HUMAN ENDURANCE – MIND OR MUSCLE?

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ABSTRACT

Two investigations have been carried out. The first studied the effects of autonomic blockade on the cardiovascular response to a step test, a 50% maximum isometric grip test and a Valsalva manoeuvre: the step test was of 5 minutes duration and the other two for as long as possible. β adrenergic blockade by propranolol diminished the blood pressure and pulse rate response to both the step test and isometric grip. The pulse rate response to the step test was also affected by cholinergic blockade with atropine. The response to the Valsalva test showed a cholinergic blockade effect of pulse rate alone and a blood pressure response alone on α adrenergic blockade by phenoxybenzamine.

The second studied psychological stressing on physical and mental ability. A potential 'punishment' situation increased the blood pressure and pulse rate response to isometric grip while decreasing the time for which it could be maintained. A potential 'reward' situation increased both the maximum grip and the time for which 50% grip could be maintained.

It is concluded that psychological factors can affect performance dependant on whether the situation is perceived as one of 'reward' or 'punishment'. A factor in the mediation of the adverse response is an inappropriate response of the autonomic nervous system.

INTRODUCTION

Athletic performance can undergo unexpected changes despite the most careful programme of training, indeed most people connected with sport remember top class athletes who were unable to rise to the big occasion. This has been ascribed to the failure of the 'surge of adrenaline', to troughs in biorhythms and to a multitude of other causes for which there is little or no foundation in scientific investigation. In recreational or adventure sports, such as mountaineering, hill walking and sailing, as well as on expeditions, survival against adverse environments is difficult to predict (Taylor, 1972).

There are three main factors which limit human performance (Åstrand and Rodahl, 1970).

1. Ability of the muscle to perform aerobic and anaerobic work.
2. Ability of the cardio-respiratory system to provide oxygen to tissue.
3. Psychological factors.

As the majority of published work deals with the first two limiting factors, which depend primarily on anthropometric type, acquired skills and training, this paper will cover work which we have carried out on problems concerning the third factor. The psychological factors will be considered under three headings:

- a) Normal exercise response
- b) Stress responses
- c) Motivation

NORMAL EXERCISE RESPONSE

When a healthy individual takes moderate exercise the cardio-respiratory system keeps pace with the increased oxygen demands of the tissues, so that there is little or no oxygen debt. The oxygen uptake by the lungs (VO_2) is increased and the parallel cardiovascular response is seen by the straight line relationship between pulse rate and VO_2 . Although the systolic blood pressure rises this is accompanied by a marked increase in the pulse pressure so that mean blood pressure rises very little. That is, the increase in cardiac output is matched by a decrease in total peripheral resistance. The physiological changes are initiated by the brain, principally by the hypothalamus and the limbic system. In the later stages local metabolites become the principal agents for muscle vasodilatation and baroreceptor reflexes are a dominant factor in the maintenance of mean blood pressure.

STRESS RESPONSE

The stress response is entirely mediated through the hypothalamus and the limbic system, giving an exag-

Blood Pressure (mm Hg)

	Ascorbic Acid	Atropine	Phenoxy- benzamine	Propanalol
Step test	-5.143 ± 3.453	-1.143 ± 4.600	+5.000 ± 3.792	-26.571 ± 7.208
50% Isometric Grip	-2.786 ± 3.366	+10.000 ± 4.775	+2.143 ± 4.464	-12.071 ± 3.281
Valsalva Manoeuvre	-3.857 ± 6.193	-7.286 ± 10.380	-12.929 ± 3.665	+ 6.429 ± 8.671

Pulse Rate (/min.)

	Ascorbic Acid	Atropine	Phenoxy benzamine	Propanalol
Step test	5.471 ± 2.911	-8.750 ± 3.894	-0.377 ± 2.740	-14.771 ± 3.288
50% Isometric Grip	5.814 ± 3.497	-3.029 ± 5.411	-2.500 ± 5.144	-10.143 ± 5.952
Valsalva Manoeuvre	-3.786 ± 7.617	-8.800 ± 3.698	-2.657 ± 7.558	+ 3.471 ± 4.457

TABLE 1

Effect of autonomic blockade on magnitude of blood pressure response to stressing. (mean difference from before drug response ± S.E.)

gerated fight or flight reaction: there is also an increase in muscle tension, even to the occurrence of tremor.

