Sweetened Beverages, Coffee, and Tea and Depression Risk among Older US Adults

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Abstract

Sweetened beverages, coffee, and tea are the most consumed non-alcoholic beverages and may have important health consequences. We prospectively evaluated the consumption of various types of beverages assessed in 1995–1996 in relation to self-reported depression diagnosis after 2000 among 263,923 participants of the NIH-AARP Diet and Health Study. Odds ratios (OR) and 95% confidence intervals (CI) were derived from multivariate logistic regressions. The OR (95% CI) comparing ≥4 cans/cups per day with none were 1.30 (95%CI: 1.17–1.44) for soft drinks, 1.38 (1.15–1.65) for fruit drinks, and 0.91 (0.84–0.98) for coffee (all P for trend<0.0001). Null associations were observed for iced-tea and hot tea. In stratified analyses by drinkers of primarily diet versus regular beverages, the ORs were 1.31 (1.16–1.47) for diet versus 1.22 (1.03–1.45) for regular soft drinks, 1.51 (1.18–1.92) for diet versus 1.08 (0.79–1.46) for regular fruit drinks, and 1.25 (1.10–1.41) for diet versus 0.94 (0.83–1.08) for regular sweetened iced-tea. Finally, compared to nondrinkers, drinking coffee or tea without any sweetener was associated with a lower risk for depression, adding artificial sweeteners, but not sugar or honey, was associated with higher risks. Frequent consumption of sweetened beverages, especially diet drinks, may increase depression risk among older adults, whereas coffee consumption may lower the risk.

Introduction

Sweetened beverages such as soft drinks, along with coffee and tea, are the most consumed non-alcoholic beverages throughout the world, and have substantial public health consequences [1]. Regular sweetened beverages contain large amounts of sugar and may have contributed to the obesity and diabetes epidemic in Western countries [2,3,4,5]. The recent trend of increasing diet drink consumption is also of possible concern. These beverages may contain artificial sweeteners such as aspartame and saccharin; although there is controversy, potential adverse effects of these substances have been suspected [6,7]. On the other hand, drinking coffee and tea has been linked to a lower risk for diabetes [8]. In addition, caffeine and its major metabolites are well-documented brain stimulants and there is growing evidence for potential benefits of caffeine towards brain health [9], including lower risk for Parkinson’s disease [10,11,12] and dementia [13].

The potential effects of drinking these beverages on depression, however, are largely unknown. In several cross-sectional studies, frequent drinking of sweetened beverages was associated with higher prevalence of depression, suicidal thoughts and acts, and other mental stress [14,15,16]. However, this relationship could be bi-directional and cross-sectional analyses cannot rule out reverse causality. A few prospective studies suggest that coffee drinking lowers the risk for suicide [17,18,19] and depression [20,21]. We evaluated relationships between consumption of sweetened beverages, coffee, or tea and depression among 263,923 participants of the prospective NIH-AARP Diet and Health Study.

Materials and Methods

Study population and case identification

The NIH-AARP Diet and Health study (http://dietandhealth.cancer.gov/), a prospective cohort, was established in 1995–1996 by the National Cancer Institute to evaluate the etiology of cancer and other chronic diseases [22]. The cohort is composed of 566,398 AARP (previously known as American Association of Retired Persons) members (ages 50–71) from six US states and two metropolitan areas who satisfactorily completed a comprehensive survey on diet and lifestyle. A follow-up questionnaire was sent to original cohort participants in 2004–2006 to update information on lifestyle and to ascertain the occurrence of major chronic diseases, including depression. A total of 318,257 participants (187,496 men and 130,761 women) returned the follow-up questionnaire and were eligible for the present analyses. On the follow-up questionnaire, participants were asked whether they had ever been diagnosed by a doctor as having depression and if so the year of first diagnosis in the following categories: “before 1985”,

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A total of 41,074 participants reported a diagnosis of depression on the follow-up questionnaire, 21,370 before 1995 (baseline survey), 8,219 between 1995 and 1999, and 11,485 since 2000. We limited the present analyses to depression cases with a first diagnosis since 2000 in order to reduce the potential impact of reverse causation, as dietary changes due to depression could possibly affect our results. Of the 277,186 participants not reporting a diagnosis of depression, we excluded 20,893 participants with missing or inconsistent information on depression diagnosis. We also excluded 3,678 participants without a depression diagnosis and 174 cases because of missing or inconsistent data on the exposures of interest. After these exclusions, the primary analyses included a total of 11,311 depression cases and 252,612 participants without depression. Participants consented to the study by returning survey questionnaires. The study protocol was approved by the Institutional Review Board of the National Institute of Environmental Health Sciences and the Special Studies Institutional Review Board of the National Cancer Institute.

**Exposure assessment**

The cohort’s baseline survey included a food frequency questionnaire that assessed consumption frequency and portion size of 124 food items in the past year, including “soft drinks, soda, pop (diet or regular)” (referred as soft drinks), “drinks such as Hi-C, lemonade, Kool-Aid” (referred as fruit drinks), “coffee”, “hot tea” and “iced-tea”. Ten consumption frequencies were allowed for each drink, ranging from “never” to “6 times/day” for soft and fruit drinks, or from “none” to “6+ cups/day” for coffee and teas. Three portion sizes were provided for consumption of soft drinks (10 oz or 1 can, 10–12 oz or 1 can, 12 oz or 1 can) and fruit drinks (1 cup, 1–1.5 cups, and 1.5 cups). We converted consumptions of soft and fruit drinks into cans per day based on reported frequency and portion size. For soft drinks, fruit drinks, and sweetened iced-tea, we further asked whether participants drank “sugar-free (diet)” or “regular-calorie” types for more than half of the time. Participants consented to the study by returning survey questionnaires. The study protocol was approved by the Institutional Review Board of the National Institute of Environmental Health Sciences and the Special Studies Institutional Review Board of the National Cancer Institute.

