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Cognitive control over immediate reward in binge alcohol drinkers

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32 No conflict declared.

33 Abstract

34 *Background:* Cognitive control deficits, as captured by inhibitory control
35 measures, are indicative of increased impulsivity and are considered a marker for
36 substance use disorder (SUD) vulnerability. While individuals with alcohol use
37 disorder (AUD) typically exhibit inhibitory control dysfunction, evidence of impaired
38 inhibitory control among harmful drinkers, who are at increased risk of developing an
39 AUD, is mixed. This study examined the response inhibition of binge drinkers using a
40 task that employed neutral, as well as both immediate and delayed reward
41 contingencies, to determine whether reward induced heightened impulsivity in this
42 population.

43 *Methods:* Binge alcohol users ($n = 42$) and controls ($n = 42$) were
44 administered a Monetary Incentive Control Task that required participants to
45 successfully inhibit a prepotent motor response to both neutral and immediately
46 rewarding stimuli in order to secure a large delayed reward.

47 *Results:* Binge drinkers had significantly worse response inhibition than
48 controls irrespective of trial condition and even after controlling for differences in
49 weekly intake. Though both binge and control participants exhibited significantly
50 worse inhibitory control in the presence of immediate reward, the control group
51 showed a greater reduction in inhibition accuracy compared to the binge group in
52 reward relative to neutral conditions. Both groups demonstrated significantly
53 enhanced control when forewarned there was an increased chance response inhibition
54 would be required. Control participants secured the delayed reward more often than
55 binge participants.

56 *Conclusions:* Despite the variability in the literature, this study demonstrated
57 consistent generalized impulse control deficits among binge drinking individuals that
58 were unrelated to reward manipulations. These findings point to mechanisms that may
59 confer vulnerability for transition from binge drinking to AUD.

60 *Key words:* Binge drinking; Cognitive control; Inhibitory control; Response
61 inhibition; Reward

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Introduction

Binge drinking refers to a pattern of alcohol consumption whereby recurrent episodes of heavy drinking are punctuated by periods of abstinence (Scaife and Duka, 2009). This type of drinking is especially prevalent among adolescents and young adults: 30-37% of young people in the United States and 21-56% of those in Europe regularly binge drink (Hibell et al., 2012; Johnston et al., 2013). The specific pattern of alcohol misuse that characterizes bingers – that is, regular acute intoxications and repeated withdrawals – appears to introduce specific cognitive deficits over and above those associated with total alcohol consumed (Petit et al., 2014). Critically, early onset of heavy drinking has been identified as a significant predictor of AUD, and binge-drinking trajectories throughout college years have been found to predict alcohol abuse and dependence ten years later (Dawson et al., 2008; Jennison, 2004). At the same time, given the worldwide prevalence of AUD is 2.3%, the vast majority of young people who binge drink do not, in fact, develop this disorder (WHO, 2014). Nevertheless, the binge drinking population provides an opportunity to investigate if the cognitive control deficits characterizing AUD individuals are also apparent in

99 binge (but not non-binge) drinkers. In this way, mechanisms influencing the transition
100 from binge drinking to AUD might be identified.

101 Current theories related to SUDs, including AUD, implicate heightened
102 impulsivity as a key factor underpinning the loss of control evident in these disorders
103 (Goldstein and Volkow, 2011). Behaviorally, impulsivity is recognized as a multi-
104 faceted concept incorporating the inability to regulate instincts and desires, and the
105 tendency to act without planning or considering consequences (Fernie et al., 2010;
106 MacKillop et al., 2011). Increased impulsivity, and hence vulnerability for SUD, is
107 postulated to arise from an imbalance between bottom-up reward-sensitive processes,
108 which are subserved by striatal and limbic areas, and top-down cognitive control
109 mechanisms, which are mediated by the prefrontal cortex (Stevens et al., 2014;
110 Verdejo-García and Bechara, 2009). Impaired inhibitory control, which refers to a
111 failure to successfully inhibit a dominant behavioral response, captures deficits in
112 cognitive control and is thus considered one independent marker of impulsivity (Field
113 et al., 2007; Murphy and Garavan, 2011). Typically, Go/No-Go and Stop-Signal tasks
114 are employed in the investigation of inhibitory control (Fernie et al. 2010). Such tasks
115 require participants to respond rapidly to specific frequently appearing stimuli, but to
116 inhibit responses to others that are presented less often (Murphy and Garavan, 2011).
117 Elevated commission errors, decreased successful inhibitions, and increased reaction
118 times on these tasks all signal poor inhibitory control, and are thereby indicative of
119 heightened impulsivity (Ahmadi et al., 2013; Lawrence et al., 2009).

120 Individuals with SUDs commonly display signs of impaired inhibitory control
121 (Bickel et al., 2012; Smith et al., 2014; Verdejo-García et al., 2008). With regard to
122 AUD, research has demonstrated that dependents, those undergoing detoxification,
123 and newly abstinent individuals have significantly longer Stop-Signal reaction times
124 (SSRTs) and substantially elevated No-Go commission errors, as compared to
125 controls (Goudriaan et al., 2005, 2006; Lawrence et al., 2009; Noël et al., 2007). By
126 contrast, investigations into the inhibitory control of non-dependent binge or heavy
127 drinkers have generally yielded less consistent results. While Smith and Mattick
128 (2013) found female heavy drinkers had significantly longer SSRTs than light
129 drinkers, other studies utilizing inhibitory control measures have been unable to
130 distinguish the performance of heavy or binge drinkers from that of healthy controls
131 (Henges and Marczinski, 2012; Moreno et al., 2012). Similarly, although Henges and
132 Marczinski (2012) demonstrated Go/No-Go performance predicted the number of

133 drinks consumed by young social drinkers on one occasion, Fernie and colleagues
134 (2010) found no evidence to suggest either Go/No-Go or Stop-Signal tasks predicted
135 alcohol misuse in healthy participants. In cases where inhibitory control measures
136 have not successfully discriminated between heavy or binge drinking individuals and
137 controls, significant brain function anomalies have nonetheless been identified in at-
138 risk drinkers during response inhibition: specifically, binge drinking has been
139 associated with altered event related potentials in frontal regions, and reduced brain
140 activation in areas associated with impulsivity (Ahmadi et al., 2013; López-Caneda et
141 al., 2012; Whelan et al., 2014; Yan and Li, 2009). Consequently, while inhibitory
142 control impairments among heavy or binge drinkers might not always be apparent
143 behaviorally, they appear more evident at the brain function level.

