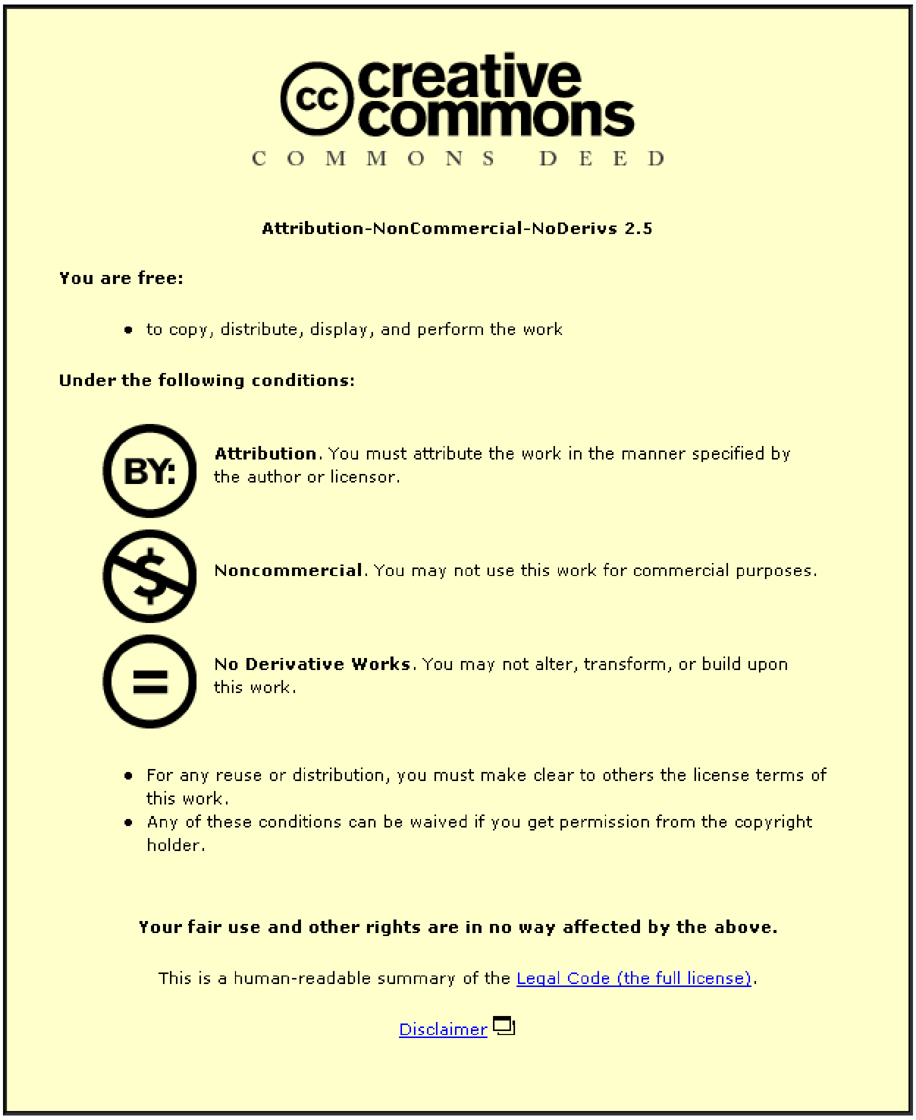

HUMAN RESPONSES TO DEMANDING MENTAL AND PHYSICAL WORK

by

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Abstract

Research into relationships between physiological activity and behaviour in humans has mainly considered performance at light work tasks. Furthermore, models of integrated activity have often been formulated around hypotheses of the arousal type, which were not particularly explicit about the interaction of the variables observed.

The purpose of this thesis is to examine psychophysiological relationships during demanding physical and mental work. Little attention has been paid previously to the interaction between mental and physical work, a topic that has important implications for athletic performance and medicine.

The first stage of the study was an examination of certain psychophysiological measures involved in human responses to demanding work. The second stage varied the stimulus by progressively increasing the metabolic load. Analyses of variance revealed that individual differences contributed substantially to the total variance. This necessitated a closer examination of the response patterns and this was explored by progressively increasing the intensity of the mental and physical load.

The results made it possible to re-examine the factors contributing to responses in humans and tentative models of the response system were developed.

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SECTION ONE

THE INTRODUCTION

1.1 THE PROBLEM

Human responses have been studied extensively, but often the physiological domain has been examined independently from the psychological domain. A limited number of workers (e.g. Duffy, 1957 and Mason, 1975) have appreciated the importance of integrating psychology and physiology, but the psychological concepts are rarely substantiated by physiological evidence. Most human responses involve both these disciplines, and it is proposed that their integration will provide a greater understanding of the mechanisms involved.

Human responses can be understood more clearly when they are placed in the context of clearly defined stimuli. The stimuli associated with resting conditions cause the state of homeostasis. This is replaced by a state of disequilibrium as additional stimuli impose on the organism. The term arousal or activation is often used to describe the extent of the displacement of the organism from homeostasis. Arousal has often been described as a continuum, ranging from very low conditions of arousal during sleep, to high conditions of arousal during excitement and physical activity. This behavioural description was given considerable psychophysiological significance by the discovery of the metabolic aspects of arousal, Freeman (1948) and the function of the reticular formation, Moruzzi and Magoun (1949). Although the concept of arousal has gained acceptance, the responses which purport to indicate changes in levels of arousal show many inconsistencies. The reason for such inconsistencies may be individual differences, physiological rigidity or varying stimulus situations.

One hypothesis is that individual differences will exist regardless of other factors because people have a genetic structure which causes unique changes in energy pathways.

A further hypothesis is that individual differences exist in the relative reactivity of different physiological systems. The divisions of arousal responses into such subgroups as: "electrocortical autonomic and behavioural" (Lacey, 1967), "reticular activating system and limbic" (Routtenberg, 1968), "motor, cardiovascular, respiratory, and ascending activating" (Berlyne, 1960), or "endocrine, autonomic, reticular and cortical" (Strelan et. al., 1972) are considered inadequate. The low correlations reported between individual measures requires further explanation. This thesis proposes that each measure is a distinct arousal subsystem. Although there are those who consider that appropriate forms of analysis will reveal substantial relationships (Lazarus, Speisman & Mordkoff, 1963, Mordkoff, 1964), it is probable that the basis of any such relationships will be a common physiological interaction. It is thus hypothesised that any generalised response to arousal is a consequence of distinct subsystems showing similar physiological effects. This study will, by using novel analytical methods, investigate some of the hypothesised physiological control systems, and also clarify the distinction between arousal subsystems which were hitherto considered as one.

The absence of a perfect correlation between measures of psychophysiological response may be considered as a systematic individual difference in response pattern. The extent to which two individuals show discriminating responses may depend largely upon the psychophysiological measure in use. While accepting this idea, Lacey (1950) went on (1952) to propose that such responses were relatively independent of the stimulus which does little more than initiate an innate response pattern. It is presently hypothesised that Lacey's proposal had limitations because it was based on evidence from similar stimuli and stable individual differences in resting pattern. This hypothesis needs to be examined further by ensuring a variety of stimuli and by using measures which may clarify individual differences.

The ambiguous relationships between psychophysiological measures were previously overcome by data transformations, procedural innovations or combinations of measures (e.g. Newmann, 1941; Sayers, 1975; Opmeer, 1973). Although these gave limited success,

> "the most practical solution appears to be in learning more about the unique properties of the different physiological systems and thereby being able to select a measure that is well suited to the particular conditions that are being investigated."
>
> Taylor and Epstein (1967)

Psychological examination of human responses suffers from less precision of description and less predictive capacity than with the more fundamental physiological mechanisms. This study attempts to improve on the solution proposed above, Taylor and Epstein (1967), by relating selected physiological measures to certain psychological concepts. The concepts of stress and arousal have not always been presented with adequate scientific rigour. Many authors have been content to use a limited number of psychophysiological measures in the examination of these concepts (see Appendix 1.1), but this approach was limited because the inter-relationship between measures was not explored fully.

The present study attempts to develop statements about human responses upon the empirical basis of psychophysiological interaction. This will be achieved by examining a variety of psychophysiological responses during demanding mental and physical work. Demanding tasks were chosen because they produce responses which are representative of the organism's total range. Mental and physical work were selected because they form the basis of all human behaviour. The relationship between them is also of scientific and medical concern, with psychosomatic complaints accounting for one third of all clinical consultations. The relatively few workers such as Hebb (1951), Moruzzi & Magoun (1949), Howard & Scott (1965), Mason (1975) and Selye (1973), who have used physiological mechanisms to interpret psychological observations were mainly concerned with neuroendocrinal responses and those associated with abnormal behaviour. Such non-specific, pathological responses are important in a clinical context. However the normal, specific changes represent a greater proportion of human responses and were adopted because of the more general application. This approach is intended to explain certain ambiguities currently reported in arousal and stress research and provide a basis for the clearer understanding of psychophysiological integration.

1.2 LITERATURE REVIEW OF THE PSYCHOPHYSIOLOGICAL CONCEPTS

The importance of the reticular activating system (RAS) in the control of arousal has been established, Moruzzi and Magoun (1949). The reticular formation and the medial septal-hippocampal system can be conceived as a series of electrical circuits each with threshold levels which if exceeded will activate other circuits. If sufficient threshold levels are exceeded then a sequence of neural activity will be fired and the impulse reach the target organ. Each person will have a unique series of 'electrical circuits' and individual threshold levels. This may be the mechanistic equivalent of the introversion - extroversion continuum. An introvert would have lower thresholds to overcome before a response was forthcoming compared with extroverts. The introvert would have a higher chronic level of arousal which would be related to high activity of the ARAS and septal-hippocampal system and would consequently show behavioural constraint. The extrovert would show the opposite dimensions, with low activity of the ARAS and septal-hippocampal system, high thresholds and an absence of behavioural constraints.

In addition to this chronic state of arousal which would be a relatively stable trait, Kane (1976), another aspect of arousal is that of arousability. Arousability can be considered as a contraction of arousal lability because it describes the lability of the organism during a specific situation. Thus chronic arousal is more specifically associated with the individual's range of arousal whereas arousability considers the movement within that range. An individual can show a high degree of arousability in the same way that he can show a high degree of introversion. The introduction of introversion as a comparable description of the organism is deliberate. Gray (1972) has been successful in showing the possible relationship between arousability and introversion as descriptive terms for a given individual.

He links introversion with the activity of the frontal cortex-medial septal-hippocampal system. It is suggested that the more active this system is, the more introverted will be the individual.

This may at first appear to contradict Eysenck's (1957) explanation of the individual differences in the introversion - extroversion continuum, because Eysenck considered that it was associated with the activity of the ascending reticular activating system (ARAS). Experiments involving electrode stimulation and pharmacological blocking have shown, Gray (1972) that the ARAS and the septo-hippocampal system are coupled together. The respective suggestions of Gray and Eysenck that the septo-hippocampal system and the ARAS underly the degree of introversion are therefore not in opposition, but complementary.

