw /day) comes from energy drinks (about 12%). Regarding single session consumption, adult energy drink consumers (N=4,180) had a caffeine intake from energy drinks only of 155.07 mg (2.16 mg/kg bw); among the P90 of adult energy drink consumers (N=486), caffeine intake from energy drinks on a single session was 373.70 mg (5.14 mg/kg bw).

Daily caffeine consumption from all sources of adolescents (N=31,070) was 149.20 mg/day (2.45 mg/kg bw/day), of which 15.91 mg/day (0.26 mg/kg bw/day) comes from energy drinks. Among adolescent energy drink consumers (N=20,713), daily caffeine consumption from all sources was 184.92 mg/day (3.01 mg/kg bw/day), of which 23.51 mg/day (0.38 mg/kg bw/day) comes from energy drinks (about 13%). Among P90 adolescent energy drink consumers (N=2,077), daily caffeine intake from all sources was 476.99 mg/day (7.30 mg/kg bw/day), of which 75.08 mg/day (1.18 mg/kg bw/day) comes from energy drinks (about 16%).

Regarding single session consumption, adolescent energy drink consumers (N=20,713) had a caffeine intake from energy drinks only of 175.62 mg (2.92 mg/kg bw); among the P90 of adult energy drink consumers (N=2,170), caffeine intake from energy drinks on a single session was 457.98 mg (7.21 mg/kg bw).

Daily caffeine consumption from all sources of children (N=4,960) was 23.35 mg/day (1.08 mg/kg bw/day), of which 3.98 mg/day (0.18 mg/kg bw/day) comes from energy drinks. Among energy drink consumers (N=930), daily caffeine consumption from all sources was 51.38 mg/day (2.37 mg/kg bw/day), of which 21.97 mg/day (1.01 mg/kg bw/day) comes from energy drinks (about 42%). Among P90 adolescent energy drink consumers (N=154), daily caffeine intake from all sources was 90.24 mg/day (4.16 mg/kg bw/day), of which 42.90 mg/day (1.98 mg/kg bw/day) comes from energy drinks (about 47%). No data on single session consumption was collected.

Regarding the sample of children, the data of Zucconi et al. has several limitations. First of all, it can be questioned if the sample is representative for Europe. About one third of children came from Italy. Other countries such as Germany (0.6%), U.K. (2.6%) and France (4.2%) were clearly underrepresented, as they together make up about 42% of the European population. Also, males were overrepresented in the survey sample. Further, there was an overlap between the children sample (3-10 years old) and adolescent sample (10-18 years old: 10 year olds were included in both categories. There are several potential sources of recall bias. For example, children had to recall consumption up to one year. Also, the fact that they were assisted by teachers while completing the survey may have biased the outcome.

Taking into account these limitation, Zucconi et al. confirmed that the contribution from energy drink consumption to total caffeine consumption in Europe is only modest: 8% for adults and 13% for adolescents. The key contributors to daily caffeine intake are coffee (65% in adults and 33% in adolescents), cola (12% in adults and 30% in adolescents) and tea (9% adults and 11% in adolescents).

In Germany, Lachenmeier et al. examined the caffeine intake of caffeine consuming children and adolescents (10-18 years old) and adults (Lachenmeier et al., 2013). For N=316 children and adolescents (9-19 years old), data from the Dortmund Nutritional and Anthropometric Longitudinally Designed (DONALD) study were used, conducted between 2007 and 2011. The average caffeine consumption based on 3 day recordings was computed. For N=15,371 adolescents and adults (14-80 years old), data from a representative national nutrition survey was used (Nationale Verzehrsstudie II), conducted in 2005 and 2006.

The average daily caffeine intake for children and adolescents was 0.9 mg/kg bw/day and 2.1 mg/kg bw/day for adults, both below the Health Canada recommendations. Percentile data showed that more than 95% of children and adolescents consume caffeine at levels below Health Canada recommendations. The data confirmed that caffeine intake increases when people grow older until the age group of 35-50 years. Caffeinated soft drinks (48.9%) and tea (38.0%) were the greatest contributors to total caffeine intake in children and adolescents, whereas coffee (5.4%), and energy drinks (0.6%) only had a small contribution to daily total caffeine intake. In adults, coffee and tea were the biggest contributors to total caffeine intake.

