Association Between Tea Drinking and Cognitive Disorders in Older Adults: A Meta-Analysis of Observational Studies

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Introduction: Previous research has shown that tea drinking has a bearing on Cognitive Disorders, but the conclusions are inconsistent. The purpose of this research was to systematically assess the published evidence pertaining to tea drinking and the risk of cognitive disorders in older adults using a meta-analysis, and to concurrently evaluate the dose-response association.

Design: A meta-analysis.

Setting and Participants: We used the PubMed and Web of Science databases for a literature search until 30 May 2021. We initially retrieved 20,908 studies (14,884 from PubMed and 6,024 from the Web of Science). Thirty-six studies met the inclusion criteria (7 case-control, 16 cohort, and 13 cross-sectional studies), involved 224,980 participants.

Methods: Pooled odd ratios (ORs) with their corresponding 95% confidence intervals (CIs) were used to evaluate the strength of the association under a fixed- or random-effect model according to heterogeneity test results.

Results: The results showed that drinking tea was negatively associated with cognitive disorders (OR: 0.76, 95% CI: 0.70–0.82). Moreover, dose-response associations were found between tea drinking and cognitive disorders (1 time/day: OR, 0.81; 95% CI, 0.70–0.95; 1 cup/day: OR, 0.86; 95% CI, 0.78–0.94). In addition, subgroup analyses were performed according to study designs, study population, types of tea drinking, outcomes and methods used to assess outcomes. Most of the results in the subgroup analyses were consistent with the main results.

Conclusion: The results of the present study provided abundant evidence that tea drinking is inversely proportional with the occurrence of cognitive disorders in older adults. A linear dose-response association between tea drinking and decreased prevalence of cognitive disorders was found.

Keywords: tea drinking, older adults, meta-analysis, dose-response, cognitive disorders
SUMMARY

Cognitive disorders are a common neurodegenerative disease among older adults. The proportional and linear associations between tea drinking and cognitive disorders were studied by meta-analysis. A total of 36 studies (224,980 participants) were enrolled in the present study. Results demonstrated that tea drinking was positively associated with cognitive disorders.

INTRODUCTION

Neurologic diseases impact the nervous system and include epilepsy, cerebrovascular disease (such as stroke), and neurodegenerative diseases (such as cognitive disorders) (Thangaraj et al., 2020). Cognitive disorders, also known as neurocognitive disorders, typically affect learning, memory, perceptual-motor function, language, attention, and problem solving (Robbins et al., 2019). Cognitive disorders mainly include delirium, mild cognitive impairment (MCI), and major neurocognitive disorder [such as dementia, Parkinson’s disease (PD), and Alzheimer’s disease (AD)] (Sachdev et al., 2014). After 65 years of age, the incidence of cognitive disorders increases sharply (Huang et al., 2009). Due to the increase in population aging worldwide, the disease burden of cognitive disorders is gradually increasing. For example, as a type of cognitive disorder, dementia affects 5–6% of people ≥ 60 years of age (Jia et al., 2020). The total number of dementia patients is expected to reach 82 million in 2030 and 152 million in 2050 (World Health Organization, 2020). Early intervention for cognitive disorders is especially effective, thus intervention can be used to help relieve the social and economic burden of AD and other types of cognitive disorders.

According to previous reports, cognitive disorders may be related to many factors, such as the aging process and lifestyle (Laundisio et al., 2008; Rabbitt et al., 2008a,b; Solfrizzi et al., 2008). Tea originated in China thousands of years ago and is widely enjoyed worldwide. In Asian countries, drinking green tea is a social custom, while Western countries prefer black tea (Cheng, 2006). It has been shown in experiments (in vitro studies, etc.) and animal studies that tea polyphenols may not only have effective neuroprotective activity, but may also help slow the progression of neurodegenerative diseases (Mandel and Youdim, 2004; Chen et al., 2018). In vitro and in vivo experimental studies have shown that tea and its components, such as catechin and theanine, have neuroprotective effects (Kim et al., 2009; Lee et al., 2009, 2013; Biasibetti et al., 2013). Some epidemiologic studies have shown that drinking tea can improve neuropsychiatric disorders (Gardner et al., 2007) and reduce the development of cognitive disorders (Feng et al., 2012). A previous study (Ide et al., 2014) concluded that drinking green tea ameliorates or delays cognitive disorders in older adults. Thus, green tea may delay the occurrence or development of cognitive disorders (Mandel et al., 2005, 2008; Song et al., 2012); however, other studies showed no association between tea drinking and the prevalence of cognitive disorders (Forster et al., 1995; Lindsay et al., 2002). These discrepant findings were the impetus for a meta-analysis to elucidate the association between tea drinking and cognitive disorders.

