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Original Article

Anthropometric and Physiological Basis of Endurance Capacity in Young Indian Field Hockey Players

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Abstract

High endurance capacity, expressed by VO_2max, is essential for optimal performance and is influenced by anthropometric and physiological parameters. 30 Indian young national level field-hockey players were studied to evaluate their endurance capacity and associated parameters. VO_2max, relative physical work capacity at 170 bpm (rPWC), heart rate recovery (HRR3/6 at 3rd/6th minute), hemoglobin concentration (Hb), resting heart rate (rHR) and blood pressure (rBP), maximum heart rate (HRmax), basal metabolic rate (BMR), demographic and anthropometric parameters were measured and analyzed. After controlling the effect of gender by partial correlation, VO_2max correlated significantly and positively with age, BMR, HRmax, HRRs, rPWC and Hb; and negatively with body weight, body fat%, BMI (body mass index), rHR and rBP. Body fat% had the maximum negative effect on endurance capacity. HRR3, rHR and rPWC together contributed a statistically significant 95.2% of the total variance in VO_2max. Various linear regression equations were generated for assessing endurance capacity.

Introduction

Endurance or aerobic capacity is a measure of aerobic or cardio-respiratory fitness of a player, which is best expressed by VO_2max (maximal oxygen uptake) (1). Aerobic fitness has been reported not only to have positive correlation with power output or total sprint time during a repeated sprint exercise (2), but also to facilitate recovery afterwards (1). The total distance covered, work intensity, the number of sprints and involvements with the ball during a team sport, like soccer, have also been found to have significant positive correlation with VO_2max (3). Hence, having high endurance capacity is essential for optimal performance.

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The game of hockey demands high VO_2max due to involvement of large number of high intensity interval training (4). Field hockey training affects many anthropometric and physiological parameters of the players. These parameters are often inter-correlated due to dependence of one on another and suggest adaptations related to training (5). For enhancing performance at the elite level, the physiological and anthropometrical demands of the sport have to be considered.

Endurance capacity of a player can be estimated through various tests. Beep test or 20-meter multistage shuttle run test is an accurate estimate of aerobic power and hence considered reliable for calculating VO_2max (6). Physical Work Capacity (PWC) also indicates aerobic power, and is measured by PWC-170 test, a sub-maximal aerobic test (7). Heart rate recovery (HRR) is measure of duration required for heart rate to return to resting level after exercise. It is another indirect index of cardio-respiratory or aerobic fitness (8). HRR has been shown to increase after endurance training and to be directly related with VO_2max (9). VO_2max also showed negative correlation with resting heart rate and positive with maximum heart rate (10). Resting blood pressure has been reported to decrease after endurance training (11). A negative association of VO_2max with systolic blood pressure, diastolic blood pressure (12), and also with percentage body fat (BF) and body mass index (BMI) (13) was reported earlier, indicating the role of increasing VO_2max for health promotion. It has also been proven that low endurance capacity as determined by VO_2max and HRR is a valid predictor of mortality (14, 15).

Since hemoglobin is the primary oxygen transporter to exercising muscles, an optimal level is essential for best performance. Due to a stronger positive correlation between total hemoglobin mass than hemoglobin concentration to VO2max, the former has even been suggested as a valid indicator for endurance capacity among elite field hockey players (16). Still monitoring hemoglobin concentration (Hb) of the players is important due to the fact that it is the most suitable determinant of anemia prevalence, and an all out athletic performance is impaired by even mild anemia (17, 18).

In this study, we measured VO_2max, anthropometric and cardiovascular variables in young Indian national level field hockey players and statistically analyzed the data to find correlates and regression equations for endurance capacity estimation; with the aim to improve our understanding of the physiological demand of the sport, and to apply this knowledge not only for better performance, selection, training and monitoring of the players, but also for general health promotion.

Methods

The present cross sectional study was carried out in Sports & Exercise Medicine Department, Sports Sciences & Fitness Centre, North-East Regional Centre (NERC), Sports Authority of India (SAI), Imphal, India. Thirteen female & seventeen male players were included in the study. All the players were field hockey trainees under the Department of Hockey, NERC, SAI, Imphal, and were playing upto national level. Record of age of the players was taken from date of birth certificates submitted by them to NERC, SAI, Imphal at the time of entry. A written and well informed consent was obtained from all subjects, with the explanation of purposes and procedures of all the tests and the possible discomforts, risks and benefits prior to the study. Tests were conducted during early morning, at temperature 25±2°C and relative humidity of 61-65%. All the players were motivated sufficiently throughout the tests by the same concerned coach, so that they gave their best possible efforts. A 10-minute generalized warm up program consisting exercises involving major muscle groups of the body was also given by the concerned coach. The study was approved by the ethical committee of the institute. Following general protocol was followed for all subjects:

a) No diuretics (if used at all) for 7 days before tests

b) No exercise within 12 hours before arrival at test site. It was instructed that players should have 8 hours of sleep and 12 hours of fasting (for basal metabolic rate (BMR) estimation).

c) Players were not allowed to eat or drink within 4 hours of the tests (for tests, other than BMR estimation).

d) Empty bladder and bowel at least 30 minutes before the tests.