In the U.K. Fitt et al. examined caffeine intake in a national representative sample of N=2,126 UK inhabitants, 1.5 years and older (Fitt et al., 2013). The data was collected between 2008 and

2010. In adults, total caffeine intake ranged from 122 to 143 mg/day. Coffee (49.5 mg/day) and tea (36.2 mg/day) were the greatest contributors of daily caffeine intake, followed by the in this study combined category of soft drinks and energy drinks (34.5 mg/day). Caffeine intake of children of 45 mg/day (4-6 years old) to 85 mg/day (10-12 years old) was below the recommendations of Health Canada. Overall, more than 95% of caffeine consumers ingest caffeine in amounts below the limits set by Health Canada.

In Austria, Rudolph et al. examined a national representative sample of N=700 Austrians aged 14 to 39 years old (Rudolph et al., 2014). This age range was chosen as energy drinks are most popular in this age group. Their mean daily caffeine intake was 357 mg/day (5.3 mg/kg bw/day). Caffeine intake at the 95th percentile (P95) was 957 mg/day (14.5 mg/kg bw/day). Most important sources of caffeine were coffee (60.8%), energy drinks (11.9%) and cola (9.5%). No significant differences were seen between men and women, or between BMI groups on a kg/bw basis. The age group 26-39 years old had a significantly higher daily caffeine intake when compared to younger participants. The data are of particular interest since Austria has a traditionally high caffeine consumption, and energy drinks have been on the market since 1987.

AUSTRALIA

The 2007 Australian National Children's Nutrition and Physical Activity Survey was commissioned by the Department of Health and Ageing, and completed by N=4,487 randomly selected children from across Australia, aged 2 to 16 years old. Although children of indigenous origin were not included, this can be regarded as a representative national sample. The data were collected on two occasions between February and August 2007, using a computer assisted personal interview (CAPI), i.e. a face to face interview conducted in the children's home,

followed 7-21 days later by a computer assisted telephone interview (CATI) with the child or its caregiver.

A first report by the Commonwealth of Australia used CAPI data to assess daily caffeine consumption (Commonwealth of Australia, 2008). They found that daily caffeine consumption (mg/day) increased with age: 3.4 mg/day (2-3 years old), 8.1 mg/day (4-8 years old), 19.2 mg/day (9-13 years old), 41.7 mg/day (14-16 years old). Boys consumed more caffeine than girls. Major sources of caffeine for children 2-3 years old was chocolate (21.7%), soft drinks for children 4-13 years old (25.7-36.7%), and coffee (32.2%) and soft drinks (29.6%) for 14-16 year olds.

Overall (N=4,487 children, 2-16 years old),19% of daily caffeine intake comes from food, 81% from beverages (Beckford et al. 2015). Regarding beverages, soft drinks and flavored mineral waters contributed most to daily caffeine intake (31%), followed by coffee (21%), tea (17%), milk beverages (5%), and other beverages (4%). Energy drinks and sports drinks combined contributed 3% to daily caffeine intake.

Beckford et al. reanalyzed data from the 2007 Australian National Children's Nutrition and Physical Activity Survey to specifically look at consumption of beverages to which caffeine is added (i.e. cola type beverages and energy drinks) (Beckford et al., 2015). The results showed that 69% of daily caffeine intake of children comes from caffeine formulated beverages (CBFs). Of N=4,487 children, N=642 (14.3%) consume CBFs. Almost all CBFs (97%) consumed by Australian children were non energy drinks. Total daily caffeine intake was 18 mg (0.43 mg/kg bw/day). Consumers of CBFs had higher total daily caffeine intake (61 mg, 95%CI: 55-67 mg)

when compared to children that do not consume CBFs (11 mg, 95%CI: 10-12 mg). Children with lower socioeconomic background were significantly more likely to consume CBFs.

In conclusion, in 2007 the total daily caffeine intake per kg bw of Australian children was below the recommended maximum daily intake level of 95 mg for children aged 5-12 years old (Food Standards Australia and New Zealand (FSANZ), 2015). The most important source of caffeine was soft drinks, followed by coffee and tea.