Further support for these links between personality and the arousal processes come from Russian psychophysiology. Much of the work of Teplov, Nebylitsyn, Shorov and Yermolayeva - Tomina and others, (Nebylitsyn and Gray, 1972) and summarised by Kane (1976) has concentrated upon the term "<u>strength of the nervous system</u>". It is becoming increasingly popular to equate this property with higher order personality dimensions. The use of the term indicates the different approaches to personality between Eastern and Western psychologists. The Russians use a bivariate approach, using mainly physiological variables and dependence upon <u>a priori</u> conceptual abstractions. Western workers have a systematic psychometric approach using a greater range of variables, Nebylitsyn and Gray (1972). Progress has been made to combine the two approaches, but little experimentation has integrated the two methods. Rozhdestvenzkaya et al (1972) tried to classify people as having a strong or weak nervous system, but the argument was circular because in each case the method was correlated to an "index of strength". A similar situation occurred with Shorov and Yermolayeva - Tomina's (1972) experiment relating extroversion and strength of the nervous system. In this case the regression equation between reaction time and intensity of sound was established. The slope of the curve is unlikely to correlate with baseline values and if expressed in standard score units would be identical to Lacey's autonomic lability score, Lykken (1968). Thus Lacey considers the process as one of lability whereas Teplov (1972) considers lability as specifically related to "the speed of initiation and termination of the nervous processes". Cattell's (1972) major criticism of the term is that he cannot produce evidence to support its place as a single dimension. A weak nervous system may be considered simplistically as one of low endurance but high sensitivity, and a strong nervous system as one of high endurance but low sensitivity. A case could be made for the "dimensions of strength of the nervous system and introversion - extroversion to be identical, both being based on arousal" Gray (1967).

It is considered that "strength of the nervous system" is not sufficiently distinct from the term arousability to merit a separate consideration. Its place in describing human responses will be examined in relation to the personality factors of extroversion and introversion by incorporating a personality questionnaire in the final experiment.

Another psychological concept which lacks clarity is that of stress. There are those who view stress and arousal as independent aspects, (Cox, 1978, Levi 1972). Closer examination revealed that stress was being used for variation in intensity and arousal was the psychophysiological response. The majority of workers in the stress area have used it, often without admission, as a reference point within the arousal continuum. Progress in stress research has been handicapped by the multiplicity of uses for the term. It has been used for behaviour itself, as in the phrase "the laboratory induction of stress", to describe a stimulus, and for a stressful situation, as in "behaviour under stress", Pronko and Leith (1956). A variety of uses may confuse the human scientist, but the term has a place in the psychological literature, and appears to be a significant area of study. The reasons for studying stress include the need for scientists to understand the phenomenon, for physicians to relieve the effect and for potential recipients to avoid the situation.

Levi (1971) argued that the modern lifestyle has made demands upon the human body for which it has not sufficiently adapted. Early man responded to emotion by action but this process has been replaced by a more socially acceptable and passive overt response. The conflict between required behaviour and physiological activity may produce disequilibrium of a potentially harmful nature. The conditions of hypertension, ulceration and coronary heart disease are examples of pathological states which are considered to be precipitated by stress, Clarke (1976).

The physicist defines stress as the "external force directed upon an object" and strain as the "temporary or permanent alteration in the structure of an object". Such a precise definition is not used in the human or behavioural sciences. It may therefore be helpful to consider the stress process on a three-part stimulus-processor-response basis.

The first stage of this simple process, the stimuli, can be classified into many types. These include psychosocial stimuli, environmental stimuli, motivational stimuli, situational stimuli, and the more common stimuli associated with demanding tasks. Psychosocial stimuli were used by Levi (1972) when he replicated certain real life situations in laboratory settings or took measurements in field situations. Rahe (1967) developed the psychosocial aspect by ranking 'life change' situations in terms of their stress response. This work, although retrospectively based on subjects who were coronary victims, can easily be interpreted to indicate potential risk. Environmental stimuli have included noise, Glass, Singer and Friedman (1969), Smookler and Buckley (1969), and Levi (1972). Further environmental variables have included deviation from normal oxygen intake, altitude changes in excess of 18,000 feet, McFarland (1937), and a hand being immersed in freezing brine, Craig and Wood (1970). Castaneda and Palermo (1955) made the assumption that although a variety of methods have been used as stimuli, (e.g. failure, excessive pacing and threat) they all affect the level of motivation. Ulrich and Burke (1957) commented on the 'motivational' stress to improved performance in cycling and Ulrich (1957) referred to the different aspects of competitive stress being anticipation, participation and denial of the expected participation. One major component of the motivational stimulus is that of threat. Threat of electric shock is a common treatment condition as exemplified by Ryan (1961), Carron (1968), Weiss (1972), Deane (1959) and Deese, Lazarus and Keenan (1953).

Certain authors consider that the 'situation' is a relevant form of stimulus. Such a relevant situation was provided by Diamond (1967) by informing all the children in an experimental group of the statuses of each other's father within a military status system. Diamond's assumption was that those children with high status fathers would be under greater pressure to excel than those with lower status parents. Similar situational stress stimuli could be seen in the work of Fenz (1964) and Fenz and Epstein (1965) when stimulus relevant words which corresponded to the situation of parachute jumping were used.

Mental tasks have been used as stimuli in much psychophysiological research. Such stimuli as mathematical tests, Blohnke et al (1967), primary and secondary tasks, Kalsbeek (1964) and a combination of tasks such as mental arithmetic and physical work, Gutin (1966) are typical. A criticism of using mental tasks as stimuli is that large inter-subject variability could occur depending on the intellectual processes involved. Mental tasks are a common form of stimuli because they approximate so well to real-life situations. It is appreciated that laboratory-based experimental stimuli can only substitute for actual conditions to a limited extent. Berkun et al (1962) argued that subjects were constantly aware of being in experimentally contrived situations and often acted accordingly. Experimental situations were contrived in which the subjects genuinely thought that they were in dangerous situations. These involved such emergencies as a forced landing of an aeroplane in the sea, accidental nuclear radiation, an approaching forest fire or misdirected incoming artillery shells.

Stress responses may be subdivided into behavioural and physiological categories. Many psychologists have been content to use the behavioural response alone (see Appendix 1.2) and to develop theories about the 'processor' without detailed physiological information. The exception were those workers who used a physiological response as an index of arousal level. Physiological responses within the stress process may be divided into metabolic and electrophysiological categories. Examples of the metabolic category are listed in Appendix 1.3 and the electrophysiological responses in Appendix 1.1.

The theories associated with the stress process are considered here to examine the 'processor' aspect of human responses. Probably the most established stress theory associated with the processor is that of Selye's General Adaptation Syndrome. Selye originally observed a stereotyped response to a stress stimulus in 1926 but his description of the process was not published until 10 years later, Selye (1936). Selye defined stress as the nonspecific response of the body to any demand made upon it. This nonspecific activity is independent of the specific reaction and according to Selye is the essence of stress, Selye (1973).

The statement,

> "It is difficult to see how such essentially different things as cold, heat, drugs, hormones, sorrow and joy could provoke an identical biochemical reaction in the body. Nevertheless, this is the case: it can now be demonstrated, by highly objective biochemical determinations, that certain reactions are totally non-specific, and common to all types of exposure"
>
> Selye, 1974

is probably unacceptable. However such a statement is far more acceptable in the knowledge that Selye's "state of stress" was defined as "the state manifested by a specific syndrome which consists of all the <u>non-specifically induced changes</u> within a biological system", Selye (1956). These non-specifically induced changes may occur as part of the stress process to a variety of stress stimuli and could be considered peripheral to the specific effects. It is considered that the development of alternative contradictory, as opposed to complementary, stress theories was accelerated by the opinion that Selye's theory applied to all facets of the stress reaction and not solely to the non-specific changes.

Individual variability for specific response as opposed to Selye's generalised response, Selye (1956) has been explained by Lacey (1950) in his <u>autonomic response specificity</u> hypothesis. Lacey proposed that there is variability between individuals in the quality of their responses to stress. The proposal was that "for a given set of autonomic functions, individuals tend to respond with a pattern of autonomic activation in which maximum activation will be shown by the same physiological function, whatever the stress." This was later extended, Lacey and Lacey (1958) to include the principle of <u>response stereotypy</u> which states that some individuals respond to different stimuli with a fixed patterning or hierarchy of autonomic activation. Lacey later developed his arguments to account for the dissociation between somatic and behavioural arousal and dissociation of those physiological functions considered to be indices of arousal, Lacey (1967). In fact Lacey presented evidence to show that electrocortical arousal, autonomic arousal and behavioural arousal could be considered as different, complex forms of arousal. Such a suggestion allowed for certain of the anomalies to be removed but in so doing questions the usefulness of stress as a general contruct.

This section illustrates the complexity of arousal and stress and demonstrates that terms which appear to have popular credibility are open to misuse which makes scientific investigation difficult.

1.3 LITERATURE REVIEW OF THE PSYCHOPHYSIOLOGICAL MEASURES

As there are many psychophysiological responses to demanding mental and physical work, it was necessary to be selective before starting a viable experimental programme.

The first stage in the selection process was to exclude the hormonal response measures. This was because the measurement of hormone levels was either too intrusive or lacked reliability. The blood analysis of catecholamines was considered unacceptable because of the need for intravenous sampling. The analysis of urine is an alternative technique for the assessment of catecholamines, but although Graveling (1978) has developed a gas liquid chromotograph method, a simple laboratory technique has not been established. Crisfield (1978) has also reported her concern over urinalysis techniques largely due to the latent period between stimulus and response and the extent to which individual differences and diurnal variations impinge on the results.

The second stage in the selection process was to choose measures which purported to show response changes during mental and physical work. Demanding mental work may produce changes in the autonomic nervous system (ANS) and it was for this reason that measures were selected which characterised the ANS. The response to physical work is usually a consequence of metabolic requirement. Those measures which reflected metabolic requirement and could be measured with ease were also selected.

The final stage in the selection process was based upon the accessibility of the measure and the intrusive nature of the recording. For this reason measures were chosen which used surface transducers and which interfered minimally with normal activity.

The measures which satisfied this selection procedure were those of:-

Electrodermal activity (EDA),
Mean Heart Rate (H_f),
Heart Rate Variability (HRV)
Temperature (T),
Respiratory Frequency (R_f), and
Simple Reaction Time (SRT).

The literature concerning these measures will be reviewed in sections 1.3.1 to 1.3.6. Additional measures were introduced as the study developed and therefore the review of these has been placed with the appropriate experimental stage.

1.3.1 Electrodermal Activity (EDA)

Definitive statements for EDA showing systematic responses during psychophysiological research are few in number. Numerous studies however (see Appendix 1.4), have used EDA as an index of autonomic activity, particularly in research designs involving descriptions of psychological state. EDA is a well established measure in psychophysiological research, but unequivocal statements relating the empirical results to autonomic activity are still lacking.

The studies which have best clarified the relationship between EDA and mental load were those involving intense stressful stimuli. The series of experiments using the noxious stimuli of the film 'Subincision', Taylor and Epstein (1967); Mordkoff (1964); Lazarus, Speisman and Osborn (1961); Malmstrom, Opton and Lazarus (1965) were characteristic. These experiments were designed to examine other aspects, such as the correlation between EDA and other autonomic changes, but they convincingly demonstrated the monotonic change in EDA during increasing levels of stimulus intensity.

Tonic skin conductance level, the EDA measurement used in this study, is determined by changes in both the epidermal and sweat gland membranes, Hume (1966), Edelberg and Wright (1964). The nervous control of the epidermal and sweat gland permeability is unusual. The vessels in human extremities are not supplied by excitatory and inhibitory fibres, nor by both sympathetic and parasympathetic fibres, but by sympathetic fibres alone, Barcroft (1960). In addition the eccrine sweat glands (those concerned with 'mental sweating') are functionally cholinergic, although anatomically sympathetic. This liberation of acetylcholine as the chemical transmitter is unique to the eccrine sweat glands, all other postganglionic sympathetic fibres being adrenergic. The functional significance of this is not clear, but the fact that the sweat gland is under sympathetic control alone, means that EDA offers an ideal indication of autonomic balance.

