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Creativity on tap 2: Investigating dose effects of alcohol on cognitive control and creative cognition

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ABSTRACT

This preregistered study aimed to replicate and extend research on the role of cognitive control in creative cognition by examining dose effects of alcohol in a randomized controlled trial. A sample of 125 participants was randomly assigned to three experimental groups, either drinking alcoholic beer (BAC = 0.03 or 0.06) or drinking non-alcoholic beer (placebo-control group). Before and after the alcohol intervention, participants completed two tests of cognitive control and two established creative thinking tasks. A BAC of 0.06 led to an impairment of verbal fluency, while working memory performance was unaffected at both alcohol levels. Alcohol had no facilitative or detrimental effects on creative thinking performance, neither in terms of RAT performance, divergent thinking fluency or divergent thinking creativity. These results indicate that moderate alcohol levels have dose-dependent, selective effects on cognitive control, and that minor impairments of cognitive control do not generally increase or attenuate creative thinking performance.

1. Introduction

Does a glass of wine or beer enhance creativity by dissolving inhibitions and increasing spontaneity, or does it rather undermine creativity by impairing relevant cognitive resources? It boils down to the underlying question about the functional role of cognitive control for creative cognition, which has proven to be a complex one (Amer, Campbell, & Hasher, 2016; Benedek & Jauk, 2018; Chrysikou, 2018). On the one hand, intelligence and executive capacity consistently predict higher creative performance, pointing to the relevance of cognitive control for creativity. On the other hand, increased creative performance was also observed in states of reduced cognitive control, such as under the influence of alcohol intoxication (Norlander, 1999). Such experimental work is particularly intriguing as it offers empirical tests of the putative link between drugs and creativity that has mostly relied on anecdotal reports (Knafo, 2008). Here, we aimed to extend available research by examining the role of alcohol dose on different types of creative thinking performance (convergent and divergent thinking creativity) in a pre-registered randomized controlled trial.

1.1. Creative cognition and cognitive control

The role of cognitive control for creative cognition has been investigated from different perspectives including individual differences approaches (i.e., correlations with intelligence or executive abilities) as well as experimental approaches. Individual differences research has accumulated robust evidence for a positive relationship between intelligence and creative thinking performance (Kim, 2005; Silvia, 2015), especially for fluid intelligence (Gf; (Jauk, Benedek, Dunst, & Neubauer, 2013; Nusbaum & Silvia, 2011),

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broad retrieval ability (Gr; Avitia & Kaufman, 2014; Benedek, Könen, & Neubauer, 2012; Silvia, Beaty, & Nusbaum, 2013), and mental speed (Gs; Forthmann et al., 2019; Preckel, Wermer, & Spinath, 2011). These findings generalize across a broad range of creative performances including divergent thinking in the context of alternate uses generation (e.g., Jauk, Benedek, & Neubauer, 2014), metaphor production (e.g., Beaty & Silvia, 2013), or humor production (e.g., Christensen, Silvia, Nusbaum, & Beaty, 2018), as well as convergent thinking creativity in the context of finding remote associates (e.g., Lee & Therriault, 2013) and insight problem solving (Gilhooly & Murphy, 2005).

Findings are less consistent at the level of individual differences in executive functions. For example, some studies observed positive associations between divergent thinking ability and working memory capacity (WMC; e.g. Benedek, Jauk, Sommer, Arendasy, & Neubauer, 2014), whereas other observed no relationship (Dygert & Jarosz, 2019; Smeekens & Kane, 2016). Creative problem solving ability is more consistently associated with higher WMC (Dygert & Jarosz, 2019; Gilhooly & Fioratou, 2009), yet it depends on the phase of creative problem solving (Ash & Wiley, 2006) and a negative association with WMC was observed in people with high domain-specific knowledge that was misleading for a given task (Ricks, Turley-Ames, & Wiley, 2007). Correlations between creative performance and other executive functions such as inhibition and switching are also occasionally reported but seem to depend strongly on the type task (Benedek, Franz, Heene, & Neubauer, 2012; Gilhooly & Fioratou, 2009; Nusbaum & Silvia, 2011; Zabelina, Robinson, Council, & Bresin, 2012). Finally, individual differences in the strategic search of memory (i.e., verbal fluency; Troyer, Moscovitch, & Winocur, 1997) are consistently related to higher creativity (see also evidence for Gr), and notably not just to divergent thinking fluency but apparently even more to divergent thinking creativity (Benedek, Kenett, et al., 2017; Silvia et al., 2013). While some work has suggested that verbal fluency draws upon WMC (Rosen & Engle, 1997), they clearly differ in referring to retrieval from long-term memory and manipulation of content in working memory. A recent study demonstrated that WMC and verbal fluency ability are correlated but the former was more strongly related to creative problem solving whereas the latter was more strongly related to divergent thinking ability (Dygert & Jarosz, 2019). Hence, WMC and verbal fluency can be considered reasonably distinct aspects of cognitive control that both are relevant to creative ability. Creative thinking performance has further been related to the effective implementation of demanding cognitive strategies (Gilhooly, Fioratou, Anthony, & Wynn, 2007; Nusbaum & Silvia, 2011), and to the involvement of prefrontal brain regions (Beaty, Benedek, Silvia, & Schacter, 2016; Gonen-Yaacovi et al., 2013). Together, these findings indicate that creative cognition broadly benefits from increased cognitive capacity and controlled, goal-directed thinking processes.

