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DYNAMICS OF HEART RATE UNDER STEP TEST LOADINGS AS AN INDICATOR OF ALTITUDE ACCLIMATISATION

DINAMIKA FREKVENCE SRCA MED STEP TESTOM KOT KAZALEC AKLIMATIZIRANOSTI NA POVEČANO NADMORSKO VIŠINO

Abstract

The human body's adaptation to the decreased partial pressure of oxygen is called altitude acclimatisation. It is particularly important for alpinists who perform high-intensity workouts at a high altitude. Assessing someone's level of acclimatisation is a difficult problem. In our study, which was conducted prior to and during an expedition to the Peruvian Andes in South America organised by the Faculty of Sports of the University of Ljubljana, our main goal was to analyse the heart rate (HR) as an indicator for assessing the level of acclimatisation to high altitudes. The experiment consisted of five testing sessions, based on a simple step test, before and during the expedition. Eleven people took part in the experiment, eight of whom were female. The analysis yielded interesting results especially in the change of HR after a prolonged time at higher altitudes. Contrary to other studies, our research showed an increase in HR after the acclimatisation period. We concluded that in future studies, it is very important, especially out in the field, to monitor all the main factors that influence HR. Only in this case can HR become useful for monitoring personal acclimatisation.

Key words: high altitude, step test, heart rate, acclimatisation

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Izvleček

Prilagajanju organizma na zmanjšan delni tlak kisika pravimo višinska aklimatizacija. Ta je ključnega pomena za alpiniste, ki plezajo na večjih višinah. Oceniti kdaj je alpinist dovolj dobro aklimatiziran za plezanje na velikih višinah je zapleten problem. Z njim se do sedaj raziskovalci niso veliko ukvarjali. V raziskavi, ki smo jo izvedli v okviru odprave v Perujske Ande pod okriljem Katedre za gorništvo, športno plezanje in aktivnosti v naravi, Fakultete za šport, je bil naš cilj preučiti frekvenco srca (FS), kot kazalec aklimatiziranosti. Ta kazalec smo izbrali zaradi relativno enostavnega merjenja in prenosa podatkov na terenu. Eksperiment je potekal v obliki petkratnega testiranja preiskovancev s testom stopanja na klopco pred in med odpravo. Meritve so bile izvedene na enajstih posameznikih od katerih je bilo osem žensk. Po analizi rezultatov pridobljenih med procesom aklimatizacije in ob zaključku odprave smo dobili zanimiva dejstva predvsem o spreminjanju FS med potekom aklimatizacije. Iz njih je razvidno povečevanje FS po obdobju aklimatizacije kar je v nasprotju z večino dosedanjih raziskav. Ugotovili smo tudi, da so meritve na terenu zahtevnejše kot v laboratoriju in da se na terenu nenehno spreminja veliko dejavnikov, ki vplivajo na FS. Smiselno je izvesti nadaljnje raziskave z več preiskovanci in večjim številom spremljanih spremenljivk, na podlagi katerih bo lahko alpinist na odpravi sam, s pomočjo merilca FS, ocenil raven svoje aklimatiziranosti.

Ključne besede: velika nadmorska višina, step test, frekvenca srca, aklimatizacija

INTRODUCTION

Humans are sensitive to changes in their environment. A person is adapted to the environment in which they live and as soon as they move to different environmental conditions the adaptation process begins. The most important goal of adaptation is to restore homeostasis. Hypoxia is one of the main environmental factors influencing the human body at a higher altitude. Considering the expansion of sports in nature, more and more people are daily encountering the problem of adapting to a higher altitude. The effects of high altitude can have serious consequences for the health of an individual. The only way to avoid the unwanted effects is to undergo a proper adaptation to altitude called altitude acclimatisation.

The main environmental changes that occur at a higher altitude are reduced air temperature, reduced humidity, increased UV radiation and, most importantly, the decreased partial pressure of oxygen (PO_2). It was only in 1878 when Bert, contrary to previous beliefs, stated that the problems at a high altitude are due to decreased PO_2 (Balado, 1996). Decreased PO_2 gradually affects the ability to perform. On top of Mount Everest (8,848 m), the maximal oxygen consumption ($VO_{2\,max}$) is reduced to 10-25 % of that at sea level (Costill, 1999). So it is essential for an alpinist to acclimatise properly if they want to perform well.

