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Indirect assessment of cardiovascular "demands" using telemetry on professional football players

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ABSTRACT

Aerobic training is not a major component of the conditioning programs of professional football players. We used telemetric ECG monitoring to examine the cardiovascular "demands" of practice and game situations in six athletes who were selected to affect a variety of positions and aerobic capacities. Heart rates commonly considered high enough for an aerobic conditioning effect were rarely attained during practice sessions. Maximum oxygen consumption testing confirmed that professional football players do not receive a sufficient amount of aerobic conditioning during practice. Telemetrically monitored heart rate response is much greater in a game situation than that experienced during practice. Telemetry results support injury statistics by indicating that aerobic conditioning should have a significant role in the training program of the professional football player.

The question of how to train for a particular sport is important to all medical practitioners. Typically, sprinting sports such as baseball and football stress anaerobic systems. Sports that require long duration and repetitive motions such as running, swimming, rowing, and cross-country skiing emphasize aerobic systems. Indeed, measurements made by investigators in these areas seem to verify these beliefs.[1-6] The adage, "specificity of training," is rigidly held to by most coaches and sports trainers. Thus, athletes training for a "sprint-type" sport train anaerobically, and those for an endurance sport train aerobically.

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Professional football players are conditioned primarily by various contact and noncontact drills of brief duration, live scrimmages, and weight lifting. Little if any emphasis is placed on aerobic conditioning of these atheletes. The aim of this study was to examine the cardiovascular "demands" of practice sessions on these individuals, both on the field and during a game situation.

MATERIALS AND METHODS

A stress test to determine maximum aerobic capacity was given to players on a professional football team as part of a comprehensive preseason physical examination. During treadmill exercise, oxygen consumption and carbon dioxide production were measured continuously. ECG's were also monitored throughout the testing protocol, with constant display of the aV_F and V_5 leads. The test had two submaximal stages, each lasting three minutes. At each new stage, there was a simultaneous increase of both speed and grade. Finally, a supramaximal stage was reached where speed and grade were maintained until exhaustion.

Six of the players tested aerobically were selected for telemetric ECG monitoring. Selection was based on performance in the aerobic test and position played, with a variety of aerobic capacities and positions chosen. An Abbott Telemetric System (ABTM, Abbott Medical Electronics Co., Houston, TX) with nonfade scope and digital heart rate reading provided accurate tracings from distances of up to 100 yards. Response time of the rate meter was not rapid enough to keep pace with the rapid rate changes experienced by the player, but this problem was circumvented by direct measurement of R-to-R intervals on the nonfade scope. A battery-powered transmitter was padded and fixed rigidly to the exterior of the shoulder pads located above the scapula (Fig. 1). Two adhesive electrodes were placed over the distal right clavicle and left sixth rib on the midaxillary line. This system yielded prominent P, R, and T waves, and artifacts were noticeable only on impact. A researcher accompanied the investigator monitoring the ECG to record events.

Temperature and relative humidity were measured before and after each 90-minute preseason workout. Prepractice and postpractice weights were compared to assess weight losses.

RESULTS

Characteristics of the six players selected for telemetric monitoring, as well as heart rate response and oxygen uptake from the maximum aerobic capacity testing, are displayed in Table 1. The standing heart rate is from the reading taken immediately before treadmill testing.

Mean values for the temperatures and relative humidities encountered and the accompanying weight losses for the practice sessions are indicated in Table 2. Climatic conditions did not pose an extreme physiologic stress but, with the addition of football equipment, the sweating rate, as indicated by the weight losses, was notable.

Results of telemetric ECG monitoring are described in Table 3. Maximum heart rate attained during monitoring is compared to that obtained with treadmill testing. As an estimate of the aerobic conditioning value of practice sessions, the duration of time the player maintained a heart rate >140 beats per minute is given.

Results of the telemetry are illustrated by the following case studies.

