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Characteristics of EEG activity during high altitude hypoxia and lowland reoxygenation

Jin-ping Zhao[a], Ran Zhang[b,1], Qian Yu[b], Jia-xing Zhang[b,*]

[a] Health Department of Beijing Military Region Air Force Logistics Department, 100005 Beijing, China
[b] Department of Physiology, Medical College of Xiamen University, Xiamen 361102, Fujian, China

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ABSTRACT

The aim of the present study was to determine the effect of high altitude (HA) immigration on cerebral electrical activity. Electro-EncephaloGraphic (EEG) activity were recorded from 25 lowland soldiers during eyes-closed resting conditions under the following conditions: 7 days at lowland before ascending to altitude (Test 1), during the first 7 days (Test 2) and 30 days (Test 3) at 3800 m altitude, and 7 days after return to lowland (Test 4). The EEG was Fourier transformed to provide absolute and relative power estimates for the alpha, beta, delta, and theta bands. HA immigrants showed changes of EEG power confined in the posterior parietal cortex, right posterior temporal cortex, and occipital cortex. Compared with baseline Test 1, acute acclimatization (Test 2) only decreased theta power; chronic acclimatization (Test 3) discriminately increased alpha and beta powers but decreased delta power; after descending to lowland (Test 4), alpha power decreased, beta power remained increase, but delta and theta power recovered to the baseline level. Our findings demonstrated different EEG patterns during hypoxia exposure at HA as time goes on and after following reoxygenation at lowland, showing hypoxia decreased lower EEG frequencies while hypoxia/reoxygenation increased higher EEG frequencies. Our findings supports for the hypothesis that certain behavioral and physiological changes induced by sojourn at altitude could be caused by alterations in central nervous system function.

1. Introduction

The number of people travelling to high-altitude (HA) for work, study, or training is rising. They usually stay at HA for several months to several years. For example, in China, Qinghai-Tibet Railway (average 4500 m) was built by more than 100,000 workers (Wu et al., 2007). Many people worked at mines in South American Andes (4500 m) and at Mauna Kea Observatories on the Big Island of Hawaii (4200 m) (West and Readhead, 2004). Each October, United States Antarctic Program scientists went in for work at the Amundsen-Scott South Pole Station (2835 m) (Anderson et al., 2011). The underlying problem with HA is that there is less oxygen. With more and more people immigrating to HA, the effects of hypoxia on body have drawn more and more attention.

It is known that the electrical activity of the brain is sensitive to its oxygen supply. Abnormal Electro-EncephaloGraphy (EEG) has been generally observed in many studies of hypoxia that induced by low oxygen gas mixtures (Schellart and Reits, 2001) and by simulated HA in hypobaric chamber (Guger et al., 2008; Kraaier et al., 1988; Malle et al., 2016; Ozaki et al., 1995; Papadelis et al., 2007; Schneider and Strüder, 2009; Shi et al., 1987), during rapid ascent to altitudes (Feddersen et al., 2015; Finnegan et al., 1985; Forster et al., 1975; Gritti et al., 2012; Guger et al., 2005; Hota et al., 2012; Kaufman et al., 1993), and in HA natives (Richardson et al., 2011).

HA immigrants have shown deficit in cognitive function (Zhang et al., 2011) and impairment in microstructure (Zhang et al., 2012, 2013), which indicated an impairment of neuronal function. However, up to now little is known about characteristics of EEG in these populations. Only two studies were performed on acclimatized lowlanders, but they were not a self-control design (Hota et al., 2012; Selvamurthy et al., 1978), and among which one study was conducted on subjects with cognitive impairment (Hota et al., 2012). Moreover, after returning to lowland, some people suffered from "HA deadaptation reaction" (Zhou et al., 2012), while most people did not feel any deadaptation. How reoxygenaration affects neuronal activity also remains unclear. In the present study, 25 lowland soldiers who immigrated to HA for 1 month were recruited for examining EEG activity before, during, and several days after HA exposure. We hypothesized that HA exposed brain could have different EEG patterns during hypoxia exposure at HA as time goes on and after following reoxygenation at lowland.

Abbreviations: HA, high-altitude; EEG, Electro-EncephaloGraphy
* Corresponding author.
E-mail address: zhangjiaxing@xmu.edu.cn (J.-x. Zhang).
[1] This author contributed equally to this work.

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2. Results

HA immigrants showed changes of EEG power confined in the posterior parietal cortex, right temporal cortex, and occipital cortex (Fig. 1).

2.1. Alpha power

There were significant increases of alpha power in Test 3 vs. Test 1 at Pz and Oz and in Test 3 vs. Test 2 at Pz, P4, O1, and Oz; whereas there were significant decreases of alpha power in Test 4 vs. Test 1 at P3, in Test 4 vs. Test 2 at P3, and in Test 4 vs. Test 3 at P3, Pz, O1, and Oz (Fig. 2; Table 1).

2.2. Beta power

There were significant increases of beta power in Test 3 vs. Test 1 at TP8, Pz, and O2 and in Test 3 vs. Test 2 at TP8, P4, and T6; whereas there were significant increases of beta power in Test 4 vs. Test 1 at Pz and O2 and in Test 4 vs. Test 2 at P4 and T6 (Fig. 3; Table 2).

