Received: 26 November 2021 | Accepted: 8 May 2022

DOI: 10.1111/add.15962

REVIEW

ADDICTION SSA

The impact of alcohol priming on craving and motivation to drink: a meta-analysis

Lauren Halsall[1] | Andrew Jones[1,2] | Carl Roberts[1] | Graeme Knibb[3] | Abigail K. Rose[2,4]

[1]Department of Psychology, Institute of Population Health, University of Liverpool, Liverpool, United Kingdom

[2]Liverpool Centre for Alcohol Research, Liverpool, United Kingdom

[3]Department of Psychology, Edge Hill University, Ormskirk, United Kingdom

[4]School of Psychology, Liverpool John Moore's University, Liverpool, United Kingdom

Correspondence
Abigail K. Rose, School of Psychology, Liverpool John Moores University, 3.20 Tom Reilly Building, Byrom Street, Liverpool, L3 3AF, United Kingdom.
Email: a.k.rose@ljmu.ac.uk

Abstract

Background and Aims: An initial dose of alcohol can motivate—or prime—further drinking and may precipitate (re)lapse and bingeing. Lab-based studies have investigated the alcohol priming effect; however, heterogeneity in designs has resulted in some inconsistent findings. The aims of this meta-analysis were to (i) determine the pooled effect size for motivation to drink following priming, measured by alcohol consumption and craving, and (ii) examine whether design characteristics influenced any priming effect.

Methods: Literature searches of PsycINFO, PubMed and Scopus in October 2020 (updated October 2021) identified lab-based alcohol priming studies that assessed effect of priming on motivation to drink. A tailored risk-of-bias tool assessed quality of lab-based studies. Random effects meta-analyses were computed on outcome data from 38 studies comparing the effect of a priming dose of alcohol against control on subsequent alcohol consumption/self-reported craving. Study characteristics that might have affected outcomes were design type (within/between-participant), dose of prime, time of motivation assessment, type of control drink (placebo alcohol/soft drink).

Results: Relative to control, alcohol had a small-to-moderate priming effect on subsequent alcohol consumption (standardised mean difference [SMD] = 0.336 [95% CI, 0.171, 0.500]) and craving (SMD = 0.431 [95% CI, 0.306, 0.555]). Aspects of study design differentially affected consumption and craving. The size of the priming dose had no effect on consumption, but larger doses were sometimes associated with greater craving (with craving generally following the blood alcohol curve). Alcohol priming effects for consumption, but not craving, were smaller when compared with placebo, relative to soft drink, control.

Conclusions: Lab-based alcohol priming studies are a valid paradigm from which to investigate the impact of acute intoxication on alcohol motivation. Designs are needed that assess the impact of acute consumption on motivation to drink in more varied and realistic ways.

KEYWORDS
Alcohol priming, choice, consumption, craving, drinking behaviour, motivation

INTRODUCTION

Alcohol consumption is a leading risk factor for mortality and ill health, and is often ubiquitous in western societies [1]. To understand alcohol-related behaviour and develop effective treatments for alcohol use disorders, it is necessary to identify the key drivers for drinking. Existing literature have highlighted three important drivers (or triggers): alcohol-related cue exposure; stress; and priming [2–4]. Alcohol priming is the provision of a typically small-to-moderate dose of alcohol. Evidence from animal models and human research demonstrates that this initial administration of alcohol can motivate subsequent alcohol seeking and consumption, in both social and heavy drinkers, and in those trying to abstain [5–8].

There are several theoretical explanations for why a priming dose might increase alcohol use. For example, acute doses of alcohol may impair executive cognitive functions such as inhibitory control [9, 10] or increase risk taking [11] that impairs restraint. Attentional bias has also been implicated, with acute doses of alcohol increasing attention toward alcohol-related stimuli that, in turn, is associated with increased craving [12, 13]. Other proposed mechanisms include activation of learned associations (either habit-like or goal-directed) [14] and altering subjective value whereby a priming dose may increase the absolute or relative value of alcohol that motivates drinking [15, 16]. These findings suggest that alcohol priming may have an important role in determining alcohol use, including hazardous behaviours such as bingeing [9] and relapse [17].

These potential psychological mechanisms of effect may involve several physiological and pharmacological processes. For example, alliesthetic processes may modulate the value of alcohol rewards and influence priming [18]. Leganes-Fonteneau and colleagues [19] recently demonstrated that a change in internal states (heart rate variability) during the ascending limb of the blood alcohol curve was positively related to alcohol-related attentional bias. Animal and human studies have attributed changes in alcohol reward to activity within the mesolimbic dopamine and μ-opioid systems mediating incentive and pleasurable processes, respectively [14, 20, 21]. Work shows that both opioid-antagonists (e.g. naltrexone) [22] and GABA-agonists (e.g. baclofen) [23] can attenuate alcohol's priming effect on ad libitum consumption and craving in humans.

However, regardless of theoretical or biological mechanisms of action, design and methodological factors can vary considerably across studies and may account for potential inconsistences in findings. The most obvious factors to consider are dose of alcohol given and the time point, at which any priming effect is assessed. Rose and Duka [6] found that a moderate (0.6 g/kg [approximately five United Kingdom (UK) units, one unit = 8 g alcohol]), but not a smaller (0.3 g/kg) dose of alcohol enhanced motivation for alcoholic drinks and self-reported craving. Similar dose findings have been found in other studies using non-clinical populations (e.g. de Wit and Chutuape) [24], but others using a clinical sample (i.e. with alcohol use disorder) have observed a priming effect using lower doses (e.g. ~2.4 units) [7].

Rose and Duka's [6] priming effect peaked 30 minutes following the priming dose, before decreasing at 60 and 90 minutes. Typically, alcohol takes about 5 minutes to reach the brain, starts to have subjective effects ~10 minutes after consumption and reaches a peak in blood alcohol concentration (BAC) between 10 and 60 minutes post-consumption [25, 26]. Therefore, dose and timing of priming assessment need to be considered, as well as an appreciation that the timing of subjective intoxication effects may vary as a function of the participant's drinking status.

The comparison drink that is used may also be important because expectancy effects may contribute toward the priming effect. For instance, Christiansen *et al.* [27] found that placebo alcohol increased subsequent alcohol consumption and craving relative to a soft drink control (participants were aware contained no alcohol). This arguably occurred through expectancy-based mechanisms and suggests that designs that use a placebo-alcohol control (e.g. to isolate alcohol's pharmacological effects) may find a smaller priming effect than studies that use a soft drink control (which allows assessment of both pharmacological and expectancy effects).

Study design may also influence results for several reasons, including carry over effects and differences in participant characteristics across samples [28]. It is worth examining whether outcomes differ across within and between subject designs. Finally, the type of outcome used to assess alcohol motivation may influence results. Behavioural measures include ad libitum alcohol consumption, arguably the most important measure of alcohol motivation, and choice behaviour (e.g. Rose *et al.*) [29]. Choice behaviour might be broken down to the strength of operant response for access to alcohol (e.g. number of button presses to gain alcohol) or the relative response rate between alcohol and another commodity (e.g. number of button presses made for alcohol compared to chocolate) (e.g. Rose *et al.*) [15]. Self-reported craving is also a common measure of alcohol motivation [30], and several craving (or alcohol urge) assessments have been developed and validated in various populations [31]. Yet inconsistent evidence regarding a positive relationship between craving and consumption has resulted in debate on its significance [32, 33]. Nevertheless, given its common usage, it is still important to determine whether craving outcomes can be impacted by the design characteristics previously listed.

The importance of alcohol priming in triggering alcohol use has been established by the existing evidence base, but there has been no systematic assessment of how design and methodological choices may impact findings. The aim of the current systematic review and meta-analyses was to identify whether lab-based priming demonstrates a reliable, positive effect of initial alcohol consumption on motivation for alcohol (assessed as subsequent ad libitum consumption or craving). Additionally, we aimed to determine what design features of priming research may influence the strength of any priming effect found.

METHOD

Data sources and search strategy

SCOPUS, PsycINFO and PUBMED were searched from inception until October 2020. Titles, abstracts and keywords were searched using a

variety of terms reflecting alcohol priming ('alcohol prim*', 'acute alcohol intoxication', 'acute ethanol intoxication', 'alcohol challenge', 'balanced placebo design' and 'alcohol preload') and motivation to drink ('ad lib*', 'consum*', 'crav*', 'desire', 'motivat*', 'reinforc*', 'choice' and 'operant'), combined using Boolean operators. Formal electronic searches were supplemented by a manual search of reference sections in eligible papers and review articles. Only research available in the English language and using human participants was considered for inclusion.

Inclusion criteria

Studies were eligible for inclusion if they (i) included explicit measures of motivation to drink, (ii) compared the effect of an alcohol prime to a control drink (placebo/soft drink), and (iii) provided a controlled priming dose (i.e. specific dosage, achieved a target BAC). Studies reporting proxy measures of motivation (e.g. attentional bias, physiological measures), without a comparison beverage or without a controlled priming dose were excluded.

Data selection

The PRISMA flow-diagram (Figure 1) represents the full article search process. In total, 696 records were screened, with 100 studies reaching full text screening. Of these 100 full texts, 51 were excluded and 49 were identified as eligible for inclusion. Reference lists of these papers were then hand-searched, identifying an additional 17 eligible papers. L.H. conducted the screening and data extraction. A.R., A.J., G.K. and C.R. cross checked the screening and data extraction. Any discrepancies in checks were discussed as a group and a decision was made based on pre-registration protocol.

