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Cognitive bias modification as a web-based intervention for problem drinkers: A randomized controlled trial with a factorial design

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ABSTRACT

Objective: Previous studies have shown that Cognitive Bias Modification (CBM) can decrease cognitive biases implicated in the maintenance of problem drinking. However, it is still unclear what the individual and combined effects of multiple CBM interventions are when delivered as an e-health intervention. The current study therefore investigated the effects of web-based modification of attention bias, selective inhibition, and approach bias in a 2 (attentional bias modification: intervention/placebo) x 2 (selective inhibition training: intervention/placebo) x 2 (approach bias modification: intervention/placebo) double-blind, randomized controlled trial in self-identified problem drinkers.
Method: Self-identified problem drinkers were randomly assigned to one of the eight CBM conditions. All participants first completed a personalized feedback intervention before completing 12 CBM sessions over six weeks. Cognitive biases were assessed with trained and untrained tasks at pre- and post-test and alcohol use was additionally measured three and six months later.
Results: 427 self-identified problem drinkers ($M_{age} = 51.2$ years, $SD_{age} = 8.69$) were included. Results showed that alcohol use decreased over time, but the reductions in drinking did not differ between CBM conditions. There was little evidence that CBM changed cognitive biases. It should however be noted that some bias measures showed inadequate reliability.
Conclusions: The results indicate that in problem drinkers, web-based CBM does not add to the effects of a brief motivational intervention to reduce alcohol use over time. Findings may be due to unsuccessful bias modification. Future studies need to delineate moderators of effectiveness and investigate new and promising inference-based CBM-variations.

Problematic use of alcohol is linked to an increased risk of a wide range of both acute and long-term physical and psychological health problems (World Health Organization, 2019). Since cognitive biases are implicated in the etiology and maintenance of problem drinking (Wiers et al., 2013), they are a promising target for intervention. For example, alcohol-related cues are thought to selectively capture attention (attentional bias, AtB), activate positive associations, and elicit the tendency to approach alcohol (approach bias, ApB). To examine the causal effects of cognitive biases on alcohol use, various procedures have been developed to experimentally manipulate each specific cognitive bias. In this way, it was shown that these biases can be changed: AtB (e.g., Field & Eastwood, 2005; Field et al., 2007; Rinck et al., 2018; Schoenmakers et al., 2007), ApB (Schenkel et al., 2023; Wiers et al., 2010), and automatic alcohol associations (Houben et al., 2011, 2012)

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could be changed, which often resulted in congruent changes in alcohol use. Regarding the latter, however, it is important to note that while alcohol-specific inhibition training (SIT, the Cognitive Bias Modification method) has been found to change evaluative alcohol associations (i.e., evaluative memory bias; Houben et al., 2012; Houben et al., 2011), several studies did not find this effect (e.g., Bowley et al., 2013; Di Lemma & Field, 2017; Kilwein et al., 2018; Stein et al., 2023) and there is also some evidence that a more general increase in inhibitory control is the underlying working mechanism (Guarriello et al., 2025; Jones & Field, 2013; Stein et al., 2023). Regardless, these findings not only supported the hypothesized causal role of cognitive biases in alcohol use but also spurred the idea that these biases may be a fruitful target for alcohol interventions.

The procedures aimed at retraining cognitive biases, collectively referred to as Cognitive Bias Modification (CBM), are computerized and can be delivered online. Although e-health interventions inherently come with potential risks, such as low-adherence and early drop-out rates (e.g. Koelen et al., 2022; Postel et al., 2010; Riper et al., 2008; Shams et al., 2023), they offer potential clinical, economical, and scientific benefits. First, web-based interventions are accessible and low-cost, and could reach problem drinkers who would not seek face-to-face treatment (Riper et al., 2018) and as such have the potential for large scale-ups (Vrijsen et al., 2024). Second, web-based CBM can be completed at home, where environmental cues have likely become associated with alcohol use. This may make a home setting a more effective, albeit less controlled, location for the assessment and modification of cue-driven biases than a lab or clinical setting (Houben & Wiers, 2008). Third, web-based studies have been able to attain large sample sizes with relatively low recruitment costs. This allows for factorial research designs, which are needed to directly compare the effectiveness of different CBM procedures. The aim of the current study was to investigate the individual and combined effects of web-based attentional bias, evaluative memory bias/inhibitory control,[2] and approach bias modification for problem drinkers (van Deursen et al., 2013).

Recently, the effectiveness of CBM in substance use has been the subject of debate (Boffo et al., 2019; Christiansen et al., 2015; Cristea et al., 2016; Field et al., 2014, 2016; Wiers, 2016; Wiers et al., 2018). CBM was found not to be effective in changing substance-related outcomes in a meta-analysis that included proof-of-principle studies, investigating the causal effects of CBM in individuals who did not intend to change their alcohol or tobacco use, and clinical studies, evaluating the effectiveness of CBM in individuals who were motivated to change their substance use (Cristea et al., 2016; Wiers et al., 2018). However, the outcome measures and sample characteristics of the included studies varied widely, and others have argued that this impedes general conclusions on the effectiveness of CBM (Christiansen et al., 2015; Wiers et al., 2018). A subsequent Bayesian meta-analysis of individual patient data only included studies with samples motivated to change their drinking or smoking, and tentatively concluded that CBM reduced relapse rates in participants who aimed to abstain, but that CBM did not affect substance use in smokers or problem drinkers who aimed to reduce their use (Boffo et al., 2019). Importantly, the results indicated that more research was needed to be able to draw firm conclusions on CBM's effectiveness as an intervention.

A closer inspection of CBM studies in problem drinkers or individuals with AUDs who are motivated to change, offers several possible explanations for the mixed results. The first is that the CBM procedures may have failed to consistently manipulate cognitive biases, which could explain the lack of effects on substance use (Grafton et al., 2017; MacLeod & Clarke, 2015; Wiers et al., 2018). However, conclusions are hampered by the fact that not all studies have assessed bias change and that not all cognitive bias measures have adequate reliability (Ataya et al., 2012), which may explain why the effects of CBM on cognitive biases have not always been in line with the effects on addiction-related outcomes. A second possible explanation is that CBM may be effective as an add-on to an in-patient treatment program aimed at preventing relapse in abstinent patients, but not as a stand-alone intervention aimed at reducing alcohol use in problem drinkers (Boffo et al., 2019; Wiers et al., 2018). Indeed, a large number of studies find that CBM (AtB, ApB, SIT modification) decreased or delayed relapse when implemented as an add-on to in-patient treatment (Eberl et al., 2013; Manning et al., 2016; Manning et al., 2022; Manning et al., 2021; Rinck et al., 2018; Salemink et al., 2021; Schenkel et al., 2023; Schoenmakers et al., 2010; Stein et al., 2023; Wiers et al., 2011; for a review, see Wiers et al., 2023). It should however be noted that Spruyt et al. (submitted) did not find an effect of CBM as add-on to treatment which is most likely explained by their used inconsistency rates in their training (87,5% push alcohol), compared with 95% in other studies (e.g., Manning et al., 2022). Additionally, two studies investigating the added effects of transcranial direct current stimulation (tDCS) on AtB modification also did not find that the CBM affected relapse (den Uyl et al., 2017; den Uyl et al., 2018). However, considering these studies were relatively small and included potential placebo effects of tDCS and den Uyl et al. (2017) did not include a non-active CBM condition, drawing conclusions about the effects of CBM on relapse rates is challenging. Conversely, studies that examined CBM (AtB and ApB modification) as an independent intervention found that CBM did not differentially reduce alcohol use in problem drinkers (Clerkin et al., 2016; Wiers et al., 2015).

Bridging the gap between these two lines of research, two studies investigated CBM in combination with a motivational intervention in problem drinkers outside the clinic. The first study combined CBM (AtB modification) with a face-to-face motivational intervention in a factorial design (Cox et al., 2015). The results of this study indicated that CBM decreased alcohol use in the short but not in the long term, and that this change was not influenced by whether participants also received motivational training. However, since both participants and the experimenter were aware of the participants' experimental condition, it could not be ruled out that expectancy effects contributed to the initial reductions in alcohol use. Furthermore, the effects of the motivational intervention only became apparent in the long term, so it remained unclear whether increasing motivation to change prior to CBM could increase its effectiveness. In the second study, CBM (SIT) was preceded by a brief computerized motivational intervention and found that CBM did not decrease alcohol use more than a placebo-CBM training (Jones et al., 2018). Since CBM also did not change the targeted cognitive bias, this study could not demonstrate whether a successful reduction in cognitive bias would have resulted in a subsequent change in alcohol use. Taken together, prior research supports CBM's effectiveness in reducing relapse over and above in-patient treatment, but so far provides little support for its effectiveness for problem drinkers who are not admitted in an addiction treatment center.

