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ARTÍCULO EN INGLÉS

Reliability of maximum heart rate in match's and comparison with predicted in young soccer players

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ABSTRACT

Objective. To verify the reliability of maximal heart rate obtained (MHR_{obt}) in official soccer games and to compare it with calculated by equations (MHR_{pre}).
Method. The study included 18 soccer players (14 ± 0.6 years, 174 ± 6 cm, 62 ± 6 kg) participant of a Brazilian state championship in U-15 category. The equations were selected [MHR = age-220]; Tanaka et al. [MHR = 208 – (0.7*age)] and Nes et al. [MHR=211 – (0.64*age)] for comparison with MHR_{obt} in competition.
Results. Bland-Altman analyze showed good agreement of MHR_{obt} and the CV (1 %) and ICC (0.95 [0.86 – 0.98]) show good reliability of the inter matches. The MHR_{obt} (202 ± 8 bpm) was lower than 220 – age equation (205 ± 1 bpm; $P < 0.05$) and higher than Tanaka et al. (198 ± 0.4; $P < 0.05$), with no difference to the Nes et al. equation (202 ± 0.5 bpm) ($P > 0.05$).
Conclusion. MHR_{obt} there is good reliability between soccer matches in competition and it is recommended to use the Nes et al. [MHR = 211 – (0.64 * age)] equation to MHR_{pre} in young soccer players.

Palabras clave:
Frecuencia cardiaca.
Ecuación de predicción.
Fútbol.
Jóvenes.
Confiabilidad.

RESUMEN

Fiabilidad de la frecuencia cardiaca máxima en el partido y comparación con la prevista en jóvenes futbolistas

Objetivo. Verificar la fiabilidad de la frecuencia cardiaca máxima obtenida (FCMobt) en los juegos oficiales de fútbol y compararla con la prevista por ecuaciones (FCMest).
Método. El estudio incluyó a 18 jugadores de fútbol (14 ± 0,6 años, 174 ± 6 cm, 62 ± 6 kg) que participaban en un campeonato regional brasileño de la categoría sub 15. Se seleccionaron las ecuaciones [FCM = = edad – 220]; Tanaka et al. [FCM = 208 – (0,7 * edad)] y Nes et al. [FCM = 211 – (0.64 * edad)] para su comparación con FCMobt en competición.
Resultados. La técnica Bland-Altman mostró una buena concordancia de FCMobt y el CV (1 %) y el ICC (0,95 [0,86 – 0,98]) muestran una buena fiabilidad entre los partidos. El FCMobt (202 ± 8 lpm) fue menor que por la ecuación 220 – edad (205 ± 1 lpm, $P < 0,05$) y más alto que por Tanaka et al. (198 ± 0,4, $p < 0,05$), sin diferencia por ecuación la Nes et al. (202 ± 0,5 ppm) ($P> 0,05$).
Conclusión. FCMobt hay una buena fiabilidad entre los partidos de fútbol en competición y se recomienda utilizar la ecuación de Nes et al. [MHR = 211 – (0,64 * edad)] para predecir la FCMpre en jóvenes jugadores de fútbol.

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INTRODUCTION

Heart rate (HR) is a physiological variable of control of exercise intensity, widely used for prescription of physical training in soccer[1-3]. With the arrival of heart rate monitors, the measurement of this variable has become very practical, accurate, fast and cheap, making their use even more accessible[4,5]. Physiologically, HR offers a high degree of relationship with physiological variables such as VO_2, even in intermittent activities such as soccer, either in professional[6,7], amateur[7-9] or youth players[1,10]. Current radio telemetry systems allow monitoring all players simultaneously in short time intervals, thus facilitating training prescription and control[11,12].

The use of HR as a training method is usually done by applying percentages of maximum heart rate (MHR), which varies according to the desired training intensity[13,14]. Thus, establishing MHR is a key factor for the accurate prescription of training intensities in order to avoid errors when defining training loads. Establishing MHR can be done directly by recording the highest HR during a maximum effort (MHR_{obt})[15] or indirectly through predictive equations (HRM_{pre})[16,17].

