Physiological analysis of human performance: a study of extreme fatigue and violent effort during sporting activities

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PHYSIOLOGICAL ANALYSIS OF HUMAN PERFORMANCE :

A STUDY OF EXTREME FATIGUE AND VIOLENT EFFORT DURING SPORTING ACTIVITIES

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It has been the author's great privilege to belong to the 'team' of ergonomists and physical educators who are tackling a wide variety of problems in human performance at the Department of Ergonomics and Cybernetics, Loughborough University of Technology. It would be invidious to refer to any members of this team in particular, but a great debt is owed to Professor W.F.Floyd, Head of the Department, for his wisdom and foresight in encouraging the team's work.

The author's metamorphosis from a 'muscle mechanic' to a 'sports ergonomist' has been due almost solely to one man - his (tor) mentor Dr. E.J.Hamley. He will never be able to sufficiently repay this debt.

To keep the mind and body in a questing and refreshed enough state for the considerable amount of work which has been undertaken, the author has had the great good fortune to be able to rely heavily upon the unfailing support of his wife - Christina.

"One man, alone, can achieve nothing"

ABSTRACT

A study was made of the application of methods of physiological examination of human performance within the field of Physical Education. These methods embrace electrocardiography, electromyography, respirometry and thermometry. The specific activities concerned were cycling, rowing, swimming, basketball, trampolining, canoeing and weightlifting. It was found that significant adaptions of normal techniques for physiological examination were necessary.

Detailed and controlled analyses were made of two of these activities.

i) An investigation into the effects of several factors upon leg muscle co-ordination in bicycle pedalling. Statistically significant differences in co-ordination patterns were discovered due to the effects of load, between muscles, and between subjects.

ii) A deep kinesiological and physiological analysis of the lifting of a very heavy weight by a world champion weight lifter. A reliable technique of measuring and presenting data was devised.

The use of such information as can be found by these methods was explored, and specific applications made in advising several international standard sportsmen during their preparation for competitions.

CONTENTS

INTRODUCTION

Physical Education may be defined as "Education of the human in and through the performance of physical skills". A physical skill is one effected by motor activity, though not necessarily producing movement, and under a certain degree of nervous control. Such skills form the total physical activity potential of the human. The ways in which skills are developed, and the effects upon skills performance by extraneous factors, are similar whatever the reasons for performing the skills.

This view of Physical Education establishes a difference between it and 'Physical Fitness' or 'Physical Training', whose aims are linked more closely with organic and local muscular endurance, or with more or less formalised methods of achieving these. It encompasses purposes of sociological, philosophical, psychological and physical nature. It gives rise to a concept of the 'complete' Physical Educator, who is aware of his total responsibilities and practised in the application of fundamental principles within each facet of physical education. This is a very broad concept, which becomes narrower if the word 'educator' is taken in its literal sense. Anyone who does not educate is not a physical educator; and if the sociological and phylosophical aspects are taken as being present, then the physical educator is left with three main functions:

1) He should be competent to analyse the physical demands of a situation.

2) He should be capable of devising the most suitable physical method of coping with these demands.

3) He should be able to educate the human operator to perform this skill as efficiently as the attendant circumstances demand and allow.

Hence, the field of action should extend from the workbench to the building site, from the kitchen to the sportsfield - in short, everywhere there is purposeful human physical action. In this case, physical educators - that is, educators of the physical - should be able to learn from and contribute to the general pool of knowledge concerning the acquisition of physical skills. Specials in certain fields of physical education such as acclimatisation, industrial fitness, lifting techniques, operative skills, fatigue resistance, remedial gymnastics etc. etc., should co-operate with one another to achieve a cohesion of information and techniques. Such is already being done by such organisations as the Ergonomics Research Society and the British Association of Sport and Medicine, which must lead to a broadening of the old aims of physical education and a development of the capabilities of physical educators.

Taking this threefold function of the Physical Educator, then he will need equipment (both intellectual and mechanical) to fulfil his intentions. His intellectual armoury will include such weapons as anatomy, physiology, bio-chemistry, kinesiology, mechanics and physics, cybernetics, coaching experience, statistics, specific technical knowledge of the activity, etc. etc. His mechanical needs are means of observing, measuring and computing, and herein lie many of the pitfalls for the Physical Educator. In acquiring the knowledge and techniques he needs, he will come into contact with people with purposes far different to his own. There will be those to whom the development of apparatus is virtually an end in itself; and those whose obsession with the sophistication of techniques of observation and measurement prevents them from observing and measuring in order to produce practicable results. The physical educator must take from these 'mentors' that which will be of practical use to him in educating the human operator. He should not be over concerned that his techniques are not as apparently sophisticated or accurate as others.

Provided that there is sufficient reliability and accuracy in his techniques to give him useful data, then he can begin to fulfil this 'threefold function'. There is, of course, a continuing demand for the further development of experimental techniques, a demand which will be satisfied by experimental technicians, amongst whose ranks will be some who are well versed in physical education. But development is a continuing process, and somewhere along the line someone has to step off the treadmill and actually use these instruments of research - and having diagnosed, then act upon the diagnosis. This is the physical educator - analysis - synthesis - education.

The Contribution of Sportsmen

Research into many aspects of human physical performance is very often handicapped by a lack of subjects who are highly skilled and efficient, possessing a high degree of motivation, and well trained to resist various unpleasant manifestations of fatigue. However, the sportsman usually possesses these qualities to a greater or lesser extent, and is usually very happy to act as a subject, especially in response to a challenge, or when the resulting information can be of value to him in his training or competition programme. Sportsmen are also more or less accustomed to regular training routines, thus lending themselves suitably to longitudinal physiological studies. This very suitability of the sportsman subject does, however, pose some difficult problems. Not the least of these is the difficulty of experimental apparatus. The majority of physiological apparatus is designed to accommodate the normal (sedentary) and sub-normal (clinical) subject even though the demands of work study and industrial fitness are leading to the development of higher range apparatus. It is the author's experience that the reliability and validity of such apparatus during 'tests-to-destruction' is always open to serious doubts. Certainly during recent investigations parameters such as Heart Rate - 252 beats per minute

Ventilation Rate - 100+ per minute

Ventilation Vol. - 200+ litres per minute

Lung Capacity - 7 litres

Work Output - 2 horse power

O_2. Consumption - 6+ litres per minute

have strained apparatus beyond breaking point. Much work is needed on the development of 'high capacity' physiological apparatus before reliability will be sufficient to permit a high degree of experiment sophistication.

A second problem lies in the application of experimental conclusions. The sportsman is an abnormal human being, and it would be foolish to blindly apply the rules governing the sportsman to normal and sub-normal subjects, a point reinforced by Haggard (1), who says .... 'the so called fatigue of the industrial worker indicated as progressively diminished performance and a feeling of tiredness is not the same as the fatigue of the athlete, and the attempt to explain it and remedy it by practices carried over from strenuous athletics leads only to erroneous explanations and wrong conclusions'. The reverse is also true - witness the development of sub-maximal isometric muscle training for hospital patients, which method was eagerly devoured by athletes seeking an easy path to supreme fitness. The subsequent results did not bear out their optimism.

The author's present studies have fallen into two main fields. The first was to devise, with the apparatus that was immediately available, methods of recording physiological parameters during strenuous work. This aspect embraced electro cardiography, electro myography, and some little respirometry and thermometry. The second aspect was to make close and controlled examination of two types of motor performance, observing the effects of various extraneous factors upon muscular co-ordination and cardiac reaction.

These varied studies have been reported in various ways, and a list of relevant publications by the author, and copies of the work, are contained in Appendices.

METHODOLOGY

(i) Electrocardiography

To the extent of using electrocardiography in measuring the performance of the human, and at extremely high heart rates, the author believes that analysis of the E.C.G. wave by normal clinical criteria will give misleading results. The normal clinical placing of E.C.G. leads is such that relatively large field disturbances can be set up between the leads by gross muscle movements. Even using the wrists when the hands are fixed in a position away from the body's main muscular effort (e.g. the normal cycling position), gives severe problems of artefact when supreme efforts bring the arm muscles strongly into play (Fig.1). In such cases the author's experience has been that selection of electrode placements should be such that:

a) The electrodes are as close as possible together without giving problems of cross conduction

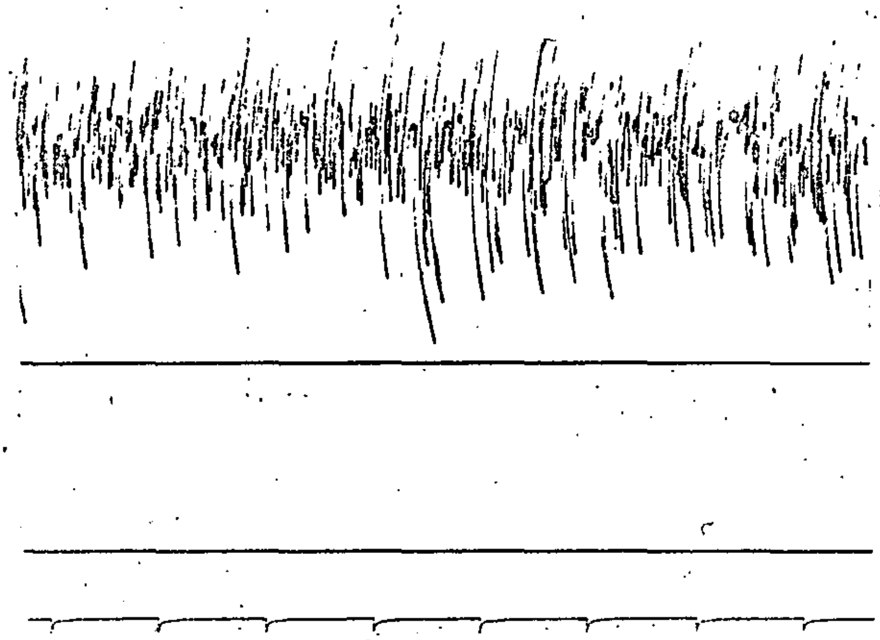
b) The electrodes are near enough to the heart to obtain maximum signal/noise ratio with the given intra-electrode distance

c) The electrodes are not directly above muscle fibres

d) The earth electrode is at any convenient bony prominence where there is little subcutaneous soft tissue

Using this electrode placement system the resultant E.C.G. wave in its normal form gives relatively large amplitude R and S components, which makes heart rate counting easier, and a sufficiently large (if slightly skewed) T wave to demonstrate inversion effects. From the clinical diagnosis aspect, it is possible for even a relatively unskilled observer to detect inversion of parts of the wave, alterations in temporal phasing of wave components, gained or lost impulses during over or under compensation, and rhythmic alterations of heart rate (Fig.2). These are discussed in detail in

ECG with artefacts, wrist electrodes.



Ediswan mains

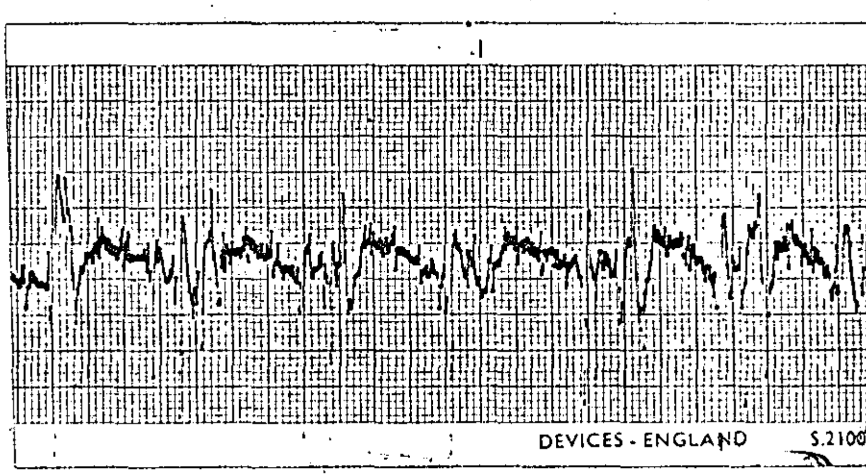
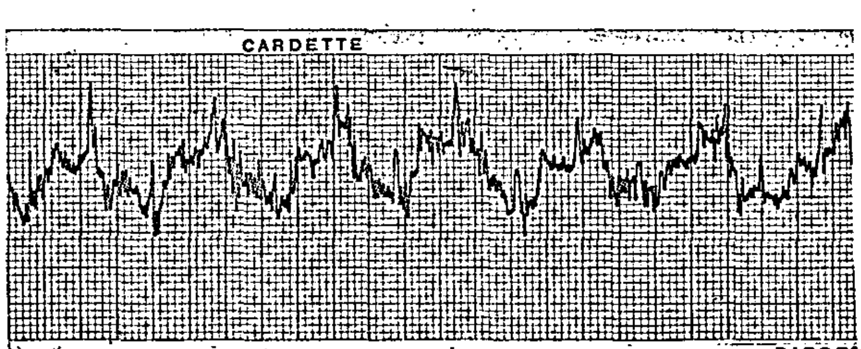
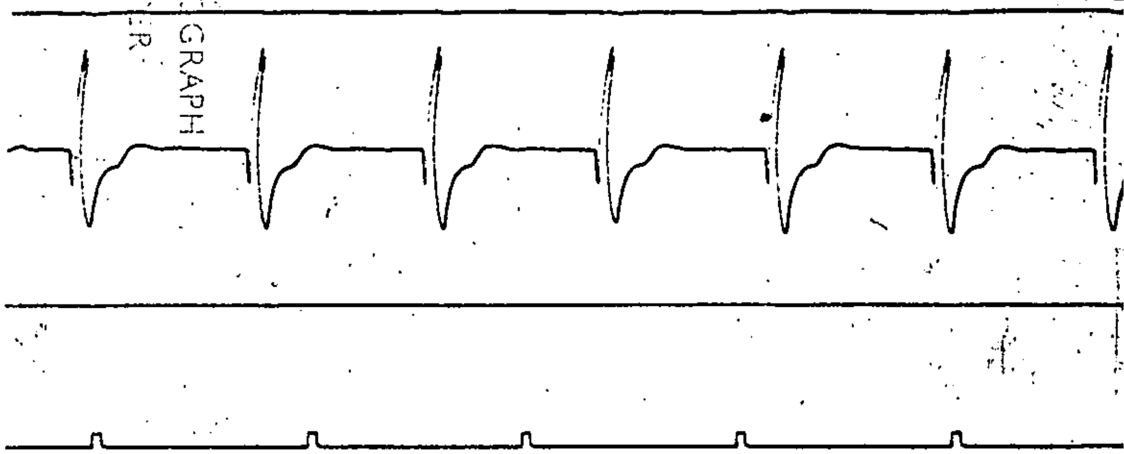


Fig. 1

Devices battery/mains portable



Cardette battery portable



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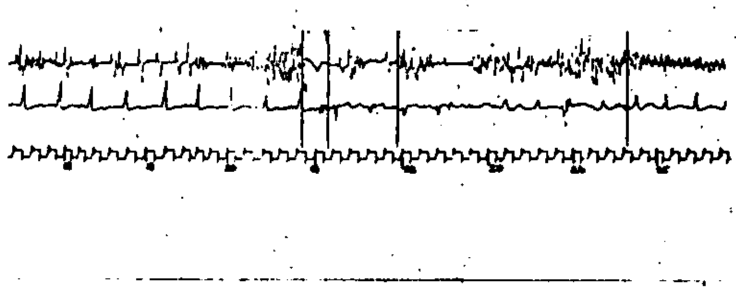
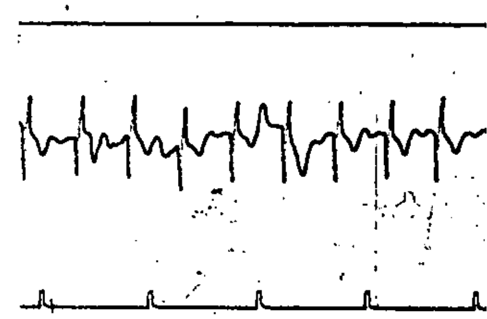




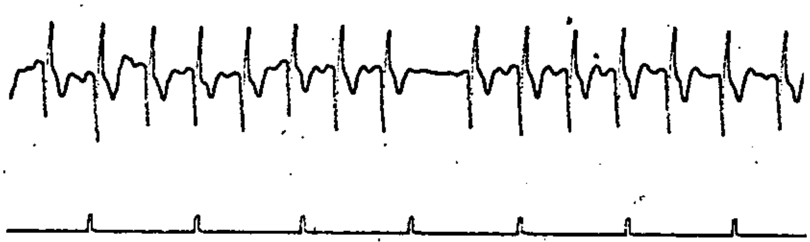
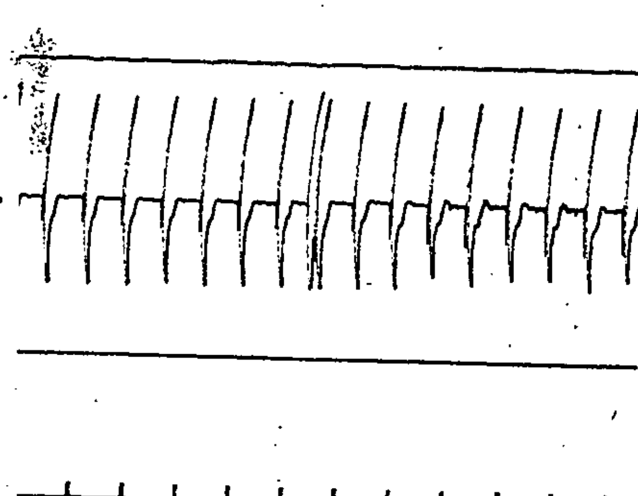
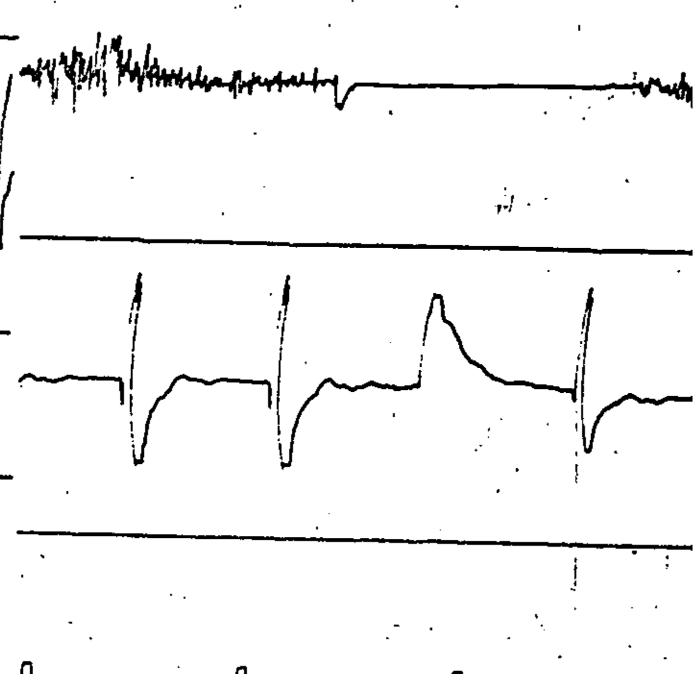


Fig. 2





A - a typical ECG

and other differences

various papers by Hyman(2). More important however to the physical educator, is heart rate - and this is generally very easy to evaluate under a wide variety of conditions. Especially valuable is the possibility of measurement of rate as accurately as it fluctuates from one beat to the next, and continuous monitoring of E.C.G. has produced some extremely interesting information during dynamic short duration power output.

Electrode Fixing

i) When the experimenter has to rely upon the voluntary and repeated goodwill of his subjects, his methods should be such as to minimise the psychological and physiological effects of his experimental techniques. When these subjects are sportsmen, many of whom have a pathological distrust of wounds (however slight) and to whom production of maximum effort is impossible when inhibited by painful, claustrophobic, or restrictive apparatus, then methods have to be simple, pain free, quick and psychologically acceptable. Such conditions preclude the use of needle electrodes, pin electrodes, strong adhesive, prolonged and/or deep skin abrasion etc.

ii) Massive muscle movements, heavy sweating and high peripheral temperature create difficult conditions, which can only be solved by very light and small electrodes (Fig.3).

iii) For long duration experiments on high cadence activities the electrode attachment to the wire needs to be very robust.

iv) For experim nts involving many subjects in a short space of time electrodes must be easy to clean.

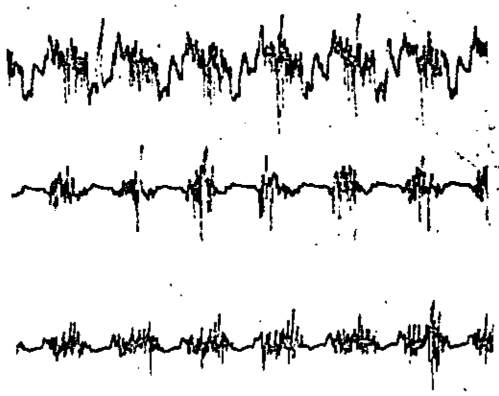
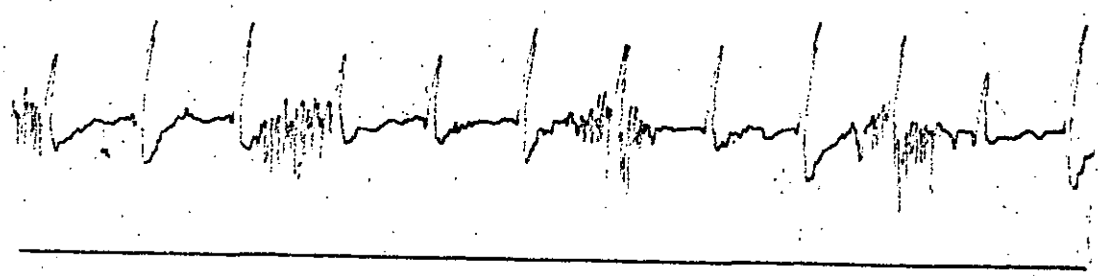


Fig. 3

3 simultaneous EMG traces showing electrode slipping in top channel.



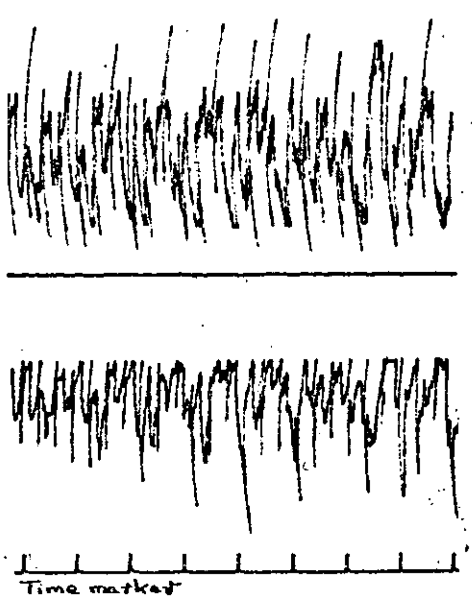


Fig. 4

Pulse counting

versus

Artefacts

Wire Placing

Hyperventilation, gross trunk movements and manual disturbance by subjects can cause large artefacts in the E.C.G. The path taken by the wire must be such as to minimise those effects. It is sometimes helpful to use such artefacts as signals of the onset and cessation of certain movements (Fig.4).

Peripheral R sistance

The strength of E.C.G. signal when using the preceding methods is relatively great, and the problems of peripheral resistance almost negligible. Merely shaving the area of skin involved, and cleaning with alcohol, is sufficient. However, the method used is so close to that developed for E.M.G. (pages 9,10,11) that the skin piercing aspect is retained even for E.C.G.

Monitoring of Signals

The circumstances controlling signal monitoring fall into three broad categories:

i) Where physical contact with the subject is either impossible or undesirable

ii) Where fairly close contact is possible, but not under 'laboratory' conditions

iii) Where subject contact is completely controllable, as in the laboratory.

i) In activities such as running, playing team or individual games of a violent and/or energetic nature, or rock climbing etc., 'wireless' transmission must be used. Many more or less efficient transmitters have been developed which give a pulse signal, reliable over relatively short ranges. The preceding methods apply, and the transmitter is usually fixed at some part of the body where it is least likely to suffer physical interference - or is placed in a vehicle near to the subject. The E.C.G. is rarely usable as a wave form, especially over longer distances, but is very reliable as a pulse counter, these pulses being seen as needle deflections, heard as short tones, or printed on a trace. Nearly instantaneous read-out of rate can be given, and recorded. The prime disadvantage of such telemetering apparatus is that, during violent activity, it becomes almost impossible to distinguish between pulse and artefact, if the amplitude and duration of the artefact is similar to that of a pulse. A great advantage of the audible signal is that minor alterations in heart rhythm are more easily detected by the ear than the eye. Such audible signals can easily be tape recorded, plus comments by the operator, for later analysis.

ii) In many activities undertaken outside the laboratory fairly close contact is possible with subjects, even though their gross movement may be considerable, provided that portable apparatus is used. Such activities under present examination are cycling, swimming and canoeing. Using the methods previously described for electrode fixing etc., portable electrocardiographic apparatus has produced some quite good E.C.G's, where some analysis of the wave is possible, and where pulse counting is very accurate even in the presence of major artefacts (Fig.4). The E.C.G. apparatus is carried by the vehicle which may be propelled by the subject, or by both. Continuous monitoring over extended periods is difficult with portable apparatus because recording paper rolls are not large enough, and collection of the paper trace may pose difficulties especially in inclement weather conditions.

iii) Under controlled laboratory conditions, provided the preceding electrode fixing method is used, the problems of obtaining E.C.G.'s during even the most violent exercise are minor. It is true that there may still be artefact due to E.M.G., electrode displacement, or skin movements - but these can be minimised or prevented completely. The exercise has to be restricted in nature - of locomotion by using stationary bicycle, treadmill or rowing machine; and of other types of work by keeping it within a close area, such as weight lifting. Though the resultant E.C.G. is the best available, the fact that it is obtained under laboratory conditions dictates extreme care in the analysis and generalised application of the results. However, from an intra-subject test - retest point of view, and even on an inter subject basis provided enough readings have been obtained to give some idea of norms, the laboratory E.C.G. is probably the most useful diagnostic weapon for the physical educator.

ii) Electromyography

The problems of monitoring gross and violent muscle activity are such that, using present available techniques, several aspects of electromyography are impracticable or misleading. Foremost amongst these are quantitative evaluation of trace, and its development to integration. Ever increasing sophistication of signal receivers, including oscilloscopes and ultra violet recorders, are making the processing of signals into something of an art. There seems to be far less concentration on the elimination of artefact at the electrode site, admittedly because there is at present very little research into violent muscle activity. The author has not succeeded in eliminating artefact from this type of E.M.G., and for that reason does not attempt any quantitative evaluation of E.M.G. traces.

In 1959 Davis made the point that the movements of the trunk grossly disturbs the record and make it nearly useless (3). However, progress in techniques has been such that the E.M.G. is now a very useful tool to the 'violent movement' kinesiologist, and the following principles have been developed so that with the equipment available at present some insight can be gained into the workings of muscle.

Regarding the general comments made on pp. 5, 6, 7 concerning electrode fixing in E.C.G., these also apply to EM.G.

Electrode Positioning

This is probably the most critical facet of this type of electromyography, the major pitfalls being:

i) skin movement relative to muscle (Fig.5)

ii) optimisation of E.M.G. signal

iii) avoidance of stray E.M.G. from other muscles (Fig.6)

iv) total movement of electrode (Fig.7)

If each of these are considered as possible sources of artefact, then it can be seen that the selection of electrode site is not only critical, but also specific to each subject and each activity. Points (i), (iii) and (iv) can only be treated on a specific individual basis, by observation of the movement of the subject and selecting a site at which the total artefact is minimised. Point (ii), the optimisation of signal, is again an individual facet, but a general rule regarding electrode spacing can be posited. The total electrical activity of the muscle being examined is usually so great as to make wide spacing of electrodes unnecessary. Using close spacing factors (i), (iii) and (iv) can be minimised and signal strength still be optimised by positioning the electrodes near the belly of the muscle, and in line with the general line of the muscle fibres.

Peripheral Resistance

Lengthy and painful preparation of the skin is not desirable for reasons which have been stated earlier (page 6). A sufficiently low peripheral resistance (7k) can be obtained by shaving the area, cleaning with alcohol, and by piercing the epidermis with a serrated needle. This small hole is then filled with electrode jelly. It is not certain that the E.M.G. recordings from a relatively small area of a muscle faithfully record the total activity of that muscle. The intermittent firing of motor end plates gives a co-ordinated activity that could be misleading if viewed from only one part of the muscle. However, the type of gross muscle activity with

Fig. 5 Skin movement

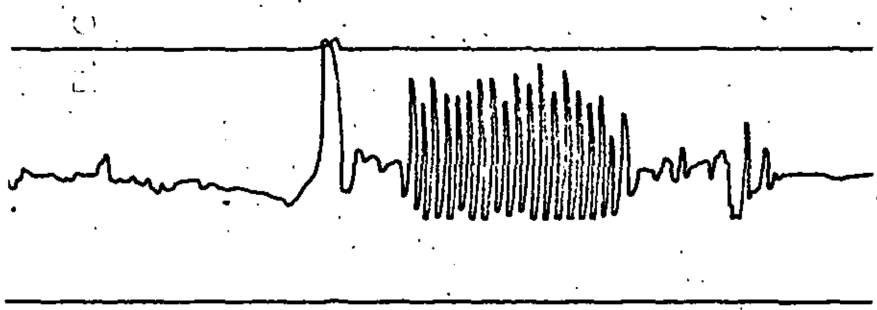


Fig. 6 Stray EMG

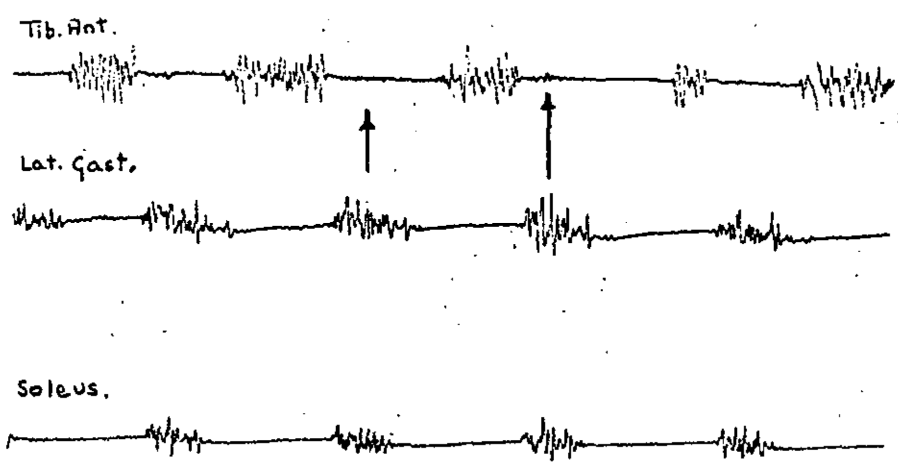
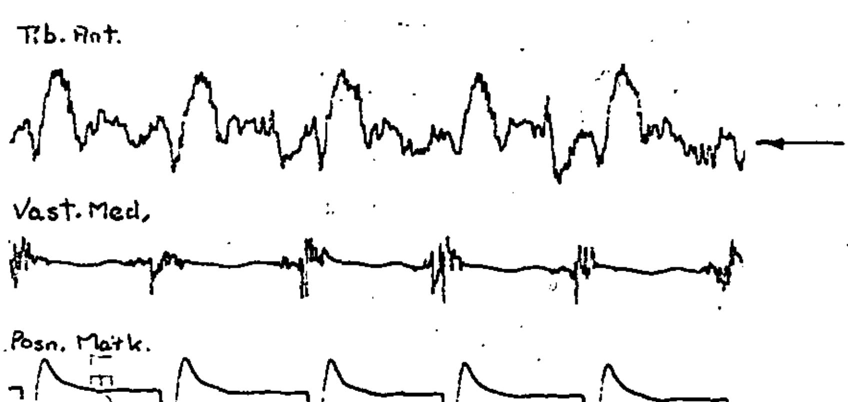


Fig. 7 Electrode movement



which these studies are concerned probably nullifies this as a significant source. Stepanov (4) has observed an 'amazingly even, regular form of action potential, reminiscent of a sinusoidal curve' and attributes this to a 'high degree of adaptation of the motor units for synchronous activity'. His electrode positioning used a 2-3 cm. spacing. If a skilled performer possesses an intra muscular motor end plate co-ordination pattern of a regular nature, then it could be expected that the amplitude of potentials recorded by one electrode pair might change in a regular pattern.

Signal Monitoring

With the present apparatus, signal monitoring has been possible only under laboratory or pseudo laboratory conditions. Apparatus can be transported to excercise sites, always indoors and near a power supply, but an AC power supply and relatively electrically disturbance free environment is advisable. In this way the author has been associated with E.M.G. of canoe rolling (Aldwinkle et al, 5) gymnastic activities (Kamon 6), and has personally performed E.M.G. of weight lifting, cycling, rowing and trampolining. Great difficulties have been experienced in overcoming artefact set up by movement in the wires connecting subject to E.M.G. (Fig.8). These difficulties have not yet been solved, but seem to vary between makes of E.M.G. apparatus, each make being different in its reaction to curative measures. The problems are magnified when the movement being examined is gross, violent, and repetitive over a long time period. However, the solution would seem to lie in either or both of two main approaches.

