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Original Paper

Impact of Oxygen Intervention on Heart Rate Variability and Cognitive Function among Individuals Consuming Alcohol at High Altitude

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Abstract

This study aimed to investigate the ameliorative effects of different oxygen administration methods on cognitive impairment and reduced heart rate variability (HRV) induced by alcohol consumption at high altitude. A repeated-measures experimental design was employed, recruiting healthy adult volunteers (M=60) who consumed moderate alcohol under high-altitude conditions. HRV and cognitive function assessments were conducted before, during, and after alcohol intake. Two intervention methods were applied: nasal oxygen inhalation and hyperbaric oxygen therapy.The results demonstrated that oxygen administration significantly mitigated the alcohol-induced reduction in HRV. Statistical analysis revealed significant improvements in 7 out of 12 HRV parameters: Time-domain indices: MeanHR, RMSSD, SD1; Frequency-domain indices: LF, HF, VLF, TP. Hyperbaric oxygen therapy showed pronounced efficacy in improving MeanHR, LF, HF, and TP, while nasal oxygen exhibited greater effects on SD1, RMSSD, and VLF. Among the four cognitive function indicators, two indicators with significant oxygen intervention effects were identified: executive control function and inhibitory control function. Hyperbaric oxygen intervention demonstrated significant improvement in executive control function, while nasal oxygen inhalation showed pronounced effects on inhibitory control function. These results indicate that oxygen therapy significantly ameliorated the reduction in heart rate variability and cognitive impairment induced by the combined effects of high-altitude exposure and alcohol intake.

Keywords

high altitude, alcohol intake, heart rate variability, cognitive function, nasal oxygen intervention, hyperbaric oxygen intervention

1. Introduction

The systemic effects of high-altitude hypoxia on human physiology and cognitive function represent a significant research topic at the intersection of environmental psychology and high-altitude medicine. The Lhasa region, with an average elevation of 3,650 meters, has atmospheric oxygen partial pressure at only 64% of sea level. This persistent hypoxic exposure triggers compensatory responses such as pulmonary hypertension and increased blood viscosity (Bärtsch & Gibbs, 2007), while also altering heart rate variability (HRV) mediated by the autonomic nervous system (ANS) (Hou et al., 2023; Shen, Chang, Zhang, Jiang, Ni, & Wang, 2017; Ando, 2018), thereby affecting human cognitive function. Oxygen inhalation rapidly increases blood oxygen levels, alleviates tissue hypoxia, and aids in restoring normal cardiac oxygen supply and metabolic function (Oliveira, Rohan, Gonçalves, & Soares, 2017; Akselrod, Gordon, Ubel, Shannon, Berger, & Cohen, 1981; Malhotra, Selvamurthy, Purkayastha, Mukherjee, Mathew, & Dua, 1976; Mussalo et al., 2001). Therefore, this study employed repeated measures analysis of variance. Healthy adult volunteers (n=60) were recruited to undergo low-dose alcohol consumption in a high-altitude environment. Two intervention methods were applied: nasal oxygen intervention (NIO) and hyperbaric oxygen intervention (HBO). Tests related to heart rate variability and cognitive function were conducted before, during, and after alcohol consumption.

2. Research Methods

2.1 Subject Selection

Sixty Tibetan graduate students aged 22–26 (M = 24, SD = 1.414) of Han ethnicity were recruited, with equal male-to-female ratios.

Exclusion Criteria:

(1) History of severe alcohol allergy;

(2) History of cardiovascular or neurological diseases, psychiatric disorders (Lutfi & Sukkar, 2012; Chopra & Tiwari, 2012; Johnson, Eisenhofer, & Lambie, 1986; Mukherjee, 2013; Sang, Chen, & Ao, 2021), head trauma, central nervous system tumors, any pathological cognitive decline, or severe chronic renal failure (GFR <30);

(3) Symptoms of sleep deprivation or sleep disorders prior to testing; (4) Consumption of alcohol- or caffeine-containing foods/beverages within 72 hours prior to testing, or medication intake within 48 hours prior to testing; (5) Exclusion of subjects with severe alcohol abuse or dependence (Alcohol Dependence Questionnaire score >8) (Li, Shen, & Zhang, 2003); (6) Normal vision or corrected visual acuity.