Both from a prevention and an economic perspective, it is important to investigate whether CBM can successfully decrease cognitive biases outside the clinic and whether these changes in turn lead to reductions in alcohol use. In addition, little is known about the relative effectiveness of different types of CBM or whether targeting more than one cognitive bias augments the effects. SIT has so far only been compared to inhibitory control training without alcohol priming (Jones et al., 2018), to a more difficult version of SIT (Stein et al., 2023) and as an add-on to in-patient treatment combined with ApB (Schenkel et al., 2023). Only a handful of studies have directly compared AtB and ApB modification (Di Lemma & Field, 2017; Rinck et al., 2018; Spruyt et al., submitted; Wiers et al., 2015). Some of these studies found differences in effects between the interventions. For example, Schenkel et al. (2023) found that ApB as an add-on to in-patient treatment decreased relapse rates and adding SIT to this existing combination did not have added benefits. Also note that

[2] Testing inhibitory control as an alternative account for SIT effects has been included after reviewer comments and was therefore not included in the protocol paper.

only Rinck et al. (2018) found CBM to be effective (both AtB and ApB modification decreased long-term relapse rates compared with sham training or no training). This study also showed that the combination of the AtB and ApB modification did not increase the effectiveness compared to either CBM version alone; however, since those who received both CBM versions only received half the number of sessions of each individual CBM procedure, this could be a result of the lower dose per training (Rinck et al., 2018).

The goal of the current study was therefore to investigate the effects of the web-based modification of AtB, SIT, and ApB in a 2 × 2 × 2 mixed factorial design, in which self-identified problem drinkers received either the intervention or a placebo version for all three CBM interventions. To increase motivation for change, all participants first received a brief computerized personalized feedback intervention, irrespective of their CBM condition. Cognitive biases were assessed before and after CBM, using the task that was also used during the CBM intervention as well as using a different task, not used for training. It was hypothesized that each CBM intervention would result in a decrease in the targeted bias relative to the placebo condition, and that three months after the intervention the CBM intervention conditions would show larger reductions in alcohol use than the placebo conditions.

1. Methods

1.1. Design

A double blind randomized controlled trial was conducted with a 2 (attentional bias modification (AtBM): intervention vs. placebo) x 2 (approach bias modification (ApBM: intervention vs. placebo) x 2 (alcohol specific inhibition training (SIT): intervention vs. placebo) x 5 (time: pre-test, post-test, and follow-ups at three, six and twelve months after the post-test) mixed factorial design. Due to increasing dropout rates for the longer-term follow-ups, the last follow-up was not included in the analyses (see Fig. 1 for the flow of participants and attrition rates through the study). Before the CBM intervention, all participants completed the first two modules of the DrinkingLess program, a brief computerized personalized feedback/motivation intervention (Riper et al., 2008).

1.2. Participants

Participants were recruited between June 2012 and July 2013[3] through newspaper articles, a TV-program with an item on CBM, the websites of DrinkingLess and the Addiction Development and Psychopathology (ADAPT) Lab, and snowball sampling. Participants were eligible if they scored >7 on the Alcohol Use Disorders Identification Test (AUDIT, Babor et al., 2001), consumed >14 (women) or >21 (men) standard alcoholic drinks per week in the past 14 days as assessed with the Timeline-Follow-Back (TLFB) method (Sobell & Sobell, 1992), were aged 18 to 65, had (near) daily internet access, and did not receive professional help for problem drinking at the start of the intervention. Included participants were automatically assigned to one of the eight CBM conditions, using the method of minimization (Scott et al., 2002) to ensure comparable sex ratios and AUDIT scores (8–19 versus >19) across conditions. Participants were randomly allocated to one of the conditions to which the fewest participants of their sex and AUDIT level had so far been assigned, not counting in those participants who did not complete the baseline assessment (including DrinkingLess) or who indicated that they wanted to discontinue the study. Participants were blinded to the allocated condition and since both the intervention and all assessments were completed via the internet in the absence of experimenters, the study was inherently double blind. The study received ethical approval by the Ethics Committee of the Psychology department of the University (University of Amsterdam), registered at the Netherlands Trial Register (NTR3875), and described in a study protocol (van Deursen et al., 2013).

1.3. Cognitive bias modification

The CBM sessions consisted of three components, targeted at different cognitive biases: AtB, EMB/inhibitory control, and ApB. Each component started with a practice phase and an assessment phase (48 trials), after which, depending on the condition, participants completed the intervention or placebo version of the CBM training (120 trials). We based this approach on the total number of trials previously proven effective (e.g., Wiers et al., 2011) but spread this total number of trials across more CBM training sessions to consider the effectiveness of the online training format of this study while minimizing participant fatigue and dropout risk (e.g. Postel et al., 2010). Validated pictures of alcoholic and non-alcoholic beverages were used as stimuli during the assessment and modification of the cognitive biases (Pronk et al., 2015). All trials started with a fixation cross presented in the middle of the screen for 500 ms, and the inter-trial interval was 500 ms. To motivate participants for the intervention, the goal of each CBM procedure was explained before the first session, but without disclosing the specific way in which the procedures were designed to achieve this goal, so that blinding was ensured. Furthermore, participants were motivated to optimize their task performance and to complete all CBM sessions, by including a game-like point system. Participants received points for every completed session, and for every accurate response, and more points could be earned when response times (RTs) were lower. Participants were encouraged to beat the score that they obtained during the previous session and were informed when they had succeeded in doing so.

Attention bias. AtB was assessed and trained using varieties of the visual probe task (VPT; MacLeod et al., 1986; MacLeod et al., 2002). In this task, participants were first presented with a picture of an alcoholic and a non-alcohol beverage for 500 ms (based on the results of Schoenmakers et al., 2010). After the pictures disappeared, a small arrow appeared at the location of one of the pictures and participants had to indicate the direction of the arrow, by pressing the up or down arrow key. Half of the assessment phase was composed of alcohol trials, in which the arrow replaced the alcoholic beverage, and the other half of non-alcohol trials, in which the arrow replaced the non-alcoholic beverage. AtB for alcohol was calculated by subtracting RTs on alcohol trials from those on non-alcohol trials, following the rationale that participants with an AtB for alcohol would be looking at the picture of the alcoholic beverage, and that they would therefore be faster to respond to the arrow if it replaced the alcoholic beverage than if it replaced the non-alcoholic beverage. In the CBM phase, participants in the placebo condition continued with a 50/50 ratio of alcohol and non-alcohol trials, while participants in the intervention condition received only non-alcohol trials. In this way, participants in the intervention condition were trained to direct their attention away from the alcoholic beverage and towards the non-alcoholic beverage.

Evaluative memory bias/inhibitory control. EMB/inhibitory control was assessed and trained using the SIT (based on the GNG-task; Houben et al., 2011). In this task, a picture of an alcoholic or nonalcoholic beverage was presented for 1500 ms, with a go (i.e. the letter 'p') or no-go cue ('f') displayed randomly in one of four corners of the picture. Based on the letter, participants had to press the spacebar (go response) or wait until the picture disappeared (no-go response). The letter-response combination (p = go and f = no-go, or vice versa) was counterbalanced across participants at pre-test, and the same combination was used at post-test. The assessment phase was composed of 25% alcohol/go, 25% alcohol/no-go, 25% non-alcohol/go and 25% non-alcohol/no go trials. Alcohol-go bias was computed by subtracting RTs on alcohol/go trials from those on non-alcohol/go trials. This alcohol-go bias was used as an indirect measure of evaluative memory

[3] Recruitment took place between 2012 and 2013 as it was part of a PhD dissertation (see van Deursen, 2019).