METHODS

Literature Search
We used the PubMed and Web of Science databases for a literature search until 30 May 2021, with the following key words: (“tea” OR “oolong tea” OR “black tea” OR “subtypes of tea” OR “drinking tea” OR “beverage of tea” OR “tea consumption” OR “tea catechins consumption” OR “green tea” OR “tea intake” OR “intake of tea” OR “component in tea” OR “caffeine” OR “caffeine intake from tea” OR “tea polyphenol” OR “tea catechins” OR “tea extracts” OR “polyphenol” OR “catechins”) combined with (“Alzheimer’s disease” OR “cognitive impairment” OR “Alzheimer’s type” OR “cognitive decline” OR “dementia” OR “MCI” OR “mild neurocognitive disorder” OR “mild cognitive impairment” OR “cognitive impairment” OR “memory impairment” OR “Alzheimer’s disease” OR “dementia” OR “cognitive dysfunction” OR “cognitive disorder” OR “cognitive defect” OR “memory disorder” OR “AD” OR “executive function” OR “Alzheimer’s“). We also searched the selected literature in other correlative meta-analysis to gain the most integrated compilation of studies possible from the reported paper. In addition, in the event several studies originated from identical research, we chose the studies with the longest duration of follow-up and/or the largest sample size. We used Endnote 9.0 software for the search and management of the selected studies. The study selection process was performed following the Preferred Reporting Items for Systematic Review and Meta-analyses (PRISMA) statement (Page et al., 2021).

Selection Criteria
The inclusion criteria for selected studies were as follows: (1) ≥ 60 of age; (2) selected studies included daily tea drinking (not tea extract) and cognitive disorder-related outcomes, such as AD, Parkinson’s disease (PD), and cognitive decline in older adults; and (3) studies that reported the odds ratios (ORs), hazard ratios (HRs), risk ratios (RRs), and corresponding 95% confidence intervals (CIs).
The animal studies, reviews, reports, and studies with unavailable data were excluded. If two or more studies shared the same population, we only selected the most recent study.

**Data Extraction and Quality Assessment**
Two research assistants collected the following data from the literature: the first author’s last name; publication year; research country; study design; number of participants and cases; OR (95% CI); HR (95% CI); and RR (95% CI), as well as variables that were adjusted in the primary analysis. The Newcastle–Ottawa Scale (NOS) and the Agency for Healthcare Research and Quality (AHRQ) were used for quality assessment.

**Statistical Analysis**
RRs and HRs are equal to ORs (Zhang and Yu, 1998; Li et al., 2012; Kim et al., 2015; Liu et al., 2017; Ran et al., 2021) when the prevalence of the outcome is low. An OR with a 95% CI determined the correlation between tea drinking and cognitive disorders. \(I^2\) was used to assess heterogeneity across studies. Based on the heterogeneity \((I^2 = 64.9\%)\), a random effect model was selected. Influence analysis was also performed to determine whether an individual study affected the overall research results. Begg’s test was applied to assess publication bias. Subgroup analyses were carried out by disease type, population, type of study design, type of tea, and type of disease assessment.

A dose-response meta-analysis was performed using Stata software (version 16; Stata Corp., College Station, TX, United States), and the glst and xbhc orders were applied to carry out the model estimation and draw linear or non-linear dose–response association maps.

**RESULTS**

**Study Selection**
The study selection process is shown in Figure 1. We preliminarily retrieved 20,908 studies (14,884 from PubMed and 6,024 from the Web of Science). First, we found 2,169 duplicate literature records through preliminary screening. Second, we screened the titles and abstracts, and 18,595 studies deviated significantly from the inclusion and exclusion criteria. Third, we conducted full-text screening, and 108 studies were excluded. Finally, 36 studies (7 case-control, 16 cohort, and 13 cross-sectional studies) met the inclusion criteria and were included for this meta-analysis with a total of 224,980 participants. Of which, 16 studies were from China, 6 were from Europe, 7 were from the North America, and 7 were from Japan.

