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The importance of individual characteristics on bicycle performance during alcohol intoxication

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Abstract: Bicycling accidents are a well-known problem for traffic safety globally. Alcohol intoxication is one possible factor, although the exact number of accidents due to intoxication is difficult to establish. Not all bicyclists act in the same way, particularly when under the influence of alcohol, i.e. bicycling performance might be related to a bicyclist's personal characteristics. This study aimed to investigate if the bicyclist's characteristics (bicycling experience, physical fitness, or sensation seeking scores) influence bicycling stability, cognitive performance, or self-rated bicycling ability ratings at different levels of alcohol intoxication. The experiment was completed on a wide treadmill, which allowed control of several influencing factors such as speed and physical effort. Intoxicated and sober participants bicycled on the treadmill five times for 10 minutes each time, and breath alcohol concentration (BrAC) levels were measured five times. Participants were given doses of alcohol up to a BrAC level of 0.8‰. The results revealed that alcohol intoxication had a significant effect on stability, cognitive executive functions, and self-rated ability to bicycle on the treadmill. Group characteristics had an effect on bicycling performance and on self-ratings of bicycling ability when intoxicated. Alcohol intoxication affects stability, cognitive performance, and perceived ability to bicycle. Group characteristics are important for examining possible self-regulated behavior, as some groups rate that they can bicycle safely, even when there is an objective decrease in stability and executive functions.

Keywords: alcohol intoxication, bicycling stability, cognitive performance, group characteristics, self-rated bicycling abilities

1 Introduction

1.1 Bicycle accidents and alcohol intoxication

In daily traffic, a bicyclist is more vulnerable and injured more often than a driver in a motor-driven vehicle in Sweden (Rizzi et al., 2020). Bicycling while intoxicated with alcohol is associated with an increased risk of sustaining severe or even fatal injuries; the risk increases with increases in blood alcohol concentration (BAC) level and is 20% higher with an alcohol level of 0.8 g/l and higher (Li et al., 2001). In general, there is greater risk of being involved in an accident when intoxicated with alcohol (Asbridge et al., 2014; Martínez-Ruiz et al., 2013).

In Europe, between the years 2010 and 2018, there were around 19 450 bicycle fatalities (Adminaité-Fodor & Jost, 2020), and every year in Sweden approximately 23 000 people seek care at an emergency hospital due to a bicycle-related incident (Schyllander & Ekman, 2013). The lack of reliable data makes it hard to establish how many of these fatalities and incidents involved alcohol. An increase of alcohol-related accidents is also related to the time of day (de Waard et al., 2016), and to gender, as males compared to females, are more likely to be injured when intoxicated (Airaksinen et al., 2018).

Drinking alcohol impairs bicycling (Kovacsova et al., 2016; van Lunteren et al., 1970; Hartung et al., 2015a,b). Although it is difficult to determine the exact impact that alcohol intoxication has on accidents, and the frequency of such events, it seems reasonable to assume that bicycling performance worsens with alcohol consumption (Andersson et al., 2023).

In Sweden, there is no alcohol limit for riding a bicycle, and this includes the increasingly popular power-driven bicycles. However, by law reckless behavior in traffic is forbidden. In this paper, we demonstrate the relation between intoxication by alcohol and bicycling performance. According to social norms, it is also acceptable in Sweden to bicycle home after a party or a night out with friends when intoxicated with alcohol (Wallén Warner et al., 2017). Furthermore, while bicycling is a legal way of transportation when intoxicated, private cars are not an option (the blood alcohol level limit for motor vehicle drivers is 0.2‰ in Sweden).

1.2 Stability, cognitive performance, and self-rated bicycling ability

One aspect to consider when investigating bicycling performance during alcohol intoxication is how the bicycle is handled by the bicyclist, i.e. the stability of the individual when bicycling. The literature on bicycling stability (balance) reveals that speed is important (Cain et al., 2016). At lower speeds, novice and skilled bicyclists show similar balance performances, but at higher speeds, skilled bicyclists use more lean control and less steer control. Hartung et al. (2015b) studied bicycling performance and found severe coordinative faults when participants bicycled under the influence of alcohol. In addition, they found differences between men and women in terms of the BAC level at which severe faults occurred.

The literature also suggests that there is an interesting and complex interplay between alcohol intoxication and cognitive performance (Cash et al., 2015; Greenstein et al., 2010; Mintzer, 2007; Park et al., 2011; Ralevski et al., 2012; Weiss & Marksteiner, 2007). Overall, the results suggest that cognitive functions are usually negatively affected by alcohol intoxication, but not always (Hoffman et al., 2015; Spinola et al., 2017). Self-ratings of ability enhance our understanding of the more self-regulated aspects of bicycling while intoxicated. Bicycling ability is negatively affected by alcohol intoxication (Hartung et al., 2015a) and by alcohol-induced hangover (Hartung et al., 2015b) . It is clear that alcohol intoxication is associated with more severe injuries, increased hospital resources and a higher mortality rate (Sethi et al., 2016). Individuals also take riskier decisions when intoxicated (George et al., 2005).

1.3 Group characteristics

In order to further explore how alcohol intoxication affects bicycling performance, several factors need to be examined. It is difficult to predict which and how different individual characteristics affect stability when intoxicated with alcohol as there is no existing research on the topic. Based on the understanding of the effects of i) familiarity on performance, ii) skill on the task, and iii) traits that are strongly related to how people perform on tasks in general, three relevant characteristics of bicycling during alcohol intoxication were chosen for the present study, i.e. bicycling experience, physical fitness and, sensation seeking personality. It is not evident from the literature whether these three characteristics play an active part in bicycling performance during alcohol intoxication.

1.3.1 Bicycling experience

Previous research on bicycling and cognition focuses mostly on different distractions, such as talking or texting on mobile phones (Westerhuis & de Waard, 2017), or auditory stimuli (i.e. listening to music with headphones; (Ahlstrom et al., 2016)). However, few studies have compared the skilled or novice bicyclist, or investigated stability when bicycling. One study showed that both skilled and novice bicyclists performed similarly in balancing tasks when bicycling at a low speed, but at higher speeds the skilled bicyclist efficiently used their body to increase their stability (Cain et al., 2016). The literature also indicates that factors associated with subjective discomfort, such as handlebar height and style, can cause the bicycle to be more unstable (Chen & Liu, 2014).

