Rev Andal Med Deporte.. 2024; **17(1-2)**

Junta de Andalucía
Consejería de Turismo, Cultura y Deporte

Revista Andaluza de
Medicina del Deporte

https://www.juntadeandalucia.es/deporte/ramd

Originales

BINGE DRINKING HAS NO EFFECT ON MUSCULAR STRENGTH AND NEUROMUSCULAR RESPONSES DURING MAXIMAL AND HIGH-INTENSITY ISOMETRIC FATIGUE PROTOCOL.

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ABSTRACT

We investigated the effects of binge drinking on maximal strength, time to exhaustion during a high-intensity isometric fatigue protocol, and neuromuscular responses of the elbow flexor muscles. Ten young male participants were randomized in two conditions: (1) alcohol consumption (ALC) or (2) placebo consumption (PLA). In each condition, volunteers ingested 1g of alcohol per kg of body mass of alcoholic beer (ALC) or non-alcoholic beer (PLA). Neuromuscular performance (elbow flexors peak torque and time to exhaustion – TTE - during an isometric fatigue protocol at 70% of peak torque) and EMG parameters (amplitude and median frequency) of biceps brachii (BB) and brachioradialis (BRA) were assessed before and after drink ingestion. A breath alcohol concentration of 1.1 ± 0.25 mg/L was observed in ALC condition. Torque was similar between-conditions ($p = 0.76$) and condition*moment interaction ($p = 0.92$), with a significant reduction in post in both conditions ($p = 0.01$; ALC: -4.4%; PLA: -4.7%). TTE and maximal EMG amplitude of BB were not affected by conditions and moments ($p > 0.05$). Maximal EMG amplitude of BRA was reduced in post in both conditions (ALC: -16.4%; PLA: -14.6%). EMG amplitude of BB and BRA during the fatigue protocol had similar behavior between moments and conditions ($p > 0.05$) and we only observed an increase during protocol ($p < 0.05$). Median frequency of BB was higher in PLA compared to ALC (+9.8%). Decreases were observed in both muscles during protocol ($p < 0.001$). Our results revealed that binge drinking did not alter maximal strength, time to exhaustion during high-intensity isometric fatigue protocol, and neuromuscular responses.

Keywords: elbow flexors; alcohol consumption; biceps brachii.

Introduction

Alcohol is consumed regularly by a significant portion of the global population (1). Moreover, binge drinking (intake of five or more standard alcohol drinks by men and four or more by women over a period of approximately 2 hours) with a prevalence over than 21% in people ages 12 and older in the United States (2). Alcohol acts as a stressor on the central nervous system and exerts selective effects on various neuronal systems, which play a significant role in the manifestation of alcohol's effects (3). Consequently, the physiological changes resulting from alcohol consumption vary depending on the amount, frequency, and duration of ingestion (3). One aspect that remains poorly explored is the effects of binge drinking on tasks involving muscle strength. This exploration could contribute to understanding how alcohol impacts muscles, particularly considering that alcoholics often develop muscle atrophy and weakness due to long-term excessive alcohol consumption.

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https://doi.org/10.33155/ramd.v17i1-2.1163
ISSN-e: 2172-5063/

In vitro studies have observed that acute exposure to alcohol led to a reduction in the available releasable Ca^{2+} for excitation-contraction coupling (4), but may have mitigates muscle fatigue by interacting with the neuromuscular nicotinic acetylcholine receptor (5). Furthermore, ethanol has been demonstrated to increase the release of acetylcholine on the neuromuscular junction, increase the activity of dopaminergic neurons, and stimulate the release of serotonin (3), which has direct actions on motoneurons (6). However, there is a scarcity of studies conducted in humans on this topic. The available findings suggest that consuming alcohol before maximal strength and dynamic endurance exercises does not seem to impair performance (7-9), nor does it affect markers of hydration status when consumed after exercise in the heat (10).

Indeed, the impact of acute alcohol intake on neuromuscular responses appears to be constrained. The study conducted by Poulsen et al. (9) showed no discernible effects of alcohol on central activation rate, as well as on changes in excitation-contraction coupling, plasma free calcium concentrations, and muscular performance. However, there is a lack of studies examining the isolated effects of alcohol on EMG responses during maximal and isometric fatigue protocols. This is a crucial area of investigation because acute alcohol intake has the potential to impact the neuromuscular junction (3, 5), which may be reflected in changes in EMG amplitude during maximal voluntary isometric contraction (MVIC), which serves as an indicator of increased excitatory input to the motoneuron pool (11), as well as in EMG responses during a sustained fatigue protocol, as they are attributed to peripheral alterations within muscle fibers rather than modifications in neural drive (12).