In 2013, the Australian Beverage Council commissioned a study on caffeinated beverage consumption and attitudes towards energy drinks. A national representative sample of N=1,105 Australians, aged 15-49 years old, completed the corresponding survey. In the past week they consumed on average 8.4 coffee drinks, 3.2 colas, 2.9 cups of green/black tea, and 0.7 energy drinks. Examining the relative contribution of different sources of caffeine revealed that 51% of caffeine intake comes from coffee drinks (33% for 15-19 year olds, 48% for 20-29 year olds), 18% from colas, 16% from tea, and 5% from energy drinks (6% for 15-19 year olds, 7% for 20-29 year olds).

NEW ZEALAND

The 2013 Food Regulatory Policy Options Paper, prepared for the Food Regulation Standing Committee (FRSC) by the FRSC Caffeine Working Group discussed New Zealand data on caffeine consumption.

In 2002, New Zealand National Children's Nutrition Survey, found that the mean daily caffeine intake of children, 5-12 years old, was 20 mg/day (0.6 mg/kg body weight). The P95 was 74 mg/day. For 5-12 year olds, main caffeine sources were tea (32%) and soft drinks (30%), followed by biscuits, cakes, muffins, pastries (11%), chocolate drinks (7%), chocolate (6%),

energy drinks (2%). For 13-15 year olds in addition to soft drinks (32%) and tea (29%), coffee (23%) was an important caffeine source. Biscuits, cakes, muffins, pastries (6%), chocolate drinks (4%), chocolate (4%), and energy drinks (3%) had a limited contribution to daily caffeine intake.

The 2008-2009 National Adults Nutrition Survey by the New Zealand Ministry for Primary Industries reported that the average daily caffeine intake of New Zealanders 15 years and older was 216 mg/day (2.8 mg/kg bw) The P95 was 557 mg/day, and overall 37.3% of participants consumed > 3 mg/kg body weight caffeine per day. The latter were most frequently participants aged 31 and older. Data were presented per age group and gender. Among 15-18 year olds, caffeine intake was 75 mg/day (1.1 mg/kg bw/day, P95: 258 mg/day) for males and 77 mg/day (1.2 mg/kg bw/day, P95: 288 mg/day) for females. Among 19-30 year olds, caffeine intake was 194 mg/day (2.4 mg/kg bw/day, P95: 634 mg/day) for males and 144 mg/day (2.2 mg/kg bw/day, P95: 413 mg/day) for females. Among 31-50 year olds, caffeine intake was 253 mg/day (3 mg/kg bw /day, P95: 614 mg/day) for males and 252 mg/day (3.5 mg/kg bw/day, P95: 614 mg/day) for females. Among 51-70 year olds, caffeine intake was 264 mg/day (3.1 mg/kg bw/day, P95: 573 mg/day) for males and 212 mg/day (3 mg/kg bw/day, P95: 468 mg/day) for females. Among those 71 and older, caffeine intake was 216 mg/day (2.7 mg/kg bw/day, P95: 433 mg/day) for males and 179 mg/day (2.7 mg/kg bw/day, P95: 360 mg/day) for females.

Overall, the highest contributors to daily caffeine intake were coffee (47%) and tea (32%). Soft drinks (7%), biscuits (3%), chocolate (4%), chocolate drinks (1%), and energy drinks (3%) only had a small contribution to daily caffeine intake. Again, data were presented for different age groups and by gender. No gender differences were found in the relative intake of different sources of caffeine. For adolescents, 15-18 years old, soft drinks followed by biscuits and coffee

were the major caffeine sources. From 19 years old, coffee is the main source of caffeine across age groups (38%-56%), followed by tea (13%-58%). Highest consumption of energy drinks was found among men 19-30 years old. In this group, energy drinks contributed to 8% of daily caffeine intake.

