

# Influence of the maximum heart rate determination criterion on the quantification of the internal load in soccer refereeing

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Received: 09.10.2017

Accepted: 10.01.2018

## Summary

The aims of this present study were, on the one hand, to analyze the differences in the match internal load (CIP) between field referees (AC) and assistants (AA) measured by different methods of quantification during official matches, and on the other hand, to know whether exist differences in the CIP using different criteria to determine the individual maximum heart rate ( $FC_{max}$ ) ( $FC_{max}$  achieved in the incremental test or  $FC_{max}$  achieved during the match). In this study participated 41 match officials who refereed during 21 official matches in a Spanish Third Division League, of which, 21 were AC and 20 were AA. CIP was determined by Edwards method (Edwards'\_CIP) and Stagno method (Stagno'\_CIP) attending to the individual  $FC_{max}$  obtained during the match ( $CIP_{PARTIDO}$ ) and during the YYIR1 test ( $CIP_{YYIR1}$ ). AC registered higher values of Edwards\_CIP and Stagno\_CIP than AA with both criteria of determination of  $FC_{max}$ . In addition, despite high-very high-extremely high differences were observed CIP methods using different criteria to determine the individual  $FC_{max}$  ( $FC_{maxPARTIDO}$  or  $FC_{maxYYIR1}$ ) in all match officials, in AC and in AA, the associations were very high and almost perfect in the CIP calculated with different criteria of determination of  $FC_{max}$ . The results of this investigation suggest that it could be appropriate to use both determination of  $FC_{max}$  criteria to quantify CIP with Edwards'\_CIP and Stagno'\_CIP methods.

## Key words:

Heart rate. Methods. Association. Competition. Soccer refereeing.

## Influencia del criterio de determinación de la frecuencia cardíaca máxima sobre la cuantificación de la carga interna en el arbitraje

### Resumen

Los objetivos de este estudio fueron, por un lado, analizar las diferencias en la carga interna de partido (CIP) entre árbitros de campo (AC) y asistentes (AA) medida mediante diferentes métodos de cuantificación en partidos oficiales, y por otro lado, conocer si existen diferencias en la CIP utilizando distintos criterios para determinar la frecuencia cardíaca máxima ( $FC_{max}$ ) individual ( $FC_{max}$  alcanzada en un test incremental o  $FC_{max}$  alcanzada en el partido). En este estudio participaron 41 colegiados que arbitraron 21 partidos oficiales de Liga de la Tercera División de Fútbol de España, de los cuales, 21 eran AC y 20 AA. La CIP fue determinada mediante los métodos de Edwards (Edwards'\_CIP) y de Stagno (Stagno'\_CIP) atendiendo a la  $FC_{max}$  individual alcanzada en algún momento del partido ( $CIP_{PARTIDO}$ ) y durante el test YoYo de recuperación intermitente, YYIR1 ( $CIP_{YYIR1}$ ). Los AC registraron mayores valores de Edwards\_CIP y Stagno\_CIP que los AA con ambos criterios de determinación de la  $FC_{max}$ . Además, a pesar de que se observan diferencias altas-muy altas-extremadamente altas en los métodos de cuantificación de la CIP utilizando distintos criterios para determinar la  $FC_{max}$  individual ( $FC_{maxPARTIDO}$  o  $FC_{maxYYIR1}$ ) tanto en todos, en AC y en AA, las asociaciones fueron muy altas y casi perfectas en la CIP calculada con distintos criterios de determinación de la  $FC_{max}$ . Estos resultados sugieren que puede ser adecuado utilizar cualquiera de estos criterios de determinación de la  $FC_{max}$  para cuantificar la CIP tanto con el método Edwards'\_CIP como con el método Stagno'\_CIP.

## Palabras clave:

Frecuencia cardíaca. Métodos. Asociación. Competición. Arbitraje.

