

Heart Rate Contribution in Soccer Players during the Competition Period

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SUMMARY

Objectives

To assess the performance of the components of the heart rate dynamic curve throughout baseline, exercise, and recovery period, according to the duration, the distance, and the intensity of treadmill and field aerobic tests, as an indicator of training and physical adaptation during the competition period in soccer players.

Material and Methods

A total of 108 male players from youth soccer, aged 17 ± 2 , were assessed with exercise stress test and aerobic field test, during the competition period. A 2400 m treadmill test and a Yo-Yo Endurance Field Test, level 2, were performed.

Results

The continuous recording of the heart rate allowed for these data: 1) a more detailed register of the changes in submaximal heart rate (89.4 ± 7.6 versus 83.0 ± 7.7 ; $p < 0.05$) on treadmill; 2) different subaximal heart rate responses in treadmill test and field test after the first minute (164.0 versus 116.6 ; $p < 0.05$) and after the second minute (176.3 versus 123.5 ; $p < 0.05$) in connection with the maximum heart rate (198.6 versus 194.0 ; $p = ns$); 3) during field testing, a greater interval of heart rate reserve in relation to the endurance capacity after the second minute (25.9 versus 19.1 ; $p < 0.05$) was observed.

Conclusions

The regular comparison of these indices gives information related to immediate and extended adaptations of the physiological functions during the annual competition cycle in order to make a rationale plan of the training loads based on the results achieved, and to maintain the optimal performance

Comparison of heart rate comparative records from soccer players during the competition cycle in aerobic exercise stress test and field test allows for the analysis of training and physical adaptation indicators. Indicators of baseline, submaximum, maximum, and recovery heart rate, as well as the interval of heart rate reserve, allow for information about performance and endurance training at different displacement speeds, resistance times and distances, in treadmill tests and field tests, which are very useful for the training guidelines during the competition period.

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Key words >

Sports - Heart Rate - Ergometry

Abbreviations >

%HR_{max}	Submaximum heart rate	AFT	Aerobic field test
%VO_{2max}	Submaximum oxygen uptake	EST	Exercise stress test
DST	Distance covered	T	Time
HR	heart rate	DS	Displacement speed
MHR	Maximum heart rate	DS_{max}	Maximum displacement speed
YSP	Youth soccer players	DS_{smax}	Submaximum displacement speed
Lac	Lactate	VO_{2max}	Maximum oxygen uptake
CPST	Cardiopulmonary stress testing		

BACKGROUND

Sports Cardiology is one of the branches of Sports Medicine that is in charge of performing the prepar-

ation physical examination (1) and evaluating the physiological adaptations of the cardiovascular and metabolic systems of athletes to training loads (2) during the competition cycle.

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The specialist performs field testing and laboratory exercise testing, analyzes and compares the results of the physiological adaptations of aerobic and anaerobic endurance according to the athlete's body composition. Specific training loads produce specific responses and adaptations that are expressed by the interdependency between functional cardiorespiratory and metabolic indices that maximize the aerobic and anaerobic energy systems in treadmill stress tests and field tests. (3)

In endurance sports, cardiopulmonary exercise test with measurement of oxygen uptake is the "gold standard" method to determine the maximum oxygen uptake ($VO_{2\max}$) and the anaerobic threshold in high-intensity aerobic training. (4-6)

In order to improve the results of the indirect laboratory or field tests it is necessary to record in a continuous fashion as many indicators of fitness and physical performance as possible. These indicators are submaximum heart rate, maximum heart rate, recovery heart rate, test duration, distance covered, displacement speed and lactate accumulation following exercise using a fixed distance protocol. (7)

A direct and positive association exists between exercise intensity, oxygen uptake and HR, with the aerobic capacity ($VO_{2\max}$) which is linear between the 50% and 85% of maximum HR. (8)

Heart rate depends on the maximum capacity of each athlete due to his own rhythm of adaptation and to how neurovegetative functions increase to compensate the changes in fluids, electrolytes, and acid-base balance that occur during training. (9)

A lower submaximum HR value for equal exercise intensity indicates a greater adaptation in cardiorespiratory endurance that increases the interval of HR reserve; (10) in this way the athlete can maintain aerobic exercise of greater intensity and duration.