The final common pathway in the spinal cord is the preganglionic sympathetic sudomotor neurons, Wang (1958). The pathways of the EDA above this level are separate and independent. Figure 1.1 has been produced by the present author to summarise the anatomical pathways for EDA which were investigated by stimulation and transection methods, (Wang, 1958, Darrow, 1937, Goadby and Goadby, 1948).

The EDA mechanism is wholly cholinergic and involves the pre secretory activity of the sweat gland, the sweat gland itself and the epidermis. Darrow and Gullickson (1970) hypothesised that there are two, serially occurring processes. The first is dependent upon pre secretory activity of sweat gland cell membranes (neural excitation) and the second upon the emergence of sweat (sweat gland activity). Edelberg and Wright (1964), although not advocating a serial response, also considered that the mechanism was comprised of two components. They advocated independent reflexes, mediated by different effectors which were most likely the epidermis and sweat gland. They established that the two reflexes manifest a high degree of response specificity. This is essential to any consideration of EDA because response specificity could account for anomalies in results during a series of similar stimuli.

EDA is more likely to be responsive to intensity of neural stimulation if it depends on whether the epidermis or sweat gland is operating. This would influence the quantity of acetylcholine released. The point may be reached when the level of acetylecholine limits any reaction to further stimuli, thus acting as a controlling mechanism on the electrical activity.

The mechanisms of EDA may therefore be influenced by a number of factors:-

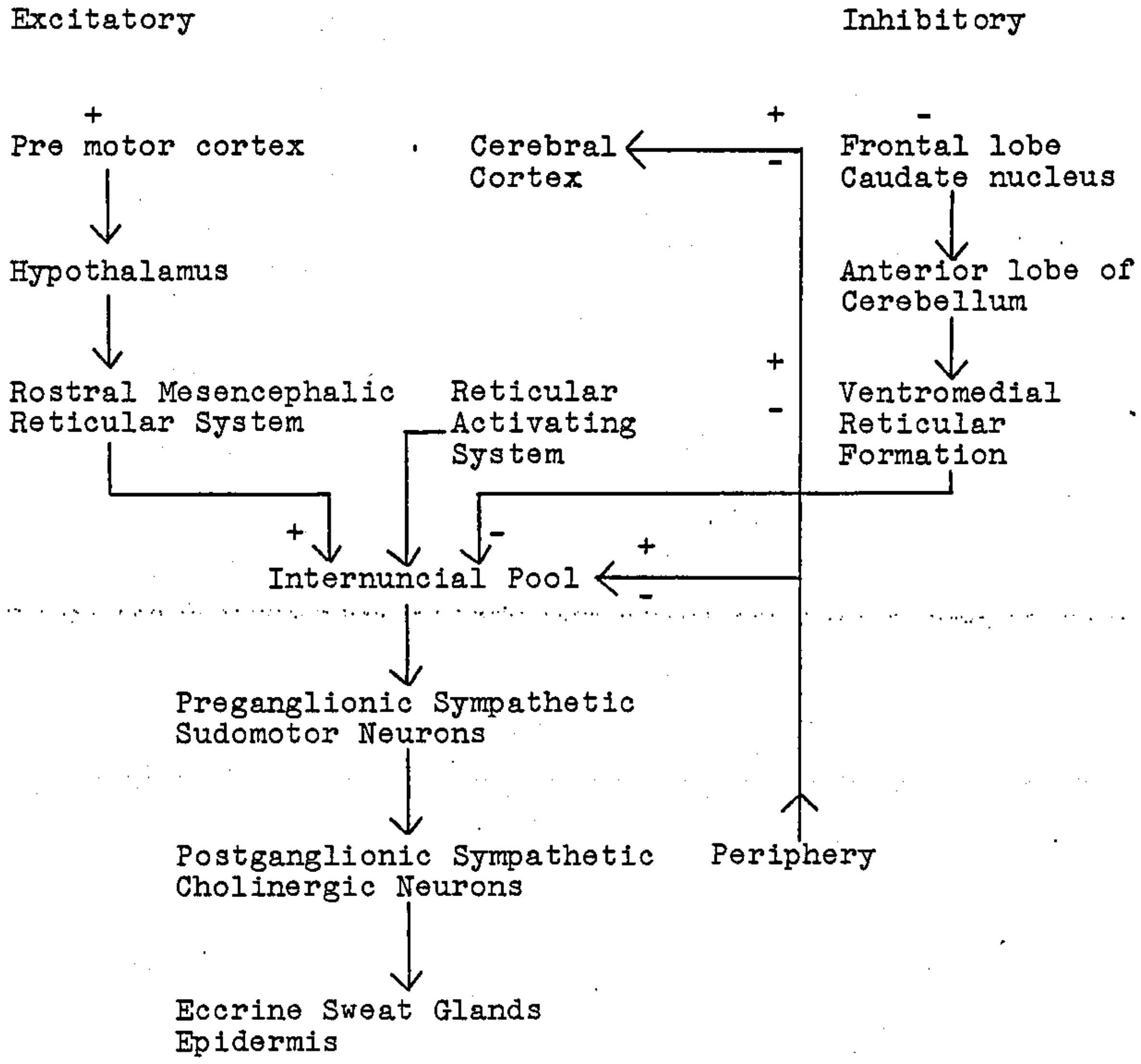


Figure 1.1 - Suggested schema for the organisation of the neural systems influencing E.D.A.

1. The efficiency of the neural pathways from the higher centres to the effectors.

2. The degree of regulation of the reticular activating system.

3. The influence of afferent impulses including those of other biological systems such as respiration.

4. The response specificity probably brought about by operation of either the epidermis or the sweat gland.

5. The quantity of acetylcholine release at the effectors.

Summary

EDA is a measure which indicates the level of arousal by responding to the sympathetic division of the ANS. The change in EDA is associated with the permeability of epidermal and sweat gland membranes. Its general consensus validity makes it a measure of potential value in assessing human responses to demanding mental work.

1.3.2 Mean Heart Rate

Mean heart rate (H_f) has been used extensively to indicate the response of the autonomic nervous system. A detailed description of the mechanisms which innervate the heart can be found in standard physiological texts, Green (1968), Keele and Neil (1966). The following reviews the mechanisms involved.

The heart is inherently rhythmic but its rate is modified by a balance between the cholinergic and adrenergic effects of the autonomic nervous system. Increase in the rate of discharge of the sympathetic nerves causes an increase in H_f, whereas a decrease in H_f is caused by greater discharge in the vagus. Under normal conditions an increase in H_f is brought about primarily by a decrease in cholinergic activity.

The cholinergic tone is maintained by the action of efferent neural impulses originating in the cell bodies of the dorsal motor nucleus of the vagus. Abolition of vagal transmission by the administration of atropine will result in the heart accelerating to 120 beats per minute. Under normal resting conditions the vagal tone exerts sufficient influence to reduce the rate to about 66-80 beats per minute.

The vagal control of the heart rate is influenced by the cardiac centre in the medulla which is in turn influenced by higher centres of the brain, the respiratory centre, the thoracic receptors, the baroreceptors and other effects such as stimulation from sensory nerves, chemoreceptor innervation and a rise in body temperature, (See Fig. 1.2).

It is generally considered that the adrenergic nervous activity has little influence on the heart at rest, but under conditions of emotional excitement or exercise the cardiac sympathetic nerves are stimulated with the resultant acceleration of the heart rate. The origin of the cardiac sympathetic nerves are the cell bodies in the intermediolateral horn of the upper five thoracic segments of the spinal cord.

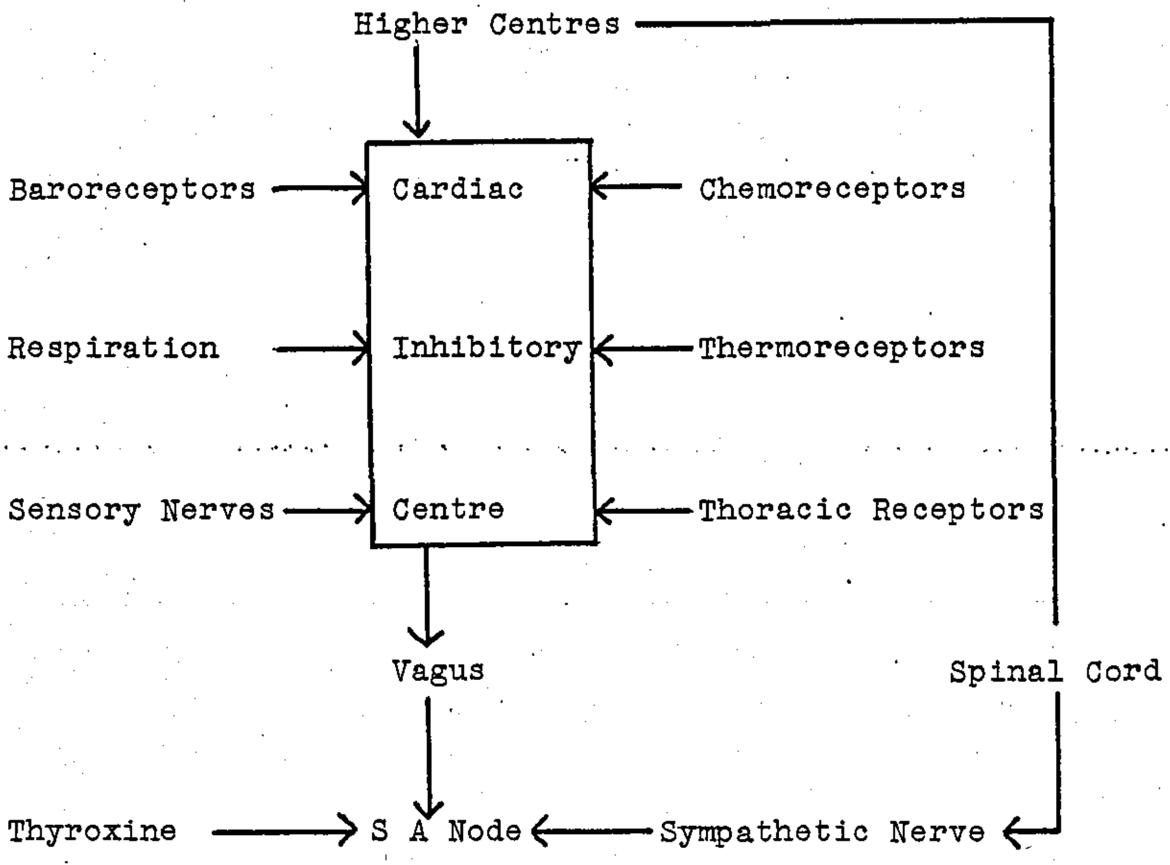


Figure 1.2 - The neural pathways controlling the heart rate.

There is a difference between the distributions of the adrenergic and cholinergic systems to the heart. The cholinergic (decelerating) neural terminations decrease in quantity when examining the heart from the sinu-atrial (SA) to the atrio-ventricular (AV) node, with the ventricles appearing to contain no cholinergic fibres. The adrenergic (accelerating) terminations increase in quantity when examining the heart from top to bottom. The adrenergic action has in addition an hormonal influence upon both the musculature and Purkinje fibres. This duality of adrenergic action has no parallel with the cholinergic system which only influences the nodes.

The cholinergic and adrenergic higher nervous centres were considered by Blom (1951) to be situated differently depending upon the complexity of the afferent impulse. He suggested that the centre mediating the reflex changes associated with posture is probably lower (medulla), but with more complex activities such as fear, the centres would be higher. This has significance when comparing heart rate changes associated with attention. Mental tasks requiring internal attention cause heart rate acceleration, but deceleration occurs during attention to the external environment, Lacey and Lacey (1970).