Many existing studies on the topic of acclimatisation agree that the process of acclimatisation starts the moment we arrive at a new altitude (Soles, 2002; Clarke, 1975). According to Wilmore & Costill (1999), the three main responses induced by altitude are metabolic, respiratory, and cardiovascular. If we focus on the cardiovascular response, the first change following an ascent to a higher altitude is an increase in the heart rate (HR) (Cornolo et al., 2004; Antezana, 1994; Revees et al., 1987). The response is different with the maximal HR, which decreases or remains the same right after the ascent (Mori, 1983; Boogard et al., 2002).

The autonomic nervous system is one of the main factors determining the organism's response to altitude. Several studies (Cornolo et al., 2004; Boushel et al., 2001) have revealed there is an increase in sympathetic and a decrease in parasympathetic activity directly after an ascent, consequently resulting in an increased HR. Heartley et al. (1974) used atropine to block the parasympathetic activity at altitude and also noticed an increase in the HR after an ascent. This result suggests that the sympathetic nervous system plays a more important role in the HR change after an ascent to a higher altitude.

The hormonal response is another important factor influencing the cardiovascular response to higher altitudes. Researchers do not agree on the changes in adrenalin and noradrenalin blood level following an ascent to altitude. Some experiments showed no changes in their concentrations (Balado et al., 1996), while others (Mazzeo et al., 1995) showed an increase in adrenalin concentrations directly after an ascent. In another study by Mazzeo et al. (1998), a statistically significant correlation between the noradrenalin level during acclimatisation and HR was reported. At the same time, the correlation between the adrenalin level and HR was lower.

Since the hormonal response can be influenced by the menstrual cycle phase (Goldstein et al., 1983; Zacur et al., 1978), gender might be an important factor influencing the process of acclimatisation. The question of the menstrual cycle's affect on the symphatoadrenal response in women at altitude was addressed by Mazzeo et al. (1998). Their results showed that the urinary and plasma catecholamine responses to 12 days of high altitude exposure are similar to those previously shown in men. The results also revealed that there is no significant difference in catecholamine levels between the follicular and luteal phases of the menstrual cycle. The same group (Mazzeo et al. 2000) also studied differences in catecholamine responses in women exercising during and following a ten-day altitude exposure (4,300 m) and showed that the responses did not differ between the menstrual cycle phases and were similar to those previously found in men.

Until recently, not many researchers have focused on the problem of assessing the quality of acclimatisation to a high altitude. So far, only a few physiological indexes have been tested for this purpose, all of which can be measured in the lab and outside in the field. Saito et al. (1994) chose the oxygen saturation of the blood (SaO_2) as a potential index and showed that the difference in SaO_2 during exercise was larger right after an ascent and was lowering during acclimatisation. They concluded that it might be possible to assess the quality of acclimatisation with a simple portable oxymeter. The second index, used by Pavlidis et al. (2005), is intra-ocular pressure (IOP). Measuring IOP is more complicated and has to be done in a tent since stable temperatures are needed. Their results show that IOP increases with an ascent and then progressively decreases during acclimatisation. They also confirm that IOP is directly connected to intra-cranial pressure so it could perhaps be a useful index for preventing serious altitude-related problems like cerebral edema.

The main aim of our experiment was to discover if HR dynamics during a step test provide a convenient index for assessing the level of acclimatisation to a high altitude. For this purpose, a series of tests consisting of step-test loadings were made before and during an expedition to the Peruvian Alps. The main goal was to determine if alpinists can use a simple wrist watch monitor to assess their acclimatisation during expeditions.

METHODS

Participants

The participants were members of an expedition to the Peruvian Andes organised by the Department of Mountaineering, Sport Climbing and Outdoor Activities at the Faculty of Sport, University of Ljubljana. The members were students and professors of the Faculty. Eight females (age 26.6 ± 7.4 yr, height 165.9 ± 6 cm, body mass 61.4 ± 7.4 kg) and three males (age 41.6 ± 15.6 yr, height 181.7 ± 9.1 cm, body mass 79.6 ± 7.9 kg) co-operated in this experiment. Together, 11 healthy volunteers were included.

