Original Article

Can maximal aerobic running speed be predicted from submaximal cycle ergometry in soccer players? The effects of age, anthropometry and positional roles

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Abstract

Background: Considering maximal aerobic running speed (MAS) as a useful tool to evaluate aerobic capacity and monitor training load in soccer, there is an increasing need to develop indirect assessment methods of MAS, e.g., submaximal tests. The aim of this study was to examine the prediction of MAS from the physical working capacity (PWC) in heart rate (HR) 170 beat/min test (PWC_{170}).

Materials and Methods: This cross-sectional study was done on adolescent (n = 67) and adult soccer players (n = 82) were examined for anthropometric characteristics, PWC_{170} and performed Conconi test to assess MAS.

Results: Midfielders scored higher than goalkeepers (GKs) and defenders in MAS while GKs scored lower than all the other playing positions. Although this trend was also observed in PWC_{170}, statistical difference was only observed between midfielders and GKs. Players with higher MAS had also higher PWC_{170} in both age groups ($P < 0.05$). The odds ratio of a player of the best PWC_{170} group to belong also to the best MAS group was 3.96 (95% confidence interval 2.00; 7.84). That is players with high-performance in the PWC_{170} were about 4 times more likely than those with low PWC_{170} to achieve a high score in MAS. Regression analysis suggested body fat (BF) percentage, PWC_{170}, maximal HR and age as predictors of MAS ($R = 0.61$, $R^2 = 0.37$ and standard error of estimate [SEE] =1.3 km/h, in total; $R = 0.74$, $R^2 = 0.55$ and SEE = 1.2 km/h, in adolescents; $R = 0.55$, $R^2 = 0.30$ and SEE = 1.3 km/h, in adults).

Conclusions: While there was only moderate correlation between MAS and PWC_{170}, the former can be predicted from the latter when BF, HR_{max}, and age are considered (large to very large multiple correlation coefficients).

Key Words: Exercise test, football, physical conditioning, physical endurance, running

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INTRODUCTION

Soccer is one of the most popular team sports played by millions of players worldwide. The success in this sport results from many physiological, psychological and social factors. Among the physiological factors that influence soccer performance, aerobic capacity is of paramount importance, because a certain level

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of endurance is necessary for the player to cope with the needs of the game as well to respond positively to the large weekly amounts of training.

Maximal aerobic running speed (MAS), that is the maximal speed recorded during a graded exercise test has been used extensively to monitor aerobic capacity[1] and determine training loads[2] in soccer. Various methods have been used to assess MAS, which usually include an incremental exercise protocol where speed increases every 1–2 min[3] or every certain distance.[4,1] Common characteristic of these tests is that they demand maximal effort. Although these tests provide accurate data about the parameters they measure, their maximal nature limits their ability to apply in various settings, e.g., competitive period. Due to the fatigue that results from such a test, special care must be given to administer a maximal test in periods considering the schedule of games and training units.

In contrast with maximal tests, submaximal tests can be easily administered independently from the schedule of games or the content of training unit. Their validity against maximal measures of aerobic capacity and reliability has been well established. A widely used submaximal test is the physical working capacity (PWC) at heart rate (HR) 170 beat/min (PWC_{170}), which is administered in a cycle ergometer and is part of the Eurofit battery.[5]

To compare PWC_{170} with MAS, we should consider certain limitations. First, body mass is supported in cycle ergometer while it has to be carried in running. Adjusting for body mass could help overcoming this discrepancy. Second, if the only available information were performance in a submaximal test, we should make the assumption about maximal scores based on some equation that predicts maximal HR (HR_{max}).[6,7]

About the significance of this study, if we could establish a strong relationship between PWC_{170} and MAS, it would provide soccer coaches and fitness trainers with a valuable, inexpensive and easily administered tool of aerobic capacity assessment. Therefore, the aim of this study was to examine the relationship between PWC_{170} and MAS, considering possible confounders as anthropometry and HR parameters.

