

Energy demand and heart rate evaluation at different phases during a match along an official soccer competition

Avaliação da demanda energética e frequência cardíaca em diferentes fases durante jogos ao longo de uma competição oficial de futebol.

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Abstract – The purpose of the present study was to analyze the energy expenditure and heart rate (HR), expressed as mean and maximal heart rate (HR_{max}), along matches of an official soccer competition. Methods: Eighteen under-20 year old (U-20) soccer players from a first-division Brazilian soccer team were evaluated during 15 matches. The relationship between HR and oxygen uptake (HR/ VO_2 relationship) was established, and a linear regression equation was developed for each individual player participating in the study. This equation was then used to determine the oxygen uptake and the corresponding energy expenditure based on the HR values measured during the games. The HR was recorded at 5-second intervals, which were clustered in phases of 15 minutes (0-15 min, 15-30 min e 30-45 min) for each half time (first half [FH] and second half [SH]). Results: The players' oxygen uptake was 308.3 ± 11.9 LO_2 /game and the energy expenditure was 17.3 ± 1.3 $Kcal.min^{-1}$ and $1,542.9 \pm 125.1$ $Kcal/game$. The results showed that there were significant differences between the HR and HR_{max} identified in the first half (FH 15-30 min) compared to the second half (SH 0-15 min and SH 30-45 min), and at FH 30-45 min compared to SH 0-15 min ($p < 0.05$). Conclusions: We concluded that soccer should be considered as an extremely arduous activity for U-20 players due to the high energy expenditure during the matches of an official championship. We also concluded that, during soccer games with young players, FH 15-30 min could be considered the most intense phase, because the highest values of HR and HR_{max} usually occur at this phase. **Key words:** Correlation; Energy expenditure; Intermittent.

Resumo – O objetivo do presente estudo foi a análise do gasto energético e da frequência cardíaca (HR), expressa pela média e pela frequência cardíaca máxima (FC_{max}), durante jogos de uma competição oficial de futebol. Foram avaliados, durante 15 jogos, dezoito jogadores de futebol da categoria abaixo de 20 anos de idade (Sub-20) de um time da primeira divisão de futebol brasileira. A relação entre FC e consumo de oxigênio (relação FC/VO_2) foi estabelecida, e uma equação de regressão linear foi desenvolvida para cada jogador. Essa equação foi utilizada para determinar o consumo de oxigênio e o gasto energético correspondente a partir dos valores de FC medidos durante os jogos. O registro da FC ocorreu em intervalos de 5 segundos, agrupados em fases de 15 minutos (0-15 min, 15-30 min e 30-45 min) em cada tempo de jogo [primeiro tempo (PT) e segundo tempo (ST)]. O consumo de oxigênio dos jogadores foi de $308,3 \pm 11,9$ $LO_2/jogo$ e o gasto energético foi de $17,3 \pm 1,3$ $Kcal.min^{-1}$ e $1.542,9 \pm 125,1$ $Kcal/jogo$. Os resultados mostraram que houve diferenças significativas entre a FC e a FC_{max} observadas no primeiro tempo (PT 15-30 min) em relação ao segundo tempo (ST 0-15min e ST 30-45min), e entre PT 30-45 min em comparação com ST 0-15 min ($p < 0,05$). Concluímos que o futebol deve ser considerado como uma atividade extremamente árdua para jogadores Sub-20, devido aos alto gasto energético durante as partidas de um campeonato oficial. Conclui-se também que, durante jogos de futebol com jogadores jovens, a PT 15-30min poderia ser considerada a fase mais intensa do jogo, porque os maiores valores de FC e FC_{max} usualmente ocorrem nessa fase.

Palavras-chave: Correlação; Gasto energético; Intermittente.

