



Original article

An examination of respiratory and metabolic demands of alpine skiing

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Abstract

Background/Objective: To measure the cardiorespiratory and metabolic variables during the giant slalom (GS) skiing activity under actual race conditions using a mobile gas analyzer.

Methods: This study included 20 voluntary male alpine ski racers (mean age, 22.00 ± 1.45 years) who participated in international races. First, incremental running test was conducted to obtain volunteers' maximal oxygen consumption (VO_{2max}) values. Second, respiratory data were measured during their performance on the GS course. Before both GS performance and incremental running test and at 1 minute, 3 minutes, and 5 minutes after the tests, blood lactate concentration was measured.

Results: VO_{2max} values of the volunteers were 51.36 ± 2.68 mL/kg/min and they used 74.96% of this during their performance on the GS course. Their blood lactate concentrations reached the maximum level of 13.69 ± 2.06 mmol/L at the 5th minute following the maximal exercise testing. After the GS performance, blood lactate values reached the maximum level of 10.13 ± 0.43 mmol/L at the 3rd minute. While the maximum heart rate was 196.5 ± 4.3 bpm during the maximal exercise testing, it reached 201.7 ± 20 bpm during the GS performance.

Conclusion: It is observed that the GS race is a high-intensity activity and that high amount of anaerobic contribution is used by alpine ski racers during the GS race. By contrast, it is understood that the aerobic contribution is also at a considerable level during such an anaerobic activity as GS.

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Keywords: alpine skiing; cardiorespiratory; performance

Introduction

Alpine skiing is a sport that requires a constant change of speed and balance position, as well as short-term, intense efforts, and is practiced in a hypobaric, hypoxic, and cold environment.¹ Alpine skiing races consist of two speed and two technical categories that are differentiated by turning radius, speed, and course length. The speed category includes downhill and super-giant slalom (GS; super-G) races. In downhill events, the racer follows the natural slope of the mountain and can reach speeds of up to 130 km/h. A downhill contest is generally over in 2–3 minutes. The super-G, by contrast, is a combination of

downhill and GS races² and includes more turns on a shorter course.³ A typical super-G race takes 1–2 minutes to complete. The technical category comprises the slalom and GS disciplines. Whereas the GS race takes 60–90 seconds, the slalom is over in 45–60 seconds and necessitates very quick and short turns.³ Many studies on alpine skiing generally examine the GS discipline as it comprises certain characteristics of both slalom and downhill races.⁴

Although elite skiers require a medium to high level of aerobic and a very high level of anaerobic power,⁵ there are different arguments in the literature. For example, Andersen et al⁶ reported that anaerobic testing results had a strong relationship to skiing performance. Furthermore, Duvillard⁷ found that anaerobic power tests had a stronger relevance to skiing performance compared with aerobic power tests. White and Johnson² reported that although anaerobic power was

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important, it did not have any significance in several categorizations of skiers. In contrast to these early studies, a recent study on the world-famous Austrian National Ski Team showed that aerobic power had a strong relationship with international success in skiing.¹ According to the results of laboratory measurements, maximal oxygen consumption ($\text{VO}_{2\text{max}}$) values of male alpine skiers ranged between 52 mL/kg/min and 70 mL/kg/min and a significant correlation was reported between the $\text{VO}_{2\text{max}}$ values and alpine skiing performance in several studies.^{1,8,9} However, it is not clear whether the contribution of aerobic power is significant for skiing races or whether it is a result of large-scale training applied by some nations.^{1,10}

Experimental data were mostly obtained through treadmill or bicycle ergometers in the laboratory. As alpine skiing necessitates complex moves and the performance of various muscle groups, it was reported that laboratory measurements do not fully reflect the aerobic power.⁹ In alpine skiing, it is difficult to measure the oxygen consumption on the snow. Therefore, only limited data are available on aerobic demand during the skiing performance. Moreover, it is impossible to measure the oxygen consumption during an actual skiing race because of its nature. So far, very limited studies were conducted on the snow during the training or during an actual race. Karlsson et al¹¹ measured the oxygen consumption on the snow during the training by applying an old method, the Douglas bag. Their study reported that skiers used 88% of their $\text{VO}_{2\text{max}}$ during a training run. In a more recent study, von Duvillard et al¹² used the breath-by-breath method in a race that did not have an actual race speed and found that the oxygen consumption of young skiers was 58% of their $\text{VO}_{2\text{max}}$ values during the GS race.

