A REVIEW OF PHYSIOLOGICAL ADAPTATION TO PHYSICAL TRAINING FOR ENDURANCE WITH SPECIAL REFERENCE TO RUGBY FOOTBALL

Part I: Training Principles and Adaptive Responses

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In the broad field of Human Performance, studies of endurance and adaptation to training procedures aimed at improving man's endurance capacity have an important and central position with respect to man's leisure and occupational activities. In education and medicine some attention has been focused on endurance capacity since it relates to man living a full and active life. Rugby football has received very little special attention. Training methods currently used depend upon:-

(1) logical application of methods apparently successful in other sports.

(2) tradition.

(3) imitation of methods adopted by successful teams.

(4) pure acts of faith.

In view of the number of physical educationists and doctors associated with the game, it is surprising that their professional interest has not been engaged to a greater extent. Even in the better researched area of athletics Bloomfield (1969) considers training to be an art rather than a science.

Training and practice are distinguished by the R.F.U. coaching pamphlets (1966) agreeing with Steinhaus (1963) that practice is for skill development and training is for the development of strength and endurance. (We do not intend here to develop any argument over the possible interrelation of the two).

Our main concern is the high performance tuning of the musculo-skeletal machine called man, having heard in a previous paper about fueling this machine. Training pre-supposes that man is adaptable. Weiss (1968) gives the view that adaptation leads to the fitness whereby an organism is harmonized with the conditions of its existence which is largely dependent on heredity and that we live in a state of equilibrium with our environmental load. For the games player the training and match play constitute part of the environmental load. Capacity for adjustment is within fixed limits set by heredity. Weiss (op. cit) refers to 'elastic' short term immediate responses and 'plastic' long term responses to changes in environmental load. Training should result in increased range over which physiological adjustments can be made leading to increased endurance capacity. Adaptation is a 'plastic' response. This moulding of a player gives a greater 'elastic' range over which he can make appropriate response to the physical work demands of the game before becoming exhausted, i.e. incapable of making further effort of his own volition. The view that adaptative responses are circumscribed by heredity is supported by the work of Gribe (1963) on identical twins and Craig (1968) who found that since 1900 man has shown only 12% improvement in endurance: this conclusion was on the basis of records of endurance athletics.

Faria (1970) indicates that empirical practices, quasi-scientific regimes and popular assumptions are incorporated in seemingly successful methods for improving physical work capacity and he draws attention to the fact that it is possible that considerable time and effort are being wasted in training. Scientific analysis should reduce this waste.

It is our intention, therefore, to examine the following domains below:-

A. Training principles

B. Adaptive responses

and C. Training methods — reported as Part II, following the present paper.

A. Training Principles

Faulkner (1968) provides three important principles:-

(1) overload

(2) specificity

(3) reversibility.

Reversibility implies that de-training occurs when training ceases or is temporarily suspended. Cooper (1968) and Fardy (1969) present evidence of the effects of de-training on metabolic measures.

The main concern of this present paper is with the positive aspects of training and this primarily involves overload and specificity. Overload training has a history reaching back into Greek legend, Harris (1964), Steinhaus (1963) states that an overload is 'any exercise which exceeds in intensity or duration the demands regularly made on the organism', a view supported by Hettinger (1961). Progressive overload is the modern practice as instanced by de Vries (1967) and examplified by weight training procedures, Pickering (1972) and circuit training, Morgan and Adamson (1957).

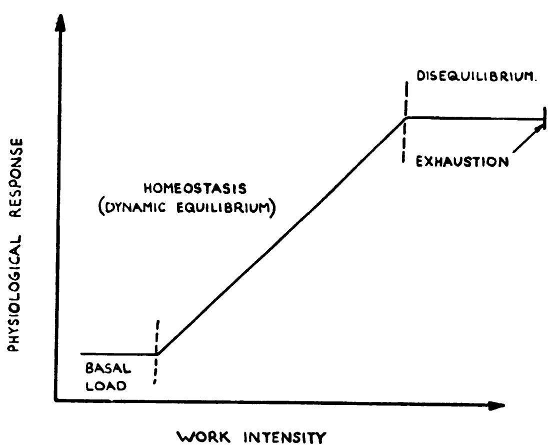
Specificity is frequently ignored or unrecognized as a training principle. Henry and Whitley (1960), as a result of experimental work in this area, conclude that there is high specificity of neuromuscular skills. Smith (1969), Alderman (1965), Bachman (1961) and Scott (1955) add further weight to this view. Studies of endurance task performance and physiological measures by Henry and Berg (1950) lead them to conclude performance was determined by psychological factors and specific skills rather than physiological limits. Nunney (1960) working with swimmers and Harper et al (1969) and Bloomfield (op. cit) refer to the work of Heusner (1963) in the USA and also their own studies with endurance athletes and give some indication of improvements where the specificity principle has been applied to training.