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INTRODUCTION

Soccer is considered a high-intensity intermittent activity¹⁻³ with different game patterns between positions⁴, and is characterized by short-duration high-speed runs, jumps, headings, and ball disputes, besides other activities, such as jogging, low-speed running, and walks. The exercise intensity during a soccer match is about 75% of the maximal oxygen uptake (VO_{2max}), and great part of the match occurs at anaerobic intensity zones⁵. It should be pointed out that the game lasts for about 90 minutes and that the players run over 10 km per game on average^{6,7}. Due to its correlation with oxygen consumption, heart rate (HR) is considered an important tool for evaluating the energy cost of sports in which the use of indirect calorimetry during the activity is not possible⁸⁻¹¹.

The exercise intensity monitoring takes maximal heart rate (HR_{max}) percent into consideration^{12,13}, identifying and using correct HR_{max} values is the key to individualized overload prescription^{14,15}. Moreover, HR_{max} values are also used to estimate the energy expenditure¹⁶. HR_{max} should be determined in real competition situations^{17,18}, because when it is estimated it might not be reliable¹².

The energy expenditure of a single soccer player calculated from the HR measured during a friendly game was 1,360 Kcal¹⁹. Using the same procedure, Garcia et al.⁹ evaluated 23 Brazilian professional soccer players during official matches and reported an average value of 11.3 Kcal.min⁻¹ and individual values ranging from 6.4 Kcal.min⁻¹ to 16.8 Kcal.min⁻¹, and Stolen et al.²⁰ reported an average value of 1,700 Kcal/game.

The knowledge of the energy expenditure during any sport competition can be used by coaches, team physicians and nutritionists as a tool for better planning the workouts, diet, and recovery activities for athletes; moreover, the correct HR and HR_{max} identification is fundamental for training monitoring and planning. Thus, the purpose of the present study was to analyze the energy expenditure and heart rate (mean and HR_{max}) along matches of an official soccer competition of the under-20 year-old category (U-20).

METHODS

Eighteen U-20 male athletes from a first-division Brazilian soccer team, who participated in competitions organized by the Brazilian Soccer Confederation, volunteered for the study. The HR of eight midfielders, five forwards, and five defenders was monitored during at least eight of twelve matches. On average, the players participated in 9.5 ± 0.8 matches.

This study was approved by the Human Subjects Research Ethics Committee (ETIC-291/09) from Universidade Federal de Minas Gerais, where it was done, and complied with all rules established by the National Health Council (Res. 196/96) regarding research with human subjects. Before the beginning of the study, all procedures, as well as possible risks and benefits,

were clearly explained to the volunteers and their parents, who have freely signed an informed consent to participate in the experiment.

The percent body fat was calculated from skinfold measurements²¹ using a manual skinfold calliper (Lange®). The subjects were weighed in kilograms (to the nearest 0.1 kg) on a calibrated scale (Filizola®, Brazil). The subjects' height was measured using a standard stadiometer connected to the scale.

The athletes' $\text{VO}_{2\text{max}}$ was measured by the open-circuit spirometry method using the Bruce protocol¹² and a BIOPAC® breath-by-breath spirometer. This device registers the oxygen uptake in each respiratory incursion and its precision is 0.01 LO_2 .

The data from the $\text{VO}_{2\text{max}}$ test were used to establish the relationship between HR and VO_2 . Hence, it was possible to establish the relationship between HR and VO_2 within an activity range that encompassed from low-intensity aerobic activity until values close to the $\text{VO}_{2\text{max}}$.

All players were evaluated in the morning, and it was assured that they did not perform any intense exercise up to 72 hours before the tests. The players' HR was recorded during matches from an official competition in which two matches were played weekly, along two months (15 games), using a recording system (Polar Electro Oy, Team System, Finland). The HR data were analyzed by the Polar Precision Performance SW 3.0 software.

Individual regression equations were developed from the HR and VO_2 measurements recorded during the progressive treadmill test. The average correlation between the HR and VO_2 of the athletes was 0.97 ± 0.05 . The figure 2 shows an example of this relationship in a soccer player.