2.2 Experimental Materials

Equipment:

(1) Hyperbaric Oxygen Chamber Parameters: This study employed a negative-ion soft-walled hyperbaric oxygen chamber for hyperbaric oxygen therapy. The chamber is elliptical in shape, measuring 2.13 meters in height and 2.55 meters in width, with a base area of 7.88 square meters. Intervention pressure: 0.11 MPa; oxygen concentration: 25%; oxygen flow rate: 10 L/min; peak oxygen partial pressure: 27.86 kPa.

(2) Nasal cannula parameters: Oxygen flow rate: 4 L/min; output oxygen concentration: 93%-96%; inhaled oxygen concentration: 22%-40%.

(3) Breathalyzer: The exhaled breath alcohol content detector comprises an air pathway, control circuitry, alcohol sensor, breath detection system, sampling system, and display/printing system. It measures alcohol concentration in human exhaled breath.

(4) Sphygmomanometer, pulse oximeter, physiological multi-channel monitor (BIOPAC-MP150);

Consumables: Several bottles of 40% vodka; Soda water; Disposable cups

(5) Alcohol Ingestion Standards:

During the alcohol ingestion phase, subjects receive 0.45g/kg of pure alcohol based on body weight, mixed at a 1:2 ratio of liquor to soda water. Under control conditions, the entire dose is mixed with soda water. To prevent subjects from identifying experimental conditions by smell, 5ml of alcohol is added to the rim of control group cups. The mixed solution is then divided equally into five cups, which subjects consume at a steady pace within 30 minutes.

Experiments were conducted in a high-altitude environment (Lhasa, elevation 3680 meters, PO_2=103 mmHg, PB=642.2 hPa, temperature 22°C ± 1°C, humidity 20% ± 5%), demographic information was collected from participants, including ethnicity, age, gender, duration of residence in Tibet, and current altitude. Standardized protocols were used to measure anthropometric indicators: height, weight, heart rate, blood pressure, blood oxygen saturation, and electrocardiogram (ECG).

During the alcohol ingestion phase, the study employed Fillmore's (2000) standard acute alcohol administration protocol. Under drinking conditions, subjects received 0.45 g/kg of pure alcohol calculated by body weight, mixed in a 1:2 ratio of baijiu (Chinese liquor) to soda water. Participants were instructed to consume one cup (one liang measuring cup) every five minutes, finishing each cup within two minutes (five cups totaling 30 minutes). During this period, participants could consume 100g of peanuts. After completion, they rinsed their mouths with cold boiled water and rested for 30 minutes. Starting 10 minutes post-consumption, blood alcohol concentration (BrAC), blood oxygen saturation, heart rate, and blood pressure were measured and recorded every 5 minutes. Physiological parameters were monitored in real-time using a physiological polygraph. Participants completed the ANT and Flanker tasks until the experiment concluded. Under control conditions, all doses were prepared with soda water. To prevent participants from identifying experimental conditions by odor, 5 ml of alcohol was added to the rim of the beverage cup in the control group (water). The prepared

solution was then divided equally into five cups, which participants consumed at a steady pace within 30 minutes.

During the intervention phase, subjects entered the hyperbaric chamber post-alcohol consumption. The protocol included a 20-minute ascent, 90-minute constant pressure phase, and 20-minute descent, totaling approximately 130 minutes. Blood alcohol concentration (BrAC) began rising 30 minutes after drinking, peaked 1–1.5 hours later, and then declined. The mid-test phase commenced during the 20-minute constant pressure period to align with peak BrAC levels.

Post-test measurements were taken upon exiting the chamber. After completing the test, participants' blood alcohol concentration was remeasured and recorded. They were then asked to rate their intoxication level on a scale of 1 (not intoxicated at all) to 7 (very intoxicated), with self-reported scores documented. Nasal oxygen intervention followed the same protocol. Participants attended the experiment weekly, with experimental order balanced across subjects. The experiment employed a 3×3 repeated measures design. Independent variables were time (pre-test, mid-test, post-test) and oxygen intervention method (control group, nasal oxygen intervention, hyperbaric oxygen intervention). Dependent variables included physiological indicators (blood oxygen saturation, blood pressure, heart rate, exhaled alcohol concentration, ANT and Flanker test performance, etc.). The pre-test represented the baseline state when subjects had neither consumed alcohol nor received oxygen. The mid-test occurs when breath alcohol concentration is rising after drinking, and the post-test occurs after completing the entire experiment, when breath alcohol concentration is either declining or at a low level.