Dual process models of creative cognition also underscore the relevance of spontaneous, undirected thought for creative cognition (Benedek & Jauk, 2018; Sowden, Pringle, & Gabora, 2015). Deliberate creative problem solving commonly runs into states of impasse and functional fixation that appear hard to overcome with increased conscious efforts, but rather benefit from incubation periods, where people engage in task-unrelated thought (Sio & Ormerod, 2009). Experimental research even offers evidence that attenuation of cognitive control can facilitate creative thinking. For example, cognitive depletion after extensive engagement in executive tasks was found to improve creative idea generation (Radel, Davranche, Fournier, & Dietrich, 2015). In contrast, sleep deprivation seems to have mostly detrimental effects on creative performance (Horne, 1988; Wimmer, Hoffmann, Bonato, & Moffitt, 1992). Finally, alcohol intoxication was shown to support specific aspects of creative cognition (see next section, for a more detailed account). Hence, there is evidence that creative cognition relies on goal-directed and spontaneous, undirected processes (Beaty, Silvia, Nusbaum, Jauk, & Benedek, 2014), and the actual effect of cognitive control on creative performance may depend on type of creative performance and the expertise of the person (Benedek & Jauk, 2019; Chrysikou, Weber, & Thompson-Schill, 2014).

1.2. Alcohol and creativity

Anecdotal reports have long suggested an association between alcohol and creativity. For example, a large proportion of American writers from the first half of last century have been linked with alcoholism (Knafo, 2008). Yet, the functional role of alcohol for creativity is unclear. It could be seen as a means to reach altered states of minds, but it could also serve to cope with the strains associated with creative work (Ludwig, 1990). So far, only few studies have empirically tested the effect of alcohol on creativity. As alcohol is known to impair cognitive control and self-regulation (Dry, Burns, Nettelbeck, Farquharson, & White, 2012; Peterson, Rothfleisch, Zelazo, & Pihl, 1990), alcohol represents a powerful means to experimentally test the role of cognitive control in creative cognition. One study examined the effect of alcohol (BAC $\sim$ 0.065) on divergent thinking (i.e., creative idea generation) and found that idea fluency was significantly reduced in both the alcohol and the placebo group compared with the control group (Gustafson, 1991). Another study found that intoxicated writers and non-writers (BAC $\sim$ 0.08) showed reduced idea flexibility but an increased number of nonobvious and original ideas (Norlander & Gustafson, 1998). Lang et al. (1984) observed no effect of alcohol (BAC $\sim$ 0.05) on divergent thinking, but the participants evaluated their performance as more creative when they thought that they had received alcohol.

A more recent study demonstrated that moderate alcohol intoxication impaired working-memory processing, and at the same time, the intoxicated group (BAC = 0.07) showed higher performance in the Remote Associates Test (RAT) compared with a control group that had not received any drinks (Jarosz, Colflesh, & Wiley, 2012). These findings were conceptually replicated by a placebo-controlled study comparing effects of alcoholic versus nonalcoholic beer (Benedek, Panzierer, Jauk, & Neubauer, 2017). In this study, even a lower alcohol level (BAC = 0.03) impaired updating performance and facilitated RAT performance but did not affect divergent thinking (DT). These findings suggest that the effect of alcohol on creative cognition is moderated by the type of creative performance. Specifically, the RAT can be solved by means of strategic semantic retrieval processes (Smith, Huber, & Vul, 2013), but also via undirected associative processes (Kounios & Beeman, 2014). There is evidence suggesting that an undirected task approach is more effective in the RAT (Aiello, Jarosz, Cushen, & Wiley, 2012), potentially as it avoids running into mental fixation (Smith &

Blankenship, 1991). When cognitive control is impaired under the influence of alcohol, spontaneous processing may become more dominant which could specifically benefit RAT performance (Benedek & Jauk, 2018). As creative solutions to DT tasks cannot be reasonably found by spontaneous processes alone, DT may rely to a relatively greater extent on cognitive control, and thus it may not benefit from very moderate levels of alcohol intoxication and might even get impaired by higher levels of alcohol.