The functional significance of the heart is in the efficient supply of metabolic nutrients to the cells. Direct neural control of effector cells in the heart and blood vessels is faster, more potent, and more selective than that achieved by indirect methods such as the stimulation of glands. The central nervous system (CNS) can be both versatile and selective by making use of several effector systems with different latencies, Gunn et al (1972). The end product of the integrated response from these effector systems is observed as the mean heart rate. Many of these responses do not reach a conscious level, but it is important to clarify the control mechanism so that inappropriate psychophysiological responses do not cause harm.

Mean heart rate is influenced by a number of factors in addition to those associated with exercise or psychological imputs. Tursky and Sternback (1967) established a statistically significant difference between four ethnic groups. Vandenberg, Clark and Samuel (1965) were unable to establish an hereditary component for resting heart rate in twins, although the change in heart rate to a stimulus suggested a genetic influence.

Other factors influencing heart rate are age, Vierordt (1888), sex and climate, Brouha and Smith (1961), postural changes, Turner (1917), time of day and ambient temperature, and recency of meals, Dill (1959). The literature is often remiss by using terms such as 'resting heart rate' when 'pre exercise heart rate' would have been correct. The lowest heart rate has been established, Boas and Goldsmidt (1962), as during the last hour of sleep. Few authors measure this, so the psychological influences on H_f, even during a resting state in a laboratory, are largely unknown. An attempt was made in this study to standardise these influences by keeping the laboratory environment constant and to select a male population of limited age range.

Heart rate has been used to indicate an arousal state in studies of the 'performance - arousal' relationship. Surwillo (1965) did not find heart rate a useful measure in replicating the inverted 'U' relationship of Yerkes and Dodson (1908), but Martens and Lauders (1970) and Hokanson and Burgess (1964) showed the characteristic association between heart rate and motor performance when heart rate was used as an index of arousal.

Tachycardia was observed in the aroused state of an oral examination, Bogdonoff et al (1960) and this tended to correlate well with other metabolic measures. The autonomic nervous system is the common mediator of these responses, but

Bogdonoff et al (1960) were unable to present biochemical evidence (adrenaline and nor-adrenaline) of sympathetic dominance. Fear may have been one of the components of arousal in this situation, but the results do not support Cannon's (1939) sympathetic arousal theory during fear. This is further evidence for the response being facilitated by both sympathetic and parasympathetic influences.

The form of stimulus is clearly important because a mental load may not produce the expected heart rate change. The explanation for differences in heart rate response was based on incorrect assessments of the influence of the sympathetic system, McGuiness (1973). Heart rate control during orienting responses was determined by the activity of the vagus, Obrist, Wood and Perez-Reyes (1965), Eckberg, Fletcher and Braunwald (1972). This suggested that cardiac changes during stimulus presentation are attributed to the parasympathetic system. The heart rate increases during demanding mental tasks were also considered by McGuiness (1973) to be attributable to vagal inhibition. This was supported by studies using pharmacological blocking agents on dogs, Obrist et al (1972).

The division of activities into those which result in cholinergic vagal or adrenergic control of the heart rate requires further examination. The intensity of the mental task, the type of task and the significance of the task, may all be variables which produce different forms of autonomic control on the heart. Similarly, the point at which the sympathetics dominate the control of the heart rate during progressively increasing exercise is relevant. This is particularly so when considering individual differences, because the balance of the two divisions could be an important determinant of heart rate stability.

It is doubtful whether the cholinergic/adrenergic dichotomy accounted for the observation of Lacey et al (1963) that certain mental activities caused heart rate acceleration, whilst others caused deceleration. They found that attention to the external environment, such as responding to visual cues, resulted in a reduction in heart rate. Cognitive activity, such as mental arithmetic, caused a heart rate increase. Lacey using the term 'intake' for the former state and 'rejection' for the latter, maintained that the heart rate was involved in the chain of events leading to the eventual behavioural outcome. This view, Lacey and Lacey (1966), Coquery and Lacey (1966), related the cardiac deceleration to cortical arousal via a reduction in baroreceptor activity. It is unfortunate that most of Lacey's work is based on a discrete period of time, namely the preparatory interval to a reaction time task, and thus represents a phasic response more than a long-term tonic response. The involvement of the baroreceptors in the Lacey model does suggest that respiratory manoeuvres could be playing an important part in the observations and it would be easier to evaluate this work if this factor were removed.

This 'afferent feedback model' was criticised extensively by Elliott (1974) who supported Obrist (1970) by stating that heart rate is simply one of many responses which make up the outcome of the interaction. Obrist proposed a 'cardiac-somatic model' in which the heart rate is closely related to the metabolic state of the organism. The behavioural response Lacey reported, namely an increased reaction time, was considered by Obrist to be related to a general quietening in the somatic and visceral components of the organism. This was indicated by a reduced heart rate.

The Obrist model, Webb and Obrist (1970) has a more logical physioligical basis - that of metabolic requirement. A useful adjunct to the controversy was the work of Tursky, Schwartz and Crider (1970) who demonstrated a higher heart rate during mental activity which terminated in an overt response.

This introduces the element of 'purposeful response', in which the body prepares for activity by making the cardiac adjustments appropriate to a changed metabolic level. In a cognitive mental task, the organism may be preparing for an appropriate response by conserving energy. This explains the heart rate deceleration.

Some activities may combine the features of 'intake' and 'rejection', or one of these combined with striated muscle activity. The task and the relevance of the situation to the subject must both be considered before expecting an accurate interpretation of the heart rate response.

Summary

Mean heart rate is the integration of the cholinergic and adrenergic activity of the ANS. Many factors influence H_f in addition to nervous control, and a variety of mechanisms have been proposed to account for the observed changes in frequency.

1.3.3 Heart Rate Variability (HRV)

The variability between the time of successive heart beats appears to indicate the extent of mental load, Luczak and Laurig (1973), Kalsbeek and Sykes (1967). Zielhuis (1971) also states that heart rate variability (HRV) is a biological indicator of external load and Biesheuval (1969) in the International Biological Programme publication specifies that:-

> "These fluctuations diminish and eventually disappear with progressive increase of the amount of information that has to be processed by the central nervous system. However, the degree of suppression is also dependent on individual reserve cerebral capacity, which in turn may depend on the extent to which the individual's information - processing capacity is pre-empted by pre-occupation or emotional reactions. Sinus arrythmia can completely disappear without any increase in pulse rate, and as acceleration of the pulse is a frequent correlate of emotional responses, this characteristic might enable one to distinguish between states of arousal with and without emotional components."
>
> Biesheuval, 1969.

This statement has to be treated with caution for two reasons. First it did not distinguish between the different aspects of emotion. It has already been shown that frustration, fear, anxiety and cognition may produce different heart rate changes. The extraction of the pulse acceleration as an emotional component with the remainder being assigned to non-emotional arousal must therefore be viewed with care. Secondly the introduction of the term 'sinus arrhythmia' needs further qualification. Sinus arrhythmia is commonly used in the literature as a synonym for HRV, but is more correctly used as the momentary fluctuations in heart rate resulting from respiratory manoeuvres.

Sinus arrhythmia is the observation of cardiac acceleration during inspiration and cardiac deceleration during expiration. This was first observed by Hering and Breuer as early as 1868. The factors contributing to sinus arrhythmia include:-

> " (i) irradiation of impulses from the inspiratory centre to the cardiac centre and (ii) vagal stretch receptors from the lung excited by inflation causing reflex inhibition of the cardio-inhibitory centre and reflex excitation of the cardio-acceleratory centre."
>
> Keele and Neil, (1966).

The use of the term sinus arrhythmia should by definition include an assessment of respiratory frequency and preferably respiratory depth. Ignoring the respiratory influence (e.g. Kalsbeek, 1973) is excluding the possibility of HRV being an artefact of baroreceptor entrainment.

The irregularity of the instantaneous heart rate in normal healthy individuals at rest has been observed by many researchers, Lacey et al (1953), Lacey and Lacey (1958), Obrist et al (1964) and Schachter et al (1965). The important feature of the decrease in HRV during mental load is its occurence in the absence of a mean heart change. This has been demonstrated by Kalsbeek and Ettema (1963) and Blitz et al (1970). Carruthers and Taggart (1973) produced one of the few studies which showed an <u>increase</u> in HRV during the emotional involvement of watching violent television programmes. This discrepancy may be explained by the prime focus of attention. Attention to the environment such as in watching T.V. appeared to cause an increase in HRV whereas mental arithmetic which is of an internal nature caused a decrease, Brodie, Brooke and Graveling (1975).

A more detailed analysis of the mental tasks used when HRV was being measured indicates the possible control mechanisms. If an apparently simple task can be broken down into perceptual, cognitive and response phases then each one of these may have a distinct cardiac pattern. Decrease in HRV was observed in tasks of a cognitive perceptual nature by Bartenwerfer (1960), Kalsbeek (1963), Porges and Raskin (1969), and Ettema (1967). Lacey (1967) suggested that the two components of the task, perceptual and cognitive, were having a different effect on the heart rate. Blatt (1961) similarly identified two phases within the task, classifying them as 'information seeking' and 'information integrating'. The heart rate shows a bi-directional response during a mental task involving perception and cognition, and the total effect is a change in variability. Porges (1972) supported the importance of the different components of a task by observing a decrease in HRV during the phase of anticipating a signal. Obrist (1964) divided his tasks into sensory - motor and perceptual, and showed that HRV can therefore be related to a discrete component of an overall task, and not simply the type of task. The components of a task must be known before the significance of the HRV changes can be fully appreciated.

The interpretation of HRV changes which occur at the same time as a large increase in mean heart rate must be treated cautiously. A decrease in HRV may be due to the law of initial values, Wilder (1958). This law states that the change in any function of an organism due to a stimulus, depends to a large degree on the pre-stimulus level of that function. A high mean heart rate may cause less fluctuation about that mean. The magnitude of the mean heart rate changes in most studies using mental load meant that this law was unlikely to be having a marked effect. Physical load on the other hand, would be far more likely to invoke the law of initial values and cause a decrease in HRV.

The neurological control of HRV is the same as mean heart rate. The reduction in HRV, without a change in mean heart rate, has not been fully explained. The autonomic nervous system is implicated because the reduction in HRV occurs during conditions of psychological load. It is unlikely that a simple quantitative increase in neural innervation from one division of the ANS will explain the changes, because heart rate is controlled by both divisions.

Any examination of heart rate control is to some degree misleading because the variation in heart rate is merely a facet of a blood pressure control system. The periodic heart rate fluctuations are primarily haemodynamic in nature and any examination of causes for HRV must come initially from the area of blood pressure fluctuation. Cells which respond to stretching of the arteries are located throughout the circulatory system, especially in the carotid sinus leading from the left ventricle. These are baroreceptor cells and they send impulses to the cardiac centre to inform the brain of the mean blood pressure. This is compared with a reference value for blood pressure and the resistance of the circulatory system is changed to restore the homeostatic level. Blood pressure is controlled in what systems engineers call a 'bang-bang' manner, Power (1975). This is not unlike the 'all-or-none' phenomenon found in other areas of physiology. Low blood pressure directs the heart rate to increase, not in a graduated way, but dramatically. These neural signals are filtered in the transfer from the brain to the pacemaker cells, so that the eventual outcome is not a violent swing in heart rates. The net result, therefore, is not a resetting and holding of levels, but a constant oscillation at a rate of about 6 cycles. min^{-1}.

This does not account for all the fluctuations in heart rate which means that there must be other periodic influences. Any mechanism which causes a baroreceptor response is likely to influence heart rate. The baroreceptors respond to increases in pressure within the arteries, and to decrease in pressure on the outside of the arteries. The latter is precisely what happens during breathing - a periodic change in pressure outside the thoracic arteries. The respiratory frequency is therefore imposed upon the blood pressure heart rate control, once again via the baroreceptors. There are thus at least two sources of variability acting upon the intrinsic rhythm of the heart, the blood pressure control and the respiratory influence.

