Effects of systems of play on the heart rate response and the contribution of aerobic-anerobic systems during selection football match play

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Abstract

This study was conducted on state level Indian footballers (N=20; 2 Goalkeepers and 6 each were Defenders, Midfielders, and Forwards) during selection matches. This study highlights the effects of two systems of play (4-3-3 and 4-4-2) on the heart rate (HR) of the Midfielders. Relative contribution of the aerobic and anerobic systems was also evaluated during matches. Results show that in both the systems, mean HR of the Midfielders were almost identical (169.4±13.8 beats/min and 170.3±14.1 beats/min respectively). The overall cardiovascular stress, as indicated by Maximum Heart Rate Reserve (MHRR), is highest on the Midfielders (75.2±2.2%) followed by Forwards (73.1±3.5%), Defenders (65.9±4.2%) and Goalkeepers (28.5±0.4%). Outfield footballers played majority of the time in the aerobic zone (76±5.9%, 79.8±4.1%, and 92.5±3.3% of the total time of play in Forwards, Midfielders and Defenders respectively) whereas the Goalkeepers played almost exclusively in the aerobic zone. The study concludes that (a) overall cardiovascular stress on the Midfielders does not vary in the 4-3-3 and 4-4-2 systems of play, (b) Midfielders and Forwards play with higher workload than Defenders and Goalkeepers, and (c) majority of the energy is derived aerobically during selection trial football match play.

Keywords: Maximum Heart Rate, Maximum Heart Rate Reserve, Aerobic, Football

Introduction

The work rate of a footballer during match play may change according to his fitness and skill, level of match play and position of play besides many other factors (Ali & Farrally, 1991; Delamarche et al, 1987; Randers et al, 2010). The work-load on a player does not vary to a large extent when the level of the games remain same because the players have learned how much they can do and they pace themselves accordingly (Van Gool et al, 1988). Heart rate (HR) has been used as an index of physiological strain in footballers during game and has been shown closely correlated to the work-rate profiles that emerged when expressed as total distance covered in a game (Van Gool et al, 1988; Ekblom, 1986; Ekblom et al, 1971). Ekblom (1971) demonstrated that high-intensity intermittent exercise, like football, gives rise to a somewhat higher average rectal temperature when compared with continuous exercise of the same oxygen consumption. He assumed that this effect comes as a result of high anerobic yield, while a Finnish study (Smaros, 1980) suggests that aerobic metabolism takes the predominant role in football game.

Physiological stress of players can also change with configurations or systems of play, such as, 4-4-2 or 4-3-3. “Total football” introduced by the Dutch national team in the 1970’s, the “Reep system” employed in the English league in the 1980’s demand higher work rate profiles than the conventional methods used in earlier days (Reilly, 1990). But it is not known whether work rate was physiologically evaluated in football matches of various team configurations. Although physiological studies on footballer during game situation have been done in many European countries but such studies on Indian footballers are seriously lacking.

The present study was aimed to:
(a) evaluate work stress of footballers in relation to position of play
(b) find out whether change of team configuration alters the work rate of footballers
(c) estimate the relative contribution of aerobic and anerobic system in football game.

Materials and methods

Subjects

Twenty footballers of state level, were the volunteers of this study. Their age, height, and weight were 27.3±3.6 years, 172.8±6.4 cm and 59.4±5.1 kg respectively. Among them 2 were goalkeepers and 6 each were defenders, midfielders, and forwards. They were attending a selection camp at NIS, Patiala. Volunteers were informed in detail about the aims and procedure of the study. The whole study was conducted in two phases.

