Cerebral Oxygenation Responses to Acute Hypotension Under Hypoxic Conditions

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Synopsis

In this study, we investigated the effects of acute hypotension, induced by thigh-cuff deflation, on mean arterial pressure (MAP) and prefrontal oxygenated hemoglobin (O_2Hb) during hypoxia. Nine students were tested under room air (RA) and hypoxic (HA; 15% O_2) conditions. Although HA caused a gradual decrease in baseline O_2Hb, the acute reductions in MAP and O_2Hb following cuff deflation were significantly smaller in HA than in RA. Furthermore, the slope of the O_2Hb decrease was less steep during HA. These findings suggest that hypoxia attenuates prefrontal O_2Hb responses to sudden hypotension in healthy individuals.

Background

The brain is a vital organ, accounting for 15–20% of cardiac output (Ainslie and Brassard, 2014) and consuming approximately 20% of total oxygen (Claassen et al., 2021), despite representing only 2% of body weight. Lassen (1959) reported that cerebral blood flow remains relatively constant even when the mean arterial pressure (MAP) ranges between 60 and 150 mmHg. However, a decrease in oxygenated hemoglobin (O_2Hb)—a proxy for cerebral blood flow—has been observed when MAP declines rapidly (Tsubaki et al., 2023). Furthermore, the effects of an acute drop in blood pressure on MAP and cerebral blood flow during hypoxia remain unclear. Therefore, in this study, we aimed to investigate the effects of acute hypotension, induced by a thigh-cuff occlusion-deflation maneuver, on MAP and O_2Hb during experimental hypoxia.

Methods

Participants

Nine healthy university students (six females; age: 21.1 ± 0.7 years; height: 164.4 ± 6.8 cm; weight: 57.7 ± 6.0 kg; body mass index: 21.3 ± 1.8 kg/m^2) participated in this study. The study was approved by the Ethics Committee of Niigata University of Health and Welfare and was conducted in accordance with the Declaration of Helsinki. All participants received both verbal and written explanations of the study and provided informed consent prior to participation.

Experimental procedures

Participants were instructed to abstain from alcohol and caffeine consumption and to avoid strenuous exercise on the day prior to the experiment. During the experiment, participants sat in a recumbent chair in a quiet laboratory, with a 105 × 750 mm thigh cuff wrapped around both proximal thighs, and rested for 5 min. Following the rest period, a digital air tourniquet (MT-960; Mizuho Corporation, Tokyo, Japan) was used to inflate the thigh cuffs to 250 mmHg for 2 min. The cuffs were then rapidly deflated to induce a decrease in MAP. This procedure was performed before (room air inhalation; RA) and after inhalation of hypoxic air (fraction of inspired

O_2 = 15%; HA) for 10 min. During the experiment, MAP, O_2Hb levels in the left and right prefrontal cortex (LPFC and RPFC, respectively), and skin blood flow (SBF) were measured.

Measurements

MAP was measured using a continuous blood pressure and hemodynamic monitoring device (Finapres NOVA; Finapres Medical Systems, Enschede, Netherlands) equipped with an arm cuff placed on the upper left arm and a finger cuff on the third finger of the left hand to detect beat-to-beat blood pressure. O_2Hb was continuously measured as an index of regional cerebral blood flow using a near-infrared spectroscopy system (LABNIRS; Shimadzu Corporation, Kyoto, Japan) positioned over the frontal lobe. The probes were placed with a 30-mm inter-optode distance in accordance with the international 10–20 system, with source and detector fibers positioned over the left and right LPFC and RPFC, respectively. Changes in SBF were measured at the forehead using a laser Doppler blood flow meter (Omegaflow FLO-CI; Omegawave Inc., Osaka, Japan), which collected data from the scalp layer within 1 mm of the probe.

Analyses

Changes in each parameter over time were calculated relative to the average resting value, and 1-s averaged data were used for analysis. The mean value during the 30 s prior to cuff release was defined as the baseline. The maximum change from baseline was defined as a decrease in O_2Hb, and the slope to the O_2Hb nadir was calculated. To compare the RA and HA conditions, a paired t-test was performed at a significance level set at 0.05.

Results

During HA, although MAP and SBF were maintained, O_2Hb gradually decreased to -42.5 ± 11.7 μM·cm in LPFC and to -34.3 ± 12.5 μM·cm in RPFC. The decreases in MAP and SBF were significantly smaller in HA than in RA. Similarly, the reduction in O_2Hb was significantly smaller in HA in both the LPFC and RPFC. The slope of the decrease following cuff deflation was also smaller in HA in both the LPFC and RPFC (Table 1).

Table 1. Comparison of MAP, SBF, and O_2Hb between RA and HA conditions.

	RA	HA	p value
MAP drop (mmHg)	-27.8 ± 5.0	-8.9 ± 6.7	< 0.001
SBF drop (a.u.)	-60.0 ± 21.1	-38.5 ± 19.7	0.008
O_2Hb drop in LPFC (μM·cm)	-15.4 ± 5.1	-5.4 ± 3.5	0.002
O_2Hb drop in RPFC (μM·cm)	-12.5 ± 4.3	-6.9 ± 4.5	0.02
Slope of O_2Hb decrease in LPFC (μM·cm, s^{-1})	-1.1 ± 0.4	-0.2 ± 0.4	0.003
Slope of O_2Hb decrease in RPFC (μM·cm, s^{-1})	-1.0 ± 0.5	-0.3 ± 0.5	0.01

RA, room air; HA, hypoxic air; MAP, mean arterial pressure; SBF, skin blood flow; O_2Hb, oxyhemoglobin; LPFC, left prefrontal cortex; RPFC, right prefrontal cortex.

Discussion

In this study, we aimed to investigate the effects of acute hypotension on MAP and O_2Hb under RA and HA conditions. The primary findings were as follows: 1) during HA inhalation, MAP and SBF were maintained, whereas O_2Hb decreased gradually; 2) after cuff deflation, the decreases in all parameters were smaller in HA than in RA; and 3) the slope of the O_2Hb decrease was less steep in HA than in RA.

The thigh cuff occlusion-deflation maneuver is frequently used as a non-pharmacological and non-invasive method to induce acute hypotension. Previous studies have reported that MAP decreases by 25–30 mmHg under RA conditions (Ogoh et al., 2014, Iwamoto et al., 2020). In the present study, the observed decrease of 27.8 ± 5.0 mmHg indicates that an appropriate reduction in MAP was achieved.

Although each parameter decreased under HA conditions, O_2Hb in both the LPFC and RPFC decreased gradually despite sustained MAP and SBF. These findings suggest that O_2Hb in the PFC may be more sensitive to hypoxia than MAP.

In addition, the slope of the O_2Hb decrease was less steep in HA. The reduction observed during the 10 min of HA inhalation was greater than that induced by the thigh cuff occlusion-deflation maneuver, which may have influenced these results.

In conclusion, this study demonstrates that hypoxia attenuates the decrease in O_2Hb levels and reduces the slope of this decline in the PFC following acute hypotension in healthy individuals.

Disclosures

The authors declare no conflicts of interest and have nothing to disclose.

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