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## Introduction

It is very important to quantify the internal match load (IML) of football referees in order to have information with which to control weekly training loads<sup>1</sup>. Such knowledge of the IML of football referees can provide the professionals in charge of their physical preparation with a suitable tool to arrive at an optimal prescription of the training dose<sup>2</sup>. The IL in football referees, though it has also been determined using subjective methods such as the rate of perceived effort (RPE)<sup>3</sup>, has chiefly been described using objective methods such as monitoring the heart rate (HR)<sup>4-6</sup>. Although the methods based on HR to determine IML have been widely used in competitions refereed by professional and/or international referees<sup>4,7,8</sup>, few studies have been conducted at lower levels of competition<sup>9</sup>, so knowing the IML in matches in these less competitive categories would also be of great interest.

The scientific literature describes different methods based on HR for the quantification of the match load<sup>10-12</sup>, especially in team sports<sup>13-16</sup>. Some of the methods for quantifying IML most used are the calculation of the percentage of time spent by the athletes at different effort intensities<sup>17,18</sup>, Edwards' method<sup>19</sup> and Stagno's method<sup>20,21</sup>. Specifically in football referees, different variables have been obtained which permit quantification of IML through methods based on HR like the time spent at different effort intensities and the match load quantification method according to Edwards' method<sup>5,22-24</sup>. These studies have observed that on-field referees (OFRs) spend approximately 95% of overall match time at over 80% maximum heart rate (HR<sub>max</sub>)<sup>23</sup>, while assistant referees (ARs) spend around 50% of the time over this intensity<sup>9,24</sup>. Greater IML values have also been reported for OFRs compared to ARs in official national league matches using Edwards' method<sup>5</sup>. These differences in IML between OFRs and ARs may be due to the AR movement pattern, based on lateral movements and short accelerations and decelerations<sup>1</sup>. We do not know, however, if other IML quantification methods (e.g. Stagno's method) are sensitive to the differences found between OFRs and ARs.

To calculate the IML accumulated by OFRs and ARs in matches using the methods mentioned, the HR<sub>max</sub> of individual referees is carefully taken as a reference<sup>23,25,26</sup> and from this value, the time spent in the different areas of intensity is determined. However, not all the studies published in the scientific literature use the same criterion to establish the individual HR<sub>max</sub> of referees. While Boullosa *et al.* (2012) used the HR<sub>max</sub> reached in an incremental field test (Yo-Yo intermittent recovery test level 1, YYIR1) for referees in non-professional Spanish league categories (regional and third division), other authors, such as Costa *et al.* (2013) or Castillo, Yanci *et al.* established the highest HR recorded in an actual match as the criterion for HR<sub>max</sub>, in these cases with Brazilian referees and third division Spanish leagues referees, respectively. Due to the disparity of criteria used to establish individual HR<sub>max</sub>, comparisons between results can be complicated. Comparisons of the results obtained in different studies are regularly made even though the method for determining HR<sub>max</sub> is different, which may lead to major errors of interpretation. In this sense,

it would be interesting to know if calculating the IML accumulated by football referees in official matches is conditioned by the criterion used to determine HR<sub>max</sub>, that is to say, if the IML is different when different criteria are used to establish HR<sub>max</sub>.

Therefore, the aims of this study were 1) to analyse the differences in internal load in official matches between on-field referees and assistant referees measured using different quantification methods, and 2) to find out if there are differences in the internal load using different criteria to determine individual HR<sub>max</sub> (HR<sub>max</sub> reached in an incremental test and HR<sub>max</sub> reached in a match). The hypotheses established were, on the one hand, that the IML recorded using different load quantification methods is greater in OFRs than in ARs and, on the other, that, depending on the criterion used to determine HR<sub>max</sub>, there could be differences in the magnitude of IML.