In sports such as soccer, in which characteristics are intermittent and maximum, there is an indication that MHR should be obtained during competition, since these values have proved to be higher than in tests of maximum effort[18-22]. However, since it is not always possible to obtain the MHR_{obt} for safety reasons regarding the athletes and the use of equipment in competitive games, the utilization of predictive equations may represent an interesting choice to relativize training load.

Despite the advantage of not requiring a maximum effort in order to be quantified, MHR_{pre} can display a high error rate and high individual variation (± 10 -12 bpm)[15], thus jeopardizing the accuracy of training requirements. This is worrying in high performance sports in which small errors in the calculation of training loads may reflect in weak stimuli, thus preventing the achievement of the desired training effects, or even generating exaggerated ones, what may lead to the non-functional overreaching[23].

There is no doubt that MHR decreases with age[16,24,25] and that among the 50 formulated equations to estimate the MHR reported by Marins and Fernández[26], only a few were developed including children or teenagers in the sample[27,28]. Therefore, using equations developed for adults in adolescents can generate an important prediction error. On the other hand, MHR_{obt} can display low reliability due to the particular characteristics of each match and this has not been the focus of researches.

Therefore, the present study aimed to: a) verify the reliability of MHR_{obt} value in matches, b) compare the MHR_{obt} of U-15 youth soccer players in official soccer matches with the MHR_{pre} through equations. As hypotheses we expect that the MHR_{obt} will present low reliability due to the random characteristics and multi-dependency that the MHR_{obt} may present in each match (tactics, environmental variation, motivation, etc.). On the other hand, we expect that the hypothesis of higher value of MHR_{obt} when compared the to the MHR_{pre} will be confirmed, as the game is a great source of stimuli for the observation of higher HR values, and therefore, that the MHR_{obt} is underestimated by some equations, since they were mainly predicted through laboratory tests of maximum effort. Thus, this type of study could help establishing more effective parameters for exercise prescription, taking the MHR as reference.

METHODS

Experimental design

This study has a cross-sectional characteristic, in which a U-15 youth soccer team was selected by convenience. The design proposed for this study was developed so that in a first moment it displayed a descriptive character, through the quantification of players' MHR_{obt} in official matches, as well as the measurement reliability through the procedures described below. Secondly, the research assumed an inferential characteristic, adopting a hypothesis test to verify the possibility that MHR could be estimated by predictive equations through players' MHR_{obt} in official matches.

During observational procedures, players were participating in the main competition of the U-15 youth level. During this period, they had one training session a day (physical-technical and tactical sessions), during 90 minutes, five times a week and played one official match per week (70 min) on Saturdays or Sundays, in which the MHR_{pre} was monitored. The training sessions consisted, primarily in the development of technical and tactical skills (80 % of training session time). Physical training was performed twice a week and aimed to develop aerobic (small-sided games and interval runs) and anaerobic performance (sprinting) and strength (plyometrics).

Individuals were also instructed to refrain from the consumption of caffeinated substances (matte, chocolate, coffee, *guarana* and coke) in the 24 hours prior to the game, aiming to avoid possible interferences.

SAMPLE

Twenty-five male players from a team that plays regularly in competitions recognized by a Soccer State Federation in Brazil agreed to participate as volunteers. All of them had experienced around 4 ± 1 years of systematic training and soccer competitions.

Players who did not play the entire matches not to have been lined up (for injury, N = 1) or replaced during the game (N = 6) were excluded from the study. Participants (n = 18) had (mean ± standard deviation) 14 ± 0.6 years old, 174 ± 6 cm in height, body mass of 62 ± 6 kg, VO_2max of 49.5 ± 2 ml.kg.min-1 obtained by Margaria et al.[29] The representation by playing position was as follows: full backs (N = 3); center backs (N = 4), midfielders (N = 7) and forwards (N = 4). The team played in a regular 4-4-2 formation, using four defenders, four midfielders and two forwards.