The continuous recording of the HR during the gradual increase in exercise stress tests or field tests enables to determine the submaximum and maximum HR reserve, and the recovery HR, as well as their association with exercise time duration, speed displacement and distance covered in order to assess the physical adaptation to endurance training and to plan aerobic training at low and high intensity. (11-14)

Heart rate is a good physiological indicator of adaptation of cardiorespiratory endurance, and continuous recording of the heart rate curve provides detailed information of its modifications. (15, 16)

The aim of the present study was to assess the performance of the components of the heart rate dynamic curve throughout baseline, exercise, and recovery period, according to the duration, the distance, and the intensity of treadmill and aerobic field tests, as indicators of training and physical adaptation during the competition period in soccer players.

MATERIAL AND METHODS

Population

A total of 108 youth soccer players (YSP) from the *Club Atlético San Lorenzo de Almagro* of the Autonomous City of Buenos Aires, Argentina, were evaluated. All the participants were men aged 17 ± 2 years and were in competitive activity. The following exercise stress tests and field tests were performed:

a) A 2400 m treadmill test (maximum speed 10 mph, elevation of 20%), using the protocol for the Conconi test previously described (9), starting from a initial speed of 4 mph followed by a gradual increase in speed every 200 meters by 0.5km/hr. The HR was continuously recorded using a Polar Accurex Plus Heart Rate Monitor with a coded transmitter attached to an elastic chest strap. This HR monitor has a Conconi test software and interface to be able to transfer and analyze the recorded information in a computer. The point where heart rate departs from linearity in an incremental exercise test ($\%HR_{\max}$), (9) displacement speed (DS), distance covered (DST) and treadmill exercise time (T) duration, are variables used to compared the adaptation of the cardiorespiratory system to aerobic training. Oxygen uptake was estimated indirectly from submaximum HR ($\%VO_{2\max}$) and maximum HR ($VO_{2\max}$) in ml/kg/min, using the linear prediction equation from the American College of Sports Medicine; submaximum and maximum displacement speeds were also calculated (DS_{\max} and DS_{\max} , respectively).

Blood lactate (Lac) levels (mmol/L) were determined immediately after the end of the test with a portable previously calibrated Accusport.

b) Yo-Yo Endurance Field Test, level 2. This test, previously described, (17) involves a continuous and progressive running between two lines 20m apart, with initial running velocity of 11.5 km/h; pace gets quicker when signaled by the recorded beeps. The test stops when the athlete is exhausted. The following variables were measured: heart rate and total exercising time during heart rate measurement using the wrist receiver, blood lactate level immediately after the test ended, displacement speed, distance covered and indirect estimation of $VO_{2\max}$.

Study Design during Soccer Competition

- Initially, 60 YSP were evaluated with the aerobic 2400 m treadmill test using the protocol for the Conconi test. The following variables was measured with the Polar Accurex Plus Heart Rate Monitor: submaximum heart rate ($\%HR_{\max}$), maximum heart rate (HR_{\max}), submaximum displacement speed (DS_{\max}), maximum displacement speed (DS_{\max}); indirect measurement of submaximum and maximum oxygen uptake ($\%VO_{2\max}$) was estimated from $\%HR_{\max}$ and HR_{\max} , respectively. The study population was divided in two groups: group A (n = 47 YSP) and group B (n = 13 YSP) selected to be promoted to a higher category. Players from group B were evaluated again after 270 days of the competition cycle (group C). The results were compared using the Student's *t* test; a p value < 0.05 was considered statistically significant.
- Thereafter, 24 YSP were evaluated with the aerobic 2400 m treadmill test and aerobic field test (Yo-Yo Endurance Test, level 2) and the following variables were compared: HR at the first minute (HR1) and at the second minute

(HR2), maximum HR (HR_{max}), DST, DS, T and Lac. The study population was divided in two groups: group A (aerobic field test, AFT) and group B (2400 m aerobic exercise stress test, (EST)). Analysis was performed using the Student's *t* test; a *p* value < 0.05 was considered statistically significant (Table 2).