Instruments

During the experiment we monitored the heart rate (HR) as one of the basic physiological indexes which can be measured outside the laboratory and which, according to previous studies, changes during acclimatisation. To measure the HR we used Polar heart rate wrist watch monitors. We continuously measured the HR of all the participants during the whole duration of the five tests. The data were transferred from the monitors to a personal computer after each test. We also measured SaO_2 during the protocols but were unable to use the data because the oxymeter did not work properly in the cold and windy conditions.

Procedure

The experiment consisted of five testing sessions before and during the expedition. In each test the members' HR was monitored while they performed a step test, which consisted of two rest periods and one exercise period – stepping on a 20 cm step with a frequency of 0.25 Hz. The

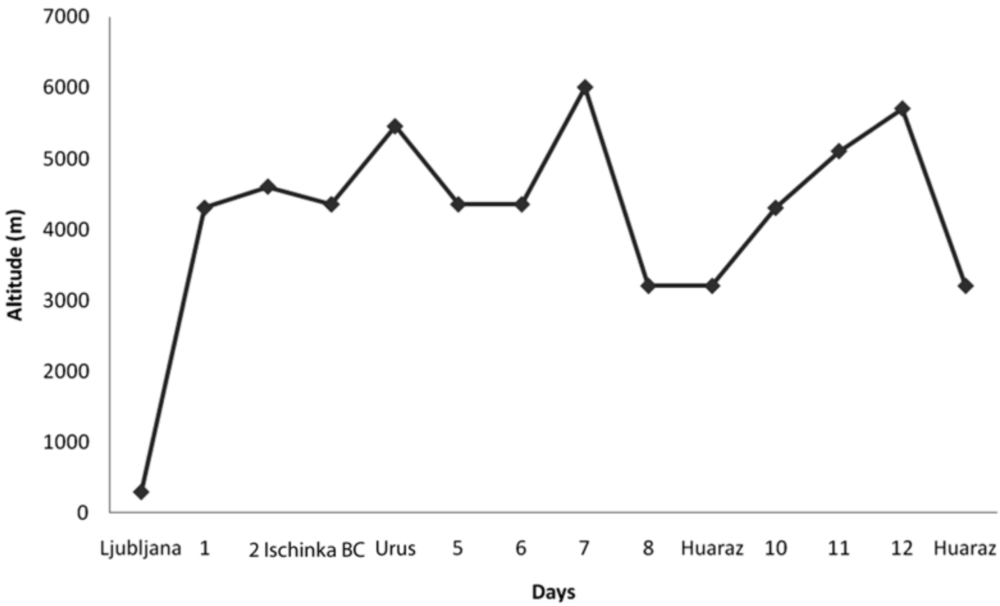

Figure 1: Altitude profile of the tour and the testing locations

Legend:
- (circles) normal days without testing
- (squares) testing days

exercise period lasted for five minutes while each rest period lasted for three minutes. To make sure that all the participants would also be able to perform the assigned step test protocol at higher altitudes, the height of the step was 20 cm. This height has already been used in other studies (Richie et al. 2005). We decided to use a step test to evaluate the changes which occur between the rest HR and HR during the step-test loading. We used the step test because of its simplicity and the possibility to use it in a mountain environment.

Except for two testing sessions (both in Huaraz at 3,200 m), all the tests were done at different altitudes. The first took place in Ljubljana (300 m) two weeks prior to departure, namely at the end of June 2005, while all the others were during the expedition. The second test was at an altitude of 4,300 m at the Ischinka base camp during the first acclimatisation climb. The third test was on the same day at an altitude of 5,100 m, after the return from the summit of Urus. The last two tests took place in Huaraz at 3,200 m above sea level. Expedition members unsuccessfully attempted to climb Mount Artesonrahu where they reached an altitude of about 5,300 m in between the last two tests. Figure 1 shows the altitude profile of the tour and testing locations.

We used Student's paired t-test for the statistical analysis considering that HR is a continuous numerical variable and the subjects in all the samples (at the different tests) were the same. The results were marked as statistically significant at $p < 0.05$.

