Effect of alcohol consumption on food energy intake: a systematic review and meta-analysis

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Abstract

The relationship between alcohol consumption and body weight is complex and inconclusive being potentially mediated by alcohol type, habitual consumption levels and sex differences. Heavy and regular alcohol consumption has been positively correlated with increasing body weight, although it is unclear whether this is due to alcohol consumption per se or to additional energy intake from food. This review explores the effects of alcohol consumption on food energy intake in healthy adults. CINAHL Plus, EMBASE, Medline and PsycINFO were searched through February 2018 for crossover and randomised controlled trials where an alcohol dose was compared with a non-alcohol condition. Study quality was assessed using the Effective Public Health Practice Project tool. A total of twenty-two studies involving 701 participants were included from the 18427 papers retrieved. Studies consistently demonstrated no compensation for alcoholic beverage energy intake, with dietary energy intake not decreasing due to alcoholic beverage ingestion. Meta-analyses using the random-effects model were conducted on twelve studies and demonstrated that alcoholic beverage consumption significantly increased food energy intake and total energy intake compared with a non-alcoholic comparator by weighted mean differences of 343 (95% CI 161, 525) and 1072 (95% CI 820, 1323)kJ, respectively. Generalisability is limited to younger adults (18–37 years), and meta-analyses for some outcomes had substantial statistical heterogeneity or evidence of small-study effects. This review suggests that adults do not compensate appropriately for alcohol energy by eating less, and a relatively modest alcohol dose may lead to an increase in food consumption.

Key words: Alcohol consumption; Food energy intake; Total energy intake; Food intake; Systematic reviews

In 2014, the WHO reported that 38% of men and 40% of women were classified as overweight and 11% of men and 15% of women were classified as obese, with prevalence of both trending upwards1. Total alcohol per capita consumption also increased from 2005 to 2010 and predicted an upward trajectory2. With an energy density of 29 kJ/g, second only to dietary fat, it is logical to hypothesise that in those who voluntarily consume alcoholic beverages, this will contribute to their overall energy intake3. However, the relationship between alcoholic beverage consumption and overweight and obesity is complex and inconsistent3. Alcohol type, habitual consumption patterns and sex are factors that may mediate the relationship between alcohol consumption and body weight. Evidence suggests that type of alcoholic beverage is important; for example, wine has been shown to be more protective against weight gain than beer and spirits in observational studies4. In women, mild to moderate alcohol consumption is associated with lower weight, whereas in men, moderate intake was associated with higher weight4. Bendsen et al.5 reviewed thirty-five observational studies on the association between beer consumption and general obesity. A positive association or no association between beer consumption and general obesity was observed in men, whereas an inverse association or no association with general obesity was observed in women5. Analyses conducted on the 2008–2014 Healthy Survey for England and the Scottish Health Survey found that in both male and female young adults, those consuming the highest levels of alcohol on a single drinking session were more likely to be overweight or obese compared with those with the lowest intake6.

Aside from alcohol type and sex differences, it has been suggested a dose-dependent response exists for ‘heavy’ alcohol drinking, defined as greater than two to three standard drinks per d, was more positively associated with increased body weight compared with low to moderate alcohol drinking4. Across all WHO regions in 2014, the prevalence of heavy episodic drinking in people aged 15 years and over was 12·3 and 2·9% for males and females, respectively2. To add further complexity, a J-shaped association between alcohol consumption and negative health outcomes has been reported, with low

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**Abbreviations:** E-beverage, energy-containing beverages; N-beverage, no beverage; NE-beverage, beverages that contained no or negligible energy.

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to moderate alcohol consumption correlated with reduced risk of multiple cardiovascular outcomes; whereas high alcohol consumption is correlated with increased risk of oral, pharyngeal and oesophageal cancers\(^{(7,8)}\).

Alcohol consumption has been suggested to stimulate appetite and potentially increase food intake. Although the mechanisms are unclear, it has been postulated that ingestion of alcohol appears to bypass the satiety mechanisms that modulate short term food intake\(^{(9,10)}\). Alcohol has been proposed to support an overall increase in food intake in two different pathways: (1) binding to type-A gamma-aminobutyric acid (GABA\(_A\)) receptors and stimulating the release of opioid and (2) decreasing the serotonin response, a hunger suppressor\(^{(3,9)}\). Alcoholic beverages may contribute to passive over-consumption of energy from foods. The relatively high energy density of alcoholic beverages may be additive to food energy intake, meaning it may be easier to unintentionally consume excess dietary energy\(^{(9,10)}\).

Studies consistently demonstrate that energy gained through the consumption of alcoholic beverages is not compensated for by eating less food in the short-term\(^{(10-12)}\). Energy compensation involves the modification of energy intake in response to previous consumption of either food or beverage and is fundamental for regulating energy balance\(^{(13,14)}\). Energy compensation in response to consumption of beverages is generally poor, particularly when compared with energy compensation in response to consumption of semi-solid or solid food\(^{(13)}\). A combination of increased appetite and poor compensation of energy from alcohol could contribute to the impact on energy intake in regular consumers of alcoholic beverages.

The effects of alcohol consumption on food intake have been reviewed before 2012\(^{(9,10,15-17)}\). Three narrative reviews\(^{(9,10,15)}\) suggested that alcohol consumption increases acute food intake, and a meta-analysis\(^{(16)}\) concluded that alcohol consumption increased the total energy intake. A minireview\(^{(17)}\) with limited scope further supported that alcohol consumption increased food energy intake, however, only at high alcohol doses and cautioned the findings due to the small sample sizes of the included studies\(^{(16)}\). No extensive systematic review with meta-analysis has been previously conducted to investigate the effects of alcohol consumption on both food energy intake and total energy intake in adult humans.

Hence, the aim of this review was to determine the impact of alcohol consumption on (1) food energy intake and (2) total energy intake (the sum of both the beverage and food consumption). This review aimed to elicit a stronger understanding of whether there is a dose response to alcohol consumption that impacts energy intake or whether other factors, such as the energy content of the comparator beverage, is important.

### Methods

A systematic review with meta-analysis of aggregate data was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines\(^{(18)}\). A review protocol does not exist.