Entrainment is a process which gives further support to the proposed sources of heart rate variability. Entrainment is the manner by which a signal can be imposed upon a system such that the system takes on the characteristics of the imposed signal. The pattern of respiration has been shown earlier to influence the fluctuations of the heart. An alteration in respiratory frequency, so that it corresponds with the blood pressure oscillations, (6 cycles. min^{-1}) would be expected to resonate with the intrinsic fluctuations and cause a maximum HRV. This happens in practice. A movement of the respiratory frequency away from the blood pressure fluctuation will prevent resonance and the HRV will be lost in mass of signals all trying to influence the heart rate at different frequencies. Breathing at a high rate will result in limited heart rate fluctuations, because the baroreceptor control will be disjointed. Computer simulation of the entrainment of the breathing rate upon the HRV has shown that the range 4.5 - 13 cycles. min^{-1} gave an enhanced HRV whereas outside that range the entrainment of the respiratory signal decreased the variability, Miwawaki, Takahashi and Takemura, (1966). Further entrainment experiments, (Kitney and Weber, 1973, Kitney, 1974, Kitney, 1975, Hyndman, 1978) have revealed the effect of thermoregulatory adjustments on the blood pressure control system. The application of a thermal stimulus, by putting an arm in and out of water at 46°C, showed evidence of entrainment of the heart rate. The mechanism again appeared to be caused by feed-back through the baroreceptors.

The scoring of HRV is not straight forward because unlike mean heart rate it has no absolute physical dimension. Indices of HRV have been used which best describe the intentions of a given experiment. HRV is purported to reduce under autonomic arousal, therefore the measure which reveals this change in a monotonic and distinct manner tends to be selected, Luczak and Laurig (1973). A popular method of scoring was by the 'tolerance' method, Kalsbeek and Ettema (1963), Biesheuval (1969). This involved a visual inspection of the non-integrating cardio-tachometer trace. The inspection required lines to be drawn at the mean frequency and at 3, 6 and 9 beats per minute either side of it. The score was computed by recording how often the time series graph crossed these lines of tolerance. Other numerical terms have been considered by various authors and the formulae have been designed to emphasise different aspects of the variability such as frequency or amplitude. Different approaches have been advanced depending on whether or not the author wishes to weight the results for mean heart rate or for pre-stimulus value. Wartna & Danev (1970) list fifteen formulae, Mulder and Mulder-Hajonides van der Meulen (1973) list nine, Luczak and Laurig (1973) list eight, and Opmeer (1973) lists twenty-five different methods of scoring heart rate variability. Variance is the traditional statistical measure of variability, but it often lacks the precision required. Alternative measures have been adopted such as the mean square successive difference, described by von Neumann et al (1941). This measure, which is the mean of the squares of successive R - R differences, does not include the effect of any trend which may be 'shifting the mean of the population', Brodie, Brooke & Graveling (1975).

The influence of the cholinergic and adrenergic transmitters upon the SA node cannot be separated easily by the methods reviewed earlier. It may be useful, therefore, to examine the nature of HRV in terms of the sequence of heart intervals or time series. A variety of methods have been applied to successive heart intervals including those of Blackman and Tukey (1958), Loos (1968), Mulder et al (1972). The basis of these methods is the use of the fast fourier transform which estimates the amount of power present in the various frequencies within a given time series. The graphical representation of the amount of power at each frequency is known as a spectrum analysis or power spectrum. This technique offers the capability to detect the rhythmic variations in a sequence of heart periods.

HRV can be displayed so that the dominant frequency components are seen, Chess, Tam & Calaresu (1975), Hyndman and Gregory (1975), Sayers (1973), Kitney and Rompelman (1975). These results have indicated that the normal HRV signal comprises three dominant frequency components, a respiratory component (R) at 0.25 Hz, a blood pressure component (B) at 0.1 Hz and a thermoregulatory component (T) at about .025 Hz. (Fig. 1.3).

This is further confirmation that HRV is influenced by blood pressure control, respiratory disturbance and by thermoregulation. The decrease in HRV, although clearly autonomic in origin, is apparently a derivative of a blood pressure control system and may be the by-product of respiratory and other influences. This indicates the necessity to establish the importance of respiration in the assessment of HRV and as a measure of mental load.

Summary

Heart rate variability is an additional method of examining cardiovascular responses. The use of time series analysis of heart intervals shows the oscillatory nature of HRV and the association with other physiological signals.

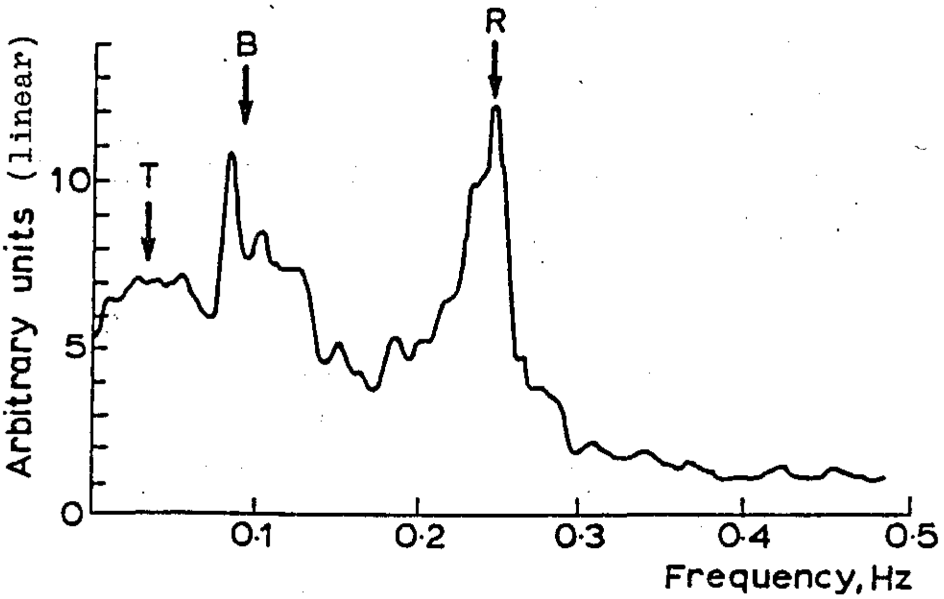


Figure 1.3 - A typical cardiac spectrum analysis showing frequency components at 0.025 Hz (thermoregulatory), 0.1 Hz (blood pressure) and 0.25 Hz (respiration).

1.3.4 Temperature (T)

Skin temperature has been reported as a valid measure of autonomic activity, although it shows a different response in different parts of the body. Its direct autonomic regulation relies upon the constriction and dilation of blood capillaries in the skin which is an adrenergic function of the sympathetic division. Finger temperature dropped after an alerting stimulus, Wenger, Averill and Smith (1968), Mittelmann and Wolff (1939), Corman (1968), Flecker (1951). Face temperature however, showed a less consistent response but tended to rise in most subjects, Helson and Quantius (1934) during an increase in mental load.

Teichner (1962) reported an 'arousal index' based on a formula relating skin temperature, core temperature and air temperature. He claimed that this was as satisfactory an indication of autonomic activity as more established variables such as EDA. This claim has not been substantiated by other workers but was used in the present study as it is the only reported measure of arousal level involving temperature exclusively. Mouth temperature was considered a satisfactory, non-invasive alternative to core temperature and was therefore used.

Temperature regulation is a highly co-ordinated function depending fundamentally on the activity of the central nervous system. Details of the regulation are available from the standard medical texts (e.g. Keele and Neil, 1966). The hypothalamus receives all the afferent neural imput associated with temperature regulation and has access to both the somatic and autonomic nervous systems for its efferent pathways. Specific areas of the cerebral cortex are concerned in the production of autonomic features of emotion and will project to the hypothalamus and reticular formation. The involvement of the cortex and reticular formation mean that aspects of learning and perception can influence the emotional response. The emotions are represented anatomically by the limbic system. The hypothalamus, a part of the limbic system, is possibly the common mediator between the emotions and temperature regulation. The specific mechanism involving decrease in skin temperature and mental load is likely to involve local vasoconstriction, but it is clear, Helson and Quantius (1934) that some subjects are more reactive to vasoconstriction than others.

1.3.5 Respiratory Factors

There appears to be an increase in respiratory frequency under conditions of psychological load, Vandenberg, Clark and Samuals (1965), Altschule (1953), Williams, Macmillan and Jenkins (1947), but respiration is not considered as an autonomic response because the respiratory muscles are controlled by the somatic nervous system.

Respiration is inherently rhythmic and is controlled by the interaction between the inspiratory and expiratory components of the respiratory centre located in the reticular formation of the medulla. This rhythmicity of the medullary centre is maintained by stimuli from non-respiratory neurons. Stimuli such as pain, cold, and photic stimulation will have a non-specific neural effect on the respiratory centre. In addition to the medullary respiratory centres, there are two pontine centres which influence the medullary centre. The first of these, the apneustic centre, stimulates the inspiratory component of the medullary centre. The other is the pneumotaxic centre which is stimulated by the inspiratory component activity. Activity of the apneustic centre can be inhibited by the pneumotaxic centre and the vagus nerve. The vagus nerve does not affect the expiratory component of the medullary centre directly but via the apneustic centre.

The regulation of pulmonary ventilation involves two feedback mechanisms. These are proprioceptive reflexes originating in the lungs and chest wall and a humoral feedback system involving chemical factors. Both of these feedback mechanisms influence the respiratory centres. The proprioceptive reflexes have most of their afferent pathways in the vagus nerve, and include the Hering-Breuer inspiratory reflexes, the paradoxic reflex of Head and deflation reflex.

Blood pressure also exerts an influence on respiration, with an increase of systemic arterial blood pressure causing hypoventilation and a decrease producing hyperventilation. The aortic and carotid sinus baroreceptors are the origin of this reflex. Baroreceptors in the walls of the atria and great veins are sensitive to an increase in blood pressure and may stimulate breathing which is an opposite action to those baroreceptors in the aortic and carotid bodies.

Certain investigators have reported increases in respiratory frequency during mental work, Altschule (1953), Williams et al (1947), Skaggs (1930), but the results are equivocal. Ellson et al (1952) have, for example, showed a slower rate of breathing during the telling of a lie, but the respiratory frequency will be modulated by talking so this study loses validity, as an indication of an autonomic adjustment to psychological demand.

Although breathing rate and amplitude do not appear from the literature to be the best indications of mental load, the reason for using them as a combined dependent variable is based upon their involvement in physiological control. Respiration is a complex measure, subject to modifying inputs from voluntary and involuntary nervous pathways as well as serving several functions in body metabolism and homeostasis.

1.3.6 Reaction Time (RT)

Simple reaction time (SRT) has been used extensively in the psychological literature as a measure of performance. The basis for such interest has been that SRT is simple to measure and involves the central nervous system. At the simplest level, reaction time requires the brain to identify a signal and initiate an appropriate response. In more complex designs using choice reaction time (CRT) the central nervous system (CNS) is involved in a greater degree of information processing.

The usefulness of SRT in understanding human response strategies is that the level of arousal may influence the CNS. This, and thus the SRT, could occur at both an individual level or in response to different treatment conditions.

The total latency of the reaction time is comprised of four components:-

(i) The time taken for the stimulus to activate the sense organ, and for the afferent impulses to travel to the brain.

(ii) The time taken for the central mechanisms of the brain to process the afferent stimulus.

(iii) The time taken for the efferent nervous volley.