**Table 1. Baseline population characteristics of the NIH-AARP Diet and Health Study, 1995–2006.**

|                | Depression | Controls | Depression | Controls |
|----------------|------------|----------|------------|----------|
| N              | 11,311     | 252,612  | 11,311     | 252,612  |
| Baseline age in years, mean (SD) | 61.1 (5.6) | 61.6 (5.3) | 61.1 (5.6) | 61.6 (5.3) |
| Men, %         | 48.5       | 61.2     | 48.5       | 61.2     |
| Race, %        |            |          |            |          |
| Non-Hispanic Whites | 92.9     | 92.6     | 92.9       | 92.6     |
| Others         | 6.0        | 6.5      | 6.0        | 6.5      |
| Missing        | 1.1        | 1.0      | 1.1        | 1.0      |
| Education, %   |            |          |            |          |
| High school or less | 25.3     | 21.7     | 25.3       | 21.7     |
| Post high school | 10.9     | 9.3      | 10.9       | 9.3      |
| Some college   | 25.3       | 22.5     | 25.3       | 22.5     |
| College and above | 35.9     | 44.2     | 35.9       | 44.2     |
| Missing        | 2.6        | 2.2      | 2.6        | 2.2      |
| Marital status, % |          |          |            |          |
| Married/living as married | 67.7     | 71.9     | 67.7       | 71.9     |
| Widowed        | 10.0       | 9.9      | 10.0       | 9.9      |
| Divorced       | 17.1       | 12.9     | 17.1       | 12.9     |
| Separated      | 4.7        | 4.8      | 4.7        | 4.8      |
| Never married  | 0.0        | 0.0      | 0.0        | 0.0      |
| Unknown        | 0.5        | 0.5      | 0.5        | 0.5      |
| Smokers, %     |            |          |            |          |
| Never          | 33.7       | 38.8     | 33.7       | 38.8     |
| Past           | 51.5       | 50.8     | 51.5       | 50.8     |
| Current        | 13.6       | 9.1      | 13.6       | 9.1      |
| Missing        | 1.2        | 1.2      | 1.2        | 1.2      |
| Body mass index (kg/m²), Mean (SD) | 27.5 (5.4) | 26.9 (4.8) | 27.5 (5.4) | 26.9 (4.8) |
| Physical activity, % |          |          |            |          |
| Never or rarely | 20.5      | 14.8     | 20.5       | 14.8     |
| 1–3 times/month | 15.4      | 13.3     | 15.4       | 13.3     |
| 1–2 times/week  | 21.5      | 22.1     | 21.5       | 22.1     |
| 3–4 times/week  | 25.5      | 28.4     | 25.5       | 28.4     |
| ≥5 times/week   | 16.3      | 20.7     | 16.3       | 20.7     |
| Missing        | 0.8        | 0.7      | 0.8        | 0.7      |
| Self-reported health status, % |          |          |            |          |
| Excellent/very good | 43.0    | 58.3     | 43.0       | 58.3     |
| Good           | 39.3       | 32.6     | 39.3       | 32.6     |
| Fair           | 14.7       | 7.2      | 14.7       | 7.2      |
| Poor           | 1.6        | 0.6      | 1.6        | 0.6      |
| Missing        | 1.4        | 1.2      | 1.4        | 1.2      |
| History of diabetes, % | 9.6      | 6.9      | 9.6        | 6.9      |
| History of heart disease, % | 13.8     | 11.6     | 13.8       | 11.6     |
| History of cancer, % | 7.9      | 7.6      | 7.9        | 7.6      |
| Energy intake (kcal/day), Mean (SD) | 1799 (931) | 1755 (822) | 1799 (931) | 1755 (822) |
| Alcoholic beverages (drinks/day), % |          |          |            |          |
| None           | 24.4       | 21.0     | 24.4       | 21.0     |
| <1             | 55.1       | 54.4     | 55.1       | 54.4     |
| 1–1.99         | 10.4       | 12.9     | 10.4       | 12.9     |

Table 1. Cont.

|                | Depression | Controls | Depression | Controls |
|----------------|------------|----------|------------|----------|
| 2–2.99         | 3.5        | 4.0      | 3.5        | 4.0      |
| ≥3             | 6.6        | 7.7      | 6.6        | 7.7      |

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“1985–1994”, “1995–1999”, or “2000 to present”. A total of 41,074 participants reported a diagnosis of depression on the follow-up questionnaire, 21,370 before 1995 (baseline survey), 8,219 between 1995 and 1999, and 11,485 since 2000. We limited the present analyses to depression cases with a first diagnosis since 2000 in order to reduce the potential impact of reverse causation, as dietary changes due to depression could possibly affect our results. Of the 277,186 participants not reporting a diagnosis of depression, we excluded 20,893 participants with missing or inconsistent information on depression diagnosis. We also excluded 3,678 participants without a depression diagnosis and 174 cases because of missing or inconsistent data on the exposures of interest. After these exclusions, the primary analyses included a total of 11,311 depression cases and 252,612 participants without depression. Participants consented to the study by returning survey questionnaires. The study protocol was approved by the Institutional Review Board of the National Institute of Environmental Health Sciences and the Special Studies Institutional Review Board of the National Cancer Institute.
mortality [24] and lower risk of Parkinson’s disease [12] and certain types of cancer [25,26].