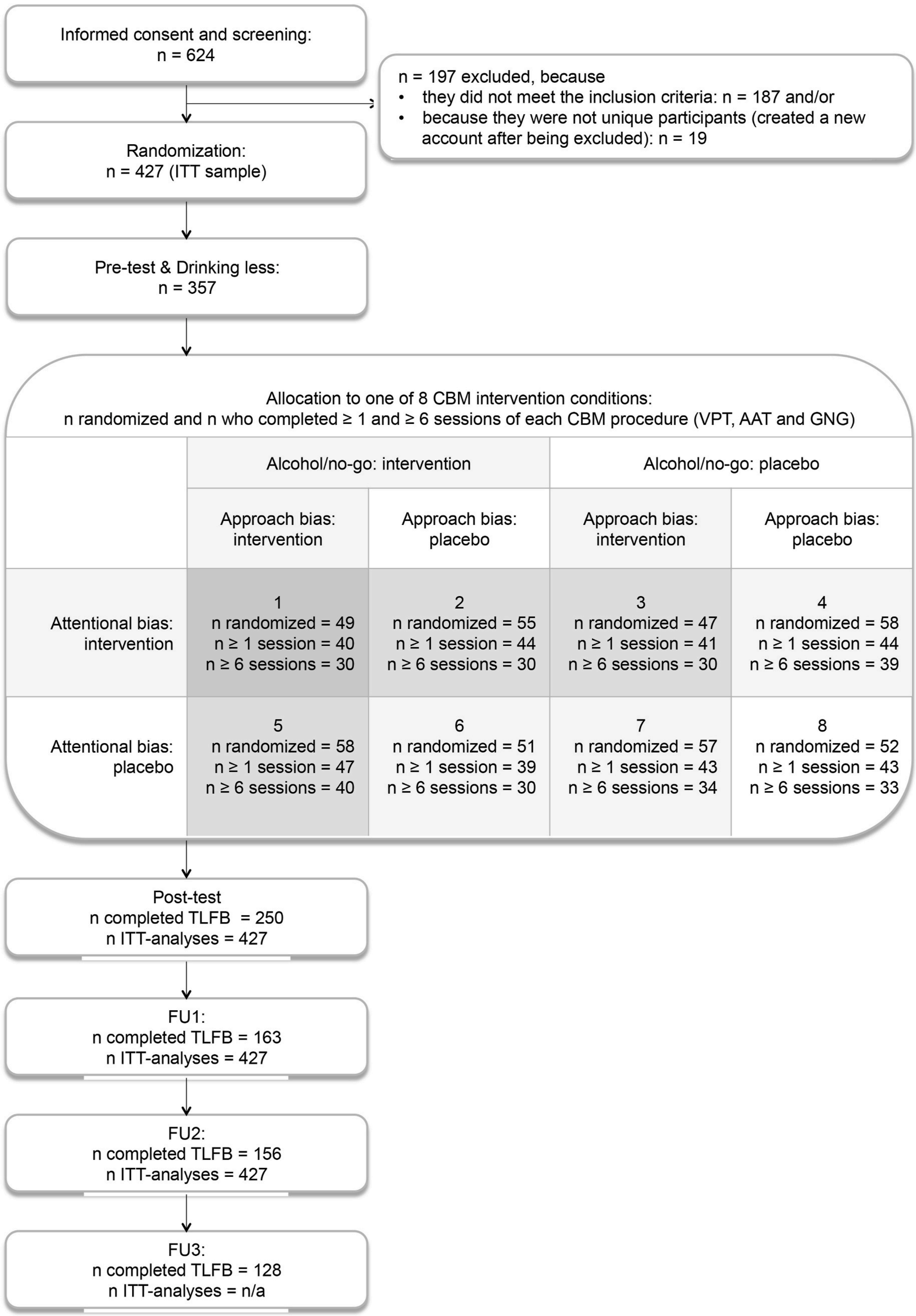

Fig. 1. Participant flow-chart.

bias for alcohol, based on the premise that positive alcohol associations evoke a stronger tendency to respond to pictures of alcoholic compared to non-alcoholic beverages, resulting in faster RTs for alcohol/go trials compared to non-alcohol/go trials. In the CBM phase, participants in the placebo condition continued to receive the same ratio of the different trial types, while participants in the intervention condition were presented with only alcohol/no-go and non-alcohol/go trials. The rationale behind the intervention is that SIT creates a response conflict, which is solved by devaluating alcoholic compared to non-alcoholic beverages, in other words decreasing EMB for alcohol (Veling et al., 2008). Note that there is also an alternative account of SIT effects, focusing on strengthening inhibition triggered by the stimulus class (Stein et al., 2023; Verbruggen & Logan, 2008). To test this alternative account, a balanced integration score was also calculated (based on Liesefeld & Janczyk, 2023), a score combining reaction times and accuracy rates to index speed-accuracy trade-offs.

Approach bias. ApB was assessed and trained with the alcohol Approach-Avoidance Task (AAT; Wiers et al., 2009). In this task, participants were presented with a picture of an alcoholic or non-alcoholic beverage, which was tilted 3° to the left or right. Based on the angle of the picture, participants were instructed to either pull the picture towards them, by keeping the downward arrow-key pressed, or push the picture away from them, by keeping the upwards arrow-key pressed. Picture size gradually increased when the pull-key was pressed, while it decreased when the push-key was pressed. The combination of the picture angle and the required response (tilted to the left = push and right = pull, or vice versa) was counterbalanced across participants, and the same combination was used at pre- and post-test. The assessment phase consisted of 25% alcohol/push trials, 25% alcohol/pull trials, 25% non-alcohol/push trials and 25% non-alcohol/pull trials. ApB was calculated by the subtracting RTs on pull trials from those on push trials, and an alcohol-specific approach bias was defined as the difference in magnitude between approach bias for alcoholic and non-alcoholic beverages. This is consistent with the idea that it would be easier for participants to follow the instructions to either pull or push based on the presented cue, when the cue would align with their existing action tendency towards the displayed beverage. In other words, participants with an ApB for alcohol would show faster pull, compared to push responses to pictures of alcoholic beverages (but not, or to a lesser degree, to non-alcoholic beverages). In the CBM phase, participants in the placebo condition continued with the same ratio of push and pull trials for alcoholic and non-alcoholic beverages, while participants in the intervention condition received only alcohol/push and non-alcohol/pull trials, thereby decreasing their alcohol ApB in favor of an avoidance bias for alcohol and an ApB for non-alcoholic beverages.

1.4. Outcome measures

The primary outcome measure was the total number of alcoholic drinks consumed in the past 14 days, which was assessed in accordance with the TLFB method (Sobell & Sobell, 1992). Participants indicated the number of standard alcoholic drinks they drank on each of the specified days, using a drop-down menu ranging from 0 to 25. In addition to the total number of drinks, two secondary outcome measures were derived from the TLFB data. Binge drinking was operationalized as the number of days (0-14) on which participants drank ≥6 (men) or ≥5 alcoholic drinks (women). Low-risk drinking was defined as drinking ≤21 (men) or ≤ 14 (women) alcoholic drinks per week in both of the past two weeks (British Medical Association, 1995)[4].

The AUDIT (Babor et al., 2001) was used to assess alcohol-related problems. The AUDIT consists of 10 items and yields a total score ranging from 0 to 40. Two versions of the AUDIT were administered: the standard 12-month version, which was assessed at baseline to check whether participants met the AUDIT criterion (>7), and a three-month version, which was assessed as an outcome measure on all time points except for the post-test. For the same reason, the Core Alcohol and Drug Survey (CADS, Presley et al., 1994) subscale regarding the frequency of substance use in the past month was not administered at post-test[5]. Participants are asked to indicate on how many of the past 30 days they used any of 12 substances. Three outcome measures were derived from this measure: cigarette use, marihuana use, and the average use of eight other substances excluding alcohol (i.e., cocaine or crack, XTC, hallucinogens, stimulants or amphetamines, sedatives, opiates, inhalants, and other club or party drugs).

Craving for alcohol was measured with the Desires for Alcohol Questionnaire (DAQ, Love et al., 1998). The DAQ consists of 14 statements and participants are asked to indicate the extent to which they agree with each of 14 statements, on a scale from not at all (1) to completely (7). The DAQ consists of four subscales: strong desires and intentions (range: 6–42), negative reinforcement craving (1-28), control (2-14), and mild desires (2-14). In addition to the DAQ, participants reported their desire to drink three alcoholic (beer, wine, whiskey) and three non-alcoholic drinks (water, orange juice, coke), ranging from not at all (1) to very much (6), in response to pictures that were used during the CBM training. Mean craving for alcoholic and non-alcoholic drinks was computed.

Self-efficacy was assessed with the Brief Situational Confidence Questionnaire (BSCQ, Breslin et al., 2000), which asks participants to indicate on a visual analogue scale how much confidence (1–100%) they have that they will not drink heavily in eight specific situations. A total score was computed by averaging scores on the eight items.

1.5. Cognitive bias measures

In addition to the assessment version of the CBM tasks, three measures of cognitive bias that were not used during the intervention were used to check if the expected change of cognitive biases generalized to untrained tasks: the alcohol Stroop task (AtB), the valence brief Implicit Association Test (valence bIAT), and the approach-avoid brief Implicit Association Test (approach bIAT).

The alcohol Stroop task (Cox et al., 2006) was used to assess AtB for alcohol. In this task, words were presented in the middle of the screen and participants were instructed to indicate the color of the word as quickly as possible. The task started with a 40-trial practice phase, during which participants learned the four key-color combinations: e (red), f (yellow), j (green) or i (blue). In the assessment phase, seven alcohol-related words (e.g. wine, whiskey), and seven neutral words that were matched on number of letters (e.g. staple) were each presented in four colors, resulting in 56 trials. An alcohol Stroop interference score was calculated by subtracting RTs for non-alcohol from RTs for alcohol-related words.

In the two versions of the brief Implicit Association Test (bIAT; Menatti et al., 2016; Sriram & Greenwald, 2009), participants determined whether or not a word cue fit into one or two categories presented at the top of the screen by pressing the designated 'yes' or 'no' buttons on the keyboard. Both versions of the task consisted of 7 blocks. In the first block of the valence bIAT (12 trials), different types of alcohol (beer, wine, vodka) or non-alcohol-containing drinks (water, juice, coke) were categorized as 'alcohol' or not. In the second block (12 trials), words were categorized as pleasant (funny, cheerful, sociable) or not (nauseous, sad, tired). In the third (12 trials) and fourth (24 trials) block, the target (alcohol) and attribute (pleasant) categories were combined.

