HEART RATE AS A MEASURE OF EXERCISE INTENSITY IN SOCCER

dr Dariusz Śledziewski[*], *prof. Emerson Silami Garcia*[**], *prof. Leszek Antoni Szmuchrowski*[**]

Introduction

The number of men and women of all ages who play Soccer is approximately two hundred million. However, the popularity of Soccer is not matched by the amount of scientific information concerning it's physiological demands. The growing interest among researchers in understanding the complexity of this sport allows coaches to improve training programs, leading to better performances in the games[1].

The intensity of exercise in Soccer has been estimated during simulated games and also during friendly games, using heart rates[2]. The physiological demand of Soccer has also been estimated using different parameters such as the distance covered by the players during the game, the average speed of the running efforts[3], the body temperature, measurement of oxygen consumption during simulated Soccer, blood lactate concentration[4].

Throughout the approximately 90 minutes of a game, the players stand still for about 17.1%, walk during 40% and run at low speeds during 35% of the total time. They run only 8% of the distance at high speeds and they carry the ball for about 2% of the overall distance covered during the game[5].

Heart rate measurements have been extensively used to estimate energy expenditure during exercise including a Soccer game, due to the existing relationship between HR and VO_2, even during intermittent exercises such a Soccer game. Since HR is influenced by a number of factors such as age, for example, Karvonen and Vuorimaa[6] suggest that we use HR as percentage of the maximum heart rate (%HRmax). The relative HR is considered a god estimate of the exercise intensity (E_{int}) for athletes, as well as for non-athletes.

Maximum heart rate (HR_{max}) is defined as the highest heart rate (HR) attained during a maximum oxygen uptake (VO_2max) test. Boudet et. al.[7] argue that there is no consensual definition of HR_{max} and points out the lack of a reliable measurement protocol.

---

[*] *Academy of Physical Education in Warsaw, Chair Theory of Sports, Water Sports and Winter - Department Theory of Sport, Poland.*
[**] *University of Minas Gerais, Belo Horizonte, Brazil.*

[1] B. Ekblom, *Applied Physiology of Soccer*, Sports Medicine, No. 3/1986, p. 50-60.

[2] L. Capranica, A. Tessitore, L. Guidetti, F. Figura, *Heart rate and match analysis in pre-pubescent soccer players*, Journal of Sports Sciences, No. 6/2001, p. 379-384.

[3] J. Bangsbo, *The physiology of soccer, with special reference to intense intermittent exercise*, Acta Physiologica Scandinavica: an international journal of physiological sciences, No. 151/1994, supl. 619.

[4] T. Reilly, *Energetic of high intensity exercise (soccer), with particular reference to fatigue*, Journal of Sports Sciences, No. 15/1997, p. 257-263.

[5] J. Bangsbo, L. Norregaard, F. Thorso, *Activity profile of competition soccer*, Canadian Journal of Sports Sciences, No. 2/1991, p. 110-116.

[6] J. Karvonen, T. Vuorimaa, *Herat hate and exercise intensity during sports activities; practical application*, Sports Medicine, No. 5/1988, p. 303-312.

[7] G. Boudet, M. Garet, M. Bedu, E. Albuisson, A. Chamoux, *Median maximal heart rate for calibration in different conditions: Laboratory, Field and Competition*, International Journal Sports Medicine, No. 4/2002, p. 290-297.

HR_{max} can be influenced by physiological factors. Among them, the most influential are the physiological changes accompanied by the increase in age, which has a reverse relation with HR_{max}. Therefore, as age increases, HR_{max} decreases and HR at rest increases. However, higher HR_{max} values for the under-17 category compared to the under-20 category would not be expected due to the small difference in age of the athletes of both categories.

HR_{max} is an important physiological variable commonly used as a reference of maximum effort intensity. As a function of the linear relation observed between HR and oxygen consumption (VO_2) in activities with progressive intensity, it is admitted that at a given effort intensity the percentage of HR_{max} ($\%HR_{max}$) corresponds to a percentage of $VO2_{max}$. As a result, through this linear relation between HR and VO_2, one can monitor HR as $\%HR_{max}$ and control the intensity of a given physical activity as well as customize physicet. training[8].