ASIA

In South Korea, Lim et al. determined the caffeine content of 1202 food and beverage products (Lim et al., 2015). Data from the Korean National Health and Nutrition Examination Survey (KNHNES), conducted in 2010-2012 was used to calculate daily caffeine intake of a national representative sample of N=21.573 Koreans. Mean daily caffeine intake for the total general Korean population was 67.75 mg/day (77.24 mg/day for men and 58.23 mg/day for women), and 81.91 mg/day for adults 19 years and older. In adolescents of 15-18 years old daily caffeine intake was 30.04 mg/day (0.52 mg/kg bw/day). In children, daily caffeine intake ranged from 1.38 mg/day (0.11 mg/kg bw/day) for up to 3 year olds to 10.05 mg/day (0.19 mg/kg bw/day) for 12-14 year olds. Highest caffeine intake was seen among 30-49 year olds (101.83 mg/day, 1.55 mg/kg bw/day). Main sources of caffeine intake were coffee (89%), followed by tea, and carbonated soft drinks. For young adults (15-19 year olds), carbonated soft drinks were the main caffeine source (30%). For heaviest caffeine consumers (30-49 year olds) coffee was the main caffeine source.

PREGNANT AND LACTATING WOMEN

Data on daily caffeine intake in pregnant or lactating women is scarce. From the 39 surveys summarized in the EFSA caffeine opinion only one study looked at pregnant women. This study, conducted in Latvia among n = 1 002 pregnant women revealed a mean (95th percentile) daily

caffeine intake from all sources of 109 mg (206 mg). Another small study conducted in Greece among n=65 lactating women reported a mean (95th percentile) daily caffeine intake from all sources of 31 mg (97 mg). The daily caffeine intake observed in these studies is below the EFSA safety recommendation of not exceeding 200 mg caffeine per day for pregnant and lactating women.

In 1999, Knight et a. 2004 examined data collected via the Share of Intake Panel (SIP), which also included a subset of pregnant women. Average daily caffeine intake from beverages in pregnant women was 58 mg/day (P90: 157 mg/day). Women of reproductive age ingested 91-109 mg/day (P90: 229-247 mg/day).

DISCUSSION

National representative studies from across the globe consistently show that average daily caffeine intake is below the recommendations of Health Canada (400 mg per day for adults and 2.5 mg/kg bw/ day for children and adolescents) and EFSA (400 mg per day for adults and 3 mg/kg bw/day for children and adolescents). Over the past decade, daily caffeine intake remained stable, despite the introduction of new caffeinated beverages. For adults, major sources of caffeine are coffee and tea, followed by carbonated soft drinks. For children, carbonated soft drinks and tea are major contributors, followed by coffee. Across all age groups, other caffeinated beverages (e.g., energy drinks) or foods (e.g., chocolate) do not significantly contribute to daily caffeine intake (together usually less than 5% to 10%).

While average daily caffeine intake from the studies presented here is below the recommendations of Health Canada, it has to be also noted that in some groups of the population

and in some countries, high consumption of foods and beverages containing caffeine lead to intakes of caffeine at the 90th or 95th percentile which are above these recommendations.

It should be taken into account that there can be large differences between countries in both caffeine intake and its sources. For example, according to EFSA (2015), the main source of caffeine in the UK and Irish adult population is tea, compared to coffee in all other investigated EU countries.

Regarding consumption trends, for adults the total caffeine intake has remained stable. The introduction of energy drinks as a new caffeinated product to the beverage market has not led to an increase in total daily caffeine consumption. Total caffeine consumption of children below 12 years old has significantly declined over the past 10 years, whereas adolescent caffeine consumption remained stable. However, interesting trends over the past 15 years include a reduction of caffeinated soft drink consumption and an increase of coffee consumption among children and adolescents.

Generally, it has to be pointed out that the studies selected from the literature are of limited comparability for several reasons:

- sampling frame and sample design of the studies to achieve national representativeness are different. In some studies, weighting procedures where applied to adjust the samples to the corresponding sampling frame, while others use a census design. Overall, the information provided on the exact statistical procedures applied is limited and comparison between studies is difficult.
- The methods used to assess food and/or beverage consumption are different in the studies, again limiting their comparability. Data derived by 24 h-recalls are different from data derived from

food frequency questionnaires and data derived retrospectively are different from prospective food consumption methods (food diaries). This is an inherent source of limited comparability. For exact comparison between different studies and between different time periods of intake estimates, standardized methods to assess food consumption are required.

- The classification of the population into different age groups differs substantially within the studies identified. There is considerable overlap between population groups from different studies as there is no global agreement on different age groups.

  These differences have to be considered when comparing the different results and limit the interpretation of the data to some extent. Some trends can still be extracted from the studies available, for ultimate comparison however harmonized approaches would be mandatory.