1.3. The present study

There is mixed evidence on the effects of alcohol on creative cognition, which could be due to important moderators of the relationship between cognitive control and creativity. First, alcohol may have different effects on creativity depending on the level of goal-directed versus spontaneous processes in the creative task at hand (Benedek & Jauk, 2019; Chrysikou et al., 2014). Second, the effect of alcohol on creative cognition may depend on the actual level of alcohol and its resulting effect on cognitive control: While a mild attenuation of cognitive control may be beneficial for certain performances, stronger attenuations may become detrimental. Finally, alcohol is known to have objective, pharmacological effects as well as subjective effects (Lang, Verret, & Watt, 1984), and, therefore, it is crucial to control for expectation effects. The present study addressed these important conceptual and methodological challenges by using different standard measures of creative cognition (RAT and DT), by varying the alcohol dosage (BAC = 0.0 vs. 0.03, vs 0.06), and by controlling for expectation effects with a double-blind placebo-controlled design. Moreover, cognitive control was assessed by two different indicators (WMC and verbal fluency; e.g., Dygert & Jarosz, 2019) that have proven relevant to different forms of creative cognition. In sum, this preregistered study aimed for a powerful examination of alcohol effects on cognitive control and creative cognition.

2. Material and methods

The hypotheses, methods, and analysis approach of this study were preregistered via the Open Science Framework (https://osf.io/2gdku).

2.1. Participants

A total of 423 people participated in an initial online screening, which assessed the criteria for participation in the main study. Specifically, participants had to be aged between 18 and 35 years (the legal drinking age in this state being 16 years for alcohol, and 18 years for strong spirits), report no medical conditions related to heart or liver, no psychological illness, no regular medication, no pregnancy, and score no larger than 8 in the Alcohol Use Disorders Identification Test (AUDIT; Saunders, Aasland, Babor, Fuente, & Grant, 1993), which is viewed as criterion of non-problematic drinking behavior. A subset of 222 people, who met all these criteria, were invited, and 129 actually participated in the main study. Four participants had to be excluded from further data analysis due to outlier values in one of the tests (> 3 SDs from the mean).

The final sample consisted of 125 participants (80 females; 64%) with an average age of 24 years (*SD* = 2.99), which closely meet the preregistered n of 120. This sample size gives sufficient statistical power for detecting small to medium between-within interaction effects ($d = 0.3, f = 0.15$: $1\text{-}\beta = .80$) and high power for medium-sized effects ($d = 0.5, f = 0.25$: $1\text{-}\beta = .99$). Participants were randomly assigned to one of the three experimental groups (with the only restriction that number of participants per group were kept about similar): the placebo-control group (n = 41), or an alcohol group with either BAC = 0.03 (n = 42) or BAC = 0.06 (n = 42), and received €15 for participation.

2.2. Experimental design

This study examined the effect of alcohol on cognitive control and creative cognition using a randomized placebo-controlled double-blind pretest–posttest design. It represents a conceptual replication and extension of previous studies (Benedek, Panzierer, Jauk, & Neubauer, 2017; Jarosz, Colflesh, & Wiley, 2012), aiming to improve the experimental design in specific ways. First, this study implemented three alcohol conditions (i.e., 0.0, 0.03, and 0.06 BAC) in order to be able to examine dose-effects; second, it realized a double-blind design to avoid any systematic expectation effects by participants and experimenters; third, we used two different measures of cognitive control: the operation span task which is arguably one of the most established measure of working memory capacity (Redick et al., 2012), and a letter fluency task, because retrieval abilities are known to be highly relevant to creative cognition (Silvia et al., 2013). Finally, the same two standard measures of creative cognition (RAT and DT) as in Benedek et al. (2017) were used, but with more items to increase reliability (RAT: same ten plus five additional tasks; DT: same two plus one additional task).

2.3. Measures

2.3.1. Self-reported alcohol use

The alcohol use disorders identification test (AUDIT; Saunders et al., 1993) is a 10-item screening of individual drinking behavior. It asks for the frequency of alcohol consumption, and for indicators of alcohol dependence and harmful alcohol use. Total scores of > 8 are viewed as indicators of potentially hazardous and harmful alcohol use (Babor, Higgins-Biddle, Saunders, & Monteiro, 2001).