Since it is an individual variable, it is recommended that we carry out either specific maximum tests for a reliable measurement of HR_{max} or determining it from the highest HR recorded during real competition as performed by Mohr et. al.[9]

The majority of studies involving Soccer players have been carried out in Europe, under cold or temperate environmental conditions. Even though Brazilian national teams have won world championships in the main categories (five times the World Cup; four times the Under-17 and Under-20 world championships), and most games in Brazil are played under a tropical environment, the information concerning E_{Int} of Brazilian players during Soccer games is sparse.

The detailed knowledge of the E_{int} of Soccer players during an official game can be also helpful for training and dietary plans. It is also important for the maintenance of a satisfactory performance level and the health of the athletes.

Material and methods

The purpose of first study was to evaluate and to compare the E_{int} of U-20 and U-17 players during official championship Soccer games, using as parameter of effort the $\%HR_{max}$. The study had also the purpose of comparing the results between the first half time and the second half time of the game. The purpose of second study was to compare the E_{int} of seven U-17 soccer players recorded during a friendly game with the average E_{int} six official games.

Twenty-five male Soccer players who have been playing this sport for an average of five years participated in the study. The athletes trained for about 16 hours and played 2 championship games weekly. The subject's characteristics are described in Table 1.

[8] H. Tanaka, K. Monahan, D. Seals, *Age-Predicted Maximal Heart Rate Revisited*, Journal of the American College of Cardiology, No. 1/2001, p. 153-156.

[9] M. Mohr, P. Krustrup, L. Nybo, J. Nielsen, J. Bangsbo, *Muscle temperature and sprint performance during soccer matches – beneficial effect of re-warm-up at half-time*, Scandinavian Journal of Medicine and Science in Sports, No. 14/2004, p. 156-162.

Table 1.

Mean and standard deviation of age, percent body fat (%Fat), height, weight and maximal aerobic power ($VO_{2máx}$) of the Soccer players who participated in the study

Category	N	Age (years)	Height (cm)	%Fat	VO_2max ($mlO_2 \cdot kg^{-1} \cdot min^{-1}$)
U-17	13	16.4 ± 0.5	175.0 ± 6.8	9.3 ± 1.0	56.1 ± 2.0
U-20	12	18.2 ± 0.7	178.0 ± 7.3	8.5 ± 1.0	58.2 ± 2.9

Source: *original research*

The studies were approved by the Ethics Committee of the Federal University of Minas Gerais, Brazil and followed the rules of the National Health Council of Brazil for research with human subjects.

During the period in which the studies were developed, the average dry bulb temperature was 23.9±2.65 Cº, the average wet bulb temperature was 18.9±2.5 Cº and the air relative humidity was 63.3±15.85%.

The HR in beats per minute (bpm) of the athletes was measured during official championship games (U-17=14 games and U-20=8 games. Six to ten athletes were evaluated during each game and only data from players who participated in three whole games were considered. Data from players who were replaced were also discarded.

The Polar Team System® was used to monitor HR during the games. Recording was set for 5-second intervals.

The determination of the $HR_{máx}$ was made according to the following procedures: 1) The highest HR value attained by each player during the matches 2) The highest HR value recorded during maximum subjective effort test (1000-meter run) performed shortly after a lactate threshold test (three 1000-meter sub-maximum trials). The athletes started the maximum test with a HR of at least 100 bpm. According to Marins et. al.[10], preparatory exercises before maximum tests are important for the progressive adaptation to effort intensities. The athletes were familiar with this protocol as it is regularly used at the club to estimate VO_2max and to determine HR_{max}.

Data are presented as mean and standard deviation. The results from the different categories were compared using the Student t-test. The significance level was set at $p<05$.

Results

The results are presented in Table 2 and Table 3.

There was a significant difference ($p<0.01$) in E_{int}, in absolute (bpm) and in relative ($\%FC_{max}$) values, in between the friendly game and the official games.

[10] J. Marins, M. Fernandez, *Comparação da freqüência cardíaca maxima por meio de provas com perfil aeróbico e anaeróbico*, Fitness & Performance Journal, No. 3/2004, p. 166-174.

Table 2.

