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Food and Chemical Toxicology

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Hourly and daily intake patterns among U.S. caffeinated beverage consumers based on the National Health and Nutrition Examination Survey (NHANES, 2013–2016)

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ARTICLE INFO

Keywords:

Beverage consumption patterns

Caffeine intake

NHANES

Dietary recall

ABSTRACT

Characterization of 'hour-of-day' or 'day-of-week' caffeine intake for the National Health and Nutrition Examination Survey (NHANES) population is limited. No study has focused on patterns from an individual perspective. The NHANES 2013–2016 survey respondents' dietary recalls were analyzed to gain a better understanding of caffeine intake patterns for different caffeinated beverage consumer types - defined by beverage type consumed and daily caffeine intake levels. Dominant caffeinated beverage consumers (≥ 143 mg) were identified by a reported daily caffeine intake level greater than or equal to the 50th percentile among those 1–80 y. Dominant caffeinated beverage consumers - irrespective of age groups investigated - typically reported the greatest caffeine intake early in the day from coffee. Analyses by consumer type, relevant age brackets and 'hour-of-day' or 'day-of-week' indicated that caffeinated beverage consumers generally do not cluster multiple caffeine intake events over short periods of time (i.e., less than four). Dominant caffeinated beverage consumers appear to maintain a relatively stable daily caffeine intake by substitution of secondary sources of caffeine. Only a small fraction (4.1%) of individuals within 13–29 y respondents consumed caffeine at levels in excess of 400 mg/day, compared to 14% within the 30–80 y old survey respondent group.

1. Background

Dietary sources of caffeine – either intrinsic or added – may come from foods, beverages, supplements, and/or medications. Added sources of dietary caffeine include conventional beverages such as carbonated soft drinks (CSDs) and energy drinks, dietary supplements such as energy shots and caffeine tablets, and over-the-counter (OTC) medication and prescription drugs (Frary et al., 2005; Bailey et al., 2014). Representative samples of the U.S. population indicate that per capita caffeine intake appears to have been stable over time despite the introduction of additional sources of caffeine (Mitchell et al., 2014; Fulgoni et al., 2015; Tran et al., 2016; Verster and Koenig, 2018).

Not surprisingly, given the stability in trends, studies of U.S. caffeinated beverage consumers have reached consistent conclusions regarding caffeine intake (Fulgoni et al., 2015; Martyn et al., 2018; Mitchell et al., 2014; Tran et al., 2016; Verster and Koenig, 2018). While the general population (2 + y) caffeine intake from beverages is approximately 165 mg/day (Mitchell et al., 2014), analyses by age reveal a steadily increasing percentage of caffeinated beverage

consumers coinciding with an increase in mean caffeine intake. For example, Mitchell et al. (2014) found that 83.2% in the 13–17 age group were caffeinated beverage consumers (mean intake of 83.2 mg/day) as compared to 93.3% in the 50 to 64 age group (mean intake of 225 mg/day). Similarly, 90th percentile caffeine intakes among younger caffeinated beverage consumers (< 35 y) are generally less than 400 mg/day as compared to approximately 500–600 mg/day in adults 50 years and older (Mitchell et al., 2014; Martyn et al., 2018; Tran et al., 2016).

Toxicological reviews of caffeine have concluded that moderate daily caffeine intake (400–600 mg/day) is unlikely to elicit adverse health effects among healthy adult caffeine consumers (Wikoff et al., 2017; Turnbull et al., 2016, 2017). A recent systematic review considering cardiovascular effects, behavioral effects, reproductive and developmental effects, acute effects, and bone status reassessed confidence in the 2003 Health Canada suggested 400 mg/day moderate caffeine intake amount for adults, as well as 300 mg/day for pregnant women and 2.5 mg caffeine/kg bw/day for children and adolescents (Wikoff et al., 2017; Nawrot et al., 2003). Separately, Turnbull et al.

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Received 2 October 2018; Received in revised form 17 December 2018; Accepted 29 December 2018

Available online 30 December 2018

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Table 1

Survey weighted mean, 95% Confidence Intervals (CI), and 50th percentile daily caffeine intake from caffeinated beverages by consumer type as reported in NHANES 2013–2016 Survey Day 1.

Consumer Type	Age Group (years)	n	% of Caffeine consumers by age group	Daily Caffeine Intake (mg)			Daily Caffeine Intake by Body Weight (mg/kg)		
				Mean	95% CI	50th	Mean	95% CI	50th
Any Caffeinated Beverage Consumer	1 to 12	749	14.3	44	38–51	32	1.42	1.21–1.63	0.90
	13 to 17	544	33.9	98	75–121	60	1.42	1.06–1.77	0.90
	18 to 24	642	47.0	149	115–184	102	1.93	1.45–2.40	1.20
	25 to 29	476	54.1	202	136–269	144	2.29	1.68–2.89	1.55
	30 to 80	5817	69.0	251	237–266	194	2.89	2.71–3.06	2.17
		13 to 29	1662	45.2	138	121–156	95	1.85	1.64–2.05
	1 to 80	8228	54.3	195	185–206	143	2.48	2.36–2.61	1.76
Coffee Consumer	1 to 12	68	9.0 ^b	60	45–75	47	2.12	1.50–2.74	1.86
	13 to 17	100	16.9	139	102–176	107	2.14	1.70–2.58	1.68
	18 to 24	197	35.3	223	176–270	167	3.11	2.45–3.77	2.10
	25 to 29	243	53.4	235	174–297	169	2.95	2.36–3.54	2.13
	30 to 80	4176	72.0	261	249–273	204	3.26	3.10–3.42	2.52
		13 to 29	540	37.6	222	179–264	160	2.93	2.47–3.39
	1 to 80	4784	62.7	255	242–267	198	3.22	3.06–3.37	2.45
Tea Consumer	1 to 12	302	41.5	42	34–50	28	1.41	1.14–1.67	0.90
	13 to 17	202	36.6	106	76–136	65	1.58	1.10–2.06	1.00
	18 to 24	212	30.3	129	106–152	77	1.84	1.49–2.20	1.09
	25 to 29	133	23.8	171	130–212	133	2.15	1.62–2.69	1.52
	30 to 80	1786	31.0	220	206–234	166	2.72	2.53–2.92	2.08
		13 to 29	547	29.4	135	113–156	87	1.86	1.56–2.16
	1 to 80	2635	31.2	196	184–208	141	2.49	2.33–2.64	1.79
CSD Consumer	1 to 12	448	59.2	45	40–49	32	1.38	1.20–1.56	0.98
	13 to 17	327	62.4	76	64–87	52	1.20	1.01–1.39	0.78
	18 to 24	355	53.6	131	108–154	73	1.83	1.49–2.16	1.09
	25 to 29	233	50.7	158	135–181	110	2.00	1.65–2.35	1.42
	30 to 80	2006	36.5	219	201–238	158	2.66	2.37–2.95	1.87
		13 to 29	915	54.6	127	114–140	75	1.74	1.55–1.93
	1 to 80	3369	41.0	184	170–198	121	2.34	2.13–2.55	1.57
Energy Drink Consumer	1 to 12	2 ^a	0.1 ^b	149	47–250	75	4.57	1.93–7.21	2.66
	13 to 17	8 ^a	2.4 ^b	185	141–230	185	2.30	1.18–3.42	1.85
	18 to 24	41 ^a	7.9	228	176–280	192	3.19	2.33–4.04	2.22
	25 to 29	23 ^a	5.2	209	176–241	174	2.59	2.14–3.05	2.30
	30 to 80	111	1.7	274	214–334	217	2.91	2.33–3.48	2.32
		13 to 29	72	5.7	217	186–249	181	2.90	2.39–3.42
	1 to 80	185	1.3	247	215–279	196	2.91	2.54–3.28	2.33