In addition to dietary habits, the baseline questionnaire collected information on demographics, lifestyle, self-evaluated health status, and diagnosis of major chronic diseases. For smoking, participants were asked whether they had smoked more than 100 cigarettes during their lifetime. Ever smokers were asked about current smoking status and typical number of cigarettes per day. Former smokers were asked the year of cessation. Consumption of beer, wine and liquor was asked as part of the baseline food frequency questionnaire. For physical activity, the questionnaire inquired whether in the prior 12 months the subject participated in activities at work or home that lasted at least 20 minutes or increased breath, heart rate, or caused sweating. Body mass index (BMI) was calculated as weight in kilograms divided by height in squared meters.

### Statistical analysis

In the analyses, drinking frequency was categorized as (cans or cups/day): none (reference), <1, 1, 2–3, and ≥4. To reduce the

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**Table 2.** Odds ratios and 95% confidence intervals of depression according to baseline beverage consumption in the NIH-AARP Diet and Health Study, 1995–2006.

| Beverages          | Overall   | Men         | Women       |
|--------------------|-----------|-------------|-------------|
|                    | Case/control | OR 95% CI | Case/Control | OR 95% CI | Case/Control | OR 95% CI |
| Soft drinks (cans/day) |           |             |             |           |             |           |
| None               | 985/23633  | 1.00        | 358/11123  | 1.00      | 627/12510  | 1.00      |
| <1                 | 8024/188196 | 1.06        | 0.99–1.14 | 3849/116075 | 1.03 | 0.92–1.15 | 4175/72121 | 1.08 | 0.99–1.18 |
| 1                  | 549/10060 | 1.26        | 1.13–1.40 | 300/6760  | 1.24 | 1.05–1.45 | 249/3300  | 1.26 | 1.08–1.47 |
| 2–3                | 881/16050 | 1.26        | 1.15–1.39 | 502/10991 | 1.27 | 1.11–1.47 | 379/5059  | 1.22 | 1.06–1.39 |
| ≥4                 | 653/10524 | 1.30        | 1.17–1.44 | 378/7225  | 1.32 | 1.13–1.53 | 275/3299  | 1.25 | 1.07–1.45 |
| P for trend        | <0.0001   | <0.0001     | <0.0001    |

**Fruit drinks (cans/day)**

| None               | 6567/144579 | 1.00 | 3035/84491 | 1.00 | 3532/60088 | 1.00 |
| <1                 | 4181/97416 | 0.98 | 0.94–1.02 | 2144/63318 | 0.96 | 0.90–1.01 | 2037/34098 | 1.01 | 0.96–1.07 |
| 1                  | 175/3341  | 1.11 | 0.95–1.30 | 105/2251 | 1.19 | 0.97–1.45 | 70/1090 | 1.00 | 0.78–1.28 |
| 2–3                | 62/1127   | 1.10 | 0.85–1.43 | 32/631   | 1.27 | 0.89–1.82 | 30/496 | 0.95 | 0.65–1.38 |
| ≥4                 | 135/1907  | 1.38 | 1.15–1.65 | 89/1327  | 1.56 | 1.25–1.95 | 46/580 | 1.11 | 0.82–1.51 |
| P for trend        | <0.0001   | <0.0001     | <0.0001    |

**Hot tea (cups/day)**

| None               | 7246/163165 | 1.00 | 3917/108660 | 1.00 | 3329/54505 | 1.00 |
| <1                 | 2087/46465 | 1.01 | 0.96–1.06 | 837/24833 | 1.01 | 0.93–1.09 | 1250/21632 | 1.00 | 0.93–1.07 |
| 1                  | 951/20948  | 1.01 | 0.94–1.08 | 355/10607 | 1.00 | 0.90–1.12 | 596/10341 | 1.01 | 0.92–1.10 |
| 2–3                | 761/17099 | 0.97 | 0.90–1.05 | 276/8150 | 1.27 | 0.89–1.56 | 485/9894 | 0.94 | 0.85–1.04 |
| ≥4                 | 203/3697  | 1.14 | 0.98–1.31 | 73/1693 | 1.21 | 0.95–1.53 | 130/2004 | 1.10 | 0.92–1.32 |
| P for trend        | 0.57      | 0.32          | 0.32       |

**Iced tea (cups/day)**

| None               | 4299/98282 | 1.00 | 2110/59885 | 1.00 | 2189/38397 | 1.00 |
| <1                 | 3377/76916 | 1.01 | 0.96–1.06 | 1649/48699 | 0.97 | 0.91–1.04 | 1728/28217 | 1.05 | 0.98–1.12 |
| 1                  | 985/22750 | 0.96 | 0.89–1.03 | 467/13060 | 1.01 | 0.91–1.12 | 518/9690 | 0.92 | 0.84–1.02 |
| 2–3                | 1910/40669 | 0.98 | 0.93–1.04 | 910/24298 | 0.99 | 0.91–1.07 | 1000/16371 | 0.99 | 0.91–1.07 |
| ≥4                 | 701/13226 | 1.03 | 0.95–1.12 | 337/8331 | 0.96 | 0.86–1.09 | 364/4895 | 1.10 | 0.98–1.23 |
| P for trend        | 0.96      | 0.69          | 0.59       |