B. Adaptive Responses

Darling (1947) embodies the theory of homeostasis in the following statement generally recognized as an important stage in the development of a fitness concept:

> "fitness consists in the ability of the organism to maintain the various internal equilibria as close as possible to the resting state during strenuous exertion and to restore promptly after exercise any equilibriums (sic) which have been disturbed".

Fig 1 Homeostasis and Disequilibrium in exercising subjects.



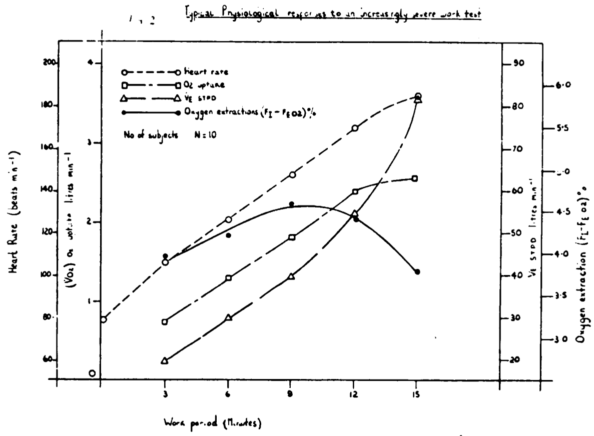
Hill (1927) recognizes in describing the steady state for oxygen consumption that this striving for a balanced internal state is dynamic. The physiological systems are involved in this striving for dynamic equilibria in response to changes in the environmental load. These are the 'elastic responses' referred to be Weiss (op. cit). Brooke (1970) deals with homeostasis as it relates to the endurance athlete. Fig. 1 presents the typical patterns of response to exercise as a subject progresses from a basal daily level of responses through to exhaustion – defined above as the inability to make further voluntary response to increased power demand. The linear increase in physiological response to linear increase in power demand characterizes homeostasis. The point is eventually reached as power demand increases when adequate response is no longer possible and disequilibrium ensues, leading to exhaustion.

Åstrand and Rodahl (1970) and Schönholzer and Weiss (1970) consider the main factors influencing physical work ability and quite clearly identify energy output dependent upon aerobic and anaerobic processes of respiration to be of prime importance. Neuromuscular and psychological factors are the important non-metabolic features which belong primarily, as previously stated, to the specificity area. The capacity for exercise is circumscribed by the limits of physiological functions according to Knehr et al (1942) who further suggest that work increments not associated with improved oxygen supply or improved anaerobic capacity must be attributed to improved efficiency. The efficiency of physiological functions such as pulmonary ventilation, cardiac function and gas exchange or efficiency of movement are clearly important variables to be considered as adaptive responses.

Direct measurements of efficiency in horizontal running tasks are extremely difficult. Åstrand (1956) refers to this problem but found that at sub-maximal speeds metabolic rate was the same in highly trained middle distance runners and non-athletes. Robinson and Harmon (1941), however, report an 8% improvement in the efficiency of running as a product of training. Johnson et a! (1942) provide support for the view that efficiency can be improved.

Åstrand op. cit, Asmussen (1965), de Vries op. cit, and Saltin (1964) are some of the many supporters for the identification of aerobic and anaerobic processes plus efficiency as the main determinants of Physical Work Capacity. The respiratory, cardiac and blood measures related to these two fundamental metabolic processes are the key areas for the study of adaptive respo..ses.

Common patterns of physiological response in the respiratory measures most frequently used in human performance studies are shown in Fig. 2.