The free informed consent about the study was signed by parents or guardians, meeting the recommendations of the National Health Council – MS, Resolution 196/196. The study's protocols were approved by the Human Research Ethics Committee of the Institution of Origin with the number *Of. Ref N ° 46/2007.*

PROCEDURES

In order to obtain the values of HR, Polar® Team System (Polar Electro Oy, Kempele, Finland) was used with an interval of measurement of 5 seconds. This device enables recording HR during an activity without a wrist monitor, which is forbidden by soccer rules, as it can harm the athlete's, teammates' and opponents' safety. In addition, a permition from the referees was obtained through the state Soccer Federation who promoted the competition. The athletes were already familiarized with this type of equipment, as it was part of their routine of evaluation and control of training load, even in friendly matches. Twenty-five minutes prior to the start of the match, the volunteers who were instructed by the club technical committee, completed the standard warming-up and stretching that simulate game actions.

As criterion to the MHR_{obt}, individual maximum peak value obtained during two complete games was used for each player in the U-15 Minas Gerais Championship. The environmental temperature during matches was monitored (TGM 100, Homis®, Brazil) and was not statistically different between the days (WBGT = 24.4 ± 1.8 °C vs. 23.6 ± 2 °C, P = 0.585, Wilcoxon Signed Ranks Test).

The exercise intensity observed during matches was 85 ± 3.7 % of MHR_{obt}. This value corroborates with other studies for different player levels[14,30-32], confirming that matches were played in the usual way.

Since there were no specific predictive equations for children and adolescents (by Medline using the keywords on 06/29/2012 "Maximum heart rate", "prediction", "young"), to compare MHR_{obt} and MHR_{pre} the following equations were selected: 220 – age as being the most widely used[15,21,25]; Tanaka et al.[33] [208 – (0.7 x age)] for having proved to be valid for boys of 10 to 16 years[34] and Nes et al.[35] (2012) [211 – (0.64 x age)] to be the latest and most developed, with a wide range sample of age groups and effects of sex, body mass index (BMI), physical activity level and maximal oxygen consumption.

STATISTICAL ANALYSIS

To assess the data normality, Shapiro-Wilk test was used. As data did not display regular distribution, descriptive statistics were presented as mean/median ± standard deviation, and also the minimum and maximum values. On the matches, the agreement limits between the pairs of measurements obtained on test and retest of the MHR_{obt}, was observed according to the suggested method by Bland and Altman[36]. The coefficient of variation (CV) was also used as a measure of reliability[37]. The CV was established for each individual, by dividing the standard deviation of each measurements pair by their mean values (CV = [(SD/mean) * 100]). Then, the mean CV was calculated through the average of the individuals' CV. In addition, to verify the reliability of the pairs of values obtained in test-retest, intraclass correlation coefficient (ICC) was used. The use of these three approaches follows the recommendations of Atkinson and Nevill[37], as it presents advantages and disadvantages in each case. To compare the MHR_{obt} data from the game with the MHR_{pre}, Kruskal-Wallis test was used and as a post hoc, Dunn's test was performed, having the match as control group. The statistical analysis was performed in Sigma Plot 11 package for Windows (Chicago, IL, USA). In all cases, the level of statistical significance was set to P < 0.05.

