



Psychology & Neuroscience

ISSN: 1984-3054

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Pontifícia Universidade Católica do Rio de
Janeiro
Brasil

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Psychology & Neuroscience, vol. 4, núm. 2, 2011, pp. 279-283

Pontifícia Universidade Católica do Rio de Janeiro

Rio de Janeiro, Brasil

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Dynamics of a Stroop matching task: effect of alcohol and reversal with training

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Abstract

Using a Stroop matching task, we evaluated how alcohol affects the time needed to overcome Stroop conflict and whether practice might reverse the effect of alcohol. Participants ($n = 16$) performed two sessions in which they had to compare the color of a color-word with the meaning of a color-word in neutral color. The two task stimuli were presented simultaneously or with a Stimulus Onset Asynchrony (SOA) of 200, 500, or 800 ms. For half of the subjects, alcohol was administered in the first session, and for the other half, alcohol was administered in the second session. The results showed that the Stroop effect was significant at the 0 and 200 ms intervals in the sober subjects. Moreover, in untrained intoxicated individuals, interference endured until the 500 ms interval, a result that was abolished in trained intoxicated subjects. In conclusion, alcohol increased the time needed for Stroop matching task conflict resolution. However, this deleterious effect was minimized by a previous practice session. **Keywords:** alcohol, feature-attention, practice, Stroop task, reaction time.

Received 5 February 2011; received in revised form 1 April 2011; accepted 13 April 2011. Available on line 10 October 2011

Introduction

The detrimental effect of alcohol on attention has been demonstrated in many behavioral studies, and a causal link between the effects of alcohol on risk-taking behavior and traffic accidents has been consistently reported (Mocaiber et al., 2011). Exploring the effects of alcohol on attention is not simple. Attention is composed of many subabilities, and alcohol is known to impair the functioning of various attentional mechanisms (Koelega, 1995). Thus, choosing adequate paradigms to isolate the desired attentional factor to be studied is a common concern. The effect of alcohol on feature-based attention has been somewhat overlooked. Understanding the effects of alcohol on processes related to selection

and comparison of feature information can provide insights into its disruptive effect on a wide range of activities, including driving. Driving requires selection and comparison among various relevant stimuli such as transit places, pedestrians, and traffic light colors in a complex and dynamic visual scene. Thus, inefficient feature-based attention under alcohol intoxication would promote risk-taking actions in this context.

The Stroop task (Stroop, 1935) is widely used to investigate the interference produced by irrelevant stimuli features in cognitive processing. In a variation of the Stroop task, congruent (e.g., the word RED in red) or incongruent (e.g., the word BLUE in red) Stroop stimuli are presented with either a colored patch, a sequence of colored "X"s, or another color-word in neutral color (Treisman & Fearnley, 1969; Machado-Pinheiro et

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al., 2010; David et al., 2011). To execute this so-called Stroop matching task, participants must determine the relevant feature of the bidimensional Stroop stimulus and match this with the relevant dimension of a second stimulus. A conflict emerges from the interaction between the participant's goals (top-down influence) related to the relevant feature and stimulus-driven contingencies (bottom-up influence) related to the distracter feature (Machado-Pinheiro et al., 2010; David et al., 2011). An event-related potential study found that feature selection plays an important role in the Stroop matching task. This attentional feature selection, reflected by the N1 component amplitude, was influenced by Stimulus Onset Asynchrony (SOA) manipulation and markedly correlated with the behavioral results (for details, see David et al., 2011). Therefore, the Stroop matching task constitutes a useful tool for exploring the effects of alcohol on feature selection under conflict. The first aim of the present study was to evaluate the effects of alcohol on feature selection during a Stroop matching task.

A second important issue is if and how practice compensates, at least partially, for the deleterious effects of alcohol. As a task becomes more practiced, its reliance on top-down control is reduced. Evidence for this comes from neuroimaging and neurophysiological studies in which weaker prefrontal activation was observed as the task became more practiced (Weissman, Woldorff, Hazlett, & Mangu, 2002). These findings suggest that practice decreases the dependence of controlled attentional resources. Because the disruptive effects of alcohol are more prominent under situations that require high cognitive demand, such effects should be reduced with practice, which decreases prefrontal dependency for controlled task execution. Therefore, one possibility is that the disruptive effect of a low dose of alcohol in the Stroop matching task might be easily observed in a novel, non-practice session but more difficult to observe after practice.