Original searches took place during October 2020, with an updated search conducted in October 2021. For inclusion in the meta-analysis, studies measuring craving or consumption (i.e., motivation to drink outcome measures) following a preload beverage, required summary statistics for these outcomes for both alcohol and control beverage conditions. Where this data was missing, corresponding authors were contacted and given a period of 1 month to respond. In the case of no response, or where no valid email could be obtained for the author, the corresponding paper was not included in the analysis. When contacted about missing data, two authors

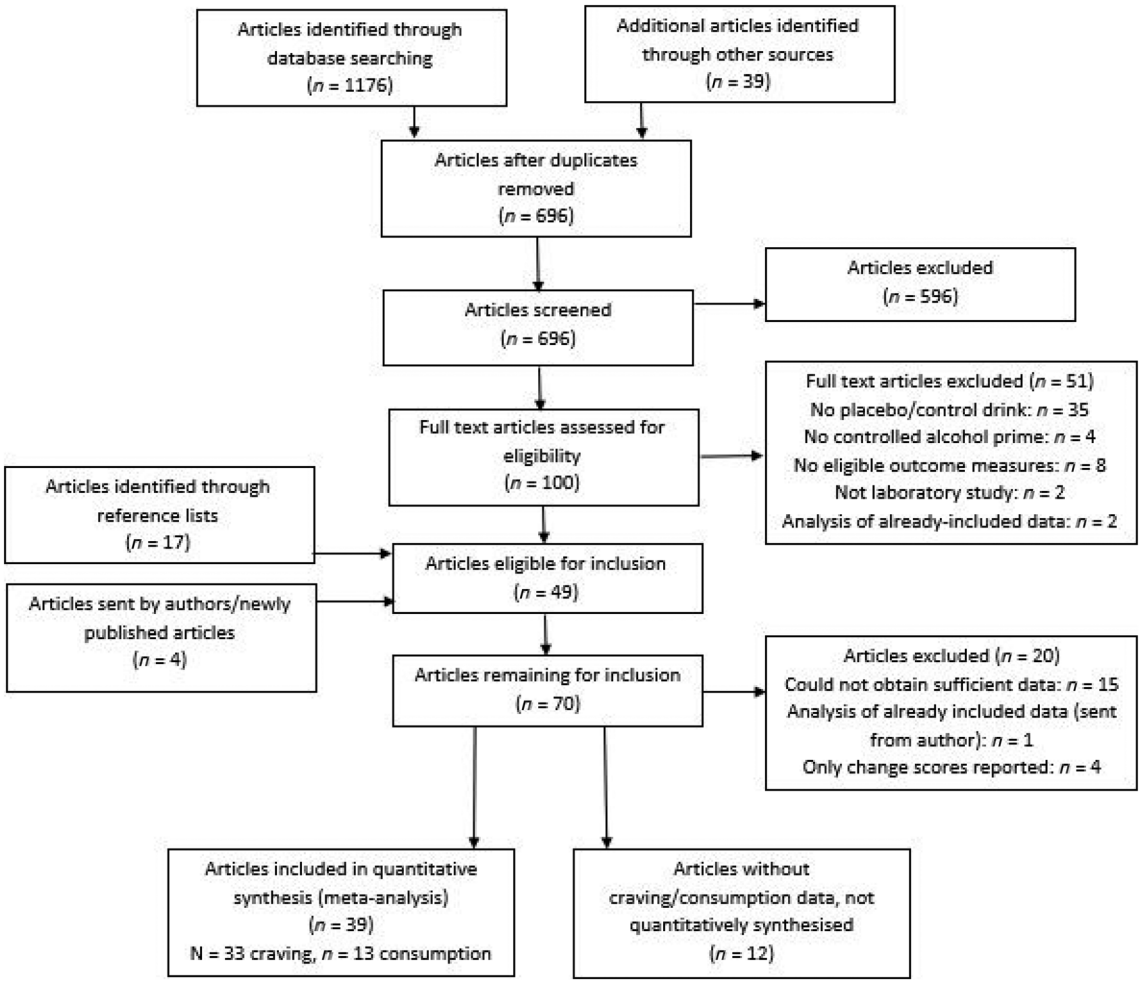

FIGURE 1 PRISMA flow diagram depicting the identification of studies for the systematic review

provided additional recent research that met the inclusion criteria. Authors were also aware of three recently published articles that met the inclusion criteria and were included. Sufficient data could not be obtained from 19 articles, which were subsequently excluded. One additional article was excluded because it used the same data as another article (but with fewer data points).

We also identified 20 studies examining alternative motivation to drink alcohol outcomes, 12 of which did not include any alcohol craving or consumption outcomes (e.g. choice behaviour, alcohol value and operant responding). However, because of the lack of data and variation in outcome measures between these studies, meta-analytical synthesis of these findings was not feasible or appropriate, so they were subsequently excluded (see Supporting information Table S1 for study characteristics and key findings). Overall, 39 articles remained for inclusion in the analysis.

Data extraction

The following data was extracted from each study: bibliographic details, study design, setting, participant drinking status, age and gender distribution, alcohol type and dosage, assessment time, BAC limb, priming procedure, control/placebo details, outcome measure and summary statistics.

Quality assessment/risk of bias

Given that only laboratory studies were included in the analysis, the following domains were assessed to determine study quality: randomisation/counterbalancing, blinding, a-priori (or justification of) statistical power made by study authors, accountability of sex, outcome reporting completeness, drop-out rate and pre-registration. Risk of bias in each domain was assessed as low, high or unclear (see Supporting information Table S2 for full criteria). The research team developed a risk of bias assessment based on Cochrane Risk of Bias tool [34], including criteria most relevant to lab-based research. The assessment was conducted by L.H. and independently cross-checked by A.J. and A.R.

Statistical analyses

If data were not included in the paper and it was possible, we used webplot digitizer [35] to estimate means and standard deviation/standard errors from figures. Standard errors were converted to standard deviations using the formula $SD = SE^{*}\sqrt{N}$.

We conducted restricted maximum likelihood, random-effects meta-analyses using the 'metafor' package in R. Data analysis and scripts are available on the Open Science Framework [https://osf.io/z6skq/]. For between participants' designs we used the 'escalc' function: 'SMD' to calculate the standardised mean difference between alcohol and control groups. For within participants' designs we used the 'escalc' function: 'SMCC' to conduct the standardised mean change score. No studies provided the within participants correlation between the outcome variables, therefore, we imputed this as r = 0.70, in line with previous research [36]. Most craving studies took measures of craving at multiple time points post priming and also took multiple different measures of craving (e.g. the Approach and Avoidance of Alcohol Questionnaire has multiple unique subscales) [37]. Therefore, to account for potential violations of independence in our effect sizes without omitting any data, we conducted a multi-level meta-analysis using the 'rma.mv' command in metafor.

We examined any outlying effect sizes for both consumption and craving using box plots of all available effect sizes. For consumption, one effect size (SMD = 0.73) and for craving four effects (SMDs = −1.12, 1.99, 2.49, 3.47) were identified. We conduct all analyses with and without the removal of these outliers. Although findings are reported with outliers removed, we note any discrepancies when they were included in analyses.

Across all models, I^2 was used to indicate heterogeneity across effect sizes, with >50% indicative of moderate heterogeneity and >75% indicative of substantial heterogeneity. For primary analyses on alcohol consumption and craving, we examined whether there were any influential cases using Trim and Fill analyses [38], Egger's test* and removing the smallest and largest effect sizes.

To resolve any heterogeneity in the primary models (consumption and craving) we conducted moderation analyses (either subgroup or meta-regressions), where appropriate. For subgroup analyses, meaningful groups were only created if ≥4 effect sizes were able to contribute to the group. Continuous analyses using meta-regressions were only conducted if >10 effect sizes were available, in line with guidance [39]. We aimed to conduct subgroup analyses on within versus between participant designs; the dose of alcohol prime (g/kg); soft drink versus placebo comparisons; and time since administration of prime.

RESULTS

Thirty-nine articles investigating the effects of acute alcohol intoxication on subsequent alcohol consumption (n = 13) and/or craving (n = 33) were included in the analysis. Within these studies, alcohol priming dosage ranged from 0.1 g/kg to 0.95 g/kg, with assessment time ranging from ~5 to 195 minutes after consumption. Most studies were conducted in a standard laboratory/office setting (n = 23), with fewer studies conducted in a recreational environment (n = 8) or simulated bar (n = 5). Spirits were the most selected alcohol prime (n = 31) with only one study using wine [40] and one using beer [41]. For the comparison beverage, a placebo control was more commonly included than a soft drink control (n = 33 and 7, respectively). The Desire for Alcohol Questionnaire [42] and the Drug Effects Questionnaire 'want more' subscale [43] were the most used craving measures (n = 9 and n = 7, respectively). Consumption was either measured as the amount consumed ad libitum (n = 9, most commonly during a bogus taste rating task) or as the number of additional drinks consumed following the priming procedure (n = 4). The characteristics of the included studies are presented in Table 1.

*Trim and Fill and Egger's test were conducted on single level meta-analytic models, as they are not compatible with multilevel models in metafor.

