Original Article

Fundamental Frequency of Voice under Normobaric and Hypobaric Hypoxia

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Abstract

Background: Hypoxia is a powerful stressor which affects health and voice of the people travelling to high altitude (HA). An attempt has been made to examine whether fundamental frequency (F0) of voice may be used as reliable indicator of HA stress.

Method: Experimental Studies were conducted in the two phases. Phase-I: Six subjects were exposed to 4 hours normobaric hypoxia (NH) for 4 consecutive days. On the day-5, all subjects were airlifted to HA of 11,500ft above sea level (MSL) and remained at HA for next four days. Phase-II: In this study, 12 subjects were taken as 6 test subjects and 6 control subjects. On day-1, test subjects performed step exercise after 4 hour of NH exposure. On day-3, all 12 subjects were airlifted to an altitude of 11500 ft and remained at HA for next six days. In both studies, voice samples were recorded before exposure at MSL, after NH exposure and at 11,500ft using mobile phone instrument. The recorded data was analysed using PRAAT software.

Results: The F0 increased after NH exposure in both studies. However, the F0 decreased closer to normoxia (MSL) at HA. After 3 days stay at HA, F0 decreased below normoxia. No significant effect of exercise was observed in study-2.

Conclusion: The research work done may provide benefits of knowing effects of normobaric hypoxia exposure on humans before going to HA. Fundamental frequency of voice may be used as non-invasive indicator of hypoxic stress for people travelling to HA.

Keywords: Normobaric Hypoxia, Hypobaric Hypoxia, Fundamental Frequency, High Altitude.

IJASM 2015; 59(2): 37-43

Introduction

Humans visit high altitude (HA) areas either by choice or under compulsion of livelihood. Physiological effects of exposure to low partial pressure of ambient oxygen start appearing above 8000ft or 2400m above MSL. This altitude is generally referred to as High Altitude (HA) [1]. Deficiency of oxygen affects mental ability, respiration, and work efficiency of an individual [2]. With higher altitude, air density decreases and with that the availability of oxygen also decreases [3]. Therefore, it is important for people going to HA to counter the hazardous effects of hypoxia for their safety and performance [4]. There is abundant literature documenting physiological adaptations and pathophysiological consequences of hypoxia. To cater to the need of hypoxic acclimatization, more recent work has been focused on exploring the functional benefits of repetitive hypoxia exposure on sports and medicine community. Beneficial effects of intermittent hypoxia exposure (IHE) in patients and exercise performance in athletes have been reported [5, 6, 7]. The IHE involves exposing a stationary or exercising

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subject to an environment of reduced ambient oxygen levels by diluting the ambient air with Nitrogen gas for varied periods in specially constructed hypoxia chambers, at normal ambient sea level atmospheric pressure.

A number of investigations have also been carried out to examine the effect of hypoxia because of changes in HA on human voice. It has been reported that, as climbers ascent to HA, they experience increase in vowel duration and difficulty in speech motor sequencing [8]. Hypoxia also changes fundamental frequency (F0) of voice [9, 10]. The F0 is the result of passive stress on vocal folds and muscles of articulators. These muscles are sensitive to environmental conditions and psycho-physiological stress. Therefore, changes in F0 may signal hypoxic, emotional or physical state of a speaker [11-14]. The hypoxia has also been reported to have different effects on speech formant structures at different altitudes [15]. A study to compare the effect of acute hypoxia and chronic hypoxia on F0 concluded that acute hypoxia resulted in small incremental change in F0, however chronic hypoxia led to considerable increase in F0, i.e. from 140 to 170 Hz [16]. In a recent study, vowels articulated at different altitudes (200, 800, 1400, 1800, 2200, 2600m) were analysed [17, 18]. It was reported that with increase in altitude; F0 increased. Subjects exposed to simulated height of 5500m (18045ft), also experienced increase in fundamental frequency (F0) [19].