The following formula:-

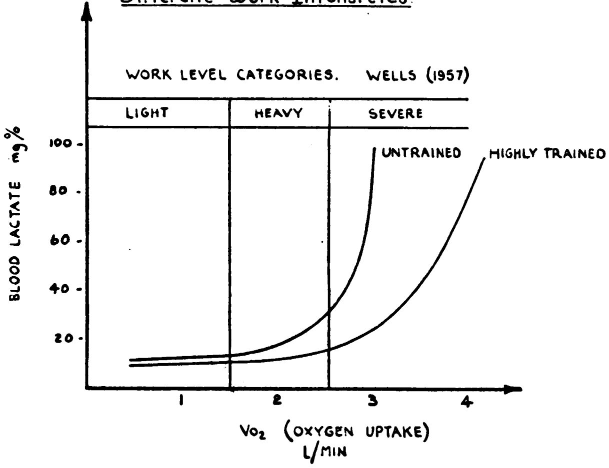
$$\dot{V}O_2 \text{ STPD} = \dot{V}_E \text{ STPD} \times (F_I - F_EO_2)\ \%\ ^*$$

expresses the relationship between oxygen uptake ($\dot{V}O_2$) pulmonary ventilation $\dot{V}_E$ and oxygen extraction from the atmospheric air by the lungs ($F_I - F_EO_2$) %. The change from linear to non-linear patterns of response and the coincidence of the start of the changes at a point where approximately 50% of the maximum work load has been achieved is indicative of the onset of disequilibrium in some functions although homeostasis is evident from the $\dot{V}O_2$ plot for a further period. These three respiratory parameters show the response pattern illustrated in Fig. 1. The initial response of the oxygen extraction to provide for the greater oxygen requirements replaced later by a greater response in ventilation is typical of physiological response patterns during exercises with increased power demand. High efficiency responses being subsequently replaced by less efficient responses has been noted by Faulkner op. cit, and Cotes (1968). Disequilibrium in oxygen uptake results in the contribution of anaerobic processes to the provision of energy, with attendant changes in blood composition.

These changes are marked by increases in lactic acid content and reduced blood pH. Wasserman et al (1964) propose the existence of an 'anaerobic threshold' as being a level or work below which a subject can exercise for prolonged periods in a steady state, i.e. in the linear, homeostatic portion of the $\dot{V}O_2$ plot, without developing metabolic acidosis. Figure 3, compiled from the data of Wells et al (1957) and Benade et al (1971) illustrates the relationship of blood lactate and $\dot{V}O_2$ in trained and untrained subjects. Knehr et al (op. cit) draw attention to the fact that a subject can work

**Symbols used through this paper are those in international use, Pappenheimer et al (1950).*

Fig 3. Relationship of Blood Lactate and $\dot{V}O_2$ in Trained and Untrained Subjects at Different Work Intensities.



AFTER WELLS (1957) AND BENADE, et al (1971)

anaerobically until an intolerable limit of oxygen debt and lactic acid is reached. Wilmore (1968) studying the influence of motivation on performance concluded that increased anaerobic metabolism related to increased tolerance to the associated pain was important in determining the capacity for increasingly severe work.

Cardiac response to exercise is another important adaptive response. Oxygen uptake in relation to cardiac output is considered by Karvonen (1959) and Åstrand and Rodahl, op. cit., Faulkner op. cit. and Vol'Khina and Kleiner (1964) assert the importance of heart rate as a valuable indicator of involvement in physical activity. The importance of stroke volume changes and their relationship to cardiac output ($\dot{Q}$) was studied using direct cardiac catheterization techniques by Åstrand et al (1964). Their work has lead to the general acceptance that much of the maximum stroke volume has been achieved when the exercise heart rate has reached 120 beats/min. The stroke volume increase markedly contributes to increased output of blood at the lower work intensities followed by reliance on increased heart rate as the work intensity becomes more severe in order to produce even higher cardiac output. This is another example of switching from higher to lower efficiency mechanisms in physiological response to increasing physical work demand. Åstrand et al (op. cit) also report no significant fall in the stroke volume at the highest loads of work eliciting heart rates close to or in excess of 200 beats/min.

Reliable techniques for the measurement of cardio-respiratory responses are essential to adaptation studies. The most commonly used parameters in this field of metabolic function are the respiratory measures

$(F_I - F_E)$ O_2%, $\dot{V}_E$, $\dot{V}O_2$, measures of blood lactate and pH and cardiac function indicated by heart rate. It is on the basis of such parameters that (a) prediction of the physical work capacity and (b) the determination of the physiological adaptations which could account for performance changes resulting from training have been made.