MATERIALS AND METHODS

For this study, 149 players volunteered to participate. Testing procedures were carried out on two consecutive days on August 2012 during the preparative period of season 2012–2013. Inclusion criteria to participate in the present study were (a) Possessing a valid sport medical certification and (b) having participate to at least 80% of the training sessions and matches during the last competition period. Exclusion criteria were the presence of injury, medication or pain during testing sessions. On day 1, the participants visited the laboratory, where they were examined for anthropometry characteristics (height, body mass and body fat [BF] percentage) and PWC_{170}. On day 2, the participants performed the Conconi test in the field. Body mass was measured with an electronic weight scale (HD-351 Tanita, Illinois, USA) in the nearest 0.1 kg and height with a portable stadiometer (SECA, Leicester, UK) in the nearest 1 mm with participants being barefoot and in minimal clothing. Body mass index (BMI) was calculated as the quotient of body mass (kg) to a height squared (m^2). A caliper (Harpenden, West Sussex, UK) measured skinfolds (0.5 mm) and BF percentage was calculated from the sum of 10 skinfolds.[8]

Physical working $capacity_{170}$ was performed according to Eurofit guidelines[5] on a cycle ergometer (828 Ergomedic, Monark, Sweden). Seat height was adjusted to each participant's satisfaction, and toe clips with straps were used to prevent the feet from slipping off the pedals. Participants were instructed before the tests that they should pedal with steady cadence 80 revolutions/min, which was given by both visual (ergometer's screen showing pedaling cadence) and audio means (metronome set at 80 beats/min). This test consisted by three stages, each lasting 3 min, against incremental braking force in order to elicit HR between 120 and 170 beats/min (beat/min). Based on the linear relationship between HR and power output, PWC_{170} was calculated as the power corresponding to HR 170 beat/min and expressed as W/kg. HR was recorded continuously during all tests in the laboratory and in the field by Team2 Pro (Polar Electro Oy, Kempele, Finland).

A modified version of Conconi test was used to assess MAS.[4] Briefly, after a 20 min warm-up including jogging and stretching exercises, participants performed an incremental running test in the field around a 200 m^2. Initial speed was set at 9 km/h and increased every 200 m by 0.3–0.7 km/h till exhaustion. During the late stages of the test, participants were cheered vigorously to make maximal effort. In addition, they had been instructed to adhere strictly to the speed that was determined by audio signals. The maximal value of HR was achieved in the end of the test (HR_{max}).

Statistical analyzes were performed using IBM SPSS v. 20.0 (SPSS, Chicago, USA). Data were expressed as mean and standard deviations of the mean. Using the "median split" technique, the participants were divided into two groups ("best" and "worst") according to the median in the MAS. Independent Student's *t*-test was used to examine differences between these groups. Effect sizes (ES) for statistical differences in the *t*-test were determined using the following criteria for Cohen's d: ES ≤ 0.2, trivial; 0.2 < ES ≤ 0.6, small; 0.6 < ES ≤ 1.2, moderate; 1.2 < ES ≤ 2.0, large; and ES > 2.0, very large.[9] One-way analysis of variance (ANOVA) was used to examine differences between positional groups. To interpret ES for statistical differences in the ANOVA we used eta square classified as small ($0.010 < \eta^2 \leq 0.059$), medium ($0.059 < \eta^2 \leq 0.138$) and large ($\eta^2 > 0.138$).[10] Associations between MAS, PWC_{170} and anthropometry parameters were examined using Pearson's product moment correlation coefficient (r). Magnitude of correlation coefficients were considered as trivial ($r \leq 0.1$), small ($0.1 \leq r < 0.3$) moderate ($0.3 \leq r < 0.5$), large ($0.5 \leq r < 0.7$), very large ($0.7 \leq r < 0.9$) and nearly perfect ($r \geq 0.9$) and perfect ($r = 1$).[11] We used linear regression to model the prediction of MAS from the other parameters. The level of significance was set at α =0.05. In addition, we classified players into two groups of PWC_{170} ("best" and "worst") and we used odds ratios (OR) to examine the possibility that a player would be classified in a similarly group of MAS and PWC_{170}.