High efficiency aircraft pilots also experience hypoxia under various operational conditions. To discover the signs of hypoxia in voice, data from cockpit voice recorder has analysed. Sound spectrograms of repeated utterances of a subject in a simulated low-pressure flight chamber were compared with the last words of two pilots of the fatal F-104J that had encountered an accident during high-altitude intercept procedures. It was reported that decrease in F0 of pilot's voice, at the stressful period of attack, was due to hypoxia [20]. In another study, effect of hypoxia in pilot's voice was investigated by monitoring the changes in utterance of sound (A) under three conditions: influence of acute hypoxia alone, combined effects of hypoxia and mental stress and under normal barometric pressure. It was reported that, acute hypoxia associated with mental stress caused greater degradation of voice structure compared to hypoxia alone or under normal barometric pressure [21]. Research till date has indicated significant physiological effects of hypoxia at HA. However, changes in voice parameters of same subjects exposed to normobaric hypoxia (NH) prior to ascent to high altitude have not yet been explored. Therefore, this study aims to investigate changes in fundamental frequency of voice under different hypoxic conditions (mentioned below). This study was exploratory in nature and was part of a larger study conducted to assess the effect of different hypoxic conditions on human physiology.

Aims and Hypothesis

(a) Study-1: Effect of normobaric hypoxia followed by hypobaric hypoxia at 11500ft above mean sea level (MSL) on the human voice.

(b) Study-2: Effect of exercise in addition to normobaric hypoxia followed by hypobaric hypoxia at 11500ft above MSL on human voice.

Material and Methods

Total 18 healthy male soldiers distributed in subgroups of 6 people participated in the study. All subjects were inhabitants of low altitude. At mean sea level (MSL), normobaric hypoxia chamber of Biomedical Instrumentation Division, Defence Institute of Physiology and Allied Sciences (DIPAS), DRDO, New Delhi, India was used. New Delhi is at an altitude of 709ft (216m) close to sea level (SL). Local barometric pressure at the time of study was 735mmHg. The length, width and height of normobaric chamber were 4.06m, 2.08m, 2.4m respectively. The chamber was programmed to simulate an altitude of 12000ft above MSL, temperature inside the chamber set at 23° C and humidity was maintained at 44%. To create the hypoxic environment, chamber was flushed with Nitrogen gas. Percentage of oxygen in the chamber was reduced to 12%. The range of CO_2 inside the chamber was set between 0.02 - 0.04 %. A feed back controlled CO_2 scrubber using soda lime was constantly run during operations. Concentration of oxygen and CO_2 was constantly controlled within the chamber with the feed-backsystem. For hypobaric exposure, subjects were airlifted to an altitude of 11500ft above sea level (MSL), their designated port of duty. Cabin altitude inside the aircraft was 8,000ft and duration of flight was 50 minutes. Five hours after arriving at 11,500ft, voice was recorded. On the subsequent days, voice was recorded in the morning between 8-10am. They remained at this altitude for a period of 4 to 6 days. No physically demanding work was given to the subjects during their stay at HA (i.e. 11,500ft above sea level). Mobile phone of Samsung (S-II model) was used to record voice in AMR file format with sampling rate of 44.1 kHz (16 bit). All audio clips were archived in .WAV format for further processing. Acoustic analysis was done using PRAAT v 5.3.56 (Boersma and Weenink, 2010) software. PRAAT is a freeware program for analysis of speech in phonetics [22]. In the present study, acoustic analysis was done on whole raw utterances 10-12 sec long (with silence removed). Statistical analysis was done using paired T- test with MS-Excel 2013. A medical doctor was present with the subjects at all times during the experiments.

Study-1: Hypoxic stress on voice

Study-1 consisted of six healthy male soldiers (age 30± 4.23 years). On day-1, all soldiers recorded their name, employment ID no, date and place of recording. Voice was recorded outside the normobaric chamber in a closed noise free room with all air conditioners and fans switched off. General introduction was chosen so that voice samples could be recorded in absence of any cognitive stress and without any prior training. After the recording, all six subjects were asked to sit inside the normobaric chamber for 4 hours. They were free to talk to each other or relax. To eliminate possibility of additional stress, subjects were not involved in any cognitive or physical task. Immediately after 4 hours exposure, voice was recorded inside the chamber. In between 4 hours, no recording was done. This followed for 4 consecutive days at SL. On day-5, all six subjects travelled to an altitude of 11,500ft by air. Subjects stayed at this height for 4 days and recorded voice every day.