2.3.2. Cognitive control

Working memory capacity was measured with a computerized version of the operation span task (OSpan; van der Malsburg, 2015). This task involves an alternating sequence of memory updating (remembering letters in correct order) and an arithmetic processing (evaluating the correctness of simple mathematical equations; e.g. $(1 \times 2) + 1 = 3$). Participants first practiced the arithmetic processing task, without the updating task, for 15 trials. In these practice trials, participants received feedback on the correctness of the response. The response times during practice trials (except for the first three trials which may reflect familiarization) served to compute the individual timeout for the actual test defined as $M + 2.5^{*}\ SD$. Participants then completed six additional practice trials with alternating memory updating and arithmetic tasks (3 or 4 memory items per trial). The memory items were displayed for 1 s, followed by the arithmetic task that was completed at own pace. The main test consisted of twelve trials (different versions for pre-and posttest), with four different load levels (4, 5, 6, 7 letters) realized in three trials each. The full test took about ten minutes. Working memory capacity was defined by the partial credit unit score (PCU), a recommended scoring that reflects the average of correctly recalled letters across trials task (Conway et al., 2005).

Verbal fluency (viz., retrieval ability; Gr) was assessed with two letter fluency tasks taken from the Regensburger Wortflüssigkeits-Test (Aschenbrenner, Tucha, & Lange, 2001; pretest: P, K; posttest: M, B). Participants had to write down as many words as possible starting with these letters within two minutes. Responses should be German words, with different word stems, and no proper names. Retrieval ability was defined by the average number of valid words across the two letter fluency tasks.

2.3.3. Creativity cognition

Creative thinking performance was assessed with the Remote Associates Test (RAT; Mednick, 1962) and divergent thinking tasks (Guilford, 1967), two established measures of creative potential (Kaufman, Plucker, & Baer, 2008). The RAT presents three unrelated words (e.g., cottage, blue, cake) and ask for a solution word that connects them by building a compound noun with each (cheese: cottage cheese, blue cheese, cheesecake). Pretest and posttest used different fixed sets of 15 items matched for item difficulty across sets (Landmann et al., 2014). The first 10 items were the same as in a previous study (Benedek, Panzierer, et al., 2017) to enable replication tests, while the extended version should offer higher reliability. The items were presented on a computer and participants entered the solution via a keyboard (timeout: 30 s). Internal consistency of the RAT was low for the pretest (.45) and posttest (.46), but slightly higher than for the original 10-item versions (see Supplemental Material). A conservative estimate of retest-reliability (ignoring any intervention effects) was modest too ($r = .32$; see Table 1).

Divergent thinking (DT) was assessed with a computer-based version of the alternate uses task (AUT), which asks to find creative uses for common objects within 2.5 min (pretest: umbrella, shoe, glass bottle; posttest: car tire, fork, tin can). Task performance was scored for rated creativity as well as for fluency. All 4296 responses were evaluated for creativity (a holistic rating reflecting the novelty and task-appropriateness of ideas) by six independent judges on a 4-point Likert-like scale ranging from (0 = uncreative, to 3 very creative). All judges completed a short training, where they were given thorough rating instructions, rated 40 responses individually and then discusses potential differences in their ratings until discrepancies were resolved. The remaining responses were rated individually. Inter-rater-reliability was high and ranged from .81 to .87 across tasks. DT creativity was defined as the average creativity rating of the three most creative ideas per task according to judge's ratings. This *max-3* creativity score aims to avoid confounds with the fluency of responses (Benedek, Mühlmann, Jauk, & Neubauer, 2013). DT fluency was measured as the number of responses per task. Scores were averaged across tasks. Internal consistency across three tasks was low to acceptable for DT originality at pretest (.54) and posttest (.68), and high for DT fluency at pretest (.88) and posttest (.89); see Supplemental Material for additional analyses for the shorter version. Similar findings were obtained for retest reliability (DT originality: .63; DT fluency: .85; see Table 1).

2.3.4. Self-assessments on alcohol effects

Prior to the intervention, participants indicated whether they believed that the consumption of alcohol would increase or decrease their performance in each task on an 11-point rating scale (-5 extreme decrease, to +5 extreme increase). After the intervention, they rated the experienced effect of alcohol on performance in each task using the same scale. Finally, they were asked to indicate their subjective level of intoxication (0 no intoxication, to 10 extreme intoxication).

2.4. Procedure

Participants were tested in groups of up to four people in a test lab. They were asked to abstain from alcohol and other drugs 24 h before the test session and to avoid eating or drinking caffeinated drinks 2 h before the session. Participants received thorough instructions on the procedure and the planned target BAC of 0.06, and gave written informed consent. Weight and height assessments were obtained from each participant and soberness was confirmed with a commercial alcohol tester ACE Neo (ACE Handels- & Entwicklungs GmbH; Freilassing, Germany).

In the pretest, participants first completed assessments of cognitive control (OSpan and letter fluency), followed by the creative cognition tests (RAT and DT), with the sequence of creative cognition tasks varying across test sessions. Directly after each test, they estimated how task performance in this task would be affected by the subsequent alcohol consumption.