144 As increased impulsivity is speculated to arise from irregularities in both top-
145 down cognitive control and bottom-up reward sensitive mechanisms, it is possible
146 inhibitory control tasks incorporating reward might better detect behavioral
147 differences between SUD individuals, or those at risk of the disorder, and healthy
148 controls. The inclusion of a reward condition has been found to significantly enhance
149 the inhibitory control of SUD individuals, but not healthy controls, and this has led to
150 the assertion reward sensitivity modulates inhibitory control among those with SUDs
151 (Chung et al., 2011). With regard to alcohol misuse, passive-avoidance Go/No-Go
152 measures, which require participants to learn No-Go stimuli via rewarding and
153 punishing feedback, have been used to demonstrate an association between heavy
154 alcohol use or binge drinking and commission errors (Castellanos-Ryan et al., 2011;
155 Colder and O'Connor, 2002). Such measures, however, incorporate an element of
156 learning, making it difficult to disambiguate the extent to which they are sensitive to
157 failures of learning or inhibitory control (or the combination therein). Employing a
158 Go/No-Go task with neutral, reward, and punishment contingencies, Rossiter and
159 colleagues (Rossiter et al., 2012) found no significant difference between harmful and
160 non-harmful drinkers under neutral conditions; however, reward significantly
161 improved the inhibitory control accuracy of the harmful drinkers, and thereby
162 differentiated harmful from non-harmful users. Thus, inhibitory control tasks
163 incorporating reward not only quantify behavioral deficits in inhibitory control among
164 sub-clinical samples, but also capture the reward sensitivity of these individuals.

165 Harmful sub-clinical drinkers include individuals who binge drink, as well as
166 those who are characterized by an elevated total alcohol intake independent of rate

167 and frequency of consumption. Previous work has not typically examined the
168 cognitive performance of bingers using inhibitory control measures incorporating
169 reward. Given the findings of greater sensitivity of such measures in the healthy
170 population, performance within the binge-drinking cohort may be more sensitive to
171 the individual differences that appear critical to the risk of transitioning to AUD. As
172 such, this study investigated differences in inhibitory control between binge drinkers
173 and controls using a novel measure that employs neutral, as well as both immediate
174 and delayed reward contingencies. This measure attempts to emulate the real-world
175 scenario encountered by bingers whereby a failure to inhibit a prepotent response for
176 a reward-related stimulus (e.g., alcohol) produces an immediate certain reward (e.g.,
177 reduced craving), with no direct immediate punishment. By contrast, successfully
178 inhibiting the impulse for alcohol tends to result in the greater delayed rewards
179 associated with abstinence (e.g., improved health). In the current task, inhibition
180 failures generate small, secure, immediate rewards, while successful inhibitions
181 contribute to the likelihood of obtaining a larger, delayed reward. Additionally, the
182 task forewarns participants of the probability response inhibition will be required.

183 It was hypothesized binge/control group differences would be more evident
184 under rewarding, but not neutral conditions, and when the probability of response
185 inhibition over reward was most likely. Specifically, it was predicted that relative to
186 the neutral condition, the immediate reward condition would reduce inhibition
187 accuracy on a Monetary Incentive Control Task (MICT) to a greater extent in the
188 binge group than the control group. We envisaged the binge group would favour a
189 strategy that maximized their chance of obtaining immediate secure reward. As
190 failure to inhibit resulted in such rewards, we therefore expected the binge group to
191 demonstrate reduced inhibitory control. By contrast, we assumed the control group
192 would adopt a strategy that enhanced their chances of securing the delayed reward,
193 namely increased inhibitory control across both neutral and reward conditions. It was
194 further predicted that inhibition accuracy on the MICT would be enhanced when
195 participants were alerted there was a 40%, compared to 20%, chance of response
196 inhibition. We anticipated this effect would be more evident in the control group.

197 **Materials and Methods**

198 *Participants*

199 Ninety-one participants (46 female, mean age 22.90) were recruited from the
200 University of Melbourne and via experimenter networks. Suitability for the study was

201 evaluated via a screening questionnaire, the Fagerström Test for Nicotine Dependence
202 (Heatherton et al., 1991), and the Drug Abuse Screening Test (Skinner, 1982).
203 Exclusion criteria included history of neurological or psychiatric illness, current use
204 of psychoactive medications, nicotine dependence, AUD, and/or abuse of drugs other
205 than alcohol. Participants were fluent in English. The University of Melbourne's
206 Human Ethics Committee approved the study in accordance with the standards for
207 ethical research of the National Health and Medical Research Council. All
208 participants provided informed consent. They were reimbursed for their time (AU\$10
209 per hour), and received additional monetary rewards commensurate with task
210 performance.