  Although some studies come from large ongoing projects with a fixed methodology (e.g., NHANES), no standardized methodology has been applied in most of the studies summarized in this review. A direct comparison of these studies is therefore difficult. Moreover, data from different methodologies could not be aggregated into one dataset, for example to allow conducting meta-analyses. Ahluwalia and Herrick (2015) summarized the main methodological differences between studies that prevent aggregation of all data (Ahluwalia et al., 2014). First of all, the dietary data collection period varied between studies. Whereas some studies applied a 24 h dietary recall period, other studies recorded caffeine consumption for several days. Second, the data was collected in different ways, including surveys, phone calls, or face-to-face interviews. Third, the year(s) of data collection varies between the studies. Fourth, the varying age categories between the studies make it especially hard to aggregate the data. Fifth, some studies presented incomplete data. For example, caffeine intake data for men and women was presented,

but no overall data was reported. Other studies omitted relevant caffeinated products in their study (e.g., energy shots or caffeine pills), combined more than 1 caffeinated beverage into 1 category (e.g., combining energy drinks and sports drinks), or focused specifically on one beverage category (e.g., energy drinks). Surveys specifically developed to assess consumption of specific foods tend to overestimate their consumption (European Food Safety Authority, 2015). Other studies only reported on caffeinated beverages but not foods (e.g., chocolate). However, the latter may be justified as all studies show that in adults caffeinated foods hardly contribute to total caffeine intake. Also, some studies did not report caffeine intake in mg/kg bw for children and adolescents, making it impossible to compare the study outcome with Health Canada and EFSA recommendations.

It is understandable that the methodological differences between the studies may have an impact on study outcomes in terms of under- or over reporting of caffeine intake. Therefore, harmonization of food intake methodologies is essential to allow for direct comparisons between future studies, and across countries. Additionally, databases providing information on typical caffeine concentration in various foods and beverages are required as these can vary substantially in particular for coffee and tea depending on different factors (Rudolph et al., 2012). Ideally, these databases should be based on analytical values from a wide range of frequently consumed beverages and should regularly be updated as consumer trends may change over time.

Finally, although this information is available online to the general public (e.g., EFSA Fact Sheet on Caffeine), studies have shown that most people are not aware of the relative caffeine content of common beverages. For example, the 2013 Galaxy Poll revealed that most people think that energy drink contains most caffeine. Only 4% of Australians correctly believe that coffee from a

café contains the highest amount of caffeine. Also, a recent study among US adolescents show that knowledge about whether common beverages contain caffeine or not is limited (Thrake et al., 2015), and recent Dutch data show that students find it hard to correctly rank caffeinated beverages according to their relative caffeine content (Mackus et al., 2016) An important reason for this lack of knowledge may be the fact that caffeine content is not labeled on all caffeine containing beverages. For example, coffee and tea and other natural products containing caffeine often do not have to record caffeine content on their label, while products with added caffeine such as energy drink do. The labeling text on a can of energy drink in Europe that the drink "contains high caffeine content" is in contrast to other unlabeled products with much higher caffeine content. For example, Starbucks coffee contains between 160 mg (Short, 236 ml) and 400 mg of caffeine (Venti, 591 ml) versus 80 mg caffeine in a typical 250 ml can of energy drink. If caffeine daily consumption is a concern, it is important to clearly inform consumers about the caffeine content of each caffeine containing product. The striking unawareness of (relative) caffeine content of common beverages support the suggestion to label caffeine content on *all* caffeine containing beverages, incl. coffee and tea products.

CONCLUSIONS

1. Mean total daily caffeine intake in children, adolescents and adults is below caffeine intake recommendations such as those by Health Canada (2.5 mg/kg bw/day for children and adolescents, and 400 mg/day for adults) and by EFSA (3 mg/kg bw/day for children and adolescents, and 400 mg/day for adults).
2. Total caffeine intake has remained stable in the last 10-15 years
3. Coffee, tea and soft drinks are the key contributors to daily caffeine intake.

4. Energy drinks contribute little caffeine to total caffeine intake.
5. The highest potential for the reduction in caffeine intake is by reducing coffee consumption, and in some countries and age groups, by reducing tea and soft drink consumption.