RESULTS

The comparison between adolescent and adult participants revealed small differences for all characteristics under examination, except weight [Table 1]. Adolescents were lighter and shorter, with lower BMI and BF, higher HR_{max}, and lower MAS than adults. PWC_{170} was lower in the younger age group than in the older age group when expressed in absolute values, but higher when expressed in relative to weight values.

Either adolescent or adult players with high MAS achieved also high scores in PWC_{170} [Table 2]. Midfielders scored higher than goalkeepers (GKs) and defenders in MAS while GKs scored lower than all the other playing positions. Although this trend was also observed in PWC_{170}, statistical difference was only noticed between midfielders and GKs [Table 3].

The OR of a player of the best PWC_{170} group to belong also to the best MAS group was 3.96 (95% confidence interval [CI] 2.00; 7.84), which was lower in adolescent (3.69 [1.34; 10.20]) than in adult players (4.19 [1.66; 10.57]). That is players with high performance in the PWC_{170} were about 4 times more likely than those with low PWC_{170} to achieve a high score in MAS. In contrast, the OR of a player of the best PWC_{170} group to belong also to the worst MAS group was in total 0.25 (0.13; 0.50), in adolescents 0.27 (0.10; 0.75) and in adults 0.24 (0.10; 0.60). PWC_{170} was 66.7, 68.4 and 67.6% sensitive in adolescents, adults and in the total sample.

After adjusting for the effect of age, MAS moderately correlated with absolute (r = 0.33, P < 0.001) and relative PWC_{170} (r = 0.40, P < 0.001). These correlations were 0.30 (P = 0.015) and 0.49 (P < 0.001), respectively, in adolescents, and 0.40 and 0.48 in adults. The correlation coefficients between anthropometry and physiological parameters are presented in Table 4. Regression analysis suggested BF percentage, PWC_{170}, HR_{max} and age as predictors of MAS [Table 5].

DISCUSSION

To the best of our knowledge, this is the first study to address the relative importance of submaximal cycle ergometry as determinant of MAS. The novel finding was that performance in an incremental maximal running test was closely related with PWC_{170} and could be predicted with a standard error of estimate close to 1 km/h from submaximal cycle ergometry combined with age, BF, and HR_{max}. While there was only moderate correlation between MAS and PWC_{170}, we observed large to very large multiple correlation

Table 1: Physical characteristics and aerobic power of participants according to age

Variables	Total (*n*=149)	Adolescents (*n*=67)	Adults (*n*=82)	Mean difference	95% CI (LL; UL)	Effect size
Age (year)	20.5±5.2	16.4±0.9	23.9±4.8	−7.5	−8.7; −6.4	−2.20, very large
Weight (kg)	71.6±9.7	67.3±9.5	75.2±8.3	−7.8	−10.7; −4.9	−0.89, moderate
Height (cm)	177.4±6.5	176.4±6.6	178.3±6.4	−1.9	−4.0; 0.1	−0.29, small
BMI (kg/m²)	22.7±2.2	21.6±2.2	23.6±1.9	−2.0	−2.7; −1.4	−1.01, moderate
BF (%)	15.8±3.2	15.2±3.3	16.2±3.1	−1.0	−2.1; 0	−0.33, small
HR_{max} (beat/min)	197.5±8.7	199.1±7.4	196.2±9.5	3.0	0.2; 5.8	0.35, small
MAS (km/h)	15.5±1.6	15.2±1.7	15.7±1.5	−0.6	−1.1; 0	−0.35, small
PWC_{170} (W)	192.0±40.6	187.3±42.6	195.9±38.7	−8.6	−21.7; 4.6	−0.21, small
PWC_{170} (W/kg)	2.70±0.51	2.79±0.56	2.61±0.46	0.18	0.01; 0.34	0.35, small