(i) To minimise the total displacement of the electrode wires

(ii) To use screened cables (Fig.9)

In most activities the artefact due to wire movement is no great

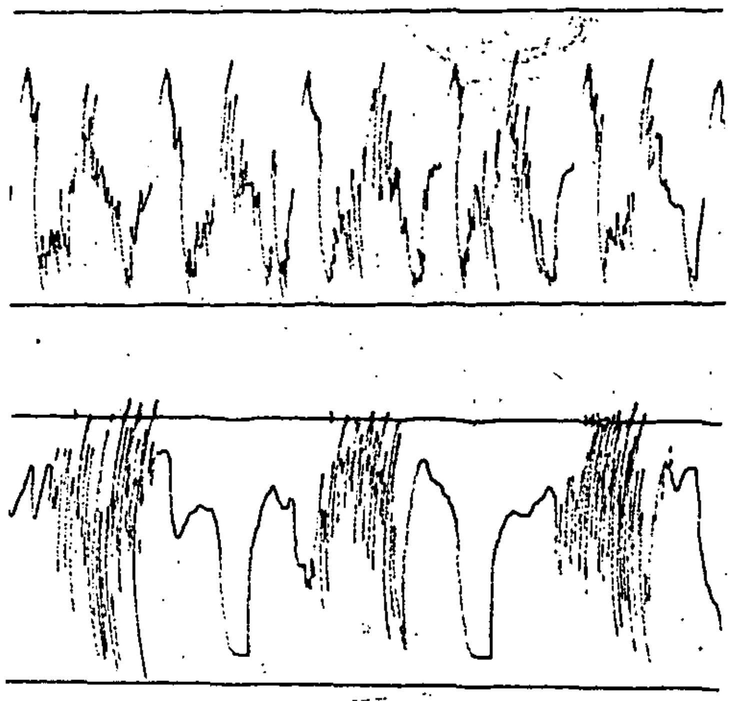


Fig. 8

EMG

wire artefact

EMG.

screened wires - gross muscle activity

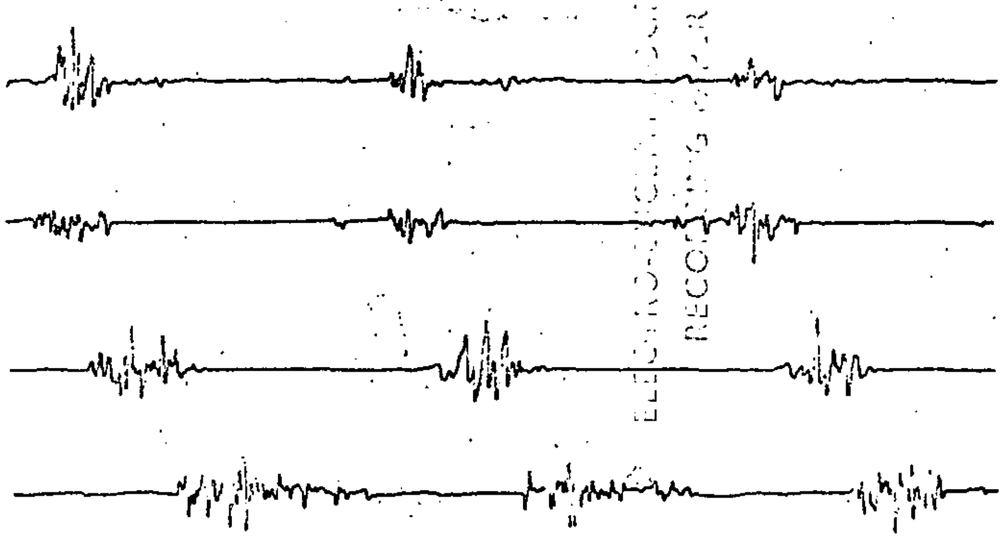


Fig. 9

hindrance to muscle co-ordination evaluation, and can sometimes be of assistance in superimposing the phasing of a movement over the E.M.G. traces (Fig.10). It does prevent one major analysis - that of reliable integration.

(iii) Respirometry

A variety of more or less reliable methods exist for measuring such parameters as ventilation, stroke and minute volumes, O_2 uptake, ventilation rate. The author has used such apparatus as Kofranyi-Michalis, Godart spirometer, Jaeger ergo spirotest, Vitalograph, Wrights flow meters, only to find that at high work rates great errors are incurred either because the apparatus has too low a capacity or because the mask or mouthpiece is inadequate. The greatest problem is certainly posed by the masking method. If the mask is sealed to the face to prevent leakage, then the restriction on jaw movement prevents subjects from opening mouths wide enough for sufficient flow rates. If very pliable masks are used, then movement within the mask creates false volumetric displacements. Problems of valve resistance impose extra loads both physical and psychological on the subject.

Respiration rate is easy to evaluate, methods used by the author including visual counting, thermistor counting, valve closure counting, pen deflections, E.C.G. wave fluctuations (Fig.11), aural counting.

Gross changes in O_2 content are more or less efficiently evaluated under almost any experimental conditions using Beckman D@S or 777 and though not of great accuracy, are probably the most dependable of the respiration measurements made by this author. The lack of time and facilities led to a deeper investigation of respirometry being postponed indefinitely.

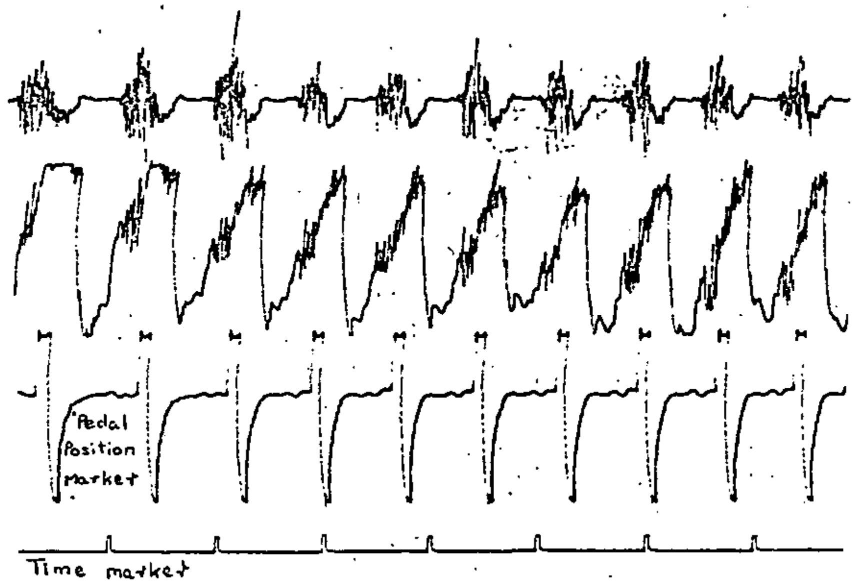
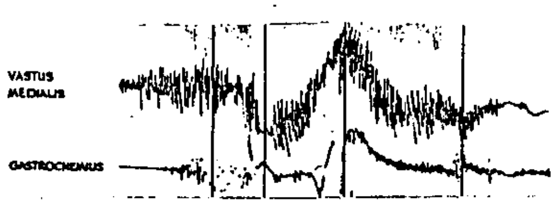


Fig. 10

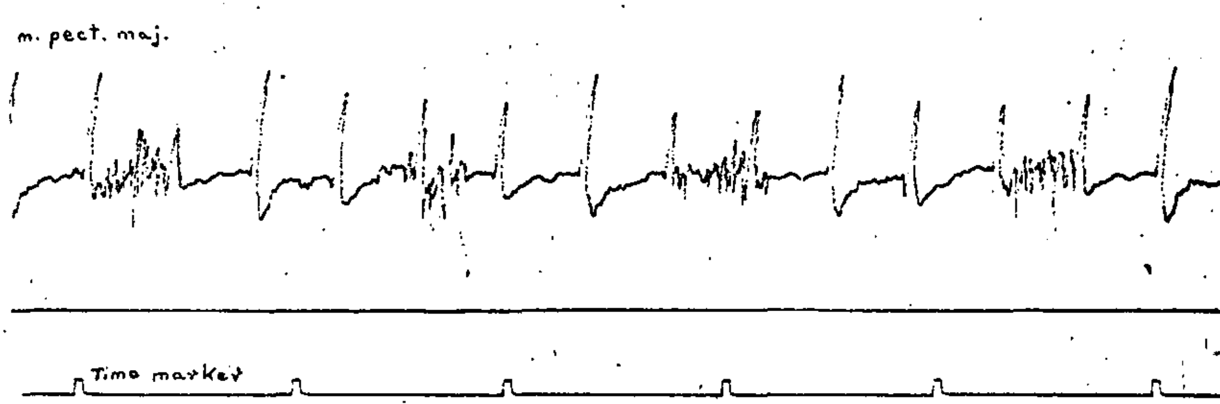
EMG. artefacts as movement phase indicators

(cycling)



(weightlifting squat)

Fig. 11



ECG, EMG and Ventilation (rowing)

(iv) Thermometry

Recent work in the Department of Ergonomics at Loughborough University has gravitated towards the use of thermometry, combined with O_2 uptake and blood lactate estimations, in assessing subject response to work. The author has used rectal thermometry on subjects riding a bicycle ergometer and collaborated with work done on surface thermometry during canoeing (Page 27). The apparatus used was a Light Laboratories thermistor which proved easy and reliable in operation. No discomfort was experienced by subjects, even during rectal thermometry.

PILOT STUDIES

In developing and practising techniques of measuring physiological parameters, the author has performed a number of pilot studies over a wide range of activities. These have been treated as such, even though the data has been of use in advising various athletes in their training and competition. Some of the data obtained is of sufficient reliability and quantity to be treated statistically, and will be used in the near future as bases for several minor papers. The athletes being advised include:

1) World Champion Weightlifter
2) National Coxless Fours Rowing Crew
3) National Sprint Cycling Champion
4) County Fast Bowl r
5) Olympic Basketball Team
6) Universities Long Distance Canoe Champion
7) Universities Race Walking Champion

Some of these pilot studies are presented, very briefly, to demonstrate variations in techniques, and depth of applicability. They are not presented as controlled experiments in an explicit and detailed format. They illustrate the author's attempts to fulfil the concept of a 'complete' Physical Educator as discussed on page 3.

1. <u>Bicycle Ergometer Test</u>

Over a period of some years at Loughborough University, Department of Ergonomics, Dr. Ernest Hamley has developed a test of cardio respiratory assessment using a bicycle ergometer as a method of applying a work load. The methodology and performance norms of this test have been established using racing cyclists as subjects, in conjunction with the British Cycling Federation. A high degree of reliability is attainable on both between subjects and within subjects bases, because of the inherent reliability of the subjects being extremely highly skilled in the activity. The test is described in the literature, (8, 9) and has also been used with other types of sportsmen as a method of cardio respiratory diagnosis and prognosis.

The author has collaborated with Dr. Hamley over the last few years, to report results of various investigations (9, 10,11) and to standardise the postural calibration of the bicycle ergometer (12). During this time the author has developed slight variations of test procedure, and also expanded the test to cover a larger range of physiological parameters and accommodate a wider variety of subjects.

The basic problems of such remedial testing of subjects fall into three categories:

(i) Application of a work load

(ii) Measurements of physiological parameters

(iii) Interpretation and application of results

Application of Work Load

One of the bugbears of work load application has been to standardise the amount of work done by the subject. The most accurate measures of the amount of work are to determine the amount of O_2 consumed, or to measure the heat production of the subject. The first method involves respirometry and the second involves calorimetry, both of which are unsuitable in that their precise evaluation demands experimental techniques which are unreliable at extremely high work rates, especially because the methods impose an extra work load which is not standard between subjects, and a psychological burden of varying effects between subjects.

If subject performance is to be measured in terms of work load, then work efficiency becomes the critical factor. Efficiency in this case is defined as effective work done as a percentage of effort (or internal work)

$$\text{i.e.} \qquad \frac{\text{Effect}}{\text{Effort}} \times 100 = \text{Efficiency \%}$$

BETWEEN SUBJECTS COMPARISONS

On a between subjects basis, then valid comparisons of physiological parameters can only be made if the subjects have similar efficiencies at the particular work task being performed. Tests of work capacity for between subjects analysis have, therefore, usually been designed around types of work in which subjects have all become optimally efficient i.e. heavily overlearned skills - usually locomotor skills. Hence step-tests, bicycle ergometers, treadmills etc., which use the common and overlearned skills of mounting steps, bicycle riding, walking and running. Hyman describes the Harvard steps, the Master Stair, the Balke Treadmill, and the Wolffe Bicycle tests (2). On the other hand, the same approach may be made to subjects having a common skill at any other work task, be it industrial or sporting. It is argued that even with this approach there are always such differences in efficiency as to make results unreliable, and such arguments have led to doubts being expressed concerning the reliability of such a widely used test as the Harvard Step test, and other tests using various ergometers (13, 14, 15, 16, 17, 18, 19, 20).

Hemley and Thomas have also made attempts to standardise the calibration of bicycle ergometers (12), such work having been prompted by similar concern to that expressed in (21), and attempted by other workers (22, 23, 24). The treadmill has also been subjected to similar analysis (25, 26, 27). Such measures may eventually optimise the conditions and work rate for subjects. They will not, however, do much to affect the differences in individual efficiencies between subjects. If the research is attempting to determine links between effort and effect, then individual subject efficiency must be evaluated - a process which is extremely difficult, and in some cases impossible. As an example, consider the cardiac reaction to a steady state work load. If the load is sufficiently high to demand anaerobic work, then it is unlikely that heart rate will achieve a steady state. If the load demands aerobic work, then the heart rate should achieve steady state - but as work progresses various fatigue elements will tend to alter subject efficiency, and thus alter heart rate. Increases in heart rate allied to increases in fatigue and/or increases in work load may be due in part to alterations in subject efficiency. That heart rate is linearly related to work load seems to have been established, up to certain levels. Brooke et al (28) have demonstrated that there is no clear pattern of heart rate reaction beyond work loads causing heart rates of about 160/min. (Fig.12). This may be due as much to alterations in

Fig. 12

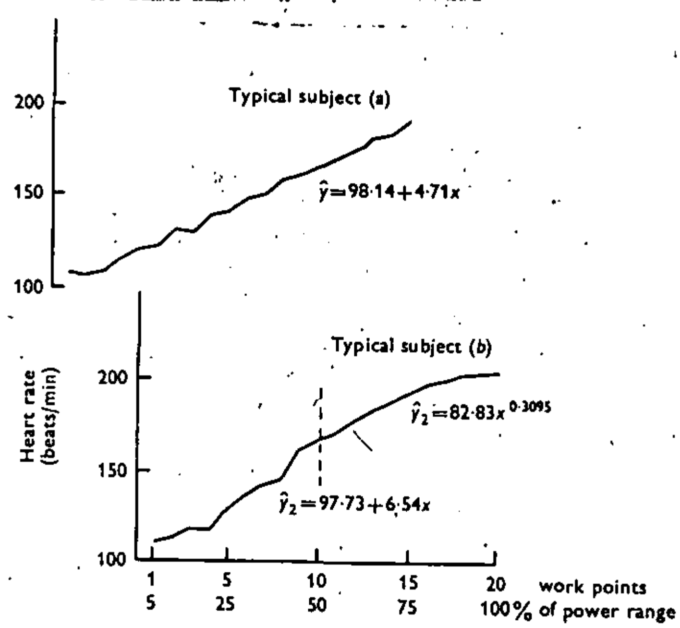


Fig. 1

Two typical heart rate reaction patterns

Brooke (28)

subject efficiency as to any other effect. Merely because work load remains constant, or varies according to some predetermined function, it is not sufficient to presume that the internal work done follows the same pattern - in fact, such an occurrence would seem to be most unlikely. In this case, tests which presume the existence of any given state of effort within the body as a function of a given external work load must be open to serious doubts concerning their validity.

On the other hand, if testing is being used as a diagnostic tool, in a specific applied situation, then subject efficiency (though variable and indeterminable) could form a part of the total evaluation. For example; if racing cyclists were to be tested on their physiological reactions to a work load, then tasting them on a bicycle ergometer could allow that their variations in efficiency on the ergometer would be reflecting similar variations in efficiency during their racing - and as such their effect upon the internal work load can be ignored, providing that linearity or any other functional relationship is not presumed. In this case, a runner needs to be tested on a treadmill, an oarsman on a rowing machine, a swimmer in a pool etc. etc. For use in tests such as these, an ergometer becomes merely a method of applying a load or resistance. Its calibration and accuracy become relatively unimportant.

WITHIN SUBJECTS COMPARISONS

In a test-retest situation, provided that the subject has not significantly altered his skill level between the tests, then it could be assumed that subject efficiency will not have changed. In this case, the internal effort/external work relationship is of much greater reliability. It was noticeable in the present test-retest of unskilled subjects, that although intervening training had affected various physiological parameters, - the subjects' efficiency at pedalling, and the total work load, had remained significantly unchanged. None of the subjects had ridden a bicycle between tests.

In this particular use of ergometry, it is very important that ergometer calibration and measurement should be precise, because the very presumption of constant efficiency proposes that all other measures are valid and reliable.

Measurement of Physiological Parameters:

Some of the factors affecting the measurement of physiological parameters have been mentioned elsewhere. Only those specific to bicycle ergometry will be covered here.

Work Load. The standard bicycle ergometer as designed by Muller, was used, having a variable cam magnetic resistance (manual or automatic), internal calibration and adjustable pedalling rate monitor. The ergometer was modified by fitting racing pedals with toeclips, extra-long saddle pillar and racing saddle, dropped racing handlebars with brake units for gripping (Fig.13).

E.C.G. A Kaiser 8 channel pen recorder, with extension plug box and electrode cables 24 inches long, 1.5 cm. silver domed electrode cups were soldered to the cables. Two of those were fixed in such a position immediately inferior to the attachment of pectoralis major and anterior to the heart as to have as little soft tissue between them and the ribs as possible. The cables were run loosely to the anterior superior iliac crest, where a third electrode was attached as an earth. The cables were then joined with tape and allowed to hang loosely to the plug box.

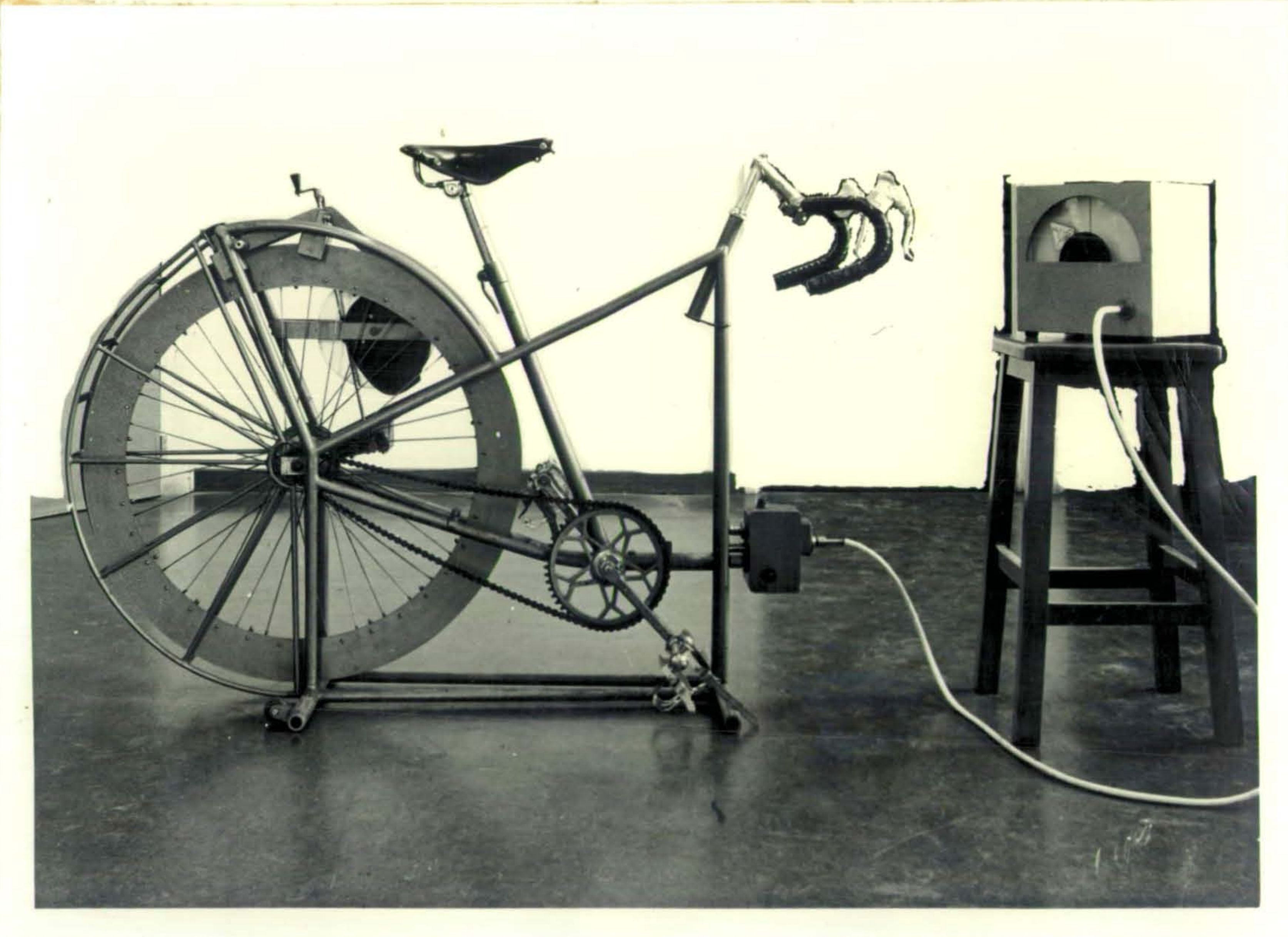


FIG. 13

Respirometry. A pneumatic face mask was fitted to a Y junction and connected to two Kofranyi-Michaelis gas meters. Samples from these were analysed on a Beckman D2S O_2 analyser. Pure oxygen was administered by filling 250 litre Douglas bags with O_2 and connecting them to the inlet ports of the Y junction (Fig.14).

Blood lactates were estimated from droplets taken from the fingers, using the method described by Strøm (29). This feature of the work was undertaken by Dr. Rabindra Nath Sen, Department of Ergonomics, Loughborough University.

Thermometry. A Light Laboratories thermistor was used with a pliable thermometer inserted 15 cm. into the rectum (Fig.15).

Procedure

The subject changed into shorts, vest, socks and shoes, and was measured for saddle height adjustment according to the method of Hamley and Thomas (12). He then lay down on a couch for 30 minutes, during which time E.C.G. electrodes were fixed. The lowest pulse rate, taken over 21 pulses, achieved during the last five minutes of this rest was taken as his Lying Resting Rate.

The subject then mounted the bicycle ergometer and was fitted with the face mask. He then rested in the seated position for 5 minutes, during which time his Sitting Resting pulse rate was obtained.

He then pedalled the machine at 90 r.p.m. and 200 watts for five minutes, this acting as a preparatory period. The work load was then raised to 250 watts, which the subject maintained for six minutes. The load was again raised, to 400 watts, which was maintained for a further six minutes. The subject then rested for five minutes, remaining on the

FIG. 14


Manufactured by
LIGHT
LABORATORIES
BRIGHTON · SUSSEX · ENGLAND
DEGREES C
LIGHT LABORATORIES
BRIGHTON ENGLAND
1
2
3
4
5
6

FIG. 15

ergometer, and the face mask was removed. The ergometer loading was reduced to 200 watts, and the subject began pedalling, with the automatic cam engaged to continually raise the work load at a rate of 30 w. per minute. This continued, with vocal motivation from the operator, until the subject was unable to continue to maintain the work rate. The subject then rested, supported on the machine by assistants, for five minutes. The mask was refitted and connected to an O_2 supply, and the cam disengaged. The subject then pedalled against the resistance atwhich he had finished his previous bout (between 405 and 475 watts) again to exhaustion (Fig.16). The mask was removed and the subject rested for five minutes. During the experiment the following physiological measurements were made:-

i) Continuous E.C.G. (Fig.17)

ii) Continuous thermometry

iii) Respiration rate }
iv) O_2 uptake } at each level of work
v) Blood lactic acid level }

The tests were repeated after eight weeks of very strenuous training, following a schedule devised by this author. This data was then tabulated (Fig.18).

Interpretation and Application of Results

The condition of the heart is widely accepted as the most reliable index of general fitness, and cardiac reation to excercise has been chosen for many years in attempts to evaluate this fitness level by such diverse organisations as Armed Forces, the International Olympic Committee, many insurance companies and industrial concerns. Due to difficulties of continuous monitoring of cardiac response, norms have been mostly

FIG. 16

Fig. 17

ECG during bicycle ergometer test

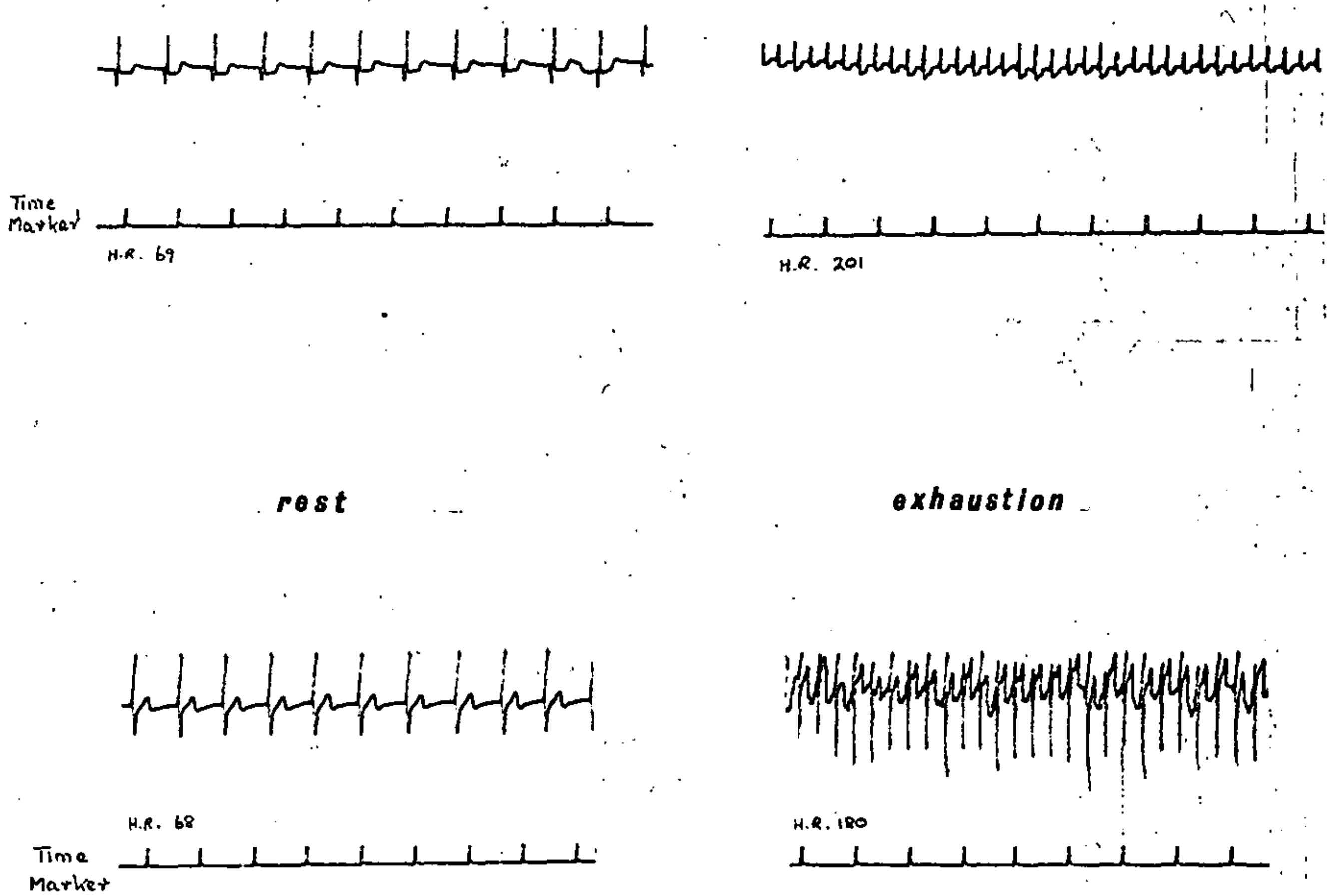


FIG. 18

SUBJECT	Lying Rest	Bike Rest	Warm Up	1st Steady State	2nd S.S.	Cam Run	Cam K.G.M.	Plat Time	Plat %	O_2 Run	Plat Time	Plat %	C.A.F.
Atypical test B.C.	58	83 68	115 140	123 154	145 176	194 182	% 43	1.45 2.30	75 75	184 174	1.30 2.45	80 75	3.3
M.S.	52	77 63	170 161	180 163	200 187	200 188	41 43	2.30 2.15	75 70	190 181	2.00 2.15	75 69	3.8
P.P.	63	83 72	165 150	184 164	194 182	196 182	43 40.4	1.30 1.45	87 78	185 184	1.30 2.00	82 76	3.1
K.S.	50	72 62	142 140	163 150	188 170	198 179	45 44	1.45 1.45	64 60	190 178	1.45 1.45	68 62	4.0
C.N.	52	63 58	132 118	153 137	179 162	180 172	45 47.5	1.0 2.15	82 71	172 169	1.00 1.30	82 78	3.5
J.S.	58	75 61	152 128	172 148	197 175	205 181	42.5 43.5	1.30 2.00	79 78	201 179	1.30 2.30	86 81	3.5
D.J.	56	88 78	158 156	177 171	200 191	208 194	47 45	2.45 2.00	69 74	204 190	1.45 2.00	75 72	3.7
R.S. Missed Retest		83	162	180	204	205	42.5	2.45	64	191	2115	68	
C.M. Missed Test	62	62	132	153	193	193	43.5	1.30	85	191	1.30	81	3.1
$\bar{x}$ Test		78.0	149.5	166.5	188.4	198.3	43.7	2.00	74%	189.9	1.40	77%	
Retest	56.4	65.5	146	155	179.5	184	43.8	2.00	74%	181.5	2.00	74%	3.5

FIG 18 cont'd....

SUBJECT	Temp.° Rise	O_2 Uptake	SSI	SSII Lactic	FINAL Acid	Resp. Rate
B.C. Atypical test	1.85 1.30	14.6 16.1	7.3 159	73.9 142	31.6 114	24 90
M.S.	1.35 1.40	16.3 16.1	115	101.9 111	59.0 115	50 82
P.P.	0.80 1.45	15.6 15.9	33.5 112	47.5 95	43.3 118	64 ?
K.S.	0.95 1.35	16.2 16.0	91	38.6 100	34.9 161	80 72
C.N.	1.60 1.60	15.0 15.5	14.7	47.2 150	43.4 150	92 92
J.S.	1.78 1.25	15.0 14.6	163	93.5 116	63.6 117	86 84
D.J.	1.60 1.45	14.3 14.6		35.3	47.8 127	? 184
R.S. Missed Retest	1.50	16.2		54.5	43.2	90
C.M. Missed Test	1.50	15.5	122	128	142	64
$\bar{x}$ Test						
Retest						

established concerning cardiac recovery characteristics - which are nevertheless somewhat unreliable due to the problems of work load standardisation mentioned earlier. One fault of these methods is that cardiac recovery characteristics may not accurately reflect cardiac performance during strenuous work. It is conceivable that cardiac fitness could be similar to skeletal muscle fitness in being specific to the activity. Training methods which aim at developing the ability of the heart to recover quickly from strenuous exercise and be ready for more strenuous work (such as Interval Training), may achieve very different results to training which aims at developing the heart's ability to withstand continuous and protracted high working rates (such as Circuit Training) or Pure Endurance Training (30). The cardiac function characteristics of the six-day cycle racer may be very different to those of a 1500 metre swimmer. It seems probable that certain types of activity create a degree of coronary anoxia (31), and demand a specific type of cardiac muscle training.

In the assessment of cardiac fitness, the author has used three main cardiac characteristics:-

i) Time taken for heart rate to drop from maximum to a recovery plateau

ii) Recovery plateau level, as a % of maximum heart rate

iii) Increase in heart rate due to exercise

The first two are recovery characteristics, and as such are used primarily in the assessment of repetitive high activity subjects. Insufficient data has been collected at this time to establish reliable norms such as percentiles and standard deviations, but what data is available suggests that sportsmen of international standard will take between 45 and 120 seconds to recover to a plateau at 60% of maximum heart rate, the average being about 90 sec nds.

The third characteristic is one of cardiac performance during exercise, and as such seems more relevant to this author. In an effort to overcome the unreliability of set work loads, a Cardiac Assessment Factor has been devised which takes the two extremes of cardiac performance and compares them. If the lying r sting pulse rate is taken as being nicely adjusted to a certain level of work, i.e. maintenance of minimum function, then the total availability of blood for work to be done can be represented as a multiple of that level. This total availability will be required at maximum function, therefore

$$\text{Cardiac Assessment Factor (CAF)} = \frac{\text{Maximum Pulse}}{\text{Resting Pulse}}$$

The author is aware that this relationship is not linear, in that cardiac stroke volume varies thr ughout the range of heart rates, and that extreme care must be taken in the measurement of resting heart rate which is easily affected by many variables. Even so, at its early stages of development the CAF seems to be a valuable aid to diagnosis. Some interesting CAF's are shown:

Name	Level of Ability	Resting H/R	Maximum H/R	C.A.F.
Vaughan Thomas (1)	National Champion (Triple International)	35	215	6.1
Jim Ryan (2)	World mile record holder	32	185	5.7
Tom Simpson (3)	World Cycling Champion	47	200	4.25
Geoff Cooke (4)	National Cycling Champion	62	205	3.3
Louis Martin (5)	World Weight Lifting Champion	64	192	3.0
Average Person (6)	----------	72	180	2.5

With these few examples, it is interesting to note the different CAF's between endurance athletes (1 and 2), endurance cyclist (3) sprint cyclist (4) and strength lifter (5). The eight international oarsmen who were the subjects of this present test demonstrated CAF's between 3.3 and 4.0

A great deal of work is required to establish the method, validity and reliability of such cardiac assessment. The author hopes to have the opportunity of undertaking this task in the near future.

<u>O_2 Uptake</u> In collaboration with Dr. Ernest Hamley, the author has over some years established norms of O_2 uptake for high performance sportsmen during testing in those laboratories. Some results have been given (9), and these form a basis for assessment of O_2 Dissociation efficiency. The diagnosis is mainly subjective, but is especially significant on an intra-subject test-retest basis. Values obtained seem to be inversely related to respiration rate, though there is as yet insufficient data on respiration for any accurate relationship to be estimated.

<u>Thermometry</u> Only one group of eight subjects has been subjected to thermometry, but an assumption that the most efficient performers are those whose thermo-regulatory systems maintain the lowest temperature [illegible], makes a comparison between and within subjects possible. Those who were relatively efficient undertook much of their training whilst warmly clad, or in warm environments. The results can be seen in the data table.