**Study Characteristics**
Table 1 summarizes the nature by country, study type, publication year, research design, etc. Supplementary Table 1 shows the distinguishing features of 36 studies (7 case-control, 13 cross-sectional, and 16 cohort studies). In the articles included in the study, different methods were used to measure tea drinking records, such as the Food Frequency Questionnaire (FFQ) and self-administered questionnaire. The great majority of studies were adjusted for latent confounding factors. We recorded the OR (95% CI) of cognitive disorders based on the highest and lowest tea drinking classifications.

Supplementary Tables 2, 3 show the quality evaluation results of the included studies. According to the quality assessment by the NOS, the mean value for the 7 case-control and 16 cohort studies was 7.1 stars. In the current study, we considered a study awarded 5–9 stars as a medium- or high-quality study because the criteria for medium- or high-quality have not been established. All documents were of medium or high-quality with scores of 5–9. The cross-sectional study used the AHRQ scale for quality evaluation, including 11 items. Each item was rated as “yes” (1 point), and “no” or “unclear” (0 point); 0–3 points represented low-quality literature, 4–7 points represented medium-quality literature, and 8–11 points represented high-quality literature. All documents were of medium- or high-quality with scores of 5–8.

**Association Between Tea Drinking and Cognitive Function**
A notable heterogeneity \((I^2 = 64.9\%)\) is shown in Figure 2. The forest map of the random effects model indicated that drinking tea was inversely proportional to cognitive disorders (OR: 0.76, 95% CI: 0.70–0.82).

**Subgroup Analyses**
Table 2 shows the combined outcomes of each subgroup. According to the type of study design, we divided all the studies into three subgroups (Supplementary Figure 1). Among all three subgroups, cross-sectional (OR: 0.69, 95% CI: 0.61–0.79) and cohort studies (OR: 0.77, 95% CI: 0.69–0.87) indicated that tea drinking was inversely associated with cognitive disorders, while case-control studies showed no association. Among the population subgroups (Supplementary Figure 2), drinking tea remarkably lowered the risk of cognitive disorders in Chinese (OR: 0.70, 95% CI: 0.62–0.79), European (OR: 0.91, 95% CI: 0.83–0.99) and Japanese (OR: 0.73, 95% CI: 0.63–0.83) subgroups; however, no association existed in North American subgroup (OR: 0.83, 95% CI: 0.59–1.17). Among the subgroup analysis of types of cognitive disorders (Supplementary Figure 3), drinking tea remarkably lowered the risk of cognitive decline (OR: 0.71, 95% CI: 0.53–0.96), cognitive impairment (OR: 0.73, 95% CI: 0.65–0.82), and dementia (OR: 0.85, 95% CI: 0.76–0.95). Nevertheless, no correlation was demonstrated between tea drinking and PD (OR: 0.73, 95% CI: 0.50–1.08). Subgroup analysis of tea types (Supplementary Figure 4) showed that drinking green tea (OR: 0.75, 95% CI: 0.66–0.84) significantly reduced the risk of cognitive disorders, but not black tea (OR: 0.86, 95% CI: 0.58–1.28). Subgroup analysis was performed according to the type of disease assessment (Supplementary Figure 5). The Mini-Mental State Examination (MMSE) (OR: 0.70, 95% CI: 0.63–0.79), Montreal Cognitive Assessment (MoCA) (OR: 0.71, 95% CI: 0.59–0.86), Kihon Checklist (OR: 0.77, 95% CI: 0.70–0.85), Informant Questionnaire on Cognitive Decline in Older Adults (IQCODE) (OR: 0.37, 95% CI: 0.24–0.58), and other assessment types (OR: 0.79, 95% CI: 0.69–0.92) were associated with cognitive function, but the modified Mini-Mental State (3MSE) (OR: 0.74, 95% CI: 0.66–0.84) showed no correlation.
0.37–1.49), Clinical Dementia Rating (CDR) (OR: 0.51, 95% CI: 0.19–1.40), and Détérioration Cognitive Observeé (DECO) scores (OR: 0.93, 95% CI: 0.80–1.07) had no correlation between tea drinking and cognitive function.