1.3.2 Physical fitness

It is not known what role physical fitness plays in the familiarity of bicycling during alcohol intoxication. Bicycling is an active transportation mode that needs a physical input from the individual, especially when intoxicated with alcohol. The literature on how physical fitness affects executive functions varies, and there are many variables to consider, i.e. intensity, type of exercise, and when the test is conducted (Chang et al., 2012). The relationship between physical fitness and bicycling stability during alcohol intoxication is unclear.

1.3.3 Sensation seeking

Sensation seeking is a personality trait influenced by both environmental and biological factors (Hittner & Swickert, 2006). Individuals with a high level of sensation seeking tend to be drawn to activities with a higher level of arousal, i.e. gambling, a non-conventional lifestyle or dangerous sports that involve more risk-taking behavior (Michel et al., 1998). Some research also shows that humans will base their perception on safety and adapt their risk-taking behavior accordingly (Gamble & Walker, 2016). For example, wearing a bicycle helmet is associated with both negative (Esmaeilikia et al., 2019; Radun et al., 2018) and positive (Billot-Grasset et al., 2016; Gamble & Walker, 2016) risk compensation. The literature has shown that high sensation seekers consume alcohol in higher quantity and more frequently, and it is also well known that alcohol influences regulation of self-control (Hittner & Swickert, 2006). Individuals that score high for risk-taking might more often bicycle when intoxicated than individuals that score low on risk-taking.

1.4 Aim

The present study aimed to investigate if individual characteristics of bicycling experience, physical fitness, or sensation seeking scores, have an effect on bicycling stability, cognitive performance, or self-rated bicycling ability at different levels of alcohol intoxication. The exploratory approach was mainly driven by the aim to increase our understanding of how individual characteristics are related to bicycling during alcohol intoxication. This study is a follow up on the work by Andersson et al. (2023), where personal characteristics were not analyzed in the experiment. Hence, the experiment and therefore the method section is the same for the two articles, but data from the same experiment was analyzed with another perspective, i.e. with the focus on group characteristics.

2 Material and methods

2.1 Participants

A total of 29 people participated in the study. These individuals had completed the health declaration and did not show any signs of harmful alcohol use or dependence symptoms as measured by the Swedish version of the World Health Organization's AUDIT (Socialstyrelsen, 2022). Of these 29 participants, 18 were given alcohol during the experiment (intoxicated group), while 11 randomized participants completed the bicycling test sober (sober group).

2.2 Recruitment and screening

The participants were recruited via a Facebook advertisement and personal contacts. The potential participants were directed to a dedicated VTI (Swedish National Road and Transport Research Institute) webpage, where the required criteria for participation (age gender, health, etc.) were checked as the first step of inclusion in the study. All the requirement criteria, which were approved by the ethics committee, were met by those who participated in the study.

The participant screening criteria included: a minimum age of 20 years old, no history of alcohol or substance addiction, good health for bicycling, and moderate alcohol consumption. The participant criteria also included living within the town of Falun (and Borlänge) (to limit costs of taxis, used to drive participants home after the experiment had ended), the sober participants did not have to live within the town of Falun. Only non-pregnant women could participate in the experiment (to avoid possible fetal damage associated with alcohol consumption) and women were offered a pregnancy test if required. Other requirements included previous experience of both bicycling and drinking alcohol.

The selection of participants included several steps, starting with the initial screening mentioned above. The screening procedure was repeated when each participant arrived at the test facility. The AUDIT scale was also completed and checked prior to testing. The participants in the intoxicated group needed to be able to stay onsite for approximately 4 hours, so that their post-experiment safety and sobriety could be monitored. The sober group were free to leave as soon as all post-test evaluations were completed.

The participants were reimbursed for their participation with approximately €150 for participation in the intoxicated group and €75 for participation in the sober group. All participants were also offered a cost-free taxi ride home.

2.3 Design

This experiment utilized a between-participant design (intoxicated versus sober participants) to investigate the effects of alcohol intoxication on participants' bicycling performance. The characteristics of interest were: (*i*) bicycling experience, (*ii*) physical fitness and (*iii*) sensation seeking.

The independent variable was the repeated measurement variable of time, i.e. the breath alcohol concentration (BrAC) level was measured five times by the Dräger Alcotest® 6810 and 6820 devices for alcohol screening (see section 2.5 for details). The dependent variables were stability (yaw and roll rate), cognitive performance (n-back score) and self-rated bicycling ability. Speed and physical exertion might affect the results as well; the experimental set-up controlled for these aspects by keeping the speed and physical exertion constant over sessions.

The experiment consisted of a 25-minute loop that was repeated five times, whereby the participants bicycled on the treadmill in 10-minute stints, with a 15-minute non-bicycling period. Only 8 minutes of the 10 minutes of stability measures data were analyzed. The starting phase and the ending phase were controlled by the experiment leader; the experiment leader stabilized the participant by holding the gantry until the target speed was reached. The same procedure was used before the treadmill was stopped. The 8-minute period was free from any form of stability support. The 15-minute non-bicycling period comprised: (*1*) a BrAC assessment (four times, two times with both instruments); (*2*) an n-back test; (*3*) a subjective bicycling ability rating; and (*4*) time for refreshments and alcoholic beverages, if necessary, as well as a rest period.

Participants initially underwent a familiarization period of bicycling on the treadmill. Participants then performed in one experimental condition, when they all were sober. This was followed by four repetitions of the intoxication experimental condition, for those in the intoxicated group. The level of intoxication was increased throughout the experiment, up to a level of 0.8‰ BrAC. The BrAC level was chosen for pragmatical reasons.

2.3.1 Group characteristics

Participants' demographic data were collected using the pre- and post-test surveys (Table 1). After completion of the experiment and based on participants' answers, all characteristics were divided into subgroups of three (high, low, or sober/control); the specifics are shown in Table 2. The intoxicated participants were divided in high and low to optimize the difference and use the data from all participants. Participants in the sober group was always sober during the experiment. The sober group is included to emphasize the results and to illustrate the difference between an intoxicated and a sober state in the three different characteristics. Cycling experience was measured by answering one multiple-choice question namely: how many times in the last couple of months had they had been bicycling in snow-free ground. The bicycling experience responses were divided into two groups: the high experience group bicycled four times a week or more, and the low experience group bicycled two to three times a week, or one to four times a month. Physical fitness was measured by a multiple-choice question that asked how often participants performed a physical activity. The high activity group performed a physical activity four times a week or more, and the low activity group performed a physical activity two to three times a week, or one to four times a month. Sensation seeking responses were divided into two groups based on their total score on the sensation seeking questionnaire (see section 2.4.3 for details). The high sensation seeking group had scores of 23 or more and the low sensation seeking group had scores of 21 or less.