[4] Note that the study was designed before the guideline was changed to 14 drinks for both men and women in the UK, and 7 drinks in the Netherlands (Gezondheidsraad, 2015)

[5] Note that in the study protocol (van Deursen et al., 2013), the frequency of alcohol and drug use in the past month was only described as a baseline measure and not as a secondary outcome measure

In the fifth block (12 trials), the opposite attribute category, unpleasant, was practiced and then combined with the target category (alcohol) in the sixth (12 trials) and seventh (24 trials) block. The approach bIAT (based on Palfai & Ostafin, 2003) followed the same structure, with the attributes ‘approach’ (take, touch, grab) and ‘avoid’ (ignore, let go, avert). Task characteristics were randomized over participants, i.e. the order of assessment of the valence or action version, the order of the combined blocks within the task (alcohol-pleasant/approach block first, or alcohol-unpleasant/avoid block first), and the pairing of the keys (‘i’ and ‘e’) and responses (yes/no). The same task characteristics were used at pre- and post-test. The outcome measure was the standardized difference in latencies between the combined blocks (D600 score, Greenwald et al., 2003).

1.6. Other measures[6]

Demographic variables included gender, age, country of birth of the participant and their parents, native language, educational level, and living situation. In addition, participants were asked to what extent they thought they needed help to change their alcohol use.

The Readiness to Change Questionnaire (RCQ, Rollnick et al., 1992) was used to assess participants’ motivation to change their alcohol use. Participants indicated to what extent they agreed with 12 statements ranging from strongly disagree (1) to strongly agree (5). Each statement reflects either the precontemplation (e.g., “It’s a waste of time thinking about my drinking”), contemplation (e.g., “My drinking is a problem sometimes”), or action stage (e.g., “I am trying to drink less than I used to”) of change. In addition to determining the stage of change that had the highest agreement score, a total score ranging from 12 to 60 was computed by reversing scores on the precontemplation items (Budd & Rollnick, 1996).

The European Addiction Severity Index (ASI; Kokkevi & Hartgers, 1995) was used to determine if participants had a first and/or second degree relative with an alcohol use disorder.

Participants’ opinion regarding the CBM intervention was measured with 6 general questions, and 5 specific questions per CBM procedure (see Supplementary Files A-B). To check whether participants were aware of the condition they were in, participants were reminded that there were two versions of every CBM procedure and were asked whether they thought they received the effective or ineffective version of the VPT, GNG, and AAT.

1.7. Procedure

After providing informed consent, participants were screened for the in- and exclusion criteria using TLFB and the 12-month version of the AUDIT. Eligible participants then completed the pre-test: the alcohol Stroop, valence bIAT and approach bIAT (in randomized order), and the questionnaire regarding their demographic variables, CADS, ASI, DAQ, Craving, and BSCQ. At the end of the pre-test, participants completed the first two modules of DrinkingLess, a cognitive behavioral internet intervention, which has been found effective in reducing problem drinking (Riper et al., 2008). In these modules, participants received personalized feedback on alcohol-related questionnaires, including the 3-month version of the AUDIT and the RCQ. Furthermore, participants were encouraged to set goals with respect to the change they wanted to accomplish in their alcohol use, e.g. the maximum number of alcoholic drinks they wanted to drink per day (0 in case their goal was abstinence).

The next day, participants were invited to complete the first of 12 CBM training sessions, which each consisted of 3 CBM procedures: VPT, AAT and GNG (in randomized order). The CBM procedures started with an assessment phase, and then changed into the intervention or placebo bias modification, dependent on the condition the participant was in. One day after the last training session and around 5–6 weeks after the pre-test, participants completed the post-intervention assessment, which consisted of the VPT, AAT and GNG assessment tasks (in the same order as at pre-test), followed by the questionnaire regarding participants’ opinion the CBM training, the TLFB, DAQ, Craving, BSCQ, and the alcohol Stroop, valence bIAT and approach bIAT (the RT measures were completed in the same order as at pre-test). At the three- and six-month follow-up, participants completed the TLFB, 3-month version of the AUDIT, DAQ, Craving, BSCQ, and the CADS.

1.8. Sample size

The required sample size was calculated using G*Power 3.1.5 (Erdfelder et al., 1996), specifying a power of .8 for each main effect or interaction and an alpha of .05. A small-to-medium effect size of $f = .15$ was specified, based on a meta-analysis of internet self-help interventions for problem drinkers that found a medium effect size (Riper et al., 2011), but taking into account that the effect size may be reduced by the active control conditions and the two modules of the DrinkingLess intervention, which participants completed irrespective of their CBM condition. This yielded a required sample size of $N = 351$. Inclusion was manually ended when around this number of participants had completed the pre-test ($N = 357$), under the assumption that the analytical sample would consist of participants who completed the pre-test and DrinkingLess and were allocated to a CBM condition. For practical reasons, however, the randomization technically took place directly after the screening, though there were no differences between the CBM conditions until after the pre-test and personalized feedback intervention were completed. Since the intention-to-treat (ITT) sample included all participants who were technically randomized (Gupta, 2011), the ITT sample consisted of 427 participants.

1.9. Statistical analyses

Pre-processing of cognitive bias scores. For the bIAT’s, D600 scores were calculated (Greenwald et al., 2003). The cognitive bias scores on all other measures were calculated by a) removing incorrect trials and RTs <150 ms and >3000 ms (for the AAT the lower and upper RT limits were 650 and 3500 ms, since the RT included the 500 ms it took to push or pull the picture by keeping the arrow key pressed); b) computing difference scores between median RTs for alcohol and non-alcohol trials in the manner that positive scores indicated a bias towards alcohol; c) excluding the data of participants with >35% error trials from the specific analyses on this measure (with the exception of the alcohol Stroop task, since this measure had 4 answer options and the highest error percentage was 39%, so no participants were removed from this analysis).

Preliminary analyses. Mean sample characteristics and comparability between conditions was based on the available data; missing data were not imputed here. Differences between conditions on all continuous baseline measures and number of completed CBM sessions was tested with 2 (VPT: intervention vs. placebo) x 2 (GNG: intervention vs. placebo) x 2 (AAT: intervention vs. placebo) ANOVA. For non-continuous baseline data and dropout ratios, comparability across the eight CBM conditions was analyzed using χ^2-tests. Three χ^2-tests were also conducted to test whether the ratio of participants who thought they were in the intervention vs. placebo condition differed across the actual conditions, for the VPT, AAT, and GNG.

[6] Only the relevant measures were reported here; an overview of all measures can be found in the study protocol

Cognitive biases.[7] For the cognitive bias measures, all analyses were conducted in the sample of participants who successfully completed this specific measure at both pre- and post-test; missing data were not imputed, since the number of variables that could reliably be imputed was limited and priority was given to the primary and secondary outcome measures. First, the Spearman-Brown adjusted split-half reliability of the measures was calculated using a Monte Carlo-based split with the splithalfr package (Pronk, 2021) as it has shown to be the most robust method with respect to several confounds such as effects of time, task design, trial sampling and non-linear scoring (see for a review: Pronk et al., 2022). Second, it was tested if baseline cognitive bias scores significantly differed from zero using one-sample *t*-tests. Also, it was examined if there were baseline differences in cognitive biases between the conditions, using independent *t*-tests comparing bias scores between the two relevant CBM conditions (VPT, GNG or AAT condition: intervention or placebo). Since the AAT yields an approach bias score for alcoholic and non-alcoholic drinks, a 2 (Drink type: alcoholic vs. non-alcoholic) x 2 (AAT Condition: intervention vs. placebo) mixed ANOVA was conducted for this measure. Third, it was examined whether the CBM procedures succeeded in changing the targeted cognitive biases, using 2 (VPT, GNG or AAT condition: intervention vs. placebo) x 2 (Time: pre vs. post) univariate ANOVAs for every measure of cognitive bias. For the AAT, Drink type was again included as an additional predictor. For the GNG, the analysis was conducted twice, once for the alcohol go bias and once for the BIS score.