211 In accordance with criteria detailed by López-Caneda and colleagues (López-
212 Caneda et al., 2012, 2013), participants were classified as binge drinkers or controls
213 on the basis of their responses to the Alcohol Use Disorders Identification Test
214 (AUDIT; Saunders et al., 1993), which asks participants to consider their alcohol
215 consumption over the previous twelve months, and other questions regarding alcohol
216 use over the preceding six months. Participants were designated as binge drinkers ($n =$
217 42) if (i) they consumed six or more standard alcoholic drinks (standard drinks
218 contain 10g of alcohol in Australia) per drinking occasion two to three times per
219 week, or (ii) if they consumed six or more standard drinks per drinking occasion two
220 to four times per month and drank in excess of two standard drinks per hour. Controls
221 consumed alcohol below the levels necessary for these criteria ($n = 42$). Regular
222 heavy drinkers ($n = 7$) were excluded from the analysis. These individuals indicated
223 they drank alcohol four or more times per week and that when drinking they
224 consumed, on average, more than four (4.86) standard drinks per session.

225 *Monetary Incentive Control Task (MICT)*

226 Inhibitory control was evaluated using the MICT (Fig. 1). Programmed using
227 E-Prime software (version 2.0, Psychology Software Tools) and running on a laptop
228 PC, MICT stimuli presentation and recording of responses were digitally controlled.
229 The task comprised one practice block followed by three blocks of 72 trials. Cues
230 indicated trials would be one of four randomly assigned conditions: Neutral20,
231 Reward20, Neutral40, and Reward40. Cue color – white or red – signified the
232 probability of an inhibition trial – 20% or 40% chance respectively. Within each
233 block, 25% of all trials were inhibition trials. Cue shape denoted the reward
234 contingency of each trial. A horizontal line (-) designated neutral conditions (50% of

235 trials), in which participants would not receive any immediate reward regardless of
236 performance, while an apex symbol (^) indicated reward conditions (50% of trials),
237 where participants could secure an immediate and certain AU\$0.20 reward,
238 depending on their response. Thus, participants were able to use cues to anticipate
239 trial type.

240 Stimuli took the form of letter X or O. During go trials, participants were
241 required to press the corresponding letter on the keyboard within 400ms, and received
242 immediate feedback regarding accuracy and monetary gain. The 400ms response
243 window was designed to encourage fast responding to go trials and was taken directly
244 from the widely used and validated Monetary Incentive Delay task (Knutson, Fong,
245 Adams, Varner, & Hommer, 2001) from which the MICT is an adaption. The
246 response time limit made it more difficult to inhibit the prepotent response when
247 required and discouraged participants from adopting a strategy of slowing their go
248 responses in order to more easily withhold their response on inhibitory trials. During
249 inhibition trials, a square appeared around the X or O after 150ms, thereby indicating
250 participants were to withhold their response. In both neutral and reward conditions,
251 successful inhibition of response did not result in an immediate certain reward, but
252 counted toward a larger delayed reward at task end. Participants were instructed that
253 successful inhibition of 60% or more of all inhibition trials would result in a large
254 delayed reward (AU\$20.00) upon task completion. Failed inhibition in neutral
255 conditions resulted in no (immediate or delayed) reward. By contrast, inhibition
256 failures during reward conditions yielded participants an immediate and certain
257 AU\$0.20 reward (but did not count toward the larger delayed reward). Thus, failure to
258 inhibit a response for a reward-related stimulus produced a small immediate certain
259 reward – much like the failure to inhibit alcohol consumption results in immediate
260 reward (e.g., reduced craving) – whereas successfully inhibiting a response for a
261 reward-related stimulus increased the chance of securing the larger delayed reward –
262 much as successfully inhibiting alcohol consumption contributes to improved health
263 and other less immediate outcomes. In short, participants needed to balance their
264 desire for immediate versus delayed reward throughout the task. Those swayed by
265 immediate certain reward were likely to adopt a strategy designed to ensure
266 successful responding to immediately rewarding (as opposed to neutral) stimuli.
267 Although profitable in the short-term, this may have diminished their ability to inhibit
268 their response when required and thus impacted their chances of acquiring the larger

269 delayed reward. Participants less influenced by immediate reward were likely to enact
270 a strategy that maximized their capacity for inhibiting a response when required.
271 Although this impacted money acquired via short-term immediate reward, it increased
272 their chance of securing the larger delayed reward at the end of the experiment.

273 Several mechanisms were employed to ensure participants thoroughly
274 understood the task prior to commencement. In the first instance, the researcher read
275 through the on-screen instructions with each participant and gave them the
276 opportunity to ask questions or seek clarification. The researcher provided a verbal
277 précis of what each cue represented, the type of feedback participants could expect
278 after each trial, the immediate/delayed reward trade-off, and the need to respond as
279 fast as possible on all trials. Participants then undertook a practice block. During this
280 block, cue symbols – white/red and -/^ – were accompanied by text – “20%”/”40%”
281 and “neutral”/”reward” – reminding participants of the significance of cues.
282 Additionally, the researcher sat beside the participant during this block and issued
283 further clarification as required, reiterated the significance of cues as necessary, and
284 reminded participants of the need to respond as fast as possible on all trials regardless
285 of their go or potential inhibitory status. If participants appeared to be adopting a
286 strategy of non-responding to go trials at any point during the practice block, they
287 were told this was contrary to task requirements and that they needed to attempt to
288 respond to all trials. Thus, prior to undertaking experimental blocks of trials,
289 researchers ensured participants understood the task and were responding to
290 cues/trials as directed by the task.

291 At the conclusion of each block, participants received feedback regarding sub-
292 400ms threshold go trial performance and total money earned from immediate
293 rewards in that block, but not inhibition trial accuracy. Running totals across blocks of
294 trials were not provided so participants were unable to determine whether their
295 behavioral responses were likely to secure the delayed reward. Upon completion of
296 the task, participants were given feedback regarding total money earned from
297 immediate certain reward, plus their inhibition accuracy in each of the reward and
298 neutral conditions across all blocks. The proportion of successful inhibitions for each
299 of the four conditions provided a measure of inhibitory control accuracy. Relative to
300 neutral inhibitory trials, reward trials provided an indication of the extent to which the
301 prospect of immediate certain reward reduced inhibitory control.