2. E.C.G. During Swimming

There appear to have been few E.C.G. studies of competitive swimmers, and these have been of a pre- or post-exercise type (32). The author's association with Aldwinkle et al (5) during electro-myography of canoe rolling led to the idea that E.M.G. and E.C.G. could become valuable tools for the researcher into aquatic activities. Aldwinkle's E.M.G. was done on a paddler performing one manoeuvre in a confined area. It could therefore use mains electrical supply. Most aquatic activities are performed during locomotion, which means that unless the activities are performed in a specially constructed training tank with controllable water flow rates (a water ergometer :), then apparatus needs to be portable. The following experiment was performed merely to establish the feasibility of swimming E.C.G.

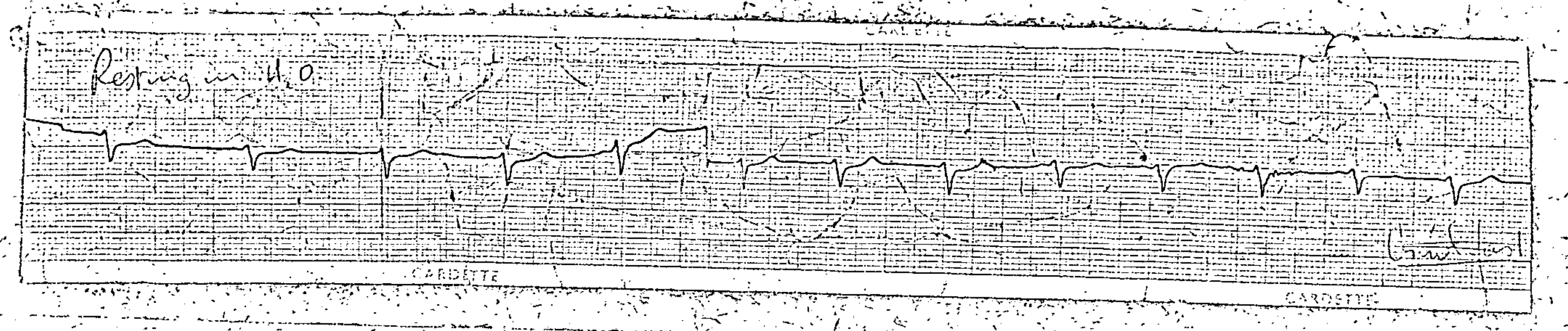
Equipment. Cardette portable battery single channel E.C.G. 20 ft. of screened triple cable, 1.5 cm. silver domed electrodes, adhesive discs, electrode jelly, serrated syringe, waterproof Elastoplast, Copidex waterproof adhesive.

Method. The surface electrodes were attached by the method described earlier. Two were positioned 2.5 cm. apart vertically on the lower aspect of manubrium sternum. The earth electrode was positioned on the spinous process of the 1st Thoracic vertebra. The sites were covered first with waterproof plaster, then with a liberal coating of Copidex. The cables were run up the sternum and over the shoulder, to leave the body near the earth electrode, running up to and along a pole held above the subject, thence to the portable E.C.G. As the subject swam through the water the operator walked alongside the bathside.

The subject gave lying resting and water immersed resting traces. Then the subject swam at various speeds and using various strokes, until finally swimming violently to exhaustion, standing immediately and resting at the bathside. The resultant E.C.G.'s are presented in Fig.19. They demonstrate the feasibility of the method, and the possibility of accurate pulse counting. The gross artefacts which occurred at higher work rates are similar to those which have been obviated during other activities by using subpectoral electrode placings.

Amongst the many interesting points in these traces the most important is probably the illustration of how quickly pulse rate can drop during the first few seconds after maximal effort.

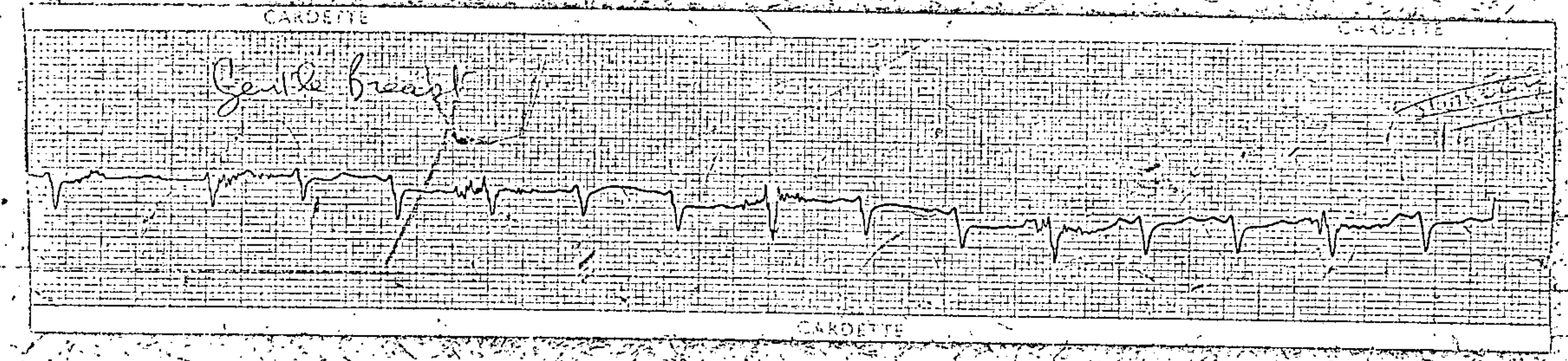
Fig. 19



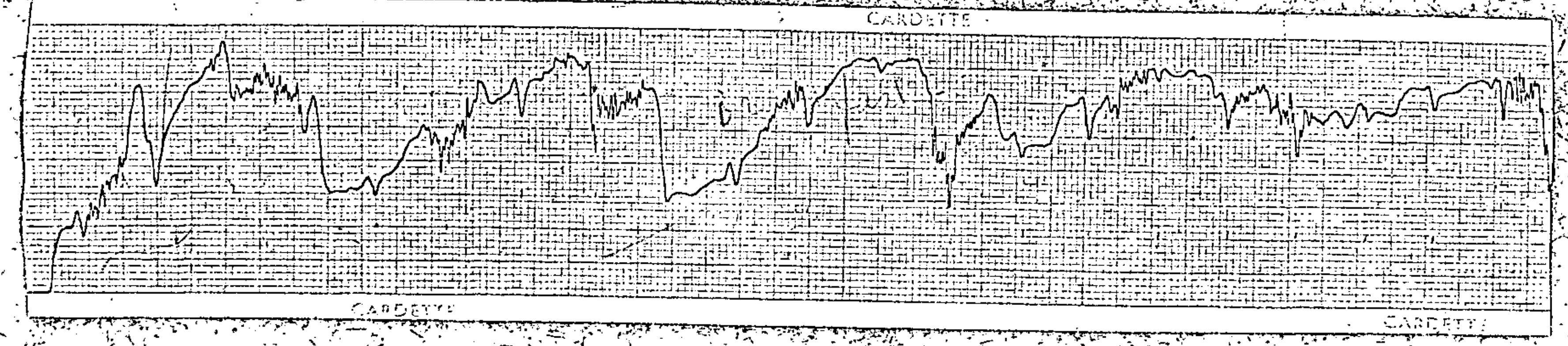
V. THOMAS. 30.5.61

RESTING PULSE, SITTING 1 HOUR BEFORE EXERCISE 44/min.

RESTING, SUBMERGED IN WATER — PULSE 71 — LEISURELY BREASTSTROKE — PULSE 86



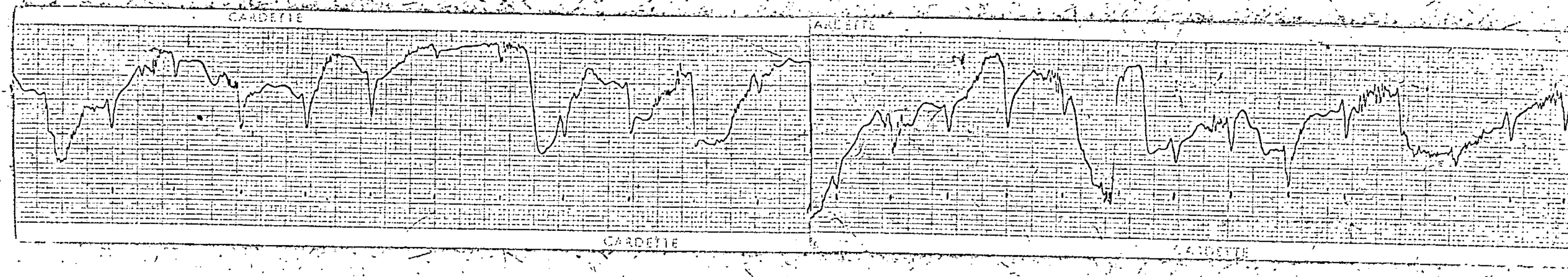
CRUISING BREASTSTROKE — PULSE 115



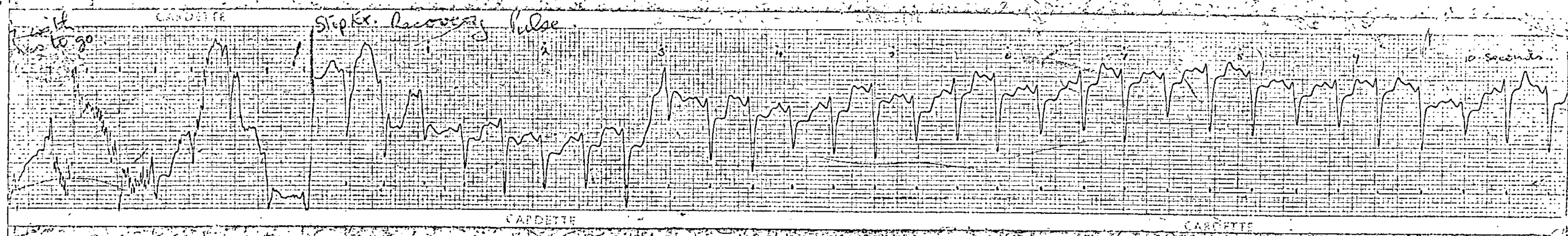
FAST BREASTSTROKE — PULSE 150 (after ½ length)

METHOD. mini Electrodes, attached ca. 1½" apart on manubrium & sternum, after rubbing down with alcohol. Syringe to pierce skin & inject jelly. Light wires running up sternum, secured away from pectorals with adhesive plaster, to screened cervical secured at back of shoulders. Cable held fairly perpendicular from swimmer by a rod held by assistant, leading to Cardette held on shoulder strap by investigator. Waterproof circular adhesive plasters over electrodes, edges protected (needlessly?) with copper. Paper speed, 1" per second.

FAST BREASTSTROKE — PULSE 150 (after ½ length)



CRUISING CRAWLSTROKE — PULSE 115 — FASTER CRAWLSTROKE (½ length) — PULSE 135



PULSE 200. STAND UP. 168 TOUCH. | PULSE: 177 173 167 167 167 165 163.5 163.5 163.5 162

FLAT OUT CRAWL (2 lengths) ↑ RECOVERY (STANDING)

3. Rowing Experiments

The problems of applying a work load have been previously mentioned. For skilled oarsmen it is probable that the greatest work load of which they are capable will be during the actual rowing action, with its very great involvement of most of the musculature.

Two experiments were performed.

Stationary Rowing:-

Apparatus: A rowing machine with sliding seat and adjustable hydraulic resistance. A Kaiser E.M.G. and accoutrements as described earlier. Metronome.

Method: The E.M.G. method described earlier was used. The subject rowed in time with the metronome at a variety of rates and against a variety of resistances. It was found that the rowing machine was incapable of providing sufficient resistance to induce very high heart rates.

Conclusions: With sufficient care in electrode placing a relatively artefact free E.M.G. is possible during stationary rowing (Fig.20). There is at present no suitable rowing machine for applying heavy work loads to skilled oarsmen, though Midlands Nautilus Rowing Club hope to have a prototype rowing ergometer ready in the near future. It is probable that sufficiently heavy work rates could be induced by using a rowing tank rather than a rowing machine. The author hopes to verify this hypothesis quite soon.

Normal Rowing:-

Apparatus: An N.E.C. 'Spurt' portable pulse telemeter. Tape recorder. Launch, and an eightman rowing boat.

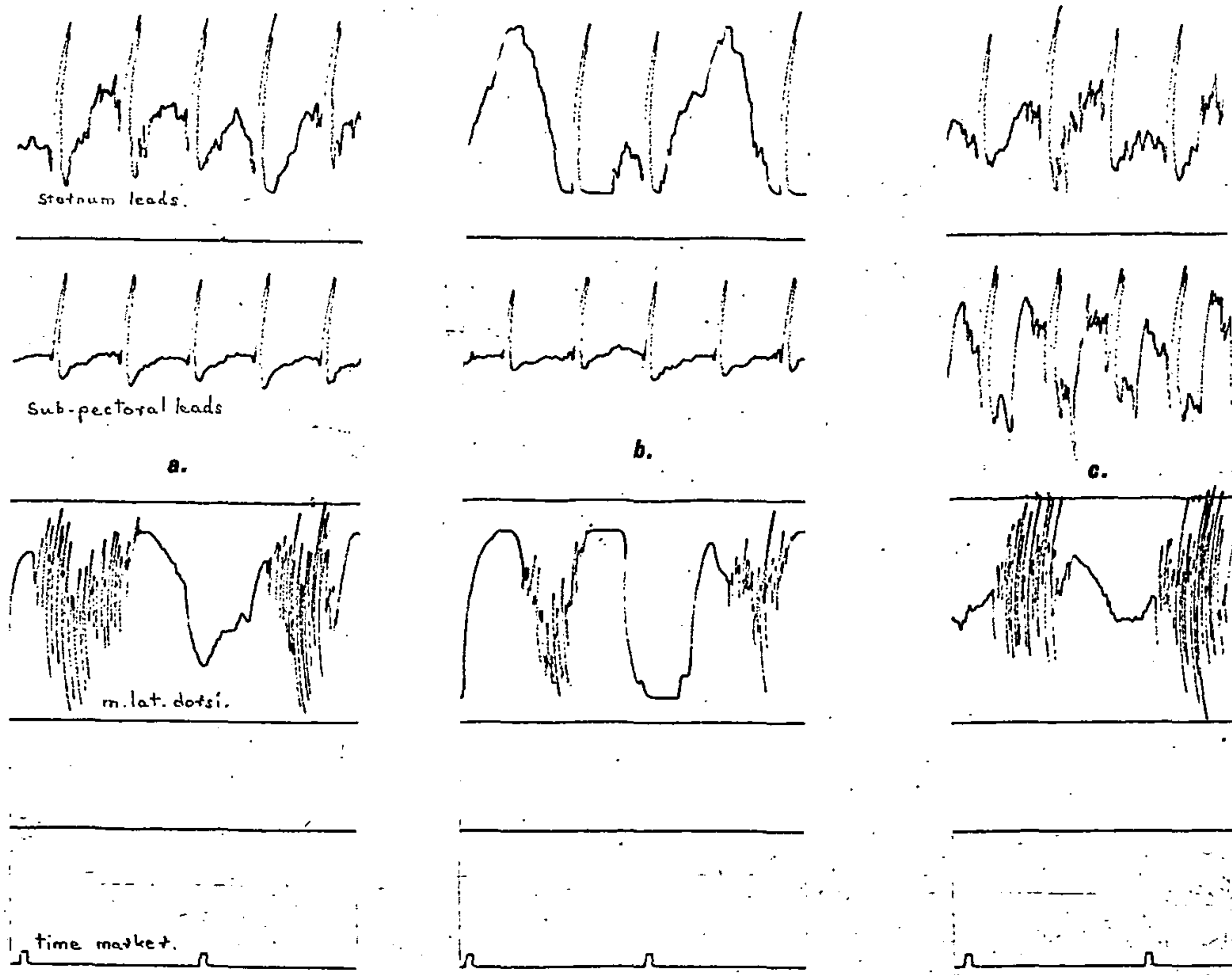


Fig. 20

ECG & EMG of rowing

showing

artefact changes at

a. Start

b. 11 mins.

c. 19 mins.

Method: Subject was cleaned and prepared according to the method described earlier. Two 3 cm. silver electrodes were taped into the sub pectoral position, with an earth electrode on the 5th Thoracic vertebra. The cables were run loosely to the waist, where a radio transmitter was strapped at the rear, well away from the moving arms of both the subject and the next man in the boat. The pulse was telemetered from a following launch which never exceeded thirty yards distance from the subject. The audible pulse was tape recorded, with suitable marker signals and operator comments, for later analysis.

Conclusions: This particular experiment was made in an attempt to correlate pulse rates during rowing with pulse rates on the same subject during the Bicycle ergometer test mentioned earlier. The crew including the subject rowed for twenty minutes of warming up, and then did two 2000 metre time trials at full speed. In neither of these did the subject's pulse rate get within ten beats of his bicycle ergometer test pulse - though his recovery characteristics were very similar. It is possible that in locomotor activities demanding great skill and/or maintenance of balance (e.g. rowing, canoeing and cycling), subjects will be limited by these factors from reaching acute exhaustion. Pulse transmission and telemetering is an efficient technique in these circumstances.

Canoeing Experiment

As a part of the preparation of competitive paddlers for a long distance canoe race, a team of investigators from the University and the College of Education at Loughborough have been conducting controlled experiments into canoe paddling. The primary aims have been to establish the energy costs and some physiological reactions to long distance paddling. This information was used as a basis for advice on diet, clothing and training methods to the competitors. The author was completely responsible for obtaining E.M.G. and collaborated with Dr. Rabindra Nath Sen in surface and core thermometry, and respiration analysis. Blood lactic acid analysis was also made. Due to the fact that the activity was long distance canoeing, it was necessary to take continuous readings over a period of an hour. The most efficient method of doing this demanded that most apparatus and readings be in the canoe, which is at best a very unstable vehicle. Another difficulty was that, on the days experiments were performed, the air temperature fluctuated around 0^{o} Centigrade. A strong breeze ensured that spray from the paddles constantly showered the operator. It says much for the experimental techniques that reliable data was obtained in almost all cases. It is extremely important that both subject and operator be well skilled in handling a double canoe - even though most apparatus was waterproofed, the consequences of a capsize could still be very serious.

Apparatus: Two man open canoe with bouyancy chambers, Kofranyi-Michelis gas meter, four football bladders, battery operated respiration counter, thermometer, barometer, wet and dry bulb thermometer, whirling hygrometer, Beckman 777 gas analyser, (lancets pipettes collecting tubes etc.), Light Laboratories thermistor thermometer, 6!

pulse stopwathh, databoard, Cardette portable E.C.G. lightweight screened cables, waterproof tape, 1.5 cm. silver domed electrodes, electrode jelly, serrated syringe, frame tent, Spurt telemeter.

Method: Tent was erected at river side, and all apparatus not needed during subject preparation installed. Subject was prepared at laboratory five miles from river. Rested reclining for approximately one hour while E.C.G. and telemetering electrodes fixed by method described earlier. Then surface thermistors were fixed on forehead, posterior aspect of wrists, sternum, abdomen and dorsal aspect of feet using waterproof adhesive. Rectal thermometer was inserted as described earlier. Readings were taken of all meters, and of ambient laboratory conditions.

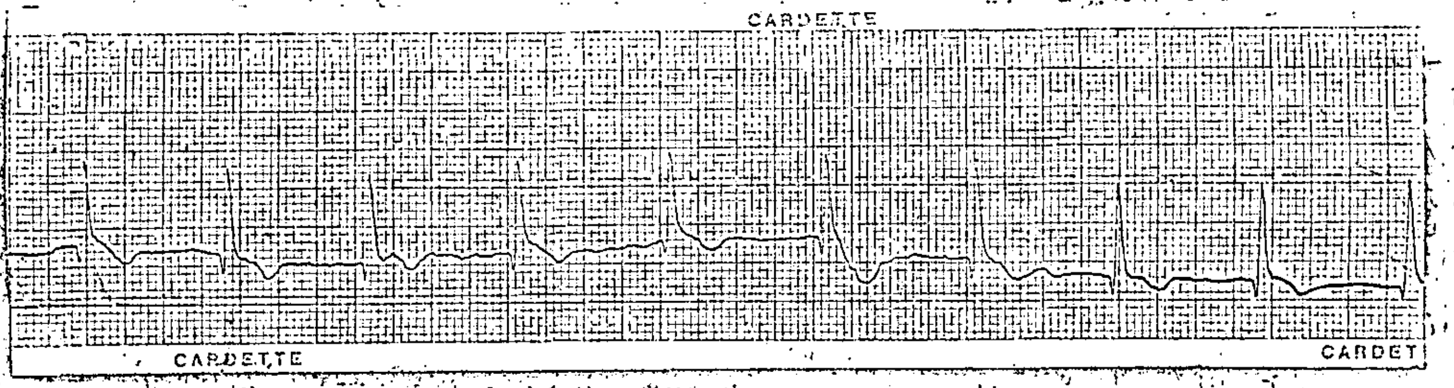
Subject and apparatus were transported to riverside, where subject preparation and local ambient readings were completed. Subject rested seated for approximately 30 minutes. Mask and all other apparatus was connected; and subject, operator and apparatus installed in the canoe. Pre-exercise readings were made. Apparatus in the canoe was: 6 volt battery, respiration counter, Kofranyi Michaelis mask and elephant tubes, thermometer, cardettes, Spurt transmitter, stopwatches, collection bladders, data board. All canoe borne apparatus was protected with polythene sheets, either loosely against spray, or tightly against immersion.

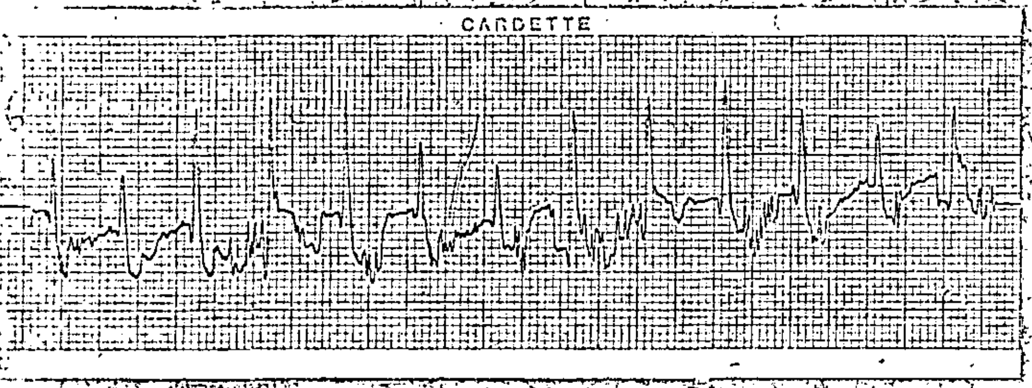
Subject and operator wore canvas shoes with socks, woollen track suit trousers, swimming trunks, thick short anorak (nylon for subject), and leather gloves for the subject.

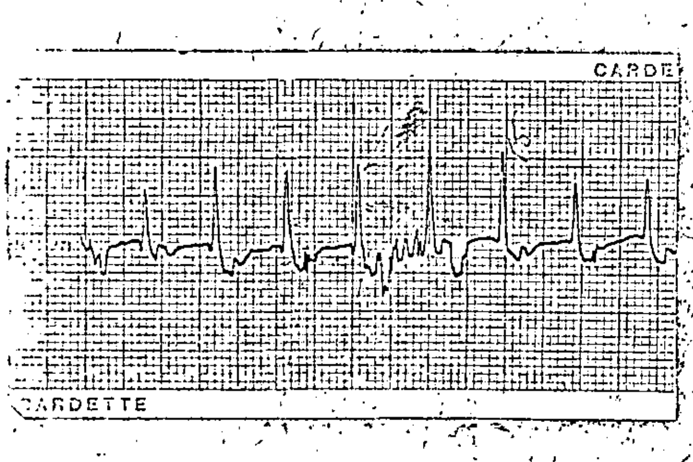
The subject then paddled for one hour at a work rate comparable to his normal long distance rate. Other than two reversals of direction the paddling was regular and continuous. Readings were taken every five minutes of respiration rate and volume, gas temperature, heart rate (using stopwatch and pen deflections), E.C.G. wave. Gas samples were collected at four equal intervals, and thrown to the riverside at convenient times. After one hour the subject stopped and immediate post exercise readings were taken of all parameters. The subject and operator left the canoe, and recovery E.C.G. was taken over 15 minutes. (Fig. 21).

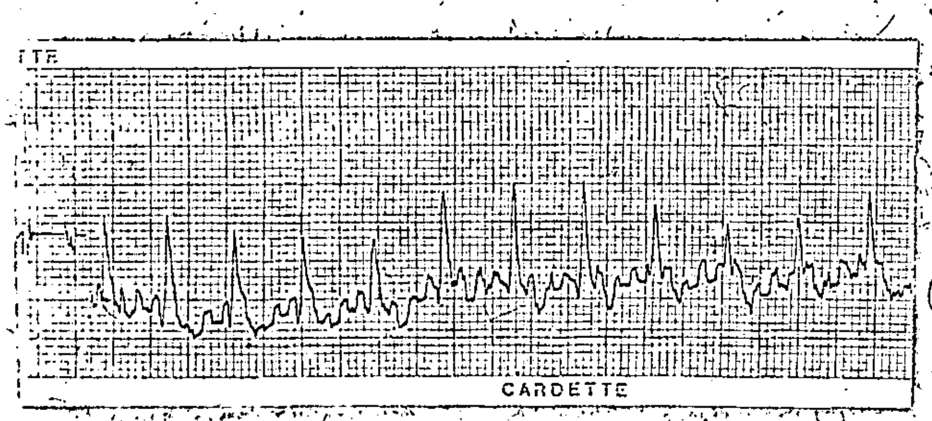
Data: Insufficient subjects were treated to provide enough data for statistical analysis. A total of six experiments were made, only two of which achieved the preceding detail. A typical data sheet is shown (Fig.22) with some of the analysis.

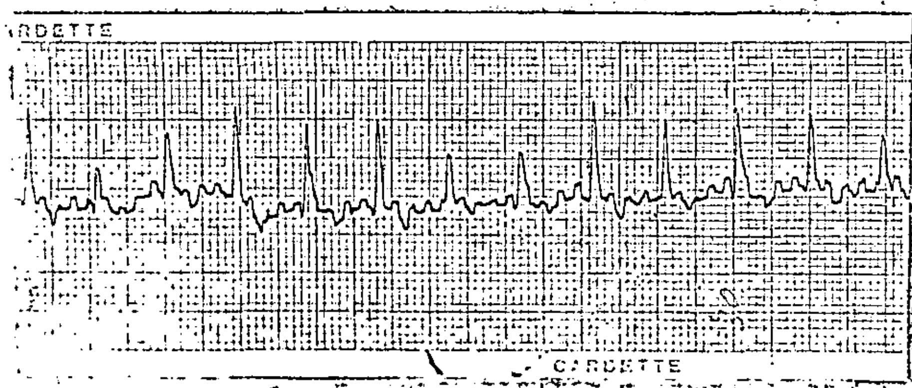
Conclusions: Certain parts of the experiment could be improved by having a following launch e.g. gas collection, pulse telemetry. Within the limits of apparatus and conditions, the methods proved very successful in obtaining useful data. However, the work rate was at such a level as could be maintained for at least 20 hours. It is doubtful if the methods would be as successful if the work rate approached maximal levels.

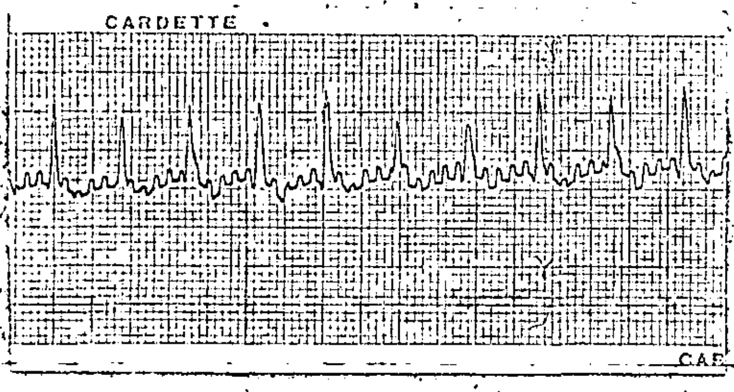


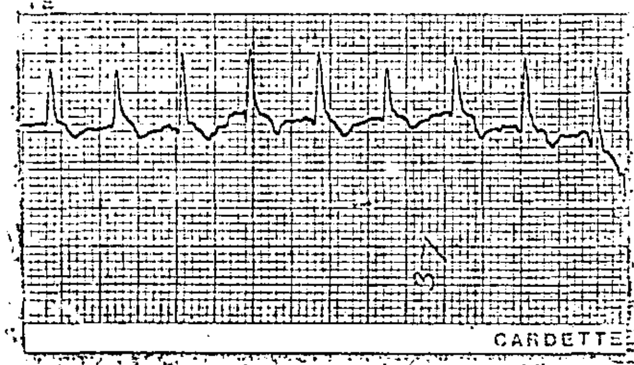


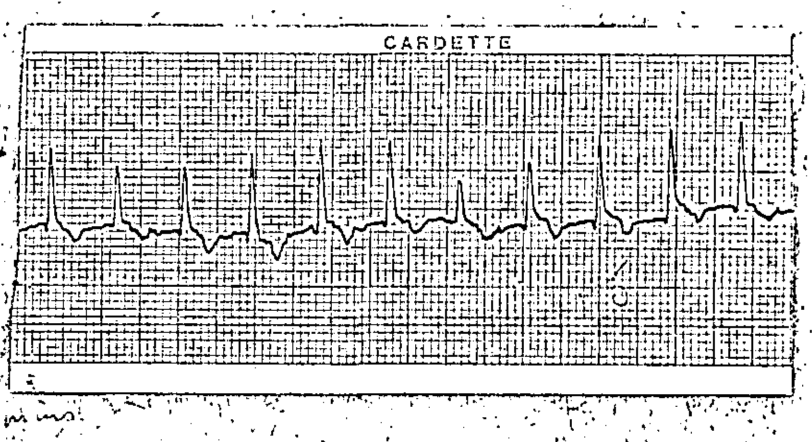


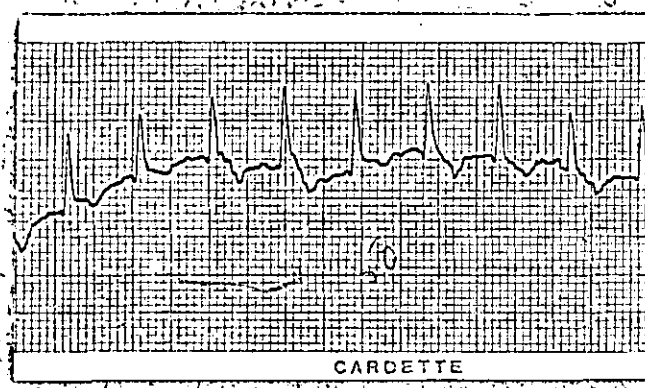


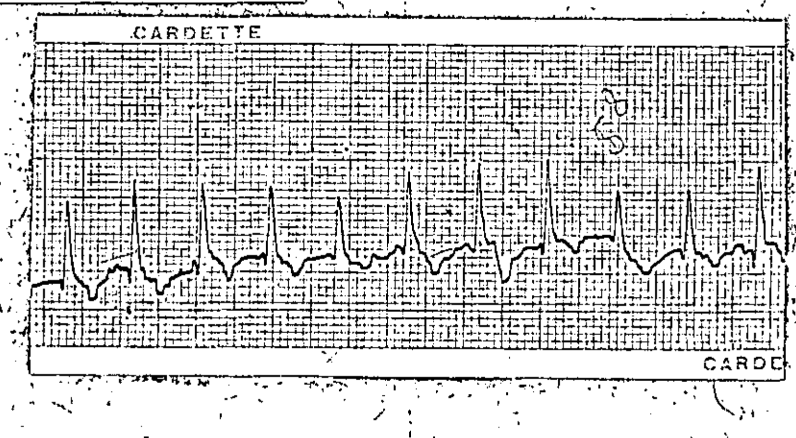


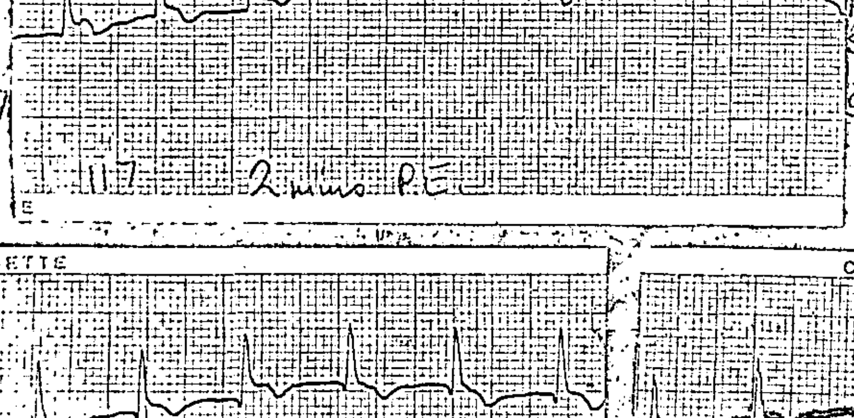


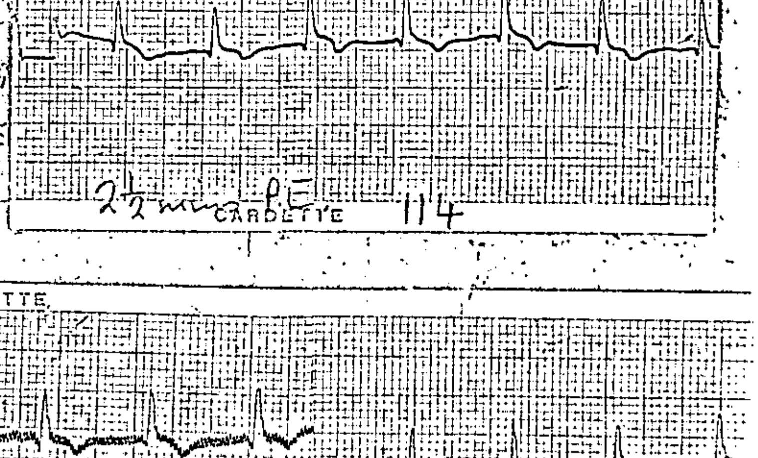


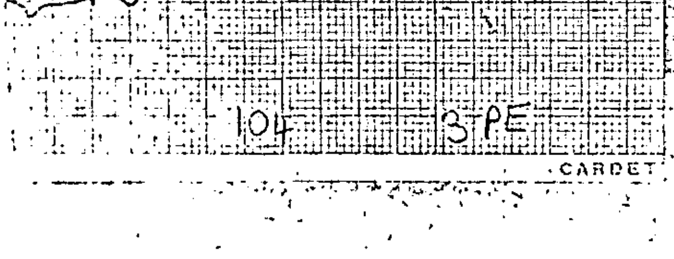


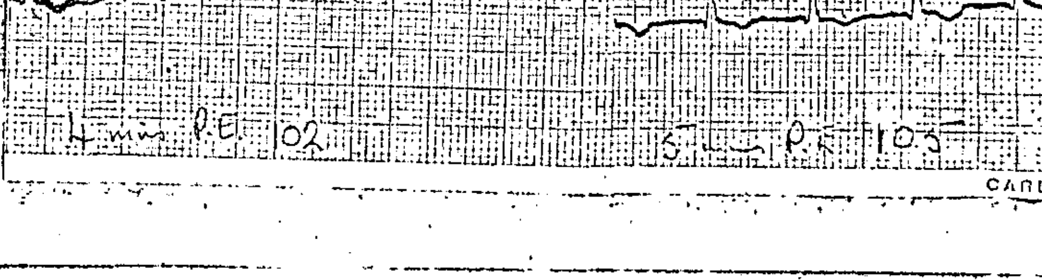












Method.

