Journal of Exercise Physiologyonline

August 2017
Volume 20 Number 4

Official Research Journal of the American Society of Exercise Physiologists

ISSN 1097-9751

JEPonline

Preparation for Altitude in the 2010 FIFA World Cup: A Study of Japan's National Team

Akiko Honda[1,2], Masako Hoshikawa[1], Yuji Kobayashi[1], Yoko Saito[1], Takeo Matsubayashi[1], Naoki Hayakawa[3], Michiko Dohi[3,4], Yasuhiro Suzuki[1]

[1]Department of Sports Sciences, Japan Institute of Sports Sciences, Tokyo, Japan, [2]Asahi University, School of Health Sciences, Gifu Japan, [3]Japan Football Association, Tokyo, Japan, [4]Medical Center, Japan Institute of Sports Sciences, Tokyo, Japan

ABSTRACT

Honda A, Hoshikawa M, Kobayashi Y, Saito Y, Matsubayashi T, Hayakawa N, Dohi M, Suzuki Y. Preparation for Altitude in the 2010 FIFA World Cup: A study of Japan's National Team. **JEPonline** 2017;20(4):108-119. A project to customize pre-acclimatization programs based on individual susceptibility to hypoxia was planned for the 2010 FIFA World Cup. To assist this project, we analyzed physiological responses and evaluated susceptibility to hypoxia. Thirty-eight Japanese national soccer team members performed the hypoxic ventilatory response (HVR) test and running test. The running protocol was set at 150 $m \cdot min^{-1}$ (Run150) and 250 $m \cdot min^{-1}$ for 3 min (Run250) under normoxia and hypoxia (simulating 2000 m). Blood lactate concentrations (La), heart rate (HR), and oxygen saturation levels (SpO_2) were monitored during the running test. The rates of change in these parameters were calculated by comparison between hypoxia and normoxia at each speed. To identify players who were severely affected by hypoxia, they were ranked using a point system based on the order of HVR and the rates of change. Large individual differences in HVR (0.000-1.520 $L \cdot min^{-1} \cdot \%^{-1}$) and rates of change in La (e.g., -11.1 to 73.7% at Run250), HR (-3.4 to 16.0%, similarly), and SpO_2 (-5.5 to -16.5%, similarly) were found. Our data suggest that understanding and assessing individual susceptibility to hypoxia is important for altitude preparation.

Key Words: Conditioning, Soccer, Hypoxia, Pre-Acclimatization

INTRODUCTION

There are many studies and reviews on the effects of hypoxia on physiological responses and performance that indicate negative outcomes in both exercising and non-exercising situations (1,6,8,9,11,12). Physiological responses associated with exercise at increased altitude or in hypoxic conditions compared to sea level include higher blood lactate concentration (La), heart rate (HR), ventilation, and perceived effort, and decrease in oxygen saturation level (SpO_2) and exercise performance. In addition, these individual responses to hypoxia widely vary (8). Even at moderate altitudes, subjects occasionally suffer from problems such as headaches, loss of appetite, dizziness, tiredness, weakness, restless sleep, and decreased quality of sleep (1,9,14,16). These symptoms are characteristic of a condition known as acute mountain sickness (AMS) and impair not only the execution of physical activities but also recovery from those exertions. The prevalence of AMS is affected by individual variability, susceptibility, or the degree of pre-acclimatization (1,7,22). Some studies suggested that altitude acclimatization is the best strategy for prevention of AMS, and pre-acclimatization before training or competition at altitude might be beneficial (5,18,25). Thus, negative effects of hypoxia might lead to deconditioning or a decline in performance unless there is prior acclimatization to hypoxia.

Previous studies (3,5,17) reported the benefits of intermittent hypoxic exposure (IHE) and indicated an increase in hypoxic ventilatory response (HVR) or a decrease in the incidence of AMS. The HVR is known as an index of ventilatory chemosensitivity to hypoxia (24). However, because there is individual variability in response to hypoxia and the process of adapting to different altitudes (2,7,8), a set protocol might be high-loading for some athletes and low-loading for others. Although the utility of IHE is recognized, an effective protocol, including set altitude and oxygen levels, times, periods, and frequencies, remains speculative (5,17). Therefore, while individualized programs based on personal susceptibility are recommended, scientists and coaches are still refining procedures.