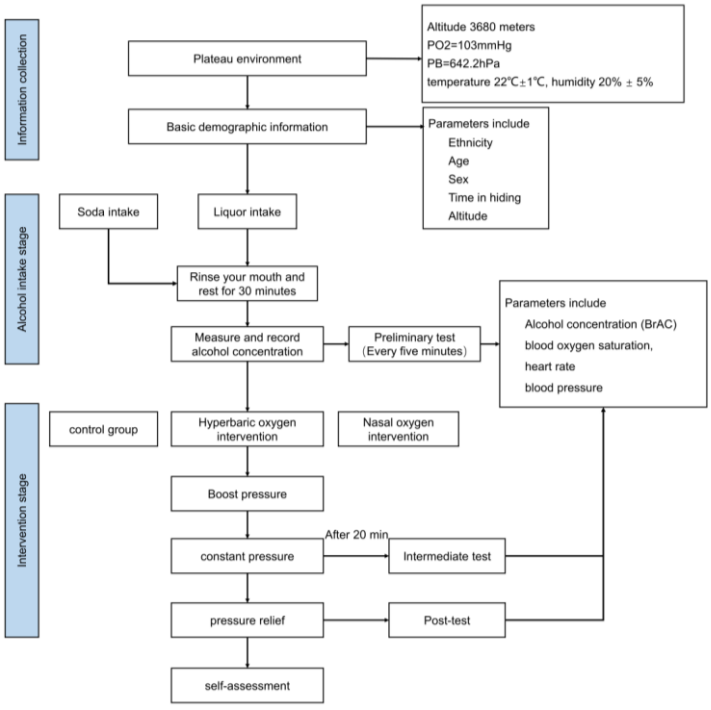

Figure 1. Flow Chart of Experiment

2.4 Data Acquisition and Analysis

The standard data collection period for assessing heart rate variability was 5 minutes. Electrocardiogram signals underwent Butterworth filtering, with the P&T method (Pan-Tompkins algorithm) used to identify each QRS complex and calculate RR intervals. Finally, MATLAB (Mathworks, Natick, MA, ver. 2016b) code was employed to compute time-domain and frequency-domain metrics of heart rate variability. Cognitive function and HRV-related indicators were analyzed (Malik, 1996), with specific physiological effects of relevant indicators shown in Table 1.

Repeated measures analysis of variance (ANOVA) was performed using SPSS 27.0 statistical software to examine changes in individual physiological characteristics and cognitive function under different oxygen intervention methods during high-altitude alcohol consumption. Pairwise comparisons between groups were conducted using the SNK method. $P < 0.05$ was considered statistically significant.

Table 1. Summary of the HRV Indicators Used in this Study

Indicators	Units	Description	Physiological significance
MeanHR	Beats/min	The mean heart rate	The mean number of heartbeats per minute
RMSSD	ms	The root-mean-square variance of adjacent RR intervals	RMSSD reflects the changes of cardiac antonomic function
SD1	ms	Standard deviation of the Poincaré plot perpendicular to the identity line	SD1 reflects the short-term dynamics of HRV
LF	ms^2	Low frequency (0.04-0.15 Hz)	LF possibly correlated to sympathetic tone or to autonomic balance
HF	ms^2	High frequency (0.15-0.40 Hz)	HF is considered to the activity of the parasympathetic system (vagus nerve)
VLF	ms^2	Very low Frequency (0.0033-0.04Hz)	VLF reflects sympathetic nerve regulation function
TP	ms^2	Total power spectral area (00.50 Hz)	TP is a broad measure of autonomic activity

3. Results

3.1 Heart Rate Variability Parameters

3.1.1 Time Domain Analysis

Following alcohol consumption, significant main effects of intervention were observed in MeanHR (mean heart rate, average number of heartbeats per minute), RMSSD (root mean square of successive RR interval differences, reflecting vagal function), and SD1 (standard deviation of the Poincaré plot perpendicular to a straight line, reflecting short-term dynamics of heart rate variability).

3.1.2 Frequency Domain Analysis

Following alcohol consumption, LF (low-frequency power, frequency band 0.04–0.15 Hz, reflecting sympathetic nervous system function or autonomic nervous system balance), HF (high-frequency power, frequency band 0.15–0.4 Hz, reflecting vagus nerve [parasympathetic nervous system] function), , VLF (0.0033–0.04 Hz, reflecting cardiac sympathetic regulation), and TP (LF+HF, 0.5 Hz, representing total HRV during the test period and serving as a broad measure of autonomic activity).

In summary, data analysis using repeated measures ANOVA in SPSS revealed that hyperbaric oxygen therapy demonstrated more pronounced effects on MeanHR, LF, HF, and TP, while nasal oxygen therapy showed greater efficacy on SD1, RMSSD, and VLF.