Study variables were measured as described previously (19-22). Stadiometer (Seca220, UK) was used to measure the height (HT) of the participants, to the nearest 0.1cm. TANITA Body Composition Analyzer (TBF310 Model, Japan, based on bioelectrical impedance analysis technique) was used to record weight (BW) and body composition variables (19). Estimated basal metabolic rate (BMR) or resting metabolic rate (RMR) was also recorded using this machine (the term BMR & RMR is used interchangeably in this study).

Beep test or 20-meter multistage shuttle run test was conducted following the standard methodology and the level recorded was converted into VO_2max (6). The players were instructed to run back and forth on a 20 m course with compulsorily touching the 20 m line. A sound signal was played from a prerecorded tape at the same time, with the frequency of the sound signals being increased from a starting speed of 8.5 km/hour by 0.5 km/hour each minute. The last stage number announced when the players could no longer follow the pace was noted. The equations used were (a) for <18 years old players: VO2max in ml/kg body weight (BW)/min = 31.025 + 3.238S – 3.248A + 0.1536AS and (b) for ≥18 years old players: VO_2max in ml/kg BW/min = –27.439 + 6.0028S; where S (speed in km/hour) = 8 + 0.5 stage no. and A = age in years.

PWC-170 test is a sub-maximal aerobic test, and was done as follows (7). Electronically operated computerized bicycle ergo-meter (Jaeger, LE900, Germany) was used. After 5 min of warm up & familiarization with minimum load at a rate of 60 revolution per minute (RPM), the player was asked to do cycling for a total duration of 4 min at power in Watt (W) fixed at 1 times BW in kg for the first 2 min and at 2 times BW in kg for the last 2 min. The RPM was adjusted so as to maintain the fixed power. Heart rate at 2nd (HR-2 in bpm) and 4th min (HR-4 in bpm) were recorded using a sports tester (Polar heart rate monitor). A linear graph was obtained with heart rate (HR in bpm) in y-axis and power (in W) in x-axis. Physical work capacity at 170 heart rate (PWC-170) was obtained as the power at HR of 170 bpm by extrapolating the above line. Relative PWC-170 (rPWC-170) was calculated as PWC-170 divided by BW.

For heart rate recovery (HRR) measurement, the same bicycle ergo-meter was used. After a passive rest of 1 hour, the payer was again asked to do warm up of 5 min. Then, the player was instructed to do an all out cycling with maximum RPM as possible at a fixed power till exhaustion. For female player, the power in Watt was fixed at 5 times their body weight in kg, and for the male, 6 times the body weight in kg (22). The maximum heart rate during the exercise (HRmax), the heart rate at 3rd minute (RHR3) and at 6th minute (RHR6) post exercise, while the player was made to sit on a chair comfortably, were recorded respectively using the sports tester (Polar heart rate monitor). To get heart rate recovery readings (HRR3 and HRR6), RHR3 and RHR6 were subtracted from the HRmax. In order to fill the gap of scanty literature on HRR3 & HRR6, we measured & used them instead of HRR1 & HRR2.

Resting heart rate (rHR) was measured early in the morning by the players (they were sufficiently trained beforehand) just after waking up, but still in the bed after a relaxing night's sleep. Resting blood pressures (systolic-SBP and diastolic-DBP) were measured using a mercury sphygmomanometer and a stethoscope (palpatory method followed by auscultatory method; an average of three readings was taken) after a sitting rest of 10 min before commencing other testing. Hemoglobin concentration (Hb) in g/dl was measured by Cyanmethaemoglobin method. The test was done after 12 hours fasting, and 24 hours after the last bout of exercise.