In the 2010 FIFA World Cup in South Africa, various matches were held at low to moderate altitudes above 1000 m. Half of the stadiums in convention sites were located at these altitudes with the highest stadium at 1763 m. Therefore, many players faced issues due to the hypoxic conditions, varying temperature, and humidity. The FIFA (Fédération Internationale de Football Association) Sports Medical Committee and FIFA Executive Committee provided recommendations and guidelines for training and playing soccer at different altitudes (2). This consensus statement and other reports recommended “several days of acclimatization” for competitions held at low altitude (above 500− 2000m), and IHE for acclimatization was not recommended (2,12). However, for Japanese soccer players, living or playing under hypoxic conditions is uncommon, and none of the national players had experience with it, even at low altitude levels. In the 2010 FIFA World Cup in South Africa, Japan’s first and third matches were held at Free State Stadium (1400 m) and Royal Bafokeng Stadium (1500 m). Additionally, as a part of the countermeasure for altitude, the national training camp prior to competition took place at Saas-Fee in Switzerland (1800 m). Therefore, we, along with the coaches and trainers, strongly recognized the importance of conditioning that incorporated pre-acclimatization to hypoxia.

In April 2010, as a primary approach, the Japan Football Association (JFA) planned to customize a pre-acclimatization program using IHE based on susceptibility to hypoxia for the

2010 FIFA World Cup in South Africa. To assist with this proposal, we initially analyzed basic physiological responses under hypoxic condition, and evaluated susceptibility to hypoxia.

METHODS

Subjects

The subjects consisted of 38 male Japanese soccer national team members and candidates (mean ± standard deviation, age: 26.4 ± 3.8 yrs; height: 178.0 ± 5.7 cm; weight: 73.3 ± 5.5 kg). Four players were goalkeepers (GKs). All subjects had already taken a pre-competition medical assessment as recommended by FIFA, and none had medical problems.

Experimental Procedures

All measurements were performed more than 2 hrs after breakfast or lunch at the Japan Institute of Sports Sciences (JISS). This study was approved by the ethical committee of the JISS. We informed the subjects of the experimental procedures, methods, and risks and started measurements only after obtaining consent from the subjects. These experimental measurements were performed from April to May in 2010.

After measuring body weight and height, the HVR test at rest was started under normoxia. After that, measurements of La, HR, and SpO_2 during treadmill running under normoxia and normobaric hypoxia (O_2 = 16.4%, simulating 2000 m) were recorded.

HVR Test

The subjects rested for 20 min before HVR measurements. The HVR was measured by a progressive isocapnic hypoxic test described in detail by Weil et al. (24). During the test, respiratory parameters were continuously measured with a gas analyzer using the breath-by-breath mode (Aeromonitor AE-300, Minato Medical Science Company, Osaka, Japan). Simultaneously, SpO_2 was measured at the tip of the left forefinger using a pulse oximeter (OLV-3100, Nihon-Kohden Company, Tokyo, Japan). At first, the subject breathed room air for 5 min and then started the test. The test was finished when SpO_2 was less than 70%, or the subject asked to stop the test. We minimized human and methodological errors by having only one person who was an experienced investigator perform the HVR measurements.

Exercise Protocol and Measurements of Physical Responses

Based on results from analysis of soccer games at the top level (20), we calculated the rates of various activity times and obtained the following data. More than 80% of game time was spent walking and jogging at a speed of less than 240 $m \cdot min^{-1}$, approximately 7% consisted of running (240 to 330 $m \cdot min^{-1}$. We chose two running speeds: “jogging” at 150 $m \cdot min^{-1}$ and “running” at 250 $m \cdot min^{-1}$. These speeds reflect actual running speed in a game, of which the subjects could maintain them for 3 min without compulsive loading.