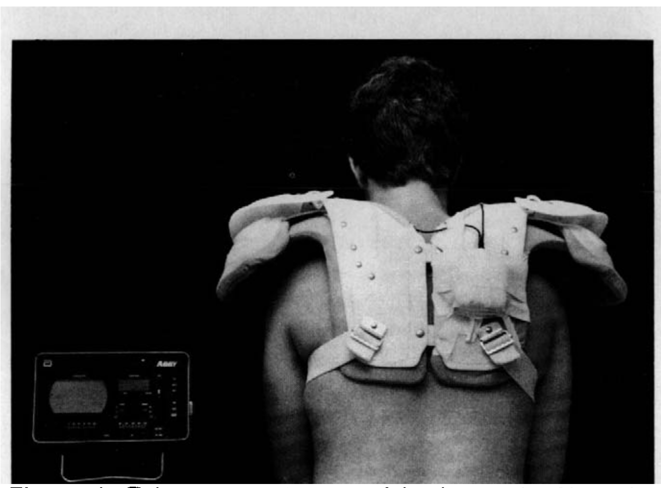

Figure 1. Telemetry system used in the study. Note the transmitter which is fixed and padded on shoulder pads over right scapula. Electrode leads act as antennae.

Case 1: Running back

This player's response to an intrasquad practice (Fig. 2) is typical of most of the players studied. He is a veteran player assured of making the squad. It is noteworthy that he rarely exceeds a rate of 140 beats per minute. Typically, instruction is given by a coach following each play, allowing time for a substantial decrease in heart rate.

Figure 3 shows the player's response to a controlled scrimmage against another football club. His rate stays above 140 beats per minute for the majority of the scrimmage. During one 15-minute period, this running back's heart rate ranged between 153 and 200 beats per minute (77 to 100% of his maximum heart rate). In the aerobic stress test, Case 1 attained a peak oxygen consumption of 46.7 ml of O_2/kg/min at 195 beats per minute.

Case 2: Defensive tackle

This individual is described for two reasons. First, his heart rate is usually higher throughout an intrasquad practice, similar to the other monitored sessions, than the response exhibited by the other subjects (Fig. 4). This is consistent with his low measured aerobic capacity of 36.6 ml of O_2/kg/min. Second, while monitoring this player, over 90 extra systoles were noted. These usually occurred at rates below 160 beats per minute and appeared most frequently imme-

TABLE 2
Mean values for temperature and humidity during telemetry with weight loss during practice sessions

	Mean	SD
Dry bulb (°C)	27	±3
Wet bulb (°C)	21	±1
Relative humidity	59%	±10%
Weight loss (kg)	1.3	±0.5

TABLE 1
Maximum aerobic capacity testing results

Position	Age	Height (cm)	Weight (kg)	Anticipatory standing heart rate	Maximum heart rate (beats/min)	$\dot{V}O_2$max (l/min)	$\dot{V}O_2$max (ml O_2/kg/min)
Defensive back	22	182	85.5	87	187	3.37	39.4
Running back[a]	23	178	97.1	100	195	4.53	46.7
Running back	23	184	101.7	95	185	4.62	45.4
Linebacker[a]	22	191	107.0	87	172	5.31	49.2
Defensive tackle	23	191	114.7	108	189	4.20	36.6
Offensive tackle[a]	22	190	122.4	110	180	5.29	43.2
Mean	22.5	186.0	104.7	97.8	184.7	4.55	43.4
±SD	0.50	5.0	13.0	9.1	7.2	0.66	4.3

[a] Signifies player made team.

TABLE 3
Telemetry results during practice

Position	Maximum heart rate (beats/min)		Activity during maximum heart rate	Heart rate: telemetry/ aerobic (%)	Duration of telemetry (min)	Min of ≥140 beats/min/ min of telemetry (%)	Min of 140 beats/min
	aerobic	telemetry					
Defensive back	187	211	Making tackle	113	99	57	55
Running back[a]	195	202	Ran pass and after running with ball	104	89	24	21
Running back	185	175	Caught pass	95	101	46	46
Linebacker[a]	172	183	Making tackle	106	85	66	56
Defensive tackle	189	203	Rushing on pass play	107	105	71	75
Offensive tackle[a]	180	180	Pushing blocking sled	100	99	29	29
Mean	184.6	192.3		104.2	96.3	48.8	47.0
±SD	7.8	13.5		6.2	5.6	19.3	17.9

[a] Signifies player made team.