The sober group always consisted of the same eleven participants, and their values on bicycling experience, sensation seeking, and physical fitness were represented in all the three different characteristics subgroups, i.e. if they had been given alcohol, they would have been included in both the high and low groups on the characteristics studied. The distribution of participants is presented in Table 2. As can be seen, the sober group's values for the characteristics studied were often between the high and low groups' values. The sober group was less bicycling experienced.

Table 1 Participants' gender, age and weight

Parameter	Intoxicated group	Sober group
Total participants (n)	18	11
Females (n)	9	6
Age range (average; years)	25–32 (28)	22–32 (26)
Weight (average; kg)	79	77.3

The first column shows data for the intoxicated group, who were given increasing amounts of alcohol while bicycling; the second column shows data for the sober group, who bicycled sober.

Table 2 Descriptive statistics for the group characteristics

Group mean	Cycling experience*	Physical fitness**	Sensation seeking***
High group	5 (6)	5 (8)	25.5 (8)
Low group	3.43 (12)	3.5 (10)	18.3 (10)
Sober group	2.45 (11)	3.8 (11)	19.2 (11)

* number of times participants bicycle per week;
** number of physical activities participated in per week;
*** SSS score.
There was a total of 29 participants; 18 in the experimental (intoxicated) groups and 11 in the sober group. The values in parentheses represent the number of participants in the intoxicated groups that have a specific characteristic.

2.4 Procedure

2.4.1 Pre-test procedure and assessment

The pre-test questionnaire included questions about the participants' age and gender, as well as their *bicycling experience* and, *physical fitness*. The Alcohol consumption habit was measured with the World Health Organization's Alcohol Use Disorders Identification Test (AUDIT) which is a 10-item self-report measure used for the screening of risky drinking habits in the adult population, and it is used in both clinical and community settings (Babor et al., 2001; Lyvers & Tobias-Webb, 2010).

The dose calculation performed to reach the target of 0.8‰ BrAC was based on the participant's gender and weight (the mean quantity of 40% spirits administered was 197 ml; standard deviation SD = 55.2 ml; range = 140–340 ml). This calculation aimed to estimate the quantity of spirits needed for each participant in the intoxicated group. These participants also stated their drink preferences; they could choose between whisky, white rum, vodka, or gin. The spirits could be mixed with soft drinks to make them more palatable. Participants were given the opportunity to change into training clothes (optional) and to use the toilet before starting the bicycling.

2.4.2 Peri-test procedure and assessment

The participants were given a safety briefing. The bicycle was adjusted to the height of each individual, and the safety harness and helmet were donned. The participants started a 10-minute familiarization bicycle ride on the treadmill. The speed of the treadmill was kept at 20 km/h for all participants; however, the gradient was adjusted between 0.2 and 2.0 degrees (mean = 0.9 degrees; SD = 0.47) to maintain a uniform level of physical workload, irrespective of fitness. After the bicycling session, the participants: completed the 20-item Borg Scale of Perceived Exertion, performed a breathalyzer test (both groups), estimated their subjective level of intoxication, rated their bicycling ability, and completed the cognitive (n-back) test to measure their cognitive performance.

The first dose of the calculated volume of spirits required (approximately 75% of the estimated dose) was given to the participants in the intoxicated group, to drink. The BrAC levels were closely monitored, to avoid exceeding the target level of 0.8‰ BrAC.

The *actual level of intoxication* was determined via measurement of BrAC level. Specifically, the mean value of four separate measurements (two for each Dräger instrument) was calculated.

Stability was estimated as the variability in the of yaw rate and roll rate measurements as the reversal rate (RR) of yaw rate and roll rate, respectively. All stability measures were calculated from the mid 8-minute segment of the 10-minute bicycling sessions on the treadmill. The first and last minutes were removed to exclude data where the experiment leader gave stability support.

The yaw and roll RR metrics were inspired by the steering wheel reversal rate (SWRR) that has been used in car driving as an indicator of distraction (Wang et al., 2019), visual deficits (Bronstad et al., 2016) and drowsiness (Xu et al., 2016). SWRR has also been shown to be affected by alcohol intoxication in curve taking (Li et al., 2019), where increased intoxication led to increased instability. SWRR is defined as the number of steering wheel reversals larger than a certain 'gap size' (Macdonald & Hoffman, 1980). How large this gap size should be when applied to yaw and roll rate reversals is not known. A 25 degrees/second were evaluated in this study based on the findings in Andersson et al. (2023).

The 20-item Borg Scale of Perceived Exertion rating was used to attain a standardized measurement of physical effort for all participants. When effort was rated high (a rating of 13 or higher), the gradient of the treadmill was adjusted accordingly, i.e. the required effort was reduced. Effort was never rated too low.

The *cognitive performance* was measured using an n-back test. In this test, over approximately 1 minute, 28 letters were presented one by one in a random order, in 2.0-second intervals, on a laptop screen (Gevins & Cutillo, 1993). The participants' task was to respond 'Yes' if the letter presented on the screen had also been presented two letters previously. For the first two letters, the participants did not have to answer anything as there were no two previous letters to compare with. Letters and Yes/No items were randomized and orthogonally balanced. However, when a letter was presented, the participant could answer Yes and be correct, or No and be correct as well. When letter A was presented and the target was A, it was a hit if the participant answered Yes. When A was presented and the target was B, it was a correct rejection if the participant answered No. When A was presented and the target was A, it was a miss if the participant responded No. Finally, when A was presented and the target was B, it was a false alarm if the participant responded Yes. Hence, four possible measures can theoretically be obtained, allowing sensitivity measurements such as d prime. The test in this study had 8 possible hits and 18 correct rejections.