The subjects ran at 150 $m \cdot min^{-1}$ for 3 min to warm up, and after 3 min, they started the main exercise. The submaximum running protocol was set at 150 $m \cdot min^{-1}$ for 3 min (Run150) and 250 $m \cdot min^{-1}$ for 3 min (Run250) with 1-min intervals under normoxia. After 20 min of rest (the first 10 min for normoxic and the following 10 min for hypoxic conditions), subjects ran again using the same protocol under hypoxia without warming up. HR and SpO_2 were monitored on the forehead every second using a multi-channel telemeter system (Web-7000, Nihon Kohden Company, Tokyo, Japan) throughout the exercise test. HR and SpO_2 in each running

session were estimated as the average of the last 30 sec. Two blood samples were taken from the fingertip immediately after each running session, and La was analyzed using a lactate analyzer (Lactate Pro, Arkray Inc., Kyoto, Japan). La was estimated by averaging the data of 2 samples. The room temperature was set at 20 to 23°C.

Assessment and Ranking

To identify players who were more severely affected by hypoxia, we ranked and scored 7 categories: absolute HVR value and the rates of change in La, HR, and SpO_2 at Run150 and Run250. The rates of change in each parameter were calculated by comparing values under hypoxia with values under normoxia at each speed.

We defined players with a lower absolute HVR value and greater rates of change in La, HR, and SpO_2 were easily affected by hypoxia compared with players with a higher absolute HVR value and lower rates of change. The highest HVR value was estimated as the best rank, and the lowest value was estimated as the worst. Similarly, for the change in ratios of La and HR, the lowest increase in rate was estimated as the best rank, and the greatest rate of change was estimated as the worst rank. By contrast, the smallest decrease in SpO_2 was estimated as the best, and the largest amount was estimated as the worst.

We created a ranking table by using a point system. The assessment points were 1 for the best rank, 2 for the second rank, and 38 for the worst rank, in order. The final ranking was established according to the total points.

Statistical Analyses

Data are presented as mean ± standard deviation (SD). Two-way (hypoxia × running speed) repeated analysis of variance (ANOVA) was used to examine the individual variables and their interactions for changes in HR, La, and SpO_2. The correlation coefficients of HVR values and rates of change were estimated by Pearson's correlation. All statistical tests were performed by IBM SPSS Statistics 19 (IBM corp., Armonk, NY), and the significance level was set at $P<0.05$.

RESULTS

HVR

In general, lower HVR values indicate lower sensitivity to hypoxia than higher values. While the HVR values ranged from 0.000 to 1.520 $L \cdot min^{-1} \cdot \%^{-1}$, the mean HVR value was 0.476 ± 0.310 $L \cdot min^{-1} \cdot \%^{-1}$. In one subject, because linear changes between minute inspiratory flow volume and SpO_2 were not found, HVR was calculated as 0.000 $L \cdot min^{-1} \cdot \%^{-1}$.

Physiological Responses during the Exercise Test

Changes in La, HR, and SpO_2 and their ranges under normoxia and hypoxia at each running speed are shown in Table 1. In addition, all individual data in each parameter at Run250 under normoxia and hypoxia are shown in Figure 1.

Table 1. Changes in La, HR, and SpO_2 under Normoxia and Hypoxia during Running.

		Run150	(range)	Run250	(range)
La (mmol·L^{-1}) ^{A,B,C}	N	1.1 ± 0.3	(0.9 ~ 1.7)	3.1 ± 0.7	(1.8 ~ 4.7)
	H	1.2 ± 0.4	(0.8 ~ 3.0)	3.7 ± 1.0	(2.2 ~ 6.1)
HR (beat·min^{-1}) ^{A,B}	N	112 ± 10	(94 ~ 149)	122 ± 10	(133 ~ 171)
	H	150 ± 12	(102 ~ 155)	159 ± 11	(141 ~ 180)
SpO_2 (%) ^{A,B,C}	N	98.2 ± 1.0	(94.7 ~ 100)	96.8 ± 1.3	(94.3 ~ 99.0)
	H	89.9 ± 2.4	(84.6 ~ 94.7)	86.6 ± 3.2.	(79.1 ~ 92.6)