The individual regression equations were used to calculate the VO_2 ($\text{mLO}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and LO_2 for all game and each phase) on the basis of the HR data obtained from each soccer player during the matches. The VO_2 values were then converted into kilocalories per minute ($\text{Kcal} \cdot \text{min}^{-1}$) and kilocalories per game (Kcal/game) assuming that $1 \text{LO}_2 = 5.0 \text{Kcal}$ ²². Both the total oxygen uptake and total energy expenditure of each volunteer were calculated using the actual individual playing time.

The individual athletes' HR_{max} was determined as the highest HR observed during all the matches from the same soccer player. For evaluation purposes, the matches were divided into phases (0-15 min, 15-30 min, and 30-45 min) for the first (FH) and second (SH) halves, and it was determined at which phase the HR_{max} was defined. After this, the percent of HR_{max} determined at each phase was calculated.

This research was done between March and April, and the average environmental conditions were: dry temperature 24.2 ± 2.7 °C (range: 21.60-29.55 °C); humid temperature 19.50 ± 3.5 °C (range: 17.01-28.83 °C); globe temperature 30.53 ± 2.15 °C (range: 25.56-37.90 °C); wet bulb globe temperature 26.13 ± 2.13 °C (range: 22.64-30.22 °C); and relative humidity 65.5 ± 7.5 % (range: 50.3-79.1 %). All matches were held between 9-11 a.m.

Statistical analysis

The data are presented as mean and standard deviation. The HR/VO₂ relationship was obtained through the correlation between the variables, using the Pearson Product Moment Correlation Coefficient. The intraclass correlation coefficient (ICC) was used to determine the within-subject reliability of energy expenditure measures among matches. The ICC was also used to determine the within-physical test reliability.

To compare HR_{max}, HR, oxygen uptake, and energy expenditure among the match phases, an one-way analysis of variance (ANOVA) was applied, followed by a Tukey's *post-hoc* test. The test power, which represents the chance to identify differences among the groups, was considered at 0.80, for a level of significance established at $p \leq 0.05$.

RESULTS

The athletes' age, height, weight, percent body fat, and maximal oxygen consumption were 18.3 ± 0.7 years, 177.3 ± 8.5 cm, 70.1 ± 4.9 kg, $8.8 \pm 1.8\%$ body fat, and 58.2 ± 2.3 mL O₂.kg⁻¹.min⁻¹ respectively. The ICCs among all physical test values were between 0.94 and 0.99.

The HR recording of one athlete during a game is shown in figure 1, as well as the match phases when the HR, expressed as mean (HR_{max}), was evaluated.

The results for HR_{max} (table 1) show that there is a difference between FH 15-30 min when compared with SH 0-15 min ($p=0.023$) and SH 30-45 min ($p=0.031$). There is also a difference between FH 30-45 min and SH 0-15 min ($p=0.015$). In the SH there is difference between SH 0-15 min and SH 30-45 min ($p=0.037$).

About the HR at each phase, the FH 15-30 min was higher than other phases but was not different than FH 30-45 min and SH 15-30 min. The HR at FH 30-45 min was higher than at SH 0-15 min ($p=0.039$) and SH 30-45 min ($p=0.040$).

The oxygen uptake (mL O₂.kg⁻¹.min⁻¹ and LO₂) was higher at FH 15-30 min when compared to SH 0-15 min ($p=0.012$) and SH 30-45 min ($p=0.020$).

The energy expenditure (Kcal.min⁻¹) at FH 15-30 min was higher than at SH 0-15 min ($p=0.011$). The energy expenditure as total Kcal per phase was higher at FH 15-30 min than at SH 0-15 min ($p=0.013$) and SH 30-45 min ($p=0.034$).

The players' total oxygen uptake was 308.3 ± 11.9 LO₂ and the energy expenditure per game was $1,542.9 \pm 125.1$ Kcal/game or 17.1 ± 2.1 Kcal.min⁻¹ (table 1). The ICC among soccer players along the competition was 0.98 for oxygen uptake and energy expenditure also.