The *self-rated bicycling ability* was measured with four questions: 'Would you be able to move 50 cm to the left with the bike and back again if you wanted to?', 'Would you be able to stand up and bicycle if you wanted to?', 'Would you be able to bicycle with only one hand on the handlebars if you wanted to?' and 'Would you be able to bicycle slalom if you wanted to?' The possible responses were: 1 = with no problems, 2 = with small problems, 3 = maybe, 4 = with big problems and 5 = absolutely not. This were to determine how well they were able to handle the bicycle during alcohol consumption. The questions were developed during pilot testing. Cronbach's alpha varied between 0.92 and 0.85 for the four ratings at each assessment time. The 'ability questions' that the participants were asked is similar to the questions asked in the study by Feenstra et al. (2010).

2.4.3 Post-test procedure and assessment

When the participants had completed a total of five bicycling sessions on the treadmill, they completed the post-test questionnaire. To measure *sensation seeking* the questionnaire included the Swedish version of Zuckerman's Sensation Seeking Scale (SSS-V) (Zuckerman et al., 1978) was completed, the questionnaire consists of 40-item forced-choice questions. The participants remained in the research laboratory facility until they became sober (several hours later) and were then offered a taxi home. The 'sober' level was negotiated to some extent; not all participants' BrAC levels were below 0.2‰ when they left the laboratory.

2.5 Materials

The experiment was carried out in the sports laboratory at Lugnets Idrottsvetenskapligt Institut (LIVI), in co-operation with Dala Sports Academy, in Falun, during July and October/November 2019 and an addition of control participants in May 2022. The participants bicycled on a motor-driven treadmill (Saturn 450/300 RS; H/P/Cosmos Sports & Medical, Nussdorf, Germany), which had a surface area of 13.5 m^2 and could be tilted to increase physical workload (if necessary). The treadmill's general specifications comprised a running surface of 450 × 300 cm, a speed range of 0–40 km/h, an elevation of -5% to +25% (-2.8 to 14.0 degrees), a 30-kW motor system (40.8 HP), and a reinforced thick rubber running belt that is also suitable for use with ski rollers, ski poles, spike shoes, and bicycles.

The participants bicycled on a mid-range mountain bike (Biltema Yosemite X-dirt bicycle), with relatively large wheel dimensions for stability (27.5 × 2.8-inch wheels). The brakes were disconnected on the test bicycle, ready for use on the treadmill. The bicycle was equipped with a V-Box data acquisition system (Racelogic 3i) and gyro sensor (Racelogic IMU02). The participants wore a pulse sensor (to monitor their physical effort), which was connected to the treadmill system. The participants also wore a safety harness, which was attached to the gantry above the treadmill (Figure 1). The harness attachment point was connected to a kill-switch, to enhance safety. All

Figure 1 Photographs showing how the accelerometer was installed, and the treadmill with several security functions (gantry, stop buttons, and the presence of the experiment leader, who always stood next to the participant).

participants wore a bicycle helmet.

The breathalyzer equipment employed in this study comprised two instruments: a Dräger 6810 (older model) and a Dräger 6820 (newer model). Both models comply with the standards required by the Swedish police (EU Police approval code: EN15964) and had valid calibration approval. The literature reveals that the Dräger 6810 is reliable, and no significant differences exist between BrAC and BAC if the instruments are used according to the manufacturer's instructions (Jurič et al., 2018).

3 Results

All intoxicated participants were divided into high or low groups based on their answers to each scale of the three group characteristics studied. All mean values and standard deviations for all conditions is presented inTable 3. The participants were relatively well distributed between high and low groups depending on the characteristic studied. The division is rather arbitrary and should therefore be interpreted with caution. The 11 participants in the control (sober) group included participants with high and low values on each of the characteristics studied i.e. the sober group had individuals with both high and low values. If they had received alcohol, sober participants would have been included in both the high and low groups for all characteristics studied. The distribution of the 18 alcohol-intoxicated participants in their subgroups did not correlate with each other, except for the SSS and physical fitness scores ($p < 0.05$), i.e. it was not the same participants that was represented in different group characteristic (see 2.3.1 andTable 2 for details).

The three characteristics studied will be analyzed by 4 Mixed ANOVAs each, one for each dependent measure presented (roll rate, yaw rate, n-back results, and self-rating abilities ratings), all in all 12 mixed ANOVAs (Table 4). For all ANOVAs computed, the statistical design was a 3 (group; high or low on the characteristic studied, and sober group) by 5 (times the specific dependent measurement was assessed) mixed ANOVA. The group factor was a between-participants variable, and the time factor was a within-participant variable. The number of participants in each group (high or low) varied for different group characteristics. Bonferroni correction was used for multiple pair wise comparisons on all ANOVAs.

Correlation analyses were performed for only the intoxicated group participants. To further understand the relations between different characteristics (bicycling experience, physical fitness, sensation seeking) and bicycling stability, cognitive performance, and self-rated bicycling ability the participants' characteristic values were correlated with participants' results for each of the dependent measurements at time 1 (when they were sober) and time 5 (when they were intoxicated). Four correlations at time 1 and four correlations at time 5, for each group characteristic.

3.1 Bicycling experience

The 3 (groups) by 5 (assessment times) mixed ANOVA on stability for roll (HBRR at 25 degrees) revealed a main effect and an interaction effect (Table 4). Pairwise comparisons showed that the sober group became more stable over time, and that both high and low bicycling experience groups became less stable (Table 3). There was no significant difference between low and high bicycling experience groups at any time. The 3 (groups) by 5 (assessment times) mixed ANOVA on stability for yaw (HBRR at 25 degrees) revealed a main effect of time and an interaction effect (Table 4). Pairwise comparisons showed that the sober group became more stable over time, and that both high and low bicycling experience groups became less stable (Figure 2). The 3 (groups) by 5 (assessment times) mixed ANOVA on the cognitive performance task revealed only a tendency of a main effect of time, indicating that cognitive performance improved overall, over time (Table 3). No differences between groups with high or low on bicycling experience. The 3 (groups) by 5 (assessment times) mixed ANOVA on self-rated bicycling abilities revealed a significant interaction effect. Pairwise comparisons showed that the sober participants' ratings of bicycling ability increased over time, and especially the group with low experience of bicycling ratings decreased over time (Table 4).

The correlation analyses (which included only intoxicated participants/groups at Time 1 and Time 5) revealed that bicycling experience scores did not correlate with any of the dependent measures (stability (roll and yaw), cognitive performance, or self-rated bicycling ability) at time 1 (when sober) or time 5 (when intoxicated).