BMI: Body mass index, BF: Body fat, HR_{max}: Maximal heart rate, MAS: Maximal aerobic speed, PWC_{170}: Physical working capacity in HR 170 beat/min, CI: Confidence interval, LL: Lower limit, UL: Upper limit

Table 2: Physical characteristics and aerobic power of participants according to the level of aerobic power (high vs. low)

Variables	Age group	Low	High	Mean difference	95% CI (LL; UL)	Effect size
Age (year)	Adolescents	16.2±0.9	16.7±0.7	−0.5	−0.9; −0.1	−0.66, moderate
	Adults	24.7±5.5	23.0±3.7	1.7	−0.4; 3.7	0.36, small
Weight (kg)	Adolescents	67.9±11.5	66.6±6.6	1.3	−3.4; 6.0	0.14, trivial
	Adults	76.2±9.1	74.0±7.1	2.3	−1.4; 5.9	0.27, small
Height (cm)	Adolescents	175.8±7.4	177.1±5.7	−1.3	−4.5; 2.0	−0.20, trivial
	Adults	179.2±6.5	177.2±6.2	2.0	−0.8; 4.8	0.31, small
BMI (kg/m^2)	Adolescents	21.8±2.6	21.2±1.5	0.6	−0.4; 1.7	0.28, small
	Adults	23.7±2.1	23.5±1.6	0.2	−0.7; 1.0	0.11, trivial
BF (%)	Adolescents	16.4±3.7	13.7±2.1	2.6	1.1; 4.2	0.90, moderate
	Adults	16.7±2.9	15.7±3.2	1.1	−0.3; 2.4	0.33, small
HRmax (beat/min)	Adolescents	198.8±8.3	199.5±6.2	−0.7	−4.4; 3.0	−0.10, small
	Adults	195.0±11.0	197.5±7.2	−2.4	−6.6; 1.7	−0.27, small
MAS (km/h)	Adolescents	13.9±0.9	16.8±0.9	−2.9	−3.3; −2.4	−3.22, very large
	Adults	14.6±0.9	17.1±0.8	−2.5	−2.9; −2.2	−2.94, very large
PWC_{170} (W)	Adolescents	175.7±46.6	201.6±32.4	−26.0	−46.0; −5.9	−0.65, moderate
	Adults	187.6±37.3	205.5±38.6	−17.9	−34.6; −1.2	−0.47, small
PWC_{170} (W/kg)	Adolescents	2.60±0.57	3.04±0.44	−0.44	−0.69; −0.18	−0.86, moderate
	Adults	2.48±0.46	2.77±0.40	−0.30	−0.49; −0.10	−0.67, moderate

BMI: Body mass index, BF: Body fat, HR_{max}: Maximal heart rate, MAS: Maximal aerobic speed, PWC_{170}: Physical working capacity in HR 170 beat/min, LL: Lower limit, UL: Upper limit

Table 3: Physical characteristics and cardiorespiratory endurance of participants according playing position