RESULTS

Our statistical analysis confirmed a statistically significant increase in the HR after an ascent to a higher altitude compared to lowland values. We included three tests in this analysis: the first test in Ljubljana, the test at the Ischinca base camp, and the test on Urus. The first test was done at an altitude of 300 m above sea level while the other two were done at altitudes of 4,200 m and 5,100 m. All three paired tests showed a statistically significant increase in HR after an ascent to a higher altitude (in all analyses p = 0.000-0.009).

The main focus of our project was the change in the HR during a prolonged time at a higher altitude. Unexpectedly, the results showed an increase in the average HR at the end of the acclimatisation period compared to the starting values. For this analysis we used the following three tests: the Ischinca base camp (4,200 m) and the two testings done in Huaraz (3,200 m). The changes in the HR at the beginning of the step test (HR at rest) at these three locations are shown in Figure 2. Figure 3 shows the changes during the step tests (average HR during exercise). Because of the difference in the altitude, the comparison between the first two tests is not as relevant as the one between the second two.

A comparison of both testings in Huaraz, which were made at the same altitude, shows that the average HR was significantly higher at the second test (p = 0.004 – 0.022). Considering the differences between males and females we performed an individual analysis which confirmed an increase in the average HR (at both rest and during exercise) between the two tests done in

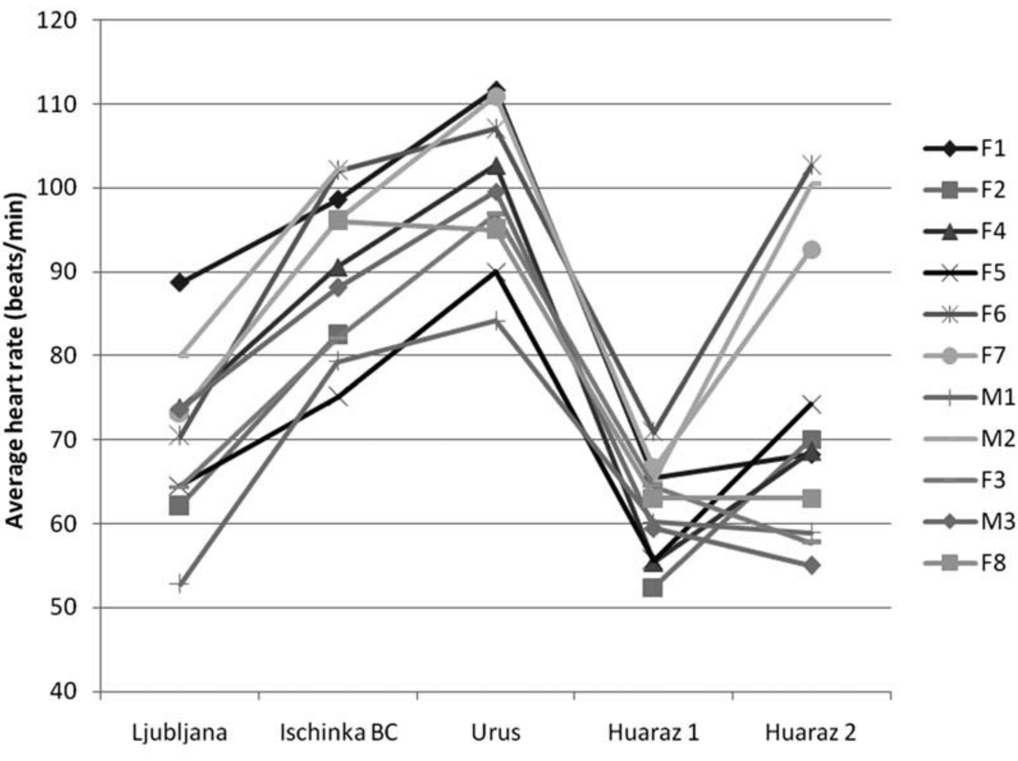

Figure 2: Individual average HR (beats/min) at the beginning of the five tests (the rest HR)