TABLE 1 Characteristics of the studies that examined alcohol craving/consumption following alcohol versus placebo/control prime

Authors	Setting	Design	Participant characteristics (author description of drinking status, mean AUDIT/consumption, gender distribution)	Alcohol prime	Assessment time (after beginning consumption)	Control vs placebo	Outcome measure(s)
Adams *et al*. [44]	Laboratory	Between participants	Light drinkers: placebo: 14 (6) units/week. 0.13 g/kg: 14 (10) units/week. 0.40 g/kg: 12 (5) units/week. Heavy drinkers: placebo: 27 (9) units/week. 0.13 g/kg: 23 (5) units/week. 0.40 g/kg: 27 (11) units/week. M:F = 36:36	37.5% ABV vodka. 0.13 g/kg and 0.4 g/kg	10 min and 30 min	Placebo	5 item craving visual analogue scales (VAS)
Amlung *et al*. [45]	Laboratory	Between participants	Moderate drinkers. Alcohol group: 1 drinking day/week, 3–4 drinks/drinking day. Control group: 2 drinking days/week, 3–4 drinks/drinking day. M:F = 48:52	190-proof pure grain alcohol. ~0.85 g/kg (M)/0.73 g/kg (F)	Immediately post-consumption, and ~35, 77 and 193 min	Placebo and control, combined in analysis	100-point craving VAS
Baines *et al*. [46]	Laboratory	Within participants	Heavy drinkers. AUDIT = 11.78 (3.89). 48.9 (25.72) units in 2 weeks before study. M:F = 19:17	37.5% ABV Smirnoff Red Vodka. 0.6 g/kg	Craving: ~ 30 min. Consumption: unclear	Placebo and control	Volume consumed ad libitum in taste test of one 250 mL beer (as % of total fluid consumed). Approach and Avoidance of Alcohol Questionnaire; inclined/indulgent, obsessed/compelled, and resolved/regulated subscales [37]
Berg *et al*. [42]	Recreationally furnished clinic video room Laboratory	Within participants.	(i) Diagnosed with alcoholism, voluntarily hospitalised and (ii) social drinkers. No AUDIT/consumption reported for either group. M:F = 24:0.	80% proof vodka. Dosage not reported	Unclear; within 45 min	Placebo	Total ad libitum consumption in 45 min period (mL)

(Continues)

TABLE 1 (Continued)

Authors	Setting	Design	Participant characteristics (author description of drinking status, mean AUDIT/consumption, gender distribution)	Alcohol prime	Assessment time (after beginning consumption)	Control vs placebo	Outcome measure(s)
Christiansen *et al*. [47]		Within participants	Social drinkers. AUDIT = 16.06 (SEM: 5.32). 39.00 (SEM: 17.29) units in 2 weeks before study. M:F = 12:19	37.5% ABV Smirnoff Red Vodka. 0.65 g/kg	Craving: 20 min and 60 min. Consumption: unclear; 60 min plus time to complete multiple questionnaires	Placebo and control	Desire for Alcohol Questionnaire (DAQ) [43]; average across subscales. Volume consumed ad libitum in taste test of one 275 mL non-alcoholic beer (as % of total fluid consumed)
Corbin *et al*. [48]	Simulated bar	Between participants	Moderate to heavy drinkers. 61.55 (39.79) drinks/mo M:F = 50.3:49.7	80-proof vodka. 0.06% BAC	Unclear; 75 min plus time to complete multiple questionnaires	Placebo	Number of alcoholic drinks consumed ad libitum within 20 min period (up to 0.12 g% BAC).
Davidson *et al*. [40]	Laboratory.	Within participants	Non-treatment seeking, alcohol dependent participants. 8.6 (SEM: 0.9) standard drinks/drinking occasion. Reported drinking on 88% (SEM: 3.9%) of 90 days before testing. M:F = 13:	Sutter Home White Zinfadel Wine. 0.05 g/dL peak BAC	~70 min	Placebo	Four 7-point craving scales (adapted from [49])
De wit *et al*. [50]	Recreational laboratory, furnished to resemble a living room	Between participants	Social drinkers. 5.97 (0.36) drinks/week. M:F = 24:13	75.5% ABV Everclear Ethanol. 0.3 g/kg (M), 0.2 g/kg (F)	15 min	Placebo	Ad libitum consumption of up to 6 drinks (as % of total fluid consumed)
Duka *et al*. [51]	Laboratory	Between participants	Social drinkers. 33 (SEM: 5) units/week. M:F = 18:0	Prime type unreported. 0.1 g/kg	10 min	Placebo	Number of drinks consumed ad libitum (up to 6)
Duka and Townshend [13]	Laboratory	Between participants	Moderate to heavy social drinkers. 23.9 (SEM: 1.4) units/week. M:F = 20:22	90% ABV alcohol. 0.3 g/kg and 0.6 g/kg	Unclear; 30 min plus time to complete dot probe task	Placebo	DAQ [43]
Fernie *et al*. [12]	Laboratory	Within participants	(i) Moderate drinkers. AUDIT = 10.00 (4.09).	Vodka. 0.4 g/kg	Consumption: unreported; before 60 min. Craving: ~15 min	Placebo	Volume consumed ad libitum in taste test of

(Continues)

TABLE 1 (Continued)

Authors	Setting	Design	Participant characteristics (author description of drinking status, mean AUDIT/consumption, gender distribution)	Alcohol prime	Assessment time (after beginning consumption)	Control vs placebo	Outcome measure(s)
			13.27 (3.83) units/week. M:F = 13:15. (ii) Heavy drinkers. AUDIT = 12.89 (4.16). 31.74 (15.43) units/week. M:F = 14:13				one 330 mL non-alcohol beer (mL). DAQ [43]
Field *et al.* [52]	Laboratory	Within participants	No description of drinking status, or AUDIT/consumption; at least 10 units in previous week. M:F = 7:12	37.5% ABV vodka. 0.4 g/kg	~15 min	Placebo	0–10 single desire to drink item. DAQ [43]
Fillmore and Rush [53]	Laboratory	Between participants	Social drinkers. 2.3 (1.3) occasions/week. 1.1 (0.7) ml/kg dose/occasion. M:F = 24:8	Absolute alcohol. 0.55 g/kg (M), 0.48 g/kg (F)	~40 min	Placebo	Desire for drug 'desire' subscale
Fillmore [54]	Laboratory	Between participants	Social drinkers. Over previous 3 months, M: 148.73 (154.70) total drinks and F: 54.21 (37.91) total drinks. M:F = 26:14	Prime type unreported. 0.55 g/kg (M), 0.48 g/kg (F)	25, 40, 55, 110, 125, and 140 min	Placebo	Desire for drug 'desire' subscale
Hobbs *et al.* [55]	Laboratory	Between participants	(i) Light drinkers. 13.7 (3.2) units in previous week. (ii) Heavy drinkers. 27.8 (11.2) units in previous week. Combined in analysis. Overall: M:F = 16:24	37.5% ABV Safeway's vodka. 0.25 g/kg	Unclear; after 25 min and completion of 'liking test' for 4 beverages.	Placebo	Volume consumed ad libitum in taste test of up to 5 drinks (mL).
Hutchison *et al.* [41]	Laboratory	Within participants	Heavy drinkers. Participants split by genotype: (i) 11.31 (4.77) drinking days during previous 30 days.	High alcohol beer. 0.15 g/kg (M), 0.11 g/kg (F)	5, 25 and 45 min	Placebo	Alcohol Urge Questionnaire (AUQ) [56]

(Continues)

TABLE 1 (Continued)

Authors	Setting	Design	Participant characteristics (author description of drinking status, mean AUDIT/consumption, gender distribution)	Alcohol prime	Assessment time (after beginning consumption)	Control vs placebo	Outcome measure(s)
			4.59 (2.78) drinks/occasion, and (ii) 11.41 (5.05) drinking days during previous 30 days. 5.00 (2.66) drinks/occasion. M:F = 51:23				
King *et al.* [57]	Comfortable, living room-like laboratory	Within participants	(i) Light drinkers. 1.9 (SEM: 0.21) drinks/occasion. 1.2 (SEM: 0.14) occasions/week. M:F = 10:4. (ii) Heavy drinkers. 4.8 (SEM: 0.43) drinks/occasions. 3.4 (SEM: 0.18) occasions/week. M:F = 16:4	180 proof alcohol. 0.4 g/kg and 0.8 g/kg	30, 60, 120 and 180 min	Placebo	Drug Effects Questionnaire (DEQ) 'want more' subscale [58]
King *et al.* [59]	A comfortable room	Within participants	(i) High risk heavy social drinkers. AUDIT = 11.6 (SEM: 0.36). 14.22 (SEM: 0.52) drinking days/month. 5.44 (SEM: 0.32) standard drinks/drinking day. M:F = 60:44. (ii) Light drinkers. AUDIT = 3.27 (SEM: 0.13). 6.41 (SEM: 0.34) drinking days/month. 1.69 (SEM: 0.05) standard drinks/drinking day. M:F = 45:41	190 proof ethanol. 0.4 g/kg (M), 0.34 g/kg (F), and 0.8 g/kg (M), 0.68 g/kg (F)	30, 60, 120 and 180 min	Placebo	DEQ 'want more' subscale [58]
King *et al.* [60]	Comfortable, living-room like laboratory	Within participants	Two groups: Low-risk, light and high-risk, heavy drinkers at baseline. Presented in analysis as with/	Prime type unreported. 0.8 g/kg (M), 0.68 g/kg (F)	30, 60, 120 and 180 min	Placebo	DEQ 'want more' subscale [58]