Table 2. Comparison of HRV in Different Intervention Groups

Mean±SD		Time-domain analysis			Frequency-domain analysis			
		MeanHR	RMSSD	SD1	LF	HF	VLF	TP
Control	Pretest	39.68±18.31	9.27±15.69	6.74±11.58	0.99±0.79	0.50±0.64	1.86±1.23	1.49±1.25
	Midtest	38.33±23.07	10.31±13.45	7.40±9.76	0.65±0.74	0.35±0.60	2.17±1.23	1.00±1.16
	Posttest	37.14±22.22	11.76±15.07	8.17±10.94	0.66±0.70	0.42±0.63	2.08±1.20	1.08±1.19
	Total	38.38±21.12	10.45±14.87	7.43±10.85	0.77±0.77	0.43±0.63	2.04±1.23	1.19±1.22
NIO	Pretest	39.68±18.31	9.27±15.69	6.74±11.58	0.99±0.79	0.50±0.64	1.86±1.23	1.49±1.25
	Midtest	30.73±21.85	17.82±21.22	12.89±15.47	0.63±0.75	0.32±0.52	2.30±1.21	0.95±1.14
	Posttest	35.08±21.11	12.82±17.31	9.23±12.62	0.62±0.72	0.34±0.52	2.21±1.22	0.96±1.15
	Total	35.16±20.61	13.30±18.65	9.62±13.63	0.75±0.78	0.39±0.57	2.12±1.24	1.13±1.21
HBO	Pretest	39.68±18.31	9.27±15.69	6.74±11.58	0.99±0.79	0.50±0.64	1.86±1.23	1.49±1.25
	Midtest	46.12±19.20	5.36±7.78	3.82±5.56	0.96±0.69	0.81±0.69	1.46±1.14	1.78±1.27
	Posttest	41.47±19.82	8.97±16.29	6.70±12.20	0.89±0.75	0.53±0.60	2.01±1.34	1.42±1.26
	Total	42.43±19.13	7.87±13.99	5.74±10.35	0.95±0.75	0.61±0.66	1.78±1.27	1.56±1.27

3.2 Cognitive Function Indicators

Following alcohol consumption, no significant main effects, time effects, or interaction effects were observed for alertness and orientation functions across intervention methods. However, a significant

main effect of intervention method was found for executive control and inhibitory control functions after drinking.

In summary, data analysis using repeated measures ANOVA in SPSS revealed that hyperbaric oxygen therapy demonstrated greater efficacy in enhancing executive control, while nasal oxygen therapy showed greater efficacy in improving inhibitory control.

Table 3. Comparison of Cognitive Functions in Different Intervention Groups

Mean±SD		警觉	定向	执行控制	抑制控制
Control	Pretest	26.21±18.04	33.85±33.06	93.14±61.09	93.50±64.67
	Midtest	16.45±23.31	34.03±27.61	84.20±27.15	87.18±27.42
	Posttest	12.24±18.40	37.42±19.08	92.91±61.09	87.77±41.08
	Total	18.30±19.80	35.10±26.58	90.08±49.78	89.48±44.39
NIO	Pretest	26.21±18.04	33.85±33.06	93.14±61.09	93.50±64.67
	Midtest	14.95±20.86	39.88±20.37	62.95±26.52	63.77±35.01
	Posttest	9.17±19.20	35.28±24.97	77.13±24.41	55.10±31.55
	Total	16.78±19.37	36.34±26.13	77.74±37.34	70.79±43.74
HBO	Pretest	26.21±18.04	33.85±33.06	93.14±61.09	93.50±64.67
	Midtest	14.85±16.50	40.51±22.97	57.77±25.41	68.53±36.64
	Posttest	10.13±19.51	31.82±22.96	57.42±20.66	56.01±37.54
	Total	17.06±18.02	35.39±26.33	59.44±35.72	72.68±46.28

4. Discussion

Hyperbaric oxygen therapy demonstrated superior overall efficacy compared to nasal oxygen therapy, particularly in significantly improving HRV's LF, TP, and executive control. However, its high equipment requirements limit its application to medical institutions or fixed wellness centers. Nasal oxygen therapy offers operational simplicity and advantages in RMSSD, VLF, and inhibitory control, making it suitable for field and individualized applications. Post-intervention results indicate both interventions produce sustained effects lasting at least 60 minutes, providing experimental support for the “on-site oxygen therapy” strategy following high-altitude intoxication.

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