### Table 1. Participant, intervention, comparator, outcome, study design, inclusion and exclusion criteria used to determine study eligibility

<table>
<thead>
<tr>
<th>Inclusion criteria</th>
<th>Exclusion criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Population</strong></td>
<td>Healthy populations</td>
</tr>
<tr>
<td><strong>Intervention</strong></td>
<td>Consumption of an alcoholic beverage with a specified alcohol dose</td>
</tr>
<tr>
<td><strong>Comparator</strong></td>
<td>Consumption of a non-alcoholic beverage or no beverage</td>
</tr>
<tr>
<td><strong>Outcomes</strong></td>
<td>Report mean differences in food intake, food energy intake or total energy intake, with or after consumption of a beverage or no provided beverage</td>
</tr>
<tr>
<td><strong>Study design</strong></td>
<td>Randomised controlled trial, randomised crossover and crossover trials</td>
</tr>
</tbody>
</table>

### Eligibility criteria

The participant, intervention, comparator, outcome, study design was used to develop eligibility criteria for study inclusion (Table 1). Original peer-reviewed randomised controlled trials (RCT), randomised crossover or non-randomised crossover trials only were eligible for inclusion.

### Search strategy

A systematic search was conducted for studies comparing alcohol consumption against a non-alcoholic comparator on ad libitum food energy intake in healthy adult participants (≥18 years of age) with no date limits and all papers up to 1st February 2018 were included. A database search was conducted of CINAHL Plus, Embase, Medline and PsycINFO by one author (A. K.). A proximal search strategy was employed, linking the terms or variations of ‘alcohol drinking’, ‘alcoholic beverages’, ‘beer’, ‘wine’, ‘spirits’, ‘food intake’, ‘energy intake’, ‘eating behaviour’, ‘appetite’ and ‘satiety’. Table 2 provides the Ovid Medline search strategy. Limits were applied to exclude non-English-language articles and animal studies.

### Literature screening

All retrieved articles were independently assessed for inclusion by two authors (A. K. and G. P.) after duplicates were removed electronically. Endnote X7 (Clarivate Analytics) was used to store all the references, and Covidence (Covidence) was used to screen articles for eligibility. Studies were excluded on the basis of title and abstract. Full-text articles were then obtained and assessed for eligibility independently by two authors. A third author (H. T.) was consulted for any discrepancies.

### Data extraction

Data extraction for each eligible study was conducted independently by two authors (A. K. and G. P.) using a specifically
developed standardised data extraction tool, which included publication details, study design, study procedures and classification of hierarchy of evidence according to the National Health and Medical Research Council guidelines(20). Sample size and participant characteristics were extracted including age, sex, baseline BMI, usual alcohol consumption and degree of restrained eating. Specific to alcohol, details of the dose, type of alcoholic beverage, volume and the non-alcoholic comparator were recorded. Non-alcoholic comparators used in the included studies were coded into three groups: (1) beverages that contained no or negligible energy (NE-beverage), (2) no beverage (N-beverage) and (3) energy-containing beverages (E-beverage). The timing of the alcohol and comparator beverage provision relative to the consumption of the food was recorded along with compliance measures, time to follow-up, potential study bias and funding sources. Outcome measures for both the alcoholic and non-alcoholic beverage comparators included differences in food energy intake (kJ), total energy intake (kJ) or food mass (g) consumed. Total energy intake was defined as the sum of food energy intake and beverage energy intake. Body weight change was also recorded where reported. For each measure, the mean and either the standard deviation or the standard error of the mean were recorded where reported or provided by authors. Sensitivity analysis was conducted using correlation coefficients of 0·5 was used to impute the standard error of the mean difference in food energy intake and total energy intake, if not reported in the publication or provided by the authors. Sensitivity analysis was conducted using correlation coefficients of 0·2 and 0·8. Heterogeneity was assessed using the Q statistic, and its P value and inconsistency were assessed using an extension of the Q statistic, the I² statistic. Values of P<0·10 or values of I²>50% suggested substantial heterogeneity. Given the diversity in clinical characteristics across studies, and our aim to estimate the average (rather than common) effect across studies, we used a random-effects model in all meta-analyses and sub-group analyses. For our primary analyses, we used the between-study variance estimator developed by DerSimonian & Laird(26) and calculated the Wald-type normal distribution CI. We also performed a sensitivity analysis using the Hartung–Knapp–Sidl–Jonkman (HKS) method for random-effects meta-analyses(27). Both a qualitative (funnel plot) and a quantitative (Egger’s regression
test) approach were used to examine the potential small-study effects, the tendency for smaller studies to have systematically different results when compared with larger studies. An influence analysis was conducted using the random-effects model (DerSimonian and Laird) to determine the effect of removing each included study on the overall effect and 95% CI. The meta-analyses, funnel plot and Egger’s regression test were conducted using Stata 13 software (Stata Corp.) with the metan, metafunnel and metabias packages. The influence analysis was conducted using MetaXL 5.3 (Epigear International). A P value of <0.05 for meta-analyses was considered statistically significant.

Results

Study selection and characteristics

A total of 18,427 papers were retrieved (Ovid Medline = 5509, EMBASE = 9480, CINAHL Plus = 2259, PsycINFO = 1179). One paper (28) reported two different studies of which both were eligible, whereas two papers (29, 30) reported two different studies with only one being eligible in each paper. In total, twenty-two separate studies met the PICOS inclusion criteria and were included (Fig. 1). The study characteristics for the twenty-two studies are provided (Table 3). Nine studies (30–38) were excluded and justification for exclusion is provided in online Supplementary Table S1.

Study design

Thirteen studies (12, 28, 29, 39–41, 47, 49–51, 54) employed a randomised crossover trial design, four utilised (24, 42, 46, 48) a randomised parallel trial design and five, a non-randomised crossover trial design (11, 43–44, 52, 53).

Sixteen studies (12, 24, 28, 39, 40, 42, 45–49, 51–54) utilised a pre-load paradigm design where ingestion of a beverage occurred a set period of time before the consumption of food. The time between consuming the pre-load and consuming the first test food varied between studies, from 10 min (46) up to 2 h (28). In all of these studies, alcohol ingestion was compared with non-alcoholic comparator conditions. Six studies (12, 29, 39–41, 45) provided a standardised control meal for participants before the start of the study, five (28, 49, 52–54) instructed participants to consume their own ‘usual’ meal and one study (28) instructed participants to fast before the testing.