^a Sample size < 60 which is the number of subjects considered to be sufficient for a reliable estimate of mean intake based on a variance inflation factor of 2.

^b Sample size insufficient for reliable estimates of percent consumers, based on design effect of 1.5.

(2016, 2017) concluded that the current weight-of-evidence based on two reviews of more than 400 studies suggests that the general population can tolerate “up to 600–800 mg of caffeine/day” without experiencing any lasting or significant neurobehavioral or cardiovascular effects.

Reviews of caffeine intake continue to reinforce its safety from conventional food and beverage sources, including energy drinks. Nevertheless, the U.S. Food and Drug Administration (FDA) has expressed interest in learning about patterns of caffeinated beverage consumption (Rosenfeld et al., 2014). The FDA noted that better characterization of the poorly understood concept of potential clustering of caffeine intake within a particular ‘time of day’ or ‘day of week’ may be warranted.

Martyn et al. (2018) recently analyzed the 7-day online Kantar Worldpanel (KWP) beverage consumption survey by time of day and day of the week to assess temporal patterns in U.S. adolescents and adults from a population perspective. In general, caffeinated beverage consumers (13+) reported the highest caffeine intake early in the day driven by coffee consumption, and there were few differences in

beverage consumption when comparing weekdays to weekend. Interestingly, caffeine intake from tea, CSDs and energy drinks was more evenly distributed during the day as compared to morning intakes observed among coffee consumers. Importantly, Martyn et al. (2018) did not assess temporal patterns within the NHANES survey.

Limited data exist for caffeine intake among caffeinated beverage consumers on an individual or event basis throughout the day, and no hourly intake trend analysis of caffeine intake has been published for an NHANES population. To address these data gaps, especially among adolescents and young adults, for whom perceived concerns have been expressed, this study evaluates percentage of caffeinated beverage consumers, and hourly and daily caffeine intake patterns within the 2013–2016 NHANES survey cycles among different caffeinated beverage consumers (i.e., ‘any’ caffeinated beverage consumer and coffee, tea, CSD, or energy drink consumers) from a population and, importantly, from an individual perspective not previously evaluated. Our analyses further focus on patterns among dominant caffeinated beverage consumers.

2. Materials and methods

2.1. Caffeinated beverage consumption data

NHANES is a program sponsored by the U.S. National Center for Health Statistics (NCHS) and the U.S. Centers for Disease Control and Prevention (CDC). NHANES assesses the nutritional status and health of children and adults across the U.S. (CDC, 2017). NHANES participants are interviewed to record the approximate food and beverage consumption events by the hour and minute. An initial Survey Day 1 interview is conducted in-person followed 3–10 days later by a Survey Day 2 telephone interview. The events are linked with United States Department of Agriculture (USDA) food codes, as well as with nutritional composition data in the What We Eat In America (WWEIA) national food survey that includes caffeine amounts. The consumption pattern analyses were conducted on the 2013–2016 NHANES survey cycles to best capture current consumption patterns of caffeinated beverages. Tran et al. (2016) previously found higher reported mean caffeine intake on NHANES survey recall Day 1 as compared to Day 2 possibly due to respondent fatigue or an artifact of the survey design, thus Day 1 responses were conservatively considered in the present study.

2.2. Survey respondent selection

All caffeinated beverage consumers between the ages of 1–80 y were considered for inclusion – children (CH, 1–12 y), TN (13–17 y), YA (18–24 y), AD (25–29 y), and older adults (OA, 30–80 y). Survey respondents who did not successfully comply with the study protocol, including completion of both dietary recall day surveys, were excluded. Survey respondents who consumed at least 1 mg of caffeine from coffee (including ‘decaffeinated’ coffee), tea (including ‘decaffeinated’ tea), CSDs, and/or energy drink beverages were included. Foods (e.g., chocolate cookies) and food-based or other beverages (e.g., chocolate milk) were excluded because of insignificant contributions to overall caffeine

intake among all beverage consumer types (Tran et al., 2016). Additionally, the intake of caffeine from dietary supplements or medications was excluded.