**Dose-Response Association Analysis**

Data for dose-response analysis were derived from 13 estimates of 11 separate studies. In addition to these studies, the remaining studies included two tea drinking datasets. Data from at least three dose levels are required for dose-response analysis, thus these data were excluded (Alexander et al., 2009). Tea drinking showed a negative linear association with cognitive disorders ($P$ for linearity $< 0.05$; Figure 3). Therefore, drinking tea was a protective factor for cognitive disorders (1 time/day: OR, 0.81; 95% CI, 0.70–0.95; 1 cup/day: OR, 0.86; 95% CI, 0.78–0.94).

**Publication Bias**

Publication bias was evaluated based on the entire dataset. The $P$-value of the Begg's test was 0.596, and the symmetric funnel plot is shown in Supplementary Figure 6. Based on the results of Begg's test ($P = 0.596$; Figure 4), we did not detect any publication bias.

**DISCUSSION**

The results of the present study showed that tea drinking is negatively associated with cognitive disorders in older adults. The
dose-response association confirmed that drinking tea markedly decreased the main outcome of cognitive disorders in older adults, especially green tea drinking.

Previous meta-analyses (Greenland, 1987; Ono et al., 2003; Li et al., 2012; Kim et al., 2015; Yamada et al., 2015; Liu et al., 2017; Ran et al., 2021) concluded that tea drinking is associated with cognitive disorders, which is consistent with the results in the present study. Caffeine is an important component in tea. Many experimental studies have shown the benefits of caffeine on cognitive function (Greenland, 1987). Other beneficial elements in tea, such as polyphenols, have anti-amyloidogenic effects (Alexander et al., 2009) and could be a key molecule for the development of preventives and therapeutics for cognitive disorders (Ono et al., 2003; Yamada et al., 2015).

Previous meta-analyses (Qi and Li, 2014; Liu et al., 2017) did not study the subgroup analysis association between tea drinking

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**TABLE 1** Summarizes the nature by country, study type, publication year, and research design.