Primary and secondary outcome measures. All analyses on the primary and secondary outcome measures were first conducted in the ITT sample. The missingness percentages were as follows: baseline: 0%, post-test: 41.5%, FU1: 61.8%, FU2: 63.5%. Little's MCAR test was significant, indicating the data was not missing completely at random (MCAR). We assumed that the missingness could best be categorized as data missing at random (MAR), which was substantiated by exploring missing data patterns using the VIM and naniar packages in R (Kowarik & Templ, 2016; Tierney & Cook, 2023). This indicated that, as also reported in the result section on p.22, that missingness was related to observed variables (e.g., DAQ scores). Additionally, drop-outs reported significantly lower intention to complete all CBM sessions. Hence, the multiple imputation approach was appropriate, considering that multiple imputation leads to unbiased and valid estimates of associations (Pedersen et al., 2017) and is implicated when data is MAR (e.g., Bhaskaran & Smeeth, 2014). Missing data were multiply imputed using the package 'mice' in R (Van Buuren & Oudshoorn, 1999), creating 25 imputed datasets and the results were pooled using the R-package 'miceadds' (Robitzsch, 2018a, 2018b). The main and combined effects of each CBM intervention on the primary outcome measure, total drinks consumed in the past 14 days, were tested with a 2 (VPT Condition: intervention vs. placebo) x 2 (GNG Condition: intervention vs. placebo) x 2 (AAT Condition: intervention vs. placebo) x 4 (Time: pre, post, FU1 vs. FU2) mixed ANOVA. This analysis was also performed on most of the secondary outcome measures, i.e. binge drinking, BSCQ, AUDIT (note that the AUDIT was not assessed at post-test, so Time had only 3 levels for this analysis). Two MANOVAs with the same independent variables were conducted to analyze the four DAQ subscales and the three CADS substances (in the latter analysis Time had only 3 levels, since the CADS was not assessed at post-test). To examine whether CBM differentially affected craving for alcoholic and non-alcoholic drinks, Drink type was included as a within-subjects predictor, resulting in a 2 (VPT: intervention vs. placebo) x 2 (GNG: intervention vs. placebo) x 2 (AAT: intervention vs. placebo) x 2 (Drink type: alcoholic or non-alcoholic) x 4 (Time: pre, post, FU1 vs. FU2) mixed ANOVA. In the absence of interaction effects, significant main effects of Time were followed up by repeated contrasts for all ANOVAs. To test if the ratio of participants who did or did not drink sensibly differed across the eight CBM conditions, χ^2-tests were conducted for the post-test, FU1, and FU2.

In addition to the ITT analyses based on the multiple imputed data, the above-mentioned analyses were repeated in the completers sample, which included all participants who completed the outcome measure of interest at both pre- and post-test and FU1, irrespective of the completed number of CBM sessions. FU2 was not included in these analyses, since dropout rates increased with time, and priority was given to maximizing the power for our primary outcome measure: alcohol use at FU1 (see Supplemental Materials B).

Assumptions. For all mixed ANOVAs in the ITT analyses, normality of the sampling distribution was assumed, since $n > 30$ for all cells of the design (Field, 2013). No adjustments were made to correct for violations of the assumption of homogeneity, given the large sample ($n = 427$) and roughly equal group sizes (n's ranged from 37 to 45). When the sphericity assumption was violated, the degrees of freedom were adjusted using the Huyn-Feldt estimate (ε′s were all>.75).

Significance and effect sizes. An alpha of .05 (2-sided) was maintained for the analyses on the effects of CBM on the primary outcome measure, while an alpha of .01 (2-sided) was applied to all other analyses in order to account for multiple testing. For hypothesized effects, *p*-values between .01 and .05 were interpreted as trends. Effect sizes (*r*) were calculated for significant effects and trends and were interpreted in line with Cohen (1992) as .10 = small, .30 = medium, and .50 = large.

2. Results

2.1. Sample characteristics

Fig. 1 depicts the flow of participants through the study. Of the 427 participants, 261 were women (61.1%), mean age was 51.20 years (*SD* = 8.69). The majority of participants was born in the Netherlands (93.4%), native Dutch speaker (97.3%), educated at college (41.4%) or university (22.4%) level and lived with their partner and/or children (66.6%). Many participants had either a first (15.2%) or a second degree (19.1%) relative with alcohol use disorder, or both (20.8%), based on self-report. The mean alcohol use in the 14 days prior to the study was 84.37 standard drinks (*SD* = 42.89), which corresponds with roughly 6 alcoholic drinks a day. The average 12-month AUDIT score was 21.32 (*SD* = 5.96), indicating on average a high risk of alcohol dependence (Babor et al., 2001). The mean RCQ total score was 49.63 (*SE* = 5.57), and all participants were in the contemplation (85.2%) or action (14.8%) stage of change, corresponding with the fact that they were seeking help to reduce their alcohol use. Abstinence was the goal of 22.1% of participants, while the rest aimed at limiting their alcohol use. None of these variables differed significantly between (any combination of) CBM conditions, with the exception of age, for which there was a trend towards a main effect of VPT condition, $F(1, 419) = 6.19$, $p = .013$, $r = .12$, with a higher mean age in the VPT placebo ($M = 52.22$) than in the VPT intervention ($M = 50.13$) condition.[8]

In the ITT sample, participants completed on average 7.57 (*SD* = 4.90) out of 12 possible sessions of CBM training, but 19.7% of these participants did not complete a single session. In the completers sample, defined as not missing on the primary outcome variable at post-test and FU1, the mean number of completed sessions was 11.44 (*SD* = 1.32), and 99.3% of these participants completed at least 6 sessions. The

[7] For the GNG assessment, it was originally planned to use the no-go error bias (difference between alcohol and non-alcohol trials in incorrect go-responses to no-go trials) as a second outcome measure, in addition to the RT-bias for go-trials (reference removed for masked review). However, since the proportion correct was .98 for both trial types, there was too little variation in the difference score ($M = .0004$, $SE = .0004$) to meaningfully relate this score to other variables.

[8] For nationality and native language, the expected count was <5 for some of the non-Dutch cells, so comparability across conditions was assumed rather than formally tested.

number of completed sessions did not differ significantly across conditions in either the ITT or the completers sample. Participants were not aware of their CBM condition, as indicated by the fact the ratio of participants who thought they were in the intervention versus placebo condition did not differ significantly between the actual conditions for any of the CBM procedures. In other words, the percentage of participants who correctly identified their VPT (51.8%), AAT (53.1), and GNG (49.0%) condition was around chance level (50%). Participants' evaluation of the CBM intervention was generally favorable, and participants reported being motivated to respond quickly and accurately during the CBM training, see Supplementary Materials A.

Dropout, defined as the ratio of participants who did or did not complete the primary outcome measure at both post-test and FU1, did not differ significantly between men and women, VPT, AAT, or GNG conditions, or the specific combinations of CBM conditions. There was a significant difference in age; those who dropped out were significantly younger ($M = 48.73$) than who did not ($M = 52.71$), $t\,(425) = 4.71$, $p < .001$, $r = .22$. Dropout was unrelated to baseline alcohol use in the past 14 days, or to any of the secondary outcome measures as assessed at baseline, with the exception of the DAQ scores on the Negative Reinforcement subscale, which were significantly higher among dropouts ($M = 12.68$) than among completers ($M = 10.62$), $t\,(258.92) = -2.62$, $p = .009$, $r = .16$. Those who dropped out did not differ from completers in RCQ-scores, perceived need for help to change their alcohol use, or treatment goal, but their intention to complete all 12 CBM sessions was significantly lower ($M = 6.24$) than that of the completers ($M = 6.48$), $t\,(409) = 2.41$, $p = .016$, $r = .12$.

2.2. Cognitive biases

As shown in Table 1, the VPT, alcohol Stroop and AAT had a very low reliability, which should be considered when interpreting the results on these measures. The reliability of the GNG and bIATs was good. At a group level, participants demonstrated significant biases towards alcohol related cues only on the alcohol Stroop, $t\,(226) = 5.86$, $p < .001$, r = .36, and the approach bIAT, $t\,(218) = 10.96$, $p < .001$, r = .60. None of the cognitive bias scores differed significantly across conditions, showing the conditions were comparable prior to the CBM. Next, it was tested whether the CBM procedures successfully changed cognitive biases (see Table 2).

AtB. The VPT scores revealed a significant main effect of VPT condition, $F\,(1, 226) = 2.00$, $p = .002$, $r = .09$, with less AtB for alcohol for the VPT intervention than the placebo condition. The Alcohol Stroop scores showed a main effect of Time, $F\,(1, 225) = 7.78$, $p = .006$, $r = .18$, with a decrease in AtB at post-test compared to pre-test. Neither the VPT, nor the Alcohol Stroop showed the hypothesized Condition × Time interaction, indicating that the AtB modification did not differentially change AtB for alcohol compared with sham-training.

EMB/inhibitory control. The GNG scores did not show the hypothesized Condition × Time interaction. Valence bIAT scores revealed a significant main effect of Time, $F\,(1, 218) = 15.91$, $p < .001$, $r = .26$, with more negative evaluations for alcohol at post-test compared to pre-rest. In addition, there was a trend towards the expected GNG condition × Time interaction effect on valence bIAT scores, $F\,(1, 218) = 4.41$, $p = .037$, with no significant change over time in the GNG placebo condition, $t\,(114) = 1.44$, $p = .153$, and a significant decrease in EMB in the experimental condition, $t\,(104) = 4.00$, $p < .001$, $r = .19$. With regards to the BIS score, results showed a non-significant effect of Time, $F\,(1, 234) = .017$, $p = .898$. The GNG condition × Time interaction was also non-significant, $F\,(1, 234) = .806$, $p = .370$. Taken together, there was little evidence that SIT differentially changed the automatic evaluation for alcohol compared with sham nor changed inhibitory control.