## Material and method

### Participants

41 referees belonging to the Navarre Committee of Football Referees who refereed Spanish league third division matches took part in the study. 21 of these were OFRs and 20 were ARs (Table 1). All the referees did at least three training sessions per week and refereed approximately three matches per month. The participants were informed of the procedures, methodology, benefits and possible risks of the study and signed an informed consent form. The study followed the guidelines set out in the Declaration of Helsinki (2013), was approved by the Ethics Committee for Research with Human Beings (CEISH) of the University of the Basque Country (UPV/EHU) and was carried out following the highest ethical standards established for research in sports and exercise science<sup>27</sup>. The associations were observed to be most likely (>99.5%) and very large-near perfect (r=0.76-0.93) in all the cases (Table 3).

**Table 1. Characteristics of all the referees, on-field referees (OFRs) and assistant referees (ARs) taking part in the study.**

	All (n = 41)	OFRs (n = 21)	ARs (n = 20)
Age (years)	26.95 ± 6.90	28.29 ± 6.44	25.55 ± 7.25
Weight (kg)	73.66 ± 7.75	72.81 ± 8.80	74.55 ± 6.57
Height (m)	1.77 ± 0.06	1.78 ± 0.07	1.77 ± 0.06
BMI (kg·m <sup>-2</sup> )	23.38 ± 2.13	22.96 ± 1.56	23.83 ± 2.58
Experience refereeing (years)	9.76 ± 5.70	11.52 ± 5.60	7.90 ± 5.31
Experience 3rd Division (years)	4.37 ± 4.75	4.38 ± 3.38	4.35 ± 5.95
HR <sub>maxYYIR1</sub> (ppm)	187.24 ± 7.86	185.57 ± 7.26	189.00 ± 8.27
HR <sub>maxMATCH</sub> (ppm)	173.63 ± 13.93	182.00 ± 8.82	164.85 ± 12.96
%HR <sub>maxYYIR1</sub>	92.78 ± 7.07	98.07 ± 2.69	87.23 ± 5.85

BMI: body mass index; HR<sub>maxYYIR1</sub>: maximum heart rate reached in the test; HR<sub>maxMATCH</sub>: peak heart rate reached in matches; % HR<sub>maxYYIR1</sub>: percentage of the maximum heart rate in the test recorded during matches.

## Procedure

This study recorded the physiological responses or IML of football referees who refereed 21 official matches of the Third Division Football League in Spain (Group XV). In order to calculate the IML for the matches, two different criteria were used to determine the individual  $HR_{max}$  for each referee, in an intermittent incremental field test ( $HR_{maxYYIR1}$ ) conducted the week prior to the match, as well as the  $HR_{max}$  reached during the official match played ( $HR_{maxMATCH}$ ). The HR values were recorded using the Polar Team 2 transmitter, strap and band (Polar Team System®, Kempele, Finland) with a sampling rate of 0.2 Hz. The participants were given instructions not to train during the 48 hours prior to the tests in order to avoid the effects of fatigue on the measurement results. The referees all had a similar diet based on 55% of total calories derived from carbohydrates, 25% fat and 20% protein. All the matches analysed were played on four pitches with similar dimensions and characteristics (100 x 64 m) and under non-adverse weather conditions (10-20 °C). The scheduled time for all the matches played was 16:00 h.

## Incremental field test to determine the $HR_{max}$

The YYIR1 test consisted in running back and forth a distance of 40 m (2 x 20 m) alternated with a 10 sec rest period in which the participants remained active by slow jogging, moving over a distance of 5 m. The running speed was progressively increased in unison with an audio signal that gradually reduced the time between the successive signals. The test ended for each participant when he was no longer able to cover the corresponding distance in the set time<sup>28</sup>. The maximum individual heart rate ( $HR_{maxYYIR1}$ ) achieved by each referee in the test was recorded using Polar Team 2 heart rate monitors (Polar Team System®, Kempele, Finland).

## Determination of $HR_{max}$ at the matches

The HR at the official matches was recorded using Polar Team 2 heart rate monitors (Polar Team System®, Kempele, Finland). The highest HR achieved by each of the OFRs and ARs was taken as the  $HR_{max}$  of the match ( $HR_{maxMATCH}$ ).