![Study selection flow diagram](https://www.cambridge.org/core/terms). Figure 1. Study selection flow diagram.
<table>
<thead>
<tr>
<th>Reference and country</th>
<th>Study design</th>
<th>Subjects (n) and sex</th>
<th>Age (years) and BMI (kg/m²)</th>
<th>Timing of beverage consumption</th>
<th>Intervention</th>
<th>Volume (ml)</th>
<th>Alcohol dose (g)</th>
<th>Comparator</th>
<th>Volume (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buemann et al. (2002)[10], Denmark</td>
<td>Three-arm, randomised crossover trial</td>
<td>22 males</td>
<td>Aged 20–33.0</td>
<td>Before and with the food</td>
<td>Red wine</td>
<td>3.2 ml/kg*</td>
<td>0.3 g/kg†</td>
<td>Carbonated soft drink</td>
<td>9.0 ml/kg*</td>
</tr>
<tr>
<td>Caton et al. (2004)[11], UK</td>
<td>Single-blind, three-arm, randomised crossover trial</td>
<td>12 males</td>
<td>Aged 18–35.0</td>
<td>30 min before food was served</td>
<td>Lager beer</td>
<td>370</td>
<td>32.0</td>
<td>No alcohol lager</td>
<td>330</td>
</tr>
<tr>
<td>Caton et al. (2005)[12], UK</td>
<td>Single-blind, four-arm, randomised crossover trial</td>
<td>12 males</td>
<td>Aged 18–50.0</td>
<td>20 min before food was served</td>
<td>Carbonated grape juice with alcohol and bland foods</td>
<td>405</td>
<td>24.0</td>
<td>Carbonated grape juice and flavoured foods</td>
<td>405</td>
</tr>
<tr>
<td>Caton et al. (2007)[13], UK</td>
<td>Three-arm, randomised crossover trial</td>
<td>12 males</td>
<td>Mean age 24.7</td>
<td>Either before or during the consumption of the food</td>
<td>Red wine (aperitif)</td>
<td>375</td>
<td>38.5</td>
<td>No beverage</td>
<td>0</td>
</tr>
<tr>
<td>Christiansen et al. (2016)[14], UK</td>
<td>Single-blind, two-arm, RCT</td>
<td>60 females</td>
<td>Mean age 19.6</td>
<td>10 min before food was served</td>
<td>Vodka and diet lemonade</td>
<td>270</td>
<td>27.6</td>
<td>Abstinence from alcoholic beverages for 6 weeks</td>
<td>NR</td>
</tr>
<tr>
<td>Cornall et al. (1997)[15], UK</td>
<td>Two-arm, crossover trial</td>
<td>14 males</td>
<td>Mean age 29.8</td>
<td>Co-administered with the evening meal daily</td>
<td>Red wine (daily for 6 weeks)</td>
<td>270</td>
<td>19.4</td>
<td>Abstinence from any alcoholic beverages for 10 weeks</td>
<td>NR</td>
</tr>
<tr>
<td>Cornall et al. (2000)[16], USA</td>
<td>Two-arm, crossover trial</td>
<td>20 females</td>
<td>Aged 30.0–50.0</td>
<td>Co-administered with the evening meal on 5 d each week</td>
<td>Red wine (each day, for 5 d each week for 10 weeks)</td>
<td>270</td>
<td>NR</td>
<td>No beverage</td>
<td>0</td>
</tr>
<tr>
<td>Follin et al. (1993)[17], USA</td>
<td>Single-blind, five-arm, parallel crossover trial</td>
<td>6 males</td>
<td>Mean age 28.2</td>
<td>Beverages were consumed at 09.30, 13.15, 16.45 and 20.15 hours</td>
<td>Low-energy cocktail of juice and alcohol</td>
<td>300</td>
<td>0.3 g/kg†</td>
<td>Low-energy cocktail of juice and dextrose</td>
<td>300</td>
</tr>
<tr>
<td>Hetherington et al. (2001)[18], UK</td>
<td>Single-blind, three-arm, randomised crossover trial</td>
<td>26 males</td>
<td>Aged 18.0–40.0</td>
<td>30 min before food was served</td>
<td>High-energy cocktail of juice and alcohol</td>
<td>300</td>
<td>0.5 g/kg†</td>
<td>High-energy cocktail of juice and dextrose</td>
<td>300</td>
</tr>
<tr>
<td>Hofmann et al. (2008)[19], Germany</td>
<td>Single-blind, two-arm, RCT</td>
<td>63 females</td>
<td>Mean age 21.6</td>
<td>10 min before food was served</td>
<td>Vodka and OJ</td>
<td>300</td>
<td>0.4 g/kg†</td>
<td>OJ</td>
<td>300</td>
</tr>
<tr>
<td>Hollister (1970)[20], USA</td>
<td>Study 1: double-blind, four-arm, randomised crossover trial</td>
<td>12 (eleven males, one female)</td>
<td>Age NR</td>
<td>Before the consumption of the milkshakes, up to 5 h beforehand</td>
<td>Diet soft drink with alcohol</td>
<td>180</td>
<td>0.8 g/kg†</td>
<td>Diet soft drink with marijuana</td>
<td>180</td>
</tr>
<tr>
<td>Hollister (1970)[21], USA</td>
<td>Study 2: double-blind, three-arm, randomised crossover trial</td>
<td>12 males</td>
<td>Age NR</td>
<td>Before the consumption of the milkshakes, up to 5 h beforehand</td>
<td>Diet soft drink with alcohol</td>
<td>180</td>
<td>0.5 g/kg†</td>
<td>Diet soft drink with dextroamphetamine sulphate</td>
<td>180</td>
</tr>
<tr>
<td>Hollister (1970)[22], USA</td>
<td>Five-arm randomised crossover trial</td>