**Coffee (cups/day)**

| None               | 1178/25783 | 1.00 | 481/14048 | 1.00 | 697/1735 | 1.00 |
| <1                 | 1898/40626 | 1.07 | 0.99–1.15 | 852/23863 | 1.07 | 0.95–1.20 | 1046/16763 | 1.06 | 0.96–1.18 |
| 1                  | 1895/41087 | 1.03 | 0.95–1.11 | 840/23284 | 1.06 | 0.94–1.19 | 1055/17803 | 1.00 | 0.91–1.11 |
| 2–3                | 4504/105351 | 0.93 | 0.87–1.00 | 2294/66195 | 0.97 | 0.87–1.08 | 2210/39156 | 0.90 | 0.82–0.99 |
| ≥4                 | 1793/38992 | 0.91 | 0.84–0.98 | 1003/26901 | 0.90 | 0.80–1.01 | 790/12091 | 0.93 | 0.84–1.04 |
| P for trend        | <0.0001   | 0.0002        | 0.0006     |

Abbreviations: CI, confidence interval; OR, odds ratio; Adjusted for age at baseline, sex, race, education, marital status, smoking, alcoholic beverage intake, physical activity, body mass index, and energy intake. Numbers may not add up to total due to missing.

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for a monotonic trend was examined by including the mid-point of each exposure category as a continuous variable in the regression model. In addition to the overall analysis, we conducted stratified analyses according to the specific subtype of each beverage that the participant drank more than half of the time: regular vs. diet, or caffeinated vs. decaffeinated. These analyses were pre-planned. Finally, we conducted post-hoc analyses to examine specific type of sweeteners regularly added to coffee or tea in relation to the risk of depression. All statistical analyses were performed by using the Statistical Analysis Systems (SAS) release 9.3 (SAS Institute, Cary, NC, USA) with two-tailed α of 0.05.

Results

Table 1 shows baseline population characteristics. As expected, depression was more likely to occur in women, current smokers, participants with low education level, and those who divorced. Further, depression was associated with higher BMI, less physical activity, poorer general health status, and a history of diabetes, CVD, or cancer.

Overall, higher consumption of soft or fruit drinks at baseline was monotonically associated with a higher risk of depression (Table 2). The multivariate OR between extreme drinking categories (≥4 cans/day vs. none) was 1.30 (1.17–1.44) for soft drinks, and 1.38 (1.15–1.65) for fruit drinks (both P for trend<0.0001). For soft drinks, the risk increase was statistically significant for all categories of >1 can per day. In contrast, coffee drinking was weakly associated with a lower risk for depression (OR for ≥4 cups/day vs. none = 0.91 (0.84–0.98), P for trend<0.0001). Overall, drinking hot tea or iced tea was not associated with the risk of depression. Similar results were found in both genders with the exception of fruit drinks where the association was limited to men.

For fruit drinks and sweetened iced tea, further analyses suggested that the association was limited to individuals who drank primarily diet beverages (Table 3). The ORs comparing the ≥4 cans/cups per day versus none were 1.51 (1.18–1.92) for diet drinks, and 1.38 (1.15–1.65) for fruit drinks (both P for trend<0.0001). For soft drinks, the risk increase was statistically significant for all categories of >1 can per day. In contrast, coffee drinking was weakly associated with a lower risk for depression (OR for ≥4 cups/day vs. none = 0.91 (0.84–0.98), P for trend<0.0001). Overall, drinking hot tea or iced tea was not associated with the risk of depression. Similar results were found in both genders with the exception of fruit drinks where the association was limited to men.

In the analyses according to caffeine content, frequent drinkers of both types of coffee (primarily either caffeinated or decaffeinated) had a slightly lower depression risk than nondrinkers (Table 4). In contrast, consumption of both caffeinated and decaffeinated soft drinks was related to higher risk of depression. Interestingly, drinking either iced-tea or hot tea was monotonically associated with higher risk of depression among drinkers who primarily drank decaffeinated teas. In contrast, among participants who drank primarily caffeinated teas, we found a null association with hot tea and a weak inverse association with iced tea. This differential pattern was less evident for soft drinks where the corresponding ORs were 1.31 (1.16–1.47) for diet and 1.22 (1.03–1.45) for regular soft drinks.

Table 2. Odds ratiosa and 95% confidence intervals of depression according to baseline consumption of regular or diet sweetened beverages in the NIH-AARP Diet and Health Study, 1995–2006.

| Beverage | Regular drinks | Diet drinks |
|----------|----------------|-------------|
|          | Case/ Control  | OR 95% CI   | Case/ Control | OR 95% CI |
| Soft drinks (cans/day) | | | |
| None | 985/23633 | 1.00 | None | 985/23633 | 1.00 |
| <1 | 3188/82825 | 0.97 | 0.89–1.04 | 4434/95590 | 1.14 | 1.06–1.23 |
| 1 | 189/3442 | 1.23 | 1.04–1.45 | 355/6500 | 1.26 | 1.11–1.43 |
| 2–3 | 230/4335 | 1.16 | 1.00–1.36 | 643/11575 | 1.29 | 1.16–1.43 |
| ≥4 | 181/2829 | 1.22 | 1.03–1.45 | 465/7578 | 1.31 | 1.16–1.47 |
| P for trend | 0.0001 | <0.0001 |
| Fruit drinks (cans/day) | | | |
| None | 6567/144580 | 1.00 | 6567/144579 | 1.00 |
| <1 | 2018/50147 | 0.92 | 0.87–0.96 | 1225/25598 | 1.06 | 0.99–1.13 |
| 1 | 87/1899 | 0.96 | 0.77–1.19 | 54/1034 | 1.09 | 0.83–1.44 |
| 2–3 | 4/124 | 0.58 | 0.21–1.57 | 56/7578 | 1.18 | 0.90–1.55 |
| ≥4 | 45/773 | 1.08 | 0.79–1.46 | 73/1585 | 1.51 | 1.18–1.92 |
| P for trend | 0.84 | 0.0005 |
| Sweetened iced tea (cups/day) | | | |
| None | 4299/9828 | 1.00 | 4299/98282 | 1.00 |
| <1 | 1167/28082 | 0.96 | 0.90–1.03 | 1308/25980 | 1.14 | 1.07–1.22 |
| 1 | 378/8592 | 0.97 | 0.87–1.09 | 373/7933 | 1.04 | 0.93–1.16 |
| 2–3 | 689/15995 | 0.90 | 0.83–0.98 | 770/14385 | 1.12 | 1.04–1.22 |
| ≥4 | 254/5214 | 0.94 | 0.83–1.08 | 291/4521 | 1.25 | 1.10–1.41 |
| P for trend | 0.036 | <0.0001 |