(Continues)

TABLE 1 (Continued)

Authors	Setting	Design	Participant characteristics (author description of drinking status, mean AUDIT/consumption, gender distribution)	Alcohol prime	Assessment time (after beginning consumption)	Control vs placebo	Outcome measure(s)
			without alcohol use disorder (AUD+/AUD- respectively) at 10 y follow up. At y 10: AUD+: alcohol problems score (based on AUDIT = 18.7 (6.2). AUD-: alcohol problem score = 8.6 (5.4). At baseline, overall M:F = 75:70				
Kirk and de Wit [61]	Comfortable, living-room like laboratory testing room	Within participants	Social drinkers. 8 (2.6) drinks/week. M:F = 10:2	Ethanol. 0.2 g/kg, 0.4 g/kg and 0.8 g/kg	~20 and 50 min (highest score used in analysis)	Placebo	DEQ 'want more' subscale [58]
Knibb *et al.* [62]	Semi-naturalistic bar laboratory Contains items incl. Stocked fridge, beer pumps, bar stools and similar seating to typical British pub	Within participants	No description of participant drinking status. Study 1: AUDIT = 12.69 (6.94). 44.12 (31.16) units consumed in 2 weeks before study. M:F = 44:37. Study 2: AUDIT = 12.13 (4.75). 45.15 (17.29) units consumed in 2 weeks before study. M:F = 14:26	37.5% ABV Co-op Imperial vodka. 0.5 g/kg	Craving: (i) ~20 mins and (ii) unclear; end of session. Consumption: unclear	Placebo	DAQ average across the 4 subscales [43]. Volume consumed ad libitum in taste test of 225 mL beers (number unreported) (mL)
Leeman *et al.* [63]	Simulated bar	Between participants	Moderate to heavy social drinkers. Typical weekly consumption: 4.36 (9.29). M:F = 50.3:49.7	80 proof vodka. 0.06% peak BAC	Craving: 45 min. Consumption: unclear	Placebo	Single 1–100 craving VAS item [58] Number of alcoholic drinks consumed ad libitum within 20 min period (up to 0.12 g% BAC)
Leganes-Fonteneau *et al.* [19]	Laboratory	Within participants	AUDIT = 7.96 (3.50). 12.60 (7.68) units/week. M:F = 16:15	190-proof Everclear. 0.4 g/kg	After ~45 mins and then at a further time point, unclear	Placebo	DAQ [64]
	Laboratory		Social drinkers.		10, 20, 40, 60 and 80 min	Placebo	

(Continues)

TABLE 1 (Continued)

Authors	Setting	Design	Participant characteristics (author description of drinking status, mean AUDIT/consumption, gender distribution)	Alcohol prime	Assessment time (after beginning consumption)	Control vs placebo	Outcome measure(s)
Marczinski *et al.* [65]		Between participants	AUDIT = M: 6.08 (3.38), F: 4.28 (1.88). No. drinks/occasion = M: 4.70 (2.21), F: 3.30 (1.95). Occasions/week = 1.28 (0.98) days. M:F = 40:40	40% ABV Smirnoff Red Lab Vodka. 0.91 mL/kg (M), 0.79 mL/kg (F)			Desire for Drug scale, 'desire' subscale [66]
McCusker and Brown [67]	(i) Simulated lounge-bar. (ii) Office room	Between participants	Social drinkers. Mean AUDIT/units unreported; 10–20 units/week. M:F = 40:0	95% ABV alcohol. 1.2 mL/kg	~15 min	Placebo and control	0–10 craving continuum
McKee *et al.* [68]	Laboratory	Within participants	Moderate to heavy drinkers. AUDIT = 11 (3.31). 23.77 (13.76) standard drinks/week. M:F = 10:6.	80-proof liquor. 0.03 g/dL	~5 min, and then at 3 further time points, variable between participants	Placebo	AUQ [56] Single Item Yale Craving scale [69]
McNeill *et al.* [70]	Laboratory	Between participants	AUDIT = 11.25 (4.64). 31.25 (25.12) units in previous 2 weeks. M:F = 43:57	Vodka/grain ethanol. 0.4 g/kg	Craving: 30 min Consumption: unclear.	Placebo and control	DAQ [43] Volume consumed ad libitum in taste test of 3 × 330 mL beers (mL)
McNeill *et al.* [64]	Laboratory	Within participants	AUDIT = 11.1 (3.58). 24.07 (15.82) units in previous two weeks. M:F = 13:17	Vodka. 0.6 g/kg (M), 0.5 g/kg (F)	Craving: 30 mins. Consumption: unclear	Placebo and control.	AUQ [56] Volume consumed ad libitum in taste test of 3 × 330 mL beers (mL).
Montgomery *et al.* [71]	Laboratory	Between participants	Participant drinking status not described. Non-cocaine users: Placebo condition: AUDIT = 13.36 (7.01). Alcohol condition: AUDIT = 11.94 (5.60). Cocaine users: Placebo condition: AUDIT = 19.52 (5.67). Alcohol	Vodka. 0.4 g/kg	~15 and 30 min	Placebo	DAQ, total across subscales [43]

(Continues)

TABLE 1 (Continued)

Authors	Setting	Design	Participant characteristics (author description of drinking status, mean AUDIT/consumption, gender distribution)	Alcohol prime	Assessment time (after beginning consumption)	Control vs placebo	Outcome measure(s)
			condition: AUDIT = 17.62 (5.80). M:F = 32:38				
Ortner *et al*. [72]	Unreported	Between participants	Drinking status/AUDIT/consumption unreported. M:F = 28:0	Prime type unreported. 0.7 g/kg	~80 min	Placebo	DEQ 'want more' subscale [61]
Rose and Grunsell [16]	Laboratory	Within participants	Moderate/heavy social drinkers, half binge-drinkers and half non-binge drinkers. Binge drinkers: 60.8 (SEM: 10.7) units/week. Non-binge drinkers: 21.3 (SEM: 0.7) units/week. M:F = 10:10	Prime type unreported. 0.6 g/kg (M), 0.5 g/kg (F)	~60 min	Placebo	AUQ [56]
Rose *et al*. [73]	Laboratory	Within participants	Sample contains variety of drinking cohorts: light and moderate drinkers, and low risk, hazardous and harmful drinkers. Combined in analysis. Overall, 11.4 (SEM: 0.9) units/week. AUDIT = 9.8 (SEM: 0.7). M:F = 22:23	Ethanol. 0.2 g/kg	40, 65, 90, and 115 min	Control	Total ad libitum consumption in 20 min period of opposite drink to prime (up to 2 pints) (mL)
Rose *et al*. [11]	Laboratory	Between participants	Moderate to heavy social drinkers. 22.92 (15.26) units/week. AUDIT = 15.17 (5.57). M:F = 67:75	Vodka. 0.6 g/kg	~40 min	Placebo	AUQ [56]
Rose *et al*. [74]	(i) Bar-laboratory. (ii) Sterile cubicle	Within participants	Social drinkers. (i) Bar laboratory: Alcohol, M: 22.2 (12.5) units/week, AUDIT = 13.8 (4.51).	37.5% ABV vodka. 0.6 g/kg	40 min and a further 10 min, plus time taken to complete multiple questionnaires	Control	AUQ [56]

(Continues)

TABLE 1 (Continued)

Authors	Setting	Design	Participant characteristics (author description of drinking status, mean AUDIT/consumption, gender distribution)	Alcohol prime	Assessment time (after beginning consumption)	Control vs placebo	Outcome measure(s)
			F: 23.5 (11.8) units/week, AUDIT = 13.9 (5.2). Control, M: 24.9 (11) units/week, AUDIT = 15.8 (5.31). F: 22 (11.6) units/week, AUDIT = 13.9 (4.1) (ii) Sterile cubicle: Alcohol, M: 38 (19.7) units/week, AUDIT = 16 (4.67). F: 20.3 (8.33) units/week, AUDIT = 14.7 (4.36). Control, M: 30.5 (15.9) units/week, AUDIT = 13.4 (3.8). F:16.5 (4.67) units/week, AUDIT = 12.2 (3.95). Overall, M:F = 48:66				
Schoenmakers *et al*. [75]	Laboratory	Within participants	Heavy drinkers. M: 43.6 (13.51) units/week, AUDIT = 15.6 (5.48). F: 27.2 (15.75) units/week, AUDIT = 13.9 (5.47). M:F = 12:11	Vodka. 0.3 g/kg	~15 min	Placeb	DAQ [43]
Söderpalm and de Wit [76]	Recreational laboratory environment, furnished to resemble a living room	Between participants	Social drinkers. 5.7 (SEM: 0.9) drinks/week. M:F = 20:0	95% ABV Everclear ethanol. 0.8 g/kg	20, 40, 60 and 90 min, average in analysis (as well as 20 min before consumption)	Placebo	DEQ 'want more' subscale [77]
Wardell and Read [78]	Recreationally furnished seating area	Between participants	Heavy drinkers. Typical weekly quantity: Alcohol, positive cue condition = 16 (9.48), negative cue condition = 15.7 (8.02). Placebo, positive cue	190-proof alcohol. 0.06% BAC	~50 min and 75 min	Placebo	Single item 'urge to drink' VAS

(Continues)

TABLE 1 (Continued)

Authors	Setting	Design	Participant characteristics (author description of drinking status, mean AUDIT/consumption, gender distribution)	Alcohol prime	Assessment time (after beginning consumption)	Control vs placebo	Outcome measure(s)
			condition = 17.39 (10.9), negative cue condition = 16.67 (8.94). Overall, M:F = 48:47				
Yates and Kamboj [79]	Unreported	Within participants	At risk social drinkers. 4.05 (1.11) drinking days/week. AUDIT = 14.3 (4.97). M:F = 20:20	37.5% ABV vodka. 0.3 g/kg	Assessed periodically, beginning at 30 min	Placebo	Mood and Physical Symptom Scale 'urge' item [80]
Zack *et al.* [81]	Unreported	Within participants	Problem drinkers. 33.7 (10.5) drinks/week. M:F = 18:0	40% ABV vodka. 0.7 g/kg	~70 min	Control	Desire for Alcohol VAS, 1–100 [77]

Note: References for outcome measures are those provided in the source article only.

