Original Article

# Maximal heart rate differs between laboratory and field conditions among female athletes

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**ABSTRACT**

The purpose of this study was to determine if maximal heart rate (MHR) varies between laboratory testing, field testing, training, competitive matches and an age predicted MHR equation among female collegiate soccer players. 21 female NCAA Division 1 soccer players had MHR determined during a maximal treadmill test (MHRGXT), a 20-meter shuttle run test (MHRFIELD), 4 weeks of early season training (MHRTRAIN), 5 competitive matches (MHRMATCH), and an age prediction equation (MHRPRED). Participants were excluded if they were injured during the data collection period or failed to obtain at least 2 out of 3 criteria during treadmill testing: 1) RER ≥ 1.1, 2) plateau in VO2, and 3) attainment of ≥90% of MHRPRED. MHR was compared across different methods by ANOVA and Spearman correlation coefficients were determined between the different methods. 15 athletes satisfied the inclusion criteria. MHRGXT (190 ± 3.1 bpm) was significantly lower than MHRFIELD (197.9 ± 7.0 bpm, p<0.001), MHRTRAIN (198.9 ± 5.3bpm, p<0.001), and MHRMATCH (196.8 ± 4.4bpm, p=0.004), but not MHRPRED (193.8 ± 0.7bpm, p=0.12). Significant correlations were found between MHRGXT and MHRFIELD (r=0.89, p<0.001), MHRTRAIN (r=0.822, p<0.001), and MHRMATCH (r=0.584, p=0.02). No differences were identified between MHRFIELD, MHRTRAIN, or MHRMATCH, but all three measures were significantly correlated (r=0.63 to 0.81). MHRPRED was not significantly correlated with any of the other methods (r=-0.216 to 0.137). MHR from laboratory testing was significantly lower than field testing, training, and Powered by Editorial Manager® and ProduXion Manager® from Aries Systems Corporation competition, although all 4 methods were highly

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correlated. The differences in these methods should be taken into account when using MHR to prescribe exercise intensity. **Key words:** $VO2_{MAX}$, MAXIMAL HEART RATE, ATHLETES, SOCCER

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## INTRODUCTION

Heart rate monitoring has become increasingly common among athletes as a non-invasive method to monitor and prescribe exercise intensity. (Alexandre et al., 2012) When used as a prescription to increase physical fitness, exercise intensity is typically expressed as a percentage of maximal heart rate, based on the known positive linear relationship between heart rate and oxygen consumption.(Arts & Kuipers, 1994; Davis & Brewer, 1993; Drust, Reilly, & Cable, 2000; Esposito et al., 2004) Therefore, when using heart rate instead of $VO_2$ as a measure of intensity, an accurate measure of maximal heart rate is essential for proper exercise prescription. For example, if the MHR value is falsely high, one is at risk of underestimating training efforts and unnecessarily increasing exercise intensity at the risk of overtraining and injury. If the MHR obtained is falsely low, on the other hand, training efforts may be overestimated, and the athlete may not be challenged in their prescribed training regime.(Boudet, Garet, Bedu, Albuisson, & Chamoux, 2002)

Maximal heart rate can be determined by a number of methods, including laboratory testing, field testing, competition, and estimation from age-prediction equations. Although progressive, maximal exercise testing is considered the "gold standard" for measuring MHR, little research has been done to specifically identify differences in MHR obtained by these different methods, with conflicting results.(Antonacci et al., 2007; Boudet et al., 2002; St Clair Gibson et al., 2000) It has been suggested that MHR may differ between testing conditions that involve intermittent versus continuous running,(Boudet et al., 2002) as well as between testing and competitive environments due to increased stress and motivation during competition.(Palmer, Hawley, Dennis, & Noakes, 1994) In a group of competitive adult male triathletes, Boudet(Boudet et al., 2002) showed that MHR did not vary across laboratory testing, field testing, and competition, but that large intraindividual differences existed between methods and all three conditions were significantly different than the age predicted MHR equation. On the other hand, other studies have demonstrated differences in MHR obtained in competition and field testing in male soccer players,(Antonacci et al., 2007) as well as between laboratory testing and competition among veteran athletes.(St Clair Gibson et al., 2000) Consequently, there is no current consensus regarding the proper method of MHR determination in athletes.

Given the increasingly common use of heart rate monitors for individual estimation of training intensity and exercise prescription in collegiate athletics, accurate estimation of MHR is paramount. We are aware of no study which has specifically compared MHR across laboratory testing, field testing, competition, and age-prediction estimation among intermittent sport athletes. Therefore, the purpose of our study is to determine if MHR varies across laboratory testing, field testing, competition or an age-prediction equation among female collegiate soccer players.