The cardio-respiratory response shows an increase in pulse rate which is disproportionate to increased oxygen uptake and an increase in systolic and diastolic blood pressure, without an equivalent change in cardiac output, so that peripheral resistance is increased. A similar response is produced to a sustained isometric contraction, such as a 50% maximum handgrip. The characteristics of the stress response which distinguish it from the normal exercise response are the increase in peripheral resistance and the over-riding of the normal baroreceptor control mechanism for the maintenance of the arterial blood pressure.

Both these responses are mediated initially from the same areas of the forebrain and are well described in standard text books of physiology (Passmore & Robson, 1976). What is not well understood is the neurohumoral mediation of the two responses. To elucidate this point a study was made of the effect of autonomic blockade on three types of stress response.

FIRST INVESTIGATION: AUTONOMIC BLOCKADE

Method 1. Investigations were carried out on seven healthy young adult students (5 male, 2 female ages 21-23 years). The three main modes of autonomic trans-

mission, cholinergic, α adrenergic and β adrenergic were studied and three types of activity.

- 'Normal' exercise response by the modified Harvard step test; 18" step, 120 movements/min for 5 minutes.
- 'Stress' response by the 50% maximum isometric grip maintained for the maximum period.
- Valsalva manoeuvre (forced expiration against a closed glottis) maintained for a maximum period.

The latter was included as it is used as a method of assessing autonomic nervous system integrity and has also been suggested as a cause of sudden collapse in conditions of stress.

After informed consent had been obtained and a medical examination eliminated cardio-respiratory disease, each subject underwent four experimental sequences on separate days in which the tests were performed before and after ingestion of identical pills, which were administered double blind. The four preparations were:

- Cholinergic blockade. Atropine 1.2 mg.
- α adrenergic blockade. Phenoxybenzamine 20 mg.
- β adrenergic blockade. Propanalol 20 mg.
- Placebo. Ascorbic acid 50 mg.

The order in which the tests were performed and the drugs given were randomised to assist later statistical evaluation.

The subjects had the heart rate measured automatically from the ECG recorded from a four electrode precordial array and the blood pressure from the brachial artery by an automatically inflated cuff and oscillometry. Both measurements were processed on-line using parallel hybrid computer techniques (Austin and Whamond, 1972). The subject was allowed to rest for five minutes before the procedure, the recording being started during the last two minutes. The response was followed during the procedure and for five minutes after completion. A 'learning' period of three days was inserted before the trial runs in order to eliminate as far as possible effects due to familiarisation.

The only subjective complaint of postural faintness was in one subject after taking ascorbic acid, and the subjects did not recognise the atropine by mouth dryness with a significant accuracy. This subjective inability to recognise autonomic blockade has recently been confirmed in studies of the effect of β blockade on the performance of surgeons (Foster et al 1979).

Results 1. The main finding of the trial relevant to this paper are presented here: a fuller report will be presented in a future paper (Taylor and Whamond - in preparation).

TABLE II

Effect of autonomic blockade on magnitude of pulse rate and systolic blood pressure change on testing

Block		Step Test	Isometric Grip	Valsalva
Cholinergic	Pulse	↓ *	0	↓ *
	BP	0	0	0
α Adrenergic	Pulse	0	0	0
	BP	0	0	↓ *
β Adrenergic	Pulse	↓ **	↓ **	0
	BP	↓ **	↓ **	0

Wilcoxon Rank Order test.

0 Not significant

* $P < 0.05$

** $P < 0.02$

The results (Table I, II) showed that the neuro-humoral mechanism of the response to the step test and to the isometric grip were similar in respect of their sympathetic component. Both showed an almost exclusive β adrenergic mediation for both pulse rate and for blood pressure. The difference between the two, in as far as mediation was concerned, was cholinergic; the step test response of pulse rate is partially mediated by a release of vagal tone, but this does not appear significant in the response to isometric grip. It, therefore, would be consistent with the mediation of the two responses being similar, but central differences occur governing the overriding of the baroreceptor reflex control in the hind brain reticular formation by descending pathways from the limbic system. The latter is well recorded in response to neuro-psychological investigations with stimulation, in particular, of the amygdala (Passmore and Robson, 1976). In contrast the Valsalva response in the overshoot phase appeared to be mediated by cholinergic inhibition and α adrenergic stimulation. It would therefore, be a poor analogue for assessing possible cardio-vascular response to exercise stress.