The energy expenditure among players in terms of tactical playing position was not tested because of the small sample size of each position group.

The most part of the soccer players' HR_{max} was determined at FH 15-30 min phase (table 2).

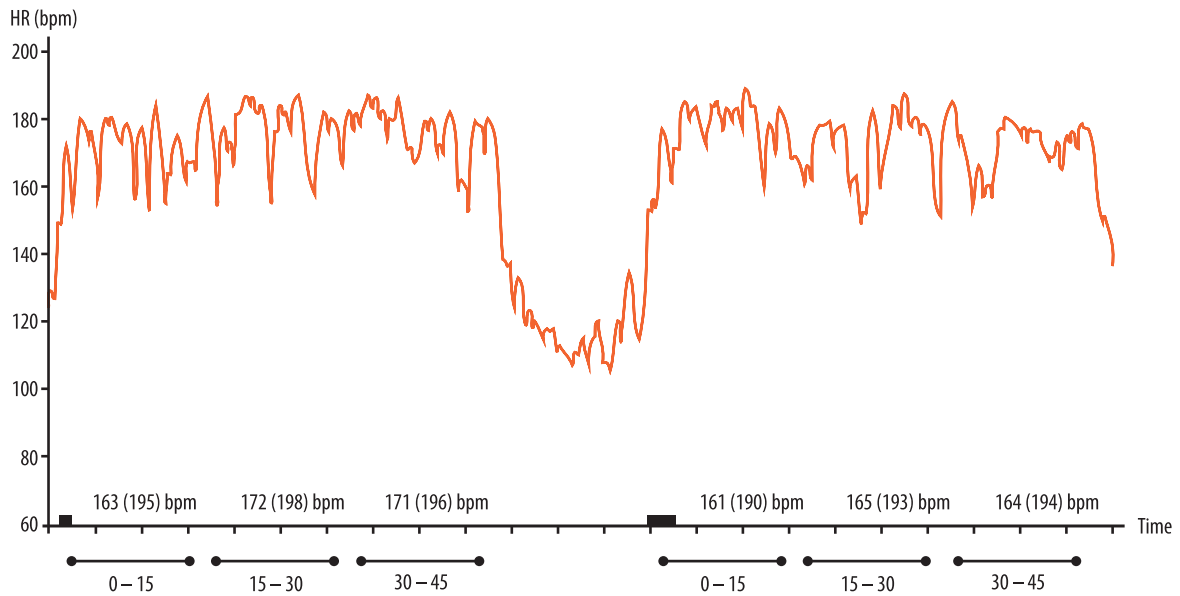


Figure 1. Sample of heart rate (HR) behavior and maximal heart rate (HR_{max}) phases evaluation from a soccer player. Under the x-axis are presented the different phases analyzed along the first and second halves of the match. Above the x-axis are presented HR mean and, in parentheses, the HR_{max} observed for this soccer player at each phase.

Table 1. Players' maximal heart rate, heart rate, oxygen uptake ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$, LO_2), and energy expenditure ($Kcal \cdot min^{-1}$ and Kcal) among different game phases and for total match.

	FH			SH			Game
	0-15 min	15-30 min	30-45 min	0-15 min	15-30 min	30-45 min	
HR_{max} (bpm)	190.3	192.9	191.5	187.1 [*]	189.8	189.8 ^{†*}	190.7
SD	±11.1	±9.9	±11.7	±9.6	±8.9	±9.7	±12.3
HR (bpm)	171.0 [‡]	176.0	173.0	163.0 [*]	170.0	167.0 [*]	170.0
SD	±10.0	±8.4	±6.9	±7.0	±8.7	±9.5	±9.2
Oxygen uptake ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$)	48.9	51.7	50.7	44.1 [*]	48.9	46.1 [*]	48.4
SD	±9.5	±12.3	±11.1	±9.5	±13.2	±8.5	±12.1
Oxygen uptake (LO_2)	51.4	54.3	52.5	46.7 [*]	50.8	49.1 [‡]	308.3
SD	±3.1	±2.8	±1.6	±2.8	±3.0	±2.2	±11.9
E. expenditure ($Kcal \cdot min^{-1}$)	16.1	17.2	16.7	14.6 [‡]	16.3	15.3	17.1
SD	±2.9	±4.7	±3.9	±3.5	±3.8	±4.7	±2.1
E. expenditure (Kcal)	244.7	258.6	250.3	222.5 [*]	241.9	233.6 [‡]	1542.9
SD	±22.1	±32.3	±27.5	±16.9	±21.7	±15.0	±125.1