Taken together (bicycling experience): results show that the stability of the sober group increased over time, and the stability decreased in both the high and low group on the measures of roll rate and yaw rate. The results showed that cognitive performance was relatively unaffected. The participants in the sober group self-rated bicycle ability ratings increased over time meanwhile the self-rated bicycle ability ratings decreased mainly in the low bicycling experience groups.

3.2 Physical fitness

The analysis on the 3 (group) by 5 (assessment times) mixed ANOVA) on physical fitness and stability for roll (HBRR at 25 degrees) revealed an interaction effect (Table 4). Pairwise comparisons showed that the sober group became more stable over time, and that both high and low physical fitness groups became less stable (Table 3). Especially the group with low ratings on self-rated physical fitness became less stable over time from time 2 and onwards. The 3 (groups) by 5 (assessment times) mixed ANOVA on stability for yaw (HBRR at 25 degrees) revealed a main effect of time and an interaction effect. Pairwise comparisons showed that the sober group became more stable over time, and that both high and low physical experience groups became less stable. There was no significant difference between low and high physical fitness groups. The 3 (groups) by 5 (assessment times) mixed ANOVA on the cognitive performance task revealed a main effect of time, indicating that cognitive performance improved over time (Figure 3). The 3 (groups) by 5 (assessment times) mixed ANOVA on self-rated bicycling abilities revealed a significant main effect of group and an interaction effect. Pairwise comparisons revealed that the more physically fit participants' self-ratings of bicycling abilities were higher at all assessment times compared to the less physically fit participants, and even higher compared to the sober group at time 1 but not after that.

The correlation analyses (which included only intoxicated participants/groups at Time 1 and Time 5) revealed that physical fitness correlated with self-rated bicycling ability only at time 5, i.e. the participants who had high values on physical fitness rated themselves as having higher bicycling ability when intoxicated at time 5 ($r = 0.61$; $p < 0.01$), but not at time 1 (when sober).

Taken together (physical fitness): results show that the stability of the sober group increased, and the stability decreased in both the high and low physical fitness groups on the measure of roll and yaw (HHRR at 25 degrees). The results showed that the cognitive performance improved over time. The results from self-rated bicycle ability ratings showed a main effect of group and especially the low group on physical fitness rated a decreased ability. Finally, the physically fit participants rated their ability higher compared to the less physically fit participants but only when alcohol intoxicated (at time 5).

3.3 Sensation seeking scores

The analysis on stability for roll (HBRR at 25 degrees) revealed a main effect of time and an interaction effect i.e. an increase of stability for the sober group and a decrease in stability for especially the group with low on sensation seeking scores. The 3 (groups) by 5 (assessment times) mixed ANOVA on stability for

Table 3 Mean values, at all five assessment times, for stability (roll and yaw at 25 degrees), cognitive performance and self-rated bicycling ability, for the characteristics studied

		Stability		Cognitive performance	Self-rated bicycling ability
	Time point	Roll 25 (SD)	Yaw 25 (SD)	N-back (SD) d-prime	Ability assessment[1] (SD)
Bicycling experience					
High bicycling experience	1	152.8 (51,5)	558.0 (84.6)	2.9 (0.6)	7.3 (1.5)
	2	158.8 (33.6)	612.5 (73.8)	4.1 (0.6)	7.0 (1.3)
	3	199.0 (39.2)	692.2 (77.8)	3.8 (0.7)	8.2 (1.6)
	4	276.8 (46.1)	777.8 (88.6)	3.0 (0.7)	8.7 (1.6)
	5	252.3 (39.1)	751.8 (83.4)	3.3 (0.6)	7.8 (1.4)
Low bicycling experience	1	184.7 (36.4)	569.6 (59.8)	2.7 (0.4)	6.3 (1.1)
	2	102.9 (23.7)	471.9 (52.2)	3.1 (0.4)	6.7 (0.9)
	3	138.4 (27.7)	548.8 (55.0)	3.3 (0.5)	8.4 (1.1)
	4	176.1 (32.6)	582.3 (62.7)	3.1 (0.5)	9.1 (1.1)
	5	165.5 (27.6)	602.3 (59.0)	3.6 (0.4)	9.7 (1.0)
Sober group	1	273.3 (63.1)	874.5 (103.6)	2.2 (0.7)	10.3 (1.9)
	2	196.3 (41.1)	796.5 (90.4)	2.2 (0.8)	7.5 (1.6)
	3	186.5 (48.0)	832.0 (95.2)	4.2 (0.9)	6.8 (2.0)
	4	177.6 (56.4)	801.0 (108.5)	4.7 (0.8)	6.5 (2.0)
	5	135.6 (47.9)	756.8 (102.2)	4.8 (0.7)	5.8 (1.7)
Physical fitness					
High physical fitness	1	120.1 (41.7)	490.8 (69.5)	2.4 (0.5)	4.8 (1.2)
	2	128.4 (30.4)	558.9 (66.8)	4.0 (0.5)	4.8 (0.9)
	3	161.6 (35.4)	623.3 (70.8)	3.7 (0.6)	5.3 (1.0)
	4	220.6 (43.0)	672.4 (82.7)	2.9 (0.6)	5.6 (0.9)
	5	195.5 (36.7)	666.9 (76.1)	3.6 (0.5)	5.8 (0.7)
Low physical fitness	1	217.2 (37.3)	625.7 (62.2)	3.1 (0.4)	8.2 (1.1)
	2	116.1 (27.2)	486.6 (59.7)	2.9 (0.5)	8.4 (0.8)
	3	156.2 (31.6)	575.3 (63.3)	3.3 (0.6)	10.8 (0.9)
	4	200.9 (38.4)	627.6 (74.0)	3.1 (0.5)	11.6 (0.8)
	5	193.6 (32.8)	640.4 (68.0)	3.1 (0.5)	11.8 (0.7)
Sober group	1	273.3 (59.0)	874.5 (98.3)	2.2 (0.7)	10.3 (1.7)
	2	196.3 (43.0)	796.5 (94.4)	2.2 (0.7)	7.5 (1.3)
	3	186.5 (50.0)	832.0 (100.1)	4.2 (0.9)	6.8 (1.5)
	4	177.8 (60.8)	801.0 (116.9)	4.7 (0.8)	6.5 (1.3)
	5	135.3 (51.9)	756.8 (107.6)	4.8 (0.7)	5.8 (1.1)
Sensation seeking					
High sensation seeking	1	201.1 (44.1)	619.8 (71.3)	2.7 (0.5)	5.7 (1.3)
	2	157.3 (28.4)	626.5 (59.2)	3.6 (0.6)	5.6 (1.0)
	3	185.3 (34.4)	680.5 (66.4)	3.9 (0.6)	6.2 (1.2)
	4	226.3 (42.8)	708.3 (80.9)	3.4 (0.6)	6.9 (1.2)
	5	210.9 (36.3)	717.6 (73.5)	3.6 (0.5)	7.1 (1.6)
Low sensation seeking	1	152.4 (39.4)	522.5 (63.8)	2.9 (0.4)	7.4 (1.2)
	2	93.0 (25.4)	432.5 (53.0)	3.2 (0.5)	7.7 (0.9)
	3	137.3 (30.8)	529.5 (59.4)	3.0 (0.5)	10.0 (1.1)
	4	196.4 (38.3)	598.9 (72.4)	2.8 (0.5)	10.6 (1.1)
	5	181.3 (32.5)	599.8 (65.7)	3.4 (0.5)	10.7 (1.0)
Sober group	1	273.3 (62.4)	874.5 (100.9)	2.2 (0.7)	10.2 (1.8)
	2	196.3 (40.2)	796.5 (83.8)	2.2 (0.8)	7.5 (1.5)
	3	186.5 (48.7)	832.0 (93.9)	4.2 (0.9)	6.8 (1.8)
	4	177.8 (60.5)	801.0 (114.4)	4.7 (0.8)	6.5 (1.8)
	5	135.3 (51.4)	756.8 (103.9)	4.8 (0.7)	5.8 (1.6)