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In the first phase, $\text{VO}_{2\text{max}}$ and maximum heart rate ($HR_{\text{max}}$) and $HR$ at the level of anaerobic threshold ($HR_{\text{AT}}$) were determined. $\text{VO}_{2\text{max}}$ was evaluated on a treadmill (Venky, India) by incremental exercise. The initial speed, in all the cases, was 8 km/h and increased by 2 km/h at every 2 min until volitional exhaustion. Respiratory gas exchange was analyzed continuously and computed every 15 s, till end, using an Oxygen Analyzer (OM-14, Sensormedics, USA) and Carbon dioxide Analyzer (Ergopneumotest, Erich Jaeger, Germany). Anaerobic threshold ($AT$) was recorded from the nonlinear rise in $V_{\text{E}}$ against $\text{VO}_{2}$ (Ghosh et al., 1988). $HR$ was monitored continuously by telemetry (Sports Tester PE 3000, Polar Electro, Finland). $HR$ at $AT$ was considered as the $HR_{AT}$. Maximum heart rate ($HR_{\text{max}}$) was considered as the highest $HR$ attained at the end of $\text{VO}_{2\text{max}}$ test.

In the second phase, $HR$ of the players was measured during three weekly trial matches. The matches were played at the late afternoon. The players were engaged in their weekly training schedule on the other days. They were asked to reduce their load minimal one day before their match(es). The first two matches were played between two common teams of equal skill and fitness status. A total of 3 players were replaced in the second match – 2 in one side and 1 in the other. The first match was played in a team configuration known $s$ 4-3-3 (i.e., 4 defenders, 3 midfielders and 3 forwards) while the second match was played in the team configuration of 4-4-2 (4 defenders, 4 midfielders, and 2 forwards). $HR$ of 7 players of different playing positions (1 goalkeeper, 2 defenders, 3 midfielders, and 1 forward) was recorded in the first game. In the second match also, $HR$ of 7 players (1 goalkeeper, 1 defender, 3 midfielders, and 2 forwards) was recorded, of which 3 midfielders were common to the first match. The third match was played between two other teams. A total of 9 players (3 each of defenders, midfielders, and forwards) were studies in the third match. All the matches were started after 20 to 25 minutes of warm up. Each half of the matches had a duration of 45 minutes, interspaced with 10 minutes interval. The scores of the first and the third matches were 3-2 and 2-2 respectively while the second match was locked at 2-2. The peak $HR$ of a player was considered as the highest $HR$ recorded during play. Minimum $HR$ has been defined as the lowest $HR$ recorded during game (but not before 2 minutes after the start of each half).

**Recording Heart Rate**

$HR$ of the volunteers was recorded by Sport Tester using an interval of 5 seconds. They were familiar with this telemetric device. However, to protect from collision with opponent players and with ground, the receivers were not worn on the wrist of the players. These were tied on backside with electrode belt, as this was found equally effective as tying on wrist. Minimum $HR$ of any player was considered as the lowest $HR$ recorded during game but at least 2 min after the start of each half. Peak $HR$ was taken as the highest $HR$ recorded while playing. Maximum Heart Rate Reserve (MHRR) was calculated using the formula (ACSM, 1978):

$$\text{MHRR} = \frac{\text{Exercise HR} - \text{Resting HR}}{\text{HR}_{\text{max}}} \times 100$$

**Data analysis**

To examine the differences among the mean values, repeated measures of ANOVA were applied with Schaffe’s post-hoc analysis. The acceptance level of significance, in all the cases, was set at $p<0.05$.

**Results**

$HR_{\text{max}}$, $\text{VO}_{2\text{max}}$, and percentages of $HR_{\text{max}}$ and $\text{VO}_{2\text{max}}$ at the anaerobic threshold ($AT$) level of the footballers have been presented in Table 1. Mean values of $HR$ range, average $HR$ and MHRR of the footballers of four different playing positions have been illustrated in Table 2. Irrespective of the position of play the MHRR was higher in the first half than the second half of the matches, although the difference in any of the cases. Most of the players (N=14) showed higher average $HR$ in the first half while average $HR$ of 6 players was higher in the second half. Considering the players’ positions, both average $HR$ and MHRR of the midfielders was highest followed by forwards, defenders, and goalkeepers. No significant difference in average $HR$ and MHRR were found between forwards and midfielders but players of both these positions showed significantly higher values than defenders and goalkeepers. Goalkeepers’ average $HR$ and MHRR were significantly lower than defenders. Peak $HR$ of the goalkeepers, as recorded during match play, were much lower than their $HR_{\text{max}}$ as determined during treadmill running. In outfield player, peak $HR$ was very close to their $HR_{\text{max}}$ (1 to 6 beats lower than their respective $HR_{\text{max}}$). During the course of the play both the minimum and peak $HR$ of the outfield players were significantly higher than goalkeepers. However, no significant difference in minimum and peak $HR$ were observed among players of different outfield positions.