To fully understand oxygen consumption, and respiratory and metabolic demands of alpine skiing, the measurements should be obtained using the mobile gas analysis method on the snow under conditions similar to actual races. That is why this study aimed to measure the cardiorespiratory and metabolic variables during the GS skiing activity under actual race conditions, using the mobile gas analyzer. It is thought that these results, which were taken on snow, would give fruitful new ideas to coaches to organize training programs and increase the skiers' performances.

Methods

This study included 20 voluntary male alpine ski racers, whose mean age was 22.00 ± 1.45 years and who have participated in international races. Approval was obtained from Erciyes University Ethics Committee for Clinical Research prior to the study (Decision No. 2015/415; Kayseri, Turkey). Furthermore, before the study, the volunteers were informed about the necessary issues, and signed an informed consent form.

Experimental design

The volunteers underwent several tests in the laboratory and, 1 week later, on the snow during the GS race. First,

physical parameters such as height, weight, and body compositions were recorded from each athlete and then they underwent incremental running test at the Performance Measurement Laboratory of Erciyes University High Altitude and Sport Sciences Research and Application Center. Blood lactate concentration was measured in the rest position, before the running test, and at 1 minute, 3 minutes, and 5 minutes after the test. Second, a GS course was set up on the GS course of the Erciyes Ski Center, whose homologation was granted by the International Ski Federation (FIS). The course consisted of 50 gates and followed the rules of the FIS.¹³ Blood lactate concentrations and heart rates of the volunteers were measured in the resting position before their performance on the GS course and their respiratory data and heart rates were measured during their performance on the course, using the mobile gas analyzer. Finally, their blood lactate concentrations were measured at 1 minute, 3 minutes, and 5 minutes after the performance.

Laboratory measurements

Body composition measurements of the volunteers were obtained with Tanita's bioelectrical impedance analysis. The volunteers then underwent an incremental running test. In this test, the volunteers ran on a treadmill (h/p/cosmos Quasarmed, Nussdorf-Traunstein, Germany) with an initial speed of 7 km/h on a 5% slope. The speed was then increased every minute by 1 km/h and the test was continued until volunteers desired to stop the exercise. The increase of respiratory exchange ratio to more than 1.10 during the test and the stability of oxygen consumption despite an increase in the intensity of the training were accepted as the necessary criteria to attain $\text{VO}_{2\text{max}}$. Respiratory measurements during the test were obtained using the VO2000 Portable Measurement System (Medical Graphics, St. Paul, MN, USA), consisting of a galvanic fuel cell, an O_2 analyzer, and an infrared CO_2 analyzer. The VO2000 (Medical Graphics) was previously validated, both at rest and during exercise.¹⁴ Before the test, the gas analyzer was calibrated according to the manufacturer's instructions. During the incremental treadmill exercise, the heart rates of the volunteers were measured using a telemeter coupled with the gas analyzer. After the tests, the respiratory data were sent directly to the computer with the help of the VO2000 device (Medical Graphics), without the need for any calculation.

The blood lactate concentrations were measured in the rest position before the incremental running test and at 1 minute, 3 minutes, and 5 minutes after the test. Blood samples were collected from a puncture to the volunteers' left earlobe using sterile disposable lancets. The earlobe was cleaned with neutral soap and water and then sterilized with 70% alcohol before puncturing. A 30- μL sample of blood was collected into heparinized capillary tubes, which was later transferred into tubes containing 60 μL of 1% sodium fluoride and then stored in a refrigerator at -20°C . Subsequently, the samples were thawed and analyzed in duplicates on the Yellow Springs Sport 1500 Lactate Analyzer device (YSA, Inc., Yellow Springs, OH, USA).

Measurements during the GS performance

GS performance

The volunteers performed the GS race on the Develi slope of the Erciyes Ski Center, whose homologation was granted by the FIS. Fifty gates were set up on the course in accordance with the international GS standards. Performance durations of the volunteers were determined using ALGE's electronic photocell (TdC 4000, Lustenau, Austria).