## Determination of the internal match load

The IML was determined by the Edwards and Stagno methods, based on the individual  $HR_{max}$  reached at a given moment during the match ( $IML_{MATCH}$ ) and also on the  $HR_{max}$  obtained in the YYIR1 test ( $IML_{YYIR1}$ ).

### Edwards Method

The IML measured by the Edwards method was calculated by multiplying the time spent at each effort intensity by a value assigned to each intensity (90-100%  $HR_{max}$  =5, 80-90%  $HR_{max}$  =4, 70-80%  $HR_{max}$  = 3, 60-70%  $HR_{max}$  = 2, 50-60%  $HR_{max}$  = 1). Subsequently the sum of all the values obtained was calculated, which represented the Edwards' value  $_IML$ <sup>10,23</sup>, for both the  $HR_{maxMATCH}$  and the  $HR_{maxYYIR1}$ .

### Stagno method

The IML measured by the Stagno method was calculated by multiplying the time spent at each effort intensity by a weighting factor for each intensity (93-100%  $HR_{max}$  =5.16, 86-92%  $HR_{max}$  =3.61, 79-85%  $HR_{max}$  = 2.54, 72-78%  $HR_{max}$  = 1.71, 65-71%  $HR_{max}$  = 1.25). The summation represented the Stagno's value  $_IML$ <sup>11</sup>, for both the  $HR_{maxMATCH}$  and the  $HR_{maxYYIR1}$ .

## Statistical data analysis

The results are presented as a mean  $\pm$  standard deviation (SD) of the mean. In order to determine the differences in the IML quantification methods (Edwards'  $_IML$  and Stagno's  $_IML$ ) between OFR and AR or between the IML calculated by the different criteria for  $HR_{max}$ , we used the inference method proposed by Hopkins *et al.*<sup>29</sup> based on calculating the magnitudes of the differences (<0.2 low; 0.2-0.6 moderate, 0.6-1.2 high; 1.2-2.0 very high; >2.0 extremely high). Furthermore, 90% of the confidence limit was calculated ( $\pm$ 90% CL) and the probability that the differences were true, based on the following ranges: 25–75%, possible 75–95%, probable; 95–99,5%, very probable; >99,5%, extremely probable<sup>29</sup>. On the other hand, we calculated the association between the IML values obtained based on the different criteria for  $HR_{max}$  through Pearson's correlation (r). To interpret the magnitudes of correlation between the IML quantification methods, the following scale was used: less than 0.1, trivial; 0.1 to 0.3 low; 0.3 to 0.5 moderate; 0.5 to 0.7 high; 0.7-0.9 very high; greater than 0.9, almost perfect<sup>29</sup>. Moreover,  $\pm$ 90% CL was calculated and the probability of true associations<sup>29</sup>. We also calculated the regression formula between the IML methods, based on  $HR_{max}$  achieved during the match (Edwards'  $_IML_{MATCH}$  and Stagno's  $_IML_{MATCH}$ ) and the IML methods based on  $HR_{max}$  achieved in the YYIR1 (Edwards'  $_IML_{YYIR1}$  and Stagno's  $_IML_{YYIR1}$ ) for the entire sample for the OFRs and ARs. The statistical analysis was made with the *Statistical Package for Social Sciences program* (SPSS Inc, versión 23,0 Chicago, IL, EE.UU.).

## Results

The differences between  $HR_{maxYYIR1}$  and  $HR_{maxMATCH}$  were moderate and probable for OFR (-0.47; 0,  $\pm$ 56) and extremely probable and very high for AR (-2.80;  $\pm$ 0.68). Table 2 shows the differences recorded in the quantification methods for the internal load (Edwards'  $_IML_{MATCH}$ , Stagno's  $_IML_{MATCH}$ , Edwards'  $_IML_{YYIR1}$ , Stagno's  $_IML_{YYIR1}$ ) between OFRs and ARs. The results obtained show that the OFRs recorded higher IML values (extremely probable and extremely high) than the ARs in both quantification methods. On the other hand, moderate, high and very high differences were observed in the IML quantification methods (Edwards'  $_IML$  and Stagno's  $_IML$ ) using different criteria to determine the individual  $HR_{max}$  ( $HR_{maxMATCH}$  or  $HR_{maxYYIR1}$ ) for all participants, and also for OFR and for AR (Table 2).