To better comprehend the immediate effects of binge drinking, which remains relatively unexplored (13, 14), this study aims to investigate the acute impacts of alcohol consumption (beer) compared to a placebo (beer with 0% alcohol) on maximal strength, time to exhaustion during an isometric fatigue protocol, and EMG responses (amplitude and median frequency) of the elbow flexor muscles.

Methods

Study design

This study employed a single-blinded, randomized controlled trial with a crossover design. Its primary objective was to examine the effects of acute alcohol consumption (beer) or placebo consumption (beer with 0% alcohol) on performance and EMG parameters. Throughout the study, participants were unaware of whether they were consuming alcohol or the placebo, and the evaluators were not informed about the intervention that the participants received.

Participants

Recruitment was conducted through announcements at the University campus and on social networks. Male participants between the ages of 18 and 35, who were physically active, were eligible to participate in the study. Exclusion criteria included individuals classified in zones III-IV of the AUDIT questionnaire, indicating higher alcohol misuse risk (15), or reported cardiovascular or metabolic diseases. Ten participants volunteered for the study (age: 23.5 ± 3.3 years; body mass: 70.2 ± 9.1 kg; height: 174.0 ± 5.1 cm; body fat: 14.9 ± 3.2%; BMI: 23.19 ± 2.73 kg/m^2). Approval from the University's Ethics Committee of Human Research was obtained (number 366.465), and all participants provided written informed consent after being informed of the risks and benefits associated with participating in the study. This study respected the ethical standards of the Declaration of Helsinki.

Experimental procedures

In order to verify the effects of alcohol or placebo intake on elbow flexors' neuromuscular responses, volunteers attended 4 days the lab during the study: i) neuromuscular familiarization (day 1); ii) basal metabolic rate evaluation (day 2); iii) two experimental conditions (days 3-4). In the 48 hours preceding the experiments, participants were instructed not to consume any alcohol, not to perform intense physical activity, and to sleep 7 to 8 hours a night (as reported by the participants themselves). During day 1, participants underwent familiarization with the tests conducted on the elbow flexors, specifically assessing maximal strength and EMG measurements. On the morning of day 2, participants' basal metabolic rate was measured after they slept in their homes. The methodology for this measurement is detailed in our previous study (16) and was used to standardize the meals provided to the participants before the experimental conditions. Subsequently, on days 3 and 4, participants experienced the two experimental conditions: alcohol intake (ALC) or placebo intake (PLA). To ensure an appropriate washout period between evaluation days, a 10-day interval was observed. The order in which the experimental conditions were administered was determined using a freely available software tool (www.randomizer.org).

During days 3 and 4, participants arrived at the laboratory at 7:30 pm. Upon arrival, participants were given a standardized meal (consisting of pizza and orange juice), the details of which can be found in our previous study (16). After a 90-minute interval, evaluations of the elbow flexors were conducted, after which participants began consuming either alcohol or a placebo, with the intake period lasting from 9:00 to 11:00 pm. To monitor the level of intoxication, breath alcohol concentration (BrAC) was measured. This measurement were taken every 20 minutes throughout the alcohol or placebo consumption period (from 9:00 to 11:00 pm). Following the completion of alcohol or placebo intake, evaluations of the elbow flexors were repeated.

Alcohol or Placebo intake

In the ALC condition, participants ingested a commercial beer containing 4.7% of alcohol, while in the PLA condition a non-alcoholic beer (0% of alcohol) from the same manufacturer was consumed. The amount of alcohol ingested was equivalent to 1g/kg of body mass, and the total volume of beer ingested was the same for both conditions. Participants had a 2-hour period to consume the total amount of beer, at a rate of 15-20% every 20 min. The mean alcohol intake was 1766 ± 218 ml, corresponding to five standard drinks, characterizing a binge drinking condition (1).

Elbow flexors evaluation

The maximal strength and isometric fatigue protocol of the elbow flexors were conducted using an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, Shirley, New York, USA). Participants were positioned on the dynamometer following the manufacturer's guidelines for elbow evaluations, with their elbow and shoulder joints set at a 90° angle of flexion. Following a standardized warm-up protocol, participants performed three maximal 5-s MVIC at an elbow flexion angle of 90° (where 0° represents full extension). A 2-min rest period was observed between each contraction to minimize fatigue. Verbal encouragement was provided during the test to motivate participants to exert their maximum effort. Maximal peak torque, obtained from the MVIC was utilized for the subsequent analysis (16).