Mean HR (bpm) and %$HR_{máx}$ of the U-20 and U-17 categories during the first half, second half and whole game. Results are presented as mean (X) and standard deviation (sd)

Category	First half		Second half		Whole game	
	HR (bpm)	%$HR_{máx}$	HR (bpm)	%$HR_{máx}$	HR (bpm)	%$HR_{máx}$
U-17	170 ± 8	84.8 ± 4.7	165* ± 10	82.5* ± 4.8	168 ± 8	83.8 ± 4.5
U-20	172 ± 10	85.9 ± 4.1	166* ± 10	83.0* ± 4.4	169 ± 9	84.5 ± 3.8
Mean	170 ± 8	85.2 ± 4.5	166* ± 10	82.7* ± 4.6	168 ± 8	84.1 ± 4.2

Source: *original research*

* Significant difference ($p<0.01$) in relation to the first half

Table 3.

Mean HR (bpm) and %$HR_{máx}$ of the U-17 during the friendly and official games. Results are presented as mean (X) and standard deviation (sd)

Category	Friendly game		Official games	
	HR		HR	
	bpm	% HR_{max}	bpm	% HR_{max}
Mean	163.7	81.2	168.3*	83.4**
Sd	± 8.7	± 4.7	± 6.4	± 4.0

Source: *original research*

* Significant difference ($p<0.01$) in relation to mean HR (bpm) of the friendly game.

** Significant difference ($p<0.05$) in relation to mean HR (%HR_{max}) of the friendly game.

Discussion

In the second half of a Soccer game, the E_{int} was found to be lower than in the first half probably due to fatigue. In the present study, the E_{int} was also significantly lower in the second half than in the first[11].

In other studies the HR there was a consistent decrease in HR in the second half as compared to the first half of the game. This was true for professional, semi-professional, college and recreational players[12]. Mohr et. al.[13] used the highest HR during a friendly game as being the HR_{max}. The results of our study agree with the results of previous studies concerning the E_{int}, but we recorded higher average absolute heart rates (178±8 bpm in the first half and 166±10 bpm in the second half time).

Capranica et. al.[14] measured the HR of 11-year old children during a Soccer match and found out that their HR remained above 170 bpm 88% of the time in the first half and 80% of the second half, but that there were no significant differences.

In most studies the results are in absolute values of HR, but we think the relative values are more useful. In our study the relative values were significantly different when comparing

[11] A. Ali, M. Farrally, *Recording soccer players' heart rates during matches*, Journal of Sports Sciences, No. 9/1991, p. 183-189.

[12] R. Kapera, D. Śledziewski, *Piłka nożna. Szkolenie dzieci i młodzieży*, PZPN. Warszawa 1997.

[13] M. Mohr et. al., *Muscle temperature*…, op. cit. p. 160.

[14] L. Capranica et. al., *Heart rate* …, op. cit. p. 381.

the first and the second half of the game (85.2±.5 e 82.7±4.6%$FC_{máx}$ respectively). Our results for the whole game, 84.1±4.2%$FC_{max,}$ was similar to those reported elsewhere[15].

The E_{int} in this study was higher than that reported by Ogushi et. al.[16] Those authors evaluated only two players during a friendly game and found an E_{int} of 82% $HR_{máx}$. Ogushi et. al. did not explain how they evaluated the $HR_{máx}$.

The E_{int} reported by de Mohr et. al.[17]approximately 85% $HR_{máx}$, during friendly games, was higher than that found in this study. It should be pointed out that those authors used only the highest HR from the friendly game as the $HR_{máx,}$ procedure that may have produced overestimated values of $E_{int.}$ Wisloff et. al.[18]suggest that during a game it's very likely that some players never reach their $HR_{máx}$. In another study, O'Connor[19] found an E_{int} of 90%HR_{max} during men´s and women´s games, but he didn't mention which method he used to determine HR_{max}.

The E_{int} found in the present study was lower than that reported by Tumilty[20] who found values of 87% HR_{max} during a simulated game. Tumilty used the HR_{max} from an laboratory test, which may have led to the underestimation of the HR_{max} and the consequent overestimation of the E_{int}. Reilly et Keane[21] have demonstrated that Soccer players may reach higher HR_{max} during games than during laboratory or field tests. That may be due to the fact that the motivation and the stress of competition.