2.3. Consumer type and categorization

Daily caffeine intake levels were determined in units of mg/day for each survey respondent by summing up the contribution of all caffeinated beverage sources (e.g., the mg/day of daily caffeine intake by a coffee consumer would include the contribution from coffee, and also include contributions from tea, CSDs, and/or energy drinks should that coffee consumer also consume these other caffeinated beverages on a given day). An individual respondent was classified under multiple consumer types if applicable (Table 1). Survey respondents (1–80 y) with daily caffeine intake levels less than the 50th percentile were considered light caffeinated beverage consumers, and those with caffeine intake levels greater than or equal to the 50th percentile were considered dominant caffeinated beverage consumers. Inclusion of CH in the 50th percentile estimate was used to identify the threshold above which a consumer is considered a dominant consumer. Consequently, the median value is in fact lower than it otherwise would be if CH were excluded from this derivation, and, as such, resulted in an increase in the number of individuals considered to be dominant consumers.

2.4. Source apportionment of caffeine

The contribution of caffeine from each caffeinated beverage type to the total daily caffeine intake (per survey respondent) was determined by dividing caffeine amounts from the respective caffeinated beverage type (for that survey respondent) by the total amount of daily caffeine consumed (for that survey respondent). The source apportionment was averaged for sub-populations defined by age bracket or consumer type (Table 2).

Table 2

Survey weighted fraction of survey respondents who reported consuming at least 200 mg of caffeine during a single consumption event and those who reported consuming caffeinated beverages with total daily caffeine intake estimates at or above referenced values of interest (143, 200, 400 and 600 mg/day) for 13–29 y, 30–80 y and 1–80 y age groups as reported in NHANES 2013–2016 Survey Day 1.

Consumer Type	Single Consumption Event		Daily Intakes							
	200 mg		143 mg		200 mg		400 mg		600 mg	
	n	%	n	%	n	%	n	%	n	%
% of 1–80 y Caffeinated Beverage Consumers by Moderate Caffeine Referenced Value as a Fraction of all Caffeinated Beverage Consumers										
Any Caffeinated Beverage	1328	22	3371	51	2263	36	630	11	234	4.4
Coffee	1223	21	2842	43	2001	32	585	11	227	4.3
Tea	338	5.7	1033	16	718	11	218	3.7	76	1.2
CSD	413	7.1	1221	19	841	14	229	4.2	83	1.6
Energy Drink	45	0.6	144	1.9	97	1.3	30	0.4	7	0.1 ^a
% of 30–80 y Caffeinated Beverage Consumers by Moderate Caffeine Referenced Values as a Fraction of 30–80 y Caffeinated Beverage Consumers										
Any Caffeinated Beverage	1201	27	2909	58	2020	42	582	14	218	5.4
Coffee	1131	25	2547	51	1840	38	547	13	212	5.2
Tea	296	6.7	886	18	638	13	199	4.5	68	1.5
CSD	357	8	985	21	704	15	206	4.9	78	2.0
Energy Drink	30	0.5	89	1.4	64	1.0	24	0.4	7	0.2 ^a
% of 13–29 y Caffeinated Beverage Consumers by Moderate Caffeine Referenced Value as a Fraction of 13–29 y Caffeinated Beverage Consumers										
Any Caffeinated Beverage	127	11	447	34	238	19	48	4.1	16	1.4 ^a
Coffee	92	8.2	290	23	159	13	38	3.4	15	1.3 ^a
Tea	42	3.0	141	9.7	79	5.3	19	1.4 ^a	8	0.6 ^a
CSD	56	5.2	227	17	132	11	23	2.0	5	0.4 ^a
Energy Drink	15	1.3	54	4.4	33	2.7	6	0.4 ^a	0	0 ^a

^a Sample size insufficient for reliable estimates of percent consumers, based on design effect of 1.5 and RSE < 30%.

2.5. Consumption patterns analyses

Data organization (including categorization by caffeinated beverage type) was performed in the R version 3 statistical package. The food item descriptions were used to assign coffee, tea, CSD, and energy drink categories to each event (Supplemental Table ST1). Survey-specific guidance was used to determine sample size considered to be sufficient for a reliable estimate of mean intake based on a variance inflation factor of 2 (NCHS, 1996; Tran et al., 2016). Mean estimates with less than the recommended minimum sample size were reported in accordance with the NCHS guidance, which advises against the suppression of estimates.

Descriptive statistical analyses were performed in the SAS version 9.4 or R version 3 software packages. General descriptive statistics, day of the week evaluations, and statistics were generated using survey-specific weighted analytical techniques adjusting for the complex survey design. Analyses were stratified by caffeinated beverage consumer types and by age groups. To assess the fraction of surveyed consumers that exceeded the moderate daily caffeine intake referenced values identified by different government agencies and others, the following referenced values were used: 143 mg/day (observed 50th percentile in 2013–2016 NHANES population), 200 mg/day (based on the European Food Safety Authority (EFSA) 2015 adult acute caffeine intake of 3 mg/kg bw), 400 mg/day (Nawrot et al., 2003; U.S. FDA, 2012; EFSA, 2015; Wikoff et al., 2017) and 600 mg/day (Turnbull et al., 2016, 2017). The 200 mg acute intake referenced by EFSA was also evaluated on a “per event” basis (Table 2). All estimates with a relative standard error (RSE) less than 30% as recommended by the NHANES analytical guidelines (NCHS, 2013) were considered reliable. Potentially unreliable estimates are annotated in the table.

Heatmaps of median intake by ‘hour-of-day’, ‘day-of-week’, and weekday (Monday through Thursday) versus weekend (Friday through Sunday) were prepared in Microsoft Excel based on the results of the SAS analyses. The heatmap analysis was limited to two age groups of caffeinated beverage consumers: 13–29y and 30–80y based on an assessment of consumption occasion event sample size (Supplemental Tables ST3 and ST4). Time periods with one or two events for a given ‘hour-of-day’ and periods of no intake were clearly noted (Figs. 2 and 3).

Consumption patterns for the dominant consumers were plotted using R Version 3.4.2 with caffeine intake shown in individual timelines. Scaled symbols were used to represent the source of caffeine, hour of the day and magnitude of intake per event (Fig. 4, Supplemental Figure SF1 – Supplemental Figure SF4).