RESULTS

The reliability of MHR_{obt} on the game was verified by Bland-Altman's analysis, which indicated the degree of agreement between the pairs of measurements obtained in test-retest (fig. 1). Only one player was outside the limits of agreement. The CV was 1 % and the intraclass correlation coefficient (ICC) with a confidence interval of 95 % was 0.95 [0.86 to 0.98]. Throughout these results, it is possible to assume that the MHR_{obt}

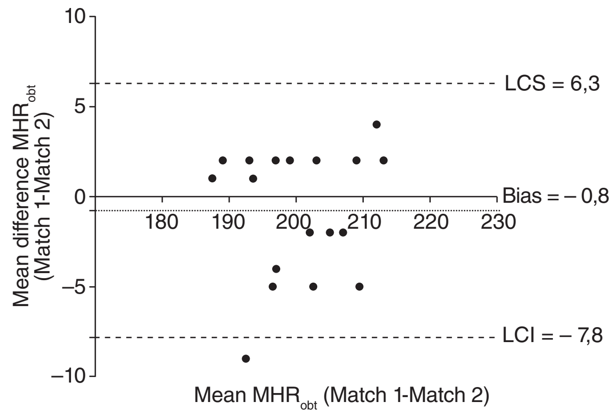

Fig. 1. Plot of the bias (mean differences) and upper and lower limits of agreement (LCS and LCI, 95 %) between the values of MHR obtained in Match 1 and Match 2, according to Bland-Altman's (N = 18) procedures.

obtained in matches did not present heterocedastic errors, in other words, good reliability was displayed.

After the analysis of Kruskal-Wallis with Dunn's post hoc tests, we observed that the predictive equation of Nes et al.[35] presented MHR_{pre} that was similar to the MHR_{obt} during match (P > 0.05). MHR_{pre} by equations 220 – age and Tanaka et al.[33] were different (P < 0.05) when compared to the MHR_{obt} during match (table 1).

DISCUSSION

Test-retest analysis of MHR_{obt} during matches displayed good measurement reliability, indicating that collection of HR during official matches through heart rate monitors can be used as a method to determine MHR_{obt} in soccer players with good accuracy. Some studies have focused on the collection of MHR_{obt} in a competitive situation[18,20-22], but none of them focused on the measurement reliability under such conditions. The present study uniquely reports that MHR_{obt} in soccer matches in youth players is a measure with guaranteed reproducibility, presenting constancy of results during "test-retest" in young players.

For juvenile and adult individuals, a physical test of maximum effort is usually employed for collecting MHR_{obt}[38,39]. However, in athletes of sports with maximum and intermittent characteristics such as soccer, MHR_{obt} obtained by analysis of matches has proved to be higher than in physical tests[18,20-22], besides being more specific and, therefore, more appropriate for athletes.

Laboratory situations can generate greater opportunities of controlling experimental conditions. However, according to Santos et al.[40] there is a strong tendency of the MHR_{obt} being higher in field tests than in laboratory tests. According to these authors, the differences between MHR values obtained in these two environments may be partly explained by the fact that as temperature and humidity are generally higher

Table 1
Maximum heart rate values obtained during matches and predicted by three different equations (N = 18)

	Mean ± Sd	Median	Mínimum and maximum
MHRobt	202 ± 8	201	188 - 214
Tanaka et al. (2001)	198 ± 0,4*	197	197 - 199
Nes et al. (2012)	202 ± 0,4	201	201 - 203
220 – age	205 ± 0,6*	205	205 - 207

* :different compared to MHR_{obt} (P < 0,05). MHR: maximum heart rate.

in a field environment, this would lead to a higher load of physiological stress. Furthermore, the psychological aspect and greater motivation to achieve high performances in competitive situations are likely to be the main reasons that enable the MHR_{obt} with higher values to be observed in competitive situations, as in other forms of intermittent feature as in Rugby[19], American Football[18] and Gaelic[20] Football.

The use of the HR has proved to be a reliable method to measure exercise intensity in soccer[3,8,41], once no significant differences were observed on the mean values of HR in two or more consecutive matches[31] and the MHR_{obt} permanence time above 85 % is also reliable for repeated measurements (CV observed [8.6 ± 5.4 %] and ICC [0,92])[22], which can ensure that similar conditions of physical effort are employed by the player. In this study, the intensity of effort between matches was 85 ± 3.7 % of the MHR_{obt} which is similar to other studies[14,30,31,41]. The great MHR_{obt} reliability could be confirmed also by CCI (0.95) observed in this study, thus demonstrating low individual variability.