During the pretest, a second experimenter randomly assigned participants to one of three experimental groups and prepared the drinks. In a first step, the amount of alcoholic beer for a target BAC of 0.06 was individually determined based on gender, age, weight, and height according to the formula by Widmark (1932) with adjustments recommended by Watson, Watson, and Batt (1980); 10% were added to account for resorption deficits (Soyka, Küfner, & Feuerlein, 2008). This resulted in about 1.0 L beer for an average male and 0.7 L beer for an average female. Participants of the placebo-control group received pure non-alcoholic beer (*Gösser*

NaturGold®, < 0.5 vol%), participants in the 0.06 BAC group received pure alcoholic beer (*Gösser Stifts-Zwickl hell*®; 5.2 vol%), and participants in the 0.03 BAC group received half alcoholic and half non-alcoholic beer. Drinks were consumed together with salty snacks in a different room within a time period of 30 min; during this time participants watched a documentation about the wildlife in Africa to ensure comparable limited levels of social interaction across test sessions and avoid specific affect induction.

After the intervention, participants returned to the test lab for posttest assessments. They completed parallel versions of all tests in the same order as in the pretest and estimated the perceived effects of alcohol on task performance in each test. In the middle of the posttest (after the cognitive control tests), the second experimenter conducted another alcohol test to verify the actual alcohol level, but without informing the participants or the first experimenter about the results.

Finally, participants were asked about their subjective level of intoxication. Then, they were debriefed and informed about their experimental condition, and asked for confidentiality regarding the experimental design. A final alcohol test was obtained, and in case of a BAC $>$ 0.05 (the local legal limit for driving), participants were invited to stay in the lab until they got below. The total test duration was about 135 min.

2.5. Ethical considerations

Only people with non-problematic alcohol drinking behavior were admitted to the study, and alcohol levels were individually adjusted (see participant section). The whole study procedure was approved by the local ethics committee. The realization of this study was financially supported by a grant from the Dutch Beer Institute (DBI), but the DBI was not involved in any other aspect of this study and unconditionally supported publication of findings. All hypotheses and methods were pre-registered prior to the start of the study (https://osf.io/2gdku).

3. Results

3.1. Descriptive statistics and inter-correlations

Table 1 presents the descriptive statistics and inter-correlations of the main dependent variables.

3.2. Manipulation check

Assessment of blood alcohol concentration (BAC) confirmed that the three experimental groups were sober at pretest, whereas at posttest they had a measured BAC of 0.000% (SD = 0.00), 0.024% (SD = 0.09), and 0.056% (SD = 0.10), which is very close to the targeted BAC levels of 0.00, 0.03, and 0.06%, respectively, and represents a very strong group effect ($F(2,119) = 459.13$, $p < .001$, $\eta^2 = .89$). BAC levels were similar across gender groups as evidenced by absence of a main effect ($F(1,119) = 0.47$, $p = .50$) or interaction with gender ($F(2,119) = 0.12$, $p = .90$). Participants of higher BAC groups reported to feel more intoxicated ($F(2,122) = 31.53$, $p < .001$; M = 1.76, 3.40, and 5.24, for the 0.00, 0.03, and 0.06 BAC groups, respectively; all pairwise post-tests: $p < .001$). Hence, the three experimental groups clearly differed in their objective and subjective alcohol intoxication levels.

3.3. Dose effects of alcohol on cognitive control and creative cognition

3.3.1. Cognitive control

In a first step, we examined potential intervention effects on cognitive control measures (OSpan and letter fluency) between pre- and posttest assessments across the three alcohol levels. The ANOVA for the PCU score of the OSpan task revealed no significant interaction between time and group ($F(2,122) = 0.35$, $p = .70$), and no main effect for the alcohol group ($F(2,122) = 0.43$, $p = .65$), but a significant time effect ($F(1,122) = 6.13$, $p = .01$, $\eta^2 = .05$; see Fig. 1). Similar findings were obtained when using other OSpan performance indicators such as ANU, PCL, or ANL. These results indicate a practice effect from pretest to posttest, but no effects of

Table 1
Descriptive statistics and inter-correlations.

	M	*SD*	*Range*	1	2	3	4	5	6	7	8	9
1 - OSpan T1	0.83	0.09	0.56–0.98									
2 - OSpan T2	0.84	0.09	0.48–0.98	.60								
3 – Letter-Flu T1	18.35	4.38	8.00–30.50	.17	.11							
4 – Letter-Flu T2	20.15	4.04	9.00–32.00	.15	.07	.70						
5 - RAT T1	5.51	2.14	2–11	.06	.06	.34	.41					
6 - RAT T2	5.66	2.30	1–12	.08	.14	.24	.24	.32				
7 - DT-Crea T1	1.35	0.28	0.57–1.89	-.05	-.12	.40	.40	.06	.00			
8 - DT-Crea T2	1.36	0.31	0.61–2.00	-.11	-.12	.30	.29	.17	-.05	.63		
9 - DT-Flu T1	7.16	2.78	2.67–17.00	-.09	-.18	.22	.22	.10	-.03	.54	.42	
10 - DT-Flu T2	7.30	2.97	2.33–16.33	-.14	-.18	.21	.20	.17	-.10	.53	.60	.85

Notes. N = 125. Correlations with $r \geq 0.17$, 0.23, 0.28 are significant at $p < .05$, 0.01, 0.001, respectively. OSpan = Operation span task, Letter-Flu = letter fluency task, RAT = Remote Associates Test, DT-Crea/Flu = Divergent thinking creativity/fluency.