<td>16 (eight males, eight females)</td>
<td>Males</td>
<td>Co-administered with a controlled snack on day 2</td>
<td>Beer (5 % alcohol)</td>
<td>1080</td>
<td>54.0</td>
<td>Cold</td>
<td>1080</td>
</tr>
<tr>
<td>Holtz (1996)[23], USA</td>
<td></td>
<td></td>
<td>Females</td>
<td></td>
<td>Beer (2.9 % alcohol)</td>
<td>1080</td>
<td>31.3</td>
<td></td>
<td>1080</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Beer (0.1 % alcohol)</td>
<td>1080</td>
<td>10.8</td>
<td></td>
<td>1080</td>
</tr>
<tr>
<td>Reference and country</td>
<td>Study design</td>
<td>Subjects (n) and sex</td>
<td>Age (years) and BMI (kg/m²)</td>
<td>Timing of beverage consumption</td>
<td>Intervention</td>
<td>Volume (ml)</td>
<td>Alcohol dose (g)</td>
<td>Comparator</td>
<td>Volume (ml)</td>
</tr>
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</tr>
<tr>
<td>Ouwens et al. (2003)²⁰, The Netherlands</td>
<td>Single blind, two-arm, RCT</td>
<td>119 females</td>
<td>Mean age 21.1 (± 2.3) Mean BMI 23.1 (± 2.6)</td>
<td>20 min before the food was served</td>
<td>Vodka and OJ</td>
<td>400</td>
<td>24.4</td>
<td>OJ</td>
<td>400</td>
</tr>
<tr>
<td>Poppitt et al. (1996)²⁰, UK</td>
<td>Single blind, four-arm, randomised crossover trial</td>
<td>20 females</td>
<td>Mean age 37.0 (± 11.4) Mean BMI 23.0 (± 2.8)</td>
<td>30 min before the food was served</td>
<td>Gin and tonic</td>
<td>392 g</td>
<td>30</td>
<td>Gin-flavoured slimline tonic and water, Gin-flavoured slimline tonic, water and maltodextrin</td>
<td>392 g</td>
</tr>
<tr>
<td>Rose et al. (2019)²⁰, UK</td>
<td>Four-arm, randomised controlled parallel trial</td>
<td>114 (sixty-six females, forty-eight males)</td>
<td>Vodka and bar-lab Mean age 20.5 (± 3.2) Mean BMI NR</td>
<td>20 min before food was served</td>
<td>Vodka and diet lemonade and bar-lab</td>
<td>400</td>
<td>0.6 g/kg</td>
<td>Diet soft drink and bar-lab environment</td>
<td>400</td>
</tr>
<tr>
<td>Schrieks et al. (2015)²⁰, The Netherlands</td>
<td>Single-blind, six-arm, randomised crossover trial</td>
<td>24 males</td>
<td>Mean age 32.0 (± 0.8) Mean BMI 23.0 (± 0.1) Excluded restrained eaters</td>
<td>45 min before the food was served</td>
<td>Vodka and OJ with 40 g butter cake consumption</td>
<td>200</td>
<td>20</td>
<td>OJ with maltodextrin and 40 g butter cake consumption</td>
<td>200</td>
</tr>
<tr>
<td>Tremblay et al. (1995)²⁰, Canada</td>
<td>Single blind, four-arm, randomised crossover trial Five-arm, randomised crossover trial</td>
<td>8 males</td>
<td>Mean age 36.4 (± 6.9) Mean BMI 23.7 (± 2.5)</td>
<td>Co-administered with both lunch and dinner</td>
<td>Vodka and OJ Beer and low-fat foods</td>
<td>200</td>
<td>20</td>
<td>OJ and maltodextrin</td>
<td>200</td>
</tr>
<tr>
<td>Westerterp-Plantenga et al. (1999)²¹, The Netherlands</td>
<td>Three-arm, randomised crossover trial</td>
<td>52 (twenty-seven females, twenty-five males)</td>
<td>Aged 20–45 BMI between 20.0 and 32.0</td>
<td>30 min before the food was served</td>
<td>White wine Beer</td>
<td>340</td>
<td>29.5</td>
<td>High-fat beverage (fruit juice and cream) High-protein beverage (fruit juice and protein) High-carbohydrate beverage (fruit juice)</td>
<td>340</td>
</tr>
<tr>
<td>Yeomans et al. (1999)²⁰, UK</td>
<td>Three-arm crossover trial</td>
<td>24 males</td>
<td>Restricted eaters Mean age 25.4 (± 2.4) Mean BMI 23.2 (± 0.8) Unrestricted eaters Mean age 23.7 (± 1.3) Mean BMI 23.2 (± 0.8)</td>
<td>20 min before the food was served</td>
<td>Carbonated alcoholic apple juice</td>
<td>330</td>
<td>14</td>
<td>Carbonated non-alcoholic apple juice Sparkling spring water</td>
<td>330</td>
</tr>
<tr>
<td>Yeomans et al. (2002)²⁰, UK</td>
<td>Three-arm, crossover trial</td>
<td>18 males</td>
<td>Mean age 24.0 Mean BMI 22.8 Excluded restricted eaters</td>
<td>20 min before the food was served</td>
<td>Lager</td>
<td>300 g</td>
<td>15</td>
<td>No-alcohol lager with maltodextrin</td>
<td>300 g</td>
</tr>
<tr>
<td>Yeomans (2010)²⁰, UK</td>
<td>Four-arm, randomised crossover trial</td>
<td>40 females</td>
<td>Mean age 22.0 Mean BMI 22.6</td>
<td>30 min before the food was served</td>
<td>No-alcohol beer with alcohol Carbonated fruit juice with alcohol</td>
<td>300</td>
<td>15</td>
<td>No-alcohol beer with maltodextrin Carbonated fruit juice with maltodextrin</td>
<td>300</td>
</tr>
</tbody>
</table>