We examined whether top-down attention to a specific feature value is effective for matching features in a conflict context under alcohol intoxication using a Stroop matching task (David et al., 2011; Machado-Pinheiro et al., 2010). We also investigated the effect of alcohol on the time-course of the Stroop matching task through SOA manipulation and changes introduced by practice. Alcohol should interfere with the dynamics of top-down control, and practice should, at least partially, reverse this effect.

Methods

Participants and apparatus

Data were collected from 16 right-handed participants (age, 20.8 years, $SD = 1.58$ years; $n = 8$ males). The subjects were undergraduate students in biomedical/biological sciences. To test the effect

of practice, the subjects performed two sessions on different days, with an interval of no more than 3 days between sessions. Alcohol was administered to half of the volunteers in the first session (Group 1) and to the other half in the second session (Group 2). Men and women were equally distributed among groups.

All subjects were previously screened on the basis of their alcohol consumption and medical history. The inclusion criteria were the following: (i) 20/25 Snellen best-corrected visual acuity or better, (ii) absence of known ophthalmological pathologies (including daltonism), (iii) absence of any medical condition that might counterindicate alcohol use, (iv) absence of any history of abuse of alcohol or other drugs, (v) not pregnant or breastfeeding. Only moderate social drinkers were tested (Cahalan & Cisin, 1968). All procedures were approved by the local ethics committee, and the subjects signed an informed consent form before the experiment.

Participants sat in front of a 14-inch video monitor (0.2 cd/m² background luminance), approximately 0.57 m from the display. A PC-Pentium computer that ran MEL2 (Psychology Software Tools, Pittsburgh, PA, USA) presented the stimuli and recorded key presses.

Procedure

Each trial began with an empty circle used as a fixation point simultaneously presented with a warning signal ("beep," 2000 Hz, 67 dB, 50 ms duration). After 700 ± 100 ms, a first stimulus (S1) was presented 1.5° above the fixation point. S1 was a color-word (YELLOW, RED, or BLUE) written in yellow, red, or blue (the Stroop stimulus). Each letter that composed the word measured $0.9^\circ \times 0.9^\circ$ of the visual angle. S1 could be (i) congruent when the word and color in which it was written were compatible (e.g., YELLOW in yellow) or (ii) incongruent when the two attributes were incompatible (e.g., YELLOW in red). After variable SOAs of 200, 500, or 800 ms or simultaneous presentation (SOA-0), a second stimulus (S2) was presented 1.5° below the fixation point (i.e., the word YELLOW, RED, or BLUE written in white). S1 and S2 remained on the screen until the manual response occurred. Participants were asked to compare the color of S1 to the word of S2 and press a key with the index finger of their dominant hand if they were the same as soon as S2 was detected. If S1 and S2 did not match, no response was required (Go/No-Go task; for details, see David et al., 2011). Go-trials occurred in 70% of the trials, and No-Go trials occurred in 30% of the trials.

Participants performed two experimental sessions (alcohol and no-alcohol) composed of four blocks of 72 trials. Each block had the same number of congruent and incongruent trials and SOAs in a randomized order. Group 1 performed the alcohol session on the first day and the no-alcohol session on the second day. The order was reversed for Group 2, so the no-alcohol

session performed on the first day worked as a “practice session.” We opted not to use a placebo group because of the controversial discussion related to its use (e.g., Curtin & Fairchild, 2003).

Anticipation (reaction time < 100 ms), omission errors (no response on Go trials or RT > 1500 ms), and commission errors (responses on No-Go trial) were analyzed separately. A feedback screen with errors and reaction times was presented for 800 ms. The next trial began after a 1000 ms intertrial interval.

Beverage manipulation

With the exception of the order of the sessions, all procedures were the same for the two groups. In the alcohol session, participants were required to abstain from alcohol (24 h) and eating (2 h) prior to the experiment. Each participant drank a mixture of vodka (Stolichnaya®) that contained 40% alcohol by volume and orange juice in a 1:1 ratio. Subjects consumed 0.40 g ethanol per kg of body weight within a period of 5 min and had to wait 25 min before beginning the experiment.

Blood alcohol concentration (BAC) was obtained indirectly by means of a breath alcohol analyzer (Alco-Sensor III, Intoximeters, St. Louis, MO, USA) with a detection threshold of 5 mg/100 ml and accuracy in the range of 0–400 mg/100 ml. Blood alcohol concentration was assessed 25 min after drinking and during the three intervals between successive blocks. Four breath measures were considered for the analysis, which were collected immediately before each experimental block (i.e., the so-called times 1, 2, 3, and 4). Once the experiment was finished, the participants had to remain in the laboratory until their BAC decreased to less than 10 mg/100 ml. Because of technical difficulties, collecting breath samples from one male participant was not possible.