Respiratory measurements

Respiratory measurements of the volunteers during their GS performance were taken using the VO2000 Portable Measurement System (Medical Graphics), which was also used in the incremental running test. First, the gas analyzer was calibrated according to the instructions of the manufacturer at the starting point. The gas analyzer was then attached to volunteers' chest with a strap and the volunteers skied on the GS course. Following the performance, the data were transferred to a laptop. During their GS performance, heart rates of the volunteers were measured using a telemeter attached to the gas analyzer. After the tests, respiratory data were sent directly to the computer with the help of the VO2000 device (Medical Graphics), without the need for any calculation.

The blood lactate concentrations were measured in the rest position before the GS run and at 1 minute, 3 minutes, and 5 minutes after the GS run. Blood samples were collected from a puncture to the volunteers' left earlobe using sterile disposable lancets. A 30- μ L sample of blood was collected into heparinized capillary tubes, which was transferred into other tubes containing 60 μ L of 1% sodium fluoride and then stored in a refrigerator at -20°C . Subsequently, the samples were thawed and analyzed in duplicates on the Yellow Springs Sport 1500 Lactate Analyzer device (YSA, Inc.).

Statistical analysis

The results of measurements were assessed on the IBM SPSS Statistics 20 package software (IBM, Armonk, NY, USA). First, descriptive statistics of the data were created. Percentage differences between the GS performance data and maximal testing data were then calculated. The relationships between values were analyzed by the Pearson correlation test. A p value < 0.05 was regarded as significant.

Results

In this study, which aimed to measure the cardiorespiratory and metabolic variables during the GS activity under actual race conditions using a mobile gas analyzer, volunteers completed the GS course in a mean time of 61.93 ± 0.76 seconds. Physical characteristics of the volunteers are presented in Table 1.

Table 2 presents the respiratory data obtained during the maximal test and the GS performance. According to the data obtained, during the GS activity, participants used 74.96% of their $\text{VO}_{2\text{max}}$ (mL/kg/min), which they acquired during the

Table 1
Physical characteristics of volunteers.

	<i>n</i>	$\bar{X} \pm \text{SD}$	Minimum	Maximum
Age (y)	20	22.00 ± 1.45	19	24
Height (cm)	20	177.20 ± 2.93	174.00	182.00
Weight (kg)	20	73.24 ± 8.06	65.10	88.20
BMI (kg/m^2)	20	23.29 ± 2.36	21.00	27.90
Body fat (%)	20	11.37 ± 4.69	7.70	21.90

BMI = body mass index; SD = standard deviation.

maximal test. Similarly, the amount of mean carbon dioxide production ($\text{VCO}_{2\text{mean}}$) that they produced during the GS performance corresponded to 75.83% of the amount produced during the maximal test.

In Table 3, some data correlations are given. According to these results, there was a significant correlation between the 3rd-minute lactate level (GS) and GS performance time. In addition, there was a negative relationship between $\text{VO}_{2\text{max}}$ and the immediately-after-exercise lactate level (GS) and a positive relationship between $\text{VO}_{2\text{max}}$ and the 5th-minute lactate level (GS; $p < 0.05$). By contrast, there was a positive relationship between $\text{VO}_{2\text{max}}$ (incremental running test) and $\text{VO}_{2\text{max}}$ (GS; $p < 0.01$). There was also a positive relationship between $\text{VO}_{2\text{max}}$ (GS) and the 5th-minute lactate level (GS; $p < 0.01$), and a negative relationship between $\text{VO}_{2\text{max}}$ and the immediately-after-exercise lactate levels (GS; $p < 0.05$).

Figure 1 shows the blood lactate concentrations of the volunteers after the maximal test and the GS race. After the maximal test, blood lactate values reached their maximum level (13.69 ± 2.06 mmol/L) at the 5th minute. After the GS performance, by contrast, their maximum lactate value reached the maximum level (10.13 ± 0.43 mmol/L) at the 3rd minute. Maximum lactate values acquired by the participants after the GS race corresponded to 74% of the maximum lactate values acquired after the maximal test.

Figure 2 shows the heart rates of the participants during the maximal test and GS race. It can be seen that the heart rates were higher during the GS performance in terms of both maximum and mean values.