Abbreviations: CI, confidence interval; OR, odds ratio.

aAdjusted for age at baseline, sex, race, education, marital status, smoking, alcoholic beverage intake, physical activity and body mass index, and energy intake.

bNumbers may not add up to total due to missing.

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Possibility that early symptoms of depression might have affected drinking habit, we only included incident diagnoses since 2000, i.e. those diagnoses that were made at least four years after baseline. Multivariate odds ratios (OR) and 95% confidence intervals (CI) were derived from logistic regression models, adjusting for age at baseline (5-year groups), sex, race (non-Hispanic Whites vs. others), education level (<3 years, 8–11 years, 12 years or high school, post-high school or some college, college and post graduate), marital status (married or living as married, widowed, divorced, separated, or never married), smoking status (never smokers; past smokers with years since last smoking; ≥25, 25–29.9, ≥30), and BMI (kg/m2; <25, 25–29.9, ≥30), and energy intake (quintiles). Further adjustment for self-evaluated health status (excellent, very good, good, fair or poor) and the presence of diabetes, heart disease, and cancer at baseline, had did not materially change the results. As these conditions might be in the pathway between drink consumptions and depression, we presented these analyses as supplemental materials (Tables S1–S4). The statistical significance possibility that early symptoms of depression might have affected drinking habit, we only included incident diagnoses since 2000, i.e. those diagnoses that were made at least four years after baseline. Multivariate odds ratios (OR) and 95% confidence intervals (CI) were derived from logistic regression models, adjusting for age at baseline (5-year groups), sex, race (non-Hispanic Whites vs. others), education level (<3 years, 8–11 years, 12 years or high school, post-high school or some college, college and post graduate), marital status (married or living as married, widowed, divorced, separated, or never married), smoking status (never smokers; past smokers with years since last smoking; ≥25, 25–29.9, ≥30), and BMI (kg/m2; <25, 25–29.9, ≥30), and energy intake (quintiles). Further adjustment for self-evaluated health status (excellent, very good, good, fair or poor) and the presence of diabetes, heart disease, and cancer at baseline, had did not materially change the results. As these conditions might be in the pathway between drink consumptions and depression, we presented these analyses as supplemental materials (Tables S1–S4).
Table 4. Odds ratios<sup>a</sup> and 95% confidence intervals of depression according to baseline consumption of caffeinated or decaffeinated beverages in the NIH-AARP Diet and Health Study, 1995–2006.

| Beverages | Caffeinated drinks | | | Decaffeinated drinks | | |
|-----------|--------------------|------------------|-------------------|-----------------|------------------|-------------------|
|           | Case/Control<sup>b</sup> | OR 95% CI | Case/Control | OR 95% CI | Case/Control | OR 95% CI |
| Coffee (cups/day) | | | | | | |
| None | 1178/25783 | 1.00 | 1178/25783 | 1.00 | |
| <1 | 770/16789 | 1.04 0.95–1.14 | 1006/21047 | 1.09 1.00–1.19 | |
| 1 | 1072/24418 | 0.98 0.89–1.06 | 789/15877 | 1.10 1.00–1.21 | |
| 2–3 | 3049/2917 | 0.91 0.84–0.98 | 1371/30352 | 0.98 0.90–1.07 | |
| ≥4 | 1380/29461 | 0.90 0.83–0.98 | 372/8736 | 0.88 0.78–1.00 | |
| P for trend | 0.0026 | 0.0029 | | | |
| Soft drinks (cans/day) | | | | | | |
| None | 985/23633 | 1.00 | 985/23633 | 1.00 | |
| <1 | 3929/96355 | 1.02 0.94–1.10 | 3531/78095 | 1.12 1.04–1.20 | |
| 1 | 276/5098 | 1.23 1.07–1.42 | 252/4632 | 1.26 1.09–1.46 | |
| 2–3 | 420/8408 | 1.13 1.00–1.27 | 429/7182 | 1.38 1.23–1.56 | |
| ≥4 | 350/5533 | 1.28 1.12–1.46 | 279/4633 | 1.29 1.12–1.49 | |
| P for trend | <0.0001 | <0.0001 | | | |
| Iced tea (cups/day) | | | | | | |
| None | 4299/98282 | 1.00 | 4299/98282 | 1.00 | |
| <1 | 2529/59555 | 0.98 0.93–1.03 | 763/15620 | 1.12 1.03–1.21 | |
| 1 | 697/16557 | 0.94 0.86–1.02 | 276/5718 | 1.07 0.94–1.21 | |
| 2–3 | 1295/29093 | 0.93 0.87–0.99 | 593/10905 | 1.15 1.05–1.26 | |
| ≥4 | 445/9406 | 0.91 0.82–1.00 | 247/3569 | 1.37 1.20–1.57 | |
| P for trend | 0.0089 | <0.0001 | | | |
| Hot tea (cups/day) | | | | | | |
| None | 7246/163165 | 1.00 | 7246/163165 | 1.00 | |
| <1 | 1216/28851 | 0.95 0.90–1.02 | 811/16413 | 1.09 1.01–1.18 | |
| 1 | 523/13075 | 0.90 0.82–0.99 | 400/7372 | 1.18 1.06–1.31 | |
| 2–3 | 450/11115 | 0.89 0.81–0.98 | 289/5500 | 1.12 0.99–1.26 | |
| ≥4 | 138/2596 | 1.10 0.92–1.31 | 61/985 | 1.27 0.98–1.65 | |
| P for trend | 0.14 | 0.0006 | | | |