Data analysis

We conducted a repeated-measures analysis of variance (ANOVA) on the correct reaction time data, with Beverage (alcohol and no-alcohol), Congruency (congruent and incongruent), and SOA (0, 200, 500, and 800 ms) as the within-subjects factors and Group (1 and 2) as the between-subjects factor. Two separate error rate analyses were performed for Go and No-Go trials using a Kruskal-Wallis ANOVA by ranks, with Beverage (alcohol and no-alcohol) as the within-subjects factor and Group (1 and 2) as the between-subjects factor. Blood alcohol concentration values in the alcohol sessions were analyzed using one-way ANOVA, with Time (1, 2, 3, and 4) as the within-subjects factor. When appropriate, the Newman-Keuls *post hoc* test was also performed, and planned comparisons were used to analyze differences between the incongruent and congruent conditions (i.e., the Stroop effect). The level accepted for statistical significance was $\alpha = .05$.

Results and discussion

Reaction time

The ANOVA revealed a main effect of Congruency ($F_{1,14} = 136.62$; $p < .001$) and SOA ($F_{3,42} = 333.41$; $p < .001$) but not Group ($F_{1,14} = 4.25$; $p > .05$) or Beverage ($F_{1,14} = 0.21$, $p > .05$). Significant interactions were found between Group and Beverage ($F_{1,14} = 36.93$; $p < .001$) and between Beverage and SOA ($F_{3,42} = 5.19$; $p < .01$). Significant interactions were also found between Beverage, Congruency, and Group ($F_{1,14} = 18.39$; $p < .001$) and between Beverage, SOA, and Group ($F_{3,42} = 21.33$; $p < .001$). Finally, the interaction between all factors (Beverage, Congruency, SOA, and Group) was also significant ($F_{3,42} = 7.62$; $p < .001$).

As expected, reaction times were shorter for congruent than for incongruent trials (421 ms vs. 495 ms, respectively). The SOA factor showed that reaction times decreased as SOAs increased (639, 480, 372, and 340 ms, respectively). The interaction between Group and Session revealed no significant difference between reaction times for Group 1 (457 ms) and Group 2 (462 ms) when subjects were sober ($p > .05$). The reaction time in Group 1 (500 ms) was slower than in Group 2 (412 ms) when subjects were intoxicated ($p < .001$). Therefore, reaction times in untrained inebriated subjects were slower than in trained inebriated subjects, but reaction times in trained and untrained subjects did not differ when alcohol was not administered.

The results of the major interaction are shown in Figure 1 and reflect Stroop effect interference (Delta = Incongruent [I] minus Congruent [C]). Figure 1a shows the results of session 1 (without previous practice) for both groups. In Group 1 (intoxicated), the Stroop effect was significant at SOA 0 (I = 782 ms, C = 604 ms, Delta = 178 ms; $p < .001$), SOA 200 (I = 611 ms, C = 465 ms, Delta = 146 ms; $p < .001$), and SOA 500 (I = 437 ms, C = 387 ms, Delta = 50 ms; $p < .01$) but not at the longest SOA of 800 ms (I = 352 ms, C = 364 ms, Delta = -12 ms, $p > .05$). In Group 2 (sober), the Stroop effect was significant at SOA 0 (I = 746 ms, C = 561 ms, Delta = 185 ms; $p < .001$) and SOA 200 (I = 562, C = 411, Delta = 151 ms, $p < .01$) but not at SOA 500 (I = 376 ms, C = 365 ms, Delta = 11 ms; $p > .05$) or SOA 800 (I = 329 ms, C = 345, Delta = -16 ms; $p > .05$).

Figure 1b shows the results for session 2 (i.e., after the practice acquired in the first session). In Group 1 (sober), the Stroop effect differed significantly at SOA 0 (I = 726 ms, C = 565 ms, Delta = 161 ms; $p < .001$) and SOA 200 (I = 518, C = 429, Delta = 89 ms; $p < .001$) but not at SOA 500 (I = 380 ms, C = 355 ms, Delta = 25 ms, $p > .05$) or SOA 800 (I = 336 ms, C = 347 ms, Delta = -11 ms; $p > .05$). In Group 2 (intoxicated), a similar pattern was found. Interference was significant at SOA 0 (I = 631 ms, C = 496 ms, Delta = 135 ms; $p < .001$) and SOA 200 (I = 459 ms, C = 387 ms, Delta = 72 ms; $p < .01$).