302 *Statistical Design and Analysis*

303 A one-way analysis of variance (ANOVA) and chi-square test were conducted
304 to assess if binge and control groups were matched demographically. Differences in
305 performance across the four conditions on the MICT were analyzed using a mixed
306 repeated measures ANOVA, with inhibition probability (20%, 40%) and reward type
307 (neutral, reward) as the within subjects factors, and group (binge, control) as the
308 between subjects factor. Age was identified as differentiating groups and was entered
309 into the analysis as a covariate. Effect sizes were computed using partial eta squared
310 values (η^2_p) and were interpreted according to Cohen's guidelines: .01 = small, .06 =
311 moderate, and .14 = large effect (Cohen, 1988).

312 **Results**

313 *Descriptive statistics*

314 Descriptive statistics are displayed in Table 1. A one-way ANOVA revealed
315 binge and control groups did not differ significantly on NART IQ, $F(1, 82) = 0.04$, p
316 $= .847$, drug use, $F(1,82) = 3.09$, $p = .083$, nicotine dependence, $F(1, 82) = 0.68$, $p =$
317 $.413$, or gender, $\chi^2(1, N = 84) = 3.08$, $p = .079$, but did differ on age, $F(1,82) = 10.67$,
318 $p = .002$, total AUDIT score, $F(1,82) = 78.93$, $p < .001$, standard drinks consumed per
319 week, $F(1,82) = 31.29$, $p < .001$, occasions consuming six or more drinks, $F(1,82) =$
320 218.37 , $p < .001$, hourly rate of consumption, $F(1,82) = 66.80$, $p < .001$, and
321 percentage drunkenness, $F(1,82) = 47.57$, $p < .001$. The binge group had higher
322 AUDIT scores, drank more standard drinks per week, consumed six or more drinks on
323 each drinking occasion more regularly, drank faster, and became intoxicated more
324 frequently than the control group.

325 *MICT performance*

326 Inhibition mean accuracy, represented as the percentage of successful
327 inhibitions for each condition, for binge and control groups is displayed in Table 2.
328 The ANOVA determined there was a significant main effect of group, $F(1, 81) =$
329 8.91 , $p = .004$, $\eta^2_p = .10$, inhibition probability, $F(1, 81) = 7.18$, $p = .009$, $\eta^2_p = .08$,
330 reward type, $F(1, 81) = 8.75$, $p = .004$, $\eta^2_p = .10$, but not age, $F(1, 81) = 0.41$, $p =$
331 $.523$, $\eta^2_p = .01$, on inhibition accuracy. Inhibition accuracy was higher for the control
332 group, as well as in the 40% probability and neutral conditions. There was a
333 significant interaction between group and reward type, $F(1, 81) = 8.25$, $p = .005$, η^2_p
334 $= .09$, with the control group showing a greater reduction in inhibition accuracy
335 compared to the binge group in reward relative to neutral conditions. There was no
336 significant interaction between group and inhibition probability, $F(1, 81) = 0.01$, $p =$

337 .909, $\eta^2_p < .01$, inhibition probability and reward type, $F(1, 81) = 1.34$, $p = .250$, $\eta^2_p =$
 338 .02, or between group, reward type and probability, $F(1, 81) = 1.79$, $p = .185$, $\eta^2_p =$
 339 .02. Age did not interact with any factors. The analysis was repeated using standard
 340 drinks consumed per week as an additional covariate. None of the significant main or
 341 interaction effects from the preceding analysis changed. There was no significant
 342 main effect of standard drinks consumed per week, $F(1, 80) = 1.54$, $p = .219$, $\eta^2_p =$
 343 .02. A chi-square test indicated that more individuals in the control group ($n = 11$)
 344 than the binge group ($n = 5$) secured the delayed reward, though this was not a
 345 significant association, $\chi^2(1, N = 84) = 2.78$, $p = .095$, OR = 0.38, 95% CI [0.12,
 346 1.21].

347 Go trial mean threshold performance, represented as the proportion of
 348 successful sub-400ms responses in each condition, for binge and control groups is
 349 displayed in Table 2. The ANOVA indicated there was no significant main effect of
 350 group, $F(1, 81) = 0.26$, $p = .609$, $\eta^2_p < .01$, or age, $F(1, 81) = 0.04$, $p = .843$, $\eta^2_p <$
 351 .001, on mean go threshold performance. There was a significant main effect of
 352 inhibition probability, $F(1, 81) = 5.22$, $p = .025$, $\eta^2_p = .06$, and reward type, $F(1, 81) =$
 353 20.45, $p < .001$, $\eta^2_p = .20$, on mean go threshold performance. Go threshold
 354 performance was higher in the 20% probability and reward conditions. There was a
 355 significant interaction between group and reward type, $F(1, 81) = 6.72$, $p = .011$, η^2_p
 356 = .08, with the control group showing a greater increase in go accuracy compared to
 357 the binge group in reward relative to neutral conditions. There was no significant
 358 interaction between group and inhibition probability, $F(1, 81) = 0.17$, $p = .683$, $\eta^2_p <$
 359 .01, inhibition probability and reward type, $F(1, 81) = 0.17$, $p = .683$, $\eta^2_p < .01$, or
 360 group, inhibition probability and reward type, $F(1, 81) = 0.66$, $p = .419$, $\eta^2_p = .01$.