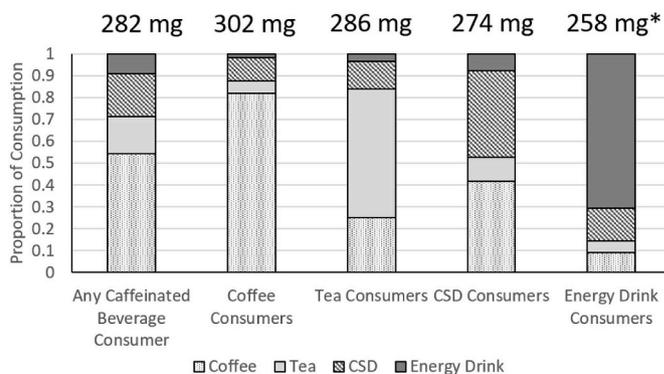
3. Results

Separate evaluations of the NHANES 2013–2014 and 2015–2016 survey cycles indicated that the intake patterns reported by respondents in the two cycles were comparable (data not shown). Thus, our analyses focused on the aggregated survey cycles NHANES 2013–2016.

3.1. Caffeinated beverage consumers demographic information

A total of 8228 survey respondents aged 1–80 y with a relatively equal distribution of males and females (data not shown) met the inclusion criteria and reported consuming at least one caffeinated beverage on dietary recall Survey Day 1 in the NHANES 2013–2016 survey cycle. The majority of caffeinated beverage consumers were ‘Non-Hispanic Whites’ (69%), with other ethnic/racial groups accounting each for 6.0–8.8% of caffeinated beverage consumers (i.e., Mexican Americans, Non-Hispanic Blacks and Other Hispanics) (data not shown).

a) Dominant Consumers 13 to 29 years of age



b) Dominant Consumers 30 to 80 years of age

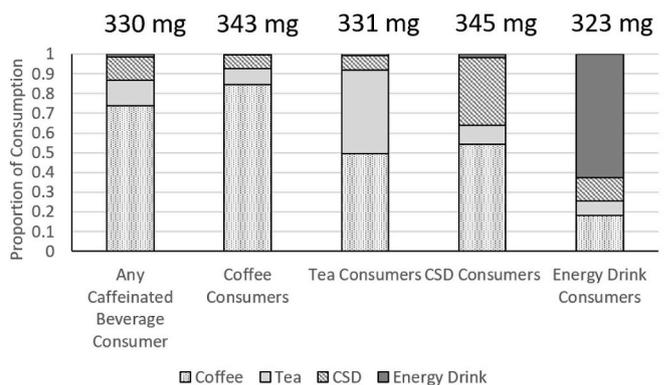


Fig. 1. Mean relative source contribution of ‘caffeinated beverage type’ to total daily caffeine consumption for a) dominant consumers (≥ 143 mg/day; 13–29 years of age) and b) dominant consumers (≥ 143 mg/day; 30–80 years of age). Survey weighted mean daily caffeine intake by consumer type is provided for each vertical bar. The sample size was sufficient ($n > 60$) for a reliable estimate of mean intake based on a variance inflation factor of 2 with the exception of energy drink consumers 13 to 29 y as noted.

3.2. Percentage of caffeinated beverage consumers by age and type

Approximately 54 percent of all surveyed respondents (1–80 y) reported intake of at least one caffeinated beverage (coffee, tea, CSD, or energy drink) on dietary recall Survey Day 1 (Table 1). This percentage is somewhat lower than previously reported for the general population because caffeinated food and beverage products, such as chocolate milk, were not considered. When evaluated by age group, CH were most likely to be CSD (59.2%) or tea (41.5%) consumers and least likely to be energy drink consumers (0.1%) with similar trends among TN. YA were characterized primarily as CSD consumers (54%), coffee consumers (35%) or tea consumers (30%). Although still showing a low consumption percentage when compared to all other caffeinated beverage types, YA were most likely to be energy drink consumers (7.9%) compared to other age groups. AD were mostly coffee (53%) and CSD (51%) consumers, and only 5.2% reported consuming an energy drink. A majority of OA reported coffee consumption (72%). Only 1.3% of the total sampled population (1–80 y) reported consuming energy drinks, as compared to 63% who reported consuming coffee.

3.3. Daily caffeine intake by consumer type

The overall mean daily intake level for all caffeinated beverage consumers (1–80 y) was 195 mg/day (95%CI: 185–206 mg/day), with a 50th percentile intake of 143 mg/day used in this study to categorize ‘dominant’ caffeinated beverage consumers (Table 1). Mean daily

a) Dominant consumers (≥143 mg/day; 13 to 29 years of age)

Day of Week	Median Caffeine Consumed by Hour of the Day Within Each Day of the Week																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sunday	<u>252</u>	0	33	72	0	<u>20</u>	81	149	128	<u>152</u>	145	99	117	68	<u>127</u>	104	33	56	70	42	35	75	28	33
Monday	0	<u>56</u>	0	<u>72</u>	0	<u>108</u>	<u>497</u>	82	165	99	<u>107</u>	18	69	34	<u>106</u>	46	<u>33</u>	81	77	<u>42</u>	57	55	<u>35</u>	<u>29</u>
Tuesday	0	0	0	0	0	<u>60</u>	122	140	120	59	<u>197</u>	102	70	59	<u>135</u>	42	0	62	65	62	69	<u>30</u>	<u>56</u>	<u>123</u>
Wednesday	0	0	0	0	0	<u>498</u>	<u>129</u>	104	142	136	79	98	41	<u>33</u>	<u>33</u>	36	<u>154</u>	87	<u>138</u>	57	45	50	<u>86</u>	0
Thursday	<u>205</u>	0	0	0	0	<u>123</u>	<u>356</u>	80	114	181	57	45	<u>67</u>	<u>133</u>	<u>33</u>	65	<u>139</u>	<u>48</u>	<u>33</u>	48	<u>101</u>	0	<u>93</u>	<u>33</u>
Friday	129	0	0	0	<u>144</u>	<u>175</u>	109	162	159	106	63	109	<u>46</u>	<u>50</u>	45	41	34	<u>44</u>	<u>120</u>	50	80	34	18	68
Saturday	90	0	<u>102</u>	0	<u>79</u>	<u>288</u>	116	125	136	148	129	68	130	74	105	91	83	59	90	60	53	49	33	50

b) Dominant consumers (≥143 mg/day; 30 to 80 years of age)