Although the use of HR is practical, and also reliable as demonstrated in this study, their responses may be influenced during matches and training sessions by several aspects besides player's physical effort. Among these, we can consider the environmental conditions such as temperature, relative humidity, altitude and air resistance, psychological aspects such as anxiety and stress, and use of medicines[18]. This indicates that the technical staff should monitor these intervening variables, when they want to obtain MHR_{obt} in field (training, testing or matches). Thus, it is worth highlighting that the individual treatment (athlete by athlete) should be given, since variability in the reproducibility of measurements for some pairs was high (fig. 1), and also for examining that the means of differences (bias) between the test-retest was not close to zero in both games.

Comparing the MHR_{obt} in official soccer matches with MHR_{pre}, we observed that the equation of Nes et al.[35] presented values that were close to those found during matches (202 ± 0.4 vs. 202 ± 8, respectively). This corresponds to a better applicability of this equation, since it can be utilized to predict the values of MHR when necessary, to relativize the effort intensity in training prescriptions for people within the same age group as the one in this study, without the need of match measurements.

The equation 220 – age, which is curiously credited to Karvonen et al. (1957), actually has an unknown authorship[15]. This equation, despite being widely used and recommended, displayed differences, overestimating MHR_{obt} compared to MHR_{obt} (in matches). In other studies, it was also observed that this equation overestimates MHR in young pepole[33,34]. This also corroborates the results found by Antonacci et al.[21] for high level Brazilian soccer players in U-17, U-20 and professional levels. Thus, the results of this study clearly indicate that exercise prescription, regarding the equation MHR = 220 – age can lead to a methodological training error for the investigated age group, since it overestimates the peak value of MHR in a situation that is very stressful by itself, such as the game. Therefore, the use of MHR_{pre} for effort regarding by the "220 – age" equation, can cause an overload of activity planned for players with characteristics similar to the present study.

The MHR_{pre} equation by Tanaka et al.[33] was also statistically different from the match. Thus, the use of this equation to the young players evaluated, would lead to a lower intensity training session with respect to the MHR_{obt}, causing loss of quality in the prescribed activity. Therefore, while other studies have established the Tanaka et al.[33] equation as valid, it can be hypothetically affirmed that the use of a treadmill test to determine MHR, may have generated a MHR value lower than what would be found in competitive situations.

Other studies have found that the equation of Tanaka et al.[33], displayed no significant differences if compared to what was obtained in physical tests[26,34]. However, all previous studies indicated that MHR was obtained during physical tests in laboratory or field. Thus, HR monitored during a competitive situation can bring a more assertive data about the athletes' MHR_{obt}, since this environment will provide different stimulus, such as thermic stress and psychological pressure of competition that causes modification of sympathetic modulation, what enables factors there are less probably to happen in a laboratory environment or conventional training.

Thus, despite the fact that literature points out that the higher values of MHR_{obt} occur in competition[18-22] situation, it is recommended that this variable is evaluated in other situations of effort and training (i.e. small-sided games) in soccer players. Therefore, there is the possibility that players express higher MHR values individually in competitive matches, improving the acuity of prescriptions and training control through relativizing MHR. With the possibility of expansion of MHR collection, it is worth ponting out the circadian influence, which modifies MHR responses. Afonso et al.[42] observed a decrease in MHR_{obt} during the dark level of the light/dark cycle in their study, using the Bruce treadmill protocol, what would report the need to consider the individual circadian variations, to observe and prescribe activities taking this variable as a parameter, mainly at late hours. It is necessary to highlight that matches were mainly played in the afternoon (13 to 15 o'clock), differently from training time, what is not frequently used by Brazilian teams for training.