Johnson (1946) considered that the quantitative assessment of physical fitness is one of the most complex and controversial problems in applied physiology.

The greater interest has centred round the maximum value for oxygen uptake ($\dot{V}O_2$ max) as an indicatory of respiratory fitness. Robinson and Harmon, op. cit, Cureton (1951), Saltin, op. cit, Åstrand (1964) all provide very high values for $\dot{V}O_2$ max obtained from elite athletes. Reliability of this $\dot{V}O_2$ max measure has caused concern as instanced by Taylor (1944). Table I shows a range of reliability coefficients (r_{11}) for $\dot{V}O_2$ max. It is clear that satisfactory replicability can be obtained for research in many situations. The paper of Shephard et al (1968) reported the World Health Organisation endorsement of the $\dot{V}O_2$ max as the reference standard of cardio-respiratory fitness (physical work capacity, PWC). Determinations of PWC are generally made during performance of treadmill, cycle ergometer or stepping tasks. Table II shows a representative sample of reliability coefficients of field measures and their correlation with $\dot{V}O_2$ max. For reasons of ease of administration and economy of time we commend, for the rugby coach, the time to complete the 600 yd run as the best practical field measure of PWC (for his players and himself).

Studies reporting the relationship between $\dot{V}O_2$ max and the performance on a laboratory ergometric device

Table I:

A sample of studies in which reliability coefficients for $\dot{V}O_2$ maximum are provided

Researcher	Number of subjects	r_{11} $\dot{V}O_2$ max.
Taylor (1944)	n = 31	0.70
Taylor et al (1955)	n = 65	0.95
Brooke (1971a)	n = 20	0.91
Ribisl & Kachadorian (1968)	n = 10	0.91

Table III:

A sample of studies showing ($p < .05$) significant relationship between $\dot{V}O_2$ maximum and performance on an ergometric device

Researcher	Ergometric Device	Correlation Coefficients	Subjects
McArdle (1972)	Treadmill	0.75	College ♀
			11 – 12 yea
Brooke & Knowles (1974)	Treadmill	0.88	old boys
Knowles (unpublished)	Treadmill	0.70	College ♂

Table II:

Examples of r_{11} of field measures and the correlation with $\dot{V}O_2$ maximum

Researcher	Field Measure	r_{11}	Correlation with $\dot{V}O_2$ max.	Subjects
Metz & Alexander (1970)	600 yd. run	–	-0.66	Adolescent ♂
Falls et al (1966)	600 yd. run	–	-0.64	Adults
Cooper (1968)	12 min. run	–	0.897	USAF 22-year olds
Ribisl & Kachadorian (op. cit.)	2 miles run	–	-0.85	
Ribisl & Kachadorian (op. cit.)	1 mile run	–	-0.79	Adults
Ribisl & Kachadorian (op. cit.)	880 yd. run	–	-0.67	
Maksud & Coutts (1971)	600 yd. run	–	-0.65	Adolescent ♂
Doolittle & Bigbee (1967)*	600 yd. run	0.97	–	Adolescent ♂
Doolittle & Bigbee (1968)	12 min. run	0.94	0.90	Adolescent ♂
Doolittle & Bigbee (1968)	600 yd. run	–	-0.62	Adolescent ♂
Doroshuk et al (1963)	600 yd. run	0.80	–	Adolescent ♂
Askew (1966)	600 yd. run	0.92	–	Adolescent ♂
Klesius (1968)	600 yd. run	0.80	–	Adolescent ♂

**In a private communication to Cooper (op. cit.)*

are few. Table III shows a few examples.

The relationship between $(F_I - F_E)O_2\%$ and work ability has been demonstrated by Brooke (1971a) and Fleisch (1951). Blood lactate and pH changes have been considered by Åstrand and Rodahl, op. cit. Although studies of heart rate have been widely reported, its poor predictive value of physical work ability is exemplified by Knehr et al (op. cit), Wilmore op. cit, and Brooke and Hamley (1972).