Variables	Goalkeepers (*n*=12)	Defenders (*n*=57)	Midfielders (*n*=57)	Forwards (*n*=23)	ANOVA	Effect size
Age (year)	20.0±4.0	20.1±5.0	21.1±5.7	20.7±4.9	F3,145=0.41, *P*=0.749	η^2=0.008
Weight (kg)	78.5±7.0^{M}	72.3±9.9	69.8±8.9^{G}	70.9±10.6	F3,145=2.93, *P*=0.036	η^2=0.057, small
Height (cm)	182.5±4.8^{M}	177.9±6.5	175.7±6.2^{G}	177.8±1.0	F3,145=4.09, *P*=0.008	η^2=0.077, medium
BMI (kg/m^2)	23.5±1.7	22.8±2.3	22.6±2.2	22.3±2.4	F3,145=0.87, *P*=0.459	η^2=0.018, small
BF (%)	18.5±2.2^{M}, ^{F}	16.2±3.1	14.9±3.0^{G}	15.2±3.7^{G}	F3,145=5.06, *P*=0.002	η^2=0.095, medium
HR_{max} (beat/min)	197.8±8.3	197.3±8.9	197.4±8.8	198.1±8.7	F3,145=0.05, *P*=0.986	η^2<0.001
MAS (km/h)	13.8±0.8^{D,M,F}	15.3±1.4^{G,M}	16.1±1.5^{G,D}	15.4±2.2^{F}	F3,145=7.75, *P*<0.001	η^2=0.138, medium
PWC_{170} (W)	181.6±29.7	188.2±40.9	200.5±42.5	185.9±38.3	F3,145=1.45, *P*=0.230	η^2=0.029, small
PWC_{170} (W/kg)	2.32±0.36^{M}	2.63±0.57	2.86±0.43^{G}	2.64±0.48	F3,145=5.04, *P*=0.002	η^2=0.094, medium

The letters G, D, M and F denote goalkeepers, defenders, midfielders, and forwards, respectively, and when appear as exponents indicate difference from the respective group. BMI: Body mass index, BF: Body fat, HR_{max}: Maximal heart rate, MAS: Maximal aerobic speed, PWC_{170}: Physical working capacity in HR 170 beat/min

coefficients when BF, HR_{max}, and age were considered. These correlations were in agreement with previous research that had examined PWC_{170} with regard to maximal oxygen uptake assessed by graded exercise test on a cycle ergometer[12-15] or treadmill.[16]

There are three main factors that explain the increase of correlation when we used multiple correlation coefficients instead of Pearson's (r). First, BF, which was the first predictor (in total and in adolescents) of MAS, has different effect on running than on cycling, because body mass must be carried in the first case, while is supported in the second case. Thus, partitioning out this effect results in strengthening the correlation between these two modes of movement. Second, the consideration of HR_{max} improves the prediction of MAS because it attenuates the discrepancy between a maximal and a submaximal exercise. When HR_{max} is not measured, the HR 170 beat/min of interest in the PWC_{170} test might represent different relative intensity even for two individuals with the same age due to the error of HR_{max} prediction equations.[6,7] Third, age influences aerobic capacity, especially during growth and development,[17] and, therefore, taking age into account improves the predictability of MAS.

The scores for weight, height, BMI, BF and PWC_{170} were similar with those reported in the literature,[17,8] while no previous data exist about the MAS of Greek soccer players. The comparison between adolescent and adult players revealed controversial findings for aerobic capacity; the older group scored higher in MAS, but lower in PWC_{170} than the younger group, however, the differences in both cases were small. This inconsistency suggests a possible limitation of these two measures to provide similar results when differences between groups are small.

Table 4: Correlation coefficients *r* between anthropometry and cardiorespiratory endurance

Variables	MAS	PWC_{170}	$rPWC_{170}$	HR_{max}	Age	Weight	Height	BMI
PWC_{170}	0.33‡ (0.35†, 0.29†)	-						
$rPWC_{170}$	0.40‡ (0.46‡, 0.42‡)	0.77‡ (0.79‡, 0.83‡)	-					
HR_{max}	0.10 (0.14, 0.14)	−0.39‡ (−0.28*, −0.46‡)	−0.25† (−0.20, −0.37‡)	-				
Age	0.07 (0.34†, −0.18)	0.28‡ (0.21, 0.40‡)	−0.03 (0.02, 0.22*)	−0.39‡ (−0.15, −0.48‡)	-			
Weight	−0.06 (−0.11, −0.19)	0.43‡ (0.46‡, 0.39‡)	−0.22† (−0.16, −0.18)	−0.24† (−0.19, −0.19)	0.45‡ (0.32†, 0.31†)	-		
Height	−0.06 (−0.01, −0.16)	0.23† (0.34†, 0.11)	−0.24† (−0.13, −0.32†)	−0.13 (−0.22, −0.04)	0.14 (0.42‡, −0.01)	0.71‡ (0.75‡, 0.69‡)	-	
BMI	−0.03 (−0.12, −0.13)	0.44‡ (0.42‡, 0.46‡)	−0.12 (−0.13, 0.04)	−0.23† (−0.10, −0.24*)	0.53‡ (0.16, 0.44‡)	0.85‡ (0.87‡, 0.76‡)	0.24† (0.33†, 0.06)	-
BF	−0.36‡ (−0.53‡, −0.27*)	0.17* (0.09, 0.23*)	−0.27† (−0.37†, −0.12)	−0.11 (−0.08, −0.10)	0.27† (−0.05, 0.33†)	0.65‡ (0.68‡, 0.60‡)	0.28‡ (0.33†, 0.20)	0.67‡ (0.72‡, 0.64‡)