361 Mean go trial threshold reaction times for binge and control groups across
 362 conditions are displayed in Table 2. The ANOVA determined there was a significant
 363 main effect of inhibition probability, $F(1, 76) = 7.12$, $p = .009$, $\eta^2_p = .09$, with go
 364 threshold reaction times slower in the 40% condition. There was no significant main
 365 effect of group, $F(1, 76) = 3.57$, $p = .063$, $\eta^2_p = .05$, reward, $F(1, 76) = 0.71$, $p = .404$,
 366 $\eta^2_p = .01$, or age, $F(1, 76) = 1.98$, $p = .164$, $\eta^2_p = .03$, on go trial threshold reaction
 367 times. There was also no significant interaction between group and inhibition
 368 probability, $F(1, 76) = 2.30$, $p = .133$, $\eta^2_p = .03$, group and reward, $F(1, 76) = 0.77$, p
 369 = .383, $\eta^2_p = .01$, inhibition probability and reward, $F(1, 76) = 0.08$, $p = .781$, $\eta^2_p <$
 370 .01, or inhibition probability, reward and group, $F(1, 76) = 3.23$, $p = .076$, $\eta^2_p = .04$.

371 Mean failed inhibition trial reaction times for binge and control groups across
372 conditions are also displayed in Table 2. The ANOVA determined there was no
373 significant main effect of group $F(1, 73) = 1.60, p = .211, \eta^2_p = .02$, reward, $F(1, 73)$
374 $< 0.01, p = .984, \eta^2_p < .01$, inhibition probability, $F(1, 73) < 0.01, p = .969, \eta^2_p < .01$,
375 or age, $F(1, 73) = 0.47, p = .494, \eta^2_p = .01$, on failed inhibition trial reaction times.
376 There was a significant interaction between inhibition probability and group, $F(1, 73)$
377 $= 9.46, p = .003, \eta^2_p = .12$, with controls exhibiting slower failed inhibition reaction
378 times than binge drinkers in the 40% relative to 20% inhibition probability condition.
379 There was no significant interaction between group and reward, $F(1, 73) = 0.06, p =$
380 $.808, \eta^2_p < .01$, probability and reward, $F(1, 73) = 0.87, p = .353, \eta^2_p = .01$, or group,
381 reward and probability, $F(1, 73) = 0.25, p = .617, \eta^2_p < .01$.

382

383 Discussion

384 This study examined differences in response inhibition among binge drinkers
385 and controls utilizing an inhibitory control task that incorporated reward. The task
386 required participants to consistently inhibit responses to reward-related stimuli –
387 despite the fact that failure to do so generated small, certain, immediate rewards – in
388 order to increase their chances of securing a larger, delayed reward. It was
389 hypothesized group differences would be apparent under rewarding, but not neutral
390 conditions, and when the probability of response inhibition over reward was most
391 likely. The results indicate that, compared to controls, bingers had a significantly
392 reduced ability to withhold their response to inhibition stimuli regardless of the
393 reward or response inhibition probability condition. Compared to the neutral
394 condition, both binge drinkers and controls performed significantly worse in the
395 reward condition. Contrary to expectations, control participants, not binge drinkers,
396 demonstrated a greater reduction in inhibition accuracy in reward relative to neutral
397 conditions. Compared to the 20% condition, bingers and controls both performed
398 significantly better when alerted there was a 40% chance they would be required to
399 inhibit a response. Controlling for weekly intake did not alter these findings.

400 Previous investigations into the response inhibition of binge and heavy
401 drinking individuals have generated mixed results. Although SSRTs have been found
402 to distinguish heavy from light female drinkers (Smith and Mattick, 2013) and
403 Go/No-Go performance has predicted the number of alcoholic beverages consumed
404 by a sample of young ‘social’ drinkers (Henges and Marczinski, 2012), inhibitory

405 control tasks have often failed to differentiate the performance of heavy or binge
406 drinkers from that of controls (Fernie et al., 2010; Moreno et al., 2012). This has lead
407 to the hypothesis that in the absence of immediate reward or punishment, such tasks
408 might be insensitive to revealing distinctions between harmful and non-harmful
409 drinkers (Fernie et al., 2010). Such a proposition is consistent with evidence
410 demonstrating heightened impulsive decision-making for reward, as measured by
411 delay discounting procedures, among non-dependent harmful drinkers (Field et al.,
412 2007; MacKillop et al., 2011). To date, many studies utilizing inhibitory control tasks
413 incorporating reward and punishment have been confounded by the inclusion of a
414 learning element (Castellanos-Ryan et al., 2011; Colder and O'Connor, 2002).
415 Previous work has not typically considered the ability of binge or heavy drinkers to
416 inhibit a response for immediately rewarding stimuli in order to secure a greater
417 delayed reward, yet this is arguably more analogous to the real-world scenario
418 encountered by this population. That is, in reality individuals must inhibit a response
419 for an immediately rewarding stimulus (alcohol) in order to increase their chance of
420 securing a larger delayed reward (healthier outcomes). While the present study
421 employed a task that attempted to model this real-world situation, controls rather than
422 binge drinkers demonstrated the greater reduction in inhibitory control in the presence
423 of immediate reward. Nevertheless, the ability of binge drinkers to exercise inhibitory
424 control – either in neutral or immediately rewarding conditions – was vastly inferior
425 to control participants, even after controlling for weekly alcohol intake. Indeed, the
426 mean inhibitory control accuracy of bingers in the neutral condition was less than that
427 of controls in the reward condition. Thus, the inhibitory control of bingers in the
428 neutral condition was already critically low and got worse still in the presence of
429 immediate reward. Furthermore, these inhibitory control deficits account for why
430 binge drinkers secured the delayed reward, which required at least 60% inhibition
431 accuracy in both neural and immediate reward conditions, at less than half the rate of
432 controls.