[1] Would you be able to … 1 = with no problems, 2 = with small problems, 3 = maybe, 4 = with big problems and 5 = absolutely not.

Table 4 Significant effects, tendency for effects and non-significant results for stability (roll and yaw at 25 degrees), cognitive performance and self-rated bicycling ability, for the characteristics studied

	Group	Time	Group × Time
Roll gap 25 degrees			
Bicycling experience	ns	F(4, 76) = 3.2, p < 0.05, MSe = 294	F(8, 76) = 3.62, p < 0.05, MSe = 294
Physical fitness	ns	ns	F(8, 76) = 2.75, p < 0.05, MSe = 315
Sensation seeking	ns	F(4, 76) = 2.65, p < 0.05, MSe = 310	F(8, 76) = 2.92, p < 0.05, MSe = 310
Yaw gap 25 degrees			
Bicycling experience	ns	F(4, 104) = 9.1, p < 0.001, MSe = 837	F(8, 104) = 5.02, p < 0.001, MSe = 837
Physical fitness	ns	F(4, 104) = 7.6, p < 0.001, MSe = 890	F(8, 104) = 3.95, p < 0.001, MSe = 890
Sensation seeking	ns	F(4, 104) = 7.1, p < 0.001, MSe = 891	F(8, 104) = 3.93, p < 0.001, MSe = 891
Cognitive performance			
Bicycling experience	ns	ns	ns
Physical fitness	ns	F(4, 104) = 2.76, p < 0.05, MSe = 1.92	ns
Sensation seeking	ns	F(4, 104) = 2.63, p < 0.05, MSe = 2.40	ns
Self-rated bicycling ability			
Bicycling experience	ns	ns	F(8,104) = 8.34, p < 0.001, MSe = 2.73
Physical fitness	F(2, 26) = 11.5, p < 0.01, MSe = 28.8	ns	F(8,104) = 9.16, p < 0.001, MSe = 2.63
Sensation seeking	F(2, 26) = 3.82, p < 0.05, MSe = 42.0	ns	F(8,104) = 8.22, p < 0.001, MSe = 2.75

ns = non-significant

yaw (HBRR at 25 degrees) revealed a main effect of time and an interaction effect. Pairwise comparisons revealed that the sober group became more stable over time compared to the low and high groups on sensation seeking that became more and more unstable. The decrease in stability for the intoxicated groups were larger than the increase in stability for the sober group. The 3 (groups) by 5 (assessment times) mixed ANOVA on the cognitive performance task revealed only a main effect of time, indicating that cognitive performance improved over time. Especially the sober group improved, and the intoxicated group's results were relatively unaffected. The 3 (groups) by 5 (assessment times) mixed ANOVA on self-rated bicycling abilities revealed a significant main effect of group and an interaction effect. Pairwise comparisons showed that the sober participants' self-rated bicycling abilities increased over time. Those who scored high for sensation seeking were relatively stable over time and the participants with low sensation seeking scores showed a decrease in ability ratings over time (Figure 4). The sober group were significantly different from the low sensation seeking scoring group (from time 3 and onwards).

The correlation analyses revealed that SSS scores correlated only with self-rated bicycling ability, i.e.

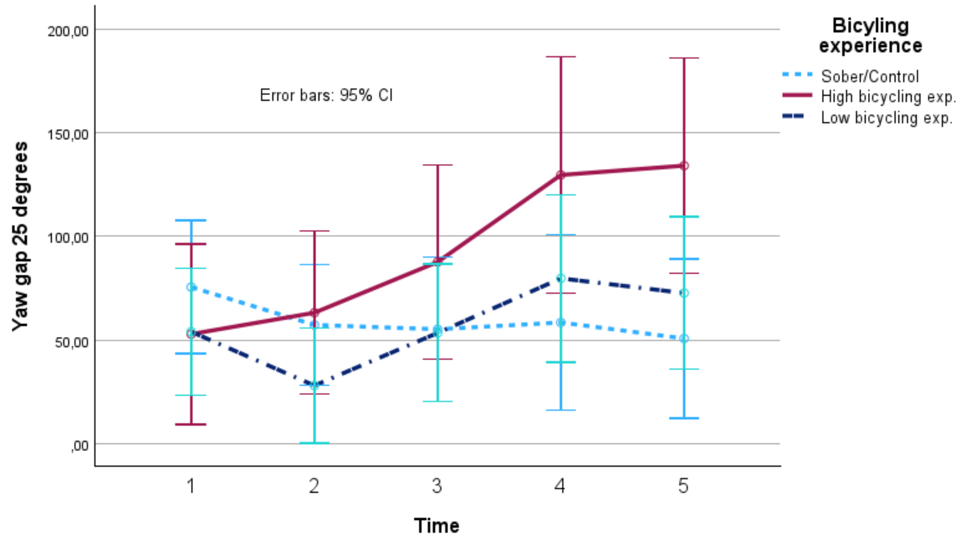

Figure 2 Yaw measurements (gap size of 25 degrees) over time for bicycling experience groups