## MATERIALS AND METHODS

### *Participants*

21 female NCAA Division 1 soccer players participated in the study. Data was collected immediately prior to the start of the season as part of the team's pre-season fitness testing protocol and during the first 4 weeks of the competitive season. This study was approved by the Internal Review Board of the University of Wisconsin School of Medicine and Public Health. Informed consent was obtained from all participants.

### *Procedures*

Participants underwent MHR determination during a maximal treadmill test ($MHR_{GXT}$), a maximal 20-meter shuttle run field test ($MHR_{FIELD}$), 4 weeks of early season training sessions ($MHR_{TRAIN}$), 5 competitive matches ($MHR_{MATCH}$), and estimated by an age prediction equation (208 - 0.7 x age; $MHR_{PRED}$). All HR measurements were obtained through the use of telemetry via a chest-strap heart rate monitor (Firstbeat, Jyvaskyla, Finland) worn throughout all of the testing, training, and match conditions. Immediately prior to the start of the competitive season, each player completed a progressive, graded maximal treadmill exercise test using a modified Bruce protocol. HR, oxygen consumption ($VO_2$), carbon dioxide ventilation ($VCO_2$), and respiratory exchange ratio ($VCO_2$ / $VO_2$) were monitored continuously throughout the test, and $MHR_{GXT}$ was determined as the highest heart rate achieved at any point during the test. Participants also completed the Yo-Yo Intermittent Recovery Test (YYIR).(Krustrup et al., 2003) Briefly, players were asked to run back and forth between lines 20-m apart in time with an automated beep sound. Between each running bout, players are afforded a 10-second period of active rest consisting of 2 x 5 yards of slow jogging. The beeps gradually increase in frequency, requiring the participants to run faster and faster between the lines until they are unable to complete the distance prior to the beep on two separate shuttles. The test was performed on an outdoor grass practice field. $MHR_{FIELD}$ was determined as the highest heart rate measured at any point during the test. The treadmill and shuttle run tests were separated by at least 24 hours and completed in an order based on individual player availability.

During the first four weeks of in-season training, HR was monitored for all players within the natural competitive environment. $MHR_{TRAIN}$ was determined as the highest HR measured during any of the training session during this time. Similarly, HR was monitored continuously during the first five competitive matches of the season and $MHR_{MATCH}$ was determined as the highest HR recorded at any time during any of the matched. Finally, an age prediction equation (208 - 0.7 x age) was used to calculate $MHR_{PRED}$ for each participant.(Tanaka, Monahan, & Seals, 2001) Participants were excluded if they were injured during the first 4 weeks of the season, they did not participate in any of the competitive matches or if they failed to obtain at least 2 out of 3 objective criteria during treadmill testing: 1) RER ≥ 1.1, 2) plateau in $VO_2$ (defined as a change in $VO_2$ of less than 2 ml/kg/min during the last 30 seconds of the test), and 3) attainment of ≥ 90 % of $MHR_{PRED}$.

### *Analysis*

To ensure that the measurements were not biased by the order of pre-season testing, $MHR_{GXT}$ and $MHR_{FIELD}$ were compared between those individuals who completed treadmill testing first and those who completed the YYIR testing first. One-way ANOVA was used to determine significant differences between $MHR_{GXT}$, $MHR_{FIELD}$, $MHR_{TRAIN}$, $MHR_{MATCH}$, and $MHR_{PRED}$. To identify significant relationships between the measured MHR, Spearman correlation coefficients (r) were determined between each of the five different methods. Significance was determined *a priori* at the .05 level and all tests were 2-tailed.

## RESULTS

15 participants satisfied the inclusion criteria (mean age 20.3 ± 1.1 years). 2 athletes failed to satisfy the maximal criteria during treadmill testing, and 4 athletes were excluded due to injury during the preseason data collection period. Differences in MHR were identified between the five methods for all participants.. The mean MHR for each condition were as follows: $MHR_{GXT}$ = 190.0 (3.1), $MHR_{FIELD}$ = 197.9 (4.4), $MHR_{TRAIN}$ = 198.9 (5.3), $MHR_{MATCH}$ = 196.8 (4.4), and $MHR_{PRED}$ = 193.8 (0.7) Field test, match, and training conditions all elicited a significantly greater maximal heart rate than a graded exercise test, while an age prediction (208 – 0.7 x age) did not. No differences were identified between those participants who completed the treadmill test first (n = 6) and those who completed the shuttle run test first (n = 9) with respect to $MHR_{GXT}$ (191.7 ± 9.4 v 189.9 ± 8.0, respectively, $p$ = .56) or $MHR_{FIELD}$ (196.8 v 198.6, $p$ = .72). Significant correlations were found between $MHR_{GXT}$, $MHR_{FIELD}$, $MHR_{TRAIN}$, and $MHR_{MATCH}$, but $MHR_{PRED}$ was not significantly correlated with any of the other methods (Table 1). The relationship between the two testing methods, $MHR_{GXT}$ and