Alcohol consumption

We identified 21 individual effect sizes (from 13 studies) after removal of one outlier. Overall, there was a small-to-moderate, statistically significant effect of alcohol priming on subsequent consumption (SMD = 0.336 [95% CI, 0.171, 0.500], z = 4.01, $P < 0.001$, $I^2 = 68.44\%$) (Figure 2). When the outlier was included, the pooled effect was slightly smaller (SMD = 0.293 [95% CI, 0.109, 0.477]). Leaving out the largest and smallest effect sizes suggested neither individual had a considerable impact on the pooled effect (minimum SMD = 0.353, maximum SMD = 0.321; *P* values < 0.001). Egger's test demonstrated no evidence of funnel plot asymmetry (z = 1.20, $P = 0.230$) (Figure S1). Trim and Fill imputed two studies to improve funnel plot symmetry, which did not substantially influence the pooled effect (SMD = 0.321 [95% CI, 0.203; 0.439], z = 5.31, $P < 0.001$).

Within versus between participants

We identified 13 effect sizes from within-participant designs and eight from between-participant designs. There was no significant difference between study designs (χ^2 [1] = 0.18, $P = 0.672$). For within-participant designs the effect on consumption was SMD = 0.362 [95% CI, 0.175 to 0.550], z = 3.78, $P < 0.001$, for between-participant designs the effect on consumption was SMD = 0.309 [95% CI, −0.042 to 0.661], z = 1.72, $P = 0.085$.

Dose

We conducted a meta-regression examining the association between priming dose (dose range: 0.1–0.65 g/kg) and effect size across 18 effect sizes with available information. The association was not significant (b = −0.221 [95% CI, −1.375 to 0.933], z = 0.38, $P = 0.707$).

Soft drink versus placebo control comparison

We identified six effects with a soft drink and 15 effects with a placebo control. The subgroup difference was significant (χ^2 [1] = 8.38, $P = 0.004$). The effect was larger when comparing priming to soft drink (SMD = 0.604 [95% CI, 0.466 to 0.742], z = 8.61, $P < 0.001$), compared to placebo (SMD = 0.250 [95% CI, 0.107 to 0.392], z = 3.43, $P < 0.001$) controls.

Self-reported craving

We identified 140 effect sizes across 33 individual studies. Overall, there was a small-to-moderate effect of alcohol intoxication on self-reported craving in the multi-level meta-analysis (SMD = 0.431 [95% CI, 0.306, 0.555], z = 6.77, $P < 0.001$) (Figure S2). When outliers were included, the pooled effect was slightly larger (SMD = 0.498 [95% CI,

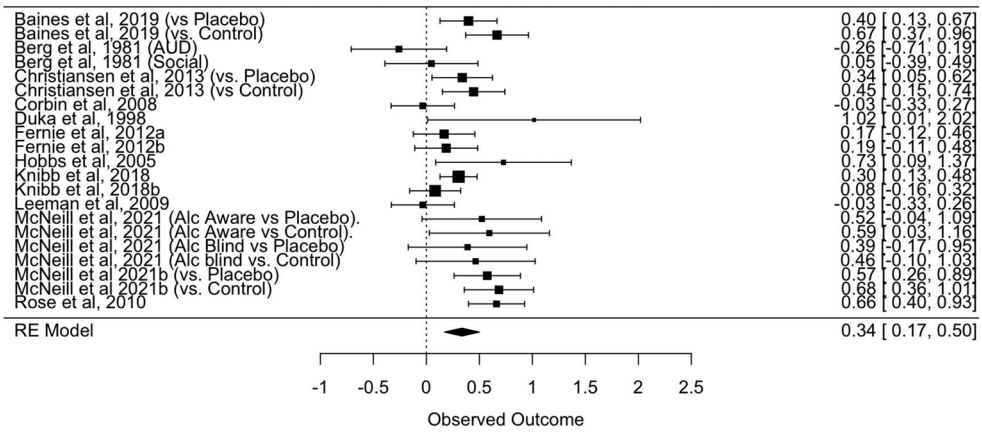

FIGURE 2 A forest plot demonstrating the effect of alcohol versus placebo/control priming on subsequent alcohol consumption. AUD = alcohol use disorder sample from Berg *et al.*; social = social drinker sample from Berg *et al* [42]. No other study split by drinking status therefore AUD/Social is not reported.

0.335, 0.659]). There was some degree of funnel plot asymmetry according to Egger's test (z = 3.53, $P < 0.01$) (Supporting information Figure S3), and Trim and Fill identified 26 effects, which when included reduced the pooled effect to SMD = 0.269 [95% CI, 0.185, 0.354].

Within versus between participants

We identified 91 effect sizes from within-participant study designs and 49 from between-participant study designs. There was no significant difference between study design (χ^2 [1] = 0.01, $P = 0.941$). For within-participant designs the effect on craving was SMD = 0.423 ([95% CI, 0.291, 0.555], z = 6.29, $P < 0.001$), and between-participant designs SMD = 0.420 ([95% CI, 0.187, 0.652], z = 3.54, $P < 0.001$).

Dose

There were 127 effect sizes, where dose of alcohol (g per kg) was provided, ranging from 0.13 g/kg to 0.95 g/kg. There was considerable variability in individual doses, therefore, to create meaningful subgroups (≥5 effect sizes) we collapsed doses into bins (e.g. 0.10–0.19 g/kg; 0.20–0.29 g/kg, and so on). At doses between 0.1–0.19 g/kg there was no significant effect ($n = 5$; SMD = 0.149 [−0.099, 0.399], $P = 0.237$). There were significant effects at doses at 0.30–0.39 g/kg ($n = 14$; SMD = 0.253 [95% CI, 0.053, 0.452], $P = 0.013$); 0.40–0.49 g/kg ($n = 31$; SMD = 0.297 [95% CI, 0.044, 0.551], $P = 0.022$); 0.50–0.59 g/kg ($n = 14$; SMD = 0.901 [95% CI, 0.465, 1.338], $P < 0.001$); 0.60–0.69 g/kg ($n = 22$; SMD = 0.420 [95% CI, 0.207, 0.632], $P < 0.001$); 0.70–0.79 g/kg ($n = 30$; SMD = 0.335 [95% CI, 0.150, 0.520], $P < 0.001$) and 0.80–0.89 g/kg ($n = 10$; SMD = 0.809 [95% CI, 0.471, 1.147], $P < 0.001$).[†] There was weak evidence of statistical significance between doses (χ^2 [6] = 13.02, $P = 0.042$), which was not significant when outliers were included ($P = 0.083$). There were significant contrasts between 0.1 versus 0.8 g/kg ($P = 0.003$); 0.3 versus 0.5 g/kg ($P = 0.019$); 0.3 versus 0.8 g/kg ($P = 0.003$); 0.4 versus 0.5 g/kg ($P = 0.014$); 0.5 versus 0.7 g/kg ($P = 0.021$); and 0.7 versus 0.8 g/kg ($P = 0.021$). When treating dose as a continuous variable in meta-regression, the association was not statistically significant (b = 0.458 [95% CI, −0.033, 0.949], $P = 0.067$).

[†]There was only one effect size from 0.20–0.29 g/kg, and two effects from 0.90–0.99, therefore we did not estimate a subgroup effect.

Soft drink versus placebo control comparison

We identified 13 effect sizes from soft drink comparisons and 123 from placebo comparisons. There was no significant difference between soft drink versus placebo (χ^2 [1] = 2.46, $P = 0.116$). Placebo comparisons, SMD = 0.403 [95% CI, 0.270, 0.536], z = 5.94, $P < 0.001$. Soft drink comparisons. SMD = 0.673 [95% CI, 0.339, 1.007] z = 3.95, $P < 0.001$. When outliers were included, this effect was significant ($P = 0.011$; soft drink comparisons (SMD = 0.957 [95% CI, 0.480, 1.422], $P < 0.001$) and placebo comparisons (SMD = 0.444 [95% CI, 0.274, 0.613], $P < 0.001$).