433 No binge/control group differences were evident upon examination of go
434 threshold accuracy data. Indeed, participants responded to reward and inhibition
435 probability manipulations largely as expected in these trials: the immediate reward
436 condition induced higher accuracy as compared to the neutral condition, whereas the
437 40% condition reduced accuracy relative to the 20% condition. While increased go
438 threshold accuracy in the presence of immediate reward intimates possible faster

439 responding in this condition, neutral and reward go threshold reactions times were not
440 dissimilar. Incentive for immediate monetary reward, not enhanced reaction time, thus
441 drove increased go threshold accuracy in the reward condition. By contrast, decreased
442 accuracy on go threshold trials in the 40% condition was probably underpinned by the
443 significantly slower reaction times participants secured in this condition. Importantly,
444 there were no reaction time binge/control group differences on go trials. Although
445 binge participants trended toward having reduced go trial threshold reaction times
446 across conditions – suggesting their incentive for monetary reward influenced the
447 speed with which they responded to all stimuli – in fact, these differences were not
448 significant. As such, this cannot account for the reduced inhibition trial accuracy of
449 binge drinkers across conditions.

450 Given the cross sectional nature of this analysis, it is difficult to determine
451 whether the reduced inhibitory control of our binge sample represents a cause or
452 consequence of their drinking behaviour. A number of studies suggest behavioural
453 inhibitory control deficits might constitute a pre-existing risk factor for alcohol-
454 related problems. A longitudinal study of 498 children, for example, has shown
455 response inhibition in early adolescence predicted illicit drug use and the onset of
456 problematic alcohol consumption, independent of other risk factors (Nigg et al.,
457 2006). Likewise, researchers have determined that individual differences in inhibitory
458 control among young adolescents predicted alcohol use and misuse six months later
459 (Fernie et al., 2013). Although few behavioural studies consider the relationship
460 between chronic bingeing and the progressive deterioration of inhibitory control,
461 imaging studies provide some insight into the consequences of binge drinking. For
462 instance, baseline differences in event-related potentials – elicited during a response
463 inhibition task – between persistent binge and control groups were found to be more
464 pronounced at two-year follow-up (López-Caneda et al., 2013). Wetherill and
465 colleagues (2013) have demonstrated that adolescents who transitioned to heavy
466 drinking had different neural activation patterns when undertaking a go/no-go task, as
467 compared to non-drinking youngsters, both prior to and following the initiation of
468 heavy drinking. Relative to non-drinkers, future heavy drinkers were characterized by
469 reduced activation prior to transition but increased activation after transition
470 (Wetherill et al., 2013). Thus, pre-existing inhibitory control impairments appear to
471 signal vulnerability for the development of alcohol-related problems. At the same

472 time, persistent alcohol misuse impacts the neural mechanisms underpinning response
473 inhibition and presumably thereby exacerbates the deficit.

474 The failure to show a specific deficit for binge drinkers in controlling
475 responses to reward may, in part, be due to the sensitivity of the MICT. The inhibition
476 trial accuracy of binger drinkers was poorer than expected, irrespective of condition,
477 with performance in the 20% reward condition demonstrating floor effects. Indeed,
478 the median (0.15) in this condition was less than the mean (0.22) and the boxplot
479 indicated 25% of all accuracy values fell below 0.08 while 75% of values fell below
480 0.23, thereby suggesting substantial positive skew. Additionally, although control
481 participants secured the delayed reward more frequently than bingers, this was not a
482 significant effect, suggesting it might not have been a sufficiently lucrative reward. In
483 order to encourage task compliance in both the neutral and immediate reward
484 contingencies, the delayed reward was linked to performance in both conditions. That
485 is, participants needed to successfully inhibit their response to all Stop stimuli at least
486 60% of the time in order to secure the delayed reward. As such, the neutral task
487 presented an incentive for cautious behavior that may have masked some of the
488 interaction between binge group and reward condition.

489 One consideration with the current study is whether our binge sample was
490 representative of the binge drinking population. Non-dependent at-risk alcohol
491 consumption is variously described in the literature as heavy, problem, or binge.
492 Heavy and problem drinking may, however, refer to total intake rather than any
493 specific binge pattern of consumption. As binge drinking has been found to result in
494 cognitive effects over and above those associated with total consumption, it is
495 important to take intake pattern into consideration (Petit et al., 2014). Indeed, the
496 number of alcohol doses per drinking occasion, as opposed to total consumption
497 levels, has been related to the cognitive and neural dysfunction identified in binge
498 drinkers (Maurage et al., 2012; Petit et al., 2014). At the same time, it has been
499 suggested operational definitions of binge drinking ought to incorporate quantity
500 consumed over a specific timeframe plus the time period of episodes (Courtney and
501 Polich, 2009). To this end, this study considered drinking episodes per week/month,
502 alcohol doses per drinking occasion, and rate of consumption over the previous six to
503 twelve months. Furthermore, heavy regular drinkers were excluded from the analysis
504 in an effort to prevent behavioral deficits related to high total intake confounding
505 results. The AUDIT scores of the current binge sample (13.21) were in keeping with

506 those of participants classified as binge in other studies (e.g., 10.4-11.2 in Fillmore
507 and Jude, 2011). Similarly, binge drinkers in this study corresponded to those
508 described in studies by Lopez-Caneda and colleagues (López-Caneda et al., 2012,
509 2013) with regard to AUDIT scores (13.21 in this study versus 10.7-12.1), occasions
510 consuming six or more drinks (2.43 versus 2.8-2.9), weekly intake (11.52 versus 13.2-
511 14.3) and percentage drunkenness (53.44 versus 52.5-55.4). Thus, the current binge
512 sample appears to be representative of the binge drinking population sampled in other
513 studies.