| Study   | Study design | Country       | Year | Number of participants | Outcome measurement method | Type         | OR/RR | LCI     | UCI     |
|---------|--------------|---------------|------|------------------------|----------------------------|--------------|-------|---------|---------|
| Forster, D. P. | Case-control study | United Kingdom | 1995 | 218                    | Others                     | –             | 1.40  | 0.81    | 2.63    |
| Paganini-Hill, A. | Case-control study | United States | 2001 | 2,715                  | Others                     | –             | 1.21  | 0.86    | 1.70    |
| Checkoway, H. | Case-control study | United States | 2002 | 557                    | MMSE                       | –             | 0.40  | 0.20    | 0.90    |
| Lindsay, J. | Case-control study | Canada        | 2002 | 4,098                  | MMSE                       | –             | 1.12  | 0.78    | 1.61    |
| Kuriyama, S. | Cross-sectional study | Japan     | 2006 | 1,003                  | MMSE                       | –             | 0.62  | 0.43    | 0.89    |
| Dai, Q. | Cohort study | United States | 2006 | 1,589                  | Others                     | –             | 1.70  | 0.67    | 4.33    |
| Ritchie, K. | Cohort study | France        | 2007 | 7,017                  | MMSE                       | –             | 0.81  | 0.65    | 1.01    |
| Verhagen, M. N. | Cohort study | France        | 2008 | 4,809                  | DECO score                 | Recent cognitive decline | 0.96  | 0.78    | 1.19    |
| Nuk, E. | Cross-sectional study | Norway     | 2009 | 2,031                  | MMSE                       | –             | 0.68  | 0.49    | 0.93    |
| Eskelinen, M. H. | Cross-sectional study | Finland | 2009 | 1,409                  | MMSE                       | –             | 1.04  | 0.59    | 1.84    |
| Huang, C. Q. | Cross-sectional study | China      | 2009 | 681                    | MMSE                       | Men           | 0.55  | 0.22    | 1.64    |
| Lindsay, J. | Cross-sectional study | Canada     | 2002 | 4,098                  | MMSE                       | Women         | 0.96  | 0.38    | 2.45    |
| Yoo, Y. H. | Cohort study | Japan        | 2010 | 2,809                  | MMSE                       | –             | 0.57  | 0.42    | 0.77    |
| Tanaka, K. | Case-control study | Japan        | 2011 | 617                    | Others                     | –             | 0.59  | 0.35    | 1.00    |
| Wu, M. S. | Cross-sectional study | China      | 2011 | 2,119                  | MMSE                       | –             | 0.99  | 0.75    | 1.30    |
| Arab, L. | Cohort study | United States | 2011 | 4,809                  | 3MSE/IQCODE                | Men            | 0.34  | 0.68    | 1.37    |
| Palacios, N. | Cohort study | United States | 2012 | 112,122                | Others                     | –             | 0.72  | 0.40    | 1.27    |
| Chen, X., Y. | Case-control study | China       | 2012 | 5,691                  | MMSE                       | –             | 0.82  | 0.68    | 1.00    |
| Yang, B., Q. | Case-control study | China       | 2014 | 720                    | MMSE                       | –             | 0.73  | 0.52    | 0.87    |
| Wang, G. | Cohort study | China        | 2014 | 223                    | MMSE                       | –             | 0.48  | 0.21    | 1.11    |
| Noguchi-Shinohara, M. | Cohort study | Japan       | 2014 | 490                    | MMSE/IQCODE                | Men            | 0.32  | 0.16    | 0.64    |
| Shen, W. | Cross-sectional study | China       | 2015 | 9,375                  | MMSE                       | –             | 0.68  | 0.54    | 0.86    |
| Zeng, Y. | Cohort study | China        | 2015 | 822                    | MMSE                       | –             | 0.59  | 0.35    | 1.01    |
| Tomata, Y (a). | Cohort study | Japan        | 2016 | 13,645                 | The Kihon Checklist        | –             | 0.73  | 0.61    | 0.87    |
| Tomata, Y (b). | Cohort study | Japan        | 2016 | 14,402                 | The Kihon Checklist        | –             | 0.79  | 0.70    | 0.88    |
| Wang, T. | Cross-sectional study | China       | 2017 | 1,302                  | MMSE                       | –             | 0.72  | 0.49    | 1.07    |
| An, R. | Cohort study | China        | 2017 | 4,794                  | MMSE                       | –             | 0.94  | 0.81    | 1.08    |
| Gu, Y. J. | Cross-sectional study | China       | 2018 | 4,579                  | Others                     | –             | 0.74  | 0.57    | 0.98    |
| Fischer, K. | Cohort study | Germany       | 2018 | 2,622                  | Others                     | –             | 0.94  | 0.86    | 1.02    |
| Feng, L. | Cohort study | United States | 2018 | 3,844                  | MMSE                       | –             | 1.19  | 0.81    | 1.75    |
| Xu, H. | Cross-sectional study | China       | 2018 | 2,131                  | MoCA                       | Green tea for men | 0.66  | 0.46    | 0.93    |
| Chuang, S. Y. | Cross-sectional study | China       | 2019 | 1,245                  | MoCA                       | Green tea for women | 0.82  | 0.58    | 1.16    |
| Shirai, Y. | Cohort study | Japan        | 2020 | 1,305                  | MoCA                       | Black tea for men | 0.74  | 0.37    | 1.49    |
| Matsuyama, S. | Cohort study | Japan        | 2020 | 2,932                  | MoCA                       | Black tea for women | 0.52  | 0.24    | 1.12    |
| Qian, Yu–Xi | Cross-sectional study | China       | 2020 | 4,579                  | MoCA                       | Oolong tea for men | 0.39  | 0.09    | 1.88    |
| Wang, Z. | Cross-sectional study | China       | 2020 | 625                    | MoCA                       | Oolong tea for women | 0.60  | 0.13    | 2.72    |
| Huang, W. C. | Cross-sectional study | China       | 2021 | 1,115                  | MoCA                       | –             | 2.23  | 0.75    | 6.68    |