Assessment time

The most common assessment times were 15 minutes ($n = 15$: SMD = 0.205 [95% CI, 0.092, 0.318], $P < 0.001$); 30 minutes ($n = 27$: SMD = 0.511 [95% CI, 0.264, 0.757], $P < 0.001$); 40 minutes ($n = 6$; SMD = 0.820 [95% CI, 0.228, 1.412], $P = 0.007$; 60 minutes ($n = 15$; SMD = 0.671 [95% CI,0.434, 0.909), $P < 0.001$]; 120 minutes ($n = 12$; SMD = 0.318 [95% CI, 0.088, 0.549), $P = 0.006$]; and 180 minutes ($n = 11$; SMD = 0.164 [95% CI, −0.170, 0.498), $P = 0.336$]. There was a significant difference between the assessment times (χ^2 [5] = 14.62, P = 0.012). There were significant contrasts between 15 minutes versus 60 minutes ($P = 0.003$); 30 minutes versus 180 minutes ($P = 0.015$); 60 minutes versus 120 minutes ($P = 0.041$); 60 minutes versus 180 minutes ($P = 0.005$).

Risk of bias

Across included studies, risk of bias was consistently high in some domains. The majority of articles did not report any pre-registration information, and only four papers included statistical power

calculations or alternative sample size justification. Contrastingly, risk of bias across other domains was consistently low; most studies involved randomisation/counterbalancing of participants and drop-out rate remained predominantly below 10%. Some domains presented more variation in quality of assessment, with details of experimenter blinding and whether sex was accounted for in recruitment/dosage procedures varying between studies. Overall, risk of bias within studies was mixed (Supporting information Table S3).

DISCUSSION

We conducted meta-analyses to determine whether laboratory-based alcohol priming studies showed a significant effect of acute alcohol consumption on increasing motivation to drink. We also determined how design characteristics may influence the alcohol priming effect, to improve future studies aiming to investigate the role acute alcohol consumption has in motivating alcohol seeking and consumption.

Our results demonstrated a small to moderate alcohol priming effect on motivation to drink in a lab-based context. The strength of the priming dose was not associated with the size of priming effect on consumption, but was associated with craving. This may reflect the fact that far fewer studies used an ad libitum consumption outcome and the range of priming doses given in these studies was smaller (0.1–0.65 g/kg). Although at some point issues of satiation are likely to inhibit further consumption [13], ethical considerations prohibit larger priming doses used in conjunction with consumption-based priming outcomes. Given these issues, we cannot make clear recommendations regarding dose to use in ad lib priming studies.

An alternative explanation is that, although alcohol consumption and craving are both measures of alcohol motivation, they are distinct, and may be differentially affected by contextual factors [30]. For example, if a participant is motivated to drink, self-reported craving may more accurately reflect this in a lab-based environment compared to drinking behaviour. The novelty of the laboratory context may supress consumption, (e.g. because of being alone or concerns about being observed) [82]. However, given inconsistencies in the craving literature concerning its association with drinking behaviour [32, 33], future research may benefit by observing participants in naturalistic settings [83] or using collateral reports [84]. Such work could provide both a more realistic priming assessment and greater clarification of any association between different motivational indices of drinking.

In terms of craving, larger doses were generally associated with increased craving, with the largest effect size at doses of 0.5–0.59 g/kg. However, there were somewhat fewer studies at this dose and the confidence intervals were widest, indicating most uncertainty around this effect. In addition, the effect of dose on craving was not linear and the heterogeneity across study designs requires caution in interpretation. However, some individual studies compared different doses (e.g. [6]) and found that moderate (0.6 g/kg), but not lower (0.3 g/kg) doses, resulted in an alcohol priming effect. Based on our findings and the existing literature, we would, therefore, recommend using a dose of at least 0.5 g/kg, providing appropriate ethical and safety procedures are followed in terms of maximum dose available (e.g. priming dose and/or priming plus ad lib dose). We were unable to determine any effect of assessment time on consumption because of too few effect sizes, but for craving, time of assessment was associated with the priming effect. Craving increased from 15 minutes to 30 and 60 minutes, before decreasing at 120 and 180 minutes after consumption. Some previous studies included multiple assessment times and found that the priming effect peaked 30 minutes after the priming dose was consumed and roughly followed the blood alcohol curve [6, 85]. Multiple individual factors can affect BAC, but on average, the majority of alcohol is absorbed within 30 to 60 minutes following consumption [86]. During the ascending and peak phase of the blood alcohol curve, the positive and stimulant effects of alcohol are experienced and the subjective value of alcohol may be enhanced [15]. This might motivate alcohol use through positive reinforcement mechanisms [6, 16]. Together, this suggests that future priming studies use a dose of at least 0.5 g/kg and assessment times should correspond with the peak portion of the BAL. Studies should record BAL several times to accurately map priming effects against BAL. If this is done by converting breath alcohol concentration readings to BAL, then measures should be taken to standardise readings (e.g. wash mouth out with water before readings are taken).

In terms of design, within-participant designs are often seen as superior to between-participant, by removing potentially important between participant group differences. However, carry over effects can be problematic with participation of an early condition affecting beliefs and/or behaviour within a subsequent condition (e.g. expectations of what type of drink may be offered, or how they should react to beverages provided) [87]. Our analysis showed no statistically significant differences between studies using within- relative to between-participant designs. However, although within-subjects design showed an effect of alcohol priming on consumption and craving, between-subject designs only showed an effect on craving. This may reflect the lower number of studies using a between subject design, but further research is needed to clarify this. Additionally, adequate sample size may be a key factor to consider when choosing a design for future work. By establishing a pooled effect size for alcohol priming on consumption and craving across different time points, this information can be used to calculate the appropriate sample sizes necessary to reliably detect changes in motivation to drink. For example, to detect a statistically significant effect on ad libitum consumption, a study would require ~57 participants in a within-participants design and 222 in a between-participants design (one-tailed hypothesis: using pooled SMD = 0.336 and 80% power). Notably, very few of the identified studies had the power to detect this effect.

Traditionally, placebos have been considered the gold standard control drink [88], and this is reflected by many more studies incorporating a placebo relative to a soft drink control. The priming effect on consumption was greater when compared to soft drink relative to placebo controls. This may reflect the role of alcohol expectation on priming and alcohol behaviour [7]. Expectations may trigger drinking by two routes: either a person may experience placebo alcohol effects (intoxication) that motivates drinking, or they do not experience any

expected effects that frustrates the drinker and triggers consumption to experience intoxication [63]. Yet, there was no effect of control drink type on craving outcomes. This may be because of the uneven number of comparisons, but we would also argue that the type of control drink should be decided based on the aims of the study. Ideally alcohol priming studies should incorporate an alcohol, placebo and soft drink condition [47]. However, if this is not feasible, studies interested in determining the individual impact of alcohol's expectancy and pharmacological effects on motivation to drink should incorporate a placebo control [5]. If the study is interested in understanding motivation to drink within more 'real world' contexts, where arguably both pharmacological and expectancy effects influence drinking behaviour [89], a soft drink control would be more appropriate. A small number of studies have included an 'alcohol naïve' condition, in which participants are given alcohol, but told soft drink (this is part of the complete 'balanced placebo design') [42, 70]. However, research demonstrates that it is unlikely that participants will believe this instruction, because of alcohol's pharmacological effects (reports of successful deception may suggest social desirability bias) [90], so we would suggest avoiding such manipulations where possible.

The key limitations of this meta-analysis are that we could not include all possible behavioural measures of motivation to drink (e.g. absolute or relative choice behaviour). This was because of lack of data and considerable heterogeneity in outcomes. Therefore, we cannot make recommendations for studies incorporating these outcome measures, although if an alcohol prime is working by increasing the value of alcohol, it is likely that a prime would have similar effects on any direct measure of motivation to drink. Second, because of the nature of the research studies and lack of data we were unable to model the combined effects of dose and assessment time; therefore, our findings should be interpreted with some caution. This analysis sought to determine the nature of priming in lab-based settings. If priming studies were conducted using more realistic parameters (e.g. multiple drinks, with other drinkers and in pseudo-naturalistic bar studies) [73, 67, 91, 92] it is possible that the dose needed and the time patterns of priming would differ. Similarly, the typical drinking habits of the participants may be important. For obvious ethical reasons, alcohol priming research does not recruit participants with historical or current diagnosis of alcohol use disorder (some early studies used clinical populations, e.g. Marlatt *et al.*) [7]. The current analysis included studies where typical drinking habits ranged from an estimated 2.28 to 41.05 units a week (although it is worth noting that of the between subject studies, 4 of 6 ad lib studies and 11 of 14 craving studies reported no difference in the drinking habits of participants by condition. The remaining studies failed to report on this issue). We advise caution and do not seek to generalise these findings to populations who may drink outside of this range.

The current meta-analysis is the first to determine the effectiveness of an alcohol prime to enhance motivation for alcohol, assessed by both consumption and self-report craving outcome measures, in lab-based research. Based on these findings, we have provided recommendations for the design of future alcohol priming studies based on the aims of any given study.

CLINICAL TRIAL REGISTRATION AND PROTOCOL

https://osf.io/apgvk

DECLARATION OF INTERESTS

None.

AUTHOR CONTRIBUTIONS

Lauren Halsall: Data curation; formal analysis; methodology; project administration. **Andrew Jones:** Conceptualization; data curation; formal analysis; methodology; project administration; supervision. **Carl Roberts:** Formal analysis. **Graeme Knibb:** Formal analysis.