Discussion

Although many researchers reported the significance of aerobic power in skiing races, there is disagreement on why and how this capacity is important.¹⁵ For instance, Tesch¹⁰ reported that maximal aerobic power or aerobic capacity could not be a determinant of success in alpine skiing. White and Johnson,² by contrast, noted that aerobic power was important, but it was not a distinctive characteristic in various categorizations of skiers. According to the results of the World Cup between 1997 and 2003, Neumayr et al.¹ stated that aerobic power had a positive correlation with the race performance. The researchers suggested that this could result from high volumes of the special exercises carried out by the athletes on the snow, rather than the physiological demands of the race.¹

Table 2
Respiratory values of maximal test and giant slalom.

	n	Incremental running test			Giant slalom		
		$\bar{X} \pm SD$	Minimum	Maximum	$\bar{X} \pm SD$	Minimum	Maximum
VO _{2max} (mL/kg/min)	20	51.36 ± 2.68	47.28	54.5	38.50 ± 2.34	34.51	41.64
VO _{2mean} (mL/kg/min)	20	37.48 ± 2.25	34.55	40.43	28.21 ± 1.63	25.56	30.32
VO _{2max} (mL/min)	20	3773.20 ± 296.25	3410	4519	2817.10 ± 214.56	2625	3389
VO _{2mean} (mL/min)	20	2754.17 ± 239.35	2438.50	3289.41	2054.86 ± 184.57	1804.49	2467.05
VCO _{2mean} (mL/min)	20	2647.23 ± 260.55	2287.68	3276.23	2007.42 ± 180.93	1761.51	2457.17

SD = standard deviation; VO_{2max} = maximal oxygen consumption; VO_{2mean} = mean oxygen consumption.

Table 3
Correlation values of respiratory, hearth rate, lactate, and giant slalom performance time.

		Giant Slalom Performance Time (s)	VO _{2max} (IRT) (mL/kg/min)	VO _{2max} (GS) (mL/kg/min)	Lactate (GS) (IAE)	Lactate (GS) (3 rd min)	Lactate (GS) (5 th min)	Heart Rate Maximum (GS) (bpm)
Giant Slalom Performance Time (s)	r	—	-0.15	-0.10	0.01	0.48 *	0.40	-0.20
VO _{2max} (IRT) (mL/kg/min)	r	—	—	0.97 **	-0.59 **	-0.10	0.54 *	0.15
VO _{2max} (GS) (mL/kg/min)	r	—	—	—	-0.56 *	-0.30	0.64 **	0.20
Lactate (GS) (IAE)	r	—	—	—	—	-0.6	-0.3	-0.39
Lactate (GS) (3 rd min)	r	—	—	—	—	—	0.17	-0.43
Lactate (GS) (5 th min)	r	—	—	—	—	—	—	0.06
Heart rate (bpm)	r	—	—	—	—	—	—	—

* p < 0.05.

** p < 0.01.

GS = giant slalom; IAE = immediately after exercise; IRT = incremental running test; VO_{2max} = maximal oxygen consumption.

In this study, VO_{2max} values of alpine skiers were 51.36 ± 2.68 mL/kg/min. There were no correlations between VO_{2max} levels and GS performance time. However, during the GS activity, the athletes used 74.96% of their maximum values (38.5 ± 2.34 mL/kg/min). This finding shows that aerobic power has a substantial contribution to the GS performance. Parallel with the findings of this study, Spirk et al¹⁶ reported that the athletes used 73.5 ± 24.6% of their VO_{2max} during the GS performance. Moreover, they stated that this value was an indicator of the considerable use of aerobic system as an energy source during the GS performance. In another study, von

Duvillard et al¹² reported that approximately 50% of the VO_{2max} is used during the GS performance. They accepted that this value was below the expected result and that it could result from two important factors. First, the skiers were asked not to hit the gates during the GS race to assure the safety of metabolic gas analyzer, which led them to ski in a nonaggressive way, and second, they reported that the metabolic demand of the GS activity might actually be low. In another study, Karlsson et al¹¹ measured the oxygen consumption using an old technique (Douglas bag) and reported that the athletes used 88% of their VO_{2max} during the GS performance.