*P<0.05, †P<0.01, ‡P<0.001. BMI: Body mass index, BF: Body fat, HR_{max}: Maximal heart rate, MAS: Maximal aerobic speed, PWC_{170}: Physical working capacity in HR 170 beat/min, $rPWC_{170}$: PWC_{170} adjusted for weight. Values represent correlation coefficients for the total sample while values for adolescent and adults are in brackets

Table 5: Prediction models of MAS from anthropometry, HR, and PWC

Total	Adolescents	Adults
BF	BF	PWC_{170}
PWC_{170}	PWC_{170}	BF
HR_{max}	Age	HR_{max}
Age	HR_{max}	
R=0.61	R=0.74	R=0.55
R^2=0.37	R^2=0.55	R^2=0.30
SEE=1.3 km/h	SEE=1.2 km/h	SEE=1.3 km/h

MAS: Maximal aerobic speed, BF: Body fat percentage, HR_{max}: Maximal heart rate, PWC_{170}: Physical working capacity in HR 170 beat/min, R: Multiple correlation coefficient, R^2: Multiple coefficient of determination, SEE: Standard error of estimate. Predictors are presented in order according to stepwise regression

According to their level of aerobic capacity, we classified participants into groups with best and worst MAS. The comparison between these groups revealed higher scores of PWC_{170} in the groups of high MAS for both adolescent and adult participants. We observed that the group with high MAS in adolescents was older than the group with low MAS, while the opposite trend was noticed in the adults, that is, the older the adult players, the worst their aerobic capacity. In addition to the age, they also differed for BF, in which the groups with high MAS revealed lower BF than those with low MAS. Therefore, the analysis of the comparison between groups with different age and level highlighted certain variables that were in agreement with the regression analysis.

Moreover, we examined the variation of physical characteristics and aerobic capacity among players with different playing positions. The higher values of weight, height and BF observed in GKs agreed with a previous study on positional roles.[18] Regarding MAS, GKs scored lower than the other positions and midfielders better than defenders. Nevertheless, these findings were not confirmed by the comparison of PWC_{170}, in which the only statistically significant difference was between GKs and midfielders. Thus, the comparison among groups with different positional roles came to terms with the comparison between age groups and level of aerobic capacity; both MAS and PWC_{170} identified similar trend of positional differences, however, differences in aerobic capacity between GKs and the other positions, and between midfielders and defenders were not statistically significant when examined with PWC_{170}. An important limitation of this study is its cross-sectional design. The findings should be also examined by a longitudinal study, in which the ability of MAS and PWC_{170} to monitor changes in aerobic capacity over a long period would be examined.

In summary, while there was only moderate correlation between MAS and PWC_{170}, the former can be predicted from the latter when BF, HR_{max}, and age are taken into account (large to very large multiple correlation coefficients). Therefore, we recommend the further use of submaximal cycle ergometer testing to assess and monitor aerobic capacity as an alternative method to maximal graded exercise testing. However, this should be done with caution in the cases, where small differences among groups would be expected.

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