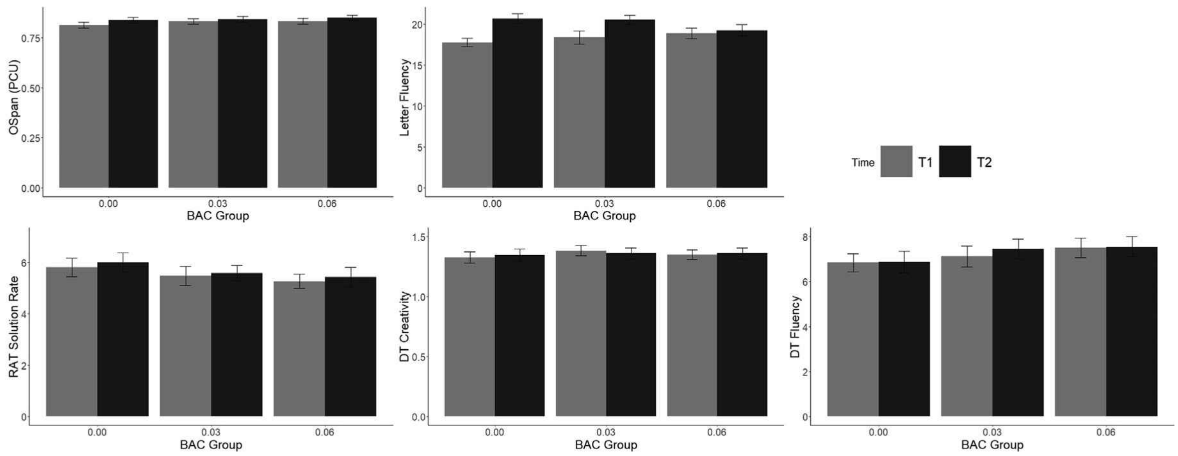

Fig. 1. Effects of different levels of blood alcohol concentration (BAC = 0.00, 0.03, 0.06%) from pre-intervention (T1) to post-intervention (T2) on different measures of cognitive control and creative cognition. OSpan = operation span, PCU = Partial credit unit, RAT = Remote Associates Test, DT = Divergent thinking.

alcohol on working memory performance.

In contrast, the ANOVA for letter fluency revealed a significant interaction between time and alcohol group ($F(2,122) = 7.41$, $p < .001$, $\eta^2 = .11$), no main effect of alcohol group ($F(2,122) = 0.11$, $p = .89$), and again a significant time effect ($F(1,122) = 42.16$, $p < .001$, $\eta^2 = .26$). Pairwise comparisons with Bonferroni correction showed that the placebo-control group and the 0.03 BAC group showed significant pre-posttest increases (both $p < .001$), whereas no significant pretest–posttest difference was observed in the 0.06 BAC group ($p = .46$; see Fig. 1). These results suggest that higher alcohol levels impaired cognitive control in terms of counteracting practice effects in letter fluency performance.

3.3.2. Creative cognition

In a next step, we examined potential intervention effects on creative cognition measures (RAT and DT) between pre- and posttest assessments across the three alcohol levels. The ANOVA for RAT performance yielded no significant interaction ($F(2,122) = 0.02$, $p = .98$), nor main effects of alcohol group ($F(2,122) = 1.03$, $p = .36$) and time ($F(1,122) = 0.43$, $p = .52$). Similarly, the ANOVAs for DT performance yielded no significant effects neither for DT creativity (group*time: $F(2,122) = 0.31$, $p = .73$; group: $F(2,122) = 0.18$, $p = .84$; time: $F(1,122) = 0.01$, $p = .91$), nor for DT fluency (group*time: $F(2,122) = 0.45$, $p = .64$; group: $F(2,122) = 0.62$, $p = .54$; time: $F(1,122) = 0.90$, $p = .35$; see Fig. 1). Additional replication analyses for shorter versions of RAT and DT yielded essentially the same results (see Supplemental Material). Moreover, excluding participants that showed a lower processing accuracy of 0.85 in one of the two OSpan assessments (cf. Conway et al., 2005) also did not change any of the findings.