Abbreviations: CI, confidence interval; OR, odds ratio.
<sup>a</sup>Adjusted for age at baseline, sex, race, education, marital status, smoking, alcoholic beverage intake, physical activity, body mass index, and energy intake.
<sup>b</sup>Numbers may not add up to total due to missing.
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Table 5. Odds ratios<sup>a</sup> and 95% confidence intervals of depression according to types of sweetener added to coffee or tea in the NIH-AARP Diet and Health Study, 1995–2006.

| Sweeteners | Overall | | | Men | | | Women | | |
|------------|---------|------------------|-------------------|---------|------------------|-------------------|---------|------------------|-------------------|
|            | Case/control | OR 95% CI | Case/Control | OR 95% CI | Case/Control | OR 95% CI | Case/Control | OR 95% CI | Case/Control | OR 95% CI |
| Non-drinkers | 408/9297 | 1.00 | 219/6044 | 1.00 | 189/3253 | 1.00 | |
| None | 4580/118082 | 0.86 0.77–0.95 | 2179/71644 | 0.84 0.73–0.97 | 2401/46438 | 0.88 0.75–1.03 | |
| Sugar or honey | 2603/59917 | 0.93 0.83–1.04 | 1390/39758 | 0.89 0.77–1.03 | 1213/20149 | 0.98 0.83–1.14 | |
| Equal or aspartame | 1778/30199 | 1.24 1.11–1.39 | 805/16989 | 1.27 1.09–1.48 | 973/13210 | 1.22 1.03–1.43 | |
| Saccharin or Sweet-n-Low | 1751/31624 | 1.14 1.02–1.27 | 825/18430 | 1.17 1.01–1.37 | 926/13194 | 1.11 0.94–1.31 | |
| Other sweeteners | 145/2349 | 1.23 1.01–1.49 | 51/1216 | 1.07 0.78–1.46 | 94/1133 | 1.35 1.04–1.74 | |

Abbreviations: CI, confidence interval; OR, odds ratio;
<sup>a</sup>Adjusted for age at baseline, sex, race, education, marital status, smoking, alcoholic beverage intake, physical activity, body mass index, and energy intake.
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Discussion

This large study included a total of 11,311 incident depression cases identified from self-reports. Although we did not conduct diagnostic confirmation, depression in this population was associated with female gender, lower education, smoking, lack of physical activity, obesity, the presence of major chronic diseases and poor health status. These data indirectly support the validity of case identification in this cohort.

Major strengths of this study include the very large sample size, prospective data collection, and detailed analyses. In comparison to retrospective data collection, prospective exposure assessment is less prone to recall bias and reverse causation. Moreover, we only included depression diagnoses occurring at least four years after exposure assessment which further reduced the potential influence of reverse causation on our analyses.

Only a few cross-sectional analyses have published data on soft drinks and depression like outcomes. A study in Australia reported that adults who consumed over a liter of soft drink per day had approximately 60% higher prevalence of depression, suicidal ideation, or mental problems [14]. One study in China and one in Norway reported a J-shaped association among adolescents with a slightly higher prevalence of suicidal plan or act [15] or mental problems [16] among never or rare drinkers of soft drinks, but a much higher risk among heavy drinkers.

To the best of our knowledge, this is the first prospective study to observe a modest positive association between frequent drinking of sweetened beverages and depression. In general, further analyses suggest that the observation may be more relevant to diet drinks. Unlike sugar-sweetened drinks, diet drinks often use artificial sweeteners such as aspartame and saccharin for the sweet taste and are calorie-free. Our further analysis found that adding these artificial sweeteners to coffee or tea, but not adding sugar or honey, was associated with higher risk of depression. Various effects of artificial sweeteners, including neurological effects, have been suspected [6,7]. For example, aspartame may modulate brain neurotransmitters such as dopamine and serotonin, although data have been controversial and inconsistent [27].

There are also possible alternative explanations. One possibility is that depressed individuals may crave sweet beverages, and one may speculate that this may occur even years before receiving a diagnosis of depression. We cannot exclude this possibility of reverse causation despite the fact that the analyses only included cases diagnosed after 2000. However, this explanation cannot explain some differential results on diet versus regular sweetened beverages, or on adding artificial sweeteners as compared to adding sugar or honey to tea or coffee. Consumption of sweetened beverages is associated with a variety of socio-economic and lifestyle factors and may contribute to obesity, diabetes and poor health, which in turn could contribute to the development of depression. Although we cannot exclude the possibility of residual confounding, we adjusted for these factors in the analyses.

Several studies have examined coffee or tea consumption in relation to depression with inconsistent results. Most were cross-sectional, which further complicates interpretation of the data [28,29,30,31,32,33,34,35]. Three prospective studies have been published. In a study of Finnish men (49 cases), heavy coffee drinkers had approximately 70% lower risk for depression than nondrinkers [21]. In the Nurses’ Health Study (2607 cases): women who drank >4 cups coffee per day had a 20% lower risk of depression than those who drank never or rarely coffee [20]. The associations were observed for caffeinated but not decaffeinated coffee, although fewer participants drank decaffeinated coffee. Caffeinated tea, soft drinks, or caffeine from non-coffee sources were not related to depression in the study [20]. The third study (363 cases) reported that tea drinking was associated with less depression among female breast cancer survivors in China [36].