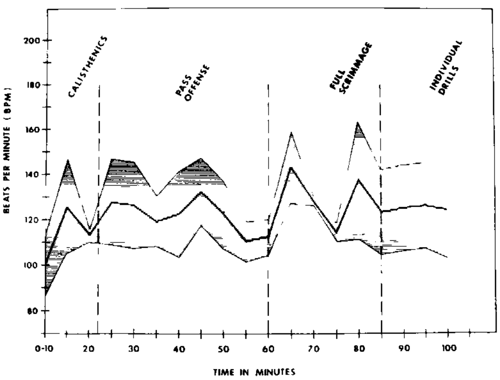

Figure 2. Case 1. Heart rate is plotted as function of time during practice for a running back. The black line is the mean heart rate, and the grey area is the standard deviation. (© 1979, Institute of Sports Medicine and Athletic Trauma. Used by permission.)

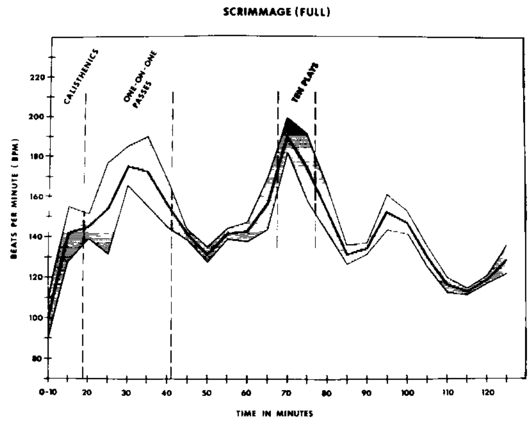

Figure 3. Same running back as in Figure 2, under game situation. Note the extended period of ten plays where his heart rate exceeds 150 beats per minute. (© 1979, Institute of Sports Medicine and Athletic Trauma. Used by permission.)

diately preceding contact of any sort. These contractions appeared to be of ventricular origin.

DISCUSSION

Telemetric ECG monitoring has been employed medically for more than two decades, with applications in intensive and cardiac care units, space flight, and exercise physiology. The technique has helped investigators study the cardiovascular demands imposed by several sports.[5-7] However, no evaluation of the training regimens of football teams or any other professional sports clubs has yet been attempted utilizing telemetric monitoring to assess these cardiovascular demands.

In order to measure aerobic power, volume of maximum oxygen uptake ($\dot{V}_{O_2}max$) was used. Maximum oxygen uptake is commonly considered the best index of cardiovascular endurance capacity, and indicates the ability of an individual to sustain heavy muscular exercise. Graded treadmill running is a simple technique, taxes a relatively large part of the total body musculature, and yields valuable and accurate cardiovascular parameters, including $\dot{V}_{O_2}max$, in a short time.[5]

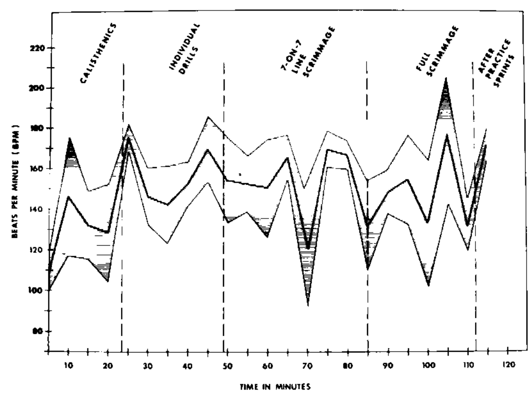

Figure 4. Case 2. Lineman's heart rate versus time in a practice session. On the average, his heart rate is higher than that of the running back during practice. (© 1979, Institute of Sports Medicine and Athletic Trauma. Used by permission.)

When compared to normal, nonathletic males of similar ages, the absolute $\dot{V}_{O_2}max$ of the football players in liters per minute seems impressive, but this may be somewhat misleading. Corrected for body weight, $\dot{V}_{O_2}max$ in milliliters of

O_2/kg/min helps account for differences by body size, and is a more accurate reflection of endurance capacity.[8] The maximum aerobic capacity results indicate that professional football players in general are in low to average aerobic condition compared to specially trained athletes in other sports.[9] The telemetric results support this conclusion and demonstrate that professional football players do not receive a sufficient amount of aerobic conditioning during their training periods.