The type of response seen to isometric grip would be inappropriate for sustained exercise, for the increase in blood pressure and pulse rate are not accompanied by a parallel increase in cardiac output, rather the reverse. This has been confirmed in observations using the isometric grip test and transcutaneous aortovelography (Bloom, Light and Vecht, 1978). Further observation (Vecht personal communication) has shown high levels of circulating adrenaline in such cases. Thus, if stress is added to exercise there may be a diminution of performance by a combination of an inappropriate sympatho-adrenal response and a central overriding of some of the normal cardio-respiratory control systems.

However, β blockade is definitely not to be recommended to improve athletic performance: it may

Fig. 1: Results of Psychological and Physiological testing of 7 subjects before (I), after (F) and at four intervals during a field trial, 2 with neutral psychological stressing (N) and one each of potential punishment (P) and reward (R). (mean $\pm$ SE).

improve performance in concert violinists where muscular tension and tremor are a problem (James, et al 1977), but it is the dominant mechanism for the normal exercise response, and in other studies (Taylor and Whamond – unpublished data) the maximum exercise capacity was reduced by β blockade and the recovery time following a step test was prolonged.

MOTIVATION

In addition to physical ability motivation is also much concerned where endurance is involved. This is much more difficult to define or to assess than cardio-

respiratory responses. The relevant Oxford English Dictionary definition of motive is "a desire, fear, reason etc., which influences a person's volition". A test which appears to depend almost entirely on motivation rather than physical fitness is the time for which a 50% maximum grip can be maintained: this can be readily demonstrated by carrying out the procedure with and without vocal encouragement.

A trial was designed to assess the contribution of motivation to physical and to mental ability. In addition awareness and capacity to cope with the environmental problem were assessed.

Methods 2. Studies were carried out on a section of 5 male officer cadets (age 19-23 years) during an exercise in a mountain wilderness which was structured so as to give readily identifiable "reward" or "punishment" situations. The investigations formed part of trial into the capacity to endure physical and psychological stress while still being able to function as a coherent and effective group.

Cardio-respiratory capacity was assessed by the measurement of maximum oxygen uptake (VO_2max) and the regression of pulse rate against VO_2 . This test was carried out the day before the exercise started, and 5 days later, immediately at the end of the exercise.

The physical strength was assessed by the maximum handgrip and the "motivation" by the time for which a 50% maximum handgrip could be maintained: both tests were performed using a hand dynamometer. Verbal encouragement was given during the timed 50% handgrip. The autonomic nervous system response was assessed by the maximum change in heart rate and systolic blood pressure during the 50% handgrip test: each was taken manually every 15 secs.

Mental ability was assessed by the speed with which a correct sequence of successive subtractions of 7 from a number between 99 and 104 without error would be carried out, and the accuracy of recall of strings of numbers and letters from 4 to 10 characters.

Awareness and ability to cope was assessed by a verbal description and was not quantitated.

All tests, apart from the step test were carried out before the exercise, at four points during the exercise, two neutral, one 'punishment' and one 'reward' and immediately at the end of the exercise. The 'neutral' situations were paired for time with the 'punishment' and 'reward' situations so as to eliminate any effect of circadian rhythm. Possible circadian rhythm effects were further minimised by placing the 'punishment' situation at 0100 hrs and 'reward' at 0500 hrs.

Results 2. Over the period of the exercise there were no significant changes in the VO_2max or the relationship of pulse rate to VO_2 . The subjects were all fit young men who were already well trained and no further improvement was expected over such a short period.

The tests of mental arithmetic and recall showed no significant variation between the observations, although on ability assessment all subjects were very tired apathetic and unable to reason clearly by the end of the exercise.