Subject prepared in laboratory with 2 × 1.2 cm domed disc electrodes fixed with adhesive discs 2 cm. apart immediately below pectoral and above heart. Earth was made on Anterior Superior Iliac crest. After 12 in. the light cable became screened, with a 1.5 metre length leading to a Cardette E.C.G. At the river the subject was seated in the rear seat of a K 2. with the operator in the front. The Cardette was loosely enclosed in polythene, keeping free from water splashes, but allowing access for paper manipulation, writing on paper, & machine adjustments. Pulse rates were taken at 5 min. intervals, using 10 pulse deflections. ECG was taken whenever the operator could spare time from the other measurements being made (Respiration rate, volume, temp°, and gas sampling). PAPER SPEED 23.7 mm/second. The times are approximate.

Fig. 21

Subject: Date: Time: Place:

FIG.22

Time (minutes)	Pulse	Resp. Rate	Volume	Gas Temp.	1	2	3	4	5	6
Pre-Ex.										
5										
10										
15										
20										
25										
30										
35										
40										
45										
50										
55										
60										
Seconds 30										
60										
90										
120										
150										
180										
210										
240										
Minutes 5										
10										
15										

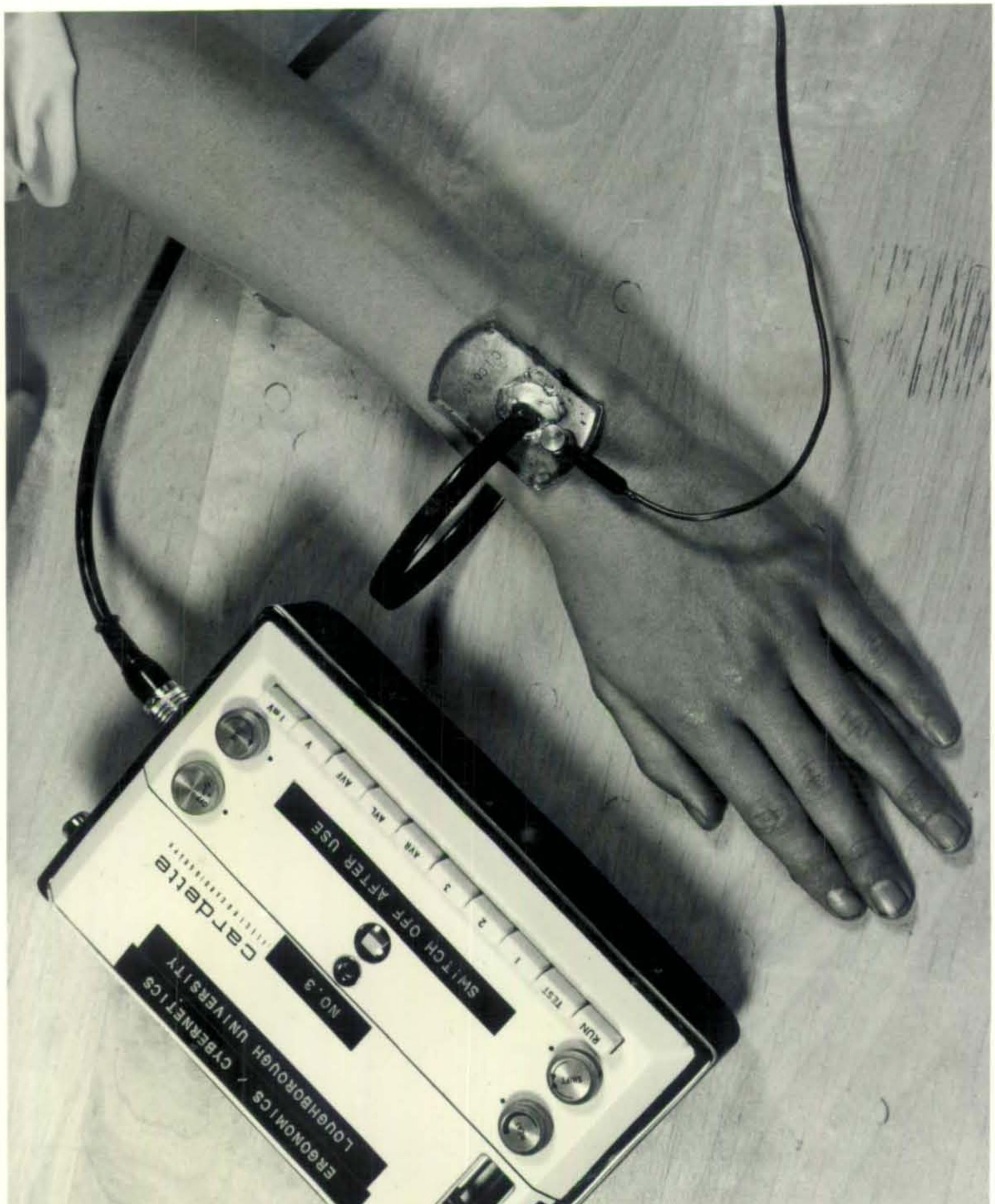
Cycling Recovery

The typical pattern of track cycle racing is that competitors will enter in several races, which may involve them in heats and repechages, and many short duration high activity bursts within a few hours. Their ability to recover quickly between these bursts of activity is an important factor in their overall performance. In an attempt to gain some information on cardiac recovery, the author performed the following investigations at the Meeting of Champions, Nottingham; assisted by Mr. Norman Sheil, the British Cycling Federation National Coach, and with the collaboration of several international cyclists.

Apparatus: Cardette portable single channel battery E.M.G. Screened leads to 1 sq. in. plate electrodes soldered to 3" diam. spring clips (Fig. 23) Stopwatch. Toothbrush, cotton wool, electrode jelly.

Method: Just before the start of the race, the posterior aspect of the wrist was scrubbed with the toothbrush impregnated with electrode jelly until a mild erythyma was produced. Immediately after crossing the finishing line at the end of the race the subject would slow down as much as possible. This is a difficult operation because subjects might be travelling at nearly 40 m.p.h., and as track bicycles have no brakes it is necessary to put backwards pressure on the fixed wheel and grip the front wheel with a hand. However, skilled subjects can stop within 200 yards (approximately 20 secs.). The subject them dismounted and sat on a chair, at the same time having the wrists rubbed a few times with cotton

FIG. 23



ERGONOMICS / CYBERNETICS
LOUGHBOROUGH UNIVERSITY
cardette
NO. 3
SWITCH OFF AFTER USE
RUN
TEST
1
2
3
AVR
AVL
AVF
V
1 mV

wool impregnated with electrode jelly. The electrodes were then clipped in position. With this method it was possible to obtain quite good E.C.G's within 30 seconds of crossing the finishing line. This E.C.G. can then be continuous during recovery. (Fig.24)

Conclusions: At the time of performing these tests there was no telemeter available. Within the restricted radius of track a pulse transmitter would be of greater use in diagnoses of cardiac performance. The author knows of no telemetering apparatus which could give an E.C.G. over these ranges, and some combination of telemetering and direct E.C.G. monitoring would be the best method of achieving a full picture of cardiac reaction to this form of athletic performance.

Basketball Investigations

Because of an interest in the cardiac demands of a team game such as basketball, and to investigate the problems of pulse telemetering in a strenuous and 'shock-full' environment, the author collaborated with Mr. Tom Corser, College of Education, York, who has similar interests. Using the N.E.C. Spurt transmitter and telemeter, and the transmitter adjustment, described earlier, very reliable data was obtained. The transmitter and aerial were covered by a vest, with the aerial vertical and close to the depression between the spinal erector muscles. Two investigations were made. The first was a continuous tape recording of the environmental sounds superimposed upon the pulse beat sounds during a 45 minute training session. The second was a continuous tape recording of pulse beat sounds with superimposed operator comments while the subject took part in an international basketball match.

Some of the data is shown in Fig. 24a.

Conclusions: The Spurt apparatus is quite reliable in this kind of activity, with the following exceptions:

1) Blows on the transmitter sometimes cause extra-pulses to be transmitted. When listening to the tape recording these disturbances to the normal rhythm are quite easily detectable.

2) The transmitter can be switched off by some shocks during play.

3) Unless sweat can be regularly dispersed from the electrode sites, extended periods of work tend to destroy the adhesion.

Weightlifting Experiment I :

The author has recently been engaged in the planning of training schedules for a world weightlifting champion, in preparation for the Mexico Olympic Games. Weight lifting in competitions is essentially a short duration explosive power event, and as such makes relatively few demands on the cardio-respiratory system. The training sessions which weightlifters have to perform in order to develop their power and technique for competitions are, however, extremely demanding on both local muscular and cardiac endurance. The weightlifter needs stamina in order to be able to train.

The subject had previously undertaken the normal bicycle ergometer test, similar to that described earlier. This gave valuable information

FIG. 24a.

Heart Rate During a Basketball Training Session

The rates represent the actual number of heart beats during the minute concerned. The total training session was split into three periods, each at a lower work rate than its predecessor, with no rest between sessions.

SESSION I		SESSION II		SESSION III	
Minute	Pulse	Minute	Pulse	Minute	Pulse
1	145	1	157	1	157
2	164	2	155	2	152
3	160	3	162	3	153
4	161	4	149	4	153
5	161	5	154	5	147
6	161	6	149	6	149
7	159	7	157	7	148
8	160	8	158	8	146
9	163	9	149	9	151
10	160	10	150	10	143
11	162				

RECOVERY	
Minute	Pulse
1	146
2	110
3	117
4	111
5	95

which could be used on a test-retest basis as a measure of improvement. Its relevance to cardiac demands of weightlifting had not been established, and so the following experiment was made.

Apparatus: Kaiser E.C.G., 10 ft. light cables, 1.5 cm. silver domed electrodes, adhesive discs, adhesive tape, electrode jelly, serrated syringe, N.E.C. Spurt pulse telemter, stopclock, Olympic bar + 450 lbs. weights, weightlifting platform.

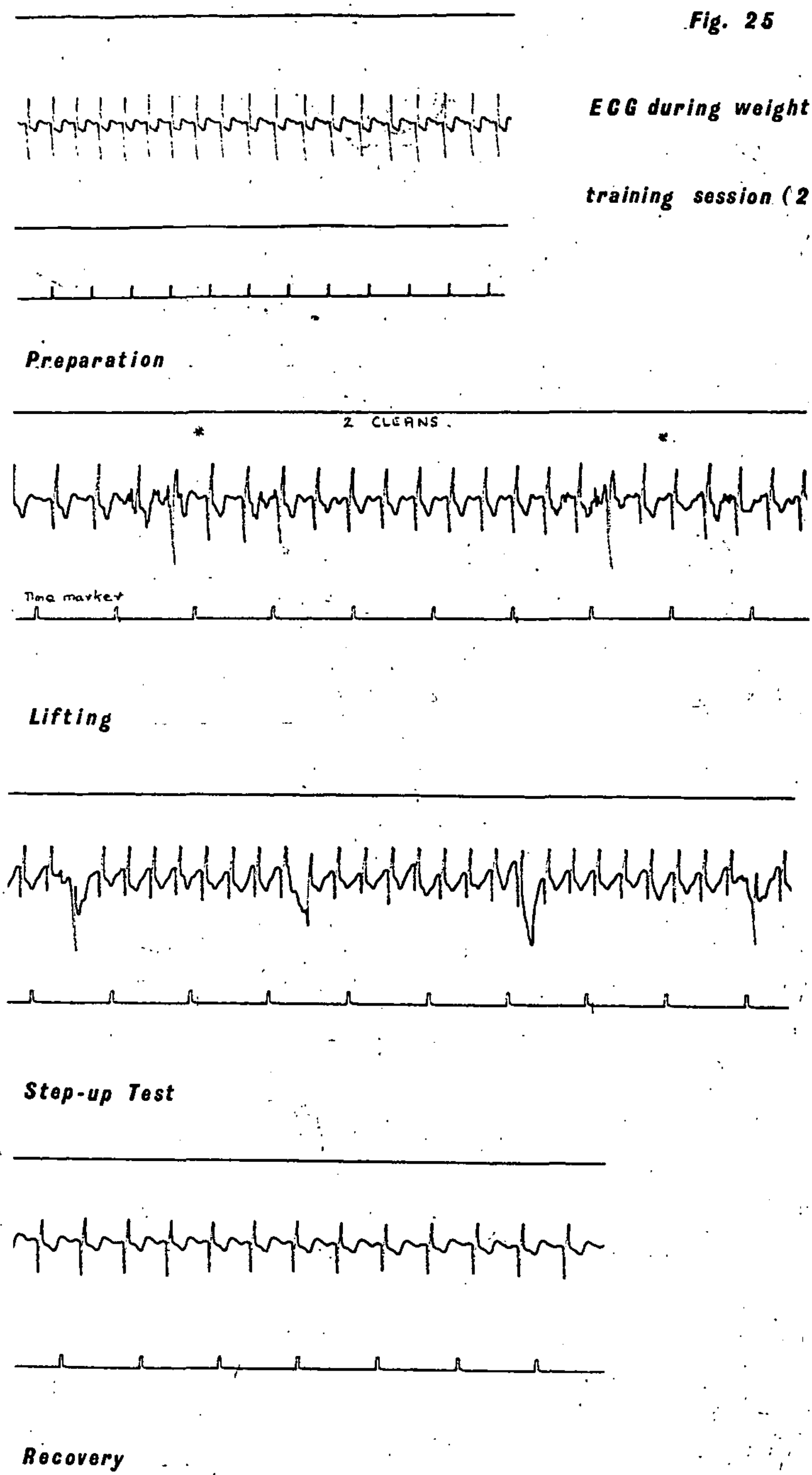
Method: The subject was prepared by the method described earlier. Continuous E.C.G. and pulse telemetry was performed during a complete weightlifting training session lasting nearly two hours, which was followed by a Step Test.

Results: The data is shown in Figs. 25 and 26.

Conclusions: During the session the subject, who is a Negro, sweated profusely. There was no displacement of electrodes. The movements being performed were in most cases extremely violent, and resulted in a certain degree of movement and E.M.G. artefact. This did not destroy the E.C.G's usefulness as a pulse counter, and gave a good signal of the occurrence of movements. However, the precise form of the E.C.G. at this point was lost. The audible pulse telemeter was especially interesting, and if amplified could make an excellent teaching aid in that the tremendous adaptation of the subject's pulse to different phases of activity was best appreciated by the ear and eye in conjunction. This adaptation showed patterns of cardiac response which could have great significance

Fig. 25

ECG during weightlifting training session (2 hrs.)



	1	168	176	40	113	40	15
	1	173	176	25	123	60	15
	1	171	182	45	129	25	15
	1	178	178	30	127	60	15
	1	179	sat down, plateau 127-121 after 120 seconds. Then dropped to 101-119 plateau for 9½ minutes.				
$\bar{x}$	=	160	168	22.5 S.D. = 10.45	125	40 S.D. = 18	14 S.D. = 8

Step Test

Gradual rise to a plateau at 180-187 for the last 105 seconds of test

(15" step 20 r.p.m. 5 minutes test)

Pulse rates taken every 15 seconds during 10 minutes recovery period

1	2	3	4	5	6	7	8
163	154	148	143	137	136	134	132
9	10	11	12	13	14	15	16
128	126	128	124	128	131	121	122
17	18	19	20	21	22	23	24
123	120	121	117	120	120	118	116
25	26	27	28	29	30	31	32
120	111	118	114	112	113	111	113
33	34	35	36	37	38	39	40
112	110	110	106	108	92	107	113

FIG. 26

Pulse Rate Fluctuations during a Weight Lifting Training Session

Every 5 seconds, a 6 pulse R-R measurement was made, converted and expressed as an r.p.m.

a. Lift	b. No.Made	c. Peak Pulse Rate During	d. Highest Peak After	e. Time in secs. to reach (d)	f. Lowest Point after (d)	g. Time in secs. (d - f)	Time in secs. f - next lift
Clean to shoulder	3	158	150	10	131	30	20
	3	160	160	20	136	30	10
	3	158	168	10	115	40	10
	2	153	163	10	111	45	20
	2	155	161	10	98	35	15
	2	151	163	15	113	35	20
	1	146	153	5	104	45	20
	1	143	159	15	108	70	25
	1	149	160	10	112	65	15
	1	139	161	85	116	60	15
	1	147	158	5	116	40	

2 minute rest to next series

a. Lift	b. No.Made	c. Peak Pulse Rate During	d. Highest Peak After	e. Time in secs. to reach (d)	f. Lowest Point after (d)	g. Time in secs. (d - f)	Time in secs. f - next lift
Clean and jerk	1	152	160	10	133	20	10
	1	164	171	35	134	20	10
	1	163	172	20	129	30	5
	1	162	171	10	119	75	10
	1	158	170	10	126	60	5
	1	166	172	25	125	90	15
	1	167	173	20	129	60	5
	1	180	185	40	149	60	5
	1	188					

long slow recovkry. Plateau at 131 after 120 seconds. Bent down to adjust kthe weights with no effect on pulse rate.

a. Lift	b. No.Made	c. Peak Pulse Rate During	d. Highest Peak After	e. Time in secs. to reach (d)	f. Lowest Point after (d)	g. Time in secs. (d - f)	Time in secs. f - next lift
					115		30
High Pulls to waist	2	148	156	40	121	55	20
	2	150	168	30	138	25	5
	2	164	178	30	132	35	20
	1	149	166	10	120	65	30
	2	160	173	35	133	15	40
	1	155	170	20	129	50	5
	2	160	174	25	140	35	0
	2	162	177	25	151	20	0
	2	169	180	35	149	25	5
	2	169	183	25	149	25	5
	2	168	175	20	[illegible]	[illegible]	[illegible]

long recovkry. Plateau at 124 after 95 seconds. Bent down to adjust the weights with no effect on pulse rate. Sat down for 8 minutes, pulse dropped to 107-125 oscillation. Missed a beat to low of 98, 20 seconds before the first of the next series

a. Lift	b. No.Made	c. Peak Pulse Rate During	d. Highest Peak After	e. Time in secs. to reach (d)	f. Lowest Point after (d)	g. Time in secs. (d - f)	Time in secs. f - next lift
Power snathh	1	159	161	25	153	10	5
	1	169	172	25	125	55	10
	1	156	167	15	125	25	15
	1	166	176	25	120	35	10
	1	154	168	30	126	15	5
	1	156	168	15	128	35	15
	1	154	168	20	119	25	15
	1	157	168	35	126	60	20
	1	148	159	25	126	15	10
	1	153	163	25	119	50	5
	1	153	157	5	sat down and reached		

a plateau oscillating 101-119 after 70 seconds. Remained seated 5 minutes

a. Lift	b. No.Made	c. Peak Pulse Rate During	d. Highest Peak After	e. Time in secs. to reach (d)	f. Lowest Point after (d)	g. Time in secs. (d - f)	Time in secs. f - next lift
Technique Press	1	149	159	30	132	30	5
	1	160	166	30	111	35	5
	1	162	164	20	123	35	5
	1	168	177	40	117	35	10
	1	172	stayed at 172 for 45 seconds, then dropped to 152 in 25 seconds then to 112 in 5 seconds				

in the training of sportsmen, and also in the understanding of cardiac function. Though the reactions of one subject cannot be taken as reliable data, it is interesting to consider some aspects of this cardiac response.

A typical pattern of response can be seen by taking the mean values of all parameters. During a lift the heart rate rose to 160, rising still further to a peak of 168 at 22 seconds after the lift ceased. The rate then dropped over the next 40 seconds to 125, and then rose gradually over the next 14 seconds to the start of the next lift.

The variation in rates at each stage reflected either the length of time spent on each lift, or the poundage lifted. Lowest rates were recorded while the subject was standing preparing for the next lift, or during prolonged seated rest pauses. They did not occur in the stopped or crouched position. At times when the subject bent down to adjust weights not as a part of a lift, there was no drop in heart rate. At times when there was a prolonged rest period deceleration of heart rate was achieved less quickly.

The highest heart rate recorded was during the performance of a 405 lb. complete lift above the head, to a rate of 188. At this point, and at the two other highest heart rate points where the lift was the last of a series, the heart rate did not continue to rise on lift completion.

During a sub-maximal step test done at the end of the session, the heart rate reached 188. The rate then took 3 minutes to recover to the mean recovery level of 125 that had been reached in a mean time of 40 seconds during weightlifting.

E.M.G. during Trampolining

Coaching methods in trampolining have for many years had to rely on subjective kinesiological analyses for the development of technical performance. In order to assess the possible value of E.M.G. in this type of activity, both the National Men's Trampolining Champion and a complete beginner, acted as subjects in the following experiment.

Apparatus: Offner 8 channel E.E.G. 10 ft. leads with 1.5 cm. silver domed electrodes and banana plugs. Elastoplast tape, electrode jelly, Rolls razor, cotton wool, alcohol, marker pen, serrated needle syringe, Nissen trampoline.

Method: The subjects were prepared by the method described earlier for E.M.G. of Tibialis Anterior, Lateral Gastrocnemius, Vastus Medialis and Lateral Biceps Femoris. Both subjects performed erect bouncing on the trampoline. The skilled subject then performed consecutive back somersaults in the straight position. The operator stood on the edge of the trampoline, holding the leads and ensuring that they did not interfere with the subjects' movements.

Conclusions: Some of the E.M.G. traces obtained are shown in Figs. 27 and 28. They demonstrate the complete possibility of E.M.G. analysis during trampolining movements. Unfortunately, the ink was old, and the traces became smudged and faint in places.

Fig. 27

EMG during trampoline bouncing

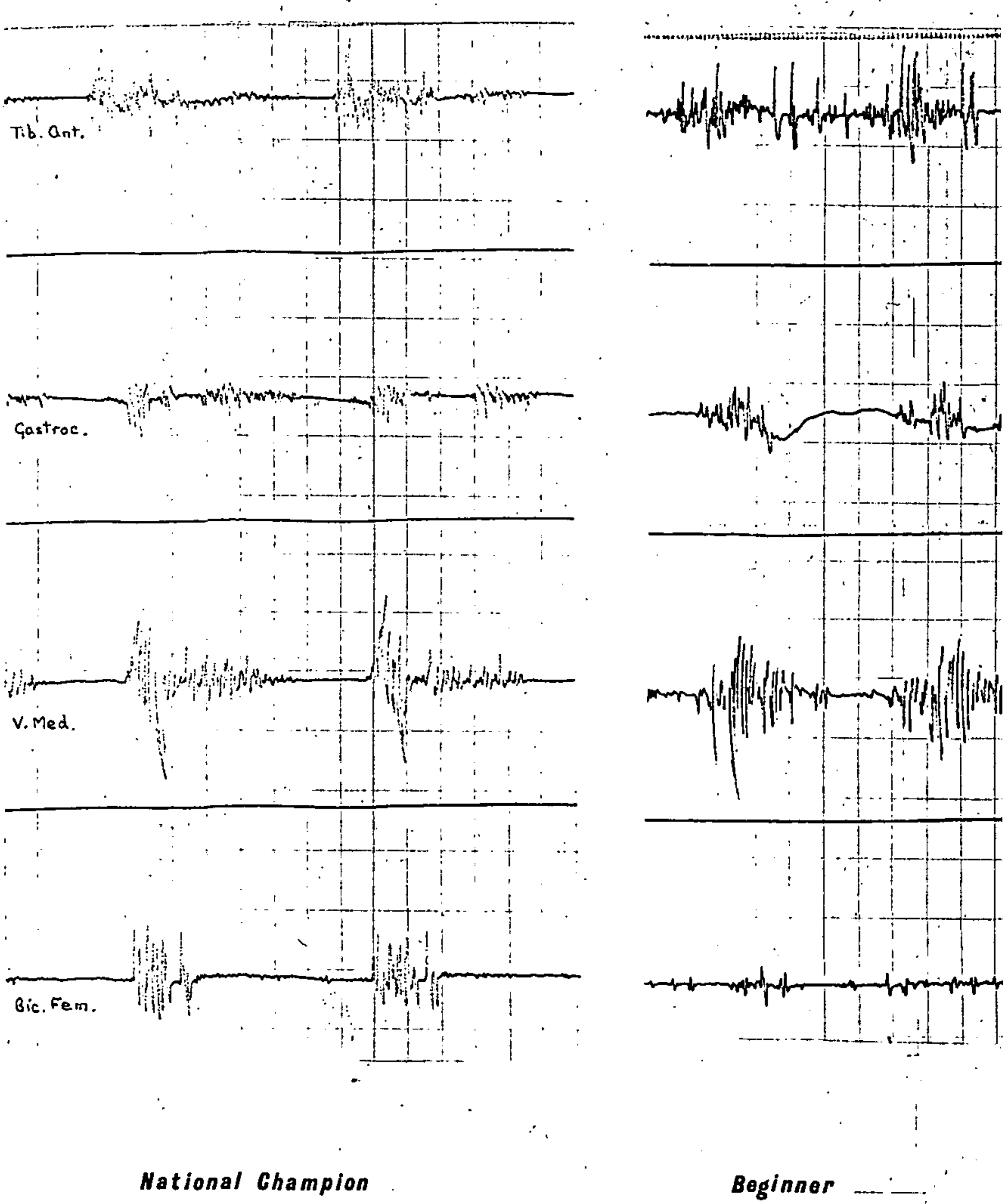
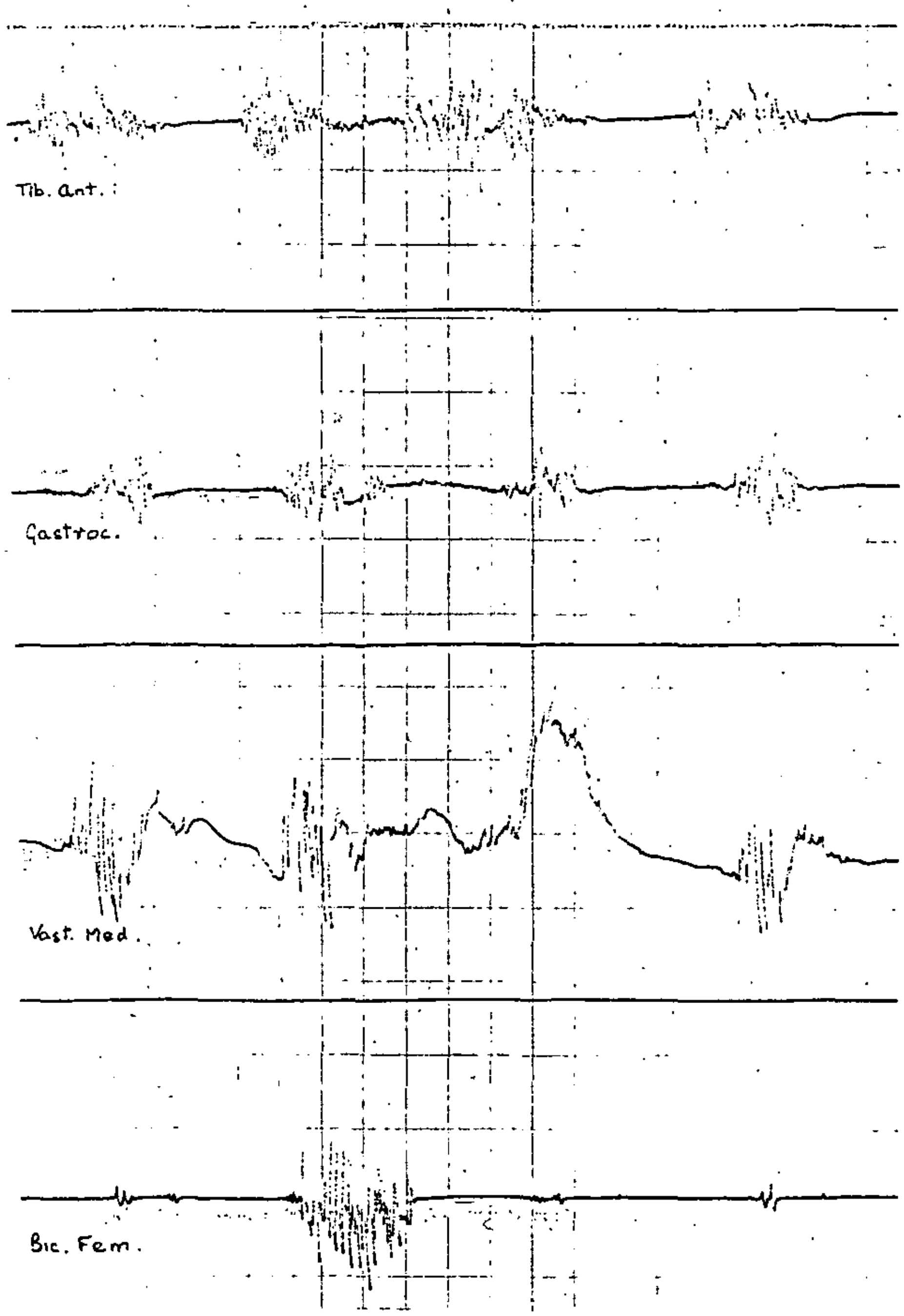


Fig. 28



EMG of back somersault on trampoline

Points of especial interest which emerge from the traces are:

i) The process of muscular adaptation during skill acquisition

ii) The difference in muscle co-ordination between skilled and unskilled subjects.

iii) The achievement of muscular relaxation during violent activity

iv) The maintenance of certain aesthetic postures during flight

v) The occurrence of large movement artefacts at certain stages in trampolining manoeuvres.

Conclusions (Pilot studies)

The foregoing tests allow a picture to be built up of an individual's state of 'fitness', especially if in conjunction with other tests, of skill, power and personality etc. In the present state of the art, physical educators must examine such overall pictures mainly from a background of experience and subjective interpretation. This is an unsatisfactory state of affairs from many points of view, especially since the relative importance of each piece of the jigsaw is not known. The final criterion in assessing individuals must be their performance at any given activity. Unfortunately, this is not a simple task when selection of teams depends upon a prediction of eventual performance, and in such cases assessments of the separate parameters is of great use - even if the correlation of allthese parameters is at an unsatisfactory level. The author has been recently concerned with giving such advice to the selectors of the Amateur Rowing Association, the British Cycling Federation, and the Great Britain Olympic Basketball Committee. These associations, and others, are using such advice in the advance selection of national teams.

In an environment where facilities, time and energy for training are limited, then such assessments of various athletic parameters can give some indication of those which would be likely to give greatest performance gains, if concentrated upon during training. In this way, the most efficient utilisation of training time can be achieved. If the tests are reliable, then they can also act as comparators of information from retesting, and be used to gauge the efficiency of training methods.

An Electromyographic Analysis of a Repetitive Locomotor Skill

Summary

Three subjects each pedalled a bicycle ergometer at various rates against various resistances. Electromyographic analysis of three major leg muscles showed that there were significant variations in the patterns of muscular co-ordination involved.

Introduction

Munrow (33) quotes the following definition of skill - "The ability .... to innervate the right muscles to the right degree with the right amount of speed at the right moment." Where the skill under examination can be described as 'closed', that is to say virtually the same however many times it is performed, there is a tendency amongst physical educators and kinesiologists to regard the muscular patterns and co-ordinations involved as highly reproducible both within and between subjects. Houtz and Fischer (34) discovered a 'high degree of repeatability among subjects and for any one subject', which may in part have been caused by their non-inclusion of atypical muscle records in the overall analysis. In another experiment (35) the same authors present evidence that 'the pattern of muscle action potentials.... was consistent', and illustrate their evidence with a diagram of the precise co-ordination and time phasing of major leg muscles during bicycle pedalling. Kamon (36) in an analysis of a non-repetitive closed skill, agrees with Houtz (37) that the muscular patterns show a 'high degree of reproducibility'. However, Kamon ignored 'atypical' records and discarded records of 'incorrect movements according to competitive aesthetic criteria'. Battye and Joseph (38) followed the practice of disregarding observations which did not fit into 'typical phases' in arriving at their conclusion that subjects show 'remarkably similar' patterns of muscular activity during normal gait. These and other observations indicate that skills, especially heavily over-learned closed skills, demand quite precise phasing and co-ordination of the muscles concerned in movement.