For the six testing sessions, the average duration of practice was 96.3 ± 5.6 minutes, of which a mean of 47.0 intermittent minutes occurred with heart rates >140 beats per minute. We assumed that a heart rate of 75% of the maximum tested heart rate (or approximately 140 beats per minute) was necessary to sufficiently tax the cardiovascular system and increase the $\dot{V}_{O_2}$max. Because this requirement was made, some interesting and possibly important distinctions appeared.

The six players were separated into those who made the squad (Group A) and those released (Group B), with the following results. Group A exceeded a heart rate of 140 beats per minute during only 38.8% of practice time (106 minutes out of 273 total minutes), while Group B was taxed over 50% more (57.7% of the practices, or 176 of 305 total minutes). If this relationship is real rather than apparent, it could be used as an additional means for team selection. A coach could evaluate the condition of his athletes by determining the extent of cardiovascular stress that the practice sessions impose. Due to the small population size, this result remains to be verified, however, and further studies are indicated.

Heart rate responses, as depicted in Table 3, show an increase in heart rate while practicing football over the maximum heart rates attained during the maximum aerobic capacity testing. In all cases, the highest heart rate achieved occurred with running short distances, similar to the findings of McArdle et al.[10] Considering the relationship between heart rate and aerobic power, these results are consistent with other sports in exhibiting a higher $\dot{V}_{O_2}$max during the specific sport activity than during graded treadmill running.[5] Therefore, the most accurate representation of an athlete's maximum aerobic capacity is not in the lab, but on the football field.

Apprehension and the accompanying anticipatory responses are due to motivational and/or emotional factors. Such responses are also accentuated by training, where the individual responds to the thought of a recognized work task with an increased heart rate.[6, 11]

Anticipatory responses are important when considering the two cases mentioned above. Case 1 maintained his heart rate at between 77 and 100% of his maximum for 15 consecutive minutes during a game situation. During telemetric monitoring of practice, however, he rarely attained rates this high. Because of the small number of subjects studied, it is difficult to say whether this was due to psychologic stimuli or increased physical exertion. In any case, the increased heart rate means an increased myocardial oxygen demand.

The greater frequency of extra systole that Case 2 experienced is disturbing. Based on American Heart Association ratings, his maximum oxygen consumption of 36.6 ml of O_2/kg/min was only "low average" for a male of his age. This is significant for the team as well as the individual, since it represents a value only slightly below the team average. Well-trained athletes, as professional football players supposedly are, certainly should not rate in the "low average" category. This confirms the need for aerobic conditioning for football players. Bellet et al.[7] reported the abnormal appearance of multiple premature beats in runs during exercise in a small percentage of apparently healthy males with neither signs nor history of any cardiovascular diseases. These premature contractions were viewed as ventricular in origin and disappeared postexercise.

Jokl and Melzer's 1971 review of acute fatal nontraumatic collapse in sport and work[12] emphasized the involvement of the circulatory system. They discussed the possible mechanisms and proposed expiratory effort (Valsalva maneuver) as an additional load on the circulatory system.[13] Case 2 appeared to have the extra systoles while involved in situations requiring isometric work which normally induce Valsalva maneuvers. This player did not demonstrate a single extra systole during the stress test under controlled conditions. (At this time, Case 2 is lost to followup. After being waived by the team, he moved from the area, and we have been unsuccessful in contacting him.)

Several studies have discussed the effects of heat stress during exercise and vigorous work.[14–18] Death has been attributed to acute hyperthermia in some athletes. Due to recognition of problems resulting from dehydration, fluid and electrolyte replacement became an integral part of the trainer's job. Our study emphasizes this point by documenting that during these 90-minute summer practices, which included a 5-minute break for fluid replacement, the average weight loss was 1.3 kg. Athletes must be watched carefully for electrolyte depletion. To prevent the severe problems associated with acute heat stress, sudden or excessive body changes must be avoided during summer football practices.

A thermal load adds an additional burden to the cardiovascular system during exercise. This is due in a large part to increased cutaneous blood flow. The heart therefore is called upon to pump a larger volume of blood and the circulation must satisfy this with adequate venous return. In the normal person, the principal role of aerobic conditioning on the heart is to augment its ability to function as a volume pump.[19] Presumably, such an adaptation will allow the football player to function better in a hot environment.