Compared to previous studies, our study is much larger and included both men and women. In the analyses, coffee drinking was linked to a slightly lower risk of depression. A similar weak association was also observed with consumption of caffeinated iced-tea, whereas the association with decaffeinated iced-tea was in the opposite direction. Coffee contains large amounts of caffeine which is a well-known brain stimulant. Caffeine and its major metabolites act on adenosine receptors in the brain [37] and increase plasticity of hippocampal CA2 neurons [38], which may in turn contribute to lower risk of depression among coffee drinkers. In addition to caffeine, coffee and tea contain many antioxidants and phytochemicals which may also be responsible for our observations.

In addition to self-reported outcome, there are several other limitations. We asked only about beverage consumption in the year prior to baseline and therefore we did not capture consumption history or changes in drinking habits over time. Measurement error was thus unavoidable. This may be particularly true for assessing diet versus regular beverages or of caffeinated versus decaffeinated drinks because we classified participants according to which particular subtype they drank more than half of the time. Therefore results on subtypes of drinks must be interpreted within context. Nevertheless, given the prospective design, these measurement errors are likely to be random and therefore would tend to attenuate true associations.

The present analysis was conducted among participants of the cohort’s follow-up survey and therefore selection bias was possible, the direction of which could not be readily predicted. Finally, the study included AARP members from selected regions of the US, therefore the generalizability of these results, particularly to younger populations, need further investigation.

In conclusion, in this large study of U.S. older adults, frequent consumption of sweetened beverages was associated with a modestly higher risk of depression, and coffee consumption with a slightly lower risk. As these drinks are commonly consumed, confirmation and further investigations are warranted.

Supporting Information

Table S1 Odds ratios and 95% confidence intervals of depression according to baseline beverage consumption, further adjusted for self-reported health status, diabetes, heart disease, and cancer.

Table S2 Odds ratios and 95% confidence intervals of depression according to baseline consumption of regular or diet sweetened beverages, further adjusted for self-reported health status, diabetes, heart disease, and cancer.

Table S3 Odds ratios and 95% confidence intervals of depression according to baseline consumption of caffeinated or decaffeinated beverages, further adjusted for self-reported health status, diabetes, heart disease, and cancer.

Table S4 Odds ratios and 95% confidence intervals of depression according to types of sweetener added to coffee or tea, further adjusted for self-reported health status, diabetes, heart disease, and cancer.
Author Contributions
Conceived and designed the experiments: HC YP NDF RS ARH AB. Analyzed the data: XG HC YP ARH AB. Performed the analysis: XG HC.