ApB. AAT scores showed a trend towards the expected AAT condition x Drink type × Time interaction, $F\,(1, 230) = 4.39$, $p = .037$. Separate ANOVAs for the two AAT conditions revealed no significant Drink type × Time interaction in the AAT placebo condition, $F\,(1, 111) = 1.19$, p = .278, and a trend towards a Drink type × Time interaction in the AAT intervention condition, $F\,(1, 119) = 3.49$, $p = .045$, with a non-significant decrease in ApB for alcoholic drinks, $t\,(119) = .90$, $p = .369$, and a non-significant increase in ApB for non-alcoholic drinks, $t\,(119) = -1.36$, $p = .178$. This Condition × Time interaction was not found for approach bIAT scores. In sum, there was little support that the ApB modification differentially changed the alcohol ApB, compared with sham ApBM-training.

2.3. Outcome measures[9]

At baseline, there were no significant differences between the conditions on any of the outcome measures, see Table 3 (ITT sample) and Supplementary Materials B (completers sample). The effects of CBM on the primary and secondary outcome measures are shown in Table 4 (ITT) and Supplementary Materials B (completers). Supplementary Materials C shows the ITT means and SEs for all outcome measures per time point and CBM condition.

Alcohol use in the past 14 days (TLFB: primary outcome measure). The ITT analysis on the total number of alcoholic drinks consumed in the past two weeks revealed a significant main effect of Time, $F\,(2.68, 3708.89) = 161.62$, $p < .001$. Alcohol use decreased significantly between pre- and post-test, $F\,(1, 955.53) = 202.73$, $p < .001$, $r = .42$, as well as between post-test and FU1, $F\,(1, 645.58) = 13.38$, $p < .001$, $r = .14$, and did not change significantly between FU1 and FU2, $F\,(1, 502.14) = 1.88$, $p = .17$. There were no significant Condition × Time interactions. In contrast to our hypothesis, participants in the CBM intervention conditions did not show a larger decrease in alcohol use than participants in the placebo conditions. The analyses in the completers sample again showed a significant main effect of Time, $F\,(2, 280) = 36.51$, $p < .001$, characterized by a significant decrease in alcohol use between pre- and post-test, $F\,(1, 140) = 44.00$, $p < .001$, $r = .49$, and no significant change between post-test and FU1, $F\,(1, 140) = 2.05$, $p = .155$. As in the ITT analyses, all Condition × Time interactions were non-significant.

Binge drinking (TLFB). The ITT analysis on the number of binge drinking days showed a significant main effect of Time, $F\,(2.89, 857.62) = 136.02$, $p < .001$. Binge drinking decreased significantly between pre- and post-test, $F\,(1, 1258.56) = 205.30$, $p < .001$, $r = .37$, and did not change significantly between post-test and FU1, $F\,(1, 763.85) = 5.36$, $p = .021$, or between FU1 and FU2, $F\,(1, 306.80) = 3.80$, $p = .052$. There were no significant Condition × Time interactions. The results in the completers sample again showed a main effect of Time $F\,(2, 280) = 37.93$, $p < .001$. There was a significant reduction in binge drinking between pre- and post-test $F\,(1, 140) = 54.31$, $p < .001$, $r = .53$, and no significant change between FU1 and FU3 $F\,(1, 140) = .28$, $p = .597$. As in the ITT analyses, no significant Condition × Time interactions between were found.

Low-risk drinking (TLFB). At baseline, all participants' alcohol use exceeded the guidelines for low-risk drinking. At post-test, 22.15% of the ITT sample adhered to this guideline; at FU1 this was 29.77% and at FU2 33.14%. The ratio of participants who succeeded in drinking sensibly was not significantly associated with condition at post-test, $\chi^2\,(7) = 2.47$, $p = .929$, at FU1, $\chi^2\,(7) = 1.81$, $p = .970$, or at FU2, $\chi^2\,(7) = .73$, $p = .998$. In the completers sample, there was a trend towards a difference between the conditions in low-risk drinking ratio at post-test $\chi^2\,(7) = 15.10$, $p = .035$. Comparisons between the intervention and placebo conditions of the VPT, AAT, and GNG only revealed a trend towards a difference in low-risk drinking ratio between the VPT conditions $\chi^2\,(1) = 3.98$, $p = .046$. The odds ratio showed that the odds of

[9] All primary and secondary outcome analyses were repeated in a mixed effects model framework. As the results from these analyses did not have any impact on the conclusions, the original data analysis plan was reported as per the pre-registration described in the protocol paper (van Deursen et al., 2013)

Table 1
Cognitive biases: baseline data.

Cognitive bias	Measure	N [a]	M [b]	Monte Carlo split-half reliability	Difference from 0 at group level	Comparison between conditions
Attentional bias (AtB)	VPT	228	−1.68	.12 [-.07, .32]	t (227) = −.44, p = .658	t (226) = −1.14, p = .256
	Alcohol Stroop	227	48.73	−.03 [-.68, −.01]	t (226) = 5.86, p < .001	t (225) = −.25, p = .804
Approach bias (ApB)	AAT	232	7.84	.10 [-.05, .22]	t (231) = .86, p = .391	F (1,230) = 5.06, p = .026
	Approach bIAT	219	.31	.77 [.71, .82]	t (218) = 10.96, p < .001	t (217) = −.01, p = .992
Evaluative Memory bias (EMB)/Inhibitory control	GNG alcohol go bias	235	3.72	.92 [.91, .93]	t (234) = 1.15, p = .250	t (233) = 1.66, p = .099
	GNG BIS	235	.000	.98 [.96, .99]	t (234) = .000, p = .500	t (234) = .992, p = .161
	Valence bIAT	220	.03	.80 [.71, .82]	t (219) = .82, p = .416	t (218) = .49, p = .627

Note. [a] Refers to the number of participants who successfully completed both the pre- and post-test and were included in all subsequent analyses for this measure. [b] All biases were calculated in a way that a higher positive score reflects biased processing of alcohol compared to non-alcohol related cues (i.e. an attentional, approach and evaluative memory bias/for alcoholic drinks). [c] BIS = Balanced Integration Score.

Table 2
Cognitive biases: manipulation check.

Cognitive bias	Measure	Condition	Time	Condition × Time interaction
Attentional bias (AtB)	VPT	F (1, 226) = 2.00, p = .002	F (1, 226) = .39, p = .531	F (1, 226) = 2.17, p = .142
	Alcohol Stroop	F (1, 225) = .53, p = .468	F (1, 225) = 7.78, p = .006	F (1, 225) = 1.28, p = .259
Approach bias (ApB)	AAT	F (1, 230) = 3.90, p = .049	F (1, 230) = 3.42, p = .559	F (1, 230) = 4.39, p = .037
	Approach bIAT	F (1, 217) = .42, p = .516	F (1, 217) = .24, p = .622	F (1, 217) = .86, p = .354
Evaluative memory bias (EMB)/ inhibitory control	GNG alcohol go bias	F (1, 233) = 6.33, p = .013	F (1, 233) = 5.77, p = .017	F (1, 233) = .02, p = .885
	GNG BIS	F (1, 234) = .008, p = .929	F (1, 234) = .017, p = .898	F (1, 234) = .81, p = .370
	Valence bIAT	F (1, 218) = 3.46, p = .060	F (1, 218) = 15.91, p < .001	F (1, 218) = 4.41, p = .037

participants adhering to the low-risk drinking guidelines at post-test were 1.48 times higher if they were in the VPT intervention condition than if they were in the VPT placebo condition. Low-risk drinking ratio was not significantly related to condition at FU1, χ^2 (7) = 8.17, p = .317.

Substance use (CADS). A MANOVA on the frequency of use of marihuana, cigarettes and other substances indicated a significant main effect of Time, V = .06, F (6, 284.36) = 3.27, p = .004. Univariate ANOVAs revealed that this effect was significant only for marihuana F (1.49, 602.11) = 10.23, p < .001, with a significant reduction in marihuana use between pre-test and FU1, F (1, 580.87) = 11.22, p = .001, r = .14, which was maintained between FU1 and FU2, F (1, 375.52) = .47, p = .493. There were no significant Condition × Time interactions. In the completers sample, no significant main or interaction effects were found.

Alcohol use and problems (AUDIT). There were no significant main or interaction effects on AUDIT scores. In the completers sample, the only significant finding was the main effect of Time, F (1, 153) = 78.70, p < .001, r = .58, indicating a reduction in AUDIT scores between pre-test and FU1.

Craving. A MANOVA on the four DAQ subscales indicated a significant main effect of Time, V = .31, F (12, 1126.17) = 13.37, p < .001, and univariate ANOVAs revealed that this effect was significant for all DAQ subscales except Control (p's < .001). Between pre- and post-test, there were significant reductions on the subscales Mild Desires, F (1, 1207.32) = 36.09, p < .001, r = .17, Strong Desires, F (1, 5188.30) = 66.22, p < .001, r = .11, and Negative Reinforcement, F (1, 331.34) = 67.88, p < .001, r = .41 Between post-test and FU1, the only significant change was a further decrease in scores on the Strong Desires subscale, F (1, 572.21) = 11.16, p = .001, r = .14, and there were no significant changes between FU1 and FU2. There were no significant Condition × Time interactions. Similarly, the only significant finding in the completers sample was a main effect of Time, V = .19, F (8,121) = 3.63, p = .001. Univariate ANOVAs showed that this effect was significant for all subscales (all p's < .01), but the only contrast that reached significance was the decrease on the Negative Reinforcement subscale between pre- and post-test, F (1,128) = 13.76, p < .001, r = .31.