Injury statistics support our findings of the need for aerobic conditioning in football players. The most recent comprehensive statistics[20] reveal a predominance of game injuries during the second and fourth quarters, 31.3 and 24.8%, respectively. Typically, the second half of a professional game is longer than the first, with more rests for the players. Hence, the game injury rate decreases.

Football is primarily an anaerobic sport with sporadic repetitions of high-intensity activity. Toward the end of the game, cardiovascular endurance plays a significant role in determining the efficacy of a player's performance. A fatigued player is at increased risk of serious injury. Aerobic conditioning, therefore, is of short-term as well as extended importance to the team.[8]

Today's professional football players are the beneficiaries of recent medical advancements for injury prevention in fluid and electrolyte replacement to prevent heat injury and extensive strengthening programs. But the present structure of football practices develops strength and skills, not $\dot{V}_{O_2}$max. Professional football clubs would be well-advised to place more emphasis on cardiovascular conditioning in training sessions, both throughout preseason and season practices and during the off-season. Aerobic conditioning should be an additional training requirement for the player on a three-day-a-week, every-other-day basis, which could occur following skills practice. Aerobic conditioning may help prevent injuries, decrease the chance of fatal nontraumatic collapse, and condition the athlete to lead a healthier life after retirement. Further studies are necessary to persuade coaches, trainers, physicians, and players to incorporate cardiovascular conditioning into training for football players at all levels.

CONCLUSIONS

1. Telemetric monitoring and direct oxygen consumption measurements revealed that professional football players do not receive enough aerobic training.
2. Telemetric monitoring demonstrated that in game situations, a player sustains heart rates of greater than 150 beats per minute for as long as 15 consecutive minutes, a duration of work requiring aerobic conditioning.
3. Injury statistics demonstrate a higher rate of injury in the last quarter of each half, a time when the player with inadequate aerobic training may be susceptible to injury.
4. Players waived by the team demonstrated higher heart rates during practice than those who remained with the team. There may be some unconscious selection by coaches of players who are in better aerobic condition.
5. These results demonstrate that football players should receive significantly more aerobic conditioning as part of the training.

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COMMENTARY

Charles E. Harrison, Jr., M.D.: I personally think this is a neat little study, although the numbers of players tested is certainly small. We have done bicycle ergometer maximum oxygen uptakes on the Atlanta Falcons for the past two years as part of their preseason physical examination. This led us to the same conclusion this article reaches; that is, professional football players are not much better than the man off the street as far as cardiovascular and aerobic training.

I am not sure how many players were monitored during game conditions. From the article, it would appear that only Case No. 1 was, and this was in a controlled scrimmage against another football club. I find it hard to believe that a majority of players' heart rates are above 150 for as long as 15 consecutive minutes under game conditions. Perhaps this ought to be critically evaluated utilizing more participants.

I am not sure whether Conclusion 4 is valid. It may be that players waived by the team had actually more practice time than the veterans. Our data indicate that rookies have better oxygen uptakes than most of the veterans. Conclusion 4 is concerned with heart rates. I do not know whether this is a valid statement. I believe that conclusion 5 is very true. I know for a fact that the Atlanta Falcons plan to increase their aerobic conditioning program.

I think the main deficiencies are in sheer numbers of players observed.

Authors' Reply: We wish to thank Dr Harrison for his comments. As we mentioned in our text, to our knowledge, this is the first telemetry study performed on a professional team. There are extensive problems involved with regard to compliance by the players, management, and trainers. We agree that more players should be monitored in game situations, if this is possible.

Figure 3 illustrates that the running back monitored during the game scrimmage did indeed maintain a heart rate in excess of 150 beats per minute for at least 15 minutes during a ten-play drive. Game time, we must remember, is considerably shorter than total elapsed time, which is on the abscissa in the graph. For example, during a game, there are times when the clock is stopped for injuries, resetting chains, penalties, etc.

We agree that there is considerable chance for an adrenergic contribution to heart rate which is beyond the physiologic need. This may play a factor in the higher heart rate of players who are not assured of making the team and in the one player monitored during the game. Making the distinction between inappropriate adrenergic drive and physiologic need is possible only in sophisticated laboratory conditions.

Our contention is that there is a great deal of evidence that points toward the need for aerobic conditioning of football players. This will be to the immediate and possibly long-term benefit of the player.