Table 3 shows the average $HR$ of the 3 midfielders who played in two different team configurations: 4-3-3 and 4-4-2. Average $HR$ of the midfielders played in these two systems of play were very similar and no significant difference was noted.

Duration of play above and below the AT level has been illustrated in Table 4. It shows that forwards played the longest period of time (23.5%) above the AT level followed by midfielders (20.2%) and defenders (7.5%). Goalkeepers played the matches exclusively below AT. No significant difference in playing time above the AT level was found between forwards and midfielders. In other cases, however, the differences were significant.

**Discussion**

Blood transfusion is a life-saving measure in various medical settings. $HR$ is used as an indicator of the total circulatory load of the players during a match (Randers et al, 2010, Seliger, 1968). $HR$ accelerates with increasing exercise intensities to raise cardiac output so that the
circulatory system can meet the demands of active muscles for oxygen. Results show that work intensity was almost identical in each half of the games, irrespective of position of play. Van Gool et al (1983) reported an average HR of 169 and 165 beats/min respectively while playing a friendly match. Ali and Farrally (1991) in their study on three standards of football matches – semiprofessional, university, and recreational, showed that average HR was slightly higher in outfield players of all the positions in the first half of play. Fatigue and/or results of matches (for example when a team is leading by 3 or 4 goals, the players may be less enthusiastic about the game), were described as the possible causes of decreased HR in the second half. However, in the present study none of the teams was leading by a margin of more than 1 goal after the end of first half. So, fatigue may be assumed as the major cause of slightly lowered HR in most of the players during second half of the matches. Average HR of the footballers during game, as observed in the present investigation, is very similar to that of field hockey players (Ghosh et al, 1991) but is higher than other team games like basketball (McArdle et al, 1971; Ramsey, 1970) and volleyball (Dyba, 1982; Fardy et al, 1976). The strain incurred by the outfield players is also higher than tennis players during singles or doubles matches (Morgans, 1987). An average HR during football game was shown to be closely related with the total distance covered by the footballers (Reilly, 1990; Van Gool et al, 1983), it can be assumed that distance covered by the footballer in each half of the games was also nearly equal or slightly more in the first half. Van Gool et al (1988) showed that total distance covered in the second half of a match was only 4.3% less than the first half.

Lower HR response in the defenders indicate that they were under least physiological stress in comparison to other outfield players. The results are also in broad agreement with other reports. Ali and Farrally (1991) in their study on semiprofessional footballers showed that the mean HR of the midfielders was highest followed by forwards and defenders (176, 173, and 166 beats/min respectively). However, when compared with the study of Reilly (1986) who found mean HR corresponded to 80% of the HR max, the level of exertion of the footballers in this study was higher to some extent. Lower HR of the defenders in comparison to other outfield players probably results from their less contribution to the game or less distance covered.

Lowest HR of the goalkeepers indicate that they were under least stress than any outfield player. Reilly (1986) also reported the mean HR of 124 beats/min for the goalkeepers in a friendly match and is in close agreement with the findings of the present study. However, in comparison to their pregame HR, this is much higher. This activity level can be partly accounted for the necessity to maintain arousal and partly for the movement within penalty area to take an active role in defense and attack. When involved in

Table 1. Physiological characteristics of the volunteers (N=20)

<table>
<thead>
<tr>
<th>HR max (beats/min)</th>
<th>VO2 max (ml/kg/min)</th>
<th>Anerobic threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (beats/min)</td>
<td>%HR max</td>
<td>VO2</td>
</tr>
<tr>
<td>194.9±5.9</td>
<td>58.6±4.4</td>
<td>180.7±4.7</td>
</tr>
</tbody>
</table>