(iv) The time taken between the efferent neural response arriving at the effector and the muscles producing the overt recorded response.

The literature gives many examples of factors which influence SRT. These include alcohol (Schultz, 1966; Carpenter, 1959; Hollister and Gillespie, 1970; Sutton and Kim, 1970; Mangeri, 1965; and Sutton and Burns, 1971), marihuana (Clark, Hughes and Edwin, 1970: Hollister and Gillespie, 1970), aspirin (Cappone, 1961; Macht, Isaacs and Greenberg, 1918; Davis, 1936), oxypertine (Adamson and Finlay, 1966) and various stimulants (Herrington, 1967; Hollister and Gillespie, 1970; Talland and Quarton, 1965).

The limitations with these studies was that dosage was not standard on either an inter-experimental or inter-subject (e.g. by body weight) basis. The number of subjects within the sample tended to be low and only one of the studies, Sutton and Burns (1971) appeared to consider the neural transmission time separately from the other components of the total SRT. These pharmacological studies, however, have confirmed CNS involvement.

There appears to be some evidence for women having a slower reaction time than men, (Henry, 1960; Bellis, 1933; Goodenough, 1935) with age also being an influencing factor, Hodgkins (1963); Weiss (1965).

Other potential influencing factors on SRT include motivation, Fairclough (1952), Cross and Eason (1969), Johanson (1922), Howell (1953) and Henry (1951). Anxiety, Davis and Warehime (1971), muscular tension, Beckman (1955), noise, Nosal (1971), exercise, Malomsoki and Szmodis (1970), and circadian rhythms, Adkins (1964), Elbel (1939), Thompson (1967) all have been reported to affect reaction time, as have other influences such as knowledge of results, McCormack, Binding and Chylinsk (1962), McCormack and McElerham (1963), Peretti (1970) and Henrickson (1971). The relevance of these studies to the present thesis is the importance of designing the experiment so that all such influences are either excluded or remain constant.

In normal populations the forewarning period or preparatory interval has been the subject of much investigation. The warning stimulus appears to cause some excitation of the reticular formation, Geblewiczowa (1963). As reaction time is influenced by the activity of the reticular activating system (RAS), Isaac (1960), the warning stimulus might be seen as a RAS stimulator.

Theories have been developed to explain the refractory period between one stimulus and another. These theories can also be used to interpret the psychological mechanisms of the preparatory interval, when the forewarning signal is considered as the first stimulus. Such theories include the central refactoriness theory, Angel (1969), the expectancy theory, Thomas (1970), the readiness theory, Poulton (1950), and the single channel theory, Broadbent (1958). These thories will not be developed here, but it is sufficient to state that they all consider central processing, which is itself related to the degree of central arousal. Each of these theories, and much work associated with the preparatory interval, are based upon phasic conditions. They relate to such features as the 'state of the organism at the time of the stimulus'. This study is concerned with the tonic level of the organism, and will consider the mean reaction time throughout any given condition to indicate central nervous involvement. The use of a preparatory stimulus would be inappropriate in such an experiment because the level of arousal may be elevated artifically prior to each reaction time signal. The SRT would not be reflecting, therefore, the true psychophysiological state.

SECTION TWO

EXPERIMENTAL STAGE ONE - EVALUATION OF PSYCHOPHYSIOLOGICAL MEASURES

The literature revealed a variety of psychophysiological responses which were valid sufficiently often to be considered as acceptable measures. However, the response characteristics for both mental and physical work were unknown, so this first experiment explored these for a limited number of measures.

The psychophysiological response to repeated stimulation was not known. This necessitated an examination of habituation for all measures.

Knowledge of the stability of each measure within a given experimental condition was also essential before any sampling procedure could be adopted.

It is particularly important to know which measures have a direct influence upon others. Electrodermal activity and temperature may come into this category because eccrine sweat glands respond primarily to psychological stimuli and the apocrine glands assist thermal regulation. The relationship was clarified in the first experiment before proceeding to use each measure independently.

2.1 Methods and Materials

2.1.1 Experimental Procedure

Three subjects were tested on 8 occasions. On four occasions the subjects completed a mentally demanding task, and on the other four occasions the subjects completed a physically demanding task. The type of task was randomly assigned on each occasion up to a maximum of four times for each type. Each individual experimental occasion took the form of:

(a) Establishment of basal conditions
(b) The task i.e. mental or physical task
(c) The recovery periods

A typical experimental procedure for one subject is shown in Figure 2.1.

The psychophysiological measures of:

Electrodermal Activity (EDA)
Electrocardiography (ECG) and
Skin temperature

were recorded throughout each occasion.

Each subject attended the laboratory for a period of 2 hours on the eight occasions which were spaced at weekly interval The subjects attended the laboratory at the same time each week to minimise diurnal variations.

(a) Basal conditions

Each subject sat in a comfortable chair and was instructed to relax as much as possible. Baseline levels were established over a period of 15 minutes. The experimenter was situated in a separate room from which all parameters were monitored.

EDA and skin temperature was recorded every 15 seconds, and ECG for a minimum of 15 complete cycles in every minute.

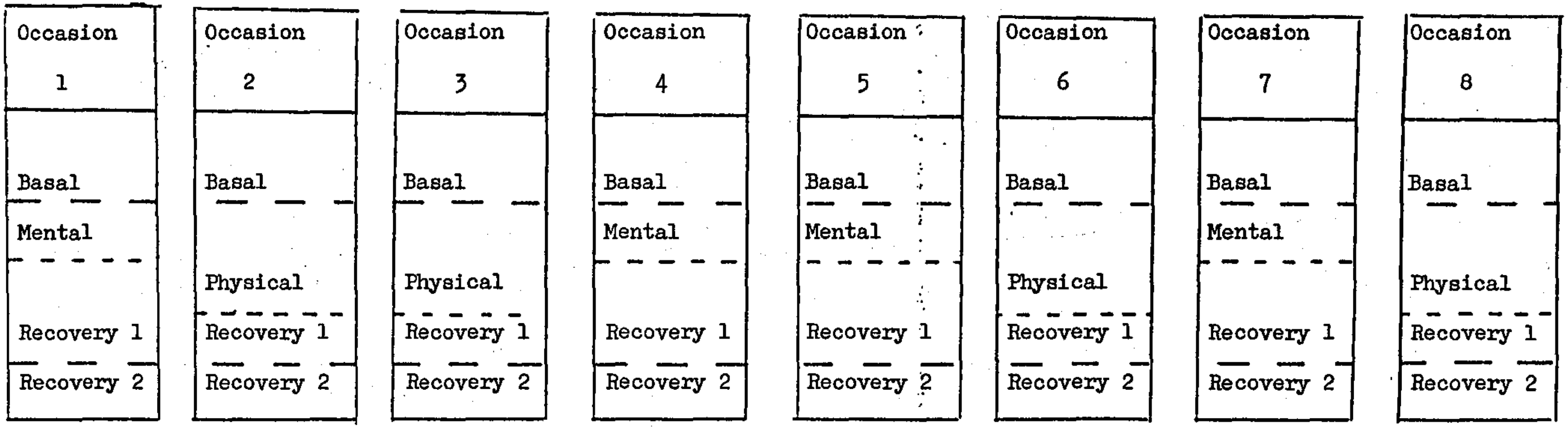


Figure 2.1 - Typical experimental procedure for one subject.

(b) Task conditions

The mental task was a series of questions from I.Q. tests, Eysenck (1962). Each subject was instructed to work accurately, and to answer as many questions as possible within the time period of 15 minutes. It was emphasised that accuracy was an important part of the experiment and before each occasion the subject was encouraged to perform well. The subject was given a sheet of paper and required to write the answer against the appropriate question number. This involved the minimum of movement as most answers were in the form of a letter or number.

The physical task was to pedal a cycle ergometer and to maintain a constant heart rate of 120 beats per minute. The heart rate was displayed to the subject on a heart rate meter (Childerhouse Ltd.) which was triggered from the output of the oscillograph. A heart rate of 120 was selected because it represented the demands of moderate physical activity. The subject adjusted his heart rate by changing the pedalling frequency. The work load was constant for the treatment period of 15 minutes.

The EDA, ECG and temperature were recorded as in the basal condition during both mental and physical tasks.

(c) Recovery conditions

The subjects relaxed for a period of 30 minutes after the experimental condition. The same measurements were recorded during this recovery condition. The period of 30 minutes was selected because a long recovery period was required to study the effects of the task. It could not be too long in case the subject became bored. The recovery period was divided into two sections of 15 minutes. This was to examine whether there were differences between the early and later parts of the recovery.

2.1.2 Subjects

Three subjects were selected from volunteers prepared to spend the time required upon the experiment. They were male students in normal health of median age 20 from the City of Leeds and Carnegie College, Leeds, England.

2.1.3 Experimental Measurements

The purpose of the experiment was explained to each subject without giving sufficient detail to influence the experimental results. This took the form of indicating that the experimenter was interested in the subject's response to the work conditions, but without explaining any of the physiological mechanisms involved.

(a) Electrodermal activity

The subject gently rinsed his hands in clean water to standardise the cleanliness of the hands and remove any excessive dirt or grease which may influence the recording. The water was at body temperature to prevent any peripheral vasodilation or vasoconstriction and the hands were dried with a dabbing motion as opposed to rubbing which could have caused abrasion and thus affected the skin resistance.

The electrodermal electrodes were placed on the volar surface of the middle phalanx of the index and ring fingers of the left hand. The electrodes were Ag/AgCl disc electrodes measuring 10 mm in diameter (S.E. Labs Ltd.) and were fixed to the skin surface by a strip of adhesive plaster with underlying gauze (Elastoplast Ltd.). Care was taken that the adhesive plaster was applied with similar pressure on each occasion and the experimenter was satisfied that no venous occlusion occurred. The electrolyte was a 0.05 M KCl paste as recommended by Venables and Sayer (1963) and was freshly made every 7 days. The electrolyte was squeezed into the electrode with a large-bore syringe to ensure that none went outside the cup of the electrode.

A variety of methods are available to record EDA, Venables and Martin (1967), and as two alternative forms were available, a pilot investigation compared them. One method (direct current system) was to connect the electrodes via an AC suppression circuit to an Elema-Schonander GSR Meter (Siemens Ltd.) which was incorporated into a Mingograph 34 ink-jet oscillograph (Siemens Ltd.). The balancing potentiometer enabled a direct reading on a digital counter of the skin resistance level. The other method of recording EDA (alternating current system) was by connecting the electrodes to a Galvanic Skin Resistance Meter 418/8160 (C. F. Palmer Ltd.), Figure 2.2, which displayed the skin resistance level in a digital form. A highly significant ($p<.001$) relationship existed between the results on the two systems, although the alternating current method was not as sensitive as the direct current method. However, manually balancing the potentiometer on the direct current system and ensuring that changes in resistance came within the full scale deflection of the oscillograph was laborious and therefore considered unsuitable for an experiment involving continuous monitoring. The alternating current system was thus adopted. The skin resistance level was recorded in kilohms and converted to conductance units by reciprocal transformation.