2.3. Delta power

There were significant decreases of delta power in Test 3 vs. Test 1 at T4, TP8, P3, Pz, P4, Oz, and O2, in Test 3 vs. Test 2 at T4, TP8, P3, Pz, P4, T6, O1, Oz, and O2, and in Test 4 vs. Test 3 at TP8, P3, Pz, O1, Oz, and O2 (Fig. 4; Table 3).

2.4. Theta power

There were significant decreases in theta power in Test 2 vs. Test 1 at T5 and O1 and in Test 2 vs. Test 4 at T5 (Fig. 5; Table 4).

3. Discussion

To our knowledge, this is the first before-and-after study in which EEG recordings were conducted at both lowland and extreme plateau. In our study, HA immigrants showed changes of EEG power confined in the posterior parietal cortex, right temporal cortex, and occipital cortex. Compared with the baseline level tested before ascending to Lasa, acute acclimatization only decreased theta power; chronic acclimatization discriminately increased alpha and beta powers while decreased delta power; seven days after descending to lowland, beta power remained increase and alpha power decreased, with delta and theta powers recovering to the baseline level.

3.1. Acute HA acclimatization decreased theta power

In our study, in the first seven days of HA exposure, acute acclimatization only decreased theta power in the left temporal and occipital areas but did not change alpha, beta, and delta powers. In agree with our findings, relative theta decreased in nine males who rapid ascend to an altitude of 4300 m (Kaufman et al., 1993). However, in disagree with our study, increase of theta frequency has been noticed during acute normobaric hypoxia evoked by breathing a hypoxic gas (Schellart and Reits, 2001).

During acute acclimatization to HA, previous studies mainly showed the changes of beta frequency. For example, beta activity was significantly reduced 1 h after the cable car ride at 2700 m (Guger et al., 2005) and within 12 h in hypobaric chamber (Guger et al., 2008); in contrast, beta powers increased after a six-day marathon at 4300 m (Gritti et al., 2012), after 2-days' mountain (3440 m) climbing (Feddersen et al., 2015), and following a 40 min hypobaric hypoxic exposure (Schneider and Struder, 2009).

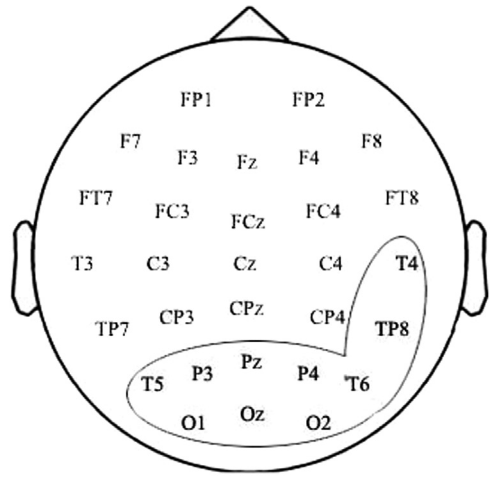

Fig. 1. Graphical representation of the changes of EEG power located at the brain.

The different results obtained from our study and the previous studies may be related to altitude level where EEG recorded. For example, in the first stage of hypobaric hypoxia (at 3000 m) alpha activity was decreased, while in a further stage starting at 5000 m theta activity was enhanced (Ozaki et al., 1995). Moreover, compared with simulated HA in hypobaric chamber, environmental factors such as hypothermia and hypobaria at HA can also affect physiological functions of the body (Malle et al., 2016). It has been shown that deep hypothermia reduced EEG power (Lamartine Monteiro et al., 2016; Niquet et al., 2015). In addition, the subjects in our study have acclimatized to HA since they spent 6 days gradually ascend to HA and the test was done 7 days later.

3.2. Chronic HA acclimatization increased alpha and beta but decreased delta power

In our study, after a 30-day HA exposure, chronic acclimatization discriminately increased alpha and beta powers in the middle posterior parietal and occipital areas and decreased delta power in the right temporal and occipital areas. In consistent with our findings, Selvamurthy et al. (1978) recorded alpha in lowlanders at HA (3500 m) from 2 up to 28 days at several time-points, respectively, and found that the mean alpha index increased and amount to 33.2% compared with lowlanders at sea level (25.5%). In subjects with cognitive impairment staying at HA (4300 m) above 12 months, there was an increased alpha power at temporal areas (Hota et al., 2012).

Previous studies suggested that delta oscillations were generated by the interplay between the intrinsic currents from the thalamocortical cells and recorded from the nucleus accumbens, ventral tegmental area, ventral pallidum, and brain stem (Güntekin and Başar, 2014). In our previous studies, changes of neuronal activity in the pon and thalamus were found in HA residents (Yan et al., 2010, 2011) and an increase of gray matter volume in pon was found in the adult immigrants during adaptation to HA (Zhang et al., 2013). Therefore, we suggest the decrease of delta power in chronic HA acclimatization may be related to the functional and structural alteration in delta generated brain regions.

3.3. Descending to lowland increased beta but decreased alpha power

Up to now, no EEG recordings were conducted in HA

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