- Finally, 24 YSP were evaluated with an aerobic field test Yo-Yo Test Endurance, level 2 and the following variables were registered: HR at the first and second minute (HR1 and HR2), maximum HR (HR_{max}), heart rate reserve from the first minute (HRR1'/MX) and from the second minute (HRR2'/MX) to HR_{max} achieved; the highest interval was considered the greatest difference in beats per minute from the first or second minute to the maximum heart rate achieved. Other variables considered were T, DST and blood Lac level after the test. The study population was divided in two groups according to the distance covered: group A, 13 YSP with a DST greater than 1475 m and group B, 11 YSP with a DST lower than 1475 m. Statistical analysis was performed using the Student's *t* test; a *p* value < 0.05 was considered statistically significant (Table 3).

RESULTS

- Athletes in group C had lower values of sub-maximum HR ($\%HR_{max}$) and submaximum oxygen uptake ($\%VO_{2max}$) measured indirectly, and lower concentration of blood lactate as an expression of a better adaptation of cardiorespiratory endurance and skeletal muscle metabolism to aerobic exercise stress test in treadmill (Table 1).
- Given an equal HRmax achieved in both aerobic tests (in treadmill or in field), the progression of the HR and Lac were directly correlated with the intensity of the tests (Table 2).
- A greater HR reserve interval from the second minute showed a direct correlation with DST and T duration of the field aerobic test, as an expression of a greater adaptation in cardiopulmonary endurance, and an inverse correlation with the lowest blood lactate levels immediately after the test (Table 3).

Table 1. Initial evaluation in aerobic 2400 m treadmill test

	Group A: 47 JFJ	Group B: 13 JFJ	<i>p</i> A.B	Group C: 13 JFJ	<i>p</i> B.C
HR_{max}	180 ± 10.5	184 ± 12.6	> 0.05 NS	182 ± 12.8	> 0.05 NS
$\% HR_{max}$	88.6 ± 6.3	89.4 ± 7.6	> 0.05 NS	83 ± 7.7	< 0.05 S
VO_{2max}	67.1 ± 11	65.6 ± 6.8	> 0.05 NS	63.2 ± 6.9	> 0.05 NS
$\% VO_{2max}$	77.2 ± 6.6	78.2 ± 15	> 0.05 NS	71.1 ± 11.8	< 0.05 S
DS_{max}	4.7 ± 0.7	4.6 ± 0.4	> 0.05 NS	4.6 ± 0.4	> 0.05 NS
DSs_{max}	3.1 ± 0.6	3.2 ± 1	> 0.05 NS	2.9 ± 0.5	> 0.05 NS
Lac	7.6 ± 2.4	7.8 ± 3.6	> 0.05 NS	5.3 ± 1.6	< 0.05 S

Table 2. Evaluation in aerobic 2400 m treadmill test and field test

24 YSP	HR1 Bpm	HR2 Bpm	HR_{max} Bpm	Lac Mmol/L	DST M	VDK m/h	T Min/sec
Group A: AFT	164.0 (82.5%)	176.3 (88.7%)	198.6	11.8	1 500	20.5	6'44"
Group B: EST	116.6 (63.3%)	123.5 (67.1%)	194.0	6.7	2 408.3	16.1	13'18"
p	< 0.05	< 0.05	> 0.05	< 0.05	< 0.05	< 0.05	< 0.05
	S	S	NS	S	S	S	S

Table 3. Evaluation in field aerobic Yo-Yo Test Endurance level 2.