Data was analyzed using SPSS (Statistical Package for Social Science) version 19. For directly measured and derived variables, standard descriptive statistics (mean±standard deviation) were determined. One way ANOVA (analysis of variance) was used for comparison of few interested parameters between female and male hockey players (given in result and discussion section, not in Tables). Partial correlation was applied to study associations between VO_2max and various variables, controlling for gender. Various regression models were generated for predicting VO_2max using linear regression analysis after taking possible multicollinearity under consideration. Durbin-Watson statistics were used to detect serial correlation. Hierarchical multiple regression analysis and semi-partial correlation R^2 calculation was done to assess the influence of a particular independent variable above and beyond others on predicting VO_2max. Statistical significance was chosen at p-value (2-tailed)<0.05.

Results

The descriptive statistics of the studied subjects are given in Table I. We found significant difference in VO_2max (ml/kg/min) between female (43.922±2.760) and male (55.847±3.944) players (F=86.202 at df: 1,28; p<0.001, not shown in Table). In further analysis, we removed the effect of gender on VO_2max by applying partial correlation and found that it had significant positive correlation with age, BMR,

TABLE I: Descriptive Statistics of the players (n=30).

Parameters	*Mean±SD,*	*(Range)*
Age (years)	15.467±2.013	12.0-21.0
DOT (years)	3.767±1.490	1.5-7.0
HT (cm)	159.537±7.281	145.8-174.0
BW (kg)	52.119±5.236	44.64-67.10
LBM (kg)	40.997±4.092	35.66-50.66
BF (%)	21.150±5.733	8.6-33.0
BMI (kg/m²)	20.507±1.864	17.4-24.7
BMR (KJ/day)	1417.56±165.96	1107.0-1682.0
rHR (bpm)	68.267±7.492	58.0-80.0
SBP (mmHg)	106.800±11.174	80.0-130.0
DBP (mmHg)	72.867±8.752	60.0-90.0
HRmax (bpm)	177.300±7.212	164.0-188.0
RHR3 (bpm)	80.367±6.077	64.0-90.0
HRR3 (bpm)	96.933±9.399	77.0-124.0
RHR6 (bpm)	74.033±7.411	52.0-86.0
HRR6 (bpm)	103.267±10.521	87.0-136.0
VO_2max (ml/kg/min)	50.679±6.918	40.870-61.760
rPWC (W/kg)	3.723±1.157	2.279-6.148
Hb (g/dl)	15.263±1.463	13.0-17.9

SD=Standard Deviation.

HRmax, HRRs, rPWC and Hb; and negative correlation with BW, BF, BMI, rHR, SBP, DBP and RHRs (Table II).

TABLE II: Statistically significant correlated variables with Endurance Capacity (VO_2max) after controlling for gender (n=30).

Variables	*Correlation with VO_2max*
Age (years)	.399*
BW (kg)	–.499**
BF (%)	–.846**
BMI (kg/m²)	–.676**
BMR (KJ/day)	.773**
rHR (bpm)	–.597**
SBP (mmHg)	–.431*
DBP (mmHg)	-.446*
HRmax (bpm)	.763**
RHR3 (bpm)	–.643**
HRR3 (bpm)	.885**
RHR6 (bpm)	–.664**
HRR6 (bpm)	.874**
rPWC (W/kg)	.713**
Hb (g/dl)	.685**

*Significant: p –value<0.05; **Highly Significant: p-value<0.01. Partial Correlation (R values given), df (degree of freedom)=27.

Many regression equations were generated for explaining the variance in VO_2max contributed by the studied variables. In order to assess the unique contribution by a particular variable out of the total variance in VO_2max, after controlling the overlapping effect of other variables, semi-partial correlation R^2 was used (Table III). Among the anthropometric variables, BMI and BF uniquely accounted for 5.3% and 7.6% of the total variance in VO_2max, over and beyond those explained by gender and BW (Table III model 1(a)); and gender, BW and BMI (Table III model 1(b)) respectively. Although relatively small, the contributions were statistically significant. Due to a Durbin-Watson statistic of 2.565 and non-significant F change, Table III model 1(c) was not considered in spite of having highest adjusted R^2 among models 1(a)-(c).

Whereas, HRmax and rHR contributed a statistically significant unique variance of 9.7% and 4.1% out of the total variance in VO_2max respectively, after controlling the overlapping effect of gender and each other (Table III model 2(a)). rHR also contributed a statistically significant unique variance of 8.1% over and beyond those explained by gender and blood pressure, out of the total variance in VO_2max (Table III model 2(c)). Table III model 3(b) shows that gender, HRR3, rHR and rPWC together contributed a statistically significant 95.2% of the total variance in VO_2max. Whereas HRR3 and HRR3+HRR6 contributed a statistically significant unique variance

TABLE III : Regression models for predicting endurance capacity (VO_2max in ml/kg/min).