All data are mean ± SD (N = 38). **La** = Blood Lactate Concentration; **HR** = Heart Rate; **SpO_2** = Oxygen Saturation Levels. **N** = Normoxia, **H** = Hypoxia. ^{A}Significant main effect in hypoxia (P<0.01); ^{B}Significant main effect in running speed (P<0.01), and ^{C}Significant interaction (P<0.01). Hypoxia and running speed significantly increased La and HR (P<0.01), and decreased SpO_2 (P<0.01). Changes in La and SpO_2 were greater under hypoxia compared with normoxia (P<0.01)

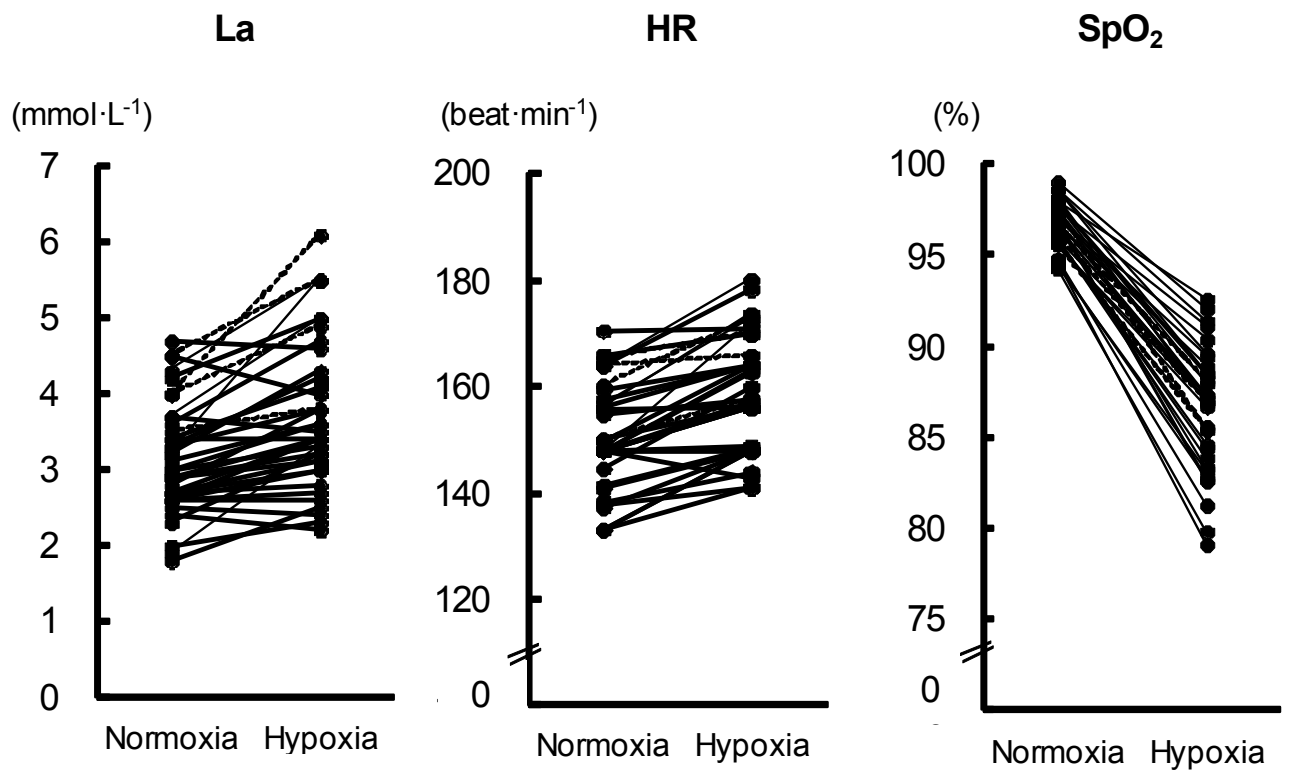

Figure 1. The Individual La, HR, and SpO_2 Data at Run250 under Normoxia and Hypoxia. **La** = Blood Lactate Concentration; **HR** = Heart Rate, **SpO_2** = Oxygen Saturation Levels. The solid lines indicate changes in field players, and the dotted lines indicate changes in goalkeepers.