On the other hand Docherty (39) expressed the philosophy that our capacities for adaption are enormous, which would seem to agree more closely with present knowledge that reinforcement is a characteristic of muscle fibre performance. Lippold et. al. (40) demonstrate migration of activity from one muscle to another after prolonged activity, and the author has demonstrated voluntary gross changes in muscular co-ordination to the Physiological Society (11) Fig.29. The

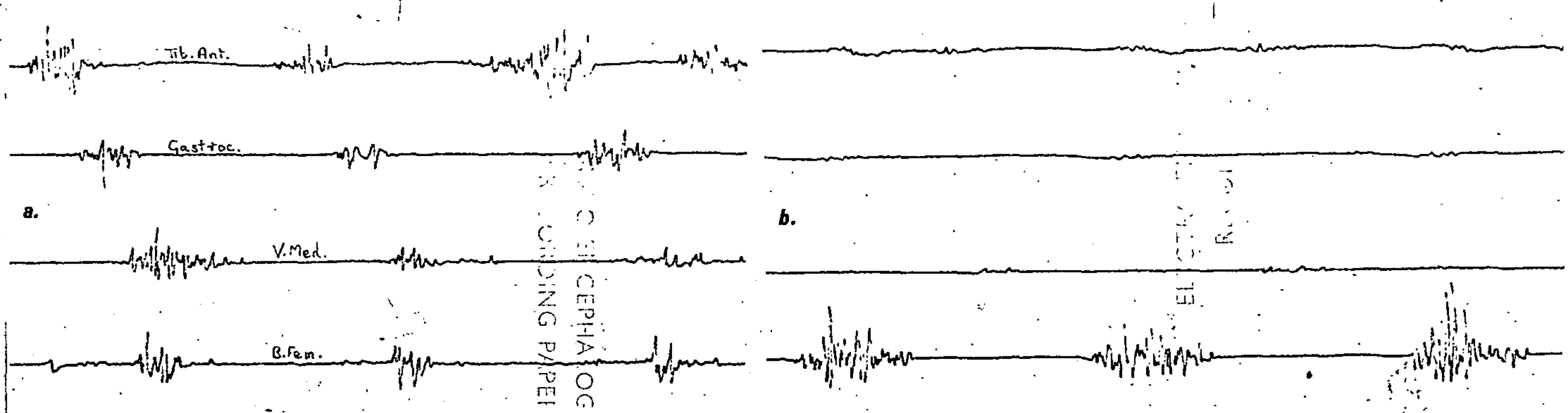
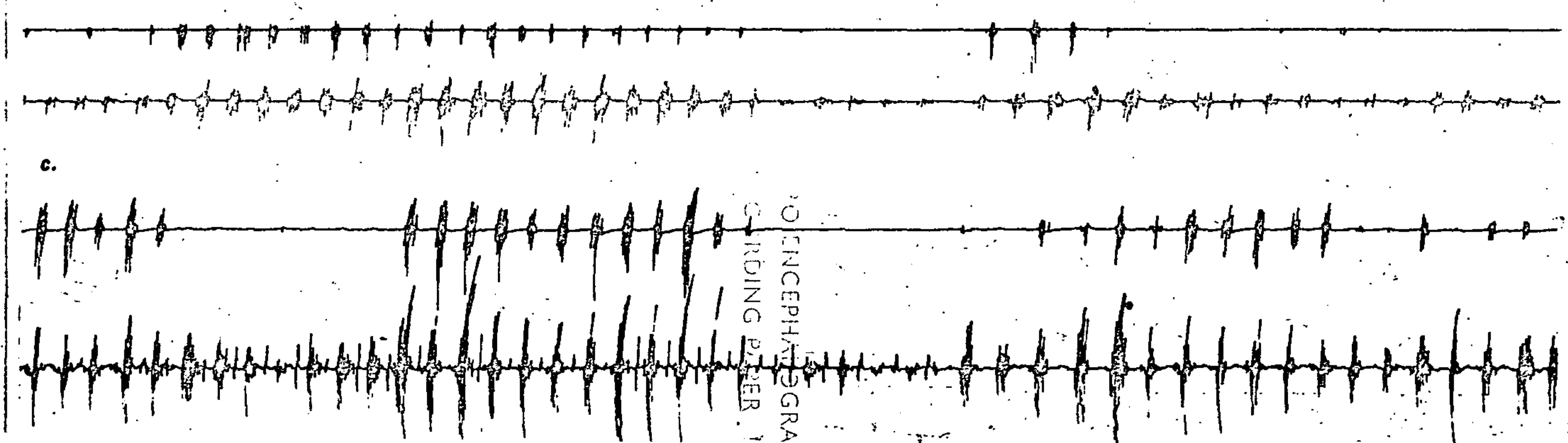


Fig. 29 EMG of bicycle pedalling. a. Normal b. & c. Conscious alterations in pattern



rehabilitation of patients having physical disability has for many years depended to a great extent on the human's ability to adopt his musculature to different patterns of movement - to develop 'trick' movements. That voluntary effort can result in changes in muscle co-ordination, whilst retaining the basic movement patterns required, seems to be well established. Constant practice of altered muscle patterns can also lead to the establishment of 'new' methods of performing a skill - which co-ordination becomes less and less conscious as learning proceeds. There does not appear to have been an attempt to discover if changes in muscle co-ordination occur involuntarily as quickly as during successive repetitions of a heavily over-learned repetitive locomotor skill.

Early in the development of the bicycle, enthusiasts attempted to devise the most efficient interface between the rider and his machine. Lever systems and machine dimensions of varying degrees of complexity were subjected to what could be described as 'ergonomic assessment' - some of a quite highly sophisticated mathematical and mechanical type (41, 42, 43). The combined effects of such investigations and of empiricism resulted in the evolution of the present chain wheel and circular pedal path system, which has eventually reached a stage of such mechanical efficiency as to permit the highly trained performer to achieve speeds of 120 m.p.h. behind motorpace, or to cover over 30 miles in one hour unpaced, or 500 miles in one day similarly unpaced. The physical parameters of this man-machine interface have not received such close scrutiny over the years, although the 'ankling' action was discussed in some detail in 1889 (44), and in 1888 by Lord Bury and G. Lacy Hillier who went into great detail regarding joint angles and limb positions (45). The studies of A.V. Hill into the development of optimal power by a muscle prompted various investigations into the rate of bicycle pedalling. His optimal contraction time of just under 1 second seemed to fit very neatly into the findings of Benedict and Cathcart (46) who suggested greatest efficiency of pedalling at 70 r.p.m. However, a pedalling rate of 70 per minute is achieved by combined muscle movements, any individual muscle hardly being capable of working normally for longer than 50% of a single revolution, giving a contraction time of $\frac{60}{140} = 0.43$ seconds. Dickenson (47), who worked closely with Professor Hill, discovered that the optimum time for one foot movement (half a pedal revolution) was 0.9 sec. This gave an optimum pedalling rate of 33 r.p.m. If this finding were to reinforce Hill's optimum contraction rate it would need to be established that each muscle was working for 50% of each revolution.

These two suggested rates of 70 r.p.m. and 33 r.p.m. differed very greatly, and Cathcart suggested to Garry and Wishart that they re-examine the question (48), the result being a figure of 52 r.p.m. (halfway between the two previous figures) and a conclusion that 'it is impossible to obtain ..... the real efficiency of effector muscles.' Such widely differing results, when allied with the almost universal preference of racing cyclists for pedalling rates between 90 and 120 r.p.m., suggest that there are other facters than optimal muscle fibre contraction rate which affect the efficiency of gross muscle movement. Previous investigations by the author into cycling saddle height, and by Hamley into trunk position (12) have demonstrated the significance of postural effects. It was decided to investigate other parameters (subjects, loads, pedalling rates, muscles) using electromyography and statistical analysis of variance.

__Subjects:__ Three male subjects, aged I 25, II 25 and III 33 were used. Subjects I and II were active sportsmen, who had been using a bicycle ergometer as a method of applying work load for cardio-respiratory training, but were not racing cyclists. Subject III was a first category racing cyclist in his 'off season', who had also used this ergometer for regular training.

__Apparatus:__ (i) A standard bicycle ergometer as designed by Müller with variable cam magnetic resistance, and pedalling rate indicator. The ergometer was modified by additions of:-

a) Racing saddle, pedals, toeclips, and handlebars.

b) A photo electric device registering a 1.5 volt output as the left pedal passed the front horizontal point.

(ii) An eight channel pen oscillograph (Offner Type T) comprising a d-c amplifier and multiswitching system suitable for electroencephalography.

(iii) 6 electrode lead pairs, with banana plugs and 1 cm. circular domed electrodes pressed from 1 mm. silver sheet.

(iv) 20 ml. syringe with No. 1 serrated tip needle, 1 cm. circular double side adhesive discs, Cambridge electrode jelly, 1" elastoplast strips, Rolls razor, cotton wool, alcohol.

(v) I.B.M. 1620 digital computer.

Method:

Equipment Preparation. The bicycle ergometer was levelled and callibrated according to the manufacturer's handbook. Saddle height was adjusted according to Hamley and Thomas (12). The oscillograph was serviced and callibrated according to its handbook. Paper spped was checked and found to be 28.1 mm. per second. Photo electric pedal position marker was checked.

Subject Preparation. Each subject lay on a clinical couch or plinth and the skin surface of the four muscles on the left leg (Tibialis Anterior, Lateral Gastrocnemuis, Vastus Medialis, and Lateral Biceps Femoris) was cleaned using cotton wool impregnated with alcohol. The subject then sat on the ergometer and the muscles were palpated while he pedalled. The electrode positions were marked on the skin surface using a ball-pen, with circles ca. 1.5 cm. diam. Positions were selected which lay directly over the main muscle belly for the majority of the leg movement and which did not lie too closely to other muscles. The inter-electrode space for each pair was 2.5 cm.

The subject then lay on the plinth and the electrodes were attached. An area ca. 3" square was shaved around the electrode site. An adhesive disc was placed within the marked circle on the skin. The serrated tipped needle of a syringe filled with electrode jelly was rotated a few times in the centre of the circle, to pierce the cornified layer of the epidermis. This small hole was then filled with electrode jelly. The domed electrode was filled with electrode jelly, and carefully but firmly applied to the adhesive disc. Any electrode jelly escaping through the hole in the dome of the electrode was removed. The electrode was then very firmly taped with an elastoplast strip, and heavy pressure applied digitally to the electrode to obtain maximum adhesion. The same method was used in fixing a single earth electrode to the patellar surface.

The electrode resistance was checked and in all cases found to vary between 4 - 7 K. The subject mounted the ergometer, and pedalled slowly, while the path of least movement over the skin for the leads was determined. The leads were then taped to run to a common point (lateral aspect of knee), from where all leads were taped together as a single cable to the E.M.G. junction box.

In addition, a pair of sub-pectoral E.C.G. electrodes were attached, to provide information for another series of experiments. Fig 30

<u>Procedure</u>. Each subject pedalled the bicycle ergometer at 60 r.p.m. against a 50 watts resistance for 5 minutes

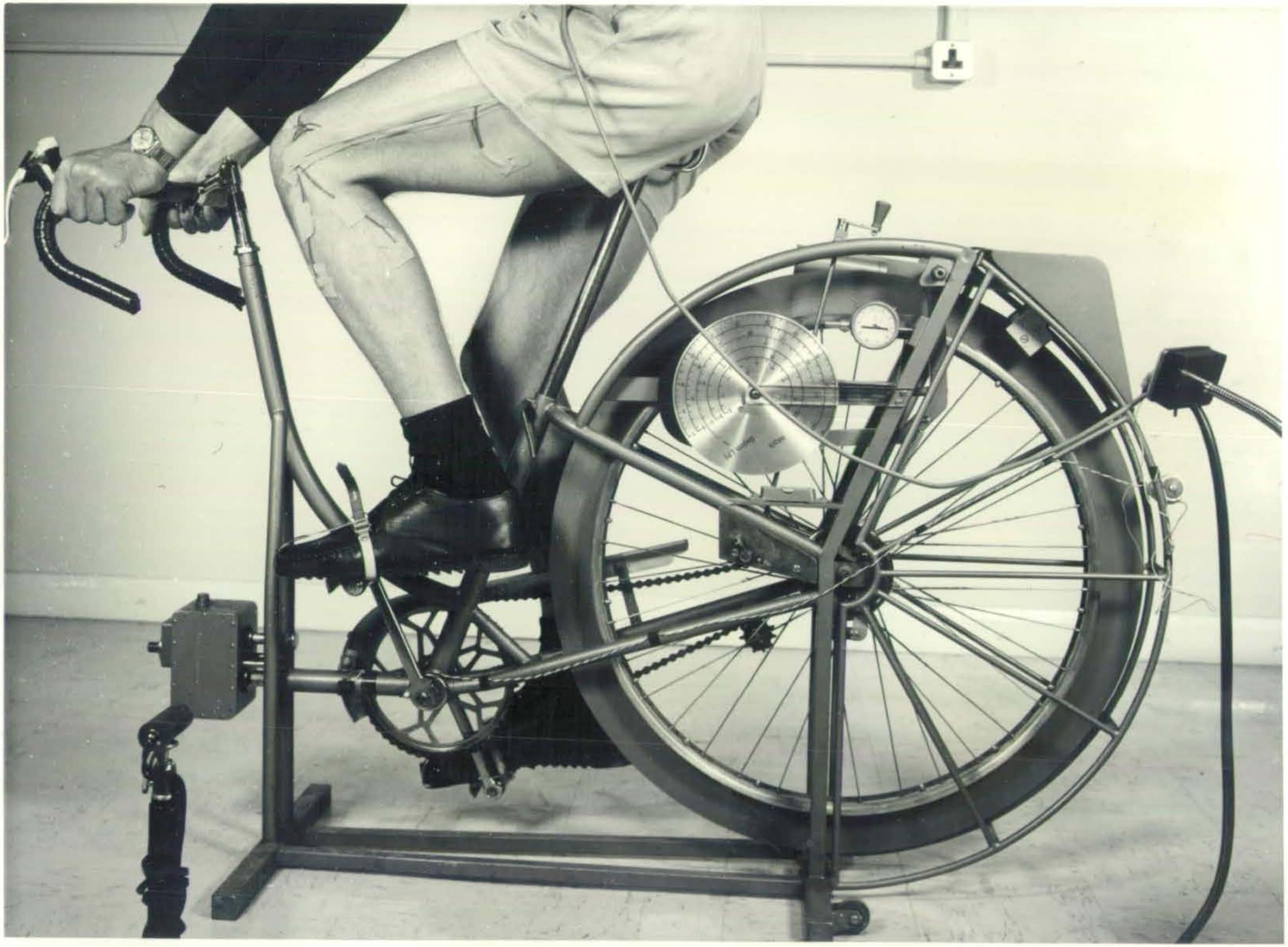


FIG. 30

with the E.M.G. continuously running. During this time the traces obtained were checked and amplifications adjusted to give a minimum of ca. 1 mm. total pen deflection amplitude for each muscle.

It was discovered that the readings given by Tibialis Anterior were unreliable, in that occasionally there would be no electromyographic activity from the muscle during pedalling. This muscle was therefore excluded from the statistical analysis, though traces obtained at heavier loads were reliable enough to suggest a typical pattern of action for the Tibialis Anterior.

The resistance was then raised gradually over a period of a minute to 150 watts. The subject then remained pedalling against this resistance for a further minute. This was repeated to a resistance of 250 watts. The subject then stopped and rested for 5 minutes.

This procedure was repeated with the subject pedalling at 75 r.p.m., and again at 90 r.p.m. The total experiment took 37 minutes, during which time subjects did not experience great fatigue

Results: The conditions of pedalling for each of the three subjects can be shown thus.

load in watts

r.p.m.	60	150	150	250
	75	50	150	250
	90	50	150	250

Under each of these nine conditions, measurements were made of the duration of activity of each of the three muscles, for ten consecutive pedal revolutions. These ten revolutions were taken at the end of the minute sepnt under the specific conditions. A muscle was considered as being active as soon as there was any discernable change in the E.M.G. thace from the noise level during inactivity (Fig.31). Each measurement was then compared with the total time for one pedal revolution at the particular r.p.m. rate; thus each reading represented the fraction of a total pedal revolution time that a particular muscle was working.

With 3 subjects(S), 3 pedalling rates (V), 3 resistance loads(L), 3 muscles (M), and 10 trails(T), there were a total of 810 measurements which were subjected to Analysis of Variance using an I.B.M. 1620 digital computer programmed by David (11). The complete data is shown in Fig. 32, and the Analysis of Variance, (Fig.33).

Fig. 31 EMG of bicycle ergometer pedalling at constant rate against various loads

FIG. 32

E.M.G. Analysis of Bicycle Pedalling Data

Each figure represents the % of a total revolution that the muscle was working.

SUBJECT I - Run I - 60 r.p.m.

Gastrocnemius

	50 watts		150 watts		250 watts
5 kgm. -	18.5	15 kgm. -	31.4	25 kgm. -	35.8
	25.3		28.4		34.4
	22.9		31.1		34.1
	20.2		29.7		40.9
	15.5		33.8		35.5
	18.5		28.4		44.3
	17.2		32.4		36.1
	17.2		29.1		38.5
	19.5		23.7		38.2
	16.5		33.5		40.2

Vastus Medialis

5 kgm.	28.0	15 kgm.	41.6	25 kgm.	45.7
	27.0		43.6		44.3
	32.0		38.5		44.7
	31.0		41.2		43.6
	36.4		42.3		45.7
	33.7		41.6		47.1
	36.4		41.6		44.7
	[illegible]		[illegible]		47.7
	34.0		41.9		44.7
	36.7		41.9		44.7

Biceps Femoris

5 kgm.	54.9	15 kgm.	52.4	25 kgm.	54.9
	53.6		54.4		56.6
	56.6		54.8		59.7
	55.9		56.1		55.2
	52.2		63.5		60.7
	49.2		58.5		60.0
	55.6		60.5		56.3
	54.6		56.8		61.7
	55.9		54.4		64.4
	53.9		60.8		66.8

SUBJECT I - Run II - 75 r.p.m.

Gastrocnemius

	50 watts		150 watts			250 watts
5 kgm.	- 23.3	15 kgm.	- 34.7	25 kgm.		- 44.4
	19.5		33.5		38.4	38.4
	16.9		30.9			40.6
	14.4		30.0			45.3
	21.2		34.7			39.3
	18.2		31.3			42.7
	16.9		30.9			41.4
	16.9		26.6			38.0
	21.6		27.5			47.4
	17.3		33.5			38.4

Vastus Medialis

5 kgm.	29.2	15 kgm.	40.3	25 kgm.	44.8
	28.8		39.5		42.3
	37.2		37.8		44.4
	33.4		39.0		42.3
	38.1		44.6		44.0
	37.6		41.2		42.3
	35.1		39.9		43.6
	34.3		42.9		42.7
	38.1		40.3		41.0
	31.7		99.9		41.8

Biceps Femoris

5 kgm.	50.8	15 kgm.	55.8	25 kgm.	63.2
	47.0		58.3		55.5
	54.1		61.8		64.9
	48.6		59.2		68.7
	47.8		54.1		65.3
	54.6		61.3		67.5
	47.4		56.2		65.8
	53.7		66.1		68.3
	54.1		57.9		67.5
	49.1		56.6		66.6

SUBJECT I - Run III - 90 r.p.m.

Gastrocnemius

	50 watts		150 watts		250 watts
5 kgm. -	25.5	15 kgm. -	26.6	25 kgm. -	46.1
	25.0		30.7		52.7
	23.5		30.7		48.6
	26.0		31.7		52.7
	22.4		31.7		47.1
	25.0		27.1		40.4
	21.9		31.2		46.1
	24.5		33.3		48.1
	26.0		32.3		52.7
	25.0		32.3		51.2

Vastus Medialis

5 kgm.	29.1	15 kgm.	36.4	25 kgm.	38.4
	28.6		35.8		38.4
	27.5		35.3		38.9
	31.6		38.4		40.4
	26.5		34.8		36.9
	[illegible].1		33.3		41.5
	30.6		35.8		42.0
	32.6		34.8		39.9
	27.5		37.9		38.4
	32.1		40.4		39.9

Biceps Femoris

5 kgm.	44.9	15 kgm.	57.9	25 kgm.	69.1
	46.4		52.7		62.0
	48.5		60.4		60.9
	49.5		57.9		64.0
	57.6		63.5		64.0
	50.5		60.9		67.1
	59.2		58.9		65.5
	52.0		61.4		64.0
	54.6		57.3		71.2
	55.1		53.8		71.7

SUBJECT II - Run I - 60 r.p.m.

Gastrocnemius

	50 watts		150 watts		250 watts
5 kgm. -	41.3	15 kgm. -	42.2	25 kgm. -	47.6
	40.2		40.8		50.7
	41.9		46.7		45.6
	39.6		41.9		48.3
	37.5		38.8		48.6
	42.6		45.0		45.9
	41.3		45.0		47.6
	37.9		41.2		48.3
	36.8		39.8		34.4
	36.8		41.2		48.3

Vastus Medialês

5 kgm.	13.3	15 kgm.	28.7	25 kgm.	38.8
	17.7		33.6		40.8
	18.8		31.8		36.7
	16.4		33.9		41.1
	18.8		29.1		35.0
	21.1		25.0		36.0
	15.3		25.6		35.7
	14.7		28.0		33.3
	13.3		30.4		32.3
	18.4		31.5		34.3

Biceps Femoris

5 kgm.	35.8	15 kgm.	48.1	25 kgm.	66.3
	33.4		38.4		66.6
	31.4		45.7		61.2
	32.7		60.9		65.6
	36.5		44.3		62.9
	38.5		45.0		59.2
	36.1		53.3		63.2
	31.4		49.1		61.9
	30.7		41.5		54.4
	31.7		56.4		58.1

SUBJECT II - Run II - 75 r.p.m.

Gastrocnemius

	50 watts		150 watts		250 watts
5 kgm. -	61.2	15 kgm. -	52.5	25 kgm. -	47.8
	53.0		63.2		52.5
	50.9		42.7		53.4
	56.0		50.4		52.1
	56.5		53.4		52.1
	53.0		55.1		54.7
	55.6		59.4		58.5
	55.2		55.5		47.8
	58.2		47.8		50.4
	58.6		54.2		49.1

Vastus Medialis

5 kgm.	26.7	15 kgm.	34.6	25 kgm.	44.8
	32.3		31.2		36.3
	27.2		39.3		43.6
	32.3		37.1		42.7
	25.9		37.1		38.4
	30.2		33.7		38.9
	33.2		35.0		37.1
	29.7		30.7		39.3
	34.5		37.6		38.4
	24.1		34.2		38.4

Biceps Femoris

5 kgm.	14.7	15 kgm.	52.1	25 kgm.	58.9
	24.1		51.2		62.3
	18.5		54.7		72.6
	18.5		48.3		67.9
	17.7		45.7		72.6
	18.1		47.4		73.0
	22.8		52.5		74.7
	20.7		48.7		64.9
	19.4		57.8		70.5
	20.3		53.4		68.3

SUBJECT II - Run III - 90 r.p.m.

Gastrocnemius

50 watts		150 watts		250 watts	
5 kgm. -	58.5	15 kgm. -	54.3	25 kgm. -	48.3
	54.5		55.3		43.2
	56.0		52.3		42.7
	55.0		50.3		45.7
	54.0		42.8		41.7
	53.4		49.3		47.2
	53.4		46.8		45.7
	49.9		45.3		49.8
	51.4		46.8		40.6
	54.5		52.3		37.1

Vastus Medialis

5 kgm.	33.1	15 kgm.	30.2	25 kgm.	34.5
	26.5		34.2		32.5
	29.5		33.7		30.5
	35.1		31.2		33.0
	27.5		37.7		32.5
	15.3		30.2		31.5
	29.5		35.7		32.0
	24.9		28.7		33.0
	31.6		37.7		29.5
	24.4		36.2		30.0

Biceps Femoris

5 kgm.	31.6	15 kgm.	41.2	25 kgm.	55.9
	27.5		43.8		58.4
	38.2		44.8		65.0
	22.9		55.3		68.6
	38.2		47.8		63.5
	30.5		51.3		68.6
	41.2		55.3		66.0
	29.5		51.3		61.0
	26.5		57.8		62.0
	37.7		48.8		55.9

SUBJECT III - Run I - 60 r.p.m.

Gastrocnemius

50 watts		150 watts		250 watts	
5 kgm. -	67.7	15 kgm. -	77.0	25 kgm. -	74.6
	65.9		75.3		64.2
	65.9		76.3		84.0
	69.4		80.0		74.6
	65.9		76.0		78.1
	71.1		77.4		77.0
	72.9		77.0		69.4
	67.7		78.0		84.0
	66.6		69.0		85.0
	65.9		77.0		81.5

Vastus Medialis

5 kgm.	38.2	15 kgm.	43.8	25 kgm.	45.1
	48.6		44.5		42.3
	41.6		45.9		45.1
	37.1		48.3		45.1
	39.9		49.0		46.2
	43.4		43.8		45.1
	39.9		45.5		45.1
	38.2		42.0		42.3
	40.9		49.0		44.[illegible]
	35.7		47.3		43.5

Biceps Femoris

5 kgm.	50.3	15 kgm.	66.5	25 kgm.	79.1
	46.8		63.0		79.8
	38.2		61.3		71.1
	43.8		68.3		86.8
	53.8		70.0		72.9
	65.9		68.3		75.6
	57.3		63.0		79.8
	46.8		64.8		74.6
	43.8		70.0		73.6
	53.8		71.8		81.5

SUBJECT III - Run II - 75 r.p.m.

Gastrocnemius

50 watts		150 watts		250 watts	
5 kgm. -	60.2	15 kgm. -	67.3	25 kgm. -	78.6
	61.5		68.6		78.1
	62.4		66.0		78.1
	61.1		68.6		71.6
	60.6		69.0		82.5
	60.2		59.9		73.8
	59.8		72.5		75.5
	55.5		62.1		78.1
	60.6		60.8		78.1
	59.3		60.8		65.5

Vastus Medialis

5 kgm.	30.1	15 kgm.	45.6	25 kgm.	43.4
	32.7		43.8		45.6
	30.5		46.0		51.2
	37.8		42.5		49.9
	32.3		35.6		46.4
	31.0		39.5		44.3
	33.5		43.4		43.4
	31.0		41.2		42.5
	36.6		42.5		45.6
	32.3		44.7		41.2

Biceps Femoris

5 kgm.	51.6	15 kgm.	62.9	25 kgm.	78.6
	50.7		66.8		74.6
	53.[illegible]		60.8		68.1
	52.9		58.6		71.2
	52.9		56.4		65.1
	55.5		54.3		76.4
	49.5		65.1		79.0
	55.9		65.1		7[illegible].3
	47.7		60.8		78.6
	58.1		62.9		73.3

SUBJECT III - Run III - 90 r.p.m.

Gastrocnemius

	50 watts		150 watts		250 watts
5 kgm. -	61.8	15 kgm. -	59.5	25 kgm. -	65.6
	62.3		67.7		77.7
	57.1		68.2		72.5
	58.6		64.6		73.5
	57.1		58.4		79.8
	54.5		63.1		76.1
	49.3		60.5		76.1
	56.6		59.5		74.0
	59.7		63.1		77.7
	61.2		62.6		70.9

Vastus Medialis

5 kgm.	41.5	15 kgm.	41.4	25 kgm.	47.3
	33.7		38.8		47.3
	38.9		39.3		47.3
	38.9		41.4		44.6
	35.8		46.5		49.9
	39.4		43.9		47.3
	35.3		40.3		52.5
	38.4		55.8		47.3
	41.5		46.5		49.9
	31.1		45.5		55.1

Biceps Femoris

5 kgm.	61.2	15 kgm.	54.3	25 kgm.	54.1
	57.1		64.6		74.0
	52.9		58.4		74.6
	54.5		64.1		67.7
	57.1		62.0		74.6
	47.7		56.9		73.5
	57.1		64.1		68.8
	57.6		61.0		74.0
	51.9		57.4		67.7
	55.5		64.1		69.3

Fig. 33

TABLE 1. Analysis of variance

Duration = (percentage of revolution muscle is active)

Source of variation	S.S.	dF	M.S.S.	Variance ratio	Significance
S = subjects	43,885·0	2	21,942·5	142·30	0·1%
P = pedalling rates	63·8	2	31·9	—	—
L = loads	29,668·8	2	14,834·4	96·20	0·1%
M = muscles	49,887·4	2	24,943·7	161·76	0·1%
S × P interaction	2,113·9	4	528·5	3·43	5%
S × L interaction	80·6	4	20·1	—	N.S.
S × M interaction	36,022·3	4	9,005·6	58·40	0·1%
P × L interaction	491·4	4	122·8	—	N.S.
P × M interaction	299·9	4	75·0	—	N.S.
L × M interaction	4,726·3	4	1,181·6	7·66	1%
S × P × L interaction	1,146·5	8	143·3	—	N.S.
S × P × M interaction	2,659·4	8	332·4	2·15	N.S.
S × L × M interaction	8,341·6	8	1,167·7	7·57	0·1%
P × L × M interaction	548·8	8	68·6	—	N.S.
Residual	2,467·1	16	154·2	—	—
Total	183,402·8	80	—	—	—

TABLE 2. Mean durations

	Subjects				Load (watts)		
Muscle	I	II	III	All	50	150	250
V. med	48·6	68·6	31·4	49·5	44·2	49·0	55·3
Gastroc	31·2	42·4	38·1	37·2	31·3	38·8	41·6
B. fem.	47·3	63·2	58·0	56·2	44·4	56·8	67·3
All	42·3	58·1	42·5	47·6	40·0	48·2	54·8
Pedalling rate (rev/min)							
60	39·5	60·6	42·1	47·4			
75	44·7	56·7	42·7	48·0		Not significant	
90	42·8	56·9	42·8	47·5			

EMG of cycling coordination - Analysis of Variance

Discussion.

The analysis of variance table shows that the variation in muscle action times between successive pedal revolutions has a probability of 0.404. Though this is not at the same degree of statistical significance as other parameters, it is worth examining the actual measurements more closely. These show that for the 81 sets of 10 consecutive pedal revolution measurements there was a mean action time of 47.64% of a revolution, and an S.D. of 15.46%. If the individual sets of 10 revolutions are examined they each show a range of values between the minimum and maximum measurement recorded. The smallest of these ranges was 3.8%, eg. the actual 10 measurements were: *44.8, 42.3, 44.4, 42.3, 44.0, 42.3, 43.6, 42.7, *41,0, 41.8 and the range of values was 41.0 to 44.8%.

The largest of the ranges recorded was:
50.3, 46.8, *38.2, 43.8, 53.8, *65.9, 57.3, 46.8, 43.8, 53.8 giving a range of values of 38.2 to 65.9% i.e. 27.7%

The mean extent of the 81 ranges for 10 consecutive recordings was 10.2%. Therefore, in spite of the high probability associated with these readings, the average block of ten pedal revolutions showed that, within these, a muscle was active on average for just under half the time, but would vary this proportion by 10%. This does not seem to reinforce the comments concerning the 'high reproducibility' of muscular co-ordination patterns mentioned earlier.

Though of greater statistical significance ($p = 0.076$), the effects of pedalling rate upon muscle co-ordination are very small. At the three rates the mean proportional activityrecordings were:

60 r.p.m.	47.4%
75 r.p.m.	48.0%
90 r.p.m.	47.5%

The other major parameters under investigation (subjects, loads and muscles) had extremely high significance levels (70.1%)

The analysis also shows in its interaction values:

ANOVA REFERENCE

SV i) Subjects varied significantly in their reactions
SM to changes in pedalling rate, and in the co-ordination of muscle groups.

VL ii) The effects of changes in pedalling rate were
VM different for different loads, and also for different muscles.

LM iii) Muscles reacted differently to variations in load.

iv) Subjects reacted very differently to:-

SVL a) the way their velocity effects were altered by load.

SVM b) the way their velocity effects differed between muscles.

SLM c) the way the load effects varied between muscles.

VLM v) Muscles varied very significantly in their reaction to the different effects of velocity upon changes in load.

SVLM VI) Subjects varied significantly in the way their muscle co-ordination adapted through the effects of different loads upon changes in pedalling rate!

This investigation has been concerned mainly with the duration of time that each muscle has worked. Due to lack of calculation time the temporal relationship between the muscles has not been analysed, and to that extent the use of the word 'co-ordination' in the text has not been strictly accurate. In establishing the large and very highly significant differences in the duration that muscles have worked, and that these variations are not standard between pedalling rates, loads and subjects, it can reasonably be postulated that there must be differences in temporal co-ordination of the muscles involved. With the existing data it will be possible to consider the precise temporal pattern of the muscles in each specific revolution and verify this hypothesis (Fig.34); and muscle co-ordination diagrams can be drawn for average and typical conditions for each subject, and compared with Houtz and Fischer (35), who have done similar work (Fig.35). Some of the differences between these will be due to the fact that different saddle height adjustments were used, that toeclips were used, and to other experimental variables. Even if all experimental conditions are standardised, there will still be gross changes in muscle co-ordination between subjects, and predominantly involuntary changes within subjects.

Any examination of muscle energy expenditure during locomotor activities needs to establish the precise length of time that muscle is working, rather than to presume such information (46, 47, 48). Examinations of muscle co-ordination in kinesiological investigations should give full accounts of experimental conditions, and of the range of results obtained (34, 35, 36, 37, 38) OR should specify the degree of 'reproducibility' between successive performances of a skill. For the practical kinesiologist, the range and power of muscle action needs to be known in devising training methods and technique adaptations.