Day of Week	Median Caffeine Consumed by Hour of the Day Within Each Day of the Week																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Sunday	64	101	38	0	193	156	<u>251</u>	148	177	164	135	102	67	71	67	63	65	67	50	59	41	56	77	43
Monday	<u>33</u>	0	<u>20</u>	0	157	209	191	142	138	165	99	46	69	69	50	35	36	<u>155</u>	72	70	32	64	29	<u>72</u>
Tuesday	<u>43</u>	20	0	114	158	167	180	164	156	128	95	67	80	75	67	59	73	38	51	57	46	47	47	33
Wednesday	0	0	90	110	266	179	189	142	140	138	134	62	73	67	57	66	67	89	45	53	66	59	45	<u>56</u>
Thursday	<u>250</u>	<u>53</u>	86	5	194	203	201	174	178	132	113	100	44	79	48	82	68	57	62	60	45	54	27	13
Friday	97	<u>138</u>	<u>144</u>	<u>213</u>	<u>224</u>	<u>227</u>	191	144	146	121	94	71	55	57	48	62	56	47	48	61	49	50	48	24
Saturday	0	0	150	175	<u>845</u>	<u>317</u>	191	173	143	143	114	75	48	67	57	73	72	60	49	74	63	58	58	<u>167</u>

Legend - Median mg of caffeine consumed						
0	50	100	150	200	250	300+

Fig. 2. Survey weighted median caffeine intake by hour of the day within each day of the week for a) dominant caffeinated beverage consumers (≥143 mg/day; 13–29 years of age) and b) dominant caffeinated beverage consumers (≥143 mg/day; 30–80 years of age) from the 2013–2016 NHANES survey cycle. Non-zero values include three or more events with the exception of underlined values, which indicate that the value represents a single event or the mean of two events. Corresponding sample sizes can be found in Supplemental Table ST3.

caffeine intakes among ‘any’ surveyed caffeinated beverage consumers for CH, TN, YA and AD were 44 mg/day, 98 mg/day, 149 mg/day and 202 mg/day, respectively. There were modest differences in caffeine intake in OA grouping when considering 10 y increments of age (Supplemental Table ST2). For example, considering ‘any’ caffeinated

beverage consumers, daily mean caffeine intake for 50 to 59 y old adults was 249 mg/day, as compared to 251 mg/day for the larger 30 to 80 y old group. Specifically, mean caffeine intakes were 198 mg/d, 220 mg/d, 249 mg/d, 237 mg/d and 174 mg/d for the sub-brackets within the OA group, i.e., 30–39 y, 40–49 y, 50–59 y, 60–69 y and

a) Between 13 and 29 years of age

Consumer Type	Median Caffeine Consumed by Hour of the Day Within Each Day of the Week																							Portion of the Week	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22		23
All	22	40	<u>67</u>	<u>72</u>	24	71	136	100	121	88	74	65	45	38	33	41	56	44	41	42	44	32	35	45	Monday-Thursday
	50	94	33	47	84	76	104	109	106	96	95	53	48	48	43	33	45	44	34	34	33	34	33	33	Friday-Sunday
Coffee	0	0	0	0	0	75	145	100	130	96	96	100	42	32	26	36	133	100	48	43	83	46	53	73	Monday-Thursday
	<u>103</u>	<u>126</u>	<u>102</u>	<u>133</u>	<u>91</u>	<u>190</u>	108	118	114	127	114	99	92	58	121	71	44	62	70	36	32	48	23	40	Friday-Sunday
Tea	<u>57</u>	<u>24</u>	<u>67</u>	0	<u>23</u>	5	72	98	64	88	70	29	50	41	60	62	25	53	62	42	33	27	35	42	Monday-Thursday
	35	0	33	35	81	50	93	76	77	48	54	46	50	67	45	34	40	45	33	33	37	33	33	33	Friday-Sunday
CSD	<u>22</u>	<u>56</u>	<u>67</u>	0	<u>24</u>	109	111	95	142	79	68	36	41	36	32	35	40	35	33	41	43	34	35	32	Monday-Thursday
	37	25	33	39	50	31	70	125	94	71	55.8	50	43	39	45	36	33	38	39	33	33	32	33	32	Friday-Sunday
Energy	<u>205</u>	<u>56</u>	0	<u>72</u>	0	<u>60</u>	<u>149</u>	83	<u>154</u>	<u>121</u>	70	<u>150</u>	92	28	85	36	<u>86</u>	61	<u>47</u>	<u>173</u>	63	0	<u>166</u>	<u>52</u>	Monday-Thursday
	0	0	<u>102</u>	0	<u>144</u>	<u>164</u>	100	157	166	56	<u>24</u>	33	118	<u>180</u>	116	36	108	68	112	98	64	34	35	33	Friday-Sunday

b) Between 30 and 80 years of age

Consumer Type	Median Caffeine Consumed by Hour of the Day Within Each Day of the Week																							Portion of the Week	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22		23
All	68	36	89	102	153	145	143	124	118	101	80	57	52	57	46	45	50	43	45	43	43	47	41	33	Monday-Thursday
	65	99	95	177	193	154	144	119	118	101	83	63	44	55	47	55	54	43	44	45	42	47	43	33	Friday-Sunday
Coffee	65	46	107	106	206	157	162	135	128	121	101	71	55	66	49	57	47	56	51	42	42	56	39	9	Monday-Thursday
	69	113	56	<u>277</u>	<u>226</u>	175	173	130	138	109	96	73	47	60	48	65	59	46	45	51	40	54	54	50	Friday-Sunday
Tea	<u>61</u>	31	69	14	62	161	96	108	96	71	50	61	46	47	46	48	42	40	46	43	44	44	40	13	Monday-Thursday
	66	<u>162</u>	100	171	134	136	109	107	99	89	78	73	54	57	47	54	47	44	48	48	42	48	48	44	Friday-Sunday
CSD	60	33	46	121	<u>177</u>	141	125	118	96	75	65	41	42	46	37	37	48	42	37	42	38	34	35	44	Monday-Thursday
	59	64	42	128	<u>234</u>	193	172	108	103	95	71	43	42	43	42	44	46	36	41	36	37	43	36	30	Friday-Sunday
Energy	<u>189</u>	14	0	0	0	<u>215</u>	<u>135</u>	143	97	159	21	135	69	66	99	41	73	119	<u>41</u>	<u>72</u>	84	34	80	0	Monday-Thursday
	<u>139</u>	0	0	<u>164</u>	<u>16</u>	<u>240</u>	108	92	107	115	<u>204</u>	93	94	55	99	62	80	76	21	15	37	44	<u>121</u>	<u>36</u>	Friday-Sunday