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Table 1: Overview of main findings of caffeine intakes (mg/day) from different age groups as reported by selected studies

	Country/region														
	USA						Canada	Europe		UK	Austria	Australia	New Zealand		South Korea
Age group			Female	Male									Female	Male	
all	164.5	186	149.8		131.9	240.7									
infants	23.7		6.9	8.4		43.5	7	0.3-30.3	23.35			3.4			1.4
children	36.6							3.5-47.		45		8.1-19.2			4.4-7.

								1							5
adolescents	83.2		46.6	69.5	62-74.9	103.4-110.5		17.6-69.5	149.20	85		41.7	77	75	10.1-30.0
adults	122.1-225.5	121-215	82.2-225.3	133.4-295.6	161.9	300.7		36.5-319.4	271.7	122-143	357		144-252	194-264	66.2-101.8
elderly	207.3	152	120.8	156.9				21.8-416.8					179	216	44.8-56-5
Method	7day beverage diar	24-hour recall	24-hour recall		14-day diar	various		various	various		Food Frequency Questionnaire				24-hour recal

	y			y									l
Year	2010-2011	2001-2010	2005-2006	2008		2001	1997-2012	2012	2008-2010	2011	2007	2008-2009	2010-2012
Reference	Mitchell et al. 2014	Instute of Medicine2014	Somogyi 2010			Knight et al. 2006	EFSA 2015	Zucconi et al. 2013	Fitt et al. 2013	Rudolph et al. 2014	FSANZ 2015	FRC 2013	Lim et al. 2015

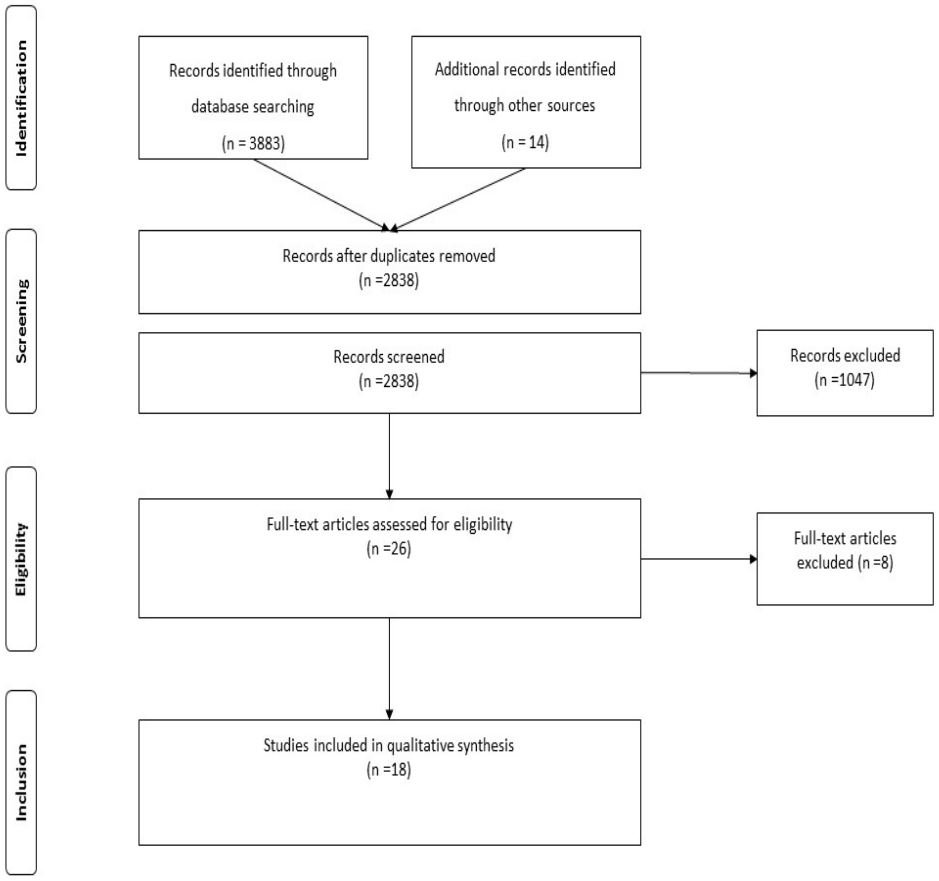

Figure 1. PRISMA Flow Diagram