(b) <u>Electrocardiograph</u>

A clear and drift-free electrocardiograph record (ECG) was required for subsequent data analysis. This necessitated high quality transducer and amplifier characteristics particularly during the physical work task. The skin site selected for the earth electrode was above the sternum. The other electrodes were placed below the left pectoralis major muscle, one directly below the nipple line in the sixth intercostal space and the other 8 cm towards the mid line. The skin was prepared by cleaning with acetone and by abrasion until skin errythema occurred. Lead electrodes (Cranlea & Co.) were placed on the prepared sites having been covered on the active surface with electrode gel (Neptic Ltd.). The electrodes were attached to the skin with

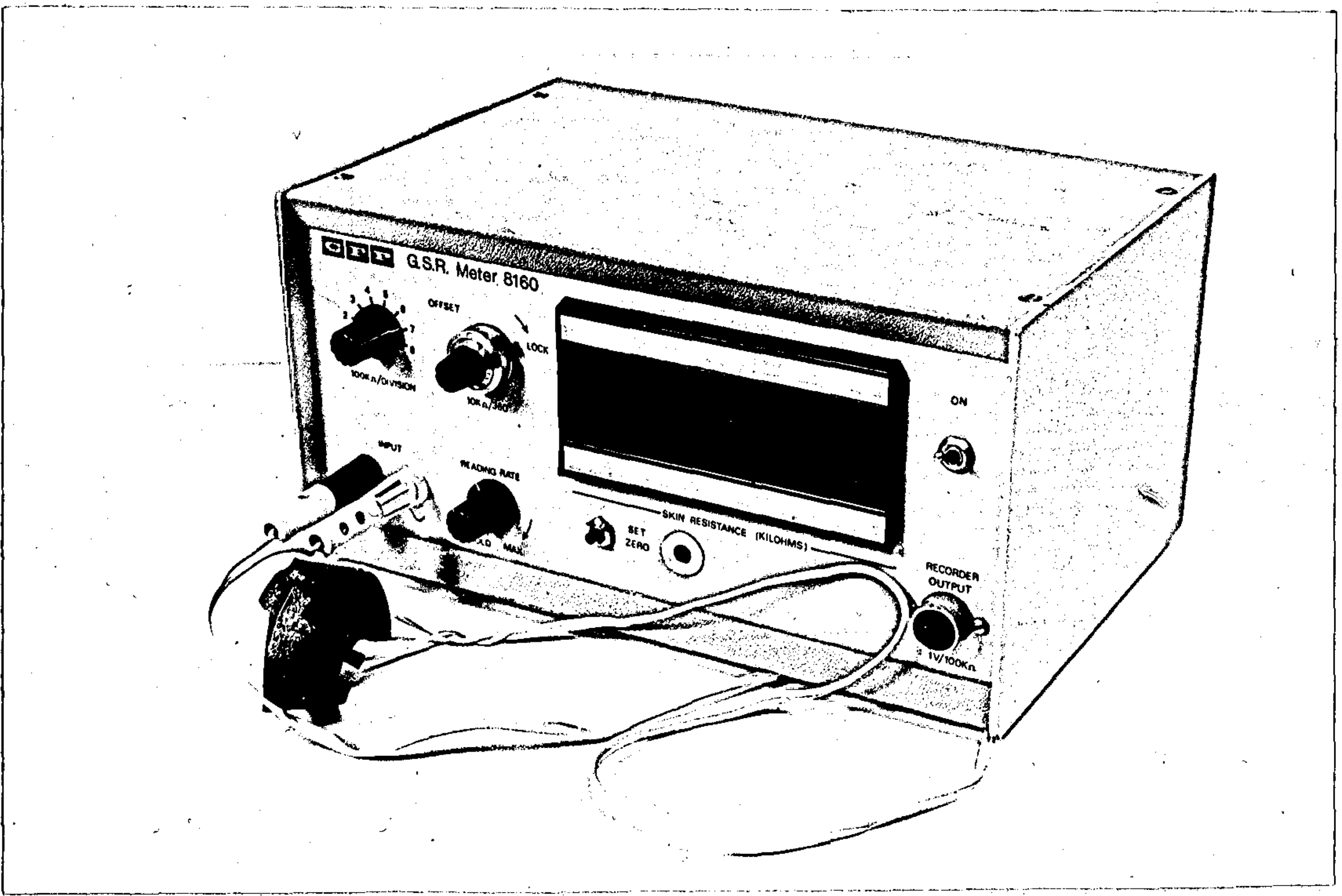


Figure 2.2 Galvanic Skin Resistance Meter 418/8160

4 cm squares of heavy duty adhesive tape through which the nipple of the electrode protruded. The electrodes were attached via an AC suppression circuit to an Elema Schonander ECG amplifier incorporated into a Mingograph 34 ink-jet oscillograph, Figure 2.3.

The paper speed of the oscillograph for ECG recordings was 25 mm sec^{-1}. An accurate and consistent chart speed was essential as the cardiac measures involved measuring the distances between successive beats. The distances were measured between the major peak of the 'QRS' component of the ECG (see Figure 2.4) and are subsequently called the 'RR' interval. The recorder was therefore calibrated against the 1 Hz tone transmitted by MSF Rugby, Brooke and Graveling (1974). The accuracy and consistency was such that no measureable difference could be observed. Inspection of the ECG indicated whether there was sufficient discrimination between the QRS complex and other components of the trace. Inspection also revealed if there was a stable iso-electric line and if any artefacts were present.

(c) Temperature

This was recorded at the same site as the EDA electrodes but on the middle finger. A flat thermistor (3 mm diameter) was attached with adhesive plaster to the skin surface. The temperature was recorded from a meter with a voltage scale equivalent to temperature (Grant Instruments Ltd.), Figure 2.5. The temperature meter was calibrated against a mercury thermometer and the battery level checked before and after each experiment.

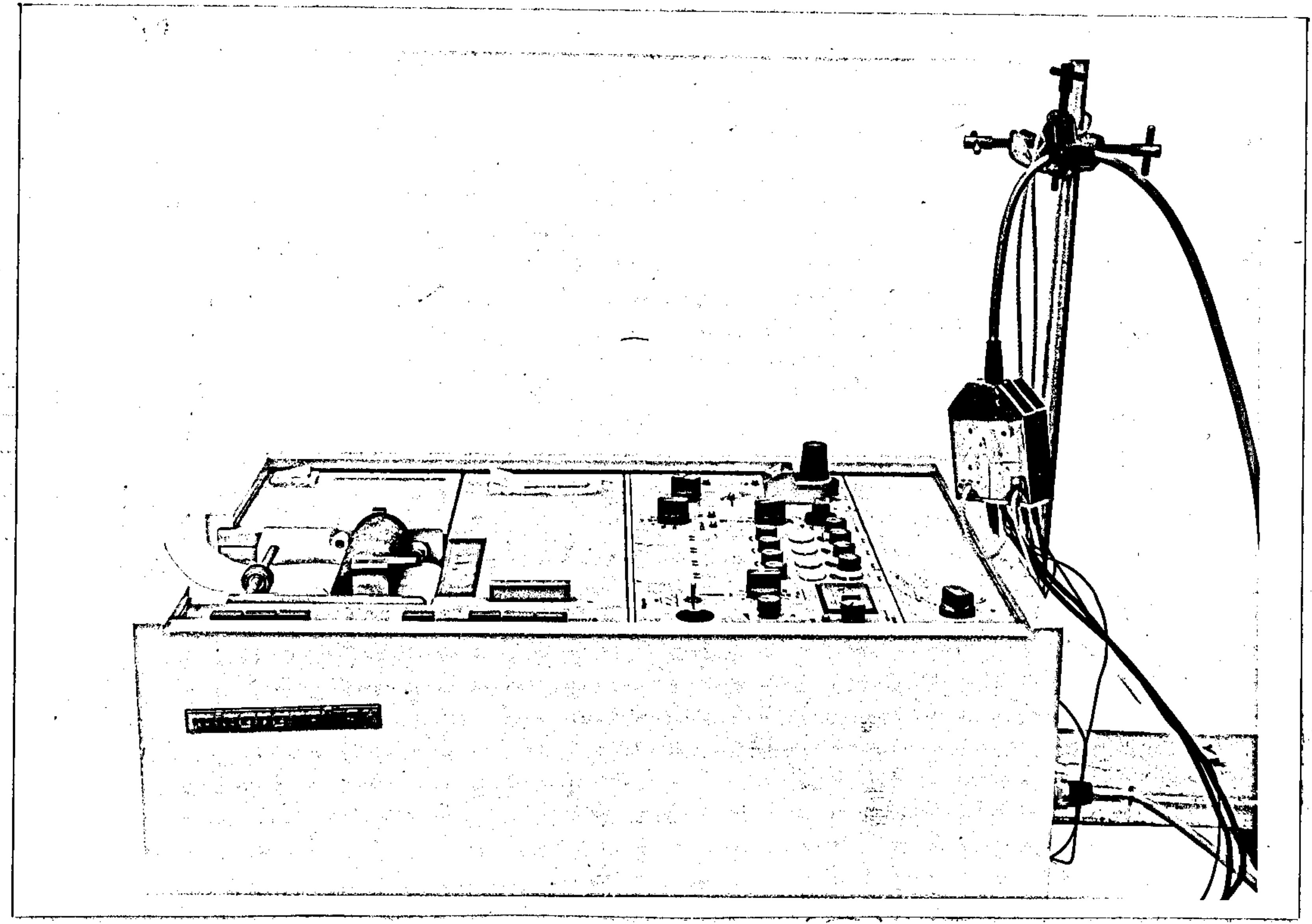


Figure 2.3 Mingograph 34 ink-jet oscillograph (Siemens Ltd.) incorporating an Elema Schonander ECG amplifier.

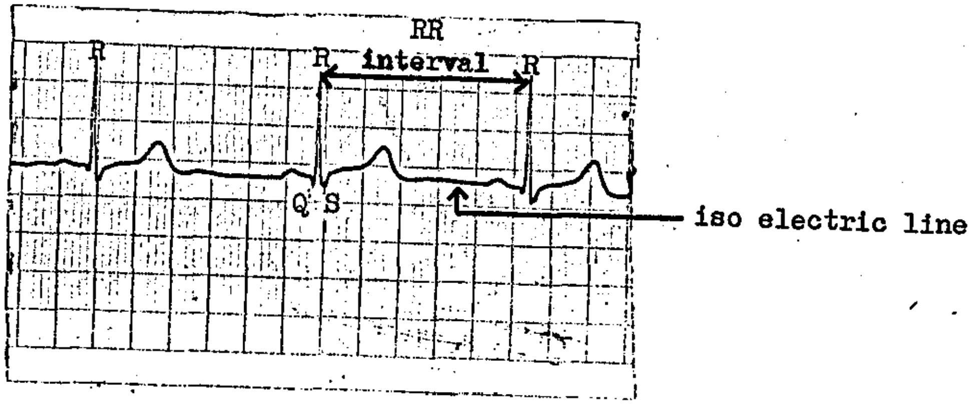


Figure 2.4 ECG Trace showing the 'QRS' component, 'RR' intervals and the iso-electric line