$MHR_{FIELD}$, is shown in Figure 1. The relationships between $MHR_{PRED}$ and $MHR_{GXT}$ and $MHR_{FIELD}$ are shown in Figures 2 and 3, respectively.

Table 1. Differences in maximal heart rate from different testing and prediction methods.

| | $MHR_{GXT}$ | $MHR_{FIELD}$ | $MHR_{TRAIN}$ | $MHR_{MATCH}$ | $MHR_{PRED}$ |
|---|---|---|---|---|---|
| All participants (n=15) | 190.0 (3.1) | 197.9 (4.4)* | 198.9 (5.3)* | 196.8 (4.4)* | 193.8 (0.7) |

Field test, match, and training conditions all elicited a significantly greater maximal heart rate than a graded exercise test, while an age prediction equation (208-0.7xage) did not.
*$p$ < .05. MHR, maximal heart rate; GXT, graded exercise test; FIELD, 20 -m shuttle run field test; TRAIN, four weeks of early season training; MATCH, 5 early season competitive matches; PRED, age prediction equation (208 - 0.7 x age).

Table 2. Correlations between maximal heart rate determinations by different testing and prediction methods.

| | $MHR_{FIELD}$ | $MHR_{TRAIN}$ | $MHR_{MATCH}$ | $MHR_{PRED}$ |
|---|---|---|---|---|
| $MHR_{GXT}$ | 0.890* | 0.822* | 0.584* | -0.093 |
| $MHR_{FIELD}$ | | 0.809* | 0.629* | -0.216 |
| $MHR_{TRAIN}$ | | | 0.803* | 0.137 |
| $MHR_{MATCH}$ | | | | 0.074 |

*$p$<0.05. MHR, maximal heart rate; GXT, graded exercise test; FIELD, 20-m shuttle run field test; TRAIN, four weeks of early season training; MATCH, 5 early season competitive matches; PRED, age prediction equation (208 - 0.7 x age).

 

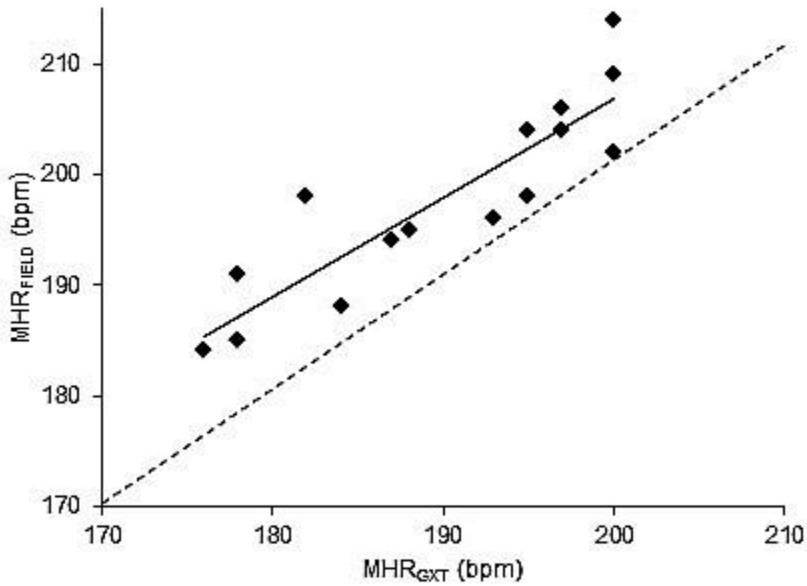


Figure 1. Relationship between maximal heart rate obtained during a graded, maximal exercise test ($MHR_{GXT}$) and a maximal 20-m shuttle run field test ($MHR_{FIELD}$).
Broken line represents a line of equality. r = 0.89, *p* < 0.00. Relationship between maximal heart rate obtained during a graded, maximal exercise test ($MHR_{GXT}$) and a maximal 20 - m shuttle run field test ($MHR_{FIELD}$). Broken line represents a line of equality. r = 0.89, *p* < .001.