Legend:
F1-F8 Female participants
M1-M3 Male participants

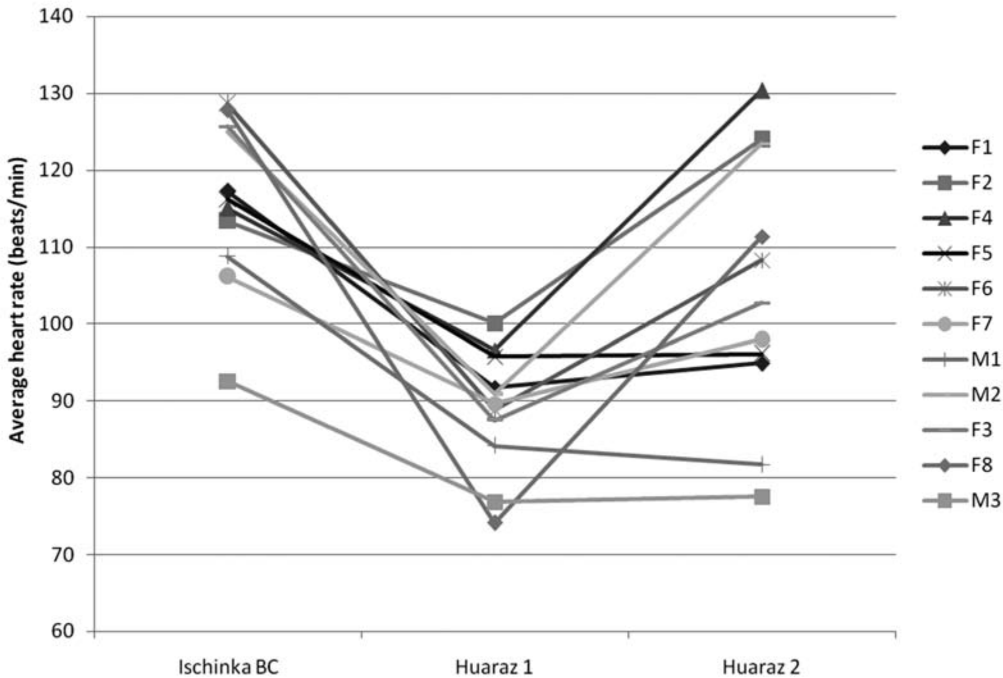

Figure 3: Individual average HR (beats/min) during the test at the Ischinka base camp and at both tests in Huaraz

Legend:
F1-F8 Female participants
M1-M3 Male participants

Huaraz, as seven out of eleven (six females and one male) participants had a significantly higher HR in the second test compared to the first. At the second test in Huaraz, only one female and one male had slightly decreased HR values at rest and only one male had a lower HR during exercise. This can also be seen in Figures 2 and 3. A statistically significant decrease of HR in the second test in Huaraz was only observed in two participants ($p = 0.000 – 0.15$). The results are contrary to our hypothesis that the HR decreases after a certain acclimatisation period.

Because of these unexpected results, we decided to compare the average HR immediately after the protocol, using the speed of recovery of the HR after a workout as an index of tiredness. The results of the analysis show no statistically significant difference ($p = 0.145 – 0.589$).

We also analysed the relative changes in the HR between rest prior to and between the protocols. We compared these changes individually in all the tests, at different altitudes and at different times. The results show no statistically significant differences (all analyses $p = 0.057 – 0.785$).

DISCUSSION

Our results reveal a statistically significant increase in the HR following an ascent to a higher altitude (Figure 2), as also shown in previous studies (Cornolo et al., 2004; Antezana et al., 1994; Revees et al., 1987). The mechanism responsible for this change has already been well explored. Due to decreased PO_2 there is an increase in sympathetic activity (Hughson, 1994) and an increase in adrenalin blood concentrations (Mazzeo, 1995) leading to increased HR. Our results show that all members of the expedition reacted as expected, namely, their HR increased after the initial ascent to a higher altitude.

On the other hand, our analysis of the HR changes during the whole expedition gave results which are contrary to previous studies (Figure 2). We predicted that HR would decrease after a period of acclimatisation, yet our results show otherwise. We compared the two tests made in Huaraz on the 9th and 13th day of the expedition and detected a statistically significant increase of the HR in the second test (Figure 3). This is contrary to other studies (Cornolo et al., 2004, Boushel et al., 2001) which showed a decrease in the HR after a period of acclimatisation, probably due to a progressive increase in parasympathetic activity and noradrenalin concentration and a decrease in adrenalin blood concentrations (Mazzeo et al., 1995).