Comparable results were observed for the other measure of craving, namely self-reported desires for alcoholic and non-alcoholic drinks. There were significant main effects of Drink type, F (1, 124.02) = 952.19, p < .001, and Time, F (2.98, 295.91) = 13.00, p < .001, as well as a significant Drink type × Time interaction F (2.94, 312.13) = 34.19, p < .001. This interaction was only significant between pre- and post-test, F (1, 474.20) = 10.24, p = .001, and was characterized by a significant decrease in craving for alcoholic drinks, t (1492) = 8.62, p < .001, r = .22, and a significant increase in craving for non-alcoholic

Table 3
Baseline comparison between CBM conditions on the primary and secondary outcome measures, in the intention-to-treat sample.

Measure	VPT Intervention vs. placebo	AAT Intervention vs. placebo	GNG Intervention vs. placebo	Interactions between conditions
TLFB: alcohol use	F (1, 419) = .03, p = .856	F (1, 419) = .54, p = .465	F (1, 419) = .03, p = .863	All n.s.
TLFB: binge drinking	F (1, 419) = .18, p = .671	F (1, 419) = 2.00, p = .158	F (1, 419) = .63, p = .427	All n.s.
CADS	F (3, 147192.06) = 1.30, p = .274	F (3, 52177.11) = 2.81, p = .038	F (3, 17526.79) = .10, p = .958	All n.s.
AUDIT	F (1, 1864.64) = .50, p = .479	F (1, 1789.96) = 2.84, p = .092	F (1, 12674.47) = .07, p = .791	All n.s.
DAQ	F (4, 6551.74) = 2.23, p = .064	F (4, 11622.17) = .40, p = .808	F (4, 6803.69) = .95, p = .435	All n.s.
Craving[a]	F (1, 39004.64) = .28, p = .594	F (1, 6824.68) = .77, p = .381	F (1, 52584.21) = .21, p = .649	All n.s.
BSCQ	F (1, 5464.65) = .19, p = .664	F (1, 32010.85) = .10, p = .754	F (1, 31707.33) = .99, p = .319	All n.s.

Note. For the sake of brevity, only the main effects of the CBM conditions are reported in columns two to four, irrespective of the condition for the other two CBM interventions. In the last column, any significant interactions between CBM conditions are reported (i.e. VPT x AAT, VPT x GNG, AAT x GNG, and VPT x AAT x GNG).

[a] Since craving was higher for non-alcoholic than for alcoholic drinks, F (1, 96638.10) = 200.33, p < .001, r = .04, all reported comparisons between CBM conditions on craving scores reflect Condition x Drink type interactions.

Table 4
CBM effects on the primary and secondary outcome measures, in the intention-to-treat sample.

Measure	Main effect of Time	Condition × Time interactions			Other effects
		VPT x Time	AAT x Time	GNG x Time	
TLFB: alcohol use	F (2.68, 3708.89) = 161.62, p < .001	F (2.68, 3529.42) = .23, p = .853	F (2.68, 9139.87) = .91, p = .424	F (2.68, 3720.02) = .38, p = .743	All n.s.
TLFB: binge drinking	F (2.89, 857.62) = 136.02, p < .001	F (2.89, 1686.28) = .18, p = .907	F (2.89, 2399.86) = 1.45, p = .229	F (2.89, 1806.12) = .17, p = .910	All n.s.
CADS	F (6, 284.36) = 3.27, p = .004	F (6, 492.40) = .72, p = .632	F (6, 723.03) = 1.04, p = .396	F (6, 245.01) = .32, p = .927	All n.s.
AUDIT	F (2, 68.39) = 3.15, p = .049	F (2, 756.07) = .99, p = .373	F (2, 258,19) = 1.10, p = .333	F (2, 452.16) = .22, p = .803	All n.s.
DAQ	F (12, 1126.17) = 13.37, p < .001	F (12, 288.86) = .64, p = .810	F (12, 423.17) = .54, p = .885	F (12, 250.34) = .42, p = .954	All n.s.
Craving[a]	F (2.94, 312.13) = 34.19, p < .001	F (2.94, 737.94) = .17, p = .915	F (2.94, 618.67) = .82, p = .479	F (2.94, 564.70) = .21, p = .886	Drink type**, Time**
BSCQ	F (3, 244.52) = 75.24, p < .001	F (3, 350.02) = .31, p = .816	F (3, 183.21) = .34, p = .796	F (3, 232.01) = .53, p = .659	All n.s.

Note. For the sake of brevity, only the main effect of Time and two-way Condition × Time interactions are reported in the first four columns. In the last column, any other significant effects are reported (i.e. main effects of Condition, interactions between Conditions, and three- or four-way interactions between multiple Conditions and Time).
*p < .01, **p < .001.
[a] In the analyses on craving scores, Drink type was included as an additional independent variable, and the reported effects in columns 2–5 represent the interactions of Drink type x Time and Drink type x Time x Condition.

drinks t (229) = −3.57, p < .001 r = .23. Craving did not change significantly after post-test and there were no significant Drink type x Condition × Time interactions.

Likewise, the analyses in the completers sample showed significant main effects of Drink type, F (1, 128) = 220.37, p < .001, and Time, F (2, 256) = 5.32, p = .005, and a Drink type × Time interaction, F (2, 256) = 17.85, p < .001. Again, this interaction was only significant between pre- and post-test, F (1, 128) = 25.75, p < .001, with a significant reduction in craving for alcoholic drinks, t (121) = 4.37, p < .001, r = .37, and a significant increase in craving for non-alcoholic drinks, t (121) = −3.98, p < .001, r = .34. There were no significant Condition x Drink type × Time interactions.

Self-efficacy: BSCQ. There was a significant main effect of Time on BSCQ scores, F (3, 244.52) = 75.24, p < .001. BSCQ scores increased significantly between pre- and post-test, F (1, 562.05) = 108.70, p < .001, r = .40, as well as between post and FU1, F (1, 227.56) = 10.31, p = .002, r = .21, but not between FU1 and FU2, F (1, 563.87) = .31, p = .575. There were no significant Condition × Time interactions. As in the ITT sample, the only significant effect in the completers sample was a main effect of Time, F (2,254) = 28.21, p < .001. Contrasts showed significant increases in SCQ-scores only between pre- and post-test, F (1, 127) = 26.87, p < .001, r = .42.

2.4. Exploratory analyses

Although none of the outcome measures showed significant Condition × Time interactions, most did show medium to large reductions in scores between pre- and post-test. Exploratory analyses showed that the degree of change in symptom scores in the completers sample was correlated with baseline RCQ scores and chosen treatment goal (maximum drinks per day) and change in BSCQ-scores, as well as changes in cognitive bias scores, see Supplementary Materials D. Changes in cognitive bias scores were not significantly related to reductions in symptom levels. Of the other variables, only changes in BSCQ scores were significantly associated with changes in other symptoms. A greater increase in BSCQ-scores (self-efficacy), was associated with greater reductions in total alcohol use, r = .27, p < .001, binge drinking, r = .28, p < .001, and AUDIT scores, r = .40, p < .001.

3. Discussion

This study investigated the individual and combined effects of web-based AtB, SIT, and ApB modification on problematic alcohol use in a double blind randomized controlled trial. The results showed little evidence that the CBM interventions changed the targeted cognitive biases. Furthermore, CBM as an add-on to an online brief motivational intervention was not effective in reducing problem drinking: none of the CBM interventions reduced alcohol use more than placebo-CBM. Irrespective of the CBM intervention, there were sustained improvements over time in clinical outcomes, and there were indications of reductions in some of the cognitive biases, but there was no relation between the degree of change in cognitive biases and clinical outcomes.

The finding that CBM was not effective in reducing alcohol use beyond non-specific effects is consistent with the results of other recent studies examining CBM in problem drinkers (Clerkin et al., 2016; Cox et al., 2015; Heitmann et al., 2021; Jones et al., 2018; Wiers et al., 2015). As in the current study, prior studies found that CBM did not produce enduring changes in alcohol use, but there were reductions in use irrespective of the experimental condition. Although the current study did not explicitly examine the effects of the brief personalized feedback intervention which all participants received, it is likely that this increased motivation to change contributed to the decrease in symptom levels. The finding that CBM did not add to this change is consistent with previous studies that combined CBM with a brief motivational intervention (Cox et al., 2015; Jones et al., 2018) and strengthens the discrepancy with the effects that were found of CBM as an add-on to in-patient treatment (Eberl et al., 2013; Manning et al., 2016; Manning et al., 2022; Manning et al., 2021; Rinck et al., 2018; Salemink et al., 2021; Schenkel et al., 2023; Schoenmakers et al., 2010; Stein et al., 2023; Wiers et al., 2011, for a review see Wiers et al., 2023). Participants in the latter category of studies also differed in the sense that they were formally diagnosed with alcohol dependence, were abstinent at the start of the CBM intervention, and aimed at preventing relapse as opposed to changing to controlled use. The combination of these differences makes it difficult to pinpoint under what exact conditions CBM is effective, but it is likely that the presence of an abstinence goal and/or combination with in-patient treatment are important boundary conditions for the effectiveness of CBM (Heitmann et al., 2021; Vrijsen et al., 2024; Wiers et al., 2018; for a review see Wiers et al., 2023).