CDR, Clinical Dementia Rating; DECO, the “Détérioration Cognitive Observeée” (observed cognitive deterioration) questionnaire; IQCODE, informant questionnaire on cognitive decline in the elderly; LCI, lower confidence limit; MMSE: Mini–Mental State Examination; OR, odds ratio; RR, relative risk; U.S., The United States; UK, The United Kingdom; UCI, upper confidence limit; 3MSE, the modified Mini–Mental State.
and cognitive disorders. In addition, some meta-analyses (Kim et al., 2015; Ma et al., 2016) did not examine the dose-response association between tea drinking and cognitive disorders. Most recently, a meta-analysis (Ran et al., 2021) showed that tea drinking has a linear association with morbidity and cognitive deficits. The results (Ran et al., 2021) showed that drinking 1 cup of tea per day leads to a 6% reduction in cognitive deficits morbidity, whereas 2 cups per day leads to an 11% decrease. No subgroup analysis was performed in this study, however (Ran et al., 2021). Moreover, the outcomes included in this meta-analysis (Ran et al., 2021) were MCI, AD, or dementia, and there was no outcome on PD, and cognitive decline. Another previous meta-analysis (Li et al., 2012) reported an association between tea drinking and PD. However, this meta-analysis only included PD as the outcome (Li et al., 2012). Overall, few previous meta-analysis studies have explored the associations between tea drinking and different kinds of cognitive disorders including MCI, dementia, AD, and PD. Thus, we conducted the present meta-analysis with the recently updated data among older adults as a multidimensional evaluation of the dose-response association between tea drinking and cognitive outcomes. Moreover, subgroup analyses were also conducted.

Cognitive disorders include a cluster of diseases (Battle, 2013; Gong et al., 2019), such as MCI, PD, AD, and dementia. The severity of these diseases differs (Roberts and Knopman, 2013; Masters et al., 2015; Tysnes and Storstein, 2017; World Health Organization, 2020). At the same time, the methods for measuring and defining diseases are different among studies.
TABLE 2 | Combined results of subgroup analysis of tea drinking and cognitive function.

| Subgroup analysis | Pooled OR (95%CI), P-value for the heterogeneity Q-test, $I^2$ statistics (%) | number of estimates in included studies (n) |
|-------------------|-------------------------------------------------|------------------------------------------|
| **Study design**  |                                                 |                                          |
| Cohort            | 0.77 (0.69–0.87); $I^2 = 72.2\%$, $P = 0.000$ | 16                                       |
| Cross-sectional   | 0.69 (0.61–0.79); $I^2 = 41.6\%$, $P = 0.030$ | 13                                       |
| Case-control      | 0.87 (0.69–1.09); $I^2 = 63.1\%$, $P = 0.012$ | 7                                        |
| **Type of tea drinking** |                                             |                                          |
| Green tea        | 0.75 (0.66–0.84); $I^2 = 64.8\%$, $P = 0.002$ | 9                                        |
| Black tea        | 0.86 (0.58–1.28); $I^2 = 55.6\%$, $P = 0.061$ | 4                                        |
| **Study population** |                                             |                                          |
| Chinese           | 0.70 (0.62–0.79); $I^2 = 55.3\%$, $P = 0.001$ | 16                                       |
| Japanese          | 0.73 (0.63–0.83); $I^2 = 45.7\%$, $P = 0.075$ | 7                                        |
| North American    | 0.83 (0.59–1.17); $I^2 = 79.8\%$, $P = 0.000$ | 7                                        |
| European          | 0.91 (0.83–0.99); $I^2 = 16.9\%$, $P = 0.301$ | 6                                        |
| **Type of cognitive disorders** |                                         |                                          |
| Cognitive impairment | 0.73 (0.65–0.82); $I^2 = 65.7\%$, $P = 0.000$ | 18                                       |
| Dementia          | 0.85 (0.76–0.95); $I^2 = 61.9\%$, $P = 0.001$ | 14                                       |
| PD                | 0.73 (0.50–1.08); $I^2 = 61.1\%$, $P = 0.036$ | 4                                        |
| Cognitive decline | 0.71 (0.53–0.96); $I^2 = 81.4\%$, $P = 0.000$ | 6                                        |
| **Type of disease assessment** |                                 |                                          |
| MMSE              | 0.70 (0.63–0.79); $I^2 = 55.6\%$, $P = 0.000$ | 20                                       |
| 3MSE              | 0.74 (0.37–1.49); $I^2 = 90.0\%$, $P = 0.000$ | 3                                        |
| MoCA              | 0.71 (0.59–0.86); $I^2 = 0.0\%$, $P = 0.904$  | 2                                        |
| The Kihon Checklist | 0.77 (0.70–0.85); $I^2 = 0.0\%$, $P = 0.464$ | 3                                        |
| CDR               | 0.51 (0.19–1.40); $I^2 = 87.9\%$, $P = 0.000$ | 2                                        |
| IQCODE            | 0.37 (0.24–0.58); $I^2 = 14.8\%$, $P = 0.279$ | 1                                        |
| DECO score        | 0.93 (0.80–1.07); $I^2 = 0.0\%$, $P = 0.659$  | 1                                        |
| Others            | 0.79 (0.69–0.92); $I^2 = 62.9\%$, $P = 0.001$ | 14                                       |

CDR, Clinical Dementia Rating; DECO, the “Détérioration Cognitive Observée” (observed cognitive deterioration) questionnaire; IQCODE, informant questionnaire on cognitive decline in the elderly; MMSE: Mini–Mental State Examination; MoCA, Montreal Cognitive Assessment; PD, Parkinson’s disease; 3MSE, the modified Mini-Mental State.