There was a wide range of values and changes. In spite of submaximum exercise and moderate altitude level, hypoxia negatively affected physiological responses during exercise in several ways. There were significant main effects of hypoxia and running speed for all of the parameters and significant interactions in La and SpO_2. The La under hypoxia was higher than under normoxia (P<0.01), and it increased with running speed (P<0.001,). This increase in La with speed was greater under hypoxia than under normoxia (P<0.001). The subjects' HR response under hypoxia was higher than that under normoxia (P<0.001), and it increased with speed (P<0.001). However, increases in HR were similar in both air conditions (P=0.089). SpO_2 under hypoxia was lower than that under normoxia (P<0.001), and it decreased with speed (P<0.001). The decrease in SpO_2 with speed under hypoxia was greater than that under normoxia (P<0.001).

The rates of change in La, HR, and SpO_2 in each running speed are shown in Table 2. For example, the mean La value was 16.0 ± 25.0% at Run150 and 19.6 ± 19.4% at Run 250. However, the range was from −33.3% to 76.5% at Run150 and from -11.1% to 73.7% at Run250. Similarly, the range in HR was -3.4% to 23.5% at Run150 and from -3.4% to 16.0% at Run250. SpO_2 decreased in all subjects and ranged from -5.3% to -13.7% at Run150 and from -5.5% to -16.5% at Run250.

Table 2. Rate of Change in La, HR, and SpO_2 at the Same Running Speed (Normoxia vs. Hypoxia).

	Run150	(range)	Run250	(range)
La (%)	16.0 ± 25.0	(-33.3 ~ 76.5)	19.6 ± 19.4	(-11.1 ~ 73.7)
HR (%)	9.2 ± 6.3	(-3.4 ~ 23.5)	5.6 ± 4.2	(-3.4 ~ 16.0)
SpO_2 (%)	-8.5 ± 2.2	(-5.3 ~ -13.7)	-10.5 ± 2.6	(-5.5 ~ -16.5)

All data are mean ± SD (N = 38).

The correlations between HVR and each rate of change are shown in Table 3. There were no significant correlations among the parameters (P>0.05).

Table 3. Correlations between HVR and the Rate of Change in La, HR, and SpO^2.

	La		HR		SpO_2	
	Run150	Run250	Run150	Run250	Run150	Run250
r	0.015	-0.130	0.034	0.006	0.003	0.087

HVR = Hypoxic Ventilatory Response; **r** = Correlation Coefficient. There were no significant correlations between HVR and the rates of change.

Assessment and Feedback

A part of the ranking table in each category is shown in Figure 2(A). The final ranking established according to the total points and assessment is shown in Figure 2(B).

(A)

	HVR		Change ratio : La				Change ratio : HR				Change ratio : SpO_2			
			Run150		Run250		Run150		Run250		Run150		Run250	
rank/ point	data	sub. No	data	sub. No	data	sub. No	data	sub. No	data	sub. No	data	sub. No	data	sub. No
1	1.520	9	-33.3	28	-11.1	25	-3.4	36	-3.4	36	-5.3	10	-5.5	16
2	1.080	16	-25.0	22	-8.3	26	-3.1	10	0.0	26	-5.4	7	-6.7	5
3	0.950	30	-16.7	36	-5.4	8	-1.0	5	0.0	16	-5.7	26	-6.9	26
4	0.790	21	-15.4	24	-4.0	21	0.0	37	0.1	19	-5.9	2	-7.0	10
36	0.050	20	55.6	34	52.5	31	20.9	31	11.3	12	-12.3	14	-14.8	3
37	0.020	11	58.3	5	71.9	1	22.0	6	11.3	38	-13.4	27	-15.3	27
38	0.000	29	76.5	31	73.7	27	23.5	4	16.0	27	-13.7	3	-16.5	14

(B)