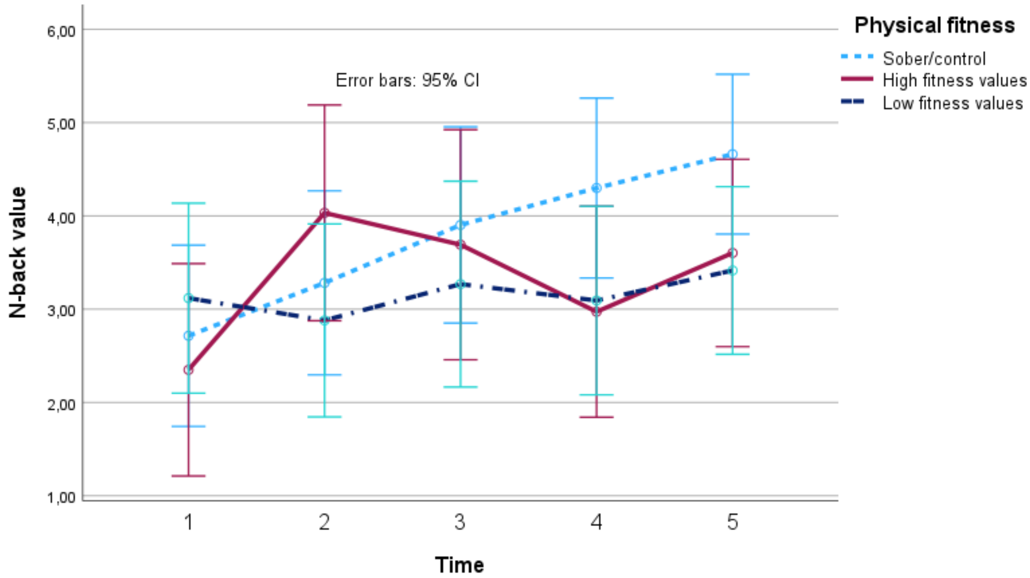

Figure 3 Cognitive performance over time for physical fitness groups

the participants who had high sensation seeking scores rated themselves as having a higher bicycling ability when intoxicated at time 5 ($r = 0.68$; $p < 0.01$), but not at time 1 (when sober).

Taken together (sensation seeking scores): results show that the stability of the sober group increased, and the stability decreased in both the high and low group in the measure of yaw and the group with low scores on sensation seeking when roll was analyzed. The results showed a main effect of time and that the cognitive performance improved over time. The self-rated bicycling ability rating revealed a significant interaction effect where those who scored high on sensation seeking were relatively stable over time meanwhile the participants with low sensation seeking scores showed a decrease in ability ratings over time.

4 Discussion

The aim of this study was to investigate if the bicyclist's characteristics (bicycling experience, physical fitness,

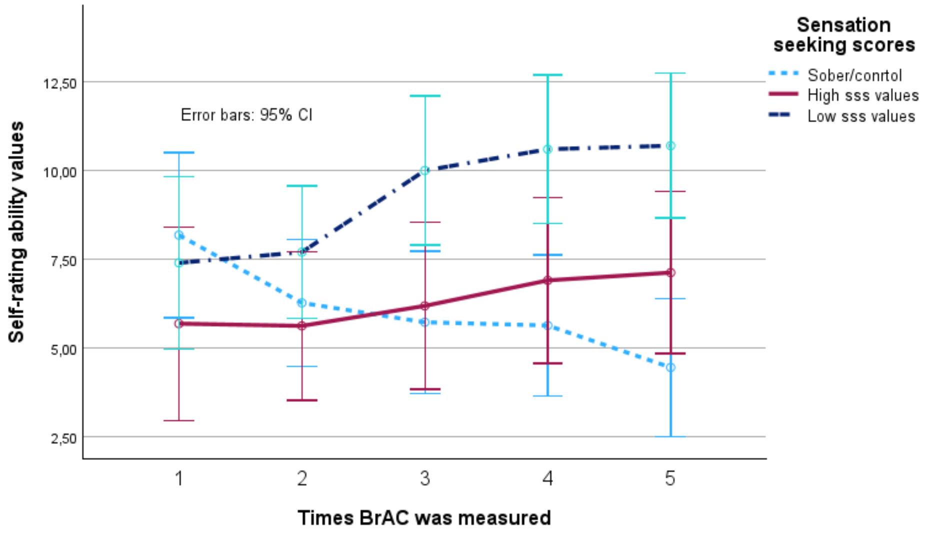

Figure 4 Self-rated bicycling over time for sensation seeking groups (Lower SCORES equals better ability)

or sensation seeking) have effect on bicycling stability, cognitive performance, or self-rated bicycling ability at different levels of alcohol intoxication.

The results revealed that, overall, stability was affected by alcohol intoxication replicating the results from Andersson et al. (2023) and Hartung et al. (2015b). The results suggest that intoxicated participants became more and more unstable independently of group characteristics. These results were more pronounced for the roll measurement (compared to yaw), although both stability measures revealed the same pattern overall (Andersson et al., 2023). Sober participants became more stable, which clearly suggests a learning effect. This indicates that the learning effect for the intoxicated groups was hidden by the effect of intoxication. A more adequate experimental design, that assesses participants already familiar with the task at hand, would be able to discriminate between learning effects and the effect of intoxication more clearly. However, it is clear that intoxication has an effect on stability, although the degree is hidden by the obvious learning effect. The task utilized also has limitations (see below). The correlation analysis revealed that participants' stability was not correlated with different group characteristics at assessment time 1 or time 5.