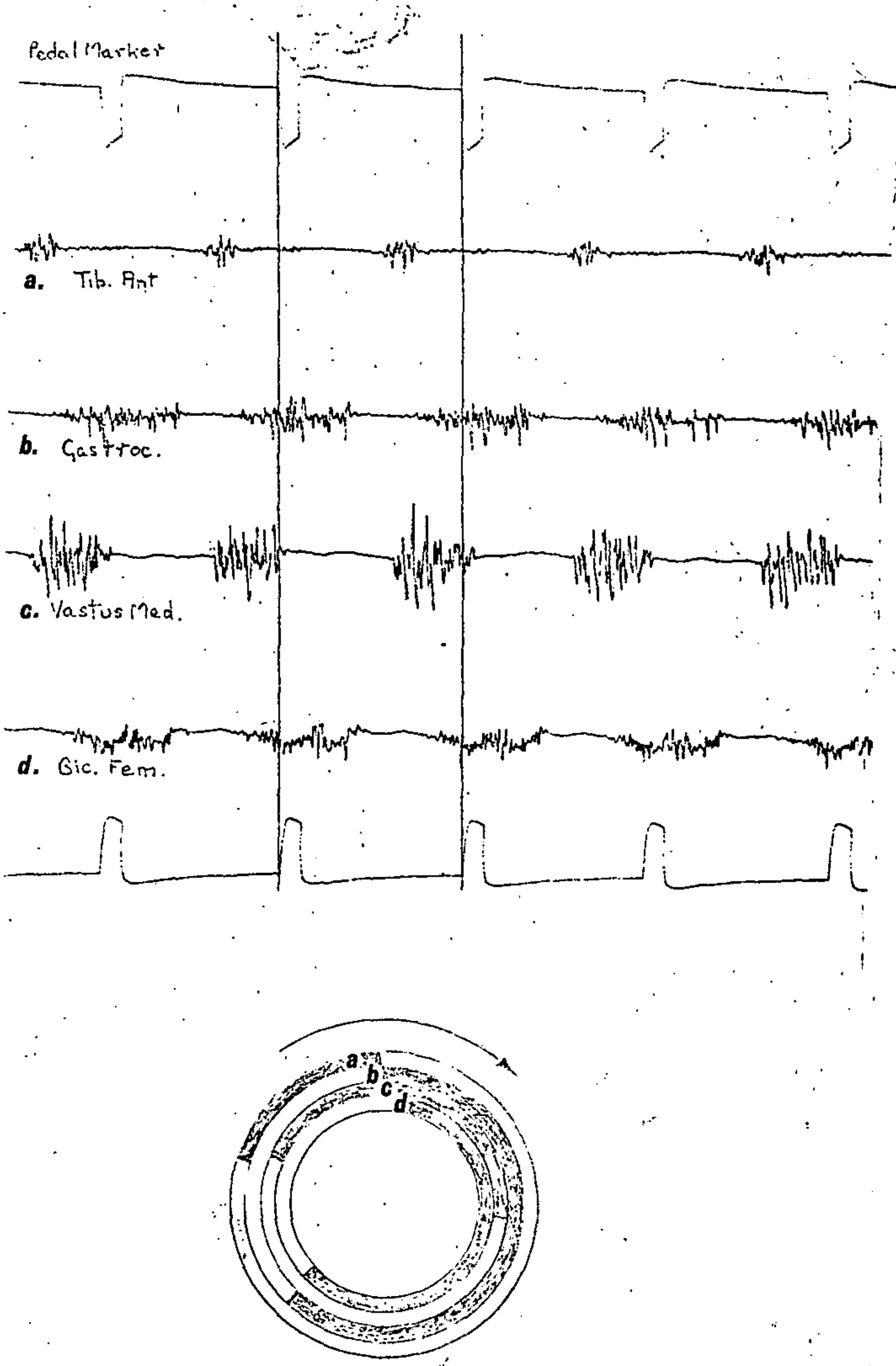


Fig. 34

EMG - temporal coordination of pedalling

Fig. 35

Leg muscle coordination of pedalling

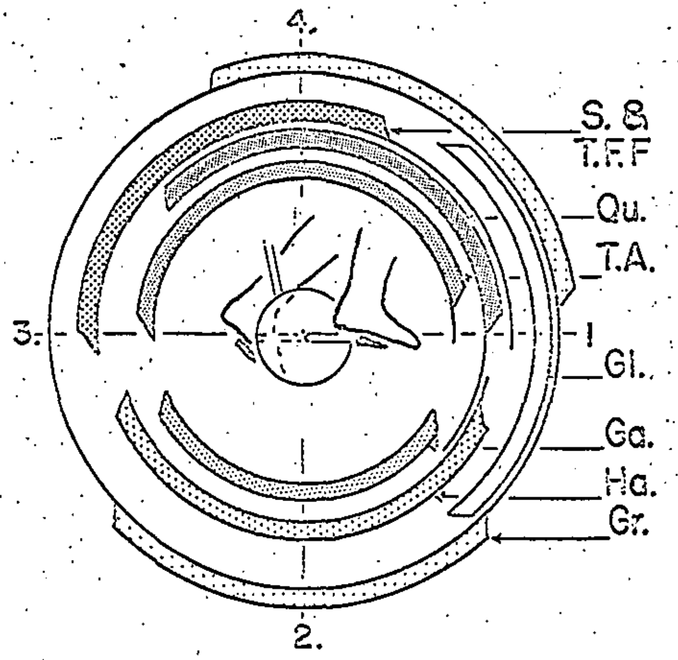


Fig. 6

Summary of muscle-action potentials during one cycle placed on a schematic time course. Greatest activity is confined within double lines, lesser activity continues as single line [Gr., gracilis; S. and T.F.F., sartorius and tensor fasciae femoris (tensor fasciae latae); Qu., quadriceps; T.A., tibialis anterior; Gl., glutaeus maximus and medius; Ga., gastrocnemius; Ha., hamstrings].

Houtz (35)

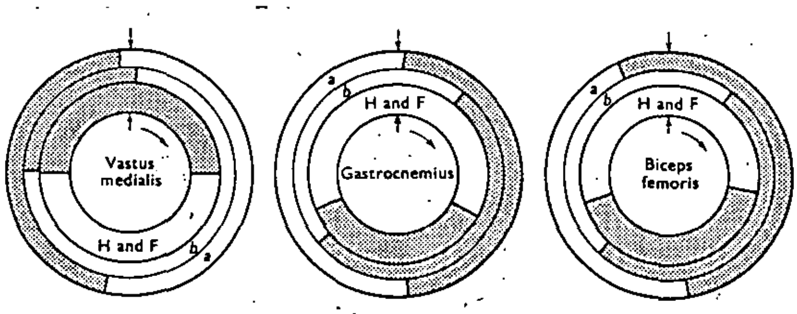


Fig. 1. Diagram to illustrate muscular activity phases during the rotary movement (shaded). (*a*) Most experienced, (*b*) least experienced subject, compared with Houtz & Fischer (1959).

Thomas (11)

It is of interest to consider the reasons for such variations in what might logically have been expected to be a very precisely learned physical skill. Overtraining of locomotor and other motor skills has been justified on the grounds that it 'grooves pathways' of neuromuscular function (49). Such effects may be justified by the apparent similarity between movements - the 'reproducibility' of movements; and may not be due to the intrinsic neuromuscular co-ordination. In the author's experience, athletes have for many years maintained the technique of continuing locomotor activity whilst varying their muscle co-ordination voluntarily; the present work reinforces the view of involuntary changes in co-ordination. When done voluntarily, these changes allow a certain degree of recovery from specific muscle fatigue, and this is possibly achieved also by involuntary changes. However, voluntary changes of co-ordination aim at giving almost complete rest to a muscle, whereas involuntary changes apparently do not. In repetitive locomotor activities, muscles achieve rest periods of varying qualities and quantities during each cycle, and these involuntary changes in muscle activity merely alter the quantity (and perhaps the quality) without affecting the frequency. Bilodeau (50) has studied the effects on power output of continuous cranking as against intermittent cranking, and has shown that continuous cyclic work is the most productive with regard to power output. These results were with untrained subjects, performing hand cranking, and may not be directly applicable to the general situation. There does not seem to be sufficient information to come to any conclusion about the reasons for changes in muscular co-ordination.

Certainly the views of some 'skill' psychologists are pertinent. Poulton has described the 'closed skill' as the building up of a pattern of movement ..... and practising this pattern so that it will become virtually a habit (51). Knapp describes 'grooved pathways' in the formation of such habits ..... learned stereotyped responses' (49). These can be described as the 'associationist' viewpoint, which would be most applicable to such a skill as bicycle pedalling. This, Poulton would call 'a closed skill with predictable requirements'. The skilful performer will be able to vary his method of achieving a highly reproducible locomotor action as a variety of responses to a variety of stimuli. However, the associationist attitude is that the performer learns a great number of habits of pedalling in order to cater for these variations in stimuli.

On the other hand Oldfield takes the viewpoint that 'in a skill the effectiveness of the behaviour is dependent upon the absence of stereotyping. The motor activity must be regulated by, and appropriate to, the external situation." (ref.53). Certainly during bicycle pedalling the external situation regulates the skill to such an extent that it could be considered an 'open skill'. With reference to another locomotor skill (swimming) Hartman has said 'It is always the total organism ..... not just those outer mechanisms that are most conspicuously involved'. These protaganists of 'field theory' of human performance say that both learning and performance of skills demand an insightful approach (54).

As so often happens with human performance the final place of locomotor skills will lie somewhere along the continuum between 'open' and 'closed'. Certainly, some aspects of the skill of bicycle pedalling will remain stereotyped and closed - the 'outer mechanisms' (op.cit.). Just as certainly, the neuromuscular mechanisms involved produce an infinite variety of effector co-ordinations to cope with the infinitely variable requirements of cycling. The feet may continue to move in a circular path, and the knees in a reciprocating arc, but the permutations of neuromuscular co-ordination are immeasurable.

The whole position is nicely summarised by Hellebrandt ([illegible]) in his review of literature concerning motor learning. 'There are many ways in which the same goal can be reached and a man unconsciously (and consciously.... author) picks and chooses among the gamut of those available, easing the burden of fatigue .....; and thus extending the range and sensitivity of his movement vocabulary. The physical therapist, shop foreman, physical educator or coach may wish to impose upon the human subject some precise and specific technique of movement, but an infinitely wise living machine ..... makes its own autonomous adjustments. Instead of surpressing these, we would do well to study them'.

Conclusions

i) There are highly significant differences in the muscular co-ordination of subjects during bicycle pedalling at various rates and against different work loads.

ii) Studies of specific bio-chemical and kinesiological parameters during bicycle pedalling should refer to the precise muscular co-ordination of individual subjects and muscles.

iii) Training for bicycle pedalling should include developmental elements for neuromuscular adaptation to environmental and fatigue changes.

Cardiac and Other Muscular Responses to Heavy Weightlifting

Summary: During the performance of an Olympic lift (two hand clean and jerk) a world champion weight-lifter (Mr Louis Martin) was studied by electro-cardiography, electromyography, cine photography, segmental movement analysis.

Introduction: There seems to have been little published work to examine cardiac and muscular performance during weightlifting as a sport, though there are many references pertaining to lifting techniques in occupational environments - summarised by David et al (55). Electromyography has been used by Stepanov in a physiology-orientated study of the effects of training on weight lifters (56), who restricts his conclusions mainly to the neuromyology of training. Ono (57) has gone so far as to say that his E.M.G. study of weight-lifting was the first to have been done. He used his results to make a Kinesiological evaluation of the various lifting techniques. However, Stepanov Sakharionts (58) and Bearn (59) would contest this statement. Ono experienced some difficulties of precision in that he was unable to define the actual body position at the moment in time, to correlate with his E.M.G. traces. Payne (60) has recently completed a force platform analysis of weightlifting which is of great assistance in any complete analysis of a lift.

E rlier investigations by the author into cardiac function during weight training suggested that a closer examination of a single lift might give valuable results. At this time the weight lifter concerned in these tests was experiencing difficulties during certain phases of his lift, and the author decided to make a full kinesiological investigation of the major leg muscles involved in lifting.

Equipment:

i) An 8 channel pen oscillograph (Offner Type T) comprising a d.c. amplifier and multiswitching system suitable for electro encephalography.

ii) 12 electrode lead pairs, with banana plugs and 1 cm. circular domed electrodes pressed from 1 mm. silver sheet.

iii) 20 ml. syringe with No. 1 serrated tip needle. 1 cm. circular double side adhesive discs, Cambridge electrode jelly, 1" elastoplast strips, Rolls razor cotton wool, alcohol, 1" circular adhesive plasters.

iv) Olympic weight lifting bar and 165 kg. of weights.

v) Bolex 16 mm. cine camera, with 16 mm. lens, 1/32 sec. shutter speed and Kodak Tri X reversal film, mounted on a tripod with camera locking device.

vi) 1.5 volt input signal from shutter closures onto oscillograph trace.

vii) Segmental analysis 'Speedframe' marked in 1 ft. divisions.

viii) 1 sec. stopclock, 1 minute stopwatch.

The oscillograph was serviced and calibrated according to manufacturer's handbook. Paper speed was checked and found to be 20.1 mm. per second. Shutter closure signals and 1/10 sec. timing signals were checked. Camera was mounted, aligned, focussed and locked in such a way as to include the complete sagittal plane of the lifter and segmental analysis frame. Camera was fully wound before each lift. Stopwatch and stopclock were both checked and found to be correct over a time range of 55 seconds. Syringe was filled with electrode jelly, care being taken to exclude air bubbles. 24 adhesive discs were prepared, and 24 2" x 1" strips of elastoplast.

<u>Method II</u> <u>Subject Preparation and Procedure.</u> The subject was a 32 years old expatriate Jamaican Negro, and had negligible hair on the skin over the muscles being investigated - shaving was not necessary. The skin was rubbed firmly with cotton wool impregnated with alcohol to clean the surface. The subject lay on a plinth and each muscle electrode site was determined by contracting the muscle over a range similar to that done during a lift. Two adhesive discs were fixed at the site of maximum peak on the muscle belly, 2.5 cm. apart and along the general line of the muscle fibres. The serrated needle syringe was rotated in the centre of each disc to pierce the epidermis, and this small hole

was filled with electrode jelly. The dome electrode was filled with electrode jelly, and carefully but firmly applied to the adhesive disc. Any electrode jelly escaping through the hole in the centre of the electrode was removed. The electrode was then very firmly taped with an elastoplast strip, and heavy pressure applied digitally to the electrode to obtain maximum adhesion. The same procedure was used in fixing an earth electrode to the anterior superior iliac crest.

The E.C.G. electrodes were attached in a similar fashion immediately inferior to the Pectoral muscle in a position where there was least subcutaneous soft tissue. All electrode resistances were checked, and found to vary between 5 - 7 k. The leads were then taped to run to a common point at the left hip, and then taped together to run to the oscillograph plug box.

The muscles concerned in this preparation were:

Left Leg: Tibialis Anterior, Lateral Gastrocnemius, Vastus Medialis, Lateral Biceps Femoris, Gluteus Maximus

Trunk: Heart, Rectus Abdominis, Erector Spinae, Pectoralis Major, Middle Deltoid.

White circular adhesive discs were placed on the right side at the external malleolus, tibial plateau, greater femoral trochanter, deltoid in line with head of humerus, lateral condyle of humerus and the end of the Olympic bar.

The subject did two preparatory lifts with 140 kg. During this time the oscillograph traces were checked on all channels, and for all muscles by selector switching. The total movement time was chekked, and the positioning of segmental analysis frame.

The subject then did four strict Olympic style lifts, at 140, 147.5, 160 and 167.5 kg. The procedure for each of these was:

i) Subject stood about 7 ft. from the bar until he felt ready to lift.

ii) Subject said 'Now' at which time the camera was started, each shutter closure being marked on the oscillograph trace.

iii) The preparation, lift, replacement and recovery were performed and all parameters were continuolly monitored.

iv) The camera was stopped after ca. 45 seconds, and recording ceased.

The leg muscles and E.C.G. were monitored during all four lifts. The other muscles were sampled at least once each. Figs. 36 + 37.

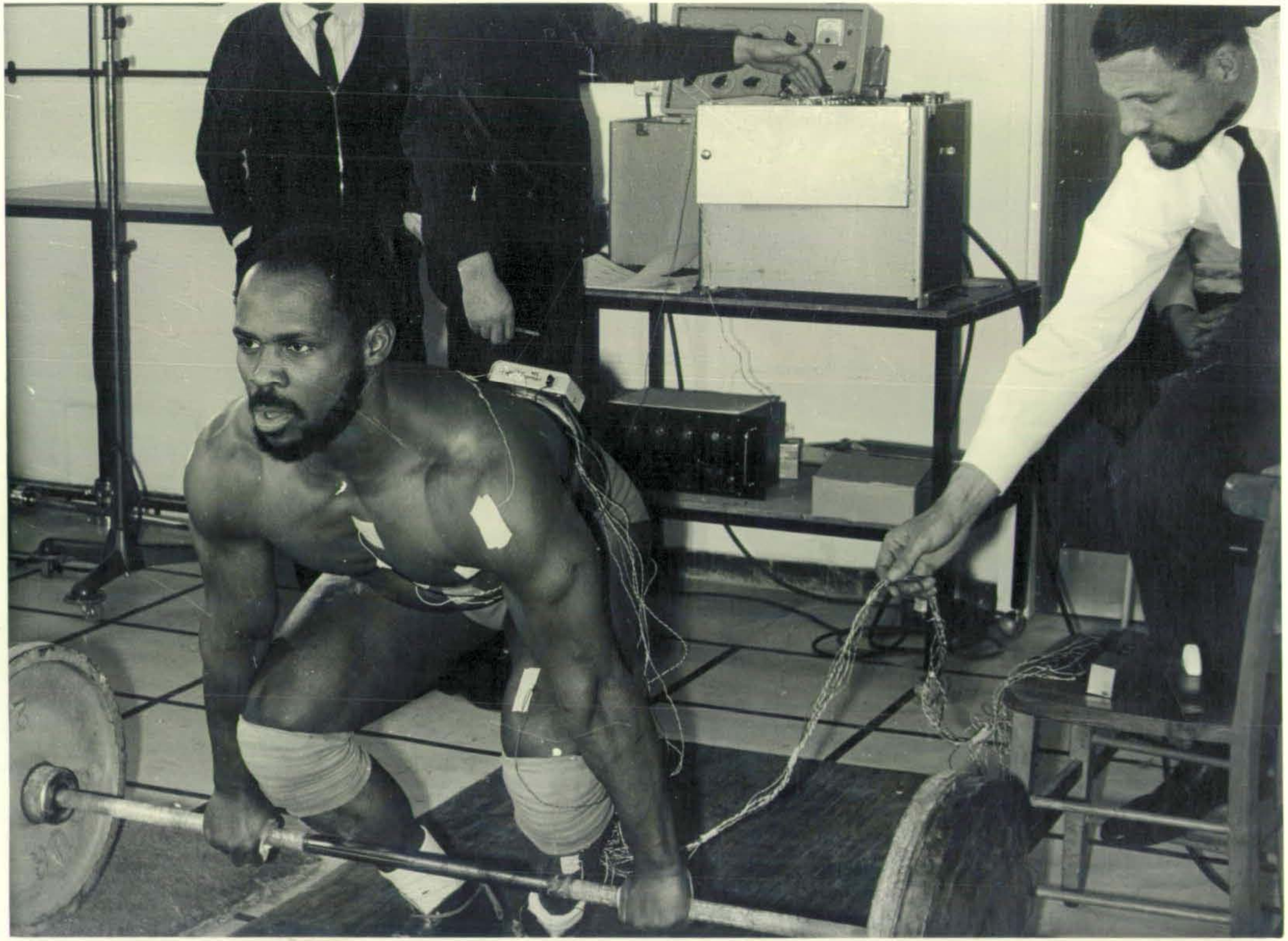
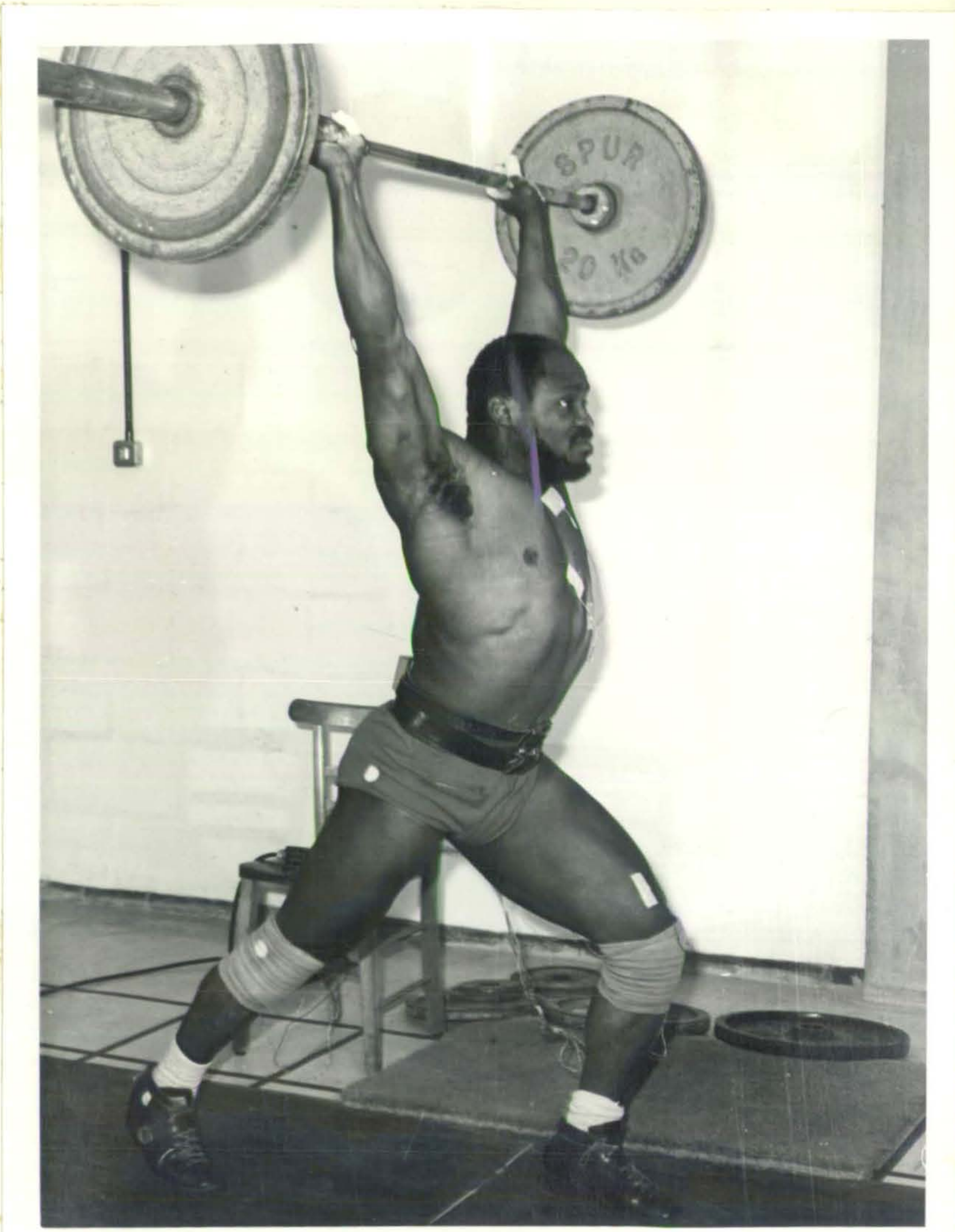


FIG. 36

FIG. 37



Results. An example of the results available from such experiments is shown in Fig.38*. Here, the cinefilm has been projected via an angled mirror onto a drawing board, and line tracings made (subseqently scaled down) of the lifter's exact position at certain key points during the lift. The segmental analysis has revealed the path of the bar, which is shown as a perpendicular height in this diagram. The numbering of the shutter closures then permits an accurate matching of the oscillograph trace to these drawings. The time markers allow very accurate measurements of the time duration of each heart beat, and the configuration of the wave is significant at certain stages of the lift. These heart rate measurements are shown in Fig. 40

Using this data, it is possible to develop a kinesiological picture of the major lower leg muscles during the lift. (Fig. 39)

* I am grateful to Mr. Brian Saville, Commonwealth Scholar, Department of Ergonomics and Cybernetics, Loughborough University of Technology, who made the line drawings.

ANALYSIS OF WEIGHT LIFTING ACTION (WEIGHT 107.5 kg)

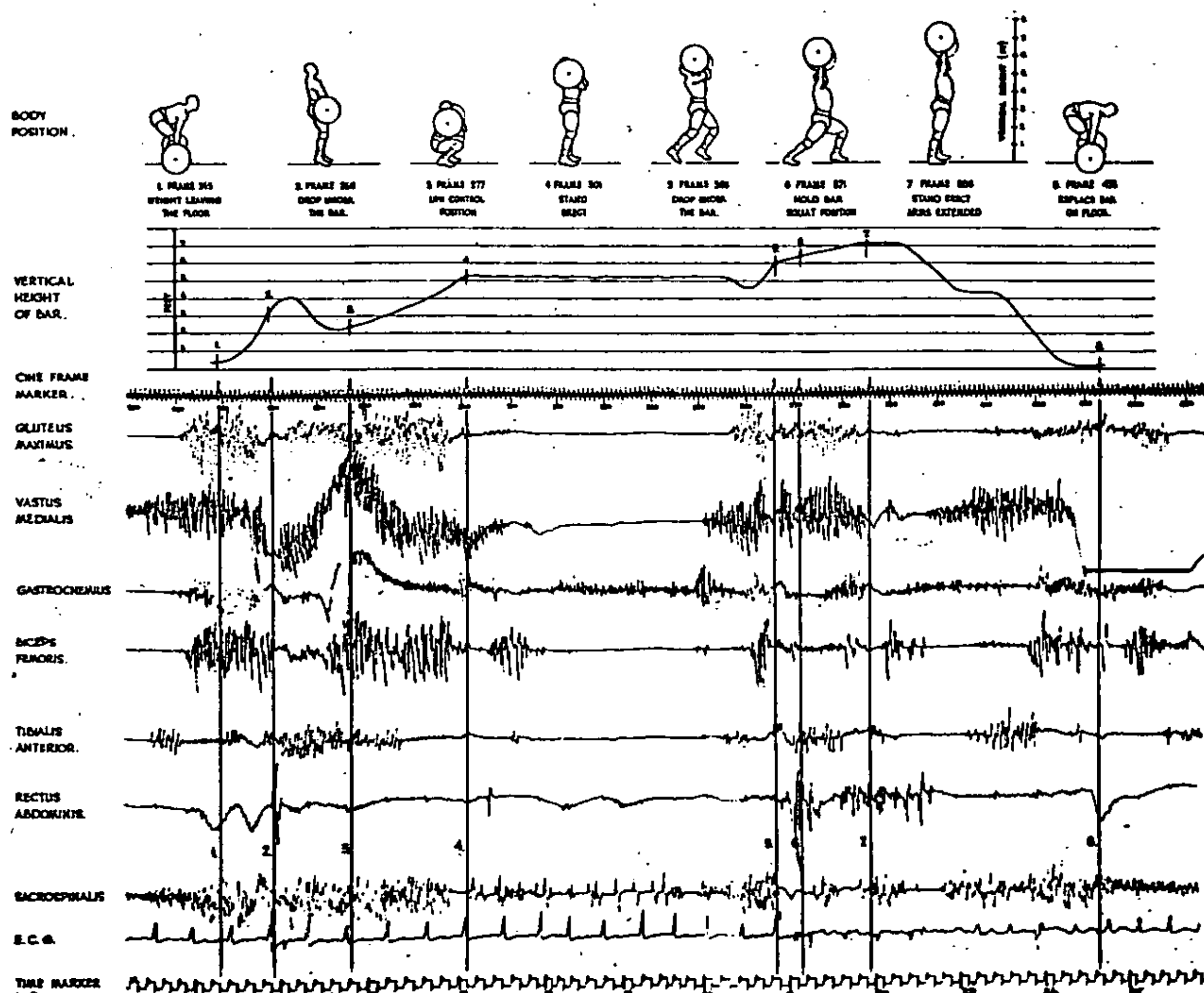


Fig. 38.

Erratum. For Abdominas Read Abdominis

FIG. 39

MOVEMENT	STARTING POSITION	TYPE	MUSCLE	FUNCTION	REMARKS
Initiating lift Stage I 249	Crouched, Gripping bar	Extension against resistance	Gluteus Maximus	Maintenance of hip angle	The major part of the leg movement takes place before the bar leaves the floor. Some body momentum is absorbed by a bending of the bar by 2-3", so that the Centre of Gravity of the bar has started to move before the discs break contact
			Vastus Medialis	Extension of knee, raising hip	
			Gastrocnemius	Slight ankle extension, then maintenance of lower leg position	
			Biceps Femoris	Maintenance of hip angle	
			Tibialis Anterior	Very slight postural effect	
			Rectus Abdominas	Negligible effect	
			Sacrospinalis	Maintenance of spinal extension	
Achieving bar height Stage 1 2 (249 - 260)	Semi-crouch	Extension against resistance	Gluteus Maximus	Extension of hip, strong in early stages	The bar is given as much upward momentum as possible, so that it continues to move upwards after the muscles relax. The majority of this phase is achieved by hip extension, and some spinal hyper-extension
			Vastus Medialis	Final extension of knee	
			Gastrocnemius	Extension of ankle, raising heel	
			Biceps Femoris	Extension of hip, strong at all stages	
			Tibialis Anterior	Burst of postural activity before relaxing as heel raises	
			Rectus Abdominas	Negligible effect	
			Sacrospinalis	Strong spinal hyper-extension	
Dropping under bar to catch position 2 2 1/10 (260 - 262)	Erect	Relaxed flexion	Gluteus Maximus	Negligible effect	This movement is produced by gravity, and also by the reaction impetus given to the body by the arms pulling the bar upwards. The Rectus Abdominas activity is probably to achieve the initial pelvic tilt which allows the lower limbs to fold under the weight of the body.
			Vastus Medialis	Negligible effect	
			Gastrocnemius	Negligible effect	
			Biceps Femoris	Negligible effect	
			Tibialis Anterior	Negligible effect	
			Rectus Abdominas	Heavy burst of activity	
			Sacrospinalis	Very little activity	
Catching and arresting the downward fall of the bar 2 1/10 3 (262 - 277)	Semi-crouch	Eccentric return from extension	Gluteus Maximus	Control of hip flexion	This movement is a gradual absorption of the bar's downward momentum, in which the knee ligaments and brac[es] play an important part. Th[e] lifter attempts to make the next movement an elastic recoil from this
			Vastus Medialis	Heavy activity at beginning and end of knee flexion control	
			Gastrocnemius	Very little activity	
			Biceps Femoris	Gradual increase in control of hip flexion down to full squat	
			Tibialis Anterior	Maintenance of ankle dorsiflexion	
			Rectus Abdominas	Negligible effect	
			Sacrospinalis	Maintenance of spinal extension	
Rising with bar on shoulders 3 4 (277 à 301)	Full squat	Extension against resistance	Gluteus Maximus	Hip extension	The 'sticking point', at which this lifter would normally fail, is shown at frames 289-291 where Vastus Medialis activity decreases momentarily. This muscle's activity is prolonged while the knee is locked in the erect position.
			Vastus Medialis	Knee extension	
			Gastrocnemius	Slight postural activity (with Tibialis Anterior)	
			Biceps Femoris	Hip extension	
			Tibialis Anterior	Slight postural activity (with Gastrocnemius	
			Rectus Abdominas	Negligible effect	
			Sacrospinalis	Maintenance of spinal extension	
Standing 4 4¾ (301 - 349)	Standing	Postural	Gluteus Maximus	Nil	A good example of a skilful performer's ability to achieve muscular relaxation. Co-ordination of Tibialis Anterior, Gastrocnemius and Biceps Femoris being sufficient to maintain a total of ca. 600 lbs. in balance.
			Vastus Medialis	Nil	
			Gastrocnemius	Maintenance of slight ankle dorsiflexion	
			Biceps Femoris	Nil (apart from one isolated postural burst)	
			Tibialis Anterior	Nil (apart from one isolated postural burst).	
			Rectus Abdominas	Negligible effect	
			Sacrospinalis	Maintenance of spinal extension	
Initiation of upward momentum 4¾ 4 15/16 (349 - 364)	Standing	Controlled flexion then extension against resistance	Gluteus Maximus	Hip extension	The weight is lowered sufficiently to allow upward momentum to be developed. Very fine co-ordination here.
			Vastus Medialis	Controlled knee flexion, then extension	
			Gastrocnemius	Unlocking of knee, then postural, then ankle extension	
			Biceps Femoris	Unlocking of knee, then hip hyper-extension	
			Tibialis Anterior	Postural co-ordination with Gastroc.	
			Rectus Abdominas	Nil	
			Sacrospinalis	Spinal hyper-extension	

Dropping under bar to catch position 4 15/16 5 3/8 (364 - 367)	Standing	Radically relaxed stiffness	Gluteus Maximus Vastus Medialis Gastrocnemius Biceps Femoris Tibialis Anterior Rectus Abdominus Sacrospinalis	After initiation of hip extension, then relaxation Nil After a burst of activity to lift foot off floor, relaxation After initiation of hip extension, then relaxation Dorsiflexion of ankle when foot is clear of ground Small amount of activity Heavy initiation of spinal hyper-extension, then relaxation	The body drops quickly under gravity and the position of the arms pushing upwards on the bar. The feet are taken off the floor, and the leg split is initiated violently. Since the E.M.G. is of the left leg, the hip flexors would be responsible for that movement, which have not been monitored.
Catching the bar in the split squat 5 3/8 6 (367 - 371)	Half squat	Maintenance of extension against resistance	Gluteus Maximus Vastus Medialis Gastrocnemius Biceps Femoris Tibialis Anterior Rectus Abdominus Sacrospinalis	Prevention of further hip extension Very heavy activity at the catch, a slight relaxation, then maintenance of posture Little postural activity Slight activity in controlling hip extension Some activity in maintaining dorsi-flexion Very heavy activity in controlling spinal hyper-extension Nil	In this catch position there is little or no downward movement with the bar. For a fuller analysis BOTH legs should be monitored. This subject's squat was not as deep as some because of chronic knee degeneration. This combination of Rectus Abdominus activity, arm elevation and inverted E.M.G. is of interest
Rising with bar above head 6 6 3/8 (371 - 385)	Half squat	Extension against resistance	Gluteus Maximus Vastus Medialis Gastrocnemius Biceps Femoris Tibialis Anterior Rectus Abdominus) Sacrospinalis)	Hip extension Knee extension Activity as left leg is lifted and replaced Hip extension, particular when foot is lifted Activities as right leg is lifted and replaced Co-ordination activity to retain trunk balance	Fine co-ordination of pro and antagonists as lifter takes two steps to achieve erect standing position. Tibialis Anterior v. Gastrocnemius and Sacrospinalis v Rectus Abdominus.
Holding the [illegible] position 6 3/8 7 1/8 (385 - 389)	Standing	Maintenance of posture	Gluteus Maximus Vastus Medialis Gastrocnemius Biceps Femoris Tibialis Anterior Rectus Abdominus Sacrospinalis	Nil Nil Nil Nil Postural burst co-ordination with Gastrocnemius inactivity Control of hyper-extension of spine Some activity co-ordinated with Rectus Abdominus	Excellent balance position. Segmental analysis shows bar and lifter Centre of Gravity in vertical linearity. E.M.G. remains inverted while arms above head.
Lowering bar to shoulders 7 1/8 7 1/3 (389 - 402)	Standing	Eccentric return from extension	Gluteus Maximus Vastus Medialis Gastrocnemius Biceps Femoris Tibialis Anterior Rectus Abdominus Sacrospinalis	Negligible Some activity mainly as bar reaches shoulders, to absorb shock Postural activity Stabilisation of hip position Nil Control of spinal hyper-extension Some activity co-ordinated with Rectus Abdominus	The pause in this position is very much briefer than it was in position 4, and the significant difference in E.M.G. trace is in the Vastus Medialis, which is controlling the slight bent knee position - necessary because the weight is passing quite quickly through this phase
Lowering bar to ground 7 1/3 7 7/8 (402 - 429)	Standing	Eccentric return from extension	Gluteus Maximus Vastus Medialis Gastrocnemius Biceps Femoris Tibialis Anterior Rectus Abdominus Sacrospinalis	Gradually increasing eccentric activity controlling hip flexion Strong eccentric control of knee flexion Little activity until end of movement - maintaining ankle position Eccentric control of hip flexion Control of ankle dorsi-flexion Negligible Eccentric control of spinal flexion	The co-ordination of Tibialis Anterior and Gastrocnemius is interesting as the body sways to accommodate the downward moving bar. Unfortunately, the Vastus Medialis trace is lost just at the end of the movement. It is possible that the large burst of Biceps Femoris activity from 425-430 is to draw the femur back from the path of the bar, thus extending the knee.