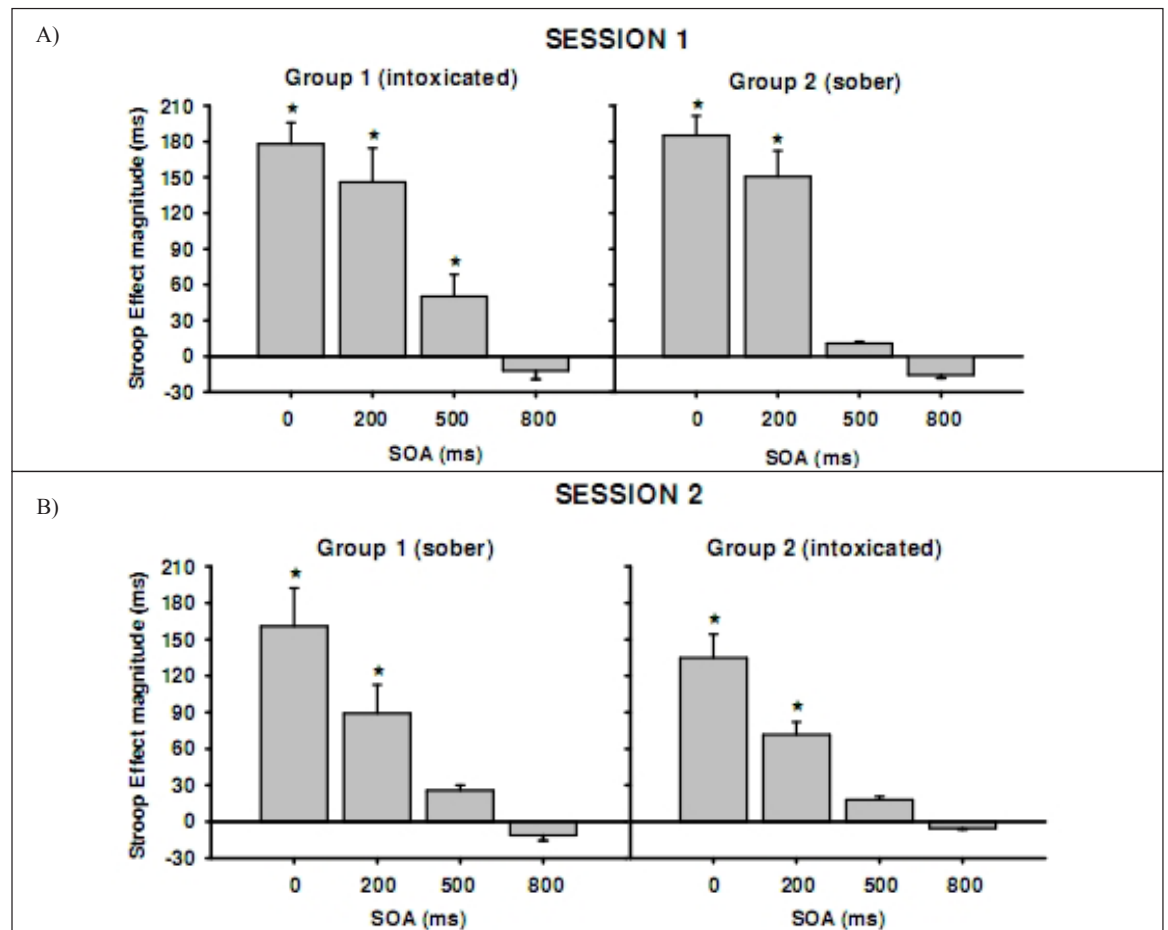


Figure 1. Stroop effect magnitude (in milliseconds) as a function of SOA (0, 200, 500, and 800 ms) for all sessions and groups tested. **(A)** Stroop effect magnitude for untrained intoxicated and sober volunteers in session 1. **(B)** Stroop effect magnitude for sober and intoxicated volunteers in session 2. The error bars indicate ± 1 standard error of the mean. Asterisks represent a significant Stroop effect. Notice that interference was significant at SOAs of 0 and 200 ms for all sessions and groups, but it was significant at an SOA of 500 ms only for untrained intoxicated subjects (upper left graph).

but not at SOA 500 ($I = 348$ ms, $C = 330$ ms, $\Delta = 18$ ms, $p > .05$) or SOA 800 ($I = 320$ ms, $C = 325$ ms, $\Delta = -5$ ms; $p > .05$).