Another explanation for the lack of an effect of CBM lies in recent theory-based advances stating that rather than a focus on alcohol-related associations as targeted in the CBM variants included in this study, a focus on alcohol-based *inferences* will likely be more effective in reducing alcohol-related clinical outcomes (van Dessel et al., 2019;

Wiers et al., 2020, 2023). These advances have led to the development of the so-called ABC training which focuses on training individuals to relate personally relevant antecedents (A) of their addiction-related behaviors to other behavioral choices (B) and to their consequences (C) in line with personally relevant goals to change their automatic outcome expectancies of drinking alcohol. A proof-of-principle study including problematic drinkers from a community sample, showed preliminary effectiveness in changing automatic outcome expectancies and alcohol drinking (in one of two studies) (van Dessel et al., 2023). These results point to the possibility that an adapted CBM intervention focused on changing alcohol-based inferences instead of the previously targeted alcohol-based associations may be more effective in helping problem drinkers to reduce without a necessary abstinence goal. However, results from clinical trials have yet to confirm the superiority of this approach. Alternatively, and in line with recent developments in intervention research (e.g., Hornstein et al., 2023), underlying mechanisms that maintain alcohol addiction may differ per individual and across time and may be related to (variability in) an individual's context. This would acknowledge the high variability in alcohol-related symptom presentation and the complex interaction of an individual with its environment (Borsboom, 2017) and calls for studies including idiographic designs that can assess underlying mechanisms and symptoms over time (Fisher & Boswell, 2016). Such a design holds great promise for personalizing CBM interventions as discussed by Mansueto et al. (2023).

Another interpretation of the lack of differential change in symptom levels is that none of the three CBM interventions was effective in reducing the targeted cognitive biases. The results with respect to bias change for the ApB and AtB should be interpreted with caution given the low reliability of most of these bias measures. However, even the bias measures that showed good reliability (approach bIAT, GNG and valence bIAT), did not show significant reductions in cognitive bias or only showed a non-significant trend towards a reduction in cognitive bias (valence bIAT) as a result of CBM. The failure to manipulate cognitive biases is consistent with some of the findings of prior research outside the addiction clinic (Clerkin et al., 2016; Jones et al., 2018), but not with studies in clinical contexts in which differential changes in both bias and behavior were found (Eberl et al., 2013; Rinck et al., 2018; Wiers et al., 2011). As a result, it remains unclear whether successfully decreasing cognitive biases in problem drinkers would cause reductions in alcohol use. From a clinical perspective, however, this question is less relevant: if our procedures do not consistently affect cognitive biases without in-patient treatment, CBM has little clinical relevance as an intervention for problem drinkers who want to reduce their alcohol use outside conventional addiction treatment settings.

The current study was the first to investigate the effects of multiple web-based CBM procedures on problem drinking in a factorial design. This raises the question to what extent the null-results on cognitive biases and clinical outcomes could be due to the combination of different CBM procedures and/or the web-based delivery. The fact that symptom levels decreased across conditions could indicate that combining different CBM procedures led to reductions in cognitive biases regardless of whether participants received real or placebo CBM. Since 50% of the trials in the placebo CBM required turning attention away from alcohol related cues, inhibiting responses to alcohol cues, and avoiding alcohol cues, this would theoretically train an unbiased processing of alcohol related information, which would represent an improvement in individuals who had strong biases prior to the intervention. However, this seems unlikely, given that a) there were few baseline indications of group-level biases towards alcohol, b) most of the biases did not show evidence of change over time, and c) there was no relation between changes in cognitive biases and changes in clinical outcomes. The web-based delivery is also unlikely to account for CBMs ineffectiveness, since the importance of avoiding distractions was explained prior to the CBM interventions, and temporary lapses in focus should be compensated by the relatively high dose of the CBM interventions. In addition, incorrect trials had to be repeated, while correct and fast responses were rewarded in a game-like point system. Participants confirmed that this motivated them to respond accurately and quickly, which is in line with the low error rates found on the bias measures. Furthermore, training in a home-based setting, which contains craving-inducing alcohol cues, would theoretically be expected to augment the effectiveness of CBM. However, the web-based delivery did mean that the ApB modification was completed using the arrow keys instead of a joystick, which was used in prior clinic-based studies (Eberl et al., 2013; Rinck et al., 2018; Wiers et al., 2011), so this may have contributed to ineffectiveness of the ApB modification in the current study. Indeed, although outside of the problematic-alcohol use domain, assessment of approach bias has been shown to be more successful when assessed with a joystick versus a keyboard when applied to erotic approach bias (Kahveci et al., 2020).

This study had several limitations. First, as is common in e-health interventions (Riper et al., 2014), there was substantial dropout. Although dropout was lower than in a previous study on web-based CBM (41.5% at post-test, compared to 56% in the study of Wiers et al., 2015) and missing data were multiply imputed, this should be considered when interpreting the results. It should be noted that dropout rates were increased by the fact that participants were technically randomized directly after the screening, even though there were no differences between the CBM conditions until after the pre-test and personalized feedback intervention were completed. This did not appear to have impacted the main findings, since the results on symptom levels were comparable between the randomized participants (the ITT sample) and the completers sample. Furthermore, given the high dropout rates, the 12-month follow-up was not included in the analyses. However, CBM was not effective in the short term, and its effects are not expected to increase in the long term. Relatedly, the data preparation and data analysis plan were pre-registered in a protocol paper (van Deursen et al., 2013), which is a strength of this study. However, it can be argued that mixed effects models may have better suited the data gathered in this study (see e.g., Barr et al., 2013), as this allows for using all available data, it accounts for the nested structure and the correlation between repeated measures. Consequently, all primary and secondary outcome analyses were repeated in a mixed effects model framework. However, none of the conclusions changed depending on the analysis approach. Second, the effectiveness of the brief personalized feedback intervention was not tested in the current study (but it was evaluated by Riper et al., 2008; Riper et al., 2009), so it is unclear to what extent this intervention contributed to the observed reductions in alcohol use. Third, possible moderators of the effects of CBM were not analyzed (e.g. baseline executive functions). Even in the absence of general effects of CBM, the intervention may have been effective for specific subgroups (cf. Eberl et al., 2013). In addition, although the relation between changes in cognitive biases and symptom levels was explored, no formal mediation analysis was conducted. Lastly, the primary outcome measures (total number of drinks consumed and binge drinking) were assessed with regards to a 14-day timeline follow-back method (Sobell & Sobell, 1992) which may not be fully representative of the full time periods in between assessments.

In conclusion, in line with other studies on CBM in problem drinkers (Clerkin et al., 2016; Cox et al., 2015; Jones et al., 2018; Wiers et al., 2015), this study found that web-based CBM is not more effective than placebo-training in reducing alcohol use. To shed light on the discrepancy with the promising results of CBM as an add-on to in-patient treatment (Boffo et al., 2019), it is imperative that future studies investigate under which conditions CBM is effective in changing both the targeted cognitive biases and alcohol use to further the field (Vrijsen et al., 2024).

CRediT authorship contribution statement

Denise S. van Deursen: Writing – review & editing, Writing –

original draft, Project administration, Investigation, Formal analysis, Conceptualization. **Lynn Mobach:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization. **Elske Salemink:** Writing – review & editing, Supervision, Conceptualization. **Matthijs Blankers:** Writing – review & editing, Supervision, Conceptualization. **Reinout W. Wiers:** Writing – review & editing, Supervision, Methodology, Conceptualization.

4. Data transparency statement

This manuscript has not been published before or submitted for publication elsewhere, but it was included in the Ph.D. thesis of (one of) the first author(s). However, the chapter in which the current study was described has not been made publicly available. The baseline data of this study were reported in an earlier paper, which was unrelated to the CBM interventions (van Deursen et al., 2015).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.brat.2025.104718.

Data availability

Data will be made available on request.

The study was pre-registered at the Netherlands Trial Register (NTR3875), and described in a study protocol: van Deursen, D. S., Salemink, E., Smit, F., Kramer, J., & Wiers, R. W. (2013). Web-based cognitive bias modification for problem drinkers: Protocol of a randomized controlled trial with a 2 × 2 × 2 factorial design. BMC Public Health, 13, 674. https://doi.org/10.1186/1471-2458-13-674.

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