Legend - Median mg of caffeine consumed						
0	50	100	150	200	250	300+

Fig. 3. Survey weighted median caffeine intake by hour of the day by consumer type and by timing during the week for all caffeinated beverage consumers (≥1 mg) for the following age brackets: a) 13–29 years of age, b) 30–80 years of age from the 2013–2016 NHANES survey cycle. Non-zero values include three or more events with the exception of underlined values, which indicate that the value represents a single event or the mean of two events. Corresponding sample sizes can be found in Supplemental Table ST4.

70–79 y, respectively.

Upper bound caffeine intakes were primarily determined by coffee and energy drink consumers as well as older adults' intakes. Mean daily caffeine intake estimates were higher for 13–29 y coffee and energy drink consumers (222 mg/day and 217 mg/day, respectively) than for 13–29 y CSD and tea consumers (127 mg/day and 135 mg/day, respectively). The trend was similar in OA with coffee (261 mg/day) and energy drink (274 mg/day) consumers having higher intakes than CSD (219 mg/day) and tea (220 mg/day) consumers. Similar patterns were observed for body weight adjusted intake (Table 1). While caffeine intake levels for energy drink consumers appear to be slightly higher than those for coffee consumers, this finding should be interpreted with caution, as the sample size for energy drink consumers was a fraction of – i.e., much smaller than – that for any other consumer type.

3.4. Dominant caffeinated beverage consumers

We defined dominant caffeinated beverage consumers as those consuming at least 143 mg/day, and light consumers as those consuming less than 143 mg/day. Dominant caffeinated beverage consumers are primarily OA (86.8%), followed by AD (6.7%) and YA (6.2%); CH and TN combined only account for 1.7% of dominant consumers (data not shown). Among dominant consumers, 81.1% are coffee consumers, followed by CSD (42.1%), tea (37.0%), and energy drink (8.1%) consumers.

Light caffeinated beverage consumers primarily consumed only one type of preferred beverage (data not shown) with relatively low caffeine intake (i.e., less than the 50th percentile). Additionally, in view of the absence of energy drink consumers in the 1–12 year age group (i.e., only 2 consumers after combining NHANES, 2013–2014 with NHANES, 2015–2016), we focused our remaining analyses on caffeine intake of dominant consumers for two age groupings: 13–29 years of age and 30–80 years of age. This approach is consistent with others' approach focusing on individuals 13 years and older (13 + yr) due to (i) the relatively limited daily caffeine intake observed amongst survey respondents 12 years and under, and (ii) the extremely small sample size of energy drink consumers in the younger age bracket (Martyn et al., 2018; Tran et al., 2016; Mitchell et al., 2014).

The fraction of caffeinated beverage consumers exceeding various caffeine intake referenced values was much higher in the 30–80 y age group when compared to the 13–29 y age group (Table 2). Of the caffeinated beverage consumers in the 30–80 y age group, 14% consumed more than 400 mg/day, and 5.4% consumed over 600 mg/day. This percentage was higher than observed in the 13–29 y age group with only 4.1% and 1.4% exceeding the 400 mg/day and 600 mg/day referenced values, respectively. In general, coffee consumers, regardless of age group, were more likely to exceed the designated referenced values than all other consumer types. For example, among 30–80 y respondents exceeding the 400 mg/day moderate daily caffeine intake reference value, most were coffee consumers (14% caffeinated beverage consumers) and the least were energy drink consumers (0.4% of caffeinated beverage consumers).

When focusing on single events, only 22% (1–80 y) reported a single event of at least 200 mg or more (Table 2). Coffee consumers, regardless of age group, more often than others exceeded the referenced value for a single consumption event (11–27% for coffee consumers across age brackets versus 0.5–8.0% for all other consumer types across same age brackets). Less than 2% of caffeinated beverage consumers 1–80 years of age reported having 2 or more intake events each at or above 200 mg across a single day (data not shown).

Light caffeinated beverage consumers primarily consumed only one type of preferred beverage (data not shown) with relatively low caffeine intake (i.e., less than the 50th percentile). Additionally, in view of the absence of energy drink consumers in the 1–12 year age group (i.e., only 2 consumers after combining NHANES, 2013–2014 with NHANES, 2015–2016), we focused our analysis on 13 + year olds. This approach

is consistent with others' approach focusing on individuals 13 years and older (13 + yr) due to (i) the relatively limited daily caffeine intake observed amongst survey respondents 12 years and under, and (ii) the extremely small sample size of energy drink consumers in the younger age bracket (Martyn et al., 2018; Tran et al., 2016; Mitchell et al., 2014). Thus, the remaining analyses focus on caffeine intake of dominant consumers for two age groupings: 13–29 years of age and 30–80 years of age. Dominant caffeinated beverage consumers between 13 and 29 years of age had overall mean daily caffeine intake ranging from 258 mg/day – 302 mg/day across consumer types. Coffee and energy drink 'dominant consumers' in this age group typically consumed their respective beverage types with over 82% and 71% of their total daily caffeine intake coming from coffee and energy drink, respectively. Over 58% of daily intake for tea consumers came from tea, followed by 25% from coffee. CSD consumers total daily intake was more diverse with contributions from coffee (41.8%) followed by CSD (39.5%), then tea (10.9%), and finally energy drinks (7.8%). The primary source of caffeine intake, regardless of consumer type, was coffee (Fig. 1a).