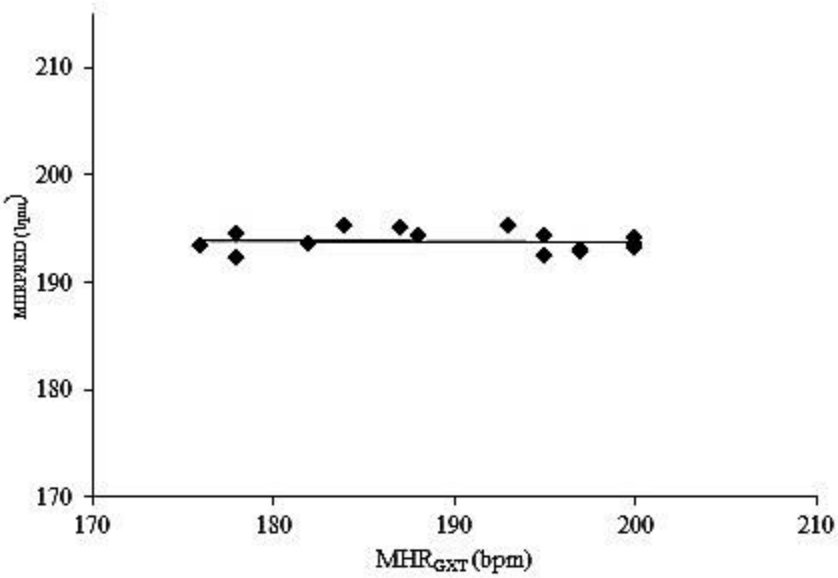


Figure 2. Relationship between maximal heart rate obtained during a graded, maximal exercise test ($MHR_{GXT}$) and an age prediction equation (208 - 0.7 x age; $MHR_{PRED}$).
Relationship between maximal heart rate obtained during a graded, maximal exercise test ($MHR_{GXT}$) and an age prediction equation (208 - 0.7 x age; $MHR_{PRED}$). r = - 0.093, *p* =0.73.

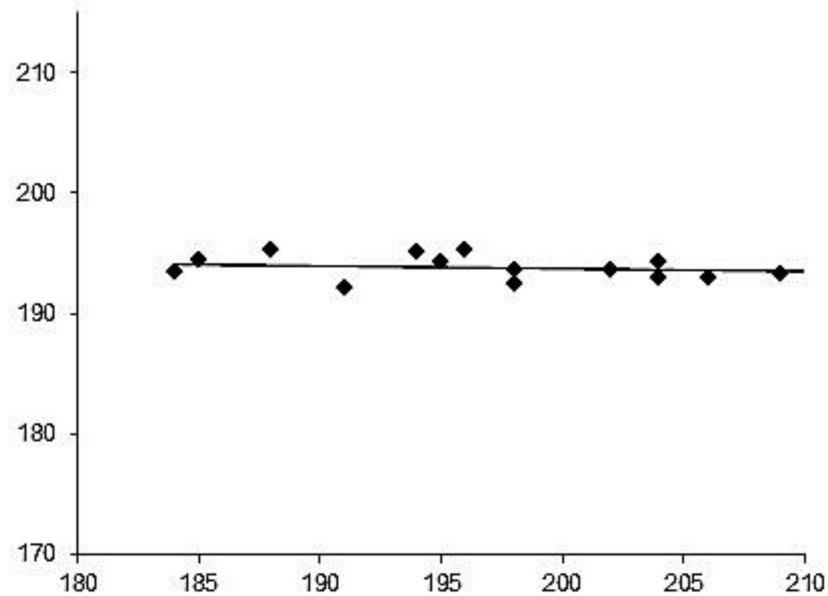


Figure 3. Relationship between maximal heart rate obtained during a 20-meter shuttle run test ($MHR_{FIELD}$) and an age prediction equation (208 - 0.7 x age; $MHR_{PRED}$).
Relationship between a maximal 20-m shuttle run field test ($MHR_{FIELD}$) and an age prediction equation (208 - 0.7 x age; $MHR_{PRED}$). r=0.14, *p*=0.64.