FIG. 40

Cardiac Pulse Frequency Measurements during a 167.5 kg. Lift

Each pulse is expressed as an equivalent r.p.m. if it were maintained for 1 minute.

Time	r.p.m.	Time	r.p.m.	Time	r.p.m.
0 secs.	121	10 secs.	119	20 secs.	134
	124		121		140
	126		132		134
	126		132		157 * d
	126		129		157
	129		117) * b.		137
	129		117)		143
	129		132)		143
	126		119)		140
	121		121		153 * e.
5 secs.	113 * a.	15 secs.	123		140
	111		123		143
	115		121		157 * f.
	115		123	25 secs.	157
	117		126		157
	117		126		157 * g.
	124		134		157
	126		157 * c.		157
	121		157		157
	126		124		?
	126		143		164
			143		149
					164
					164
					160
				30 secs.	153
					149
					178
					153
					149
					153
					153
					153
					157

Difference in rate between successive pulse $\bar{x}$ = 5.4 r.p.m.
S.D. = 6.5. r.p.m.

- * a. Has been in crouch position 2.5. seconds
- * b. Sinks back to lowest squat and begins to lift
- * c. Erect position reached, bar on shoulders
- * d. E.C.G. inverted, erect position, arms above head
- * e. Bar reaches shoulders on way down, erect
- * f. Bar reaches floor, stooped position
- * g. Stand up, no weight

Discussion

In his E.M.G. analysis of the arm and pectoral girdle in weight lifters Zakhariants (58) concluded that top grade performers achieve better co-ordination of movements as a result of their rich motor experience; they are able to concentrate considerable muscular effort at the right moment and to relax their muscles during individual phases in the execution of a movement. This has been observed by this author in earlier work on trampolining, and is nicelyshhown in the present weightlifting traces (Fig.38), see stages 2 (260), 4½ (330), 5 (366), 7 (386). Individual muscles demonstrate the facility of interposing sudden and complete periods of E.M.G. silence of only 1/10 th. second within periods of very great activity. Relaxation periods of longer duration, e.g. 3 seconds for Gluteus Maximus, are probably integral to the performer's resting and marshalling of forces in preparation for another massive effort. It is unlikely that the very short pauses have this main function, and it is more likely that the relaxation of tension is aimed at facilitating the initiation of sudden and/or powerful movements by antagonist muscles and/or gravity. As soon as this initiation has been made, the muscles are then called into eccentric action to control the movement which by then has gravity as the prime mover. It is possible that this EMG. silence is only apparent, and that electromuscular activity beyond the frequency range and outside the amplification level of this particular electromyograph is in fact taking place. The precise phasing of the recorded E.M.G. fits the mechanical analysis so well that it is probable that even if some E.M.G. activity is being missed, it is unlikely to be of significance in this gross muscular movement analysis.

Davis (62) in his discussion of lifting mechanics, noted that 'above certain weights (of the order of 50 kg.), the lifter may convert from a knees bent to a stooping posture during the lift. Indeed there may be a weight limit of about this magnitude above which weights cannot be lifted in the squatting or knees bent posture.' These remarks were relevant to general working donditions, and 50 kg. to a normal worker would probably have the same effect as perhaps 100 kg. to an immensely strong weight lifter. However, the principles may apply equally well to both when lifting at or near maximal weights. Certainly with this subject, the majority of the preliminary knee flexion had disappeared before the weight left the floor EVEN THOUGH THE SUBJECT'S PROFESSED TECHNIQUE WAS DESIGNED TO AVOID THIS. Close analysis of the cine film shows that the spinal extensor muscles still played a mainly stabilising function, in maintaining the flat or hyper-extended spinal configuration. The main part of the body movement, and thus the weight movement, comes from hip extension. The E.M.G. trace at this stage (1 - 2) shows a decreasing effort by Vastus Medialis, and fairly constant Biceps and Gluteus Maximus activity. It may also be that pneumatic mechanisms are important at this stage, a point made by Davis (3). The decreased E.C.G. amplitude is probably indicative of increased intra-thoracic pressure, and the next series of experiments with this subject will include abdominal pressure telemetry to illuminate the problem.

In the lifting of such massive weights, it is more likely that the very nearly straightening of the legs is a necessary manoeuvre to remove the knees from the path of the ascending bar. The original bar inertia is certainly overcome (whilst the bar is bending) with the aid of strong knee extension (this point being shown quite clearly in a force platform analysis of this movement by Payne - personal communication Fig.41); but the almost exactly vertical bar path, which is also closely coincident with subject Centre of Gravity path, dictates the early withdrawal of the knees. In doing very heavy squat movements, such as between stages 3 - 4, the achievement of full knee extension is a much more gradual process. Here, of course, the ascending bar path does not necessitate withdrawal movements of the knees. However, this is the point at which the lifter would normally fail, and the acceleration of the bar as indicated by the vertical height/time graph is much smaller during this stage. The body positions and knee and hip extension characteristics are very similar between these two lifting movements, and the ability of the lifter to achieve approximately twice the power during the first stage that he can in the second may be a fortuitous result of the posturally necessary knee <u>then</u> hip extension technique used.

Floyd and Silver (63, 64) have shown electromyographically that there is little muscular activity in maintaining the erect balanced position. The present work indicates that this is true even when the subject is balancing a total of well over 200 kg., shown in stage 4 - 5 - at least for the muscles of this investigation.

The reproducibility of muscular co-ordination has already been discussed at length c.p. (pages of previous cycling paper). Weight lifting can be described as a closed skill, with predictable requirements, and as such it could be anticipated that the patterns of

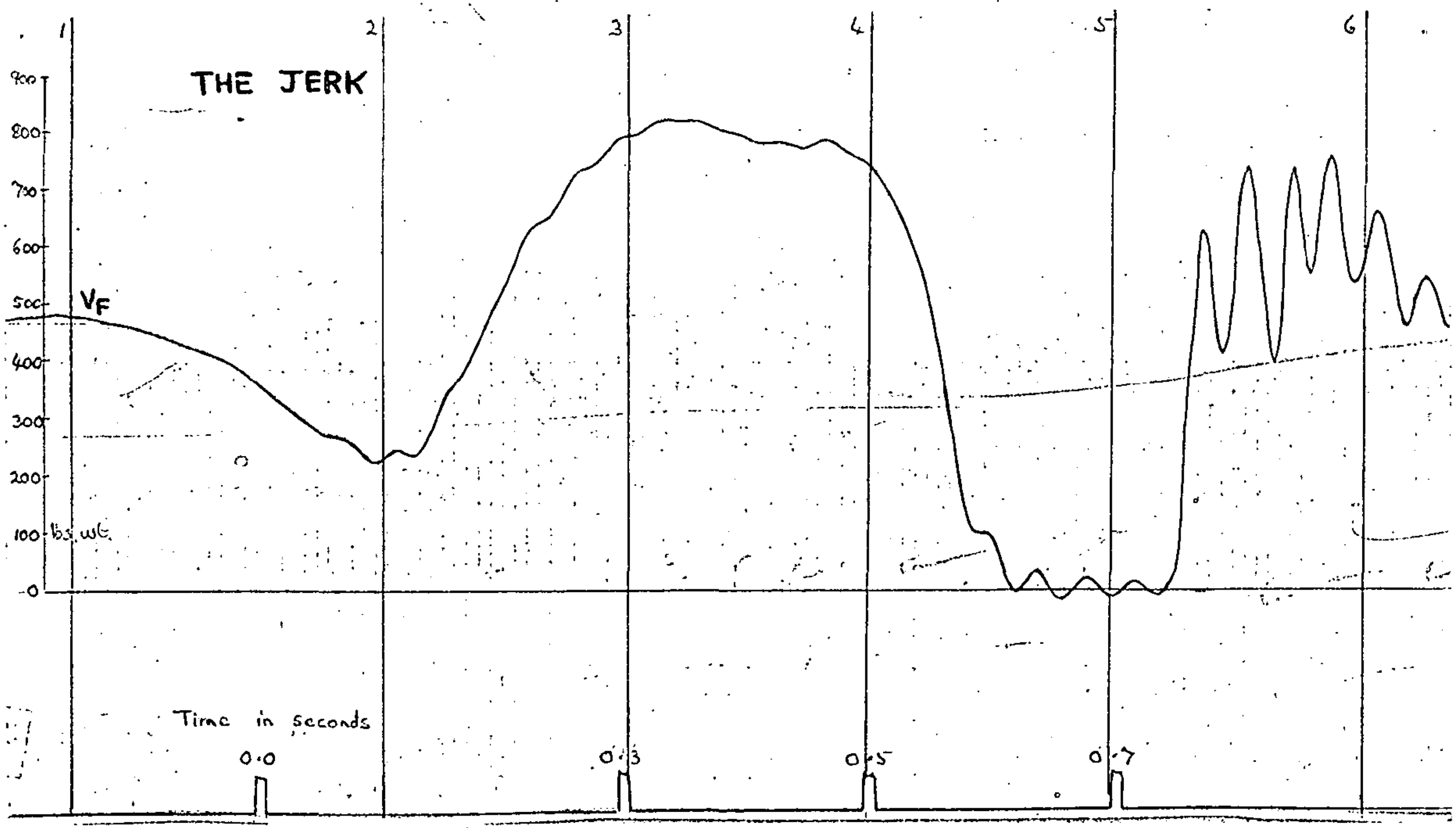


FIG. 41

Force platform record of weightlifting (Payne) muscular co-ordination would be quite reproducible. Ono (58) notices the difference in E.M.G. amplitudes between repetitions of the same lift using different weights, in line with generally held opinions that integrated E.M.G. is proportional to the level of muscular activity. The present study shows, in addition to amplitude changes, quite marked variations in pattern of activity at different resistances; not only of a temporal nature but also of a phasing nature. These are quite different to those observed for locomotor activity in an earlier work (10,11), and can be seen in Fig.41b and represent actual alterations in body movement patterns, shown in cine analysis. This agrees with Ono's statement that 'the co-ordination of acting muscles occuring on lifting to one's 100% capacity is observed only at this very situation, but not at any other conditions'. Further to this, the co-ordinations will also vary between successive repetitions of lifts with any given weight. As Saunders (65) has said, "When considered in detail, the adaptation of an individual even to a simple highly defined task, is unique to that individual with respect to his capabilities and limitations".

The pulse rate records (Fig.40) demonstrate great cardiac tolerance. Earlier experiments had revealed that this subject had typical cardiac reactions to various phases of his weight lifting, particularly in varying his pulse rate reactions to different types of effort, different lengths of rest and different preparations for lifting (page 34). This study showed that:

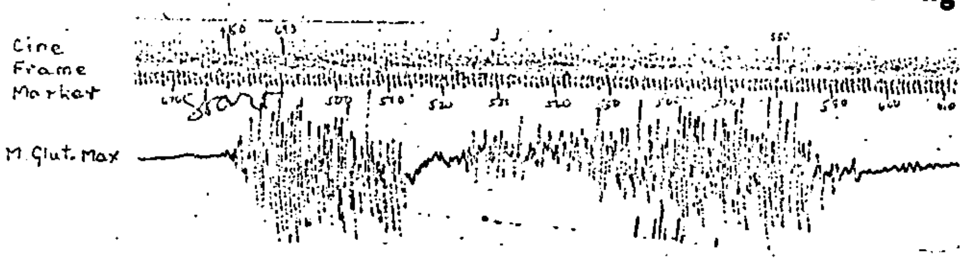
i) bending down did not immediately affect rate

ii) rate lowered at critical preparation points

iii) significant rate increase on achieving erect position

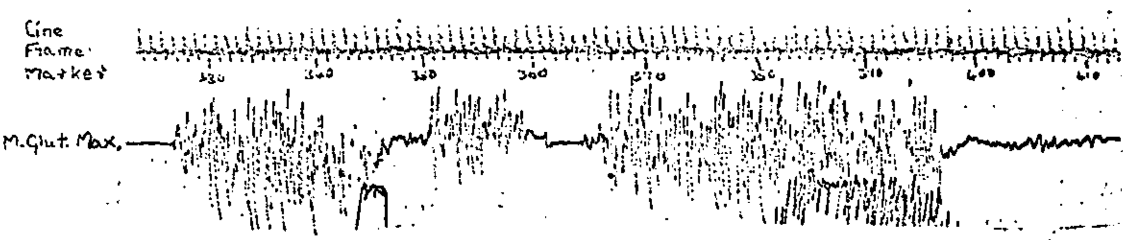
Fig. 41 b

140 kg



Changes in EMG pattern when lifting two different weights

160 kg



iv) no significant increases during effort

v) inversion of wave as arms and weight were elevated above shoulders

vi) significant rate increase as subject stoops to replace bar

vii) oscillating plateau of rate for 10 seconds after exercise

The unusual form of the trace mentioned in V. was almost certainly due to the electrode placing. Previous investigations had not revealed E.C.G. wave inversion during similar activity. During such activity, the heart's positional relationship with the electrode sites will change, and cause such reversals of polarity. It is not certain whether wave fluctuations at various points are artefact or extra systolic effects. However this subject had no previous history of such effects during extensive periods of continuous E.C.G. monitoring in weightlifting sessions, or work capacity tests on a bicycle ergometer; and the reasons are probably artefactual. The information content of the present records is very great, and only a few points have been discussed in any detail. The system of acquiring and presenting the information as in Fig.38, has lent itself to easy duplication and distribution of the record. As such, many kinesiologists and coaches, have been able to use the information for theoretical analysis, and practical field application.

The subject and his coach were able, with the author, to undertake an exhaustive and valuable analysis of the lifting technique, which led to some alteration in technique (particularly of foot placing and effort phasing), which were followed by increased lifting performance. It should also be mentioned that the subject reacted beneficially to the psychological effects of such scientific enquiry.

Conclusions :

1. Simultaneous E.M.G., E.C.G., cine film and segmental analysis is a valuable aid to the understanding of human motor performance.
2. The skilled subject is capable of achieving very short periods of E.M.G. silence during extended periods of great activity.
3. Great weights may be lifted from a stooped position very efficiently by a skilled performer whose spine is maintained in hyper-extension throughout the lift.
4. Very heavy weights are lifted most easily if the path of the Centre of Gravity of the weight is closely coincident with the perpendicular line of force of the lifter.
5. There is little muscular activity when a skilled subject maintains an erect standing position carrying a very heavy weight.
6. Muscle co-ordination patterns are not closely reproducible between successive repetitions of a lift using constant loads, or between similar lifts using different loads.
7. Cardiac rate responses to work done while lifting heavy weights are subject to varying time lags and follow different correlation constants. These are dependant upon the type, duration, periodicity and load of the lift - and upon physiological factors such as held inspiration, intra-thoracic pressures, anatomical disposition, etc.

Epilogue

This work has sought to establish a two way link between ergonomics and physical education within the field of physiological assessment. Its author has covered a broad spectrum of physical motor performance and discovered a fascinating infinity of avenues of research; also he has become convinced that great advances in the understanding and development of human motor performance will occur in the near future as these avenues become insightfully explored. Due to the shortness of time available for such work, some topics did not receive the fuller examination that their importance warranted, especially:

i) Effects on muscle co-ordination patterns by extraneous factors

ii) Methods of obtaining, evaluating and presenting data concerning human motor performance.

iii) Cardiac reactions to exercise, and the establishment of reliable cardiac performance tests.

The author hopes to have the opportunity of developing his work in these fields, especially since there is a growing need for such information within the scope of Physical Education.

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APPENDIX

Titles and Some Examples of the Author's Published Papers and Articles

XXIV Int.Cong. of Phys.Sciences, 1968, Hamley,E.J., Thomas, V., Electromyographic Analysis of Leg Muscle Co-ordination during Bicycle Pedalling.

Cycling Journal, January 7, 1966, Thomas,V., Saddle Height.
February 26, 1967, Thomas,V., In Search of a Definition.
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XXIV INTERNATIONAL CONGRESS OF PHYSIOLOGICAL SCIENCES

1968

ELECTROMYOGRAPHIC ANALYSIS OF LEG MUSCLE COORDINATION DURING BICYCLE PEDALLING.

E.J.Hamley and Vaughan Thomas, Dept.Ergonomics, Loughborough University, England.

Analysis of skilled and unskilled subjects pedalling a bicycle ergometer showed significant differences in the pattern and duration of activity of their four main leg muscles (Tibialis anterior, Gastrocnemius - medial head, Vastus medialis and Biceps femoris - long head). The results indicate that unskilled performers show more consistent repetition of the myogram but utilize their muscles in a markedly different pattern from the skilled performers who show considerable variation in muscle interplay. This interplay produced good augmentation between muscles and marked economy of high activity duration when working against higher loads. Three loads (50, 150, 250 watts) and three pedalling rates (60, 75, 90 rpm) were tested. In general increased loads resulted in increased duration of activity. Skilled performers showed more obvious economy of activity at higher loads and pedalling rates. Their myograms were more closely related to loads; different pedalling rates for handling the same load caused little change in pattern. The myogram also altered with posture. Changes in saddle to pedal distance above or below 109% of leg length (Hamley & Thomas, J.Physiol.1967, v 191, 55-57P.) caused more activity and changed both duration and relative position of activity in the cycle action. Our records indicate that there are considerable skill and posture factors in the dynamics of the bicycle ergometer. These must be considered when assessing the work output of unskilled performers.

IN SEARCH OF A DEFINITION

THE sport of cycling is full of gimmicks and old wives' tales and there is no aspect of the game that is clouded in more mystery and about which more rubbish is talked than "souplesse" in English words, smoothness, or fluidity of movement.

The first difficulty one encounters is in defining the term, and I have taken some trouble to ask eminent cyclists and coaches what the word means.

The most common reaction is a vague spluttering, and then some indeterminate waffle about how *souplesse* is obtained rather than what it is.

I shall attempt to overcome the difficulty by discussing the mechanics of cycling from first principles, hoping to arrive at *souplesse* before very long.

As with the car, we feed fuel into the body, which burns fuel to make power, giving by-products (heat, water, carbon-dioxide or monoxide and residual substances, etc.).

This combustion is a fascinating operation, about which racing cyclists should be well informed, but it is not the subject of this article. Our concern is with the transmission of this power into moving the vehicle.

Through a system of levers, both the car and the body convert this power into movement. However, the RATE at which fuel is burnt up depends upon the speed, mechanical efficiency and gearing of the engine and vehicle.

In general, higher gears and lower revs mean a saving of fuel, but this doesn't provide quick acceleration and needs a stronger propulsive unit.

That U.S. study!

Where the machine is being designed for racing, mechanical efficiency with regard to fuel consumption becomes of less importance, with quick acceleration and high cruising speeds being obtained from efficient gear-ratios and high power-to-weight ratios.

These are all simplified facts which apply equally well to motor car and racing cyclist: it is there that the similarity tends to become obscured by old wives' tales.

Whereas we can put a motor racing engine on a test bed and, through experiment, work out the most suitable gears and the most efficient rate of revolving the drive shaft, this is a long and arduous business with cyclists.

Studies have been done in the United States with non-racing cyclists, which suggest that the most efficient pedalling rate is just under 40 revs per minute—by comparison with the racing cyclists' 90-140 plus per minute!

Obviously, to be of any use to racing cyclists, any experiment on pedalling rate needs to be very carefully designed to take account of all the varieties of pedalling required in this very varied sport.

However, the supreme obstacle is the variability of physique and temperament found amongst cyclists. There is no ONE magic formula of gear ratios, etc., and efforts to restrict gear ratios, both here and in other countries, is bound to result in injustice.

The restrictions might have no effect on the type of rider who functions best at high revs, but be a severe limitation to the rider who is at his most efficient on high gears.

Because of this variability in human performance, subjective opinions on gearing become even less reliable. I will go so far as to say that with our limited knowledge of cycling mechanics, it is not possible for gearing or pedalling rates to be specified for any individual on an *a priori* basis.

By this I mean that in order to determine his most suitable gearing, the rider (and his coach, if he has one) must experiment over a full range of gear ratios and over a variety of conditions, using a stop-watch as the final criterion.

The similarities between motor and rider, having diverged a little, we must now strain the likeness still further. Transmission systems can be designed for the car to give as high a mechanical efficiency as is possible with the techniques at hand.

Nature has taken a long time to reach the present stage of human design, and we have to make do with our bodies as they exist.

The evolution of the bicycle itself is an example of man's efforts to achieve even more efficient self-propulsion.

Having reached what must be near optimum development of his vehicle, the only course left for the racing cyclist is to develop those other aspects of propulsion that I mentioned earlier—efficient gearing, high power-to-weight ratio, and mechanical efficiency.

The gearing will be solved by personal experiment, power-to-weight ratio by building up power and keeping down weight; but mechanical efficiency is perhaps the definition we have been seeking for "souplesse."

To expand this definition (which, may I say, is mine—so you are free to adopt or discard it as you wish!), *souplesse* is the ability more-or-less efficiently to transmit power from the human body into the bicycle. *Souplesse* is, therefore, a skill. And like any other skill it is dependent in part on natural ability, and in part on learning (practice).

Souplesse is demonstrated just as much by Anquetil in turning his big gears, as by Charly Gaul in twiddling like a clockwork toy: for each is operating at a high level of efficiency.

It used to be widely thought that *souplesse* was to a great extent dependent on "ankling" ability, but efficient anklers like Peter Gordon, Arthur Metcalfe and Tommy Simpson would find it a difficult job to convert efficient non-anklers like Eric Thompson.

A part of the learning process lies in adopting one's most suitable riding position. Even in considering leg action alone, factors such as crank length, toe-clip length, horizontal and perpendicular saddle adjustment are of great importance.

Experiments I have just concluded show a highly significant effect on power output of saddle height—I would expect somewhat similar effects from the other adjustments mentioned.

Don't be shocked

The permutations of these factors (and others, ie reach and rake) are very numerous, and the only hope of a rider discovering his most efficient riding position is, as with gears, by intelligent and careful experimentation.

A further factor involved in *souplesse* is that of suppleness. Here the position is a complicated one. Co-ordination can be achieved by practice, but it is important to note that any practice of a co-ordinating action should be:

(a) at the revolution rate required in racing;
(b) in the same position as in racing;
(c) with the same resistance, ie gear ratio, as in racing.

I know that the wise heads will shake at this, but these are the facts of skill learning, and I believe that they are as applicable to cycle racing as to any other skill.

Having said this, I must also say that the ability to rev quickly will come from low-gear training—and that power will be developed by high-gear training. Training schedules should contain an element of each, but the co-ordination will only come from training on the "happy medium" gear.

Joint mobility and muscle viscosity for the cyclist, who does not require extreme ranges of movement in his joints, may be obtained in several ways.

Firstly, if the rider firmly believes in it, almost anything could be effective—even embrocation! There are, however, strong schools of thought which suggest that warmth, massage, avoidance of long periods of standing, etc., are efficient methods of heightening this kind of suppleness.

But even here, the rider is best advised to discover for himself what suits him—and discovery will only come from experiment.

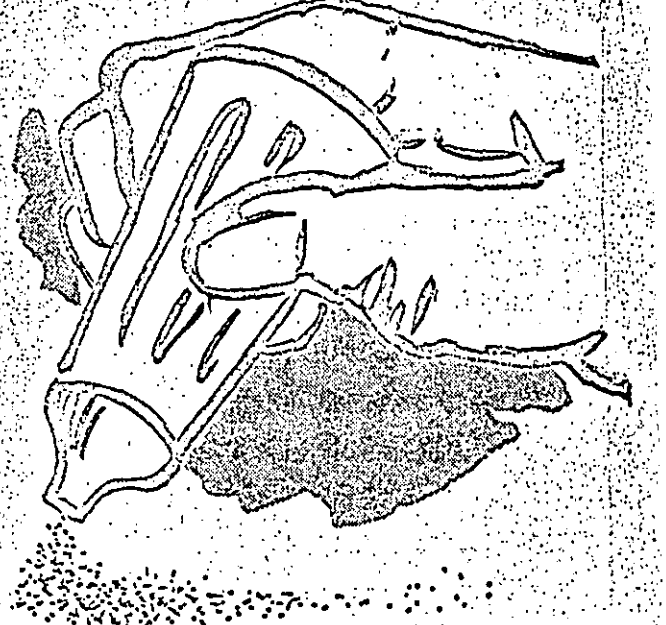
Too many seem to slavishly follow the techniques of the "fast man" without giving any consideration to their suitability.

To be sure much that is valuable can be learned from the experience of others in the sport, but the recent fantastic success of Russian sprinters who train and race on very big gears are but one indication of the benefits of an original and personal approach to cycle racing and training.

Vaughan Thomas

CZECH RIDERS Jiri Hava (left) and Jan Wenczel undergo a step-up test in a medical check on riders nominated for this year's Peace Race.

TAKE YOUR TRAINING WITH A PINCH OF SALT!



HOW much do you know about salt? How much do you care? If the answer to either of these questions is near-zero, then you may not be obtaining as much benefit from your training, or as much success in your racing, as you could. Recent comments in the CYCLING, and conversation with racing cyclists of all categories, have revealed a surprising lack of knowledge on one of the basic facts of cycling fitness.

Now don't get me wrong chewing your way through a block of cooking salt every day isn't going to turn you into a world beater—but many a race has been lost through an inexplicable attack of the "bonk," and salt could very well be the root of some of these mysterious weaknesses.

First it would be as well to cover the basic principles of the salt-and-water balance in humans. I shall describe an extremely-complicated system in a very-much-simplified way, and in layman's terms. I hope that the more scientifically minded reader will skip the next couple of paragraphs, rather than become bored.

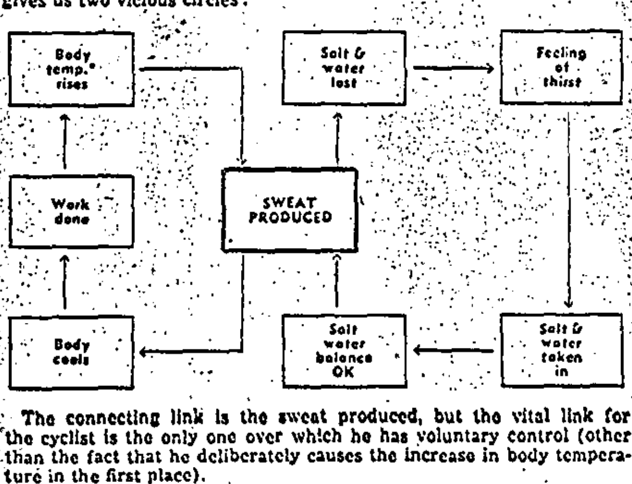
The body is composed of microscopically-small cells, suspended in a fluid. The correct function of these cells depends on the maintenance of good working conditions, and one important aspect of this environment is the balance kept between the salt and the water in the body.

Under normal conditions of minimum work the kidneys cope quite adequately with the maintenance of this balance. But as soon as conditions become unusually hot or humid, other factors are introduced which may upset the balance and cause inefficiency in the body's working parts.

For cyclists there are two major changes in conditions, one—an increase in the rate of work, and two—an increase in external temperature or humidity. In both these cases the normal result is an increase in sweating.

Now, though it seems illogical for the body to start upsetting this delicate balance just at a time when it needs to be at peak efficiency, there is as usual a very good reason In addition to maintaining the salt-water balance, the body must also maintain a near-constant temperature, and the mechanism of sweating is designed to do just that. I use the term "sweating" in its physiological sense, meaning the secretion of the sweat glands. Perspiration, on the other hand, refers to the constant mild permeation of fluid through the skin.

As body temperature increases, either due to muscles working hard or the external temperature rising, the sweat glands automatically cover the skin with fluid (a mixture of salt and water). Heat from the surrounding area of the body is then used up in evaporating the fluid, giving a cooling effect to the body as a whole, and leaving the salt on the surface of the skin. One important point here is that the fluid must evaporate, and not just be mopped off or fall off in droplets, otherwise the cooling effect is lost. The whole procedure gives us two vicious circles:



The connecting link is the sweat produced, but the vital link for the cyclist is the only one over which he has voluntary control (other than the fact that he deliberately causes the increase in body temperature in the first place).

The body, in its natural innocence, has sweated a salt solution—the cyclist, in his natural ignorance, merely takes in water (in any of its more-or-less pleasant forms) and neglects to replace the salt. For a short while the resulting salt water imbalance has a negligible effect, but as the activity is extended over a period of hours, or the hot weather keeps up, the imbalance becomes serious—being associated with increasing degrees of lethargy, cramps, or other signs of body inefficiency.

At this point I must refute a letter written by Doctor Christopher Woodard in the December 11 issue of CYCLING, which criticises some of the statements I made in a previous letter about salt acclimatisation.

More or less recent research (1, 2, 3 and many other standard texts) has shown that the human body will adjust to prolonged sweating by altering the 'proportion' of salt in the fluid secreted. In fact, an international bible of medical practitioners (4) gives tables showing the rate of alteration of this proportion.

The body, being the wonderful mechanism that it is, will gradually acclimatise itself to regular sweating by decreasing the amount of salt given up per unit volume of sweat. It also alters this proportion from minute to minute as the duration of a period of sweating increases.

These are the physiological facts, and upon these facts I must base my consideration of the preparation racing cyclists should undergo to prevent salt deficiencies occurring.

There seem to be two ways of tackling the salt-water balance problem. The first is to acclimatise the body to heavy and prolonged sweating (as the furnace worker or stoker does); the second is to ensure immediate replacement of salt loss. The second method would seem to be the easiest, especially if the salt is taken in a palatable form; but the method must be a rough and ready one in that the rider can never be sure just how much salt he is going to lose, and it would tend to be a case of replacing something already lost, rather than not losing it in the first place.

The first method might give the best results in the long run, and I have first-hand experience of the efficiency of acclimatisation under artificial conditions (boiling kettles etc. in a bathroom!!) to strengthen my opinion.

Acclimatisation in training should not have the aim of reducing the cyclists' tendency to sweat, because this is part of his temperature-regulating system. Rather should his training conditions be such as to produce constant sweating—even in midwinter!

Of course, I refer to specific training sessions—profuse sweating during a predominantly-social ride in very cold conditions should be avoided other than perhaps over the last section of the ride. During training sessions riders should follow the Continental practice of wrapping up well—"Long Johns" are ideal!! Of course the resulting warmth will also do no harm to muscle viscosity and joint suppleness.

Whichever method one chooses, or even if one uses both methods simultaneously, matters little. As long as racing cyclists are aware of the possible effects of salt water imbalance, and take some steps to combat the problem, then one of the possible causes of "bonk" will no longer turn the form book upside down.

VAUGHAN THOMAS
(Loughborough College)

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JOINT MEETING OF THE

BRITISH ASSOCIATION OF SPORT AND MEDICINE

AND THE SOCIETY OF REMEDIAL GYMNASTS

Loughborough July 8th 1967

ABSTRACTS OF COMMUNICATIONS

A method of calculating stride length from anthropometric data in race walkers.

Farley, G.R. Loughborough College of Education, and
Thomas, V., Loughborough University of Technology.

The total population of international race walkers currently competing in Great Britain (N = 19) was studied in an attempt to discover the existance of a relationship between stride length in racing and leg length. The subjects' leg measurements were taken, using a standard 'Abawerk' anthropometer, from floor to inferior pubic ramus, the subjects standing unshod on the floor in the anatomical position. Stride length was measured physically, from indentations made by the feet within a specially marked piste during an actual race. Cine film was taken of all subjects, a) to ensure that their walking action remained within the definition laid down by the Race Walking Association, and b) to assist in the analysis of the individual subjects.

The statistical analysis included the calculation of a product moment coefficient of correlation, and a regression coefficient to obtain a prediction formula for stride length.
The results were:

a.) There is a correlation between leg. length and racing stride length of international race walkers (r = 0.556) which is significant at 0.01.

b.) The racing stride length of international race walkers can be predicted within a mean error of 5% from the formula

$$Y = 1.34\,X - 2.15 \text{ cms}$$

where Y = stride length and X = leg length.

Some physiological methods of assessing the performance of racing cyclists

HAMLEY, E.J. and THOMAS, V.

Department of Ergonomics and Cybernetics,
Loughborough University of Technology
Leics.

Physiological assessments are being made of racing cyclists (i) at rest, (ii) during a gradually increased work load test, (iii) during a constant load test at high rate of power output maintained to exhaustion. The physiological parameters being investigated are:

(a) Electrocardiogram
(b) Oxygen uptake
(c) Total ventilation.

Together with an investigation into the subjects' racing and training habits, the results of test-retest in the laboratory allow an assessment to be made of the subjects' racing fitness, a guide given as to future training and a prognosis of racing performance.

Norms have been established of central tendency and dispersion of these physiological parameters amongst racing cyclists.