Another remark to the applicability of the results within this study refers to the fact that the MHR_{obt} observation must occur from time to time, according to cardiovascular system adaptation and the intrinsic and extrinsic mechanisms of cardiac control. Thus, an athlete evaluated early in the season, will present along this time a lower MHR_{obt} value, for adaptation reasons previously mentioned. Another comment concerns the decrease of ~1 beat/min per year, that occurs after 30 years of age[25,30,43], possibly due to the lower activity of the autonomic cardiac muscle, that is inherent to aging[43]. Therefore, in order to observe an acceptable applicability of the results within this study for the routine of soccer teams, the adequacy of the athletes profile to those of the present study should be evaluated, since they are adapted to workout routines and soccer competitions. In this case, further studies over validity of predictive equations for different age groups are suggested.

To Nes et al.[35], there is no evidence of interaction between gender, physical activity level, BMI or VO_2max and MHR_{obt}. On the other hand, they point out that the lack of standardization of tests to determine MHR as a factor that may cause differences in the results, and consequently in the more suitable predictive equations. Thus, in the case of sports with characteristics of maximum and intermittent effort such as soccer, basketball, handball, futsal or even cycling competitions, in which fluctuations of exercise intensity are extreme, it is recommended, whenever possible, monitoring HR during competitive period, aiming to obtain the highest MHR_{obt} value .

The absence of fatigue indicators during, for example, blood lactate, muscle pH or level of plasmatic K^+, may be considered as a limitation of the study. These parameters help to better characterize matches, and monitor maximum effort exerted, or not, by the players in the evaluations and to differentiate physiological and/or motivational limitations for such procedure. However, it is necessary to emphasize that these are invasive measures, and represent implications with the ethics committee, as our volunteers are young. On the other hand, the fact that it is a high level competition for this age group, we believe that motivation may have led them to really spend the maximum individual effort.

Taking into consideration the practical applications of utilizing HR, it should be noted that its analysis during a soccer match, considering only the absolute values (bpm), it must be done carefully, since players' age, together with individual response, can induce misinterpretations regarding the true metabolic pathway (aerobic/anaerobic) that the player is using. Thus, the HR used in correspondence with some parameter of metabolic threshold, should be thought to individualize the training sessions, and in the meantime to adequate stimuli that meet the complexity of soccer, and compensate deviations that may occur when prescribing the MH_{Robt} percentage in predetermined zones. This demonstrates that coaches can structure HR zones, which correspond to 2-4 mM of blood lactate, thus individualizing working intensity in small-sided games, as well as other technical-tactical activities for soccer players[3].

It is worth considering that monitoring training loads through other methods such as PSE may complement HR measurement, since this method evaluates the overall result of the effort exerted by the athlete, and helps to understand the internal load proposed by the technical staff, both in physical, technical and tactical training sessions.

Future studies should be conducted with the aim of carrying out comparisons between MHR_{obt} in competitive scenarios with other equations, and even field protocols and/or spirometer. These measures will aim to highlight the most valid and reliable assessment procedures for MHR determination in young soccer players, where there is a great limitation of published knowledge.

Finally, the present study demonstrated that statistical analyses revealed agreement in MHR_{obt} in the test-retest situation, demonstrating good reliability of the measurements collected during competition. The equations of Tanaka et al. (2001) and 220 – age failed to predict the MHR when compared with MHR values obtained in matches. On the other side, the equation of Nes et al. (2012) proved valid for MHR_{pre}, being suitable for use as a parameter of training prescription, in cases where the MHR_{obt} is not available.

Thus, coaching staff can use the MHR_{obt} in matches when they need to find parameters to relativize training loads, paying attention to equations that better represent these values, since there may be a wide variation (underestimating or overestimating) training loads. The use of the model of calculation of match difficulty, related to the HR measure can provide additional information, helping coaches and physical coaches in structuring, planning and monitoring training load in Soccer.

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Conflict of interest

The authors declare that they have no conflict of interest.

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