## DISCUSSION

The primary finding of this study is that MHR differed significantly between laboratory and field conditions. Specifically, we found that $MHR_{GXT}$ was lower than $MHR_{FIELD}$, $MHR_{TRAIN}$, and $MHR_{MATCH}$ in every single participant. These results are similar to prior research that found MHR was higher in two different field tests than on a laboratory treadmill test among a group of male youth soccer players, (Aziz, Tan, & Teh, 2005), as well as two prior studies that found lower MHR during laboratory testing than competitive environments among athletes from multiple sports (St Clair Gibson et al., 2000) and veteran cyclists.(Palmer et al., 1994) On the other hand, our findings differ from those of Metaxas (Metaxas, Koutlianos, Kouidi, & Deligiannis, 2005) who found no differences in MHR obtained between laboratory and field test in youth soccer players. Similarly, Boudet (Boudet et al., 2002) found that median MHR did not differ between laboratory and field testing conditions among competitive adult triathletes, although considerable intraindividual variability was noted between methods. The results in the present study, however, were very consistent, as every participant demonstrated a higher MHR during field testing compared to laboratory testing and we found significant correlations between $MHR_{GXT}$ and each of the field-based measures.

We found no significant differences between $MHR_{FIELD}$, $MHR_{TRAIN}$, or $MHR_{MATCH}$ and all three were significantly correlated with each other. This is similar to the aforementioned study of competitive triathletes, whose MHR did not differ between competition and several exhaustive field tests.(Boudet et al., 2002) On the other hand, Antonacci (Antonacci et al., 2007) looked at MHR among youth and professional soccer players and found that MHR was significantly lower in field testing than game situations for all three age groups tested, attributing the differences to decreased motivation during field testing. Unlike that study, our results suggest that when players are sufficiently motivated during field testing, MHR results are very similar to competitive environments.

Together these results suggest that while all 3 field-based measures are very similar, $MHR_{GXT}$ is highly related to, but consistently lower than, field-based measures in this group of athletes. It could be suggested that this represents a lower effort during laboratory testing, although we have specifically excluded any participants who failed to meet our stringent criteria for maximal effort. The underlying physiology responsible for this finding is unclear and beyond the scope of this study. Nonetheless, it has been suggested that intermittent testing protocols elicit a higher MHR than continuous protocols,(Boudet et al., 2002) and it is possible that the intermittent nature of soccer competition and the field-based testing modality resulted in a higher MHR value than progressive, graded exercise testing. Indeed, this may explain the fact that Boudet(Boudet et al., 2002) did not find differences between laboratory and field conditions among continuous sport athletes, while we and others(St Clair Gibson et al., 2000) found differences in intermittent sport athletes. Further research is necessary to identify the mechanisms responsible for these differences in MHR and to determine whether this difference is consistent across other populations of athletes.

Although prediction methods are used extensively to approximate MHR in athletes and the general public, we found that the age prediction equation utilized here was not a good representation of MHR obtained from field or laboratory-based methods. $MHR_{PRED}$ differed significantly from all three field-based measures and demonstrated no significant correlation with any other method. These findings are consistent with prior research evaluating the utility of age prediction equations in athletes. Nikolaidis (Nikolaidis, 2015) found that MHR from two separate age prediction equations was significantly different from those obtained during field testing among adolescent and adult soccer players. In a study of collegiate female athletes, Esco(Esco et al., 2015) found that several commonly used age-based equations failed to accurately predict the MHR obtained from treadmill testing. Given this, $MHR_{PRED}$ should be used with caution among athletes, as it may result in inaccurate estimations of MHR and therefore exercise intensity, resulting in exercise prescription that could either fail to increase cardiovascular fitness or increase risk of overtraining and injury.

These results have important implications for how exercise intensity is monitored and prescribed among athletes. Since exercise intensity is typically determined as a percentage of MHR, it is important that this value is as accurate as possible. If MHR is spuriously high, intensity may be under estimated and exercise prescription based on this could lead to overtraining and increased injury risk. Similarly, if the MHR value is inappropriately low, then prescribed exercise intensity may be insufficient to promote adaptation and improve performance. Consequently, the differences in MHR between conditions that are identified here should be taken into consideration when attempting to define the MHR for an individual athlete as a guide for exercise prescription.

This cross-sectional study has limitations. Given the nature of the study we are not able to identify changes in MHR over time and whether the relationship between the measurement methods is different in the middle or end of the competitive season. The sample of athletes included here is based on a convenience sample of athletes participating for a single team during a competitive season, and is not based on an *a priori* power analysis. Finally, it includes only a population of young adult, female collegiate soccer athletes from a single institution, and these findings may not be generalizable to other populations.

## CONCLUSION

In summary, MHRGXT was significantly lower than MHR obtained from field testing, training, and competition, although all 4 methods were highly correlated. In agreement with prior studies, MHRPRED was not a good predictor of any of the other MHR measurements. Given the importance of proper training load to improve performance while minimizing the risk of overtraining and injury, the differences in these methods should be taken into account when attempting to define MHR in order to properly monitor and prescribe exercise intensity.

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