Table 2. Heart rate of footballers during match play

<table>
<thead>
<tr>
<th>Position of play</th>
<th>HR max (beats/min)</th>
<th>HR range (beats/min)</th>
<th>Mean HR</th>
<th>MHRR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minim.</td>
<td>Peak</td>
<td>%HR max</td>
<td>1st Half</td>
</tr>
<tr>
<td>Goal</td>
<td>195.0±4.2</td>
<td>102.5±4.9</td>
<td>153.5±6.4</td>
<td>121.3±13.8</td>
</tr>
<tr>
<td>Defense</td>
<td>193.3±8.3</td>
<td>115.8±4.4</td>
<td>189.0±10.0</td>
<td>155.5±15.8</td>
</tr>
<tr>
<td>Midfield</td>
<td>198.7±6.4</td>
<td>124.2±7.1</td>
<td>196.3±7.0</td>
<td>169.7±16.0</td>
</tr>
<tr>
<td>Forward</td>
<td>194.8±3.3</td>
<td>120.8±8.0</td>
<td>191.3±5.0</td>
<td>166.9±17.3</td>
</tr>
</tbody>
</table>
the play, the goalkeepers need to be able to react quickly and with agility. Although the work rate profile is low, goalkeepers are directly involved in play more frequently than any single outfield players (Reilly & Thomas, 1976). However, frequent attack by the opponent team may raise work rate of the goalkeepers. The study also indicates that the HR response of the football goalkeepers is very close to field hockey goalkeepers (Ghosh et al, 1991) but much less than handball goalkeepers (Soars, 1988). A large variation of HR during game indicates high intensity intermittent nature of football match play. Although HR of outfield players came down to as low as 111 to 127 beats/min but careful observation on two players (a defender and a forward) show that during play lowest HR were 149 and 142 beats/min respectively. It was also observed that minimum HR, as recorded in this experiment, were attained when rest pauses were relatively prolonged such as foul play, offside or in any situation when the ball was outside the field. Because of relatively short rest pauses in football, HR stays at high level and fluctuations during play are not very large. Taking this into consideration, the results can be compared with basketball game. McArdle et al (1971) reported that HR of female basketball players ranged from 152 to 204 beats/min. Ramsey et al (1970) reported that HR of a male college basketball player ranged from 155 to 195 beats/min and also showed that even during rest pauses such as foul shots or “time-outs” HR did not decrease below 155 beats/min.

In football game the intensity of play changes rapidly from moment to moment and movement pattern changes frequently every 5 sec or less. However, there is certainly no movement, on average, which lasts for 15 sec or more (Raven et al, 1976; Withers et al 1982). This study indicates that even the intensity changes to a large extent for each 5 min period, for example, the average HR changes from 159 beats/min in the 76 to 80 179 beats/min during 11 to 15 min period of play. But there is only small and no systematic differences with time in the average intensity per 15 min of play. Probably, number of attacks, rest pauses, and distance covered per 15 min of play remains unchanged and thus no remarkable difference is observed. This is also in close agreement with the study of Ekblom (1986).

Average HR of the outfield players was about 84% of their HRmax and some of the players played in an average close to 90% of HRmax. It indicates that many players were exercising close to their HRmax for long periods during game. This is also in accordance with the study of Smoldlaka (1979) who reported that the HR was above 85% of HRmax about 2/3 of the time during a game. In general, this is also in close accordance with the results published by Reilly (1986) and Alexandre et al (2012) who reported that mean HR of outfield footballers corresponds to 80% to 90% of their HRmax. So, it is obvious that the aerobic energy yield is very high during football matches. HR-VO2 relationship also shows

<table>
<thead>
<tr>
<th>Player</th>
<th>Average HR (beats/min) 4-3-3 system</th>
<th>Average HR (beats/min) 4-4-2 system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edison</td>
<td>163.9 ± 19.3</td>
<td>166.7 ± 18.6</td>
</tr>
<tr>
<td>Norbert</td>
<td>174.7 ± 14.9</td>
<td>173.9 ± 14.3</td>
</tr>
<tr>
<td>Satinder</td>
<td>169.7 ± 16.4</td>
<td>170.3 ± 16.8</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>169.4 ± 13.8</td>
<td>170.3 ± 14.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Position of play</th>
<th>Time of play (%) Below AT</th>
<th>Above AT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward</td>
<td>76.5 ± 5.9</td>
<td>23.5 ± 5.9</td>
</tr>
<tr>
<td>Midfield</td>
<td>79.8 ± 4.1</td>
<td>20.2 ± 4.1</td>
</tr>
<tr>
<td>Defence</td>
<td>92.5 ± 3.3</td>
<td>7.5 ± 3.3</td>
</tr>
<tr>
<td>Goal</td>
<td>100 ± 0.0</td>
<td>0 ± 0</td>
</tr>
</tbody>
</table>