OA dominant consumers had mean daily caffeine intake levels ranging from 323 mg to 343 mg depending upon consumer type (Fig. 1b). Over 82% of caffeine intake for coffee consumers was from coffee with the remainder of their intake primarily split between tea (8%) and CSD (7%). Coffee contributed substantially to daily caffeine intake for both CSD (54.4%) and tea (49.9%) consumers. For energy drink consumers, daily caffeine intake was distributed between energy drinks (62.6%), coffee (18.3%), tea (7.1%) and soda (12.0%). For all consumers between 30 and 80 years of age, energy drinks only accounted for 1.5% of daily caffeine intake.

When focusing on single events, coffee consumers, regardless of age group, more often than others exceeded the referenced value for a single consumption event. For example, 8.2 and 25% of 13–29 and 30–80 y 'any caffeinated beverage' groupings, respectively, exceed 200 mg/day, as compared to 0.5–8.0% for all other consumer types across same age brackets. Less than 2% of caffeinated beverage consumers 1–80 years of age reported having 2 or more intake events each at or above 200 mg across a single day (data not shown).

3.5. Heatmaps - hourly caffeine intake by 'day-of-week'

Most caffeine intake from beverages in dominant consumers occurred in the morning hours between 5 AM and 11 AM, regardless of 'day-of-week' or age group (Fig. 2). For TN, YA, and AD dominant consumers, peaks in consumption occurred between 5AM and 10AM with afternoon consumption events typically including consumption events of 100 mg of caffeine or less (Fig. 2a). As compared to the younger groups, OA dominant consumers had higher median consumption levels in the morning and were more likely to consume caffeine between midnight and 4 AM (Fig. 2b).

A second heatmap analysis assessed the distribution of caffeine intake during the week (Monday – Thursday) and on weekends (Friday – Sunday) by consumer type (Fig. 3). Patterns of consumption of 13–29 year olds (Fig. 3a) was similar to that of OA (Fig. 3b). Caffeine intake levels over time were similar during weekdays and weekends and there were no appreciable differences between consumer types. Coffee consumers generally reported caffeine intake patterns resulting in higher intake levels than tea and CSD consumers. The ability to draw definitive conclusion for energy drink consumers is limited due to the paucity of data for this group.

3.6. Survey respondents' caffeine-time activity patterns

Individual hourly caffeinated beverage consumption timelines were plotted for the dominant consumers to better understand behavior across age groups and consumer types (Fig. 4 and Supplemental Figures SF1-SF4). Most caffeine was consumed in the morning hours predominantly from coffee except among TN, whose caffeine intake was

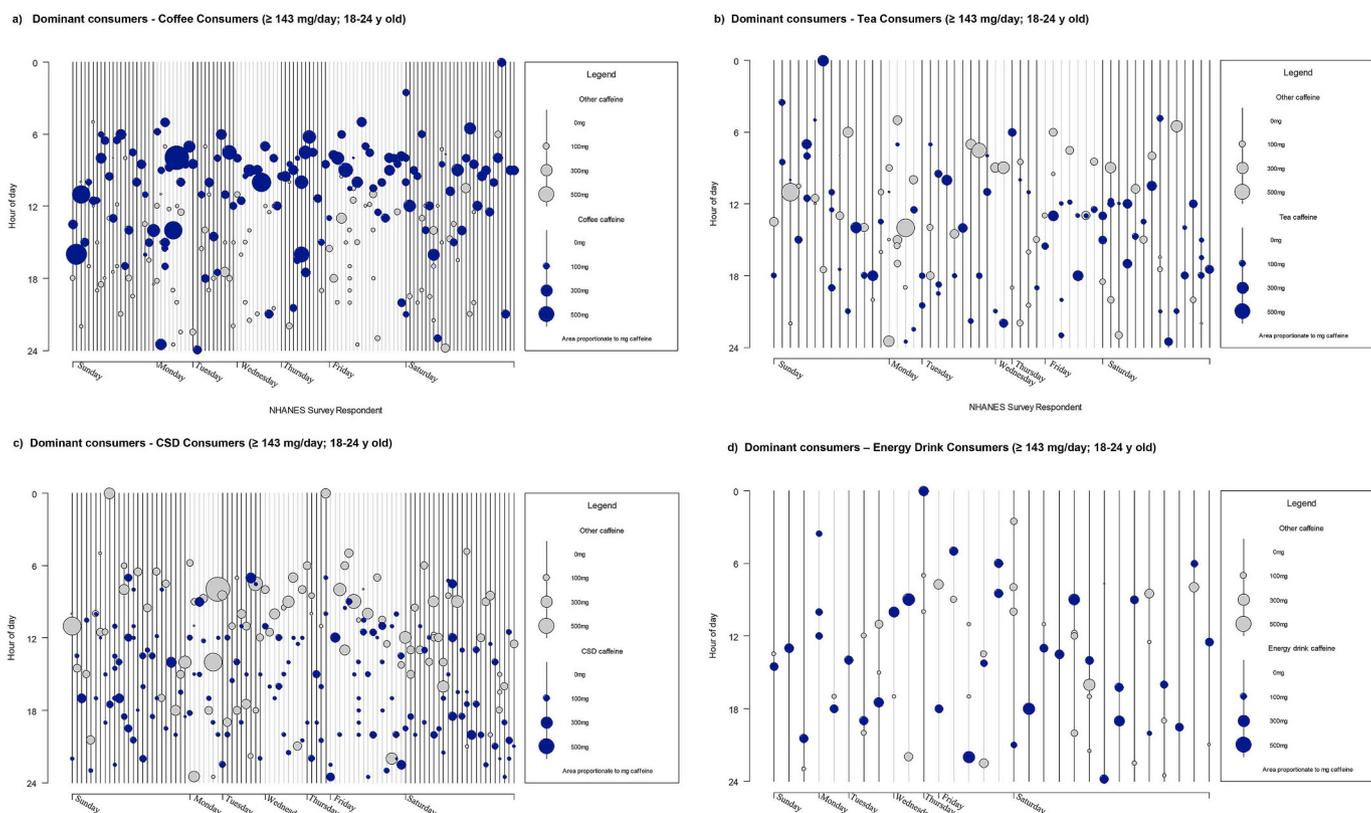


Fig. 4. Individual “2013–2016 NHANES Survey Day 1” hourly caffeine intake for dominant consumers ($\geq 50^{\text{th}}$ percentile or ≥ 143 mg/day) for each respective consumer type. The 18–24 y old age group is presented here in a simplified format to illustrate patterns for a) Coffee consumers, b) Tea consumers, c) CSD consumers and d) Energy drink consumers. Detailed plots including NHANES respondent sequence number, gender and total daily caffeine index are presented for the 13–17, 18–24, 25–29 and 30–80 y old age groups in [Supplemental Figures SF1, SF2, SF3 and SF4](#), respectively. Each vertical line corresponds to a single NHANES survey respondent. The dark scaled symbols represent the caffeinated beverage consumption event(s) corresponding to the caffeinated beverage consumer type, while the light scaled symbols indicate an alternative caffeinated beverage source. The size of the circle provides a visual comparison of the amount of caffeine consumed during any single consumption event.