In the isometric fatigue protocol, participants were instructed to sustain a torque level equivalent to 70% of their isometric peak

Table 1. Exercise performance and EMG amplitude during MVIC between conditions and moments

	ALCOHOL		PLACEBO	
	Pre	**Post**	**Pre**	**Post**
Torque (Nm)	66.10 ± 10.34	62.90 ± 9.57#	64.77 ± 7.92	61.77 ± 8.94#
TTE (s)	49.20 ± 6.28	48.00 ± 7.63	52.10 ± 6.82	54.10 ± 7.47
EMG BB (mV)	1.36 ± 0.36	1.10 ± 0.44	1.30 ± 0.67	1.20 ± 0.84
EMG BRA (mV)	0.95 ± 0.35	0.82 ± 0.43#	0.89 ± 0.29	0.75 ± 0.27#

Table caption TTE: time to exhaustion; BB: biceps brachii; BRA: brachioradialis* different between conditions# different between moments

torque for as long as they could. The objective was to maintain this target torque value until they reached a point where they could no longer sustain the force level, even after three consecutive warnings from the investigators. At that moment, the test was concluded, and the time to exhaustion (TTE) was recorded (16). During the sustained contraction, participants were provided with visual feedback of the exerted torque, which was displayed on the screen of the dynamometer. The torque visual feedback was presented as a horizontal line, and an upper target line representing the target torque level was fixed on the display. Verbal encouragement was administered during the test to motivate participants and enhance their performance.

EMG data acquisition

An 8-channel EMG system (AMT-8, Bortec Biomedical Ltd., Canada) connected to a Windaq data acquisition system (Dataq Instruments Inc., USA) was synchronized with the dynamometer and used to evaluate the electrical activity of BB and BRA during elbow-flexors tests. Skin preparation and electrode positioning for EMG evaluation followed standard procedures of SENIAM. Transparency film maps were developed using anatomical reference points (i.e., lateral epicondyle) and skin marks (i.e., vessels and scars) to ensure the same electrodes' position in all evaluations. A reference electrode was fixed on the surface of the clavicle. The EMG data obtained during the MVICs were subjected to further processing. The maximum value recorded during the 5-s period was then considered as the MVIC for each muscle.

EMG data analysis

The raw EMG signals were sampled at a frequency of 2000 Hz per channel using a DI-720, 16-bit analog-to-digital board (Dataq Instruments Inc.) and saved for subsequent analysis. To prepare the data for analysis, all EMG signals were filtered using a 4^{th} order recursive Butterworth filter with a bandpass range of 20-500 Hz and rectified. For MVICs, the root mean square (RMS) of the EMG amplitude was calculated from 1-s segments of the EMG signals that were synchronized with the peak torque of the elbow flexors. In the isometric fatigue protocol, the EMG amplitude and median frequency values were determined at three specific moments: (i) at the start of the test (time 1), which corresponds to when the target torque value was achieved; (ii) in the middle of the individual test (time 2), which corresponds to the window at the middle time of the test and (iii) immediately preceding exhaustion (time 3). EMG amplitude were normalized using the value of MVIC of each moment. All time points were calculated using a window size of 5 s (16). All analyses of the EMG data were performed using a custom-written code (MATLAB v R2021b, Mathworks Inc., Natwick, WY, United States).

Statistical Analysis

Data normality was tested through the Shapiro-Wilk test. Data sphericity was tested by the Mauchly test and the Greenhouse-Geisser correction factor was used when the sphericity was violated. A Factorial ANOVA (2 conditions – ALC or PLA; 2 moments – pre and post) was performed to compare elbow flexors torque, EMG amplitude of BB and BRA during MVIC and TTE. Moreover, a factorial ANOVA (2 conditions – ALC or PLA; 2 moments – pre and post; 3 times - 1, 2 and 3) was performed to analyze EMG amplitude and median frequency of BB and BRA during the fatigue protocol. After each ANOVA performed, the LSD post hoc test was used to compare conditions and moments, according to analysis. A 5% significance level was adopted for all analyses and all statistical procedures were performed in SPSS 22.0 (SPSS Inc., Chicago, IL, USA).