OPEN RESEARCH BADGES

This article has earned a Preregistered Research Designs badge for having a preregistered research design, available at https://osf.io/apgvk.

ORCID

Andrew Jones https://orcid.org/0000-0001-5951-889X
Carl Roberts https://orcid.org/0000-0003-4275-601X
Graeme Knibb https://orcid.org/0000-0001-9974-834X
Abigail K. Rose https://orcid.org/0000-0003-3267-7318

REFERENCES

1. Organisation WH. Global status report on alcohol and health 2018. Geneva; 2018.
2. Sinha R, O'Malley SS. Craving for alcohol: Findings from the clinic and the laboratory. Alcohol Alcohol. 1999;34(2):223–30.
3. Kuhn BN, Kalivas PW, Bobadilla A-C. Understanding addiction using animal models. Front Behav Neurosci. 2019;13.
4. Nieto SJ, Grodin EN, Aguirre CG, Izquierdo A, Ray LA. Translational opportunities in animal and human models to study alcohol use disorder. Transl Psychiatry. 2021;11(1):496.
5. Hodgson R, Rankin H, Stockwell T. Alcohol dependence and the priming effect. Behav Res Ther. 1979;17(4):379–87.
6. Rose AK, Duka T. Effects of dose and time on the ability of alcohol to prime social drinkers. Behav Pharmacol. 2006;17(1):61–70.
7. Marlatt GA, Demming B, Reid JB. Loss of control drinking in alcoholics: An experimental analogue. J Abnorm Psychol. 1973;81:223–41.
8. Rodd ZA, Bell RL, Sable HJK, Murphy JM, McBride WJ. Recent advances in animal models of alcohol craving and relapse. Pharmacol Biochem Behav. 2004;79(3):439–50.
9. Field M, Wiers RW, Christiansen P, Fillmore MT, Verster JC. Acute alcohol effects on inhibitory control and implicit cognition: Implications for loss of control over drinking. Alcohol Clin Exp Res. 2010;34(8):1346–52.
10. Rose AK, Duka T. The influence of alcohol on basic motoric and cognitive disinhibition. Alcohol Alcohol. 2007;42(6):544–51.
11. Rose AK, Jones A, Clarke N, Christiansen P. Alcohol-induced risk taking on the BART mediates alcohol priming. Psychopharmacology (Berl). 2014;231(11):2273–80.
12. Fernie G, Christiansen P, Cole JC, Rose AK, Field M. Effects of 0.4g/kg alcohol on attentional bias and alcohol-seeking behaviour in heavy and moderate social drinkers. J Psychopharmacol. 2012;26(7):1017–25.

13. Duka T, Townshend JM. The priming effect of alcohol pre-load on attentional bias to alcohol-related stimuli. Psychopharmacology (Berl). 2004;176(3–4):353–61.
14. de Wit H. Priming effects with drugs and other reinforcers. Exp Clin Psychopharmacol. 1996;4:5–10.
15. Rose AK, Brown K, Field M, Hogarth L. The contributions of value-based decision-making and attentional bias to alcohol-seeking following devaluation. Addiction. 2013;108(7):1241–9.
16. Rose AK, Grunsell L. The subjective, rather than the disinhibiting, effects of alcohol are related to binge drinking. Alcohol Clin Exp Res. 2008;32(6):1096–104.
17. Shaham Y, Shalev U, Lu L, de Wit H, Stewart J. The reinstatement model of drug relapse: History, methodology and major findings. Psychopharmacology (Berl). 2003;168(1–2):3–20.
18. Verdejo-Garcia A, Clark L, Dunn BD. The role of interoception in addiction: A critical review. Neurosci Biobehav Rev. 2012;36(8):1857–69.
19. Leganes-Fonteneau M, Bates ME, Vaschillo EG, Buckman JF. An interoceptive basis for alcohol priming effects. Psychopharmacology (Berl). 2021;238(6):1621–31.
20. Domi E, Domi A, Adermark L, Heilig M, Augier E. Neurobiology of alcohol seeking behavior. J Neurochem. 2021;157(5):1585–614.
21. Courtney KE, Ghahremani DG, Ray LA. The effect of alcohol priming on neural markers of alcohol cue-reactivity. Am J Drug Alcohol Abuse. 2015;41(4):300–8.
22. O'Malley SS, Krishnan-Sarin S, Farren C, Sinha R, Kreek MJ. Naltrexone decreases craving and alcohol self-administration in alcohol-dependent subjects and activates the hypothalamo-pituitary-adrenocortical axis. Psychopharmacology (Berl). 2002;160(1):19–29.
23. Farokhnia M, Deschaine SL, Sadighi A, Farinelli LA, Lee MR, Akhlaghi F, et al. A deeper insight into how GABA-B receptor agonism via baclofen may affect alcohol seeking and consumption: Lessons learned from a human laboratory investigation. Mol Psychiatry. 2021;26(2):545–55.
24. de Wit H, Chutuape MA. Increased ethanol choice in social drinkers following ethanol preload. Behav Pharmacol. 1993;4(1):29–36.
25. Jones AW. Alcohol, its absorption, distribution, metabolism, and excretion in the body and pharmacokinetic calculations. WIREs Forensic Sci. 2019;1(5):e1340.
26. Medicine NW. How Alcohol Impacts the Brain 2021. [Available from: https://www.nm.org/healthbeat/healthy-tips/alcohol-and-the-brain.
27. Christiansen P, Townsend G, Knibb G, Field M. Bibi ergo sum: The effects of a placebo and contextual alcohol cues on motivation to drink alcohol. Psychopharmacology (Berl). 2017;234(5):827–35.
28. Charness G, Gneezy U, Kuhn MA. Experimental methods: Between-subject and within-subject design. J Econ Behav Org. 2012;81(1):1–8.
29. Rose AK, Brown K, MacKillop J, Field M, Hogarth L. Alcohol devaluation has dissociable effects on distinct components of alcohol behaviour. Psychopharmacology (Berl). 2018;235(4):1233–44.
30. de Wit H. Laboratory-based assessment of alcohol craving in social drinkers. Addiction. 2000;95(Suppl 2):S165–9.
31. Kavanagh DJ, Statham DJ, Feeney GFX, Young RM, May J, Andrade J, et al. Measurement of alcohol craving. Addict Behav. 2013;38(2):1572–84.
32. Sayette MA. The role of craving in substance use disorders: Theoretical and methodological issues. Annu Rev Clin Psychol. 2016;12(1):407–33.
33. Tiffany ST, Wray JM. The clinical significance of drug craving. Ann N Y Acad Sci. 2012;1248:1–17.
34. Sterne JAC, Savović J, Page MJ, Elbers RG, Blencowe NS, Boutron I, et al. RoB 2: A revised tool for assessing risk of bias in randomised trials. BMJ. 2019;366:l4898.
35. Rohatgi A. WebPlotDigitizer. V4.5 2021. [Available from: https://automeris.io/WebPlotDigitizer.
36. Johnsen TJ, Friborg O. The effects of cognitive behavioral therapy as an anti-depressive treatment is falling: A meta-analysis. Psychol Bull. 2015;141(4):747–68.
37. McEvoy PM, Stritzke WG, French DJ, Lang AR, Ketterman R. Comparison of three models of alcohol craving in young adults: A cross-validation. Addiction. 2004;99(4):482–97.
38. Duval S, Tweedie R. Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. Biometrics. 2000;56(2):455–63.
39. Fu R, Gartlehner G, Grant M, Shamliyan T, Sedrakyan A, Wilt TJ, et al. Conducting Quantitative Synthesis When Comparing Medical Interventions: AHRQ and the Effective Health Care Program Rockville, MD: Agency for Healthcare Research and Quality Methods Guide for Comparative Effectiveness Reviews; 2010.
40. Davidson D, Tiffany ST, Johnston W, Flury L, Li TK. Using the cue-availability paradigm to assess cue reactivity. Alcohol Clin Exp Res. 2003;27(8):1251–6.
41. Hutchison KE, McGeary J, Smolen A, Bryan A, Swift RM. The DRD4 VNTR polymorphism moderates craving after alcohol consumption. Health Psychol. 2002;21(2):139–46.
42. Berg G, Laberg JC, Skutle A, Öhman A. Instructed versus pharmacological effects of alcohol in alcoholics and social drinkers. Behav Res Ther. 1981;19(1):55–66.
43. Love A, James D, Willner P. A comparison of two alcohol craving questionnaires. Addiction. 1998;93(7):1091–102.
44. Adams S, Ataya AF, Attwood AS, Munafò MR. Effects of acute alcohol consumption on alcohol-related cognitive biases in light and heavy drinkers are task-dependent. J Psychopharmacol. 2011;26(2):245–53.
45. Amlung M, McCarty KN, Morris DH, Tsai C-L, McCarthy DM. Increased behavioral economic demand and craving for alcohol following a laboratory alcohol challenge. Addiction. 2015;110(9):1421–8.
46. Baines L, Field M, Christiansen P, Jones A. The effect of alcohol cue exposure and acute intoxication on inhibitory control processes and ad libitum alcohol consumption. Psychopharmacology (Berl). 2019;236(7):2187–99.
47. Christiansen P, Rose AK, Cole JC, Field M. A comparison of the anticipated and pharmacological effects of alcohol on cognitive bias, executive function, craving and ad-lib drinking. J Psychopharmacol. 2013;27(1):84–92.
48. Corbin WR, Gearhardt A, Fromme K. Stimulant alcohol effects prime within session drinking behavior. Psychopharmacology (Berl). 2008;197(2):327–37.
49. Carter BL, Tiffany ST. The cue-availability paradigm: The effects of cigarette availability on cue reactivity in smokers. Exp Clin Psychopharmacol. 2001;9(2):183–90.
50. de Wit H, Soderpalm AH, Nikolayev L, Young E. Effects of acute social stress on alcohol consumption in healthy subjects. Alcohol Clin Exp Res. 2003;27(8):1270–7.
51. Duka T, Tasker R, Stephens DN. Alcohol choice and outcome expectancies in social drinkers. Behav Pharmacol. 1998;9(7):643–53.
52. Field M, Mogg K, Bradley BP. Alcohol increases cognitive biases for smoking cues in smokers. Psychopharmacology (Berl). 2005;180(1):63–72.
53. Fillmore MI, Rush CR. Alcohol effects on inhibitory and activational response strategies in the acquisition of alcohol and other reinforcers: Priming the motivation to drink. J Stud Alcohol. 2001;62(5):646–56.
54. Fillmore MT. Cognitive preoccupation with alcohol and binge drinking in college students: Alcohol-induced priming of the motivation to drink. Psychol Addict Behav. 2001;15(4):325–32.
55. Hobbs M, Remington B, Glautier S. Dissociation of wanting and liking for alcohol in humans: A test of the incentive-sensitisation theory. Psychopharmacology (Berl). 2005;178(4):493–9.