Variables used	*Sl. No.*	*Regression equations [Durbin-Watson statistics]*	*Adjusted R^2 (%)*	*Semi-Partial correlation R^2(%) for significant predictors*	*R^2 Change (%)*	*F-value (df)*
Demographic & Anthropometric (+BMR)	1(a)	^VO2max=91.356-7.354(G#) -1.629(BMI)-.078(BW) [1.678]	85.4	G#(11), BMI(5.3)	–	57.432** (3,26)
	1(b)	^VO2max= 79.031-5.352(G#)-.662(BF) -.141(BW)-.229(BMI) [2.218]	93.6	G# (5.3), BF(7.6)	7.6**	107.776** (4,25)
	1(c)	^VO2max=58.757-6.959(G#)-.492(BF) -.192(BW)+.006(BMR)+.209(Age)+.155(BMI) [2.565]	94.3	G#(5.9), BF(2.8), BW(1.1)	1.0	81.446** (6,23)
Cardiovascular	2(a)	^^VO2max=-14.925-1.703(G#) +.511(HRmax)-.355(rHR) [1.635]	93.2	HRmax(9.7), rHR(4.1)	–	133.076** (3,26)
	2(b)	^^VO2max=3.138-2.909(G#)+.451(HRmax) -.364(rHR)-.049(SBP)-.015(DBP) [1.501]	93.3	HRmax(5.8), rHR(3.7)	.60	81.502** (5,24)
	2(c)	VO2max=106.265-7.954(G#) -.509(rHR)-.203(SBP)+.059(DBP) [1.768]	86.8	G#(8.3), rHR(8.1)	–	48.716** (4,25)
Aerobic	3(a)	^^^VO2max=20.906-8.022(G#) +.315(HRR3)+.718(rPWC) [2.305]	94.6	G#(22.7), HRR3(7.2)	–	170.999** (3,26)
	3(b)	^^^VO2max=34.459-6.468(G#) +.313(HRR3)-.178(rHR)+.234(rPWC) [2.325]	95.2	G#(6.4), HRR3(7.1)	.70	143.627** (4,25)
	3(c)	^^^VO2max=33.639-6.435(G#)+.300(HRR3) -.181(rHR)+.169(Hb)+.144(rPWC) [2.334]	95.0	G#(6.3), HRR3(5.2)	<.01	111.489** (5,24)
	3(d)	VO2max=34.060-6.824(G#) +.144(HRR3+HRR6)-.171(rHR) +.139(Hb)+.061(rPWC) [2.181]	94.6	G# (7.1), HRR3+HRR6 (4.8)	–	102.754** (5,24)

**Highly significant: p-value<0.01. #G(Gender)=0 for male & G=1 for female player. ^,^^ & ^^^ Hierarchical Multiple Regression Analysis. df=degree of freedom.

of 7.1% and 4.8% out of the total variance in VO_2max, after controlling the overlapping effect of gender, rHR and rPWC (Table 3 model 3(b)); and gender, rHR, Hb and rPWC (Table III model 3(d)) respectively. In Table 3 model 3(d), HRR3+HRR6 was used instead of using HRR3 and HRR6 individually to avoid the problem of multicollinearity.

Regression equations comprising all the variables: demographic, anthropometric, cardiovascular and aerobic variables could not be generated due to the problem of multicollinearity among the various dependent variables; also the β-weights of most of them were non-significant.

Discussion

Male and female players were comparable for age (F=1.647 at df=1,28; p=.210), duration of training or DOT (F=2.273 at df=1,28; p=.143), nutritional aspects and physical activity habits as both the groups stayed in similar hostels, were given food with same menu per day, and had similar field hockey training. Both groups showed significant difference in VO_2max, which may be attributed to more lean body mass (LBM) (F=4.241 at df=1,28; p=.049) and hemoglobin concentration (F=7.881 at df=1,28; p=.009) among the studied males, as was reported in an earlier study (23). Another reason may be the higher maximum cardiac output (COmax) and stroke volume (SVmax) among males due to larger heart and plasma volume, although not assessed in our study (24, 25).

For younger subjects, VO_2max or peak VO_2 has been reported to increase with age or maturity and shows adolescence growth spurt (23). The positive correlation of VO_2max with age in our study (Table II) is thus understandable. Among the anthropometric variables, BW, BF and BMI showed negative correlation with VO_2max (Table II), explaining the necessity of lean body (5) and low body fat in field hockey, which also improves strength to weight ratio and hence performance (21, 26). The significant negative relation of VO_2max by weight with BW, irrespective of the cause (increase in LBM or fat mass) (13), and positive relation of absolute VO_2max with LBM (13, 27) had been reported earlier. As LBM presents the muscle mass mainly, the positive relation of LBM with aerobic capacity is thus understandable (27). However, VO_2max when expressed per BW will be less if there is increase in BW. In our study the relation between VO_2max (by BW) and LBM was not significant. Significant negative correlation of VO_2max with BMI, BF, BW and non-significant with LBM, as found in our studied subjects, had been reported earlier in physically active men (13).