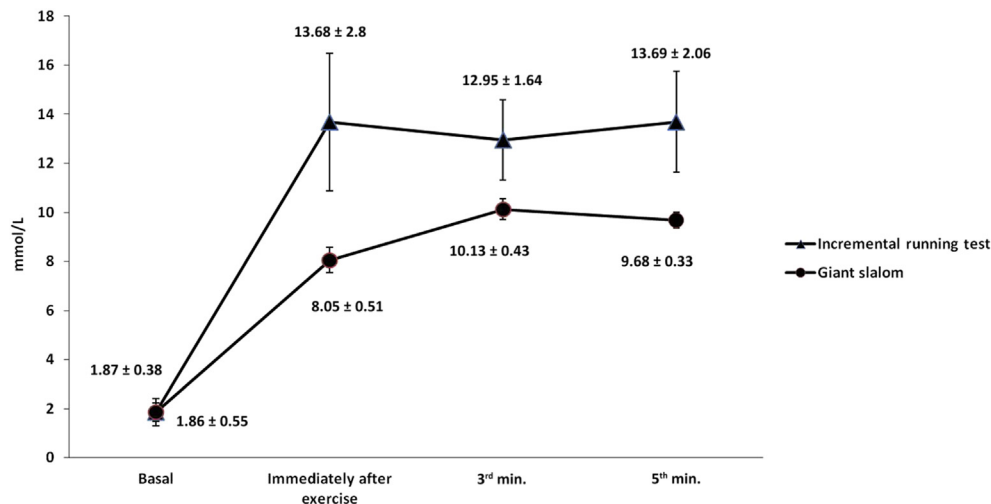


Figure 1. Lactate values.

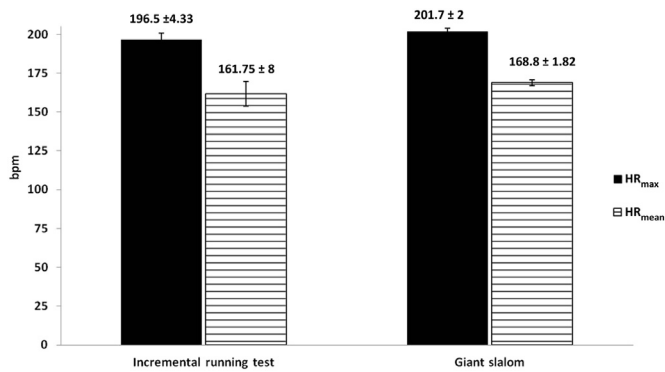


Figure 2. Heart rate (HR) values. bpm = beats per minute.

Veicsteinas et al⁹ and Saibene et al⁴ examined the relative energy contribution during skiing. Both groups of researchers reported that 65% of the energy contribution during a skiing race was met by the anaerobic system and suggested that the exercises should focus on power production and neuromuscular coordination. Moreover, they both determined the blood lactate measurement and energy metabolism by assuming that a blood lactate concentration of 1 mmol/L corresponded to 3.15 mL O₂/kg.^{4,9} However, the authors reported that this equation included some errors and that certain conditions such as altitude and high-intensity exercises might have contributed to erroneous results.^{4,9} Both Veicsteinas et al⁹ and Saibene et al⁴ concluded that anaerobic power contribution was greater than aerobic contribution in alpine skiing. It was also suggested that more aerobic power led to a greater decrease in the neuromuscular system load, and thus decreased the dependency on anaerobic power and power production/exercise.^{7,17}

Blood lactate level can be used in the determination of metabolic acidosis and contribution rates of the energy systems during the exercise.¹⁸ In this study, blood lactate concentrations attained their highest value at the 5th minute during the maximal exercise test and were determined to be 13.69 ± 2.06 mmol/L. After the GS race, by contrast, blood lactate concentrations reached their maximum value at the 3rd minute and were determined to be 10.13 ± 0.43 mmol/L. During their GS performance, the athletes' lactate concentrations were around 74% of those measured in the laboratory. The blood lactate values measured after the GS race showed that anaerobic contribution was high during the GS performance. Interestingly, the results of this study determined that, after the GS performance, the 3rd-minute-taken lactate level and the GS performance time have a significant correlation ($p < 0.05$), which supports the importance of anaerobic support during the GS performance. Spirk et al¹⁶ reported that the maximum lactate level was reached at the 3rd minute after the GS performance (8.7 ± 2.2 mmol/L) and that the athletes produced around 69% of the lactate accumulated after the ergometer test conducted in the laboratory. von Duvillard et al¹² stated that maximum lactate concentration was 13.7 ± 4.4 mmol/L (at the 3rd minute), following the maximal treadmill test in the laboratory and 5.6 mmol/L at the 3rd