56. Bohn MJ, Krahn DD, Staehler BA. Development and initial validation of a measure of drinking urges in abstinent alcoholics. Alcohol Clin Exp Res. 1995;19(3):600–6.
57. King AC, Houle T, de Wit H, Holdstock L, Schuster A. Biphasic alcohol response differs in heavy versus light drinkers. Alcohol Clin Exp Res. 2002;26(6):827–35.
58. Johanson CE, Uhlenhuth EH. Drug preference and mood in humans: Diazepam. Psychopharmacology (Berl). 1980;71(3):269–73.
59. King AC, de Wit H, McNamara PJ, Cao D. Rewarding, stimulant, and sedative alcohol responses and relationship to future binge drinking. Arch Gen Psychiatry. 2011;68(4):389–99.
60. King A, Vena A, Hasin DS, DeWit H, O'Connor SJ, Cao D. Subjective responses to alcohol in the development and maintenance of alcohol use disorder. Am J Psychiatry. 2021;178(6):560–71.
61. Kirk JM, de Wit H. Individual differences in the priming effect of ethanol in social drinkers. J Stud Alcohol. 2000;61(1):64–71.
62. Knibb G, Roberts CA, Robinson E, Rose A, Christiansen P. The effect of beliefs about alcohol's acute effects on alcohol priming and alcohol-induced impairments of inhibitory control. Plos One. 2018; 13(7):e0201042.
63. Leeman RF, Corbin WR, Fromme K. Craving predicts within session drinking behavior following placebo. Personal Individ Differ. 2009; 46(7):693–8.
64. McNeill AM, Monk RL, Qureshi AW, Litchfield D, Heim D. The effects of placebo and moderate dose alcohol on attentional bias, inhibitory control and subjective craving. Alcohol Alcohol. 2021; 56(6):763–70.
65. Marczinski CA, Fillmore MT, Henges AL, Ramsey MA, Young CR. Mixing an energy drink with an alcoholic beverage increases motivation for more alcohol in college students. Alcohol Clin Exp Res. 2013; 37(2):276–83.
66. Chutuape MAD, Mitchell SH, de Wit H. Ethanol preloads increase ethanol preference under concurrent random-ratio schedules in social drinkers. Exp Clin Psychopharmacol. 1994;2(4):310–8.
67. McCusker CG, Brown K. Alcohol-predictive cues enhance tolerance to and precipitate "craving" for alcohol in social drinkers. J Stud Alcohol. 1990;51(6):494–9.
68. McKee SA, Krishnan-Sarin S, Shi J, Mase T, O'Malley SS. Modeling the effect of alcohol on smoking lapse behavior. Psychopharmacology (Berl). 2006;189(2):201–10.
69. Bartoshuk LM. Comparing sensory experiences across individuals: Recent psychophysical advances illuminate genetic variation in taste perception. Chem Senses. 2000;25(4):447–60.
70. McNeill AM, Monk RL, Qureshi A, Heim D. Intoxication without anticipation: Disentangling pharmacological from expected effects of alcohol. J Psychopharmacol. 2021;35(11):1398–410.
71. Montgomery C, Field M, Atkinson AM, Cole JC, Goudie AJ, Sumnall HR. Effects of alcohol preload on attentional bias towards cocaine-related cues. Psychopharmacology (Berl). 2010;210(3):365–75.
72. Ortner CNM, MacDonald TK, Olmstead MC. Alcohol intoxication reduces impulsivity in the delay-discounting paradigm. Alcohol Alcohol. 2003;38(2):151–6.
73. Rose AK, Hobbs M, Klipp L, Bell S, Edwards K, O'Hara P, et al. Monitoring drinking behaviour and motivation to drink over successive doses of alcohol. Behav Pharmacol. 2010;21(8):710–8.
74. Rose AK, Hardman CA, Christiansen P. The effects of a priming dose of alcohol and drinking environment on snack food intake. Appetite. 2015;95:341–8.
75. Schoenmakers T, Wiers RW, Field M. Effects of a low dose of alcohol on cognitive biases and craving in heavy drinkers. Psychopharmacology (Berl). 2008;197(1):169–78.
76. Söderpalm AHV, de Wit H. Effects of stress and alcohol on subjective state in humans. Alcohol Clin Exp Res. 2002;26(6):818–26.
77. Fischman MW, Foltin RW. Utility of subjective-effects measurements in assessing abuse liability of drugs in humans. Brit J Addict. 1991;86(12):1563–70.
78. Wardell JD, Read JP. Interactive effects of contextual cues and acute alcohol intoxication on the associations between alcohol expectancy activation and urge to drink. Exp Clin Psychopharmacol. 2014;22(5): 407–18.
79. Yates M, Kamboj SK. Alcohol related mental imagery: The effects of a priming dose in at risk drinkers. Addict Behav Rep. 2017;6:71–5.
80. West R, Hajek P. Evaluation of the mood and physical symptoms scale (MPSS) to assess cigarette withdrawal. Psychopharmacology (Berl). 2004;177(1):195–9.
81. Zack M, Woodford TM, Tremblay AM, Steinberg L, Zawertailo LA, Busto UE. Stress and alcohol cues exert conjoint effects on go and stop signal responding in male problem drinkers. Neuropsychopharmacology. 2011;36(2):445–58.
82. Gough T, Haynes A, Clarke K, Hansell A, Kaimkhani M, Price B, et al. Out of the lab and into the wild: The influence of portion size on food intake in laboratory vs real-world settings. Appetite. 2021;162:105160.
83. Field M, Jones A, Kersbergen I, Robinson E. Experimental research requires valid and sensitive measures of alcohol intake, and this is a step in the right direction: Commentary on Leeman and colleagues (2018). Alcohol Clin Exp Res. 2018;42(6):1019–21.
84. Hagman BT, Cohn AM, Noel NE, Clifford PR. Collateral informant assessment in alcohol use research involving college students. J am Coll Health. 2010;59(2):82–90.
85. Lukas SE, Mendelson JH, Benedikt RA. Instrumental analysis of ethanol-induced intoxication in human males. Psychopharmacology (Berl). 1986;89(1):8–13.
86. Koob GF, Arends MA, Le Moal M. Chapter 6 - Alcohol. In: Koob GF, Arends MA, Le Moal M, editorsDrugs, Addiction, and the Brain San Diego: Academic Press; 2014. p. 173–219.
87. Jhangiani RS, Chant IA, Cuttler C, Leighton DC. Research Methods in Psychology 4th ed. Canada: Pressbooks; 2019.
88. Galindo MN, Navarro JF, Cavas M. The influence of placebo effect on craving and cognitive performance in alcohol, caffeine, or nicotine consumers: A systematic review. Front Psych. 2020;11:849.
89. Bodnár V, Nagy K, Cziboly Á, Bárdos G. Alcohol and placebo: The role of expectations and social influence. Int J Mental Health Addic. 2020;19:2292–2305.
90. Sayette MA, Breslin FC, Wilson GT, Rosenblum GD. An evaluation of the balanced placebo design in alcohol administration research. Addict Behav. 1994;19(3):333–42.
91. Clarke N, Rose AK. Impact of labeled glasses in a Bar laboratory setting: No effect on ad libitum alcohol consumption. Alcohol Clin Exp Res. 2020;44(8):1666–74.
92. Schoenmakers TM, Wiers RW. Craving and attentional bias respond differently to alcohol priming: A field study in the pub. Eur Addict Res. 2010;16(1):9–16.

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Halsall L, Jones A, Roberts C, Knibb G, Rose AK. The impact of alcohol priming on craving and motivation to drink: a meta-analysis. Addiction. 2022. https://doi.org/10.1111/add.15962