	HR1 Bpm	HR2 Bpm	HR_{max} Bpm	HRR1'/MX Beats	HRR2'/MX Beats	LacMmol/L	TSec.
Group A > 1 475 11 JFJ	161.5	173.1	199.0	37.5	25.9	10.7	439.2
Group B < 1 475 13 JFJ	166.0	179.0	198.2	32.1	19.1	12.7	342.1
p	> 0.05	< 0.05	> 0.05	> 0.05	< 0.05	< 0.05	< 0.05
	NS	S	NS	NS	S	S	S

DISCUSSION

The 2400 m treadmill test using the protocol for the Conconi test provides detailed information of %HR_{max}, HR_{max} and recovery HR. The concentration of blood lactate immediately after the test is lower than the levels achieved in field aerobic tests as the initial speed is low and workload increases gradually during longer stages. (18-20)

Conversely, field aerobic test starts with a higher displacement speed and had greater workload increases; this test is associated with an early chronotropic response that continues until HR_{max} is achieved. Heart rate recorded continuously and minute by minute, allows determining intervals of HR reserve in cardiorespiratory endurance from the first and second minute until the HRmax is achieved. Blood lactate levels immediately after exercising are greater in field tests than in treadmill tests. (21-24)

Both tests offer indicators of HR, DS, DST, T and Lac that could be used to evaluate the gradual cardiorespiratory and metabolic adaptations to workloads. (25) These tests are used to assess training during the annual competition period with their respective phases in series, repetitions, intensities and recovery, each of them with a different energetic orientation, and to evaluate the changes produced according to the individual adaptive response of the athlete. (17, 26, 27)

The cardiopulmonary stress testing (CPST) remains as the gold standard method to determine the VO₂max and the anaerobic threshold in relation to HR, DS, T and DST. (4, 22, 28)

In indirect VO₂max testing in treadmill or field tests, the relation between HR and the intensity of the test is linear until submaximum velocities are achieved (8), and the use of intervals of HR_{max} provides useful information for the aerobic training.

Continuous recording of the components of the dynamic HR curve allows determining DS, T, DST and Lac after the test which are used as indicators of cardiorespiratory endurance and metabolic skeletal muscle adaptations during low and high-intensity training. (29, 30) In addition, it also shows the variations of %HR_{max} y HR_{max} (that remains somewhat stable during the competition cycle) and allows calculating the changes in the heart rate reserve and a greater HR recovery as a physiological indicator of adaptation of cardiorespiratory endurance and, in consequence, a lower submaximum HR for an equal time, distance and speed displacement.

The increase of the heart rate reserve interval between the %HR_{max} y la HR_{max} allows performing greater workload and cardiopulmonary endurance.

The assessment of body composition, cardiorespiratory and skeletal muscle metabolism indices before the beginning of the season informs about the initial level of aerobic, skeletal muscle and metabolic condi-

tioning due to the modifications produced during the competition recess. (25, 31)

The indices of cardiorespiratory endurance and flexibility decrease 2 to 3 weeks after reducing physical activity, while reduction in muscular endurance, strength and power takes longer. (32-34)

The evaluation after the maintenance period during the off-season and before the athlete returns to pre-season reconstruction allows determining the initial performance level to plan the intensity and the volume of the training loads. (17, 35, 36)

The different performance serves to plan the selective stimulus of the intensity and the volume of loads for a gradual adaptation to prevent pre-season lesions and interruptions in the process of adaptation during cardiorespiratory, metabolic and muscular endurance conditioning. (37-39) The association of indices is used in sports training and in the evaluation of the development of physiological adaptation of cardiorespiratory endurance and skeletal muscle metabolism. It is also used in the correlation of aerobic and anaerobic energy supply processes, in accordance with the intensity and duration of training loads. Such indices require regular monitoring for planning their intensity and volume.

The performance of the soccer player is related to the production of energy from aerobic and anaerobic processes. A neuromuscular function with adequate strength, coordination and technical movements, which are physiological factors of regulation, supply, transportation, damping and coordination of the functions of the of different systems, as well as the adaptation of cardiovascular, respiratory and central nervous functions determines the process of development of physiological adaptation to sports modality. (40)

Soccer, as a sport of intermittent characteristics, uses aerobic and anaerobic energy. In consequence, soccer players should undergo periodic control of the energetic systems used by means of treadmill test and field test using as many indices as possible.