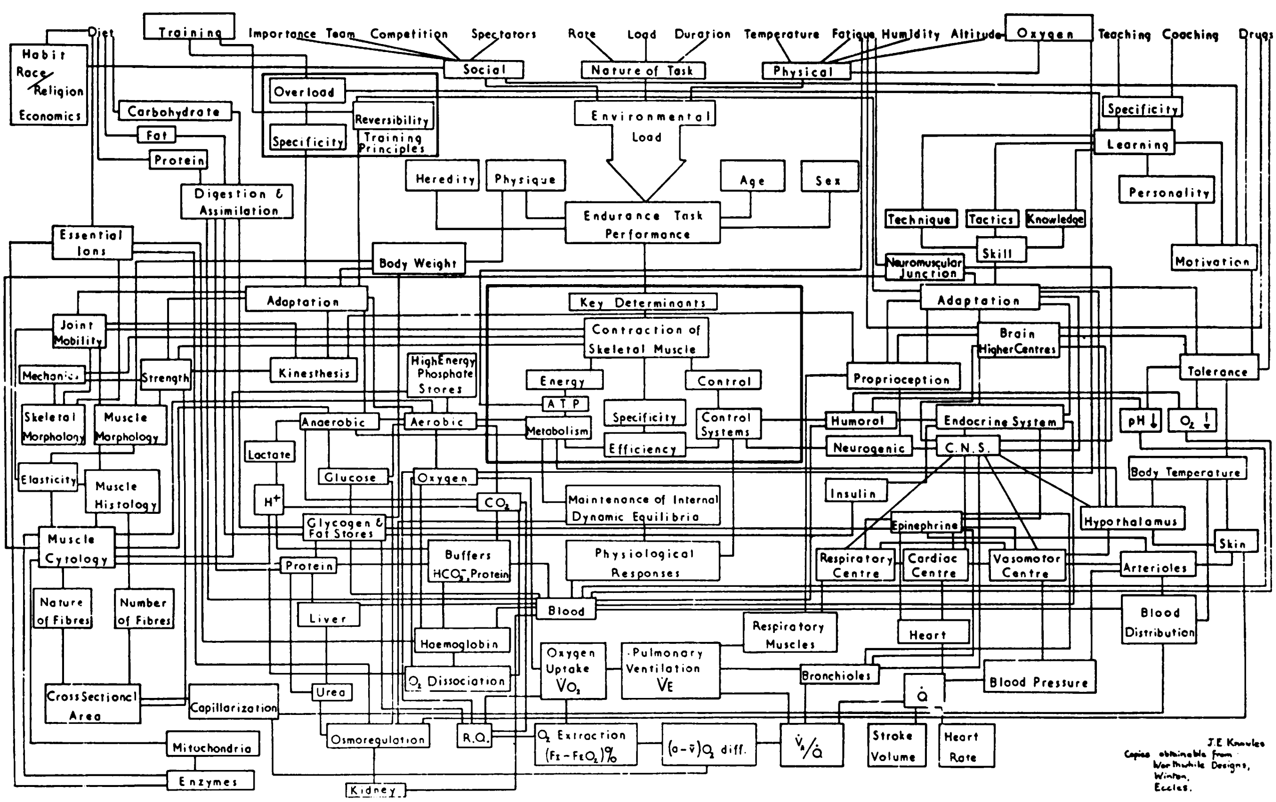
The use of measures associated with the aerobic processes in the study of physiological adaptation is supported by Faulkner, op. cit, who considers that "a maximum training stimulus to the respiratory and circulatory system probably requires a maximum demand on the oxygen transport system". He notes that it is "unfortunate that the best method to elicit the demand has not been determined" and adds later that "the mechanism that evokes the respiratory training stimulus is an enigma".

In summary of this review of scientific knowledge about training principles and human adaptive physiological responses to exercise, it is pertinent to return briefly to a wider perspective and observe the extreme complexity of interacting factors involved in such physical performance.

Figure 4 is an attempt to represent the environmental variables and the major factors which are thought or known to be related to man's ability to perform an endurance task. Taylor, op. cit, finds that oxygen uptake accounts for only 30% of the variance in an all out treadmill task. A similar conclusion is provided by Adams (1967). The model in Figure 4, by its very complexity, supports this recognition of the enigmatic character of the adaptive responses to training stimuli. For many of the responses included, the necessary tools or sufficiently sensitive techniques for their measurement in the intact human being are lacking. Only in a few of the sections of Fig. 4 are reasonably effective probes available. The limitations of the following paper on training methods should be seen in this light.

FIG. 4. ENVIRONMENTAL INPUT VARIABLES AND PHYSIOLOGICAL RESPONSES RELATING TO ENDURANCE TASK PERFORMANCE.

INPUT VARIABLES



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