A E_{int} found in the present study was a little lower than that reported by Helgerud et. al.[22] who measured the HR of U-20 players during a friendly game and found an E_{int} of 85.6%HR_{max}. The HR_{max} in the study of Helgerud was also determined only during a laboratory test. In the literature there are no studies comparing E_{int} during official games to that of friendly games.

Conclusions

The E_{int} of was lower in the second half time of the game suggesting that there might have been a decrease in performance capacity of the players.

HR_{max} measured during specific maximum test may be underestimated in relation to that measured during competition, probably because the test represents an artificial situation for the soccer player, who does not feel as motivated as they do during competitions.

---

[15] T. Reilly, S. Keane, *Estimation of physiological strain on Gaelic football players during match-play*, (In:) Fourth World Congress of Science and Football, No. 4/1999, Sydney. London: E & FN Spon, 2002, p. 157-159.

[16] T. Ogushi, J. Ohashi, H. Nagahama, S. Isokawa, S. Suzuki, *Work intensity during soccer match-play (a case study)*, (In:) Second World Congress of Science and Football, No. 2/1991, Eindhoven. *Proceedings.* London: E & F. N. Spon, 1993, p. 121-123.

[17] M. Mohr et. al., *Muscle temperature* …, op. cit. p. 161.

[18] U. Wisloff, J Helgerud, J Hoff, *Strength and Endurance of elite soccer players*, Medicine and Science in Sports Exercise, No. 3/1998, p. 462-467.

[19] D. O'Connor, *Time – Motion analysis of elite touch players*, (In:) Fourth World Congress of Science and Football, No. 4/1999, Sydney. London: E & F. N. Spon, 2002, p 126-136.

[20] D. Tumilty *The relationship between physiological characteristics of junior soccer players and performance in a game simulation*, (In:) Second World Congress of Science and Football, No. 2/1991, Eindhoven, *Proceedings.* London: E & FN Spon, 1993, p. 281-286.

[21] T. Reilly, Keane S., *Estimation of physiological* strain …, op. cit. p. 158.

[22] J. Helgerud, L. Engen, U. Wisloff, J. Hoff, *Aerobic endurance training improves soccer performance,* Medicine and Science in Sports Exercise, No. 11/2001, p. 1925-1931.

The E_{int} of was also lower during the friendly game than during the official games. It is possible that motivation also plays a role causing this difference. The E_{int} from a friendly game should not be used as reference for official games.

References:

Ekblom B., *Applied Physiology of Soccer*, Sports Medicine, No. 3/1986, p. 50-60.

Helgerud J., Engen L. C., Wisloff U., Hoff J., *Aerobic endurance training improves soccer perf*ormance. Medicine and Science in Sports Exercise, No. 11/2001, p. 1925-1931.

Kapera R., Śledziewski D., *Piłka nożna, Szkolenie dzieci i młodzieży*, PZPN Warszawa, 1997.

Ali A., Farrally M., *Recording soccer players' heart rates during matches*, Journal of Sports Sciences, No. 9/1991, p. 183-189.

Bangsbo J., *The physiology of soccer, with special reference to intense intermittent exercise*, Acta Physiologica Scandinavica: an international journal of physiological sciences, No. 151, supl. 619/1994.

Capranica L., Tessitore A., Guidetti L., Figura F., *Heart rate and match analysis in pre-pubescent soccer players*, Journal of Sports Sciences, No. 6/2001, p. 379-384.

O'Connor D., *Time - Motion analysis of elite touch players*, (In:) *Fourth World Congress of Science and Football*, No. 4/1999, Sydney. London: E & FN Spon, 2002, p. 126-136.

Ogushi T., Ohashi J., Nagahama H., Isokawa S., Suzuki S., *Work intensity during soccer match-play (a case study)*, (In:) Second World Congress of Science and Football, No. 2/1991, Eindhoven. *Proceedings.* London: E & FN Spon, 1993, p. 121-123.

Reilly T., Energetic of high intensity exercise (soccer), with particular reference to fatigue, Journal of Sports Sciences, No. 15/1997, p. 257-263.