Error rate and blood alcohol concentration

The error rate for the Go tests was 1.38% (95 errors in 6,912 trials). Most of the errors were omissions (93 trials [1.35%]). Anticipation occurred in only two trials, so it was excluded from the analysis. Kruskal-Wallis ANOVA revealed that untrained inebriated subjects (Group 1) committed more omission errors than trained inebriated subjects (Group 2; 2.20% vs. 0.58%, $H = 9.46$; $p < .01$). However, errors for the no-alcohol session did not differ between trained and untrained volunteers (1.04% for Group 1 and 1.56% for Group 2, $H = 1.29$; $p > .05$). The error rate for No-Go trials (commission errors) was 5.64% (130 errors in 2,304 trials). The Kruskal-Wallis ANOVA revealed no differences between Groups 1 and 2 in the alcohol ($H = 2.82$; $p > .05$) and no-alcohol ($H =$

3.11; $p > .05$) sessions for the No-Go trials.

No significant main effect was found for Time ($F_{3,42} = 1.71$; $p > .05$). ANOVA showed that BACs did not significantly vary among the four experimental blocks, with a mean value of 55 mg/100 ml ($SE = .6$; 57 mg/100 ml vs. 52 mg/100 ml for females and males, respectively, $p > .05$).

The time-course results of the Stroop matching task replicated previous findings from our group (David et al., 2011; Machado-Pinheiro et al., 2010). The matching feature decision appears to be driven initially by incoming information, but it is also gradually influenced by controlled attention when extra time is provided. The reaction time results showed that the Stroop effect was generally abolished at SOA 500. However, subjects exposed to the task for the first time and under the influence of alcohol required more than 500 ms to fully suppress Stroop interference. Functional brain imaging Stroop studies have consistently identified the dorsolateral

prefrontal cortex and anterior cingulate cortex as the main structures involved in controlled attention during this task (e.g., MacDonald et al., 2000). Inebriated individuals perform poorly on cognitively demanding tasks, possibly because of the effects of alcohol on this controlled attention network (Curtin & Fairchild, 2003). The extra time needed to solve the conflict, revealed by the Stroop effect found at SOA 500, may reflect a disruptive effect of alcohol on such cognitive processing.

Our results highlight the importance of practice in modulating the effects of acute alcohol intoxication on Stroop interference. As mentioned above, the effect of alcohol was only found for untrained subjects. Determining how practice affects the influence of alcohol by considering the overall reaction times is also possible. Groups 1 and 2 differed significantly when intoxicated (500 ms vs. 415 ms) but not when sober (457 ms vs. 462 ms). An improvement in performance was found in Group 1 on the second day of testing compared with the alcohol session performed previously. However, this improvement was only sufficient to reach the reaction times obtained on the first day of testing in Group 2 when they were untrained. When alcohol is consumed in the first session, its deleterious effect appears to continue to impact the results of the second day of testing. Subjects in Group 2 exhibited a clear benefit from the first session performed without alcohol consumption, reflected by their much quicker reaction times in the second session, despite being intoxicated. The results of the error analysis reinforce our reaction time data. Intoxicated untrained subjects committed more omission errors than intoxicated trained subjects. These data provide additional evidence of the importance of practice on the effect of alcohol. Together with other findings on similar topics (Harrison & Fillmore, 2005), our results indicate that prior practice should be considered when evaluating the effects of acute alcohol intoxication on behavioral responses. With practice, a task that is initially guided by cognitive effort can gradually become automatic [i.e., less dependent on controlled attention (Weissman et al., 2002)]. Our findings provide additional support for the hypothesis that alcohol mainly affects cognitively demanding tasks, and its effects can be minimized with practice.

Considering the BACs in our study and their relationship to the reversal effect of practice is also important. Holloway (1995) proposed that a BAC of 50 mg/100 ml may be the minimum threshold for producing deleterious effects on psychomotor and reaction time tasks. Volunteers may have more difficulty overcoming the effects of alcohol by means of training under higher BACs. This interesting hypothesis needs to be tested further. Moreover, the age of the participants included in our study may have contributed to the pattern of results. Our participants were young. Other

studies (Pardo et al., 2007) showed that controlled attention declines during the normal aging process. Whether our results would be different with older participants needs to be tested in future studies.

In summary, we demonstrated that the Stroop matching task time-course is affected by acute ingestion of a low dose of alcohol (BAC = 55 mg/100 ml). This suggests that low-dose alcohol intoxication can maintain the salience of irrelevant features for a prolonged period of time, preventing attentional resources from gating irrelevant features during long SOAs, such as 500 ms. However, this impairment can be overcome when subjects perform a practice session prior to the alcohol session. Thus, the level of practice appears to be an important factor in modulating the effects of alcohol on behavioral responses, at least at low doses.

Acknowledgments

This research was supported by CNPQ, CAPES, and PROPP-UFF.

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