RCT, randomised controlled trial; NR, not reported; OJ, orange juice.

* ml/kg of body weight.
† g/kg of body weight.
‡ Grams of beverage was reported.
Of the twenty-two studies, fifteen included an E-beverage comparator (11,12,24,39,40,45–48), nine included an NE-beverage comparator (12,24,28,42,47,51–53) and four included an N-beverage comparator (11,41,45,51). The two longer term studies (45,44) did not specify the comparator type as participants abstained from consuming alcoholic beverages in free-living conditions. Two studies by the same author (28) used NE-beverage comparators comprising diet soft drink with marijuana, dextroamphetamine sulphate or marijuana with the cannabinoids removed.

The energy content of the E-beverage was important to take into account, and five studies (11,12,24,41,53,54) included an E-beverage comparator that was energy matched with the alcoholic beverage and eleven studies (12,29,39,40,45–48,50,52,54) included a hypocaloric E-beverage comparator, which was lower in energy content compared with the alcoholic beverage.

**Participants**

A total of 706 participants were in the included studies. The minimum number of participants in a study was six (11) while the maximum was 119 (48). There were a higher proportion of female (n 424, 60%) than male participants (n 282, 40%). Twelve studies (11,28,29,39–41,43,45,49,50,52,53) recruited only male participants, and six studies recruited only female participants (12,42,44,46,54). Studies mainly recruited younger participants whose mean age ranged from 19.6 (42) to 37.0 years (12). Mean body weight was reported in five studies (11,24,43,45,50) and it ranged from 65.4 (42) to 78.6 kg (43). Where reported, the mean BMI (12,41,42,44,46–50,52,53,54) ranged from 20.8 (42) to 29.8 kg/m² (44). Fourteen studies (11,24,29,39–45,47,48–50) reported either participants’ usual alcohol consumption or participants’ specified usual alcohol consumption in their participant eligibility criteria, where the intake ranged from a minimum of 28·0 g alcohol per month (43,44) to 267·3 g alcohol per week (48).

**Outcomes**

Food energy intake and the total energy intake for the included studies are presented in the online Supplementary Table S2.

**Food energy intake**

Participants’ food energy intake was reported by twelve studies (11,12,24,28,41,42,45,47,51–53) when compared with NE- or N-beverage comparator conditions. Alcohol consumption increased food energy intake in three studies (41,42,45) and remained unchanged in eight (12,24,28,47,51–53). One study (11) demonstrated a dose-dependent effect, with no change in food energy intake with a low-dose alcoholic beverage, but a significant decrease with the high-dose alcoholic beverage.

Of the fifteen studies (11,12,29,39,40,45–54) that compared an alcohol dose against an E-beverage on food energy intake, seven (40,45,46,49,51,53,54) reported a significant increase in food energy intake and eight studies (11,12,29,39,47,48,50,52) reported no significant change. Of the five studies (11,49,51,53,54) utilising an isoenergetic non-alcoholic comparator, four (49,51,53,54) showed that alcohol consumption increased food energy intake, when compared with the comparator. Of the thirteen studies (11,29,39,40,45,46,48–54) that compared a low-dose alcoholic beverage (<30 g or <0·6 g/kg) with E-beverages, seven studies (40,45,46,49,51,53,54) demonstrated that food energy intake increased with consumption of a low-dose alcoholic beverage when compared with E-beverages and six studies (11,29,39,48,50,52) showed no significant change. In contrast, of the four studies (11,12,39,47) that compared a high-dose alcoholic beverage (≥30 g or ≥0·6 g/kg) with E-beverages, all four studies (11,12,39,47) demonstrated no significant change in food energy intake.

Twelve studies (12,24,39–42,46,49,52–54) involving 417 participants reported mean data on food energy intake for both intervention and comparator groups enabling them to be included in a meta-analysis using a random-effects model. Alcoholic beverages resulted in statistically significant higher food energy intake compared with non-alcoholic beverage comparators (weighted mean difference 343 kJ, 95% CI 161, 525 kJ) (Fig. 2). Statistically significant heterogeneity and a substantial amount of inconsistency were observed. Sensitivity analysis using the HKSJ method (27) resulted in wider CI, although this did not change our conclusion (weighted mean difference 343 kJ, 95% CI 109, 577 kJ).

The asymmetrical funnel plots and Egger’s regression test suggests small-study effects may exist in the meta-analysis for food energy intake (Egger’s test: P = 0·002) (online Supplementary Fig. S1). There are several possible reasons for this asymmetry, including reporting biases, or clinical and methodological heterogeneity. A sensitivity analysis conducted using correlation coefficients of 0·2 and 0·8 to estimate the standard error of the mean difference in crossover trials did not substantially change the results of the meta-analysis. The influence analysis demonstrated that removing each study one by one did not substantially alter the overall effect (online Supplementary Table S3).

**Total energy intake**

Total energy intake (the sum of both the beverage and food consumption) was reported in eight studies (11,12,24,41,42,47,51,53) that compared the alcohol dose with either an NE-beverage or an N-beverage. Seven of those studies (11,12,24,41,42,51,53) showed a significant increase in the total energy intake with alcohol consumption, and one study (47) demonstrated no change with low-dose (31·3 g alcohol) but a significant increase with high-dose (54·g alcohol) alcoholic beverages. Of the seven studies that increased the total energy intake, five (11,12,24,41,42) utilised an alcohol dose ≥30 g or ≥0·6 g/kg.

Total energy intake was reported in nine studies (11,12,29,39,40,47,50,51,53) that compared the alcohol dose with an E-beverage. Alcohol consumption increased the total energy intake compared with E-beverages in two studies (40,53), no significant change was observed in three studies (11,29,51), and both a significant increase in total energy intake and no significant change was observed in four studies (12,29,47,50).

Two separate studies conducted by Cordain et al. (45,44) did not specify the type of non-alcoholic beverage comparator as these were both long-term free-living studies, however, they reported no significant change in the total energy intake between the alcohol consumption and abstinence periods.
None of the studies reported a decrease in food energy intake or total energy intake following consumption of alcohol.

Eight studies involving 269 participants reported data on total energy intake and were pooled and included in the meta-analysis. Total energy intake was increased with consumption of an alcoholic beverage compared with a non-alcoholic beverage or no beverage (weighted mean difference 1072 kJ, 95% CI 820, 1323 kJ) (Fig. 3). When compared with a non-alcoholic beverage, consumption of an alcoholic beverage resulted in an increase in total energy intake. Statistically significant heterogeneity and a substantial amount of inconsistency were observed. The 95% CI for the meta-analysis when using the HKSJ method were wider, although this did not alter the conclusion (weighted mean difference 1072 kJ, 95% CI 693, 1450 kJ).