Study-2: Hypoxic stress and physical stress on voice

To investigate the effect of exercise in addition to normobaric hypoxia exposure (NHE), a study similar to study-1 was conducted. Twelve healthy male soldiers (age 29 ± 6.75 years) participated in this study. These subjects were different from the subjects of study-1. They were divided into two groups of six subjects each and designated as control group (CG) and hypoxia exposed test group (TG). On day-1, voice of all 12 subjects was recorded outside the normobaric chamber in a closed noise free room with all air conditioners and fans switched off. After the recording, six test subjects were exposed to normobaric hypoxia in the chamber described in study-1 for 4 hours. After the exposure, subjects exercised following the Queen College test protocol (25). They exercised at the rate of 24 steps per minutes using a low height wooden stool of 16.25 inches. Immediately, after exercise, voice was recorded inside the normobaric chamber itself. On day-3, all 12 subjects travelled to an altitude of 11500ft by air and stayed at this height for six days. Voice was recorded every day.

Results

Effect of normobaric and hypobaric hypoxic exposure on human voice was investigated. Henceforth in this paper, AE will refer to the average of F0 of all subjects before exposure on day-1 at mean sea level (MSL) i.e. ambient pressure. Delhi is referred as close to sea level (SL) due to insignificant physiological changes at height of Delhi (709ft or 216m). Fig 1 shows a plot between F0 and four hour normobaric hypoxia exposure (NHE) for four consecutive days. It was observed that F0 increased after acute 4 hour NH exposure on each day. On fourth day, after the exposure, F0 was higher than that on day-1 before exposure (BE). Increase in fundamental frequency (F0) (averaged across subjects) was statistically significant ($p < 0.01$) (BE vs. AE) (Fig 2). On day-1 at HA, a marginal increase in F0 was observed as compared to BE on day-1 at MSL (Fig 2a). F0 decreased on day-3 at HA. Fig 2(a) compares the shift in F0 of all subjects on day-1 BE, day-1 AE and day-1 at 11500ft. Fig 2(b) and 2(c) shows similar comparisons on day-3 and day-4 respectively.

The study-2 investigates impact of exercise in addition to normobaric hypoxia exposure (NHE). Fig 3(a) shows the shift in F0 of control group (CG) at 11500ft with respect to ambient pressure at MSL. Fig 3(b) shows the shift in F0 of test group (TG) on day-1 BE, day-1 after exposure (AE) of NH with exercise and day-1 at 11500ft. In Fig 3b, (D-1) BE refers to Day-1 at MSL before exposure and (D-1) AE+ Ex refers to after NH exposure with exercise on day-1 itself. Similarly, (D-1) HA refers to day-1 at high altitude i.e. 11,500 ft above sea level (SL). Significant increase [**p=0.00017 (BE vs. AE)] in fundamental frequency (F0) was observed after 4 hour NHE with exercise as seen in Fig 3(b). Fig 3(c) compares the response of CG and TG on day-1 at SL and on day-1 at HA. On initial exposure to HA, F0 for test group was only slightly higher than F0 at SL before exposure (BE), however for control group, F0 at HA was significantly higher than at SL. Furthermore, on day-3 at HA, F0 decreased for both groups. The percentage changes in fundamental frequency (F0) of control group (CG) and test group (TG) are given in Table 1. Percentage change was calculated on all days at high altitude with respect to these baseline values. At MSL, baseline F0was 114.75 ± 6.74 Hz and 142.2 ± 18.07 Hz for control subjects and test subjects respectively.

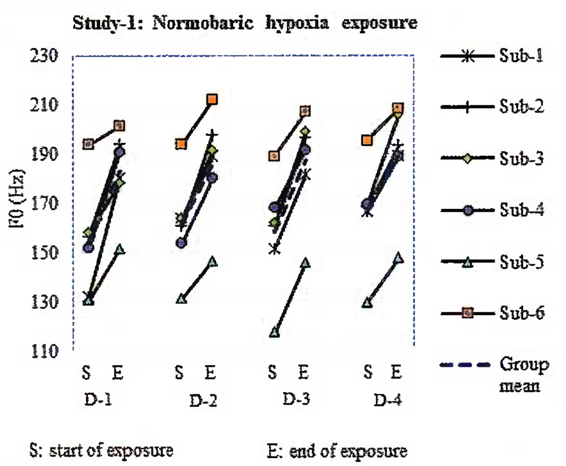

Fig 1. Shift in F0 (averaged across subjects) under the influence of normobaric hypoxia exposure (NHE) on D-1 (Day-1); D-2 (Day-2); D-3(Day-3) and D-4 (Day-4).