Di Salvo V., Pigozzi F., *Physical training of football players based on their positional rules in the team*, The Journal of Sports Medicine and Physical Fitness, No. 38/1998, p. 294-297.

Karvonen J., Vuorimaa T., *Herat hate and exercise intensity during sports activities; practical application*, Sports Medicine, No. 5/1988, p. 303-312.

Boudet G., Garet M., Bedu M., Albuisson E., Chamoux A. Median maximal heart rate for calibration in different conditions: Laboratory, Field and Competition, International Journal Sports Medicine, No. 4/2002, p. 290-297.

Tanaka H., Monahan K.D., Seals D. R., *Age-Predicted Maximal Heart Rate Revisited*, Journal of the American College of Cardiology, No. 1/2001, p. 153-156.

Mohr M., Krustrup P., Nybo L., Nielsen J., Bangsbo J., *Muscle temperature and sprint performance during soccer matches – beneficial effect of re-warm-up at half-time*, Scandinavian Journal of Medicine and Science in Sport, No. 14/2004, p. 156-162.

Marins J. C. B., Fernandez M. D., *Comparação da freqüência cardíaca maxima por meio de provas com perfil aeróbico e anaeróbico*, Fitness & Performance Journal, No. 3/2004, p. 166-174.

Reilly T., Keane S. Estimation of physiological strain on Gaelic football players during match-play, (In:), Fourth World Congress of Science and Football, 4, 1999, Sydney. London: E & FN Spon, 2002, s. 157-159.

Wisloff U., Helgerud J., Hoff J., Strength and Endurance of elite soccer players, Medicine and Science in Sports Exercise, No. 3/1998, p. 462-467.

Tumilty D., *The relationship between physiological characteristics of junior soccer players and performance in a game simulation*, (In:) Second World Congress of Science and Football, No. 2/1991, Eindhoven, *Proceedings*, London: E & FN Spon, 1993, p. 281-286.

Summary

The purpose of this study was to evaluate and to compare the exercise intensity of U-20 and U-17 players during official championship Soccer games, using as parameter of effort the $\%HR_{max}$. The study had also the purpose of comparing the results between the first half time and the second half time of the game and was to compare the HR_{max} recorded during a friendly game and six official games.

Twenty-five male Soccer players who have been playing this sport for an average of five years participated in the study. The athletes trained for about 16 hours and played 2 championship games weekly.

The results showed if the exercise intensity was lower in the second half time of the game suggesting that there might have been a decrease in performance capacity of the players.

The exercise intensity of was also lower during the friendly game than during the official games. It is possible that motivation also plays a role causing this difference. The exercise intensity from a friendly game should not be used as reference for official games.

Key words: soccer, heart rate, friendly and official games analysis

TĘTNO MIARĄ INTENSYWNOŚCI ĆWICZEŃ W PIŁCE NOŻNEJ

Streszczenie

Celem badań była ocena oraz porównanie intensywności ćwiczeń realizowanych przez piłkarzy nożnych U-20 i U-17 w trakcie gier mistrzowskich, przy wykorzystaniu wskaźnika procentu tętna maksymalnego ($\%HR_{max}$). Dodatkowym celem pracy było porównanie poziomu tętna grających zawodników, jakie wystąpiło u nich w pierwszej i drugiej połowie meczu oraz w meczu towarzyskim i w meczach mistrzowskich (6 spotkań).

W badaniach uczestniczyło 25 piłkarzy, o średnim stażu treningowym 5 lat. Przeciętne obciążenia treningowe dla badanych to ok. 16 godzin zajęć treningowych i dwa mecze mistrzowskie w tygodniu.

Wyniki badań wykazały, że intensywność ćwiczeń (gry) była niższa w drugich połowach meczów, co sugeruje, że obserwowany spadek mocy był spowodowany przygotowaniem wydolnościowym piłkarzy.

Intensywność gry była też znacząco niższa w grze towarzyskiej niż w meczu oficjalnym. Możliwe, że wpływ na obserwowany poziom tętna miała motywacja. Tym niemniej – poziom intensywności gry z gier towarzyskich nie powinien być porównywany z wynikami obserwacji intensywności gry w meczach mistrzowskich.

Słowa kluczowe: piłka nożna, tętno, mecze towarzyskie i mistrzowskie – analiza