No evidence of small-study effects in the meta-analysis of total energy intake was observed, based on visual inspection of a funnel plot and Egger's regression test ($P=0.8$) (online Supplementary Fig. S2). A sensitivity analysis conducted using correlation coefficients of 0·2 and 0·8 to estimate the standard error of the mean difference in crossover trials did not substantially change the results in the meta-analysis. The influence analysis demonstrated that removing each study one by one did not substantially alter the overall effect (online Supplementary Table S4).

**Impact of comparator type, alcohol dose and sex on food energy intake and total energy intake**

To explore the effects of comparator drink (NE-, N- and E-beverages), alcohol dose (defined by low and high alcohol dose) and sex (male only studies and female only studies), subgroup analyses were performed (Table 4). The subgroup analyses for comparator type indicated that alcohol consumption significantly increased food energy intake when compared with NE- and N-beverages as well as E-beverages. While food energy intake increased to a greater extent with alcohol consumption when E-beverages were compared with NE- and N-beverages, overlapping 95% CI were observed. Alcohol consumption significantly increased the total energy intake when compared with both NE- and N-beverages and E-beverages. The total energy intake increased to a greater extent with alcohol consumption when NE- and N-beverages were compared with E-beverages; however, overlapping 95% CI were observed. For food energy intake, both low-dose and high-dose alcohol increased food energy intake. Low-dose alcohol increased food energy intake to a greater extent compared with high-dose alcohol, although overlapping 95% CI were observed. Both low-dose and high-dose alcohol increased the total energy intake, when compared with non-alcoholic comparators. High-dose alcohol increased to a greater extent than low-dose alcohol, although overlapping 95% CI were observed. Subgroup analyses for sex demonstrated that with both male-only studies and female-only studies, alcohol consumption significantly increased food energy intake, when compared with non-alcoholic comparators. Food energy intake was increased to a greater extent with alcohol consumption in male-only studies when compared with female-only studies; however, overlapping 95% CI were observed. Both male-only studies and female-only studies observed a significant increase in the total energy intake.
when compared with non-alcoholic comparators. Similar to food energy intake, total energy intake was increased to a greater extent with alcohol consumption in male-only studies when compared with female-only studies; however, overlapping 95% CI were observed.

**Body weight change**

Body weight change was reported in three studies which had a duration of between 13 d and 10 weeks\(^\text{(28,46,48)}\). Two of the studies reported no significant differences in body weight change between the alcoholic intervention period, abstention period and baseline\(^\text{(43,44)}\). One study reported that weight increased significantly by a mean of 0.9 (\(\text{SE} 0.4\)) kg between the first and last day, although this weight change could not be directly attributable to the consumption of a specific beverage\(^\text{(11)}\).

**Quality assessment and risk of bias**

Eighteen studies\(^\text{(11,12,24,29,39–45,47,49–54)}\) achieved a strong rating as defined by the EPHPP quality assessment tool, four studies\(^\text{(28,46,48)}\) were moderate and no studies were identified as weak (Fig. 4 and online Supplementary Table S5). Inadequate reporting of the randomisation method was the main reason for lower quality ratings. Nine studies\(^\text{(23,39,40,42,47,48,52–54)}\) did not report a source of funding that would present a conflict of interest, and five studies\(^\text{(12,29,43,44,51)}\) reported either industry funding or industry supply of alcohol for the study. Only two experiments\(^\text{(28)}\) used double-blind conditions, while twelve studies\(^\text{(11,12,29,39,40,42,45–50)}\) were single-blinded. Single-blind conditions were achieved by disguising either the true nature of the study to participants or the non-alcoholic beverage or a combination of both.

**Discussion**

To our knowledge, this is the first systematic review with meta-analyses performed for all available RCT and non-randomised crossover studies that compared the effect of alcohol consumption on both food energy intake and total energy intake in humans. All twenty-two studies consistently demonstrated that participants did not reduce their food energy intake to compensate for the energy consumed from alcoholic beverages.

**Food energy intake**

Previously, it has been suggested that alcoholic beverage consumption may increase food energy\(^\text{(10)}\). In this review, the studies indicate that energy consumption as food is acutely increased by an average of 343 kJ after alcohol consumption. Rather, alcohol's pharmacological effects on several neurotransmitters in the central nervous system that influence
<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Subgroup</th>
<th>No. of trials</th>
<th>Participants</th>
<th>Statistical method</th>
<th>Test of heterogeneity (P)</th>
<th>Heterogeneity (I²), %</th>
<th>Net change (kJ)</th>
<th>95 % CI</th>
<th>P for meta-analysis</th>
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<tbody>
<tr>
<td>Food energy intake</td>
<td>N- and NE-beverage comparators</td>
<td>8</td>
<td>271</td>
<td>Mean difference (IV, random, 95 % CI)</td>
<td>0.04</td>
<td>52</td>
<td>215.03</td>
<td>16.53, 413.53</td>
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<tr>
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<td>E-beverage comparators</td>
<td>10</td>
<td>232</td>
<td>Mean difference (IV, random, 95 % CI)</td>
<td>&lt; 0.001</td>
<td>87</td>
<td>410.46</td>
<td>143.91, 677.02</td>
<td>0.003</td>
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<tr>
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<td>N- and NE-beverage comparators</td>
<td>7</td>
<td>245</td>
<td>Mean difference (IV, random, 95 % CI)</td>
<td>0.002</td>
<td>71</td>
<td>1150.46</td>
<td>857.81, 1443.11</td>
<td>&lt; 0.001</td>
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<td>E-beverage comparators</td>
<td>5</td>
<td>84</td>
<td>Mean difference (IV, random, 95 % CI)</td>
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<td>74</td>
<td>746.75</td>
<td>338.82, 1154.69</td>
<td>&lt; 0.001</td>
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<tr>
<td>Food energy intake</td>
<td>Low alcohol dose (&lt;30 g or &lt;0.6 g/kg)</td>
<td>9</td>
<td>212</td>
<td>Mean difference (IV, random, 95 % CI)</td>
<td>&lt; 0.001</td>
<td>86</td>
<td>388.94</td>
<td>121.85, 656.03</td>
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<tr>
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<td>High alcohol dose (≥30 g or ≥0.6 g/kg)</td>
<td>6</td>
<td>217</td>
<td>Mean difference (IV, random, 95 % CI)</td>
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<td>4</td>
<td>64</td>
<td>Mean difference (IV, random, 95 % CI)</td>
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<td>81</td>
<td>759.29</td>
<td>263.79, 1254.79</td>
<td>0.003</td>
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<tr>
<td>Total energy intake</td>
<td>High alcohol dose (≥30 g or ≥0.6 g/kg)</td>
<td>6</td>
<td>217</td>
<td>Mean difference (IV, random, 95 % CI)</td>
<td>&lt; 0.001</td>
<td>80</td>
<td>1229.37</td>
<td>830.25, 1628.49</td>
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<td>125</td>
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<td>37</td>
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<td>Mean difference (IV, random, 95 % CI)</td>
<td>&lt; 0.001</td>
<td>90.4</td>
<td>321.17</td>
<td>-0.48, 642.82</td>
<td>0.05</td>
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<td>75</td>
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<td>76.5</td>
<td>1146.56</td>
<td>712.30, 1580.83</td>
<td>&lt; 0.001</td>
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<td>80</td>
<td>Mean difference (IV, random, 95 % CI)</td>
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<td>66.9</td>
<td>710.48</td>
<td>208.69, 1212.28</td>
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N-beverage, no beverage; NE-beverage, beverages that contained no or negligible energy; E-beverage, energy-containing beverages.
behaviour may explain this effect\textsuperscript{(10,56)}. Alcohol binds to GABA\textsubscript{A} receptors at low to moderate doses, which is involved in the control of food intake in mice\textsuperscript{(9,56,57)}. In vitro and animal studies have also shown that alcohol consumption stimulates the release of opioid peptides, which has been postulated to be associated with orosensory reward aspects that influence food intake\textsuperscript{(58,59)}.