RANKING

Rank	Total Point	Sub. No
1	44	16
2	51	26
3	76	19
36	204	27
37	210	14
38	218	3

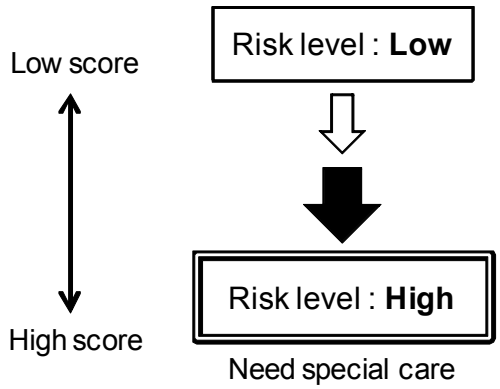

Figure 2. Profiles of Ranking (A) and Assessment (B). The parameters were scored as follows: the best rank was 1 point, the second rank was 2 points, and the worst rank was 38 points (A). Based on ranking by total points, we defined that high-scored players had a higher risk level than low-scored players under hypoxia (B).

The mean value of the total points was 137 ± 44. The highest score was 218 points (the worst rank), and the lowest score was 44 points (the best rank). The total points were not dependent upon field position (e.g., total points were 152 ± 41 in forwards, 122 ± 39 for midfielders, and 129 ± 52 in defenders, and there were no significantly statistical differences). Subjects with higher points were defined as being more severely affected by hypoxia compared to those with lower points.

DISCUSSION

In this study, we found large individual differences in the subjects' physiological responses to hypoxia, even at low to moderate altitude levels and during submaximal exercise. Therefore, our data suggest that understanding and assessing individual susceptibility to hypoxia is important for preparation for altitude. In addition, we also suggest that customizing pre-acclimatization programs based on individual susceptibility is important.

We consider HVR to be one useful index for evaluating performance, recovery, and conditioning under hypoxia, as well as for ventilatory acclimatization. We recently reported that HVR levels reflected the quality of sleep under hypoxia (15). Subjects with lower HVR values showed a decrease in slow-wave sleep (non-rapid eye movement sleep) compared to subjects with higher HVR values under simulated hypoxic conditions (2000 m). Sleep plays a key role in recovery from physical activities. In addition, the relationship between HVR level and ventilatory acclimatization during the first period of hypoxic exposure were observed (21).

However, in our study, the lowest value of HVR was 0.000, and subsequent values of 0.020, 0.050, and 0.060 were observed. A previous study also showed low values of HVR in well-trained endurance athletes (23). These results suggested that we need to recognize blunt chemosensitivity to hypoxia in some athletes. In addition, the HVR levels reflect a decrease in VO_2 max and SaO_2 during exercise under hypoxia (19). Therefore, we expected to find relationships between HVR and each change ratio, but we did not find any significance. We do not know what level of HVR is required to minimize the negative effects such as AMS, decreased performance, and/or deconditioning under hypoxia.

At altitude, many negative physiological and performance effects were observed (1,6,8,9,11,12). We also found some negative effects of hypoxia on physical responses. Additionally, our results showed a wide range of values and changes. For example, the SpO_2 level of several subjects were very low (approximately at or <80%) at Run250 under hypoxia, while some subjects maintained levels of greater than 90%. The GK tended to have higher La and HR and lower SpO_2 during exercise compared with field players. This finding indicates a difference based on the GK's specific role and training.

The findings indicate that players with larger rates of change in La, HR, and SpO_2 were more susceptible to hypoxia than subjects with smaller values. The range of rates in these parameters was also large. For instance, some subjects had a significant increase in the rate of La change at Run250 (e.g., 71.9%, 3.2 $mmol \cdot L^{-1}$ in normoxia and 5.5 $mmol \cdot L^{-1}$ in hypoxia, respectively), while some showed a small or no change in rate (e.g., 3.4 $mmol \cdot L^{-1}$ for both normoxia and hypoxia, respectively 2.6 and 2.7 $mmol \cdot L^{-1}$). Similarly, in the SpO_2 analysis, one player had -14.8% (97.0% in normoxia and 82.6% in hypoxia) while another had -5.5%

change (98.0% and 92.6%, respectively). Thus, hypoxia had a significant impact on physiological responses for some, but not for all subjects. This individual variability in the 7 categories was reflected in the ranking. Subjects with a higher rank tended to have higher points in several categories than those with lower rank and, therefore, their risk of hypoxia was also high. Consequently, we advised the team staff to provide more attention and care to high-risk players.