Results

Regarding the BrAC, the mean of measurement immediately before the tests was 1.1 ± 0.25 mg/L in the ALC condition, while no detectable alcohol was observed in the PLA condition. Regarding the torque, no significant effect of the condition [$F_{(1;\ 18)}$ = 0.09; p = 0.76] and condition*moment interaction [$F_{(1;\ 18)}$ = 0.009; p = 0.92] were observed. However, we found a significant moment effect [$F_{(1;\ 18)}$ = 8.11; p = 0.01], with a significant reduction in post in both conditions (ALC: -4.4%; PLA: -4.7%). We did not find significant effect of the condition [$F_{(1;\ 18)}$ = 2.99; p = 0.10], moment [$F_{(1;\ 18)}$ = 0.05; p = 0.83] and condition*moment interaction [$F_{(1;\ 18)}$ = 0.79; p = 0.39] for TTE (Table 1).

Regarding the EMG amplitude of BB during MVIC, no significant effect of the condition [$F_{(1;\ 18)}$ = 0.05; p = 0.83], moment [$F_{(1;\ 18)}$ = 1.82; p = 0.19] and condition*moment interaction [$F_{(1;\ 18)}$ = 0.42; p = 0.52] were observed. For EMG amplitude of BRA during MVIC, no significant effect of the condition [$F_{(1;\ 18)}$ = 0.20; p = 0.66] and condition*moment interaction [$F_{(1;\ 18)}$ = 0.01; p = 0.90] were observed. However, we found a significant moment effect [$F_{(1;\ 18)}$ = 17.03; p = 0.001], with a significant reduction in post in both conditions (ALC: -16.4%; PLA: -14.6%) (Table 1).

Regarding the EMG amplitude of BB during the fatigue protocol, the behavior was similar between moments and conditions (p > 0.05) and we only observed a time effect [$F_{(2;\ 36)}$ = 7.73; p = 0.006], with a significant increase in time 3 compared to time 1 (p = 0.006) and time 2 (p = 0.027), and time 2 compared to time 1 (p = 0.045) (Figure 1A). A similar result was observed in EMG amplitude of BRA, where only a time effect was observed [$F_{(1.34;\ 24.21)}$ = 7.02; p = 0.009], with an increase in time 3 compared to time 1 (p = 0.012) and time 2 (p = 0.009) (Figure 1B).

Regarding the median frequency of BB, we observed a significant effect of the condition [$F_{(1;\ 18)}$ = 6.79; p = 0.018], with higher values in PLA compared to ALC (+9.8%) and a time effect [$F_{(2;\ 36)}$ = 17.16; p < 0.001], with a decrease in time 3 compared to time 1 (p < 0.001) and time 2 (p = 0.001), and time 2 compared to time 1 (p = 0.029) (Figure 1C). Regarding the median frequency of BRA, the behavior was similar between moments and conditions (p > 0.05) and we only observed a time effect [$F_{(1.47;\ 26.52)}$ = 13.70; p < 0.001], with a significant decrease in time 3 compared to time 1 (p = 0.001) and time 2 (p = 0.001), and time 2 compared to time 1 (p = 0.028) (Figure 1D).

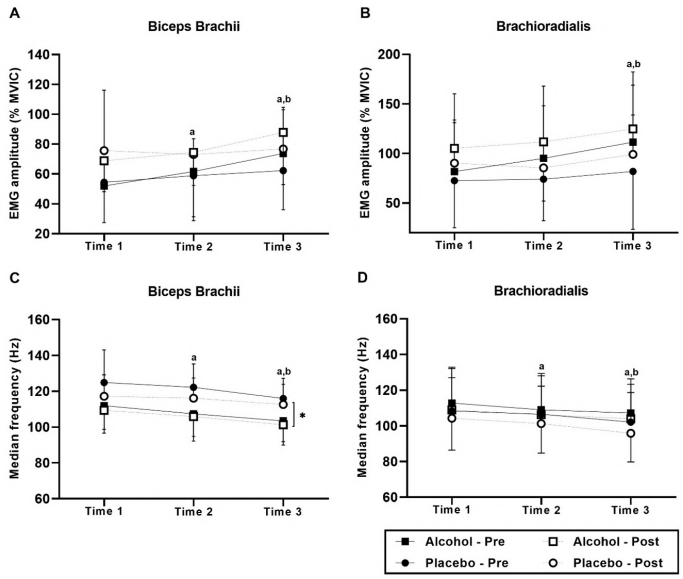

Figure 1. EMG amplitude (A-B), and median frequency (C-D) during fatigue protocol. [a] different from time 1; [b] different from time 2;* different between conditions