Table 3 shows the associations between the IML methods based on  $HR_{max}$  achieved during the match (Edwards'  $_IML_{MATCH}$  and Stagno's  $_IML_{MATCH}$ ) and the IML methods based on  $HR_{max}$  achieved in the

**Table 2. Results obtained in internal load quantification for all the participants, on-field referees (OFRs) and assistant referees (ARs).**

Methods	All	OFRs ARs	Differences OFR-AR	Effect size (%; ±90% CL)	OFR-AR; ±90% CL/Likelihoods
Edwards'_IML <sub>MATCH</sub> (AU)	348.06 ± 58.35	383.50 ± 33.65	310.84 ± 55.95	-19.8; ±55.9	-2.08; ±0.70 / ****
Edwards'_IML <sub>YYIR1</sub> (AU)	291.43 ± 91.69	363.68 ± 36.57	215.57 ± 66.83	-43.2; ±7.5	-3.90; ±0.76 / ****
Differences MATCH-YYIR1 (%; ±90% CL)	-32.0; ±9.9	-5.1; ±5.0	-34.1; ±9.4		
Effect size MATCH-YYIR1; ±90% CL/Likelihoods	-0.95; ±0.48 / ***	-0.57; ±0.52 / **	-1.63; ±0.56 / ****		
Stagno's_IML <sub>MATCH</sub> (AU)	254.67 ± 67.05	304.20 ± 40.22	202.67 ± 46.96	-34.6; ±7.0	-2.43; ±0.55 / ****
Stagno's_IML <sub>YYIR1</sub> (AU)	194.14 ± 103.92	278.52 ± 50.17	105.54 ± 62.87	-68.3; ±8.7	-3.32; ±0.58 / ****
Differences MATCH-YYIR1 (%; ±90% CL)	-54.7; ±13.3	-9.1; ±8.3	-57.5; ±12.2		
Effect size MATCH-YYIR1; ±90% CL/Likelihoods	-0.89; ±0.47 / ***	-0.61; ±0.57 / **	-1.99; ±0.61 / ****		

CL: confidence limits; ES: effect size; Edwards'\_IML<sub>MATCH</sub>: internal match load quantified with Edwards' method based on peak heart rate reached during matches; Stagno's\_IML<sub>MATCH</sub>: internal match load quantified with Stagno's method based on peak heart rate reached during matches; Edwards'\_IML<sub>YYIR1</sub>: internal match load quantified with Edwards' method based on maximum heart rate reached in the Yo-Yo intermittent recovery test level 1; Stagno's\_IML<sub>YYIR1</sub>: internal match load quantified with Stagno's method based on maximum heart rate reached in the Yo-Yo intermittent recovery test level 1; AU: arbitrary units.

Interpretation of likelihoods: \*possible (25%-75% [probability that the true correlation is...]) \*\*likely (75%-95%); \*\*\*very likely (95%-99.5%); \*\*\*\*most likely (>99.5%).