Where should the team coach be?

by Vaughan Thomas

Ask the players — if they are a losing team the answer will be a warm one! If they are winners, then they will probably accept that the coach is a handy man to call substitutions and timeouts, and launder the team uniforms!! There are a few, however, who believe the coaches' functions to extend far beyond these limits. It is interesting to trace in the evolution of team games a changing attitude towards coaching. Very soon in the development of any team game the players discover what Gestalt psychologists have formulated, that is, 'the whole is greater than the sum of the parts'. A team has attributes that are not simply the total of players attributes, and to achieve this it is necessary that the players have some common purpose. The purpose could merely be to play basketball for fun, or to satisfy self assertive tendencies at all levels of the conscious or sub-conscious, or many other combinations of motives. Whatever their purpose, the players find a need to establish common methods of achieving their aims, and the idea of the team captain and/or committee evolves. There is then an ultimate authority to govern the methods of the team, this authority being more or less democratic depending on the type of team.

In the team captain we see the embryo of the coach; indeed, some team games never go beyond this stage — but as the demands on the captain/coach develop, then we find in some games that different people will take over some functions. They go under many titles — manager, trainer, coach, non-playing captain etc. — and examples can be currently seen of all these in the international sporting scene e.g. soccer, rugger, basketball, tennis, etc.

The main point of this article, however, is to discuss how a coach can be best placed to discharge his duties to the team. Firstly, what are these duties? Neglecting the trivial or purely administrative, they approximately comprise :—

Pre-Game: Physical Preparation; Technical Preparation; Psychological Preparation.

Game: Tactical Direction; Team Administration; Team Motivation.

These basic headings are not clear cut, and form many subdivisions. The point is, how many could be better done as a player, and how many as a non-player? As far as pre-game preparation is concerned, a team captain with the game qualifications could achieve as much or more than a coach, in that he can set an example to inspire his team in their efforts. The situation is more complicated regarding 'game' leadership. Opinions are sharply divided about tactical direction. It takes an unusually perceptive and experienced player to make good tactical assessments during a 'clutch' situation, and many player-coaches have found either their playing or their coaching (or both) suffer under the strain. There are some players, however, whose close involvement with the situation does not lead to an inability to 'see the wood for the trees', and whose close proximity to their team mates enables them to more efficiently control the play. How many times has a coach sat grinding his teeth on the bench, just dying to get on court and make the thing work!

Team administration is a different problem. There is much that a bench coach can do that is impossible for a player-coach. Paramount is the preparation of a substitute for entry to the game, but also :- spot analysis of statistics, time elapsed checks, treatment of minor injuries, etc., etc. Much of this could be carried out by a good team follower (or manager), but the analytic preparation of a substitute, especially in man for man, is a matter for a bench coach.

Team motivation is certainly easier from the floor than from the bench. And in a game where motivation and confidence play the major part in the performance of skills, the direct contact of the player coach can make the most significant difference to a team's performance. Wales' international victories both in this country and the continent over the last couple of years have been due to this massive morale and confidence, which can overcome even the most talented of opponents.

Before coming to any conclusions on this issue, consider the situation in this country in senior men's basketball at the start of this season :

International Champions: Wales; National Club Champions: Oxford; London League Champions: Vauxhall; Inter Area Champions: Bedfordshire, runners-up East Midlands; Intermediate Champions: Loughborough, runners-up Doncaster Panthers; Universities Ath. Union Champions: Birmingham, runners-up Loughborough. (All Player Coached).

The majority of the major titles are won by player coached teams. It may be that the environment is different here — but an American report says that the coach of the world's top pro. team, Boston Celtics, has become team manager, and that in future they will be player-coached by Bill Russell!!

So what? There is, as yet, no proof on this issue. If there has to be a decision between a good player-coach, and an equally good coach, then hopefully the issue will be decided as objectively as possible. In this country the situation is, however, very rare! What is more common is when the best coach available is also a star player. The issue here can only be settled by balancing the loss to the team on either count if the person does not fulfil both functions, or by equating the relative loss of efficiency on one count with the gain on the other if the person does fill both roles! Decisions where the issue is not in balance, due to gross deficiencies as player and/or coach, are relatively easy to make.

Accepting that such paragons as good player-coaches exist, under what conditions should they operate?

(1) They must hold their place in the squad easily on playing merit.

(2) They should play in such positions that they can control both offence and defence, e.g. quarter-back (playmaker) on offence, and (if possible) pivot on defence; whether zone, man for man or combination.

(3) They must adhere to the code they set the players, but also act so as to command respect as a coach. Herein lies perhaps the greatest difficulty, to be 'one of the boys' whilst remaining something the others are not.

There is no doubt that the player-coach system will remain for many years in this country — certainly until coaching becomes a sufficiently attractive vocation to get the services of the best men. Whilst it remains, there will be more harmony and success if all concerned consider the problems of the player-coach, as the benefits the system can bring.

TECHNICAL

The tragic death of former World Champion Tom Simpson in the 1967 Tour de France startled the athletic world. Vaughan Thomas, our English research scientist correspondent from Longbrough University, has sent us this explanation of some of the modes of operation of the "Human Engine" — which will be of interest to all cyclists, and of particular interest to top riders, and to sometimes over-zealous coaches. We hope it may prevent a similar tragedy in this country.

—Fred DeLong

THE HUMAN MACHINE

by VAUGHAN THOMAS

Recent occurences in the various fields of sport, particularly in cycle racing, have posed some intriguing and vital questions to those who are concerned with the development of the human's ability to produce power. This aspect of human performance is usually measured in sport by the ability to move an object such as a barbell, a discus, a javelin, or to move the body with or without a vehicle—in locomotion. The most vital problems arise in the locomotor sports such as running, walking, cycling, rowing, canoeing, sking, swimming, etc. especially when these are continued for extended distances. In their efforts to improve performance, cyclists have pushed themselves to serious collapse, and even to death. The coach or the cyclist if he has no coach, has a tremendous responsibility to understand how the human (loco)-motor works, because he is literally playing a game of life and death.

An Anology

Desirable though it may be, very few coaches and performers have a more than sketchy knowledge of human physiology and body mechanics. It has been my experience that the basic concepts can best be grasped by an anology between the human machine and the motor car, though one can often run into difficulties if the analogy is carried too far. Especially, one must be continually aware that the higher mental processes of the human provide control mechanisms that cannot be applied to the internal combustion engine. Still, with these provisions in mind, we can begin to examine our analog.

No engine can do work without fuel, and the human processes the food he eats into a sugar substances called glucose, which is the basic fuel of the human engine. The liver acts as a fuel tank, from which glucose is taken by the blood to wherever combustion is to take place. The fuel pump is the heart, which has an automatic inbuilt ticking-over rate, this rate being speeded or slowed by impulses from the nervous system.

The glucose cannot burn without oxygen, which is filtered from the air in the lungs, and then joins the glucose in the blood. This fuel oxygen mixture is then taken to the combustion chamber of the muscle fibre. However, the human engine has far more than six cylinders, in fact there are millions, though they do not all fire synchronously. This fine control is mainly a feedback mechanism activated by demand at particular site(s).

The actual chemical combustion in the muscle is extremely complex, and even yet not fully understood. However, a broad view shows that the ignition is sparked by a nervous impulse to the muscle fibre, which then uses the energy released to contract—thus exerting a force and tending to shorten the muscle. If enough cylinders are firing, then resistance to movement will be overcome, and the muscle will produce movement. The rate of this nervous 'sparking' is again under the control of the nervous system and the timing is such that one spark is followed by a short recovery phase (similar to the cylinder refilling phase) during which time the fibre cannot be re-used. The smoothness and strength of the power output of a given muscle, and of the total body output, is a product of the timing (coordination) and force of all the collective muscle fibres, as is the running of the automobile engine. The development of skilled and efficient locomotion is very much a matter of ensuring that when power is desired that it is in the correct direction, unopposed by power exerted in another direction, at just the right power output, and that the muscles concerned are the most efficient for the job, and acting within their most efficient range.

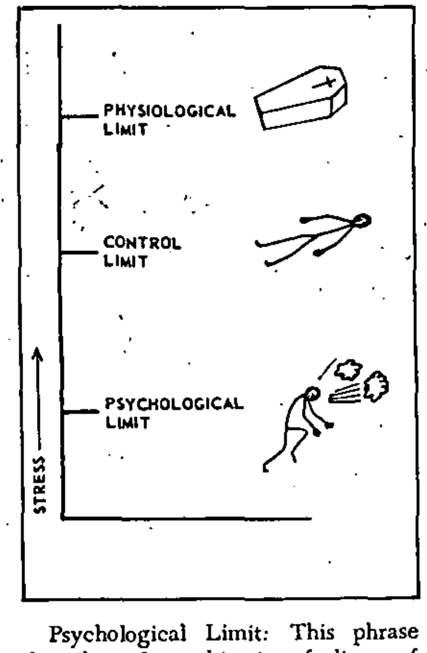
The combustion in the muscle fibre gives waste products, some of which are resynthesized within the muscle, but the remainder have to be eliminate through the body's exhaust system, in that this level is monitored at various control centers which then assess the demand for more fuel and oxygen. They then alter the rate of the heart and lung operation. Here is, then, the first fundamental difference between the human engine and the internal combustion engine. Human control is basically by feedback of information from within the organism, motor car control is basically feed-forward of in formation by the operator (who, being human, is still operating on his own feedback mechanisms!)

The Cooling System

Virtually all machines have an operating temperature at which they function most efficiently, and a danger temperature at which the machine will seize up. The human is no exception to this rule. One of the products of combustion in the engine is heat, and machines usually have cooling systems which operate on the basis of feedback control. The desired operating temperature is used as a 'set point', and the actual temperature compared with this. If the actual temperature is too high, then the cooling system comes into operation. In the automobile, this 'set point' and comparator is a thermostat; the human is a kind of living thermostat, where each locality operates its own cooling system depending upon its own temperature, and where the whole body can assist in the general dispersal of heat.

The Control System

We have previously seen that the basic difference between the human and the automobile machine is the type of control. The motorist can disregard, if he wishes, the signals which reach him that all is not well with this machine, and thrash the machine until it breaks without suffering any direct inhibitory factors himself. Of course, most cars have a governor, which prevents over reving the engine, but the human responses to all the stresses on his own various systems are virtually automatic — they are virtually all governors: Moreover, these governors are all interconnected in a complex manner, which normally prevent the human from harming his 'engine' by locomotor activity. This can be illustrated by a diagram.



Psychological Limit: This phrase describes the subjective feelings of fatigue (pain, stiffness, heat, breathing difficulty, visual acuity, coordination defects, etc.) which will eventually cause the human to either stop or decrease activity. At that point, the psychological limit for that individual has been reached. This limit can change under a variety of stimuli (e.g. training, acclimatization, motivation, drugs) and is the main point of attack for the locomotor athlete's coach, attempting to get as close as possible to the control limit.

Control Limit: At this point, where body systems are being stressed to dangerous levels, some measure of 'cut out' control will be established. Muscles may fail to contract, movements become totally uncoordinated, or, most commonly, so much blood will be diverted to the working muscles that the brain will receive slightly less than it needs and become unconscious. It is possible that training and acclimitazation can alter these levels, and it is certain that some drugs can overcome these controls. The moral and ethical aspects of this kind of athletic preparation are beyond the scope of this article. However, it should be pointed out that some of the deaths in locomotor sport, particularly in tour cycle racing, have resulted from attempts to artifically alter this control limit.

Physiological Limit: At this stage, complete control of some functions is lost, particularly respiration and circulation, resulting in system collapse and death. The normal, healthy, human being cannot reach this limit. By delaying the psychological limit by some means such as stimulant drugs, the extra-ordinarily fit cyclist runs the risk of reaching this limit.

One probable example of this risk is the recent tragedy of the death of ex-world road champion — Tom Simpson. Without intimate access to the French documentation of his death, it is impossible to speak with complete certainty, but I had given Tom some intense physiological experimentation during the previous winter and base my comments on my personal knowledge of his physical condition and habits. Here was an immensely strong and experienced rider, in good general health and with a very sound heart, who succumbed to a variety of control over-riders, and died. His basic preparation was quite sound, though it is doubtful if it included enough acclimitization to fierce heat and high altitudes. He, unfortunately, did not take a great deal of salt, which indicated a possibility of salt-water imbalance. However, these slight defects would normally have resulted only in a performance decrement or a blackout, quite within the capabilities of his normal mechanisms. The critical combination of:

(a) intense motiviation
(b) drugs
(c) alcohol

which over-rode his normal responses

Tom Simpson undergoing heart and breathing checks during cycling to exhaustion Longbrough University

to intense heat, altitude, exhaustion and salt-water imbalance — allowed him to reach his physiological limit. It seems farily certain that other deaths have resulted from similar circumstances, both in the world of cycling and in other locomotor events —not only deaths, but also collapses resulting in physiological damage.

We have considered just a few facets of the complex machine that is a cyclist. Such an article can do no more than scratch the surface of the subject. It is my fervent hope that these words may lend some caution to the activities of coaches and cyclists in their search for ever-improving performances.

American Cycling Journal 1967 June

TECHNICAL

American Cycling's Technical Section's aim is to bring its readers the facts on bicycling as a "Space Age" sport. The following article, written exclusively for our readers deserves your careful attention, re-reading, and filing for future reference. I am sure you will find it worth careful study.

I've followed the author's instructions and have altered saddle heights that seemed correct to me for years on many tours. In a very short time those bikes that were not yet altered then felt amiss. The recommendations below appear applicable for both racing and touring cyclists.

Vaughn Thomas is presently doing research for his doctorate at Loughborough University, England. He was National Cyclo-Cross Champion in 1955, played Olympic basketball in 1960 and 1964, was English National Champion and International Racewalker in 1963, has coached six sports ranging from volleyball to mountaineering, and is widely known for his writings on preparation of cyclists and athletes for competition, tactical coaching and sports physiology.

Fred DeLong, Technical Editor

Scientific Setting of Saddle Position

By VAUGHN THOMAS
Dipl. Phys. Ed.

THE DEPARTMENT OF Ergonomics and Cybernetics of Loughborough University, England, is concerned with an overall examination into the factors affecting human performance on the bicycle. This research embraces physiological, psychological, mechanical, kinetic and other factors. Our work is furthered by the willing co-operation of many British racing cyclists — a two way benefit — who, by acting as experimental subjects, allow experimentation to extend to the limits of both human and machine performance. It is our hope to eventually build an analog of cycling performance, in order that a computer may be programmed to give complete insight into all the parameters of cycling.

The most critical factor of cycling is, of course, the leg action. This may be considered as a co-ordination of many factors: —

(a) Toeclip length.
(b) Degree of ankling.
(c) Crank length.
(d) Pedal path.
(e) Degree and position of knee flexion.
(f) Amount of limb movement.
(g) Saddle position (horizontal or angle).
(h) Saddle composition (flexibility).
(i) Pedalling rate.

These are all inter-related to varying degrees of complexity, and we decided that it would be better, at first, to standardise the mechanical variables (a.c.d.g. and h.), and to combine the overall effect into one parameter — saddle height. One of the principle problems of this type of experiment is that of standardising or eliminating variables which will affect the item being measured. There were the problems of fatigue, position, warm-up, learning, motivation, etc., in addition to those already mentioned. Consequently, the experiment design became one of a short duration, maximal power test, with all variables, except the saddle height, standardised or accounted for in the statistical analysis.

The Experiment

A Mueller bicycle ergometer was adapted with racing equipment, all dimensions being standardised except saddle height. A harness was designed which, (a) ensured that the cyclist sat on the saddle in a position which put his axis of hip rotation as near as possible to the saddle pillar, and (b) prevented him moving from this position. *(See Illustration 1).*

Illustration 1
Vaughan Thomas on the Mueller Ergometer

The equipment was: — Christophe long toeclips, 6¾" cranks, circular pedal path, Unica plastic saddle.

A heavy work load was set (500 kg/m) and the subject timed in performing this work load at four different saddle heights. One hundred subjects, ranging from beginners to world champion Tommy Simpson, thus gave 400 readings which were subjected to statistical analysis.

The saddle heights were respectively 105, 109, 113 and 117% of inside leg, the measurements being obtained

(a) of saddle height from pedal spindle to top of saddle, along the line of the seat tube. *(See Illustration 2),*

Illustration 2
Measuring saddle height

(b) of inside leg from floor to the bone in the crotch, known as pubic symphasis palpation, subject standing without shoes. *(See Illustration 3).*

Results

The experiment showed very conclusively (significance level of better than 0.1%) that for a short duration task of power output on a bicycle —

(a) Alterations in saddle height of 4% of inside leg measurement affected power output by approximately 5%.

(b) The most efficient saddle height is 109% of inside leg measurement.

These values were average figures, and there will be variation between cyclists due to individual build and idiosyncracies. However, recent studies have shown that the better the rider (in terms of his racing ability) the nearer does he tend to have his saddle to this recommended height (rho = 0.665). Large variations tend to be compensated by alterations in the degree and even the direction of ankling.

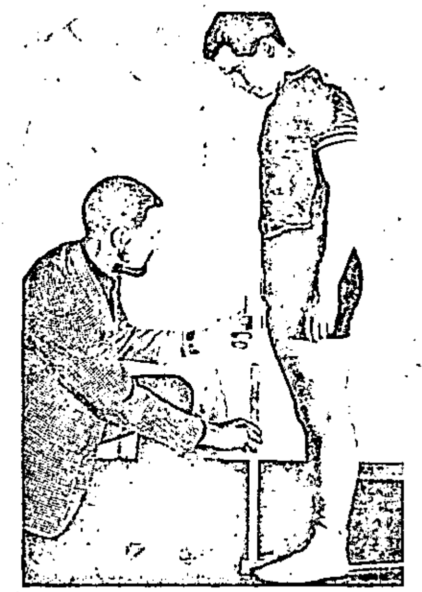


Illustration 3
Measuring leg length

Discussion

Having obtained these results, of what use are they? The experiment was highly specific — to racing cyclists, to ergometer performance, to short duration power output. We are wary of reading too much general application into specific facts, but in the absence of other information then we can look for leads and possibilities in what facts we have. Firstly, for short duration events such as sprints and pursuit the formula height is the one most likely to enhance power output. We believe that this likelihood will also extend to longer events, the only valid factor against this extension of application being one of comfort. However, comfort is more a case of what the rider becomes accustomed to. The skill of pedalling a bicycle is learnt by very many repetitions of a very similar movement, and the most skillful cyclists usually take great care in maintaining their saddle height at the level to which they have accustomed themselves. Any alteration to this height will tend to lead to discomfort, which will become more manifest as the duration of effort is extended. The beginner cyclist will not experience this problem of alteration discomfort if he sets his saddle initially at his most efficient height. The experienced cyclist will need to make any changes in small amounts and at long intervals. For instance, the average cyclist could make up the distance between his present saddle height and the formula height by four or five adjustments of ¼" at monthly intervals.

Secondly, this formula height was determined after standardising the other parameters of leg action. Individual riders can make adjustments to the formula height by considering their own pecularities — short feet on long legs, placing of shoe plates, position of saddle clip, "give" in saddle material etc. We are not yet in a position to derive a formula to embrace all these details, though we are at present working on electromyographic strabophatic assessments of leg and ankle action.

Most researchers like to not only discover 'what', but also 'why'. Our opinions at the moment on the 'why' may be summarised:

(a) Changing saddle height results in alterations of the amount of angular movement made by the thigh. We have no precise figures for this as yet, but it seems that the following graph approximates to the situation.

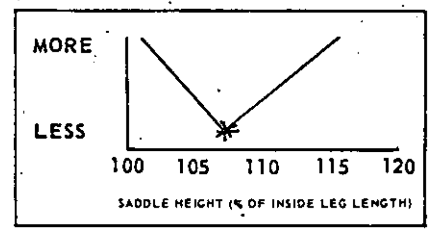
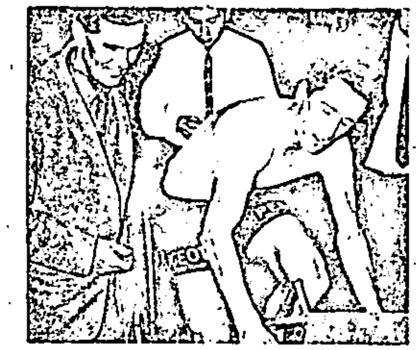


Illustration 4
Angular Displacement of Thigh in Pedalling

(b) Muscles in particular movements have optimum strength ranges. These ranges are highly specific to the activity, and it is probable that the leg is capable of exerting more power when it approaches the fully extended position. On the other hand, fluidity of movement (suplesse) is also important. The cyclist is concerned with converting angular oscillation of the thigh to almost linear reciprocation of the lower leg, and then into an elliptical path of the ankle joint and circular motion of the toes. Any complete straightening of the knee proves a disruptive factor. The formula height seems to provide the optimum conditions for both power ouput and suplesse.



1965 World Champion Tom Simpson undergoing tests

The results of this research have aroused fierce controversy in Britain. After the initial scepticism had died down, the position is now emerging as one of strong support from the ranks of international cyclists, divided opinions from the coaches and a variety of informed support from the scientists in the field. This position is a favourable one in which to pursue our research. We hope that readers of American Cycling will voice their opinions, either through the magazine or directly. We, in our turn, hope to keep our American colleagues informed of any progress we make in this field.

Journ. Physiol. 1967 191(2) 55-57

D. 9

Physiological and postural factors in the calibration of the bicycle ergometer

By E. J. Hamley and V. Thomas. *Department of Ergonomics and Cybernetics, University of Loughborough*

Because performance on the bicycle ergometer is measured by heart rate and oxygen uptake related to work calibrated in kg.m/sec or watts, it has become a standard method for assessing physical work in other activities where only physiological observations can be made. This has been simplified by using the progressive load increase device designed by Müller which gives a continuous correlation between physiological and physical parameters. The calibration curves shown were constructed from data using skilled cyclist-athletes instructed to use the ergometer without changes in style during the experiment. Unskilled performers gave much more varied results. From the demonstration it will be seen that precise adjustments of the ergometer to suit the performer are essential.

Three main points were examined.

(1) The effect of saddle to pedal distance on power output is most marked. Statistical analysis gave a significance level of 0·1 between saddle heights and between the 100 performers. In a few cases habitual use of shorter heights by a performer altered the curve to the left. The test involved the time required to complete a preset load of 500 kg.m. Leg length was measured from floor to symphysis pubis palpation on the standing performer. Saddle height was measured from saddle surface to pedal axle surface in a straight line along saddle pillar and crank. The results show that in a power output test the most effective distance is 109%.

(2) Different styles in use of the handlebars alter the efficiency of doing the test work. This is more marked in heart rate than in oxygen-uptake changes with change in work-load. Styles concerned with an 'upright stance', i.e. no support from the arms or simple support without extension of the shoulders, result in lower heart rates for lower work-loads than styles using the full extension of the racing position allowing 'grip and pull' action by the hands. At high work-loads the grip and pull stance caused lower heart rates and lower oxygen uptakes. In these tests saddle heights were set as in (1), the handlebar surface at the same height and pedal rate at 90 r.p.m. Heart rate was recorded continuously by e.c.g. and oxygen uptake by multi-inlet facemasks, respirometers and continuous oxygen analysers.

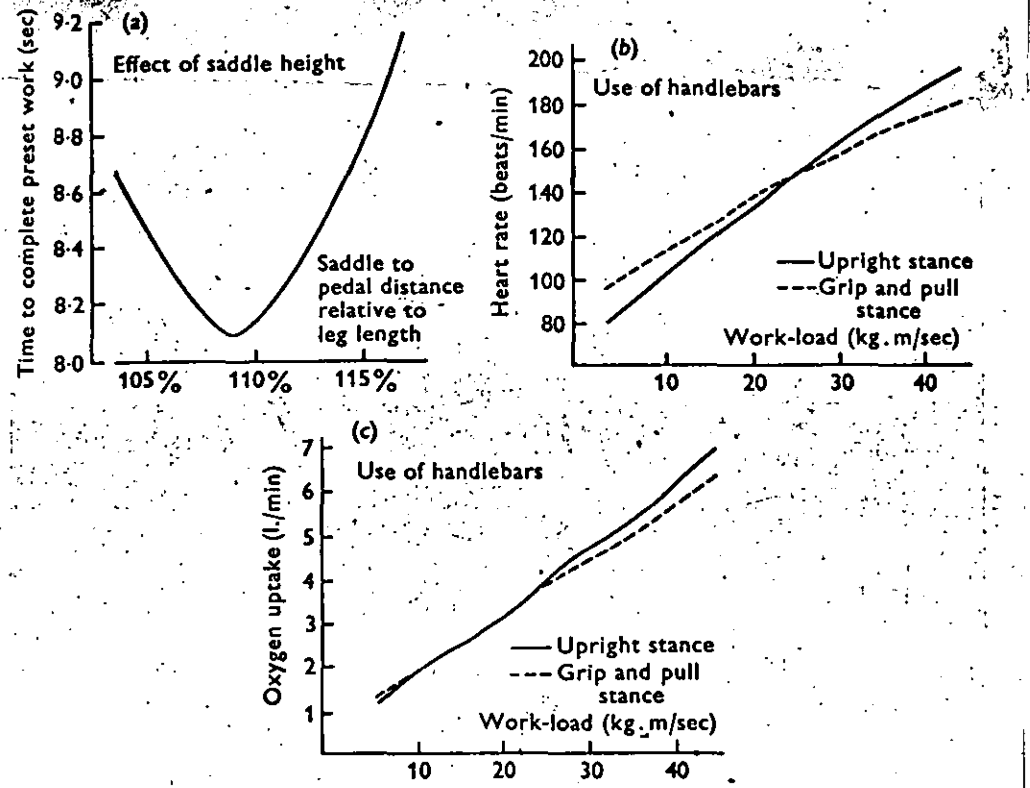


Fig 1

(3) Preliminary myographic and photographic studies of pedalling action show that much of the movement of the ankle compensates for changes in saddle height. There is minimum movement when the optimum saddle to pedal distance is used. The effect on performance of changes in cadence varies with the range of work-load such that pedalling rates below 60 r.p.m. give irregular data when the load is above 10 kg.m/sec but at lower loads low cadence is preferential. For higher work-loads, pedalling rates over 60 r.p.m. give better linearity of data, but it may be that our results are related to the skill of our performers who habitually use cadences of 90 to 120 r.p.m.

Analysis of leg muscle action in a repetitive locomotor skill

By H. David, E. J. Hamley and V. Thomas. *Department of Ergonomics and Cybernetics, University of Loughborough*

Skills may be divided into those which are repetitive and highly reproducible and those which are not. Locomotor skills are amongst the most repetitive and there is a common pattern of muscular co-ordination which is overlearned and therefore efficiently utilized. Electromyographic analysis of three major leg muscles (vastus medialis, gastrocnemius and biceps femoris) was made during pedalling on a bicycle ergometer. Three subjects of different cycling experience were used and tested on three loads (50, 150 and 250 W) and at three pedalling rates (60, 75 and 90 rev/min), the results being related to the rotary movement (Fig. 1). This diagram shows there are greatly differing muscular patterns in the skill of bicycle pedalling.

The muscle interaction was also analysed statistically. For each of the twenty-seven trials the percentage of time during which each muscle was active (duration) was obtained by averaging over ten successive pedal revolutions. The eighty-one means so obtained were analysed by factorial analysis of variance, Table 1. The statistically significant means are given in Table 2.

There are statistically very significant differences between subjects, between loads and between muscles in duration. Variations in pedalling rate produced no change in duration averaged over all individuals, but individuals differed significantly in their responses to different pedalling

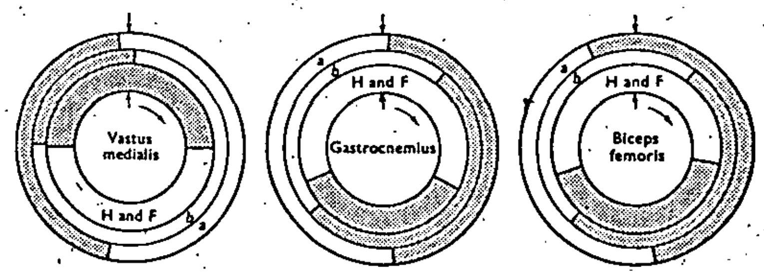


Fig. 1. Diagram to illustrate muscular activity phases during the rotary movement (shaded). (*a*) Most experienced, (*b*) least experienced subject, compared with Houtz & Fischer (1959).

Table 1. Analysis of variance

Duration = (percentage of revolution muscle is active)

Source of variation	S.S.	dF	M.S.S.	Variance ratio	Significance
S = subjects	43,885·0	2	21·942·5	142·30	0·1 %
P = pedalling rates	63·8	2	31·9	—	—
L = loads	29,668·8	2	14,834·4	96·20	0·1 %
M = muscles	49,887·4	2	24,943·7	161·76	0·1 %
S × P interaction	2,113·9	4	528·5	3·43	5 %
S × L interaction	80·6	4	20·1	—	N.S.
S × M interaction	36,022·3	4	9,005·6	58·40	0·1 %
P × L interaction	491·4	4	122·8	—	N.S.
P × M interaction	299·9	4	75·0	—	N.S.
L × M interaction	4,726·3	4	1,181·6	7·66	1 %
S × P × L interaction	1,146·5	8	143·3	—	N.S.
S × P × M interaction	2,659·4	8	332·4	2·15	N.S.
S × L × M interaction	8,341·6	8	1,167·7	7·57	0·1 %
P × L × M interaction	548·8	8	68·6	—	N.S.
Residual	2,467·1	16	154·2	—	—
Total	183,402·8	80	—	—	—

Table 2. Mean durations

	Subjects				Load (watts)		
Muscle	I	II	III	All	50	150	250
V. med	48·6	68·6	31·4	49·5	44·2	49·0	55·3
Gastroc	31·2	42·4	38·1	37·2	31·3	38·8	41·6
B. fem.	47·3	63·2	58·0	56·2	44·4	56·8	67·3
All	42·3	58·1	42·5	47·6	40·0	48·2	54·8
Pedalling rate (rev/min)							
60	39·5	60·6	42·1	47·4		Not significant	
75	44·7	56·7	42·7	48·0			
90	42·8	56·9	42·8	47·5			

rates. Muscle co-ordination differed greatly between individuals. It was affected by load but was not affected by pedalling rate. There were no other significant interactions.

It is probable that some of these differences were due to the skill of the performer. It can be demonstrated that both selection of an efficient range of contraction for the muscles and the ability to shift within this range to accommodate to varying conditions are important factors in this skill.

REFERENCE

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Cardiac and other muscular responses to heavy weight lifting

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The activity involved in heavy weight lifting tasks presents problems of skill as well as cardiac tolerance. Analysis of this skill is difficult in cases where the load is very great as the duration of the lift may frequently be determined by the need to prevent injury, or too great compression of the thorax. In an attempt to develop suitable methods co-operation was offered by an international weight lifter. The recordings taken afford an interesting demonstration of the information obtained by standard eight-channel pen-oscillography and synchronized cinephotography.

The figure shows the recordings with traced outlines from the relevant cine frames taken of a standard Olympic lift of 167·5 kg. It will be seen that a complete analysis can be made of the exercise in spite of the very short phases of actual activity. The muscular co-ordination was highly skilled and has quite discrete periods of almost complete e.m.g. silence from the major leg muscles at several stages in the lift. The total exercise was completed in 33 sec.

The e.c.g. was from chest leads on the left seventh rib about 7 cm from sternum. Analysis of the trace shows several distinct changes in cardiac function.

(*a*) Marked slowing occurred in anticipation of the lift while bent forward.

(*b*) Changes in heart-rate from beat to beat were markedly constant during the lift; calculated as beats/min the mean difference between consecutive beats was 5·4, s.d. 6·5 with only one beat significantly different. This occurred at the 'clean' position (no. 4) where the consecutive beats calculated to rate/min were 134, 157, 137, and may have been caused by the very sudden inhalation at this stage.

(*c*) Inversion of q.r.s. complex occurred in the full arm extension (no. 6) during the period of high intrathoracic pressure. Probably this also caused the apparent missed beat as the weight was lowered.

(*d*) Full elevation of heart-rate to maximum values only occurred after the exercise had been completed.

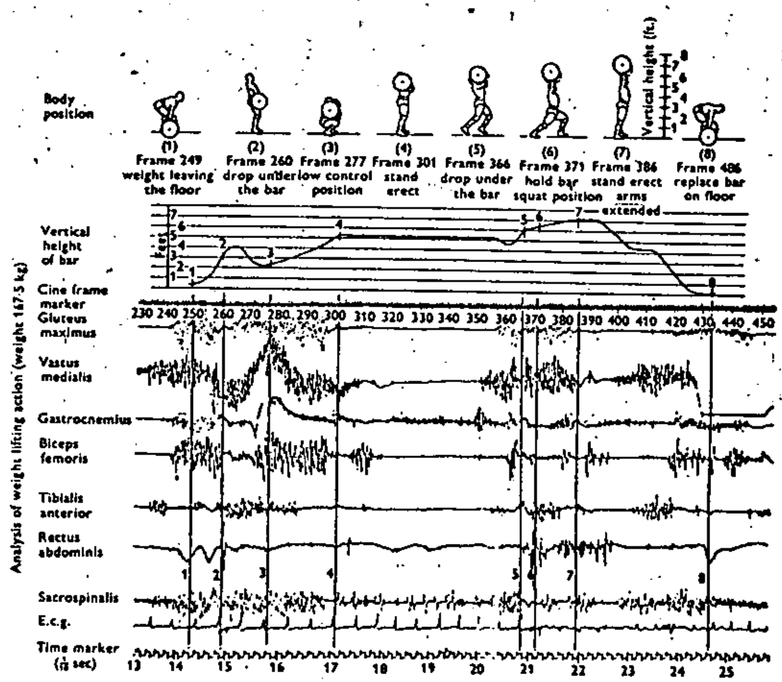

Fig. 1

While it can be demonstrated that a large part of the skill in lifting heavy weights is concerned with achieving periods of e.m.g. silence, it is probable that this also minimizes the conditions which might potentiate cardiac embarrassment. No signs of cardiac intolerance were detected in this particular performer during heavy weight lifting.

We are most grateful to Mr Louis Martin, world mid-heavy weight lifting champion for his willing co-operation.