References
1. Popkin BM, Armstrong LE, Bray GM, Caballero B, Frei B, et al. (2006) A new proposed guidance system for beverage consumption in the United States. The American journal of clinical nutrition 83: 529–542.
2. Malik VS, Popkin BM, Bray GA, Desprez JP, Willett WC, et al. (2010) Sugar-sweetened beverages and risk of metabolic syndrome and type 2 diabetes: a meta-analysis. Diabetes care 33: 2477–2483.
3. Malik VS, Schuler MB, Hu FB (2006) Intake of sugar-sweetened beverages and weight gain: a systematic review. The American journal of clinical nutrition 84: 274–288.
4. Mozaffarian D, Hao T, Rimm EB, Willett WC, Hu FB (2011) Changes in diet and lifestyle and long-term weight gain in women and men. The New England journal of medicine 364: 2392–2404.
5. Qi Q, Chu AY, Jung JJ, Jensen MK, Curhan GC, et al. (2012) Sugar-sweetened beverages and genetic risk of obesity. N Engl J Med 367: 1387–1396.
6. Whitehouse CR, Boullata J, McCauley LA (2008) The potential toxicity of artificial sweeteners. AAONH J 56: 251–259.
7. Humphries P, Prentice E, Nouri H (2008) Direct and indirect cellular effects of aspartame on the brain. European journal of clinical nutrition 62: 451–462.
8. Huxley R, Lee CM, Barzi F, Timmermeister L, Czernichow S, et al. (2009) Coffee, decaffeinated coffee, and tea consumption in relation to incident type 2 diabetes mellitus: a systematic review with meta-analysis. Archives of internal medicine 169: 2053–2063.
9. Lara DR (2010) Caffeine, mental health, and psychiatric disorders. Journal of Alzheimer’s disease: JAD 20 Suppl 1: S187–204.
10. Ascherio A, Zhang SM, Hernan MA, Wakuishi I, Colditz GA, et al. (2001) Prospective study of caffeine consumption and risk of Parkinson’s disease in men and women. Ann Neurol 50: 56–63.
11. Ross GW, Abbott RD, Petrovitch H, Morris MS, Grundtner A, et al. (2000) Association of coffee and caffeine intake with the risk of Parkinson disease. JAMA 283: 2674–2679.
12. Liu R, Guo X, Park Y, Huang X, Sinha R, et al. (2012) Caffeine intake, smoking, and risk of Parkinson disease in men and women. American journal of epidemiology 175: 1200–1207.
13. Santos C, Costa J, Santos J, Vaz-Carneiro A, Lampe NT (2010) Caffeine intake and dementia: systematic review and meta-analysis. Journal of Alzheimer’s disease: JAD 20 Suppl 1: S187–204.
14. Shi Z, Taylor AW, Wittert G, Goldney R, Gill TK (2010) Soft drink consumption and mental health problems among adults in Australia. Public health nutrition 13: 1073–1079.
15. Pan X, Zhang C, Shi Z (2011) Soft drink and sweet food consumption and suicidal behaviours among Chinese adolescents. Acta paediatrica 100: e215–222.
16. Lien L, Lien N, Heyerdahl S, Thoresen M, Bjertness E (2006) Consumption of soft drinks and hyperactivity, mental distress, and conduct problems among adolescents in Oslo, Norway. American journal of public health 96: 1815–1820.
17. Klatsky AL, Armstrong MA, Friedman GD (1993) Coffee, tea, and mortality. Annals of epidemiology 3: 375–381.
18. Kawauchi I, Willett WC, Colditz GA, Stampfer MJ, Speizer FE (1996) A prospective study of coffee drinking and suicide in women. Archives of internal medicine 156: 521–525.
19. Takanashi K, Tsujiimoto J, Vinnamaki H, Vartiainen E, Lehtonen J, et al. (2000) Heavy coffee drinking and the risk of suicide. European journal of epidemiology 16: 789–791.
20. Lucas M, Mirrazi F, Pan A, Okerke OE, Willett WC, et al. (2011) Coffee, caffeine, and risk of depression among women. Arch Intern Med 171: 1571–1578.
21. Ruusunen A, Lehto SM, Tohmonen T, Mursu J, Kaplan GA, et al. (2010) Coffee, tea and caffeine intake and the risk of severe depression in middle-aged Finnish men: the Kuopio Ischaemic Heart Disease Risk Factor Study. Public health nutrition 13: 1215–1229.
22. Schatzkin A, Subar AF, Thompson FE, Harlan LC, Taugria J, et al. (2001) Design and severity in establishing a large cohort with wide dietary intake distributions: the National Institutes of Health-AARP (America) Association of Retired Persons Diet and Health Study. Am J Epidemiol 154: 1119–1125.
23. Thompson FE, Kipnis V, Midthune D, Freedman LS, Carroll RJ, et al. (2008) Performance of a food-frequency questionnaire in the US NH-AARP (National Institutes of Health-AARP) Diet and Health Study. Public Health Nutr 11: 183–195.
24. Freedman ND, Park Y, Abnet CC, Hollenbeck AR, Sinha R (2012) Association of coffee drinking with total and cause-specific mortality. The New England journal of medicine 366: 1291–1294.
25. Sinha R, Cross AJ, Daniel CR, Graubard BI, Wu JW, et al. (2012) Caffeinated and decaffeinated coffee and tea intakes and risk of colorectal cancer in a large prospective study. The American journal of clinical nutrition 96: 374–381.
26. Gunter MJ, Schauf JA, Xue X, Freedman ND, Gazet MM, et al. (2012) A prospective investigation of coffee drinking and endometrial cancer incidence. International journal of cancer 131: E530–536.
27. Magnuson BA, Burdock GA, Doull J, Kroes RM, Marsh GM, et al. (2007) Aspartame: a safety evaluation based on current use levels, regulations, and toxicological and epidemiological studies. Crit Rev Toxicol 37: 629–727.
28. Benko CR, Farias AG, Farias LG, Pereira EF, Louzada FM, et al. (2011) Potential link between caffeine consumption and pediatric depression: A case-control study. BMJ pediatrics 11: 73.
29. Groden JF, Fontaine P, Labusky M, Chamberlin K (1978) Anxiety and depression associated with caffeinism among psychiatric inpatients. The American journal of psychiatry 135: 963–966.
30. Smith AP (2009) Caffeine, cognitive failures and health in a non-working community sample. Human psychopharmacology 24: 29–34.
31. Whalen DJ, Silk JS, Semel M, Forbes EE, Ryan ND, et al. (2008) Caffeine consumption, sleep, and affect in the natural environments of depressed youth and healthy controls. Journal of pediatric psychology 33: 350–367.
32. Leenen D, Fries PW, Burtko JI, Mosel DE, Rosenthal NE (1993) Depressive symptoms and the self-reported use of alcohol, caffeine, and carbohydrates in normal volunteers and four groups of psychiatric outpatients. The American journal of psychiatry 150: 294–301.
33. Luebert AM, Bell DJ (2009) Mountain Dew or mountain don’t? a pilot investigation of caffeine use parameters and relations to depression and anxiety symptoms in 5th- and 10th-grade students. The Journal of school health 79: 380–387.
34. Niu K, Hoszawa A, Kuriyama S, Eshbara S, Guo H, et al. (2009) Green tea consumption is associated with depressive symptoms in the elderly. The American journal of clinical nutrition 90: 1615–1622.
35. Himuku K, Toshimori T, Honkalampi K, Haatikainen K, Kivimaa-Honkalen H, et al. (2005) Daily tea drinking is associated with a low level of depressive symptoms in the Finnish general population. European journal of epidemiology 20: 359–363.
36. Chen X, Lu W, Zheng Y, Gu K, Chen Z, et al. (2010) Exercise, tea consumption, and depression among breast cancer survivors. Journal of clinical oncology: official journal of the American Society of Clinical Oncology 28: 991–996.
37. Morelli M, Carta AR, Kachroo A, Schwarzwaldt MA (2010) Pathophysiological roles for purines: adenosine, caffeine and urate. Progress in brain research 183: 203–208.
38. Sinoms SB, Caruana DA, Zhao M, Dudek SM (2012) Caffeine-induced synaptic potentiation in hippocampal CA2 neurons. Nature neuroscience 15: 22–23.