The regular comparison of those indices gives information related to immediate and extended adaptations of the physiological functions during the annual competition cycle in order to make a rationale plan of the training loads based on the results achieved, and to maintain the optimal performance.

CONCLUSIONS

Continuous HR monitoring enabled to identify different indicators of adaptations to physical training in soccer players during the competition period.

Maximum HR has the best correlation with myocardial oxygen uptake. The different intensity of continuous or intermittent workload in aerobic treadmill test or field test allows interpreting the components of the heart rate dynamic curve during

the adaptation to physical training in the competition cycle.

The greatest intensity and speed of displacement achieved in field tests produce an early chronotropic response showing a greatest heart rate reserve interval in soccer players who have better capacity adaptation to high-intensity training.

Gradual increases during treadmill test allow identifying in detail the modifications of the heart rate dynamic curve in relation to the $\%HR_{max}$ and HR_{max} achieved with a lower energetic cost, expressed by lower blood lactate levels after the test to evaluate the adaptation of cardiorespiratory endurance to low and high-intensity aerobic training.

In this population of soccer players, continuous HR recording enabled to analyze the HR dynamic curve and to identify $\%HR_{max}$ and HR_{max} . These variables associated with indicators of SD, DST, T and Lac after the test make the evaluation of the physiological adaptation in cardiorespiratory endurance to training loads possible.

RESUMEN

Aporte de la frecuencia cardíaca en futbolistas durante el período de competencia

Objetivos

Evaluar el comportamiento de los componentes de la curva dinámica de la frecuencia cardíaca basal, intraesfuerzo y de recuperación de acuerdo con el tiempo, la distancia y la intensidad de pruebas aeróbicas en cinta ergométrica y de campo como indicador de entrenamiento y adaptación física durante el período de competencia en jugadores de fútbol.

Material y métodos

Se evaluaron 108 jugadores de fútbol juvenil, masculinos y de 17 ± 2 años, con prueba aeróbica ergométrica y de campo durante el ciclo competitivo. Se realizó prueba de 2.400 metros en cinta ergométrica y *Yo-Yo Test* en campo (*Endurance* nivel 2).

Resultados

El registro continuo de frecuencia cardíaca permitió observar: 1) un registro más detallado de las modificaciones de la frecuencia cardíaca submáxima ($89,4 \pm 7,6$ versus $83,0 \pm 7,7$; $p < 0,05$) en cinta ergométrica, 2) diferentes respuestas de frecuencia cardíaca submáxima en prueba ergométrica y de campo al primer minuto ($164,0$ versus $116,6$; $p < 0,05$) y al segundo minuto ($176,3$ versus $123,5$; $p < 0,05$) en relación con la frecuencia cardíaca máxima ($198,6$ versus $194,0$; $p = ns$), 3) en pruebas de campo se observó un intervalo mayor de reserva de frecuencia cardíaca en relación con la capacidad de resistencia a partir del segundo minuto ($25,9$ versus $19,1$; $p < 0,05$).

Conclusiones

El registro comparativo de la frecuencia cardíaca durante el ciclo competitivo en jugadores de fútbol en pruebas aeróbicas ergométricas y en prueba de campo permite el análisis de indicadores de entrenamiento y adaptación física. Los indicadores de frecuencia cardíaca basal, submáxima,

máxima, de recuperación e intervalo de reserva de frecuencia cardíaca permiten información de rendimiento y entrenamiento en la resistencia a diferente velocidad de desplazamiento, tiempo de permanencia y distancia en pruebas de cinta ergométrica y de campo, de gran utilidad para las pautas de entrenamiento durante el período de competencia.

Palabras clave > Deportes - Frecuencia cardíaca - Ergometría

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