Generally, cognitive performance was affected by alcohol intoxication supporting the results found by Cash et al., 2015, but group characteristics were unrelated to a decline in cognitive performance. The pattern was the same in all three analyses, i.e. the sober group performed better over time and the intoxicated groups performed equally well (as each other) over time. First, the interpretation is that intoxication and learning effects interact. The sober group's increase in performance was interpreted as a learning effect, and the flat curve for intoxicated participants suggests that the learning effect was reduced by the intoxication. Second, the group characteristics were unrelated to cognitive performance over time. Experience of bicycling, physical fitness and, sensation seeking, did not affect how alcohol intoxication affects participants' cognitive performance differently. The correlation analysis revealed that participants' cognitive performance was not correlated with different group characteristics at assessment time 1 or time 5.

The analyses of self-rated bicycling ability revealed differences in group characteristics. Participants classified as high on different characteristics differed to participants classified as low. The group differences were most pronounced when the physically fit were compared to the less physical fit, and especially when the high group were compared with the low group on sensation seeking scores. Overall, sober participants' self-ratings of bicycle abilities increased over time, indicating that sober participants believed they became more proficient at the treadmill bicycling tasks, i.e. a learning effect. The sober group became slightly more stable over time. The participants classified as low on

SSS was more unstable over time and rated that their ability decreased. However, the group that was high on SSS became less stable over time. Their ability ratings were however stable over time. This suggests that participants in the high groups believed they would be able to bicycle perfectly well even if they had a higher instability when bicycling. This supports previous studies that states that individuals with a higher level of sensation seeking tends to be drawn to activities that involves more risk-taking behavior (Michel et al., 1998).

Self-rated bicycling ability correlated with physical fitness and sensation seeking, but not at time 1, only at time 5. Self-rated bicycling ability and high sensation seeking, for instance, did not correlate when participants were sober, only when intoxicated. The participants were not more stable and did not perform better on cognitive tasks at assessment time 1 or time 5. This indicates that participants that rated high on physical fitness and sensation seeking overestimated their level of ability, but only when intoxicated. The results enhance our understanding of the more self-regulated aspects of bicycling while intoxicated. All intoxicated participants become more unstable, seems to become less cognitive fit. The important difference exists in how the intoxicated participant interpret the reduced abilities, i.e. some understand that they will perform less well others do not. The results can however not reveal if the less risk-taking participants would act accordingly, avoid taking the bicycle when intoxicated. That was not an option in the experiment.

Taken together, group characteristics mainly interacted with self-rated bicycling ability. Participants with high scores on sensation seeking or high physical fitness do not believe that intoxication affects their ability to perform the task at hand to the same extent as the groups with low scores on these group characteristics.

The results from this study on group characteristics and bicycling during alcohol intoxication can result in some possible implications to make bicycling during alcohol intoxication safer. One possible implication is a drink-drive limit for riding a bicycle. The second possible implication is that results can be helpful for creating aimed information campaigns that can appeal to bicyclist with a high sensation seeking personality since the results in the study showed that these participants did not believe that intoxication affected their ability to ride a bicycle. Further research in this area is needed before we can be certain of what implications can be established.

4.1 Limitations and weaknesses

Five limitations of the experiment need to be addressed to avoid overemphasized conclusions. First, the task at hand was bicycling on a treadmill on an unfamiliar bicycle. This is not the same as bicycling on a road with your own bicycle. All participants were unfamiliar with the task, and stability was hence more difficult. The participants felt uncomfortable at the beginning of the task indicating that more practice sessions should be longer in future.

Second, the participants were divided into high and low groups for each characteristic posteriori. The basic idea was to investigate and collect data on characteristics that could be related to different aspects of bicycling on a treadmill when intoxicated with alcohol, but the groups were not chosen a priori, i.e. the participants were divided into high and low groups based only on their subjective statements after completion of the experiment. A more controlled selection of participants would of course be more appropriate, especially if participants had high values for some characteristics and low values for others.

Third, the learning effect was larger than anticipated. Future studies should attempt to reduce the learning curve to allow for enhancement of the effects of interest.

Fourth, the small group sizes could be discussed, even if it is argued that this did not affect the results in a substantial way. This limitation would be more problematic if the analyzes revealed tendencies for differences rather than clear significant differences, i.e. when it is unclear if a significant effect would be obtained with more participants. That was not the case here; although the number of participants was small, significant effects were obtained.

A fifth limitation is that the group size is rather small and homogenous and that the findings can't be generalized to bicyclists in general. Further research is needed.

4.2 Future studies

Bicycling during alcohol intoxication needs to be studied in more realistic settings. This experiment has revealed several interesting results, but the interpretations should not be overemphasized in light of the exploratory approach and the limitations discussed above. From an experimental perspective, the lessons learned are also noteworthy. The participants' learning curves should be considered more carefully, even if the experiment is performed in a more realistic setting. The cognitive task chosen should be also compared to other cognitive tasks. This study suggests that cognitive performance was affected by alcohol intoxication overall. Self-rated bicycle ability ratings interacted with group characteristics, despite stability measures being similar for all intoxicated groups. This experiment does not suggest that the cognitive performance task used here affects self-regulated behavior, i.e. all intoxicated groups cognitive performance were negatively affected but self-ratings varied due to group characteristics. The question is however how self-rating of bicycle abilities is related to self-regulating behavior (Hittner & Swickert, 2006; Spinola et al., 2017). This finding needs to be investigated further.

5 Conclusions

Alcohol intoxication affects bicycling stability, cognitive performance, and self-rated bicycling ability for all characteristics studied. While bicycling stability and cognition was affected by intoxication in a similar way for all intoxicated participants, self-rated ability depended on the group characteristics studied. Participants who scored high on the characteristics studied did not consider their bicycling ability to have been affected, compared to ratings from the low scoring groups studied. This understanding is important in the outreach in society. However, the study was performed in an artificial situation on a treadmill and need to be studied in a more natural setting.

6 Glossary

BAC = blood alcohol concentration

BrAC = breath alcohol concentration

SWRR = steering wheel reversal rate

AUDIT = Alcohol Use Disorders Identification Test

SD = standard deviation

HBRR = handlebar reversal rate

SSS = Sensation Seeking Scale

ANOVA = analysis of variance

MSe = mean square error

CRediT contribution statement

Caroline Andersérs: Formal analysis, Investigation, Project administration, Resources, Writing—original draft. **Jan Andersson:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Writing—original draft. **Henriette Wallén Warner:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Writing—review & editing.

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Ethics statement

This study was approved by the Swedish Ethical Review Authority [approval number 2019-01268].

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