**Table 3. Association (r; ± confidence limit (CL), interpretation and likelihoods) and regression formula between the internal match load methods based on the maximum heart rate reached in matches (Edwards'\_IML<sub>MATCH</sub> and Stagno's\_IML<sub>MATCH</sub>) and the internal match load methods based on the maximum heart rate reached in the Yo-Yo intermittent recovery test level 1 (Edwards'\_IML<sub>YYIR1</sub> and Stagno's\_IML<sub>YYIR1</sub>) in the total sample, in on-field referees (OFRs) and assistant referees (ARs).**

Methods	Edwards'_IML <sub>MATCH</sub>				Stagno's_IML <sub>MATCH</sub>			
	Edwards'_CIP <sub>YYIR1</sub>		Stagno's_CIP <sub>YYIR1</sub>		Edwards'_IML <sub>YYIR1</sub>		Stagno's_IML <sub>YYIR1</sub>	
Referees	r; ± 90% CL	Regression formula	r; ± 90% CL	Regression formula	r; ± 90% CL	Regression formula	r; ± 90% CL	Regression formula
<b>All</b>	0.88; ±0.06 *** VL. 100/0/0	y = 185.12 + 0.56x + 28.23	0.86; ±0.07 *** VL. 100/0/0	y = 254.15 + 0.48x + 30.01	0.93; ±0.04 *** NP. 100/0/0	y = 55.89 + 0.68x + 24.48	0.93; ±0.04 *** NP. 100/0/0	y = 138.25 + 0.60x + 25.06
<b>OFRs</b>	0.82; ±0.06 *** VL. 100/0/0	y = 107.54 + 0.76x + 19.53	0.76; ±0.17 *** VL. 100/0/0	y = 241.79 + 0.51x + 22.49	0.87; ±0.10 *** VL. 100/0/0	y = 43.33 + 0.96x + 20.43	0.82; ±0.13 *** VL. 100/0/0	y = 121.39 + 0.66x + 23.69
<b>ARs</b>	0.81; ±0.14 *** VL. 100/0/0	y = 164.77 + 0.68x + 33.76	0.82; ±0.14 *** VL. 100/0/0	y = 234.13 + 0.73x + 33.17	0.84; ±0.13 *** VL. 100/0/0	y = 76.16 + 0.59x + 26.53	0.83; ±0.13 *** VL. 100/0/0	y = 137.89 + 0.61x + 27.49

Interpretation of likelihoods: \*possible (25%-75% [probability that the true correlation is...]) \*\*likely (75%-95%); \*\*\*very likely (95%-99.5%); \*\*\*\*most likely (>99.5%). Magnitude of correlations: T: trivial; S: small; M: moderate; L: large; VL: very large; NP: near perfect.

YYIR1 (Edwards'\_IML<sub>YYIR1</sub> and Stagno's\_IML<sub>YYIR1</sub>) for all the referees, and also for the OFRs and ARs. It was observed that the associations were extremely probable (>99.5%) and very high almost perfect (r=0.76-0.93) in all cases (Table 3).

## Discussion

The aims of this study were 1) to analyse the differences in internal load in official matches between on-field referees and assistant referees

measured using different methods of quantification, and 2) to find out if there are differences in the internal load using different criteria to determine individual HR<sub>max</sub> (HR<sub>max</sub> reached in an incremental test and HR<sub>max</sub> reached in matches). The main results show that the OFRs reported higher values of IML than the ARs, both when calculated using Edwards' IML method and when calculated using Stagno's IML method. Meanwhile, even though large-very large-extremely large differences were observed in the IML calculated using the different criteria to determine individual HR<sub>max</sub> (HR<sub>maxMATCH</sub> and HR<sub>maxYYIR1</sub>), associations between the two methods were very large and near perfect for all the participants,

OFRs and ARs. The chief finding of this research is the large association observed between the two IML quantification methods, meaning that either can be used, provided that one is consistent and that results obtained using different criteria are not compared.