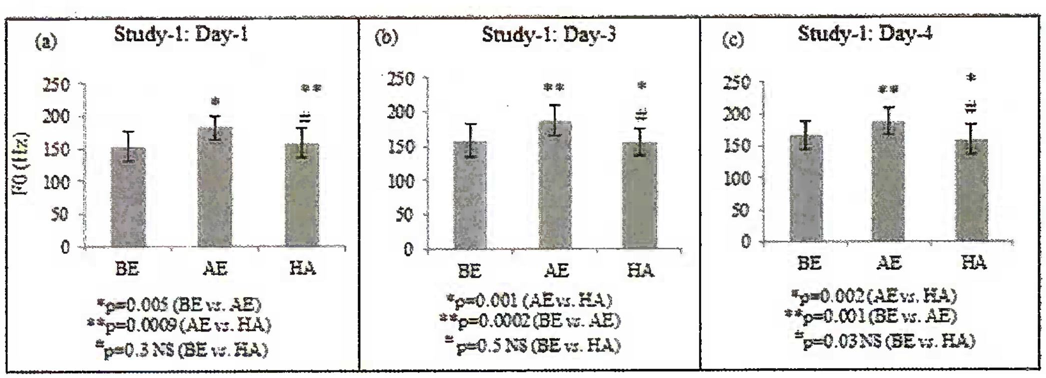

Fig 2. Day wise comparison of shift in F0 (averaged across subjects) before exposure (BE) at MSL, after NH exposure (AE) and at 11500ft (HA) on (a) Day-1, (b) Day-3 and (c) Day-4 respectively. (Values are means ± SD). NS: Non-significant.

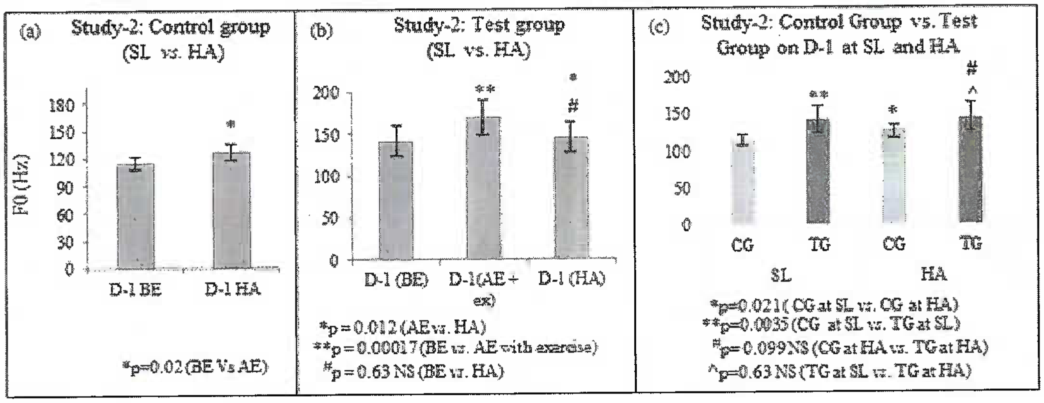

Fig 3. Shift in F0 (averaged across subjects) for (a) control group (b) test group (c) comparison of response of control group (CG) and test group (TG) on Day-1 at SL and on Day-1 at HA (Values are means ± SD). NS: Non-significant.

Table 1. Percentage change in F0 of control group (CG) and test group (TG) during six days at high altitude (HA) with respect to MSL. (Values are means ± SD).