We considered the increased tiredness of the participants as a probable cause of these contradictory results. Since the speed of the HR recovery to rest values is an appropriate index of assessing tiredness (Ušaj, 1995), we compared the HR between the exercise and right after it. Our analysis shows no statistically significant differences in the HR recovery between test Huaraz 1 and test Huaraz 2, which did not confirm this hypothesis. Another possible interpretation of the results could be that the majority of participants were in the initial (sympathetic) phases of overtraining syndrome which is characterised by excessive training that results in several adverse effects, the main one of which is a decrement in performance (Rogero et al., 2005).

When we carefully studied the overall expedition we found three important factors which could have caused this. The first is the difference in time between coming to Huaraz and performing the protocol. The first test in Huaraz was in the morning of the second day after returning to Huaraz from the first acclimatisation tour. Contrary to that, the second test in Huaraz was in the afternoon of the same day, after the participants had descended from an altitude of 4,300m. The second main factor is the difference in work loads that were substantially larger on the second acclimatisation tour (before the second test in Huaraz) compared to the first one. The third possible factor is the quality of food intake on the second acclimatisation tour, where the participants had low supplies of food which was also of less quality. This was confirmed by the fact that the participants' body weight decreased on average by 4.3 kg for the males and 1.8 kg for the females.

One of the main problems in all studies dealing with indicators of acclimatisation is that the level of acclimatisation is hard to define. In our study we simply used the time spent at a higher altitude as the determinant of the level of acclimatisation. We assumed that the longer someone stays at a certain altitude or above it the more they are acclimatised. According to our results, judging only by HR, one could think that the participants were less acclimatised at the end than during the expedition. This is, of course, highly improbable and other possible explanations should be considered, as was done in the previous paragraph. In future research it would therefore be reasonable to measure several indicators of acclimatisation at the same time. For example, Pavlidis (2005) and Saito (1994) showed that SaO_2 and IOP can be used as potential physiological indexes indicating the level of acclimatisation. The drawback of their studies is that they do not specify how one can do that in practice. They also do not clarify how the level of acclimatisation should be assessed. Pavlidis (2005) suggests using the Lake Louise scale, which is generally employed for assessing altitude sickness, as an indicator of acclimatisation quality. This scale could be used in addition to physiological indexes (HR, SaO_2) to compare the participants' sensations with physiological measurements.

Although gender is a factor that might be important in the cardiovascular response to higher altitudes, some recent studies (Mazzeo et al. 1998, 2000) show there are no specific differences in symphatoadrenal responses between men and women at altitude. Also, there is no agreement on the actual influence of the menstrual cycle phase on cardiovascular and other responses to exercise. The latest findings (Smekal et al. 2007) suggest there are no significant differences in the performance ability of women between different phases of their menstrual cycle. On the other hand, some studies show differences in exercise performance during different phases of the cycle, not only due to hormonal changes but also due to blood loss causing a reduced plasma volume and haemoglobin concentrations (de Jonge, 2003). We first analysed the results of the male and female participants together but re-evaluated them with individual analysis and found no significant differences. However, we did not monitor the phase of the menstrual cycle in the women, but will include this in future studies.

The main problem of using HR as an index of the acclimatisation level lies in its complex regulation mechanism. It is especially difficult to monitor all the influential factors outdoors and at a high altitude. Throughout the research we realised that some improvements to the standardisation of the protocol should be made. The time between a previous workout and the protocol must always be the same. Also, the time scale of the testing sessions during the expedition should be exactly appointed in advance. For example, in our research there was no initial test done right after arriving in Huaraz (on the first day in Peru), which would have provided some orientation starting values. It would be easier to quantify the changes during the acclimatisation compared to these values.

Our research confirmed that HR does change significantly during altitude acclimatisation and it is therefore an appropriate physiological index to be monitored at a higher altitude, especially because it can be easily and non-invasively measured. It seems reasonable to co-monitor certain other indexes like SaO_2 and IOP in further studies and use them together in combination with the Lake Louise scale to assess the acclimatisation level.

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