Finally, we also explored dose effects in terms of whether pre-posttest changes in cognitive control were related to pre-posttest changes in creative cognition. Pre-posttest change scores in OSpan performance and letter fluency performance were unrelated to pre-posttest change scores in RAT and DT performance (all $rs < 0.08$, $ps > 0.40$).

3.4. Self-reported alcohol effects

At pretest, participants estimated the presumed effect of the upcoming alcohol consumption on the performance in each task (-5, extreme decrease, to 5, extreme increase), and expected the highest performance decrease in the OSpan task ($M = -2.54$, $Md = -3$, $CI_{95} = [-2.73, -2.36]$), followed by the RAT ($M = -1.57$, $Md = -2$, $CI_{95} = [-1.89, -1.24]$), and the letter fluency task ($M = -0.72$, $Md = -1$, $CI_{95} = [-1.03, -0.41]$), whereas they expected slightly increased task performance in the DT task ($M = 0.74$, $Md = 1$, $CI_{95} = [0.45, 1.03]$).

At posttest, participants estimated the perceived effect of alcohol consumption on the performance in each task. They experienced weak detrimental effects on task performance in the OSpan task ($M = -0.64$, $Md = -1$, $CI_{95} = [-0.97, -0.31]$) and in the RAT ($M = -0.76$, $Md = 0$, $CI_{95} = [-1.09, -0.43]$), but weak facilitative effects on letter fluency (Gr: $M = 0.63$, $Md = 0$, $CI_{95} = [0.38, 0.89]$) and on divergent thinking tasks ($M = 0.27$, $Md = 0$, $CI_{95} = [0.00, 0.54]$). Importantly, these subjective effects were not moderated by alcohol group for any task (OSpan: *Kruskal-Wallis-H*(2) = 2.58, $p = .28$; Gr: *Kruskal-Wallis-H*(2) = 3.84, $p = .15$; RAT: *Kruskal-Wallis-H*(2) = 1.12, $p = .57$; *Kruskal-Wallis-H*(2) = 0.03, $p = .99$).

4. Discussion

This study investigated dose effects of alcoholic versus non-alcoholic beer on cognitive control and creative cognition in a randomized controlled trial with double-blind assessments. Alcohol had a selective, dose-dependent effect on cognitive control: While we observed no alcohol effect on working memory performance, retrieval ability was impaired at BAC = 0.06 compared to BAC = 0 and

0.03 conditions. Yet, these moderate alcohol levels had no significant effect on creative cognition, neither on convergent thinking creativity (Remote Associates Test; RAT) nor divergent thinking creativity (Alternate Uses Test; AUT). These results are consistent with previously reported modest alcohol-related impairments of cognitive control, they replicate null-effects on divergent thinking but do not replicate previous findings reporting positive effects of alcohol on RAT performance.

We found no significant effect of alcohol on working memory performance measured with the OSpan task at BAC = 0.03 and 0.06, whereas working memory impairments had been previously reported for this measure at BAC = 0.07 (Jarosz et al., 2012) and for the 2-back task at BAC = 0.03 (Benedek, Panzierer, et al., 2017). The OSpan task is a well-established measure of working memory capacity (Conway et al., 2005) and was experienced as highly demanding by the participants, but they performed very well even after alcohol consumption. A potential reason for this discrepancy could be found in the automated version used in this study, which does not require verbal responses for the intermediary arithmetic task and thus may imply lower executive control; however, automated versions of complex span tasks are widely used and considered reliable and valid (Redick et al., 2012). Alcohol effects on cognitive control were evident, however, in terms of missing practice effects in the letter fluency at BAC = 0.06 compared to BAC = 0.0 and 0.03 conditions. Letter fluency, a common measure of verbal fluency, is an indicator of broad retrieval ability (Gr) according to the CHC-model of intelligence (Carroll, 1993) and a common index of executive control (Gilhooly et al., 2007). Here, we provide further evidence that moderate alcohol levels (BAC = 0.06) lead to inhibition of broad retrieval abilities rather than potential disinhibition effects (Peterson et al., 1990). This finding underlines the high executive demands needed for strategic search of semantic memory, which involves the suppression of proactive interference from previous responses. Still, alcohol effects on cognitive control were not very strong, which is in line with other research showing consistent impairments of cognitive functioning only at high BAC levels (Dry et al., 2012; Peterson et al., 1990).