Hypoxic Exposure	Control group (CG)	Percentage change in F_0 of CG (%)	Test group (TG)	Percentage change in F_0 of TG (%)
D-1 at HA	127.13±8.46	10.78	145.5±18.31	2.32
D-2 at HA	133.54±7.21	16.37	150.01±19.49	5.49
D-3 at HA	130.23±7.99	13.49	145.82±20.76	2.54
D-4 at HA	129.08±11.50	12.48	140.5±19.26	-1.19
D-5 at HA	130.1±10.48	13.3	142.86±19.61	0.46
D-6 at HA	131.05±11.60	14.20	141.94±17.65	-0.18

Discussion

Structured analysis of acoustic measures, under the influence of normobaric hypoxia and hypobaric hypoxia indicated strong correlation between hypoxic stress and fundamental frequency (F0) of voice in both studies. Normobaric chamber simulated to 11500ft resulted in increase in F0 (Fig 1). Obtained results are in agreement with the findings of Milkica N. et.al (2009) where the subjects were exposed to height of 5500m (18045ft) and experienced increase in F0. Prolonged exposure to 5500m, resulted in still higher values of F0. Milivojevic Z.N. et.al (2012) examined influence of different altitudes on human voice and reported that F0 increases with increase in altitude. In the present study, acute hypoxia of 11500ft resulted in a marginal rise in F0, however it failed to reveal any significance (#p=0.3 NS (BE vs. HA) on day-1 (Fig 2a); (#p=0.5 NS (BE vs. HA) on day-3 (Fig 2b) and (#p=0.03 NS (BE vs. HA) on day-4 (Fig 2c). The probable reason for marginal increase in F0, may be as subjects were pre-exposed to NH, prior to ascent to HA (Fig 2a). Non-significant effect of high altitude on F0 indicated beneficial effects of pre-exposure to NH before ascent to HA. In contrast, Satio et al.,

(1980) reported that hypoxia was the reason for decrease in fundamental frequency (F0) of pilot's voice, during the stressful period when fatal F-104J encountered accident. However, reported research also states an increase in the F0 for initial period of 16 minutes and 17 minutes that led to a continuous drop later on till the fatal accident occurred [20]. There is variation of individual sensitivity to hypoxia in humans. Further, conditions of stated research study do not conform to healthy individuals who are exposed to and are conditioned to hypoxic stress as compared to healthy volunteers of current study.

Exercise in addition to NHE resulted in significant increase in F0 (Fig 3b). Percentage change in F0 due to NHE with exercise was 19.26% (study-2) whereas that due to pure effect of hypoxia was 18.9% (study-1). Literature documents increase in F0 due to exercise alone in absence of hypoxia [14, 23, 24]. However, in study-2, combined effect of hypoxia and physical stress was marginally the same as that due to hypoxia alone indicating no significant effect of exercise. Exercise did not add to physical stress probably because subjects were soldiers who exercised regularly. According to Johannes et al., (2007), F0 remains unchanged, till the physical load is within the tolerance limit of the subject, and increases shortly before physical exhaustion. At HA, significant increase [(*p=0.02 (BE vs. HA)] in F0 of control group (CG) was observed (Fig 3a). Furthermore, at HA, F0 of test group (TG) did increase marginally, but failed to reach any statistical significance [#p=0.63 NS (BE vs. HA) Fig 3b)]. This indicates that exposing subjects to NHE before sending them to HA, helps early acclimatization and protects from AMS. Fig 3c compares the response of CG and TG on day-1 at SL and day-1 at HA. At SL both groups were breathing ambient air. At HA, the CG and TG behaved almost in the same pattern (Fig 3c) except that F0 of TG was higher than that of CG over the entire duration of stay at HA. Furthermore, it was observed that F0 rises during initial two days at HA for both groups and then slightly shifts downwards on day-3. This conforms to the stress level and follows the hypoxic stress pattern. Change in voice at HA was also discernible by normal ear. The results of the main study indicated that exposing subjects to normobaric hypoxia (NH) before sending them to high altitude, helps early acclimatization.

Conclusion

Effect of hypoxia on all subjects during an acute four hour normobaric exposure was seen in both study 1 and study 2. The F0 increased on exposure to normobaric hypoxia. Normobaric hypoxia exposure (NHE) with and without exercise resulted in no significant change in F0 at high altitude (HA) as compared with baseline. On day-3 at HA, F0 decreased following the physical acclimatization pattern of exposure. The effect of hypobaric hypoxia was found more in the control group as compare to test group. It concludes indication of benefits of NHE on test group before going to HA. Further, the F0 may be considered as a potential vocal indicator of hypoxic stress.

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