514 In sum, cognitive control impairments, as captured by inhibitory control tasks,
515 are indicative of heightened impulsivity. Although increased impulsivity has been
516 identified as a key factor underpinning the loss of control apparent in AUD, evidence
517 of cognitive control impairments in non-dependent binge or heavy drinkers has been
518 mixed. This study utilised a novel inhibitory control task that incorporated reward to
519 explore the cognitive control of binge drinkers. We found that relative to control
520 participants, bingers were characterised by significantly lower response inhibition
521 performance, regardless of the reward or response inhibition probability condition. In
522 the reward condition, where participants were required to consistently inhibit a
523 response for reward-related stimuli – even though failure to do so generated small,
524 certain, immediate rewards – in order to increase their chances of securing a larger
525 delayed reward, both groups demonstrated reduced inhibitory control as compared to
526 the neutral condition. At the same time, reward improved go trial threshold accuracy
527 in both groups. It is possible aspects of the task contributed to the unexpected finding
528 with regard to the interaction between binge group and reward across inhibitory trials.
529 In particular, the balance between the immediate but secure small reward and the
530 delayed but uncertain larger reward was perhaps not sufficiently refined. The current
531 data nonetheless provide encouragement that novel response inhibition tasks can
532 furnish unique indicators of control problems in binge drinkers that might be used for
533 identifying those at risk of transitioning to AUD.

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694 **Fig. 1.** Examples of Monetary Incentive Control Task (MICT) display sequences. A
 695 fixation point of 1000ms followed by a cue of 2000ms preceded each trial. (a) Go trial
 696 in the Neutral40 condition. The red horizontal cue indicated a 40% probability of
 697 response inhibition plus no immediate monetary reward (i.e., neutral) for a successful
 698 response. If the participant responded to the go stimulus within 400ms, the feedback
 699 screen signaled a *hit*; otherwise, a *miss* was indicated. As the trial was neutral, there
 700 was no monetary reward for a *hit* or *miss*. (b) Go trial in the Reward20 condition. The
 701 white apex cue indicated a 20% probability of response inhibition plus immediate
 702 monetary reward for a successful response. If the participant responded to the go
 703 stimulus within 400ms, the feedback screen signaled a *hit* and the participant was
 704 rewarded AUS\$0.20; otherwise, a *miss* was indicated and there was no monetary
 705 reward. (c) Inhibition trial in the Neutral20 condition. The white horizontal cue
 706 indicated a 20% probability of response inhibition plus no immediate monetary reward
 707 (i.e., neutral). If the participant successfully inhibited their response to the inhibition

708 stimulus, the feedback screen signaled *correct*; otherwise, *wrong* was indicated. As the
709 trial was neutral, there was no monetary reward for *correct* or *wrong*. (d) Inhibition
710 trial in the Reward40 condition. The red apex cue indicated a 40% probability of
711 response inhibition plus immediate monetary reward. If the participant successfully
712 inhibited their response to the inhibition stimulus, the feedback screen signaled
713 *correct*; however, there was no immediate reward as this successful response counted
714 toward securing a larger delayed reward at task end. If the participant failed to inhibit
715 their response, *wrong* was indicated and there was an immediate monetary reward. In
716 this case, the participant secured an immediate reward, but their response did not
717 increase their chance of receiving the larger delayed reward at the completion of the
718 experiment.
719

Table 1. Means, standard deviations, and confidence intervals of demographic and alcohol use data for the analysis sample ($N = 84$), including binge ($n = 42$) and control ($n = 42$) groups.

	Total		Binge		Control	
	<i>M (SD)</i>	95% CI	<i>M (SD)</i>	95% CI	<i>M (SD)</i>	95% CI
Age	22.77 (5.26)	[21.63, 23.91]	21.00 (3.31)	[19.97, 22.03]	24.55 (6.21)	[22.61, 26.48]
Age range	18-43		18-35		18-43	
Gender (F:M)	46:38		19:23		27:15	
NART IQ	111.48 (5.24)	[110.34, 112.61]	111.36 (4.85)	[109.85, 112.88]	111.59 (5.66)	[109.82, 113.35]
DAST	0.99 (1.57)	[0.65, 1.33]	1.29 (1.57)	[0.80, 1.77]	0.69 (1.54)	[0.21, 1.17]
FTND	0.05 (0.26)	[-0.01, 0.11]	0.07 (0.34)	[-0.04, 0.18]	0.02 (0.15)	[-0.02, 0.07]
AUDIT	8.99 (6.07)	[7.67, 10.31]	13.21 (5.41)	[11.53, 14.90]	4.76 (2.95)	[3.84, 5.68]
Occasions consuming six or more drinks*	1.60 (0.98)	[1.38, 1.81]	2.43 (0.50)	[2.27, 2.58]	0.76 (0.53)	[0.60, 0.93]
Drinks per hour**	2.45 (1.05)	[2.22, 2.68]	3.15 (0.69)	[2.94, 3.37]	1.75 (0.88)	[1.48, 2.02]
Drinks per week**	7.76 (7.20)	[6.20, 9.33]	11.52 (8.25)	[8.95, 14.09]	4.00 (2.81)	[3.13, 4.88]
Percentage drunkenness**	33.23 (33.55)	[25.95, 40.51]	53.44 (30.30)	[44.00, 62.88]	13.02 (22.89)	[5.89, 20.16]

Table 2. Mean inhibition trial accuracy (represented as the proportion of successful inhibitions), go trial accuracy (represented as the proportion of successful sub-400ms responses), go trial reaction time (RT), and failed inhibition trial RT as a function of trial condition for binge ($n = 42$) and control ($n = 42$) groups.