Mean and standard deviation (SD) of maximal heart rate (HR_{max}) evaluated at each match phase and per game. [‡]Difference in relation to FH 15-30 min, ^{*} difference in relation to FH 30-45 min, and [†] difference in relation to SH 0-15 min ($p < 0.05$). FH- first half; SH- second half.

Table 2. Percentage distribution of HR_{max} reached during the different match phases.

Phases	FH			SH		
	0-15 min	15-30 min	30-45 min	0-15 min	15-30 min	30-45 min
Percentage	20.45%	31.82%	18.18%	4.54%	11.38%	13.63%

FH- first half; SH- second half.

Figure 2 shows the HR/ VO_2 relationship curve from one of the soccer players.

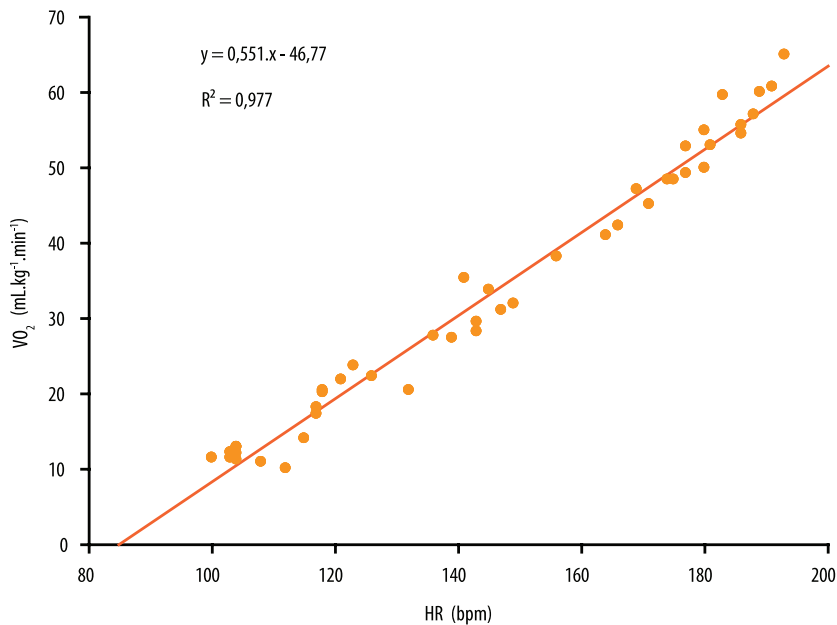


Figure 2. Individual's sample heart rate (HR) and oxygen uptake (VO₂) from one volunteer.

DISCUSSION

The main finding of the present study was that the oxygen uptake and energy expenditure of players who participated in the U-20 category during official matches of an official competition were 48.4 ± 12.1 mL.O₂.kg⁻¹.min⁻¹ and 17.3 ± 1.3 Kcal.min⁻¹ respectively, which corresponded to a total average of 308.3 ± 11.9 LO₂/game or $1,542.9 \pm 125.1$ Kcal/game. In addition, FH 15-30 min seems to be the most intense phase because of the high HR and HR_{max} values.