OFRs and ARs are in charge of controlling the behaviour and conduct of players during matches. To meet their function on the field of play, each needs to play a different role, the ARs having their activity limited to half the pitch in order to judge, above all, off-sides and the OFRs moving all over the pitch to call the infringements that occur during the match. This fact, coupled with the fact that OFRs register higher values in the external load indicators (e.g., total distance covered, number of accelerations and decelerations, changes of direction, etc.)<sup>5,7,9</sup>, may have led the ARs to register lower IML values than the OFRs with the methods used in this study. These results are consistent with those observed by Castillo, Weston, et al. (2016) with non-professional referees, because they also noted that the IML of OFRs is greater than that of ARs. Other studies have also observed higher  $HR_{max}$  values in national professional OFRs compared to ARs, albeit not in IML values but in certain HR parameters<sup>8,26</sup>. Other research with national referees has observed that OFRs record HR values that correspond to 87% of  $HR_{max}$  while ARs obtain values of 78%  $HR_{max}$ <sup>26</sup>. In the same vein, it has been observed that OFRs spend more time over 90%  $HR_{max}$  than ARs (35 vs. 15 min.)<sup>24</sup>. Given that both the IML and the external load factors, such as the distance covered at high speeds (OFRs = 2783 ± 630 m vs. ARs = 793 ± 268 m), recorded by OFRs and ARs during matches are different, mainly due to the roles they play and the limits of the playing field<sup>1</sup>, it would be interesting to implement different training protocols for OFRs and ARs based on the specific demands of match situations and, in this way, programme the most suitable training loads and recovery strategies on the basis of IML.

Many scientific studies use different methods to determine the  $HR_{max}$  with which to calculate IML<sup>8,22,28</sup>. Normally, the results obtained in the different studies are compared with each other even though HRmax has been obtained using different criteria. This could generate a problem because to date we do not know if the IML values are the same when different criteria to determine  $HR_{max}$  are used. In the present study, it has been observed that despite the differences in IML (both in Edwards'\_IML and in Stagno's'\_IML) calculated on the basis of  $HR_{max}$  reached in YYIR1 and in matches, both in OFRs and ARs, the associations between the IML quantification methods using different criteria for determining  $HR_{max}$  are very large-near perfect ( $r = 0.76-0.93$ ). This is the first study to analyse the influence of the  $HR_{max}$  calculation criterion on IML. The results obtained in our study show that the criterion to determine  $HR_{max}$  reached in YYIR1 or in matches influences the magnitude of IML. In this regard, it should be noted that the percentage of  $HR_{max}$  reached in tests with respect to that registered during matches (% $HR_{maxYYIR1}$ ) is greater in OFRs than in ARs, meaning that the criterion of  $HR_{max}$  used may determine differences in IML. This shows that it may not be appropriate to compare IML values measured using different  $HR_{max}$  determination methods. However, the IML values obtained from  $HR_{maxMATCH}$  show a large-very large-extremely large association with the

IML values obtained on the basis of  $HR_{maxYYIR1}$ . The strong associations observed between the two criteria for determining  $HR_{max}$  ( $HR_{maxMATCH}$  and  $HR_{maxYYIR1}$ ) to quantify IML, both with Edwards'\_IML method and Stagno's'\_IML method, reveal that either of these methods to quantify IML can be used for football referees during matches since they provide similar information, but that it is not appropriate to compare IML results obtained using different criteria.

## Conclusions

The main conclusions of this study were 1) that OFRs record higher IML values than ARs when measured with different methods (Edwards'\_IML and Stagno's'\_IML), and 2) that the large-very large-extremely large differences and the very large and near perfect associations between the IML quantification methods (Edwards'\_IML and Stagno's'\_IML) using different criteria to determine individual  $HR_{max}$  ( $HR_{maxMATCH}$  and  $HR_{maxYYIR1}$ ) with all the referees, both OFRs and ARs, suggests, on the one hand, that it may not be appropriate to compare IML results calculated using different individual  $HR_{max}$  determination criteria and, on the other, that either of these criteria is valid to determine HRmax in order to quantify IML with either Edwards'\_IML method or Stagno's'\_IML method.

## Our thanks to:

The Navarre Committee of Football Referees (CNAF) for its involvement and collaboration in this research project.

## Grant

This project was funded by the Basque Government through the Department of Education, Language Policy and Culture's Non-PhD Research Staff Training Programme.

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