Altitude acclimatization might be useful to enable the achievement of maximum performance and prevent AMS in hypoxic conditions (5,18,25). IHE is one potential pre-acclimatization strategy for elite athletes prior to training or competition at altitude (5,25). However, the optimal IHE protocol remains speculative (5,17). In addition, there was individual variability in responses to hypoxia, the prevalence of AMS, and the adaptation to different altitudes (1,2,7,8,22). We considered the importance of customizing pre-acclimatization based on a subject's susceptibility to hypoxia for subjects unfamiliar with the hypoxic environment.

Hence, we approved the project planned by JFA to customize pre-acclimatization program using susceptibility to hypoxia and initially analyzed basic physiological responses during rest and while exercising. We evaluated individual susceptibility to hypoxia by ranking according to the order of HVR values and the rates of change in La, HR, and SpO_2. Pre-acclimatization using IHE was performed under the initiative of JFA. Based on experimental data, selected members were divided into 2 groups according to susceptibility to hypoxia and performed IHE in their own homes using personal altitude simulators (AltoLab ELITE Kit, AltoLab, Phoenix, AZ). The breathing oxygen level was set at approximately 3000 m (O_2 = 14.5%) for high-risk subjects and 4500 m (O_2 = 12.0%) for low-risk subjects. The IHE program consisted of 6 sets of breathing low oxygen for 6 min and, then 4 min of ambient air at rest. The subjects carried out the IHE program 7 times before departure to the altitude training camp in Switzerland.

Limitations of this Study

There are an increasing number of studies on physiological responses and performances under hypoxic condition in soccer players (4,10,13). However, in 2010, there were just a few studies focused on these concerns. Thus, we were seeking effective measurements under limited time and methods as the first attempt. The present study has several limitations. The major limitation is the experimental time. We had to measure all test within a 3-hr period that included the explanation of the experiment, informed consent, determination of HVR and exercise tests. If there was more time and multiple sessions, we could have improved the measurement of respiratory data such as including VO_2 max and some performance tests under hypoxia and normoxia. Second, although we evaluated susceptibility to hypoxia by simply ranking the HVR value and the change ratios, there might have been superior assessment methods available. Finally, we did not directly follow up with the effect of IHE intervention on pre-acclimatization and performances. Although these evaluations were essentially necessary, we could not take additional measurements because of the limited player's schedule. However, all players maintained their health status and performance without any altitude problems throughout the competitive period. The coaches and our research team felt this approach to altitude preparation was advantageous for conditioning and performance in the FIFA World Cup in South Africa.

CONCLUSIONS

This study shows that there are large individual differences in resting and exercise-induced physiological responses in elite soccer players who are not acclimated to altitude. Therefore, understanding and assessing individual susceptibility to hypoxia is important in preparing for altitude. Our approach, customizing a pre-acclimatization program based on individual susceptibility to hypoxia, advantageously contributed to the conditioning and performance of the Japanese soccer players in the 2010 FIFA World Cup. Measurements of physiological responses to hypoxia, including HVR and exercise-induced parameters, are useful in the preparation of Japanese soccer players for altitude.

ACKNOWLEDGMENTS

This work was supported by the Japan Football Association and the JISS. We thank all of the national members who participated in this study, as well as the staff of the Japan Football Association and members of the hypoxic research project at JISS. We are particularly grateful to Masaaki Sugita for implementation of IHE and conditioning.

Address for correspondence: Akiko Honda, PhD, Department of Sports Sciences, Japan Institute of Sports Sciences, 3-15-1 Nishigaoka Kita, Tokyo, Japan, 115-0056, Email: a_honda@alice.asahi-u.ac.jp

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