Therefore, we conducted subgroup analyses according to types of cognitive disorders and disease assessment. In addition, different types of tea have different ingredients and different health effects (Mhatre et al., 2021). Different regions have different drinking habits and prefer different types of tea (Cabrera et al., 2006; Cheng, 2006; Chacko et al., 2010; Johnson et al., 2012). Therefore, we conducted subgroup analyses according to types of tea drinking and the study population. Finally, the study design (Mann, 2003) affects the reliability of the results. Thus, a subgroup analysis according to different study designs was performed.

The subgroup analysis showed that drinking tea was associated with cognitive impairment, cognitive decline, and dementia, but no apparent association was found in the outcome of PD. This finding may be partially attributed to the limited evidence between tea drinking and PD in the studies we included. The subgroup analysis showed that drinking tea may be associated with cognitive disorders among Chinese, Japanese, and European subgroups, but no such association was found in the North American subgroup. We speculate that the main reason for this
finding may be related to the different kinds of popular tea in different areas. For example, North Americans prefer black tea to green tea. The nutritional and functional components of black and green teas are not quite the same. For example, the levels of catechin (ECGC) are highest in green tea, followed by black tea (Lin et al., 2003). Moreover, green tea contains ascorbic acid and a high intake of ascorbic acid is related to a reduced risk of AD (Engelhart et al., 2002); however, black tea does not contain ascorbic acid (Noguchi-Shinohara et al., 2014). This finding was also confirmed by our subgroup analysis which showed green tea, but not black tea, was negatively associated with cognitive disorders. Subgroup analysis also showed that the type of disease assessment can have an impact on the outcome. Future studies should take into consideration the type of assessment used when assessing different cognitive disorders.

The advantages of this meta-analysis were as follows: First, the symmetric distribution included in the study enhanced the reliability of the statistical analysis. Second, the literature included in our meta-analysis was of medium-to-high quality, which made the result more stable. Third, this meta-analysis included as much literature as possible (Kim et al., 2015), which not only expanded the sample population, but also added the subgroup analysis, which enhanced the evidence strength of the study. Finally, the dose-response analysis improved the quality and intensity of our findings.

The present meta-analysis had some potential limitations. First, we detected slight heterogeneity in the study, which could be interpreted by differences in population source, study design, tea drinking type, cognitive disorders detection, and analysis strategies. Second, some important confounding factors were not adjusted in the initial study, such as lifestyle (diet and interest), and some related conditions (urinary disease and dyslipidemia). Therefore, we could not rule out confounders, such as accidental, residual, or unmeasured factors, which may have caused our results to be biased. Third, in most of the studies included, the data of tea drinking came from self-administered questionnaires, which inevitably lead to misclassification. Fourth, although the result was derived from a few studies, the studies were not comprehensive in terms of tea subtype, study population, study type, assessment type, and disease type, which may have led to unstable or limited secondary analysis results. Finally, we treated HR/RR equal to OR according to the published studies (Li et al., 2012; Ran et al., 2021) which may have affected the results. A previous study (Bigby, 2000) suggested that using the OR as an approximation of the RR produces progressively larger errors as the outcome rate rises above 1%.

CONCLUSION
In conclusion, a total of 36 independent observational studies were included and supported that tea drinking is inversely proportional and linear associated with the occurrence of cognitive disorders in older adults. Future randomized controlled trials of tea (not tea extract) are needed to confirm our results.

DATA AVAILABILITY STATEMENT
The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS
MS: conceptualization, formal analysis, visualization, and writing-original draft. LC: writing-review and editing, and supervision. HL, YZho, and YZha: writing-review and editing. YX: conceptualization, resources, writing-review and editing, supervision, and funding acquisition. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL
The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnagi.2022.845053/full#supplementary-material

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