Discussion

The main findings of this study indicate that, in comparison to the PLA condition, binge drinking did not significantly affect torque, TTE, or EMG responses of either elbow flexor muscle during MVIC or the fatigue protocol. However, we observed a noteworthy decrease in torque and EMG amplitude of the BRA muscle following both ALC and PLA ingestion during MVIC evaluations. Additionally, higher median frequency in BB were noted in the PLA condition during the fatigue protocol. Furthermore, there were observed increases in EMG amplitude of both BB and BRA, alongside decreases in median frequency during the fatigue protocol.

Previous studies have shown a wide range of time intervals between alcohol intake and neuromuscular testing, varying from minutes (8) to days (17, 18). This variation makes it challenging to compare findings across studies. However, considering that our tests were conducted after a few minutes of alcohol consumption, the results of similar previous studies suggest that muscle performance may not be significantly impaired by alcohol intake before a neuromuscular test (7-9), agreeing with our results. However, strength and EMG amplitude of BRA during MVIC reduced in the post-consumption evaluations. This decrease in amplitude during MVIC may be indicative of the decreased excitatory input to the motoneuron pool, which indicates a lower motor units recruited or are firing less (11), and help to explain the reduction in maximal strength. We attribute these reductions due to residual fatigue induced by the fatigue protocol prior to consumption, as the post-consumption maximal strength evaluations were conducted approximately 2 hours later.

We found a similar behavior of EMG parameters between conditions and moments during fatigue protocol. It is worth noting that simulation studies have suggested that peripheral factors within the muscle fibers themselves appear to play a crucial role in influencing EMG parameters during fatigue, rather than changes in neural activation (12). Indeed, one possible mechanism that could provide insights into our observations regarding EMG parameters is the possibility of inadequate muscle perfusion, especially during prolonged isometric contractions, due to hypoxic conditions. This is the central mechanism when the contraction strength reaches or exceeds 60% of the MVIC (19). Under hypoxic conditions, there is a notable buildup of metabolites, particularly Pi and H^+, during prolonged exercise. This excessive accumulation of metabolites is known to be associated with an increase in EMG amplitude and a decrease in the median frequency of the EMG signal (20), as observed in our study. This contributes to enhanced activation of group III and IV afferent nerve fibers, ultimately leading to a reduction in the neural drive (11). We observed higher median frequency values of BB in the PLA condition. It's important to note that this effect was consistent across all evaluation moments, including the pre-consumption period, indicating that the values recorded under the PLA condition appeared to be consistently higher than those under the ALC condition. However, since we did not find an interaction between condition and moment, this result may not be considered significant.

Ethanol has been demonstrated to increase the release of acetylcholine on the neuromuscular junction, increase the activity of dopaminergic neurons, and stimulate the release of serotonin (3), and alters neuromuscular nicotinic acetylcholine receptor function (5), which may influence action potential and impact EMG responses (21). However, such effects were not observed in our study. Recent reviews have indicated that acute alcohol consumption decreases protein synthesis, increases protein degradation, and impairs mitochondrial function and extracellular matrix remodeling (13, 14). Therefore, our study found that binge drinking was not able to modify maximal strength, time to exhaustion in high-intensity isometric contraction, and neuromuscular responses. These findings provide important insights into acute alcohol consumption, as recommended in these previous reviews (13, 14).

The study has some limitations that should be acknowledged. Firstly, there were no measures taken to assess peripheral changes (e.g., resting twitch) or central changes (e.g., superimposed twitch during MIVCs), which could have provided valuable insights. Secondly, the lack of self-reported measures during fatigue protocol (e.g. rate of perceived exertion). Thirdly, it is worth noting that beer consumption can acutely increase plasma antioxidant capacity due to its polyphenol content, potentially leading to a positive impact on performance (22). Fourthly, the participants in this study had an AUDIT score of 8.93 ± 1.37, indicating potentially harmful drinking behaviors (15). Therefore, caution should be exercised when generalizing these findings to individuals with different drinking patterns, as this could have other consequences that were not measured in the participants. Fifthly, the small sample size of the crossover study design limited the statistical power of the study. Despite these limitations, this study provides valuable insights into the effects of binge drinking on physical and neuromuscular performance.