	Neutral20		Reward20		Neutral40		Reward40	
	<i>M (SD)</i>	95% CI	<i>M (SD)</i>	95% CI	<i>M (SD)</i>	95% CI	<i>M (SD)</i>	95% CI
Inhibition trial accuracy								

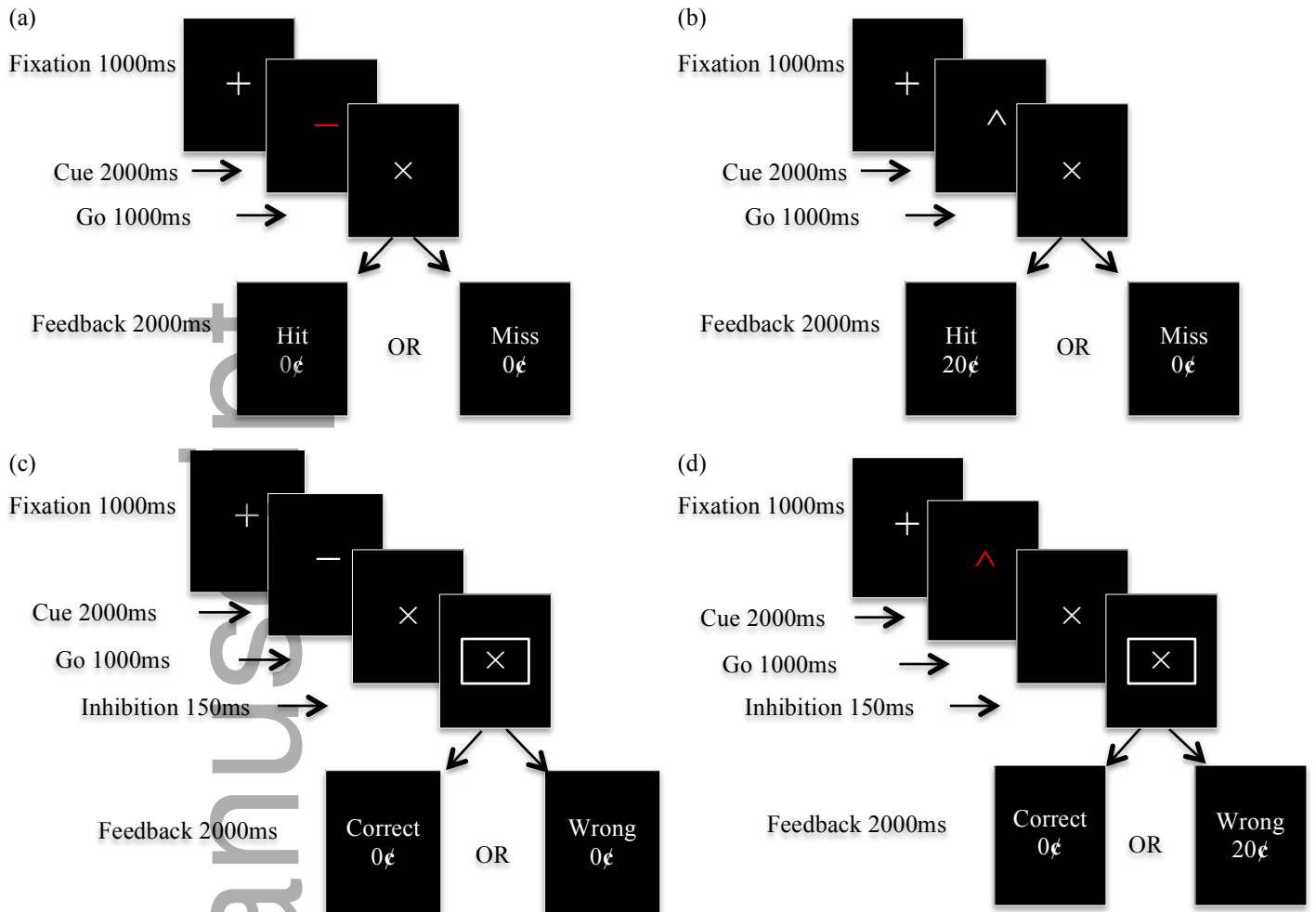
Binge	0.29 (0.28)	[0.20, 0.38]	0.22 (0.23)	[0.15, 0.30]	0.44 (0.32)	[0.34, 0.54]	0.40 (0.28)	[0.31, 0.48]
Control	0.50 (0.28)	[0.42, 0.59]	0.33 (0.25)	[0.25, 0.41]	0.62 (0.29)	[0.53, 0.71]	0.52 (0.26)	[0.44, 0.60]
Go trial accuracy								
Binge	0.43 (0.15)	[0.38, 0.48]	0.55 (0.12)	[0.51, 0.59]	0.30 (0.17)	[0.25, 0.36]	0.39 (0.15)	[0.34, 0.43]
Control	0.39 (0.15)	[0.34, 0.43]	0.55 (0.14)	[0.51, 0.60]	0.27 (0.16)	[0.22, 0.32]	0.42 (0.16)	[0.37, 0.47]
Go trial RT (ms)								
Binge	328.82 (41.63)	[315.84, 341.79]	331.10 (38.12)	[319.22, 342.98]	331.38 (41.97)	[317.78, 344.99]	335.84 (41.06)	[322.88, 348.00]
Control	351.74 (46.17)	[337.16, 366.31]	345.80 (44.19)	[331.85, 359.75]	354.36 (47.03)	[339.32, 369.40]	361.75 (45.71)	[347.51, 376.00]
Failed inhibition trial RT (ms)								
Binge	321.12 (86.82)	[292.98, 349.27]	331.13 (53.68)	[313.73, 348.53]	294.63 (118.42)	[256.24, 333.02]	289.78 (107.96)	[254.78, 324.77]
Control	323.89 (99.81)	[290.61, 357.17]	331.28 (53.68)	[308.34, 354.23]	332.43 (120.19)	[292.36, 372.51]	337.15 (93.17)	[306.08, 368.21]

Table 1: Legend

NART IQ = National Adult Reading Test predicted IQ. DAST = Drug Abuse Screening Test score. FTND = Fagerström Test for Nicotine Dependence score. AUDIT = Alcohol Use Disorders Identification Test total score. Drinks refers to self-reported alcohol consumption in Australian standard drinks (1 drink = 10 g alcohol). CI = confidence interval.

* Participants were asked to consider drinking occasions over the preceding twelve months.

** Participants were asked to consider standard weeks in the preceding six months.



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