This study further found no effect of alcohol on two standard measures of creative thinking, RAT and DT performance. The former finding was unexpected given that facilitative effects of alcohol on RAT performance have been observed in two previous studies (Benedek, Panzierer, et al., 2017; Jarosz et al., 2012). It should be noted that the present study employed an improved experimental design compared to these earlier studies using double-blind assessments and slightly more participants per experimental group. Moreover, unlike Jarosz et al., this study employed a within-subject design, which is much more sensitive to intervention effects than between-subject designs. In fact, the post-hoc determined statistical power to observe effect sizes similar to the previous studies was 99.9%. An obvious issue with RAT assessments was the low reliability. While we used more RAT items than Benedek et al. (2017) and the same number as in Jarosz et al. (2012), reliability evidence was still low in terms of both internal consistency and retest reliability. Assuming similarly low reliability for RAT assessments in previous studies, the true effect size would be very large, and the empirical effect should be hard to miss in a well-powered study.

We also found no effect of alcohol on divergent thinking ability, neither on the number nor creativity of ideas. This result replicates the findings from Benedek et al. for BAC = 0.03 and is consistent with findings by Lang et al. (1984), whereas other studies reported negative effects on DT fluency and flexibility and positive effects on originality (Gustafson, 1991; Norlander & Gustafson, 1998). The validity of DT scores was supported by substantial correlations with Gr, which is a very consistent finding in the literature (Forthmann et al., 2019; Silvia et al., 2013). In this context it is interesting to note that Gr was slightly impaired at BAC = 0.06, but despite the substantial correlation between Gr and DT, we observed no effect on DT performance. This suggests that reduced executive control may have been compensated by other facilitative effects of alcohol on divergent thinking.

Another interesting finding of this study was that people generally expected alcohol to have detrimental effects on convergent thinking tasks that require single correct solutions (OSpan and RAT), but weaker impairments or even benefits were expected for divergent thinking tasks that have many different solutions (Gr and DT). This may reflect the lay assumption that alcohol increases disinhibition tendencies which may facilitate divergent thinking but undermine convergent thinking. This was clearly not the case according to actual performance and the post-intervention self-reports, where participants correctly recognized that alcohol had no strong (differential) effects on their task performance.

5. Limitations and future directions

A few limitations need to be noted. This study attempted to realize a placebo-controlled double-blind design in order to control for expectation effects by participants and experimenters. Self-reports on subjective intoxication, however, revealed that participants in the higher alcohol groups felt more inebriated, which may imply differential expectation effects across experimental groups. Yet, the a priori expected changes due to alcohol did not reflect actual performance – the only actual negative effect of alcohol on letter fluency stands in contrast to an expected minor facilitative effect on this task, which suggests that participant expectation had no strong effects on task performance. While it may be impossible to ensure full “blindness” at higher doses of alcohol, a placebo control condition and double-blind assessments appear still important to limit expectation effects as well as motivation effects (e.g., low motivation in a no-drink group) as far as possible.

Another potential limitation is related to the moderate alcohol level. Since a previous study had observed alcohol effects for BAC = 0.03, we aimed to replicate these effects and extend them for higher alcohol levels of 0.06. While these alcohol levels are commonly used in this field, consistent alcohol effects are often found only for higher doses of alcohol (BAC ≥ 0.08) and rather for low-level cognitive processes but not necessarily for more complex cognitive performance (Dry et al., 2012; Peterson et al., 1990). Therefore, more pronounced alcohol effects could be expected at yet higher alcohol doses, but it is unclear whether any positive effects of alcohol on creative cognition can be reasonably expected at high levels of alcohol.

It should also be noted that this study has not assessed how many RAT tasks were solved with subjective experience of insight. This differentiation was an important factor in one study (Jarosz et al., 2012) but not in others (Benedek, Panzierer, Jauk, &

Neubauer, 2017; Zabelina & Silvia, 2020). The RAT is commonly approached by strategic retrieval processes (K. A. Smith et al., 2013), but can also be solved by undirected, associative processes, and even seems to benefit from employing a more intuitive, undirected mind set (Aiello et al., 2012). As the capacity for strategic retrieval was impaired at higher alcohol dosage, more strategic, analytical approaches may have become less effective. Since there were no dosage effects on general RAT performance, this either had no substantial effect or was compensated by increased employment of undirected task approaches.

Taken together, this study revealed that moderate alcohol levels of 0.03 to 0.06 have only limited detrimental effects on cognitive control, and no significant positive or negative effect on creative cognition. It is possible that alcohol supports specific spontaneous processes and impairs goal-directed processes that both are relevant to high-level creative cognition (Benedek & Jauk, 2019; Chrysikou, 2018; Sowden et al., 2015), which results in no general effect of alcohol on creative performance. Therefore, future research should focus on more specific creativity-related cognitive processes (Benedek & Fink, 2019), and only turn to more complex forms of creative cognition once any (especially positive) effects of alcohol on relevant low-level cognitive processes have been established.

CRediT authorship contribution statement

Mathias Benedek: Funding acquisition, Project administration, Conceptualization, Supervision, Writing - original draft. **Lena Zöhrer:** Methodology, Investigation, Data curation, Formal analysis, Writing - review & editing.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2020.102972.

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