Conclusions

Our results revealed that binge drinking did not alter maximal strength, time to exhaustion during high-intensity isometric fatigue protocol, and neuromuscular responses. Future studies should explore the impact of binge drinking on other types of activities more common in daily life, such as those involving sustaining lower levels of strength. Nevertheless, high alcohol intake should not be recommended due to the potentially dangerous physiological and health consequences.

CRediT author statement

RR: conceptualization; formal analysis; investigation; methodology; formal analysis; project administration; writing - original draft; and writing - review & editing; **RAF:** investigation; methodology; roles/writing - original draft; writing - review & editing; **BCT:** investigation; methodology; roles/writing - original draft; writing - review & editing; **RCOM:** investigation; methodology; roles/writing - original draft; writing - review & editing; **FD:** investigation; methodology; formal analysis; roles/writing - original draft; writing - review & editing; **BMB:** investigation; methodology; funding acquisition; roles/writing - original draft; writing - review

& editing; **MAV:** investigation; methodology; funding acquisition; project administration; roles/writing - original draft; writing - review & editing

Award id

12/2115-6

Funding

This work was supported by the Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul (FAPERGS) under Grant [number 12/2115-6].

Funded by: Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul (FAPERGS)

Acknowledgments

This work was conducted during the course of a scholarship supported by the International Cooperation Program CAPES/COFECUB at the Federal University of Rio Grande do Sul, financed by CAPES – Brazilian Federal Agency for Support and Evaluation of Graduate Education within the Ministry of Education of Brazil and the National Council of Scientific and Technological Development (CNPq) Brazil for the provision of scholarships (FD, BMB, and MAV).

References

1 WHO. Global status report on alcohol and health 2018.

2 SAMHSA. Center for Behavioral Health Statistics and Quality. 2021 National Survey on Drug Use and Health 2021 [Table 2.42A—Binge alcohol use in past month: among people aged 12 or older; by age group and geographic and socioeconomic characteristics, numbers in thousands, 2021]. Available from: https://www.samhsa.gov/data/sites/default/files/reports/rpt39441/NSDUHDetailedTabs2021/NSDUHDetailedTabs2021/NSDUHDetTabsSect2pe2021.htm#tab2-42a.

3 Eckardt MJ, File SE, Gessa GL, Grant KA, Guerri C, Hoffman PL, et al. Effects of moderate alcohol consumption on the central nervous system. Alcohol Clin Exp Res. 1998;22(5):998-1040 https://doi.org/10.1111/j.1530-0277.1998.tb03695.x

4 Cofán M, Nicolás JM, Fernández-Solà J, Robert J, Tobías E, Sacanella E, et al. Acute ethanol treatment decreases intracellular calcium-ion transients in mouse single skeletal muscle fibres in vitro. Alcohol Alcohol. (Oxford, Oxfordshire). 2000;35(2):134-8. https://doi.org/10.1093/alcalc/35.2.134

5 Noori HR, Mücksch C, Vengeliene V, Schönig K, Takahashi TT, Mukhtasimova N, et al. Alcohol reduces muscle fatigue through atomistic interactions with nicotinic receptors. Commun Biol. 2018 Oct 3:1:159. https://doi.org/10.1038/s42003-018-0157-9

6 Kavanagh JJ, McFarland AJ, Taylor JL. Enhanced availability of serotonin increases activation of unfatigued muscle but exacerbates central fatigue during prolonged sustained contractions. J Physiol. 2019 Jan;597(1):319-332 https://doi.org/10.1113/JP277148

7 Lundin L, Hallgren R, Lidell C, Roxin LE, Venge P. Ethanol reduces myoglobin release during isokinetic muscle exercise. Acta Med Scand. 1986;219(4):415-9. https://doi.org/10.1111/j.0954-6820.1986.tb03332.x

8 Clarkson PM, Reichsman F. The effect of ethanol on exercise-induced muscle damage. J Stud Alcohol. 1990;51(1):19-23. https://doi.org/10.15288/jsa.1990.51.19

9 Poulsen MB, Jakobsen J, Aagaard NK, Andersen H. Motor performance during and following acute alcohol intoxication in healthy non-alcoholic subjects. Eur J Appl Physiol. 2007 Nov;101(4):513-23. https://doi.org/10.1007/s00421-007-0511-y