In the 'punishment' situation there was a significant reduction in the period for which a maximum grip could be maintained (Fig. 1, Table III) and despite this shorter period of isometric stress the increase in systolic pressure was significantly higher ($P < 0.01$ Wilcoxon) by an average of 12 mm Hg. The pulse rate change increased by 9 beats per minute which was significant ($P < 0.05$ Wilcoxon).

TABLE III

Results of physical and psychological tests during (1-4) and after (5) trial compared to pre-trial values

	1 Neutral	2 Punish	3 Neutral	4 Reward	5 Final
C.V. Response					
BP	0	↑ ***	0	0	0
Pulse rate	0	↑ *	0	0	0
Max Grip	0	0	0	↑ *	0
Time 50% Grip	0	↓ *	0	↑ ***	0
Arithmetic	0	0	0	0	0
Recall	0	0	0	0	0

Wilcoxon Rank Order test.

0 = N.S.

* $P < 0.05$

** $P < 0.02$

*** $P < 0.01$

In the 'reward' situation the time for which a 50% maximum grip could be maintained was very significantly prolonged ($P < 0.02$ Wilcoxon) despite the magnitude of the maximum grip itself being significantly increased ($P < 0.05$ Wilcoxon). There were no significant differences in the autonomic cardio-vascular response in this situation.

DISCUSSION

In a study on the heart rate response to rock climbing Williams, Taggart and Carruthers (1978) concluded that it represented an anxiety — type of psychological stress rather than physical stress. They further concluded that the autonomic response to stress could be blocked by

oxprenalol without affecting performance adversely. The recent studies of Foster et al (1979) have shown a similar type of response in surgeons while operating and again report that while oxprenalol reduced the heart rate response it did not affect tremor or manual dexterity.

The initial studies with β blockade showed that it affected both the normal response to aerobic exercise and the isometric grip stress. This would agree with the findings of Imhoff et al (1969) on ski jumpers, but would not support their contention that the blockade only affected the anxiety factor. Both the normal response to exercise and to stress have predominant β adrenergic mediation by the sympathetic, but the associated cholinergic inhibition on aerobic exercise would explain the lack of complete abolition of the tachycardia on aerobic work by β blockade. The differences between the two responses appears to lie in the extent to which normal baroreceptor reflex control of blood pressure and pulse rate is overridden by neural influences from the limbic system as part of anxiety stress feedback loop (Breggin, 1964).

These findings would be supported by the field trial results, for when additional psychological stress was imposed by a 'punishment' situation the blood pressure response to isometric grip was significantly increased, while the strength of grip and its duration were reduced. Although the tachycardia also increased by 16% it was less statistically significant.

When there was a 'reward' situation the autonomic response to stress was not altered, but both the maximum handgrip and the duration for which a 50% grip could be maintained increased significantly.

Thus, a potentially rewarding situation both increased maximum muscle power and also the ability to maintain an effort; the latter being the most marked response showing a mean increase of 41%. Conversely a potential 'punishment' situation resulted in an increase of psychological-stress type cardiovascular response with an

inappropriate increase in blood pressure. From the results of Bloom, Light and Vecht, (1978) it is possible that the stress response would have resulted in a decrease in the change of cardiac output.

It was of interest that although all the observers agreed on the deterioration of awareness and alertness, particularly in the potential 'punishment' situation there was no significant change in the results of the tests for mental ability and recall. A similar inability of standard psychological tests capable of being carried out in the field to detect mental deterioration to stress has been observed previously to cold water immersion (Passmore, Forrester and Taylor – unpublished data).

The answer to the question posed by the title is that psychological factors are important in endurance, but that the mechanism varies according to how the subject perceives their situation.

If the person believes that they will not win or survive, then a psychological stress spiral is induced (Imhoff, et al 1969) resulting in an inappropriate cardiovascular response with a tachycardia and hypertension in excess of changes in cardiac output. That is, far from there being a lack of the 'surge of adrenaline' there is probably too much: a contention supported by the circulating catecholamine concentrations reported in rock climbers (Williams, Taggart and Carruthers, 1978). In contrast when the person believes they will win or survive although there is no change in cardiovascular response both the maximum muscle power and the duration of a sustained effort are increased.

These results would indicate that attention to psychological factors is as important as physical fitness when endurance or the will to survive are important.

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