The only study\textsuperscript{390} in this review that investigated a dose–response relationship between alcohol and food consumption reported that alcohol increased food energy intake only after consumption of 32 g of alcohol. Conversely, the present review found no increase in food energy intake after consumption of a high alcohol dose (\geq 30 g or \geq 0.6 g/kg) compared with NE- or N-beverages and E-beverages. The discrepancy in findings may be due to the differences in methodologies among the reviewed studies as well as the review pooling available data from the included studies. Reviewed studies used both fixed and adjusted alcohol, different alcohol doses and types of alcohol. However, the highest fixed dose of alcohol used in a study was 54 g\textsuperscript{(47)} and the highest adjusted alcohol dose was 0.75 g/kg\textsuperscript{(20)}. In 2016, 26.9\% of the UK drinking population reported binge drinking alcohol on their heaviest drinking day, which means that males and females had consumed in excess of 64 and 48 g of alcohol, respectively\textsuperscript{(600)}. This is greater than the included review’s highest alcohol doses of 54 g and 0.75 g/kg in one sitting, for fixed dose and adjusted dose, respectively. As this review’s findings are inconsistent with the findings of one study\textsuperscript{390} that investigated a dose–response relationship, further research is warranted to investigate a possible dose–response relationship between alcohol consumption and food energy intake. Differences in study populations, types of alcoholic beverages provided and the usual eating habits could vastly influence the dose–response relationship observed\textsuperscript{390}.

In addition, the combination of the type of alcohol ingested and the types of food served may influence results. It has previously been suggested that consumers value food pairings with wine, although this was less important with beer\textsuperscript{(61)}, which was reported to pair well with ‘junk or snack-type food’. Food that were identified to be consumed with beer were snacks or convenience foods such as nuts and crisps\textsuperscript{(61)}. In the studies reviewed here, beer was predominantly used as the intervention alcoholic beverage, although the food provided varied. More research needs to be performed to see whether types of alcoholic beverages and their consumption with specific types of food influence food energy intake. For example, if drinkers were provided a choice when they drink beer, it would be insightful to investigate whether they prefer to consume more or less energy-dense foods.

### Total energy intake

The present review demonstrated that alcohol consumption, when compared with non-alcoholic NE- or N-beverages, increased the total energy intake by an average of 1072 kJ, which is the sum of food energy and beverage energy intake. However, due to inconsistent reporting of total energy intake within the five studies that used isoenergetic non-alcoholic E-beverages comparators, no associations were able to be determined. All twenty-two reviewed studies consistently reported that participants did not compensate for the energy that was consumed as part of the alcoholic beverage by eating less food, which was similarly reported by Yeomans\textsuperscript{(10)}.

An increase in total energy intake following consumption of alcohol is supported in a previous meta-analysis\textsuperscript{(16)}. The high energy content of the alcoholic beverages used in the intervention conditions contributes to the increase in total energy intake reported in the studies and therefore is more evident when compared with the negligible energy content of NE-beverages or N-beverages.

The subgroup analyses showed that both low-dose (<30 g or <0.6 g/kg) and high-dose (\geq 30 g or \geq 0.6 g/kg) alcoholic beverages increased the total energy intake, although high-dose alcoholic beverages increased it to a greater extent; however, overlapping 95\% CI were observed. This present review suggests that high alcohol dose may stimulate total energy intake, when compared with N- or NE-beverage, as five of the eight studies that increased the total energy intake used a high alcohol dose. The observed increase in total energy intake is likely due to the higher energy content of the high-dose alcoholic beverages compared with the low-dose alcoholic beverages. Interestingly, when considering epidemiological studies and the relationship between alcohol consumption levels and body weight, only heavy alcohol consumption is associated with increased body weight in males\textsuperscript{(4)}. It is likely this was due to the limited reporting of total energy intake in low alcohol dose studies and the inclusion of the two studies that used a low alcohol dose with relatively longer study durations. Furthermore, the finding that total energy intake increased in response to high alcohol dose to a greater extent than low alcohol dose was not supported when the high alcohol doses were compared with E-beverages. This suggests that E-beverages also increase the total energy intake, which may negate any marked differences in the increased total energy intake when compared with alcoholic beverages. The review and subgroup meta-analyses suggest that alcohol consumption increases the total energy intake, with the review's...
findings suggesting that high-dose alcohol has a stronger effect on increasing the total energy intake than the low-dose alcohol.