10 Jiménez-Pavón D, Cervantes-Borunda MS, Díaz LE, Marcos A, Castillo MJ. Effects of a moderate intake of beer on markers of hydration after exercise in the heat: a crossover study. J Int Soc Sports Nutr. 2015 Jun 6:12:26. https://doi.org/10.1186/s12970-015-0088-5

11 Taylor JL, Gandevia SC. A comparison of central aspects of fatigue in submaximal and maximal voluntary contractions. J Appl Physiol (1985). 2008 Feb;104(2):542-50. https://doi.org/10.1152/japplphysiol.01053.2007

12 Arabadzhiev TI, Dimitrov VG, Dimitrov GV. The increase in surface EMG could be a misleading measure of neural adaptation during the early gains in strength. Eur J Appl Physiol. 2014 Aug;114(8):1645-55. https://doi.org/10.1007/s00421-014-2893-y

13 Caceres-Ayala C, Pautassi RM, Acuña MJ, Cerpa W, Rebolledo DL. The functional and molecular effects of problematic alcohol consumption on skeletal muscle: a focus on athletic performance. Am J Drug Alcohol Abuse. 2022 Mar 4;48(2):133-147. https://doi.org/10.1080/00952990.2022.2041025

14 Simon L, Bourgeois BL, Molina PE. Alcohol and Skeletal Muscle in Health and Disease. Alcohol Res. 2023 Nov 2;43(1):04. doi: 10.35946/arcr.v43.1.04

15 Babor TF, Higgins-Biddle, John C, Saunders, John B, Monteiro, Maristela G & World Health Organization. Dept. of Mental Health and Substance Dependence. AUDIT: the Alcohol Use Disorders Identification Test: guidelines for use in primary health care. In: WHO editor. 2 ed. Geneva, 2001. https://www.who.int/publications/i/item/WHO-MSD-MSB-01.6a

16 Rodrigues R, de Azevedo Franke R, Teixeira BC, Cauduro Oliveira Macedo R, Diefenthaeler F, Baroni BM, et al. Can the Combination of Acute Alcohol Intake and One Night of Sleep Deprivation Affect Neuromuscular Performance in Healthy Male Adults? A Cross-over Randomized Controlled Trial. J Strength Cond Res. 2019 May;33(5):1244-1251. doi: 10.1519/JSC.0000000000003124

17 Barnes MJ, Mundel T, Stannard SR. Post-exercise alcohol ingestion exacerbates eccentric-exercise induced losses in performance. Eur J Appl Physiol. 2010 Mar;108(5):1009-14. https://doi.org/10.1007/s00421-009-1311-3

18 Barnes MJ, Mundel T, Stannard SR. The effects of acute alcohol consumption and eccentric muscle damage on neuromuscular function. Appl Physiol Nutr Metab. 2012 Feb;37(1):63-71. https://doi.org/10.1139/h11-137

19 Dimitrova NA, Arabadzhiev TI, Hogrel JY, Dimitrov GV. Fatigue analysis of interference EMG signals obtained from biceps brachii during isometric voluntary contraction at various force levels. J Electromyogr Kinesiol. 2009 Apr;19(2):252-8. https://doi.org/10.1016/j.jelekin.2007.08.007

20 Vestergaard-Poulsen P, Thomsen C, Sinkjaer T, Stubgaard M, Rosenfalck A, Henriksen O. Simultaneous electromyography and 31P nuclear magnetic resonance spectroscopy--with application to muscle fatigue. Electroencephalogr Clin Neurophysiol. 1992 Dec;85(6):402-11. doi: 10.1016/0168-5597(92)90054-f

21 Dimitrova NA, Dimitrov GV. Interpretation of EMG changes with fatigue: facts, pitfalls, and fallacies. J Electromyogr Kinesiol. 2003 Feb;13(1):13-36. https://doi.org/10.1016/S1050-6411(02)00083-4

22 Wynne JL, Wilson PB. Got Beer? A Systematic Review of Beer and Exercise. Int J Sport Nutr Exerc Metab. 2021 Sep 1;31(5):438-450. https://doi.org/10.1123/ijsnem.2021-0064

Abbreviations

ALC
: alcohol consumption

ANOVA
: analysis of variance

BB
: bíceps brachii

BRA
: brachioradialis

BrAC
: breath alcohol concentration

CNS
: central nervous system

EMG
: electromyography

Hz
: hertz

MVIC
: maximal voluntary isometric contraction

PLA
: placebo consumption

TTE
: time to exhaustion