Table 3. Average heart rate of the midfielders in two systems of play

Table 4. Playing time above and below the anaerobic threshold level of the footballers
that outfield players were exercising at an average of 71 to 76% and with a mean value of 74% of their VO_{2max}, whereas goalkeepers utilized about 44% of their maximal aerobic power. This is also in agreement with findings of Reilly (1979) who estimated that outfield players used about 75% of their VO_{2max} in the first division English Football League. Using a similar approach Van Gool et al (1988) calculated that Belgian players also exercised at an average of approximately 75% of their VO_{2max}. This is also comparable to the exercise intensity of marathon runners who tend to race at about 75% VO_{2max} (Reilly, 1990). This comparison gives some indication of the aggregate intensity of football game. However, a footballer does not cover as much ground in a game of 90 min as would a competent marathon runner. So, the energy expenditure in football is likely to be grossly underestimated is based solely on HR measurement.

Systems of play in football game have been expected to alter the work rate profile of a player. In the match, which employed the 4–3–3 team formation, 3 midfielders were supposed to take the major workload in the midfield against 4 midfielders in the team configuration of 4–4–2 system of play, and thus total workload may be expected higher in the midfielders in 4–3–3 system. But results suggest that workload on the midfielders in both the configurations of play were identical. An explanation may be that the excess load on the 3 midfielders played in 4–3–3 system was distributed by other outfield teammates. However, whether change of systems of play affects the work rate of other outfield players need further study.

The results also suggest that the strain on the circulatory system of the footballers during simulated match play is high. Exercising at this intensity should provide a good training stimulus, provided such participation is frequent enough. Differences in relative physiological strain between positional roles are small but to demonstrate the individual work rate profiles of various positions. The anaerobic demand of football game was frequently evaluated by observing blood lactate level although there are some limitations of this process (Ekblom, 1986; Reilly, 1990). Studies show that AT_{HR} of an individual can be successfully used to indicate whether any work is performed aerobically or anaerobically (Conconi, 1982). The results suggest that aerobic process play the predominant role for energy supplement in football game. Although in midfielders and forwards anaerobic systems also contribute a significant role but in defenders it is much less. In goalkeepers, the role of anaerobic system is very less.

Nevertheless, HR is used as an index of physiological strain incurred by a footballer during game but HR does not always reflect the physiological demand, as football game is characterized by several unorthodox movements, such as, moving backwards or sideways that cost extra energy and increase disproportionately with speed (Reilly, 1990; Reilly & Bowen, 1984). Beside these, dribbling a ball, tackling or jumping also require additional physiological demand that may underestimate if workload is expressed as HR response only (Reilly & Ball, 1984). Moreover, psychological and thermal effects can elevate HR and thus, can overestimate the true workload on a player (Gaesser & Brooks, 1984).

In our study, most of the donors came from young aged population. Replacement donors were predominant, while volunteers were only handful in number. That could be due to that fact that currently lots of organizations are working hand in hand in Bangladesh to promote blood donation awareness among young generation. In this study, males were much more involved in blood donation compared to female which can be attributed to social condition or being unfit for blood donation. Most of the documented donors were Muslims.

**Conclusion**

The present study concludes that:

1. Forwards and midfielders play with higher workload than defenders and goalkeepers. The work intensity is least in goalkeepers.

2. Aerobic energy system is activated for majority of the time in football game. But in forwards and midfielders anaerobic system also plays a significant role (about 1/5). Goalkeepers play almost exclusively in the aerobic zone.

3. 4–4–2 and 4–3–3 systems of play do not cause any remarkable variation of cardiovascular load in midfielders. However, this aspect needs further detail study on other players.

**Competing interest**

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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