**Implications**

As obesity continues to increase globally, there is a need to understand the impact of habitually consuming energy-dense alcohol. Passive overconsumption of dietary energy, with poor compensation for energy intake consumed as alcoholic beverages, may lead to positive energy balance and promote weight gain in people who regularly consume alcohol. Previous reviews have reported conflicting evidence on the relationship between the consumption of alcoholic beverages in general or specifically beer and body weight. Alcohol dose and type of beverage may also be a confounding factor that is evident in two crossover studies included in the present review. These studies measured changes in body weight with alcohol consumption and failed to detect any changes after 6 weeks of daily and 10 weeks of 5 d/week of red wine consumption.

Our findings suggest alcohol consumption can likely predispose individuals to energy imbalance by increasing both acute food energy intake and total energy intake. This was not only evident for consumption of low alcohol doses but for higher doses as well. Although further investigation with additional high-quality studies to confirm the effect of alcohol consumption on food energy intake is strongly warranted, the present review has implications for alcohol consumption guidelines. Alcohol consumers need to be aware that whether they fail to compensate for the energy ingested from alcohol the next day, this becomes an additional source of energy that will influence the overall energy balance. These public health messages have to focus on the settings where alcoholic beverages are commonly consumed, such as restaurants, pubs, sporting events and at home. Furthermore, these messages can be directed at vulnerable population groups who frequently consume alcoholic beverages or frequently consume a high number of alcoholic beverages on single occasions and who may also be at risk of weight-related problems due to the low socioeconomic status. The vulnerable population groups in both Great Britain and Australia are young adults and middle-aged adults who are particularly at risk.

**Limitations**

A number of limitations were identified. First, studies were conducted predominantly with young adult female participants and hence, the generalisability of these studies to other age groups, such as older males and females, is limited. Second, reporting of participant baseline characteristics, such as age, BMI, usual alcohol consumption levels and ethnicity, was not consistent across the twenty-two studies. Third, the cut-offs used to classify unrestrained and restrained eaters were markedly different for studies that measured this factor, despite using similar questionnaires such as the DEBQ, TFEQ or their respective restraint subscales. Finally, the definitions regarding low, moderate and high usual alcohol consumption levels were not consistent across studies as they were conducted in different countries with different interpretations for the alcohol content of a standard drink and different guidelines for consumption.

Experimental designs and methodologies differed considerably, which created challenges in comparing studies and the synthesis of data. A range of different alcoholic beverage types and doses were utilised for the interventions. Blood alcohol concentration (BAC) is influenced by the alcohol type, dose and rate of drinking. As an example, consumption of spirits is shown to result in a higher BAC than wine and beer, despite ingestion of the same alcohol dose. Furthermore, associations have been demonstrated between spirits and beer and body weight, which are stronger than the associations found between wine and body weight. The impact of alcohol on body weight is further influenced by characteristics such as sex, alcohol type and total consumption patterns. Despite this, many factors, known to have an impact on body weight, have not been accounted for in previous studies; such as sex, physical activity levels and sleep habits and, therefore, may contribute to the lack of a clear demonstrable relationship between alcohol consumption and body weight. In addition, the use of deception and disguising of the non-alcoholic beverages was utilised irregularly across studies.

The test food provided varied between studies, with different savoury and sweet foods used, such as chocolate snacks and pasta meals. Also, the primary outcomes of food energy intake and the total energy intake were not consistently reported. Lastly, very few studies measured the participants’ liking of the food provided, which may have influenced the amount of food they consumed.

At the review level, limitations are that non-English-language studies were excluded from the search strategy, which may have resulted in language bias. Furthermore, a number of studies that investigated the effects of alcohol consumption on the intake of liquid meals were also excluded. No hand searching of the reference list of the included studies was conducted due to the extensive number of records retrieved. There are several potential limitations with the meta-analysis.
First, since this was an aggregate data meta-analysis, there is potential for ecological fallacy, specifically Simpson’s Paradox, to exist(67). Second, some of the statistically significant findings may have been due to chance, given the large number of statistical tests that were conducted. Third, as the studies were not randomly assigned to covariates or subgroups in the meta-analysis, they are considered to be observational in nature, and the results of the subgroup analyses do not support causal inferences. Lastly, some of the sub-group meta-analyses were conducted on the basis of small numbers of studies with high \( I^2 \) values, which may have influenced the findings.

**Further work/directions**

The reviewed studies predominantly utilised a fixed alcohol dose although very few studies included an isoenergetic non-alcoholic comparator. To determine whether the effect on food energy intake is attributable to the pharmacological effects of alcohol rather than the energy content of the alcoholic beverage, the use of an isoenergetic non-alcoholic comparator is recommended. Furthermore, for research studies that utilise a broad inclusion criteria for age and BMI, it is recommended to utilise adjusted alcohol dose (g/kg body weight), rather than fixed alcohol dose, to reflect differences in body size and alcohol metabolism. Standardisation of study methods, such as the type of alcohol used for the beverages and foods used and to test in a range of different age groups, is also warranted. The consumption of beer and spirits is positively associated with weight gain to a greater extent compared with wine intake.(44) Consistent reporting of both food energy intake and total energy intake outcomes and participant characteristics is fundamental to provide additional evidence for meta-analyses. Lastly, consideration of the participants’ liking of the test food with food liking questionnaires is crucial to minimise a potential confounding factor for energy intake.

**Conclusion**

This review demonstrates that compared with non-alcoholic beverages or no beverage, the consumption of alcoholic beverages significantly increases both food energy intake and total energy intake by 343 and 1072 kJ on average, respectively. This quantity of energy has implications for the body weight of those who consume alcoholic beverages and food provision in the settings in which they do so, as chronic passive over-consumption of alcoholic beverages will add fuel to the obesity epidemic.

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A. K. and H. T. conceptualised the analytical protocol. A. K. conducted the literature search. A. K. and G. P. assisted with table and figure creation and extracted data. A. K., A. L. D., G. P. and M. J. P. conducted the study data analyses. A. K. and M. J. P. conducted the meta-analyses. A. K. was the primary writer. H. T., A. L. D., G. P. and M. J. P. reviewed the content of the manuscript and provided editorial feedback.

None of the authors have any conflicts of interest to declare.

**Supplementary material**

For supplementary material/s referred to in this article, please visit [https://doi.org/10.1017/S0007114518003677](https://doi.org/10.1017/S0007114518003677)

**References**