The use of the HR/VO₂ relationship to calculate the energy expenditure from the HR measurements has been shown to provide reliable results by Esposito et al.³, who did not find any difference between the estimated VO₂ and that measured in athletes who performed soccer-specific activities wearing a portable spirometer.

From the average energy expenditure expressed in Kcal.min⁻¹ reported in the present study, soccer is classified as an extremely arduous activity, according to McArdle et al.²². Other authors, using different methods, have reported similar estimated values to those of the present study. Shephard⁶, based on a literature review, estimated that the energy expenditure for a soccer match would be 17.4 Kcal.min⁻¹ or 1,565 Kcal in a 90-minute match. Stolen et al.²⁰, assuming that the oxygen uptake during a soccer match would be of approximately 75%VO_{2max}, suggested that players weighing 75 kg and with VO_{2max} of 60, 65 and 70 mL.kg⁻¹.min⁻¹ would have energy expenditures of 1,519, 1,645 and 1,772 Kcal/game respectively.

Our results are also similar to those reported by Reilly & Thomas²³, who conducted an experiment using the HR/VO₂ relationship to evaluate the energy expenditure of 23 professional players during a single simulated match and suggested a value of 17.4 Kcal.min⁻¹. In their study, Reilly

& Thomas²³ estimated the values of energy expenditure by extrapolation from the time actually played by each player, since their playing time was different and some did not play for the whole 90 minutes. This point is different from the present study, in which each soccer player was monitored along all the matches. It has been suggested that the effort intensity of simulated or friendly matches is lower than that of real matches²⁴ due to lack of motivation¹⁸.

The calculated energy expenditure in our study was higher than the value proposed by Bangsbo¹⁹, who used the core temperature of a single athlete to estimate his energy expenditure during a soccer match and reported a value of 1,360 Kcal. Other authors used the total daily energy expenditure to estimate the caloric cost of a soccer match²⁴. Sports nutritionists could use this information for planning special dietary strategies for the athletes²⁵. In our study, we have evaluated athletes from different tactical playing positions during a series of 15 matches over a 2-month time span, to improve the reliability of our results¹⁹.

The results (table 2) show that the majority of athletes reach their HR_{max} , and the higher mean HR is observed in the intermediate phase of the FH (FH 15-30 min). It can occur because both teams would be studying each other at the beginning of the match, trying to take a tactical advantage. In this phase, soccer players do not have optimal physical conditions to get the best muscular performance. One of these conditions could be adequate body temperature²⁶. Thus, the maximal effort would happen in the middle of the FH.

It is possible to notice a visual decrease between the same phases of the FH and SH (table 2). The FH shows higher percentage values of HR_{max} than the SH. The results of the present study agree with those from other investigations^{27,28} that found a decrease in HR at the SH. This intensity decrease should be attributed to glycogen depletion or dehydration²⁹.

During the last phase of the match (SH 30-45 min), a discrete increase in HR_{max} cases was observed (table 2). This fact can be attributed to the importance of this phase for the match.

For many decades, the evaluation of the exercise intensity in team sports was possible only during practice and workouts, but that has changed with the new technologies now available in the market worldwide. The possibility of assessing the energy requirements with HR measurements during official matches will represent an important step in the process of offering to athletes better strategies for the training loads and the diet, as well as weight control and recovery between matches over the season³⁰.

The use of the HR/VO_2 -relationship to calculate energy expenditure is practical, relatively inexpensive, and shows a good external validity, because a lot of real situations in sports can be monitored and significant samples are reached. Despite this, the data generated should be interpreted considering that this is a calculated and not a direct measure. It should be pointed out that the HR can be influenced by several factors, such as temperature, hydration state, and emotional factors. This can be viewed as a limitation of the present study.

CONCLUSIONS

We concluded that soccer presents high values of energy expenditure during the matches of an official championship, and, due this fact, it is classified as an extremely arduous sport.

It is suggested that the intermediate phase of the FH is the most intense, because some of the parameters present higher values at this phase and the majority of soccer players present their HR_{max} at this phase.

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