minute following the GS performance. In a previous study, it was reported that Italian National Team athletes had blood lactate concentrations of 9.0 mmol/L after the international GS race, which had a mean duration of 82 seconds.⁴ Karlsson et al¹¹ found that elite Swedish skiers had mean blood lactate concentrations of 13.0 mmol/L after the GS race, which had a mean duration of 93 seconds. It was reported that elite alpine skiers had higher levels of blood lactate concentrations than lower degree skiers.¹⁹ Both the lactate data obtained in this study and those determined in the literature showed that anaerobic contribution was considerably high during the GS race.

As skiing races are mostly organized at high altitudes, the lactate amount accumulated by the skiers during the GS performance might show an extra increase because of the hypoxic environment.⁴ It was also reported that aerobic metabolism was obstructed because of the vascular occlusion, which occurs due to isometric contractions during the skiing races.¹⁸ This occlusion results in a higher increase in lactate production as in the hypoxic environment of high altitudes. A cold and hypobaric hypoxic environment causes a decrease in the alveoli and arterial oxygen pressures. When an exercise performed under these circumstances was compared with the same exercise performed at a lower altitude and warmer temperature, glycolytic rates showed a higher increase and glycogen storage showed a higher decrease, which caused a greater difficulty for the anaerobic system.^{20,21}

Furthermore, it was reported that sustained muscle contractions and a large degree of knee flexions, which are typical in skiing races, caused a decrease in VO_{2max}. The blood perfusion of active muscles decreases because of a higher decrease in blood volume, an increase in lactate accumulations, and nonproportionally high heart rates. It was reported that this situation resulted in muscle ischemia and higher dependency on anaerobic metabolism.¹⁸

Although the main factor of success in GS is anaerobic performance, alpine skiers should be encouraged to have higher levels of VO_{2max}.¹⁶ It was reported that an efficient aerobic system was important for recovery between each runs and between long and tiring races, and for ensuring continuity in exercises on the snow.¹ Koistinen et al²² examined both strength and endurance athletes with high aerobic capacity and reported that they were capable of tolerating more aerobic activities and higher levels of lactate at high altitudes. However, higher numbers of more efficient slow twitch (ST) fibers might decrease peripheral obstructions caused by hypoxia, hypobaria, and hypothermia, which might help to cope with these environmental conditions by decreasing the anaerobic load.²¹

In this study, the maximum levels of athletes' heart rates were determined to be 196.5 ± 4.33 bpm, whereas mean rates were 161.75 ± 8 bpm during the maximal exercise test. During the GS race, by contrast, maximum rates were 201.7 ± 2 bpm and mean rates were 168.8 ± 1.82 bpm. These rates show that the GS race is an intensive activity. It is thought that higher heart rates during the GS race compared with the maximal test are the result of an increase in the sympathetic activity due to the high speed during the GS performance as well as the

hypobaric and hypoxic environments. Moreover, it is thought that the increase in sympathetic activity was also triggered by the athletes' desire not to make a mistake during such a high-speed race. Astrand and Rodahl²³ reported that athletes' heart rates at the start gate of the race were 160 bpm and that this resulted from emotional and nervous factors. Once the race starts, a rapid increase is observed at the heart rates of the skiers, which reach maximum levels near the end of the course.²⁴

In conclusion, both high heart rates of the athletes and the accumulated lactate levels during their GS performance show that the GS race is a high-intensive skiing activity and that high amount of anaerobic contribution is used during the GS race. However, using 75% of the VO_{2max} during the GS race shows that aerobic contribution is also at a substantial level during the anaerobic GS races. Furthermore, as a high aerobic capacity will shorten the recovery times during the repetitive runs of the trainings, it is quite important to increase the efficiency of the training and should not be ignored in the training programs.

In this study, the VO_{2max} value used by alpine skiers during GS performance was determined. In future studies, the support rates of aerobic and anaerobic capacities in GS must be determined. In this study, in order to determine the VO_{2max} values of volunteers, incremental running test have begun at 7 km/h. While it takes long time, incremental running test could also be started at higher speeds for the athletes who are expected high VO_{2max} .

Conflicts of interest

The author has no conflicts of interest to declare.

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