generally in the afternoon hours between 12 and 8 PM from coffee, tea, and CSDs. Among dominant consumers (13+), CSDs were consumed primarily in the afternoon hours. Notably, generally there was no clustering of caffeinated beverage consumption events over short time periods (i.e., less than a four-hour span). When viewed from an individual perspective, coffee rather than tea, CSDs, or energy drinks is the most prominent and frequent contributor to caffeine intake among dominant consumers. Individual dominant consumers exhibited substitution of caffeinated beverages to maintain a stable caffeine intake ([Fig. 4](#) and [Supplemental Figures SF1–SF4](#)).

4. Discussion

This study presents the first published analyses of individual hourly and daily patterns of caffeinated beverage consumption in a NHANES study population, and summarizes the most recent NHANES survey cycles (2013–2016). We found that coffee was generally consumed in the morning hours whereas tea, CSD and energy drinks consumption were more often distributed throughout the day. In dominant coffee consumers, many individuals exhibited a pattern of initial consumption (and therefore caffeine intake) in the morning followed by several consumption events of lesser caffeine amounts throughout the day spaced three to four hours apart.

Our unique analyses should serve as a novel basis for evaluating NHANES self-reported data for a variety of dietary components to better understand patterns of consumption on an individual – not a population – basis and assess whether consumption events typically cluster or not. Notably, when analyzed on an individual basis among NHANES respondents, we did not find evidence to support clustering of caffeine

intake events over short time spans of less than four hours or by any day of the week.

We note that the sample size for some of the energy drink age groupings was less than that considered to yield statistically reliable estimates of mean intake or prevalence. Additionally, there was a limited number of consumption occasions/events ($n < 60$) for several hour and day combinations in the heatmaps, particularly for energy drink consumers and for hours of the day where there is limited caffeinated beverage consumption ([Supplemental Tables ST3 and ST4](#)). While these results should be interpreted cautiously in view of the limited sample size, they have been presented in this study because the available data provides useful information regarding patterns in the context of the overall NHANES dataset, and allows the opportunity to build upon these data in other studies. Future research evaluating individual consumption among caffeinated beverage consumers in other surveyed populations may provide useful information concerning similarities or differences with the patterns observed in the NHANES populations included in this study if and when they become available. Additionally, our heatmap analyses revealed similar hourly and daily population consumption patterns across consumer types, and knowledge of these patterns should be useful in the design of future research studies.

A regression analysis of NHANES data performed by [Tran et al. \(2016\)](#) suggested that substitution rather than source addition occurs among ‘dominant’ energy drink consumers. We found that most coffee and energy drink ‘light’ and ‘dominant’ consumers, along with tea and CSD ‘light’ consumers, derived much of their caffeine from their respective caffeinated beverage source. In contrast, ‘dominant’ tea and CSD consumers appear to substitute between coffee and their respective

caffeinated beverage source maintaining a relatively stable daily caffeine intake amount.

Generally, upper bound caffeine intake estimates within each age group were observed in the consumption patterns of coffee and energy drink consumers. Among 13–29 y olds, a small fraction of survey respondents – typically coffee consumers – exceeded the various referenced moderate daily caffeine intake amounts. In general, we found that increases in caffeine intake among caffeinated beverage consumers in the NHANES population were associated with an increase in coffee consumption, which is consistent with prior analyses (Martyn et al., 2018; Tran et al., 2016).

OA and coffee consumers were more likely to have single events exceeding the referenced 200 mg caffeine per consumption event referenced value than other consumers (Table 2). Very few 13–29 year old consumers exceeded 200 mg (11%) in a single event compared to 27% of OA and 21% of coffee consumers. Energy drink consumers were the least likely to exceed these levels for a single event. These findings are consistent with the 2015 and 2016 American Association of Poison Control Centers (AAPCC) annual summary of cases, which associated a small fraction of cases with ‘energy products’ exposures (Mowry et al., 2016; Gummin et al., 2017). Similarly, an analysis of 2010–2014 reports to Texas poison centers found that serious adverse events associated with ‘energy beverages’ are rare (Borron et al., 2018).

5. Conclusion

This study provides context to caffeinated beverage consumption patterns among Americans by leveraging information contained within the NHANES dataset in a novel manner. We found that most caffeine was consumed in the morning, driven primarily by coffee, and that dominant caffeinated beverage consumers maintain a relatively stable daily caffeine intake lending credence to the notion of substitution. Caffeine daily intake estimates rarely exceeded the referenced moderate daily caffeine intake amounts of either 400 mg/day or 600 mg/day, with the highest percentages observed within the coffee consumer 30–80 y group (1.3% and 5.2%, respectively). Likewise, acute caffeine intakes were rarely greater than 200 mg/event, with the highest percentages observed within the coffee consumers (21%; 1–80 y) and OA group (27%; ‘any’ caffeinated beverage consumers). Finally, we found that the percentage of energy drink consumers remained relatively low in the NHANES 2013–2016 survey cycle at 1.3% of the general population.

Acknowledgements

This research was funded by the American Beverage Association. Important contributions in study design, interpretation, and manuscript review were provided by Dr. Maia Jack at the American Beverage Association.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.fct.2018.12.053>.

doi.org/10.1016/j.fct.2018.12.053.

Transparency document

Transparency document related to this article can be found online at <https://doi.org/10.1016/j.fct.2018.12.053>.

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