From Table III model 1(a) and 1(b), it becomes clear that out of the three negatively correlated anthropometric variables, BF accounted for the most negative effect on VO_2max over and beyond others and irrespective of gender. The sequence, in decreasing order of negative effect on VO_2max, is BF>BMI>BW. VO_2max increases by nearly 1 ml/kg/min with decrease in BF by 1.5% at constant BW and BMI in both the gender (Table III model 1(b)). In fact, endurance capacity of even those players with higher BW and BMI will increase significantly with reduction in their BF.

In our study, there was positive correlation between RMR and VO_2max. However, earlier studies have shown contradictory results (28, 29). The positive correlation may have important implication. As RMR or BMR is the major component of the daily energy expenditure, having high aerobic fitness means losing more weight (fat) for health promotion in obese and overweight individuals.

Since lower resting heart rate, blood pressure, and higher HRR have been considered as indicators of cardio-respiratory or aerobic fitness (30), our finding of negative correlation of VO_2max with rHR, SBP and DBP, and that of positive with HRRs is thus explained. The possible factors responsible are increase in parasympathetic and/or decrease in sympathetic tone associated with higher aerobic fitness (31, 32). The relatively higher values of SBP and DBP in some players might be due to inadequate rest before measurement or anticipatory rise before exercise testing.

Out of all the resting cardiovascular variables, rHR has the highest significant impact on VO_2max (Table 3 model 2(c)). Lowering rHR by 2 bpm increases VO_2max by nearly 1 ml/kg/min at constant SBP and DBP in both the gender. HRmax, on the other hand, contributed 9.7% and 5.8% variance significantly and uniquely over and beyond those by rHR and blood pressure out of the total variance in VO_2max (Table 3 model 2(a) and 2(b)). HRmax was also a significant positive correlate of VO_2max in our study (Table 2). This may due to the fact that increase in cardiac output (CO = HR X SV) at higher exercise intensity, specially beyond 40% to 60% of VO_2max, mainly depends on increase in heart rate (HR) due to the plateauing of stroke volume (SV) (33). And VO_2max = COmax X maximal arterial-venous O_2 concentration difference, with COmax as the ultimate limiting factor (33, 34).

Similarly, HRR3 was found to have the maximum significant effect on VO_2max among all the studied aerobic variables (Table III model 3(a), 3(b) and 3(c)). Increase in HRR3 by just 3 bpm increases VO_2max by nearly 1ml/kg/min at constant rHR and rPWC irrespective of the gender (Table III model 3(b)). Although rPWC and Hb had no significant unique contribution in the total VO_2max variance (Table III), they were, however, both significant positive correlates of VO_2max (Table II).

The significant positive correlation between rPWC and VO_2max is understandable since, PWC-170 is a submaximal aerobic test, and hence both absolute and relative PWC is greater in more aerobically fit individuals (7). The endurance training which increases VO_2max has been shown to reduce submaximal heart rate (11), and hence more work load is possible with lesser heart rate, thereby increasing physical work capacity at a fixed heart rate of 170 bpm. The positive relation between hemoglobin mass and/or concentration to VO2max has also been reported earlier (35). Relatively lower Hb values of the studied players indicate the need for necessary dietary intervention to improve Hb level and hemoglobin mass so that further improvement in aerobic capacity may be there (35).

Sample size was a limitation for this study, as number of desired participants was limited at the institute during the study period. The power of the study was thus less, leading to more probability of β error and causing generalization of the result less reliable. Non-randomization and cross-sectional design are other limitations.

This study revealed that BF had the maximum negative effect on endurance capacity in our subjects. Among other studied parameters, HRR3, rHR and rPWC together contributed a statistically significant 95.2% of the total variance in VO_2max. HRR3 was one of the most important variables having significant positive effect on VO_2max. Various linear regression equations were generated which may be used for predicting endurance capacity, and may also help in monitoring training. These results help us to understand physiology related to sports and physical performance and training related physical adaptations. The data can be utilized for future research comparing other sporting or non-sporting populations and for understanding factors influencing aerobic fitness. This study can also be a guide for significant relevant data acquisition and analysis in areas where resources are limited or restricted.

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