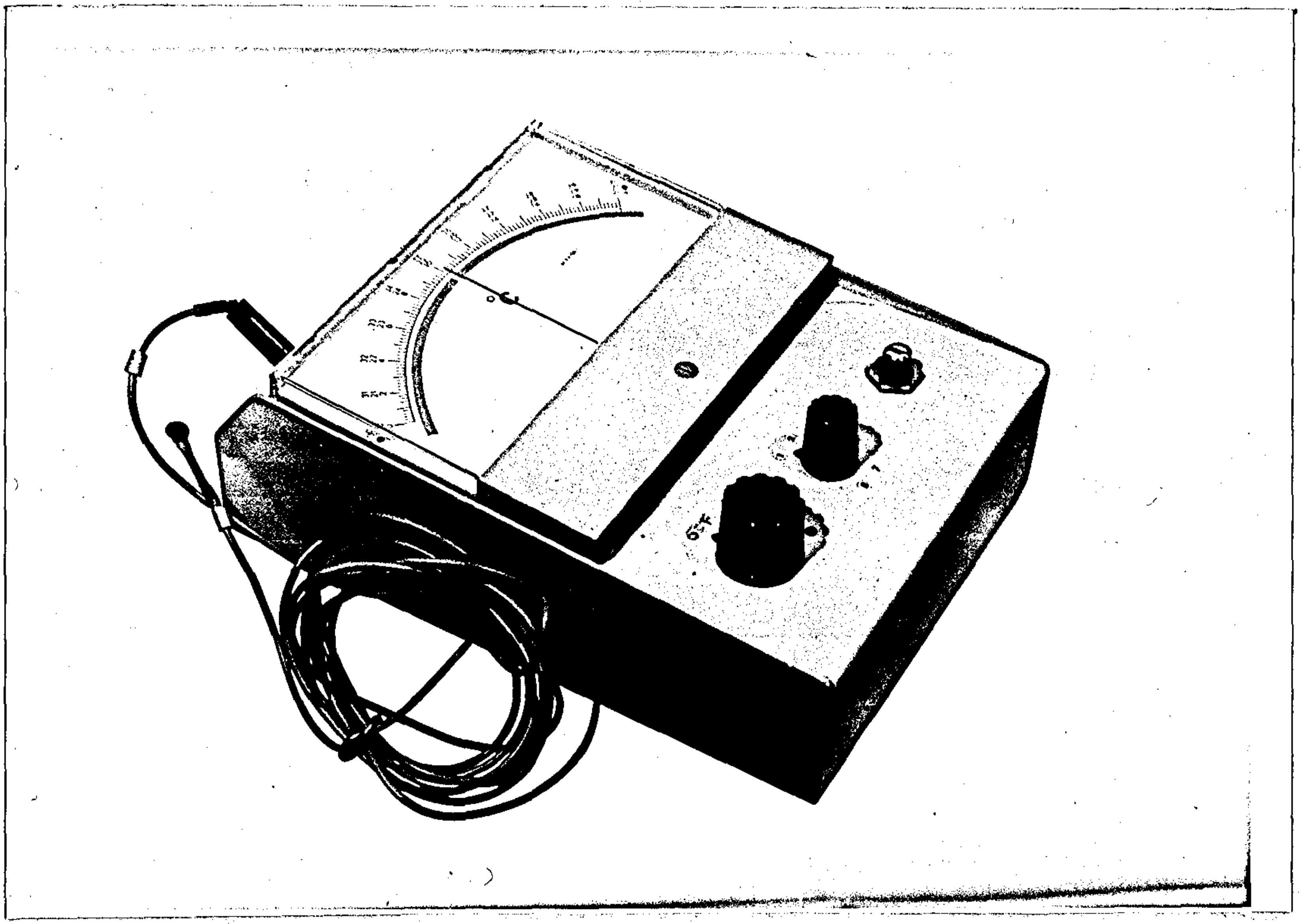


Figure 2.5 Thermistor and Temperature Meter

2.2 Results and Statistical Analysis

The measures are presented individually to simplify the analysis. The first 5 minutes of each condition were not included. This was because any novel situation may have changed the autonomic processes to a level which was more representative of 'change' than the actual condition. Two minutes is the minimum period required to compensate for this possibility and anything longer than 5 minutes would not leave sufficient time to analyse the response fully. A 'settling period' of 5 minutes seemed to satisfy both criticisms and was therefore adopted.

2.2.1 Minutes effect on each measure

The literature suggests that many workers use a single score for each treatment condition. This procedure is satisfactory if no sampling has been incorporated as part of the data collection. As data were collected for Experiment 1 over a period of 60 minutes, sampling was essential because of the expense of consumable materials particularly the oscillograph records. As a 15 second record was taken in every one minute epoch, it was necessary to establish whether this sampling procedure was producing variable data within each condition. A one way analysis of variance of the minutes effect for each condition for each subject for each measure was computed. This involved a comparison between each of the individual minutes over the 10 minute condition. This procedure was applied to every subject for every measure. There was a total of 144 analyses of variance which were computed on Salford University Simple Statistics Package NWDS. In every case there was no significant F value,(for example see Appendix 2.1) which showed that there was no difference between each minute. This shows that the measures maintain the same response level over the 10 minute treatment period.

It is known that demanding physical work, even of constant intensity, will cause an increase in organic disequilibrium. This is mainly due to the primary fuel sources being time limited and alternative energy mechanisms having to operate as time progresses. This experiment showed no evidence of this and suggested that any disequilibrium over the full ten minutes was within the range of the metabolic adjustment of the first minute. Also,the change to a new level caused by the mental or physical load was immediate. This suggested a short latency period for the autonomic measures under examination. They thus have an advantage over alternative autonomic measures such as the hormonal ones which do not show a change in urinalysis for up to 40 minutes.

This stability of autonomic measures over time within a given treatment condition will allow a single mean value to be used in any further data processing.

2.2.2 Electrodermal activity

The mean of the four EDA scores for each minute was used for the statistical computations. A two way analysis of variance procedure was established to examine the conditions and occasions effect for each individual subject. The design used was Type RB-4, (Kirk, 1973 p.133) which produced a series of ANOVA tables as exemplified in Table 2.1

Table 2.1 - Analysis of Variance Table for EDA.

Source	SS	df	Ms	F	p<
1. Between occasions	14955	3	4985	9.93	.01
2. Between conditions	5700	3	1900	3.78	NS
3. Residual	4516	9	502		
4. Total	25171	15			

The following table (Table 2.2) shows a summary of the F ratios and levels of significance between "occasions" and "conditions" for either the mental experimental condition or the physical experimental condition. The "occasions" were the four occasions that the subject attended the laboratory to complete either the mental or physical tasks. The "conditions" were either the basal, experimental, the first recovery or the second recovery conditions.

Table 2.2 - Summary F ratios for EDA

	Mental		Physical	
	Occasions	Conditions	Occasions	Condition
Subject 1 (D.S.)	9.93***	3.78*	7.43***	4.27**
Subject 2 (N.G.)	81.63***	4.20**	48.4 ***	3.08*
Subject 3 (S.G.)	14.8 ***	0.88	61.38***	4.92**

* p<.10
** p<.05
*** p<.01

All the occasions showed significant differences for all subjects. Two subjects showed a significant difference between the conditions involving the mental experimental condition. All subjects showed a significant difference between the conditions associated with the physical task.

The overall test of significance led to the rejection of the null hypothesis in certain of the ANOVAs. The data was therefore explored to find the source of those effects.

An _a posteriori_ multiple comparison test devised by Tukey (1953) was called the HSD (honestly significantly difference) test was used. The HSD test makes all pairwise comparisons among means. This _a posteriori_ comparison established the levels of significance between pairs of means throughout all analyses which showed an overall significant effect. Table 2.3 shows a typical single HSD test result.

Table 2.3 - Differences between means of EDA for the mental condition on four occasions.

HSD = 49.4 ($p<.05$); = 66.7 ($p<.01$)

Mean EDA	Occasion 1	Occasion 2	Occasion 3	Occasion 4
198 Occasion 1	-	27	85**	37
171 Occasion 2		-	58*	10
113 Occasion 3			-	48
161 Occasion 4				-

* $p<.05$
** $p<.01$

The differences between means on occasions 3 and 1 exceed the HSD value at a level of significance of $p<.01$. Occasions 3 and 2 exceed the HSD value at a level of significance of $p<.05$.

Figure 2.6 expresses these results graphically and shows that there was a significant lowering of skin resistance on the third occasion. This was not maintained as a significant difference on the fourth occasion. It may be appropriate, therefore, to allow a period of two occasions for habituation. The first two occasions in later experiments were subsequently

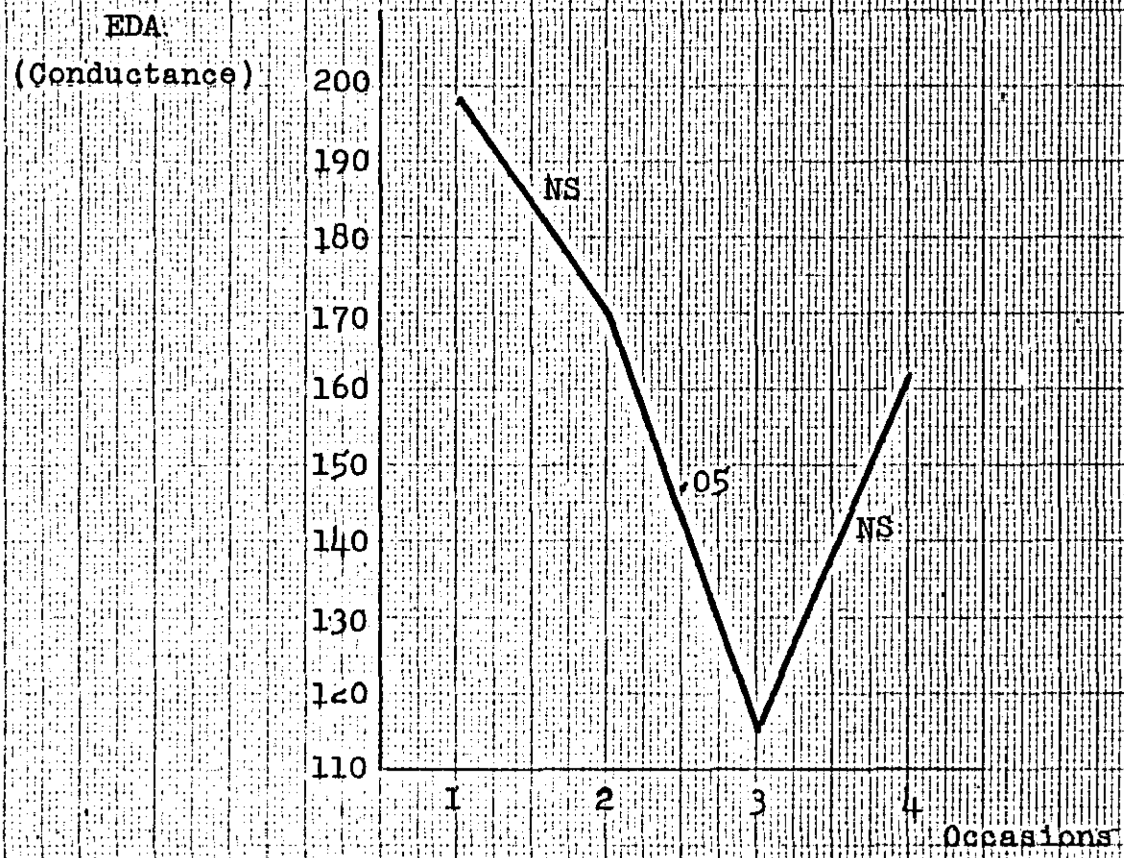


Figure 2.6 Differences between means of EDA for the mental condition on four occasions.

ignored for statistical purposes.

This initial analysis of the data revealed a high degree of individual differences between subjects. It was therefore appropriate to assess the contribution that subjects made to the total variance. The data were re-examined in a randomized block factorial design (Kirk, 1973, p 237). Table 2.4 summarises the F ratios in these analyses of variance.

Table 2.4 - Summary of F values showing contribution of subjects, conditions and occasions for EDA

	F Ratio SUBJECTS	F Ratio CONDITIONS	F Ratio OCCASIONS	Interaction
Mental	7.5***	0.97	15.23***	0.40
Physical	5.8***	3.24**	17.40***	0.31

*** p<.01

** p<.05

* p<.10

The following graphs (Figures 2.7 and 2.8) summarise the significant differences between pairs of means by Tukey's HSD test as described earlier.

The significant occasions effect in both mental and physical conditions questioned the reliability of EDA as a consistent measure on a day to day basis. It suggested that each subject is a different 'person' in terms of EDA every time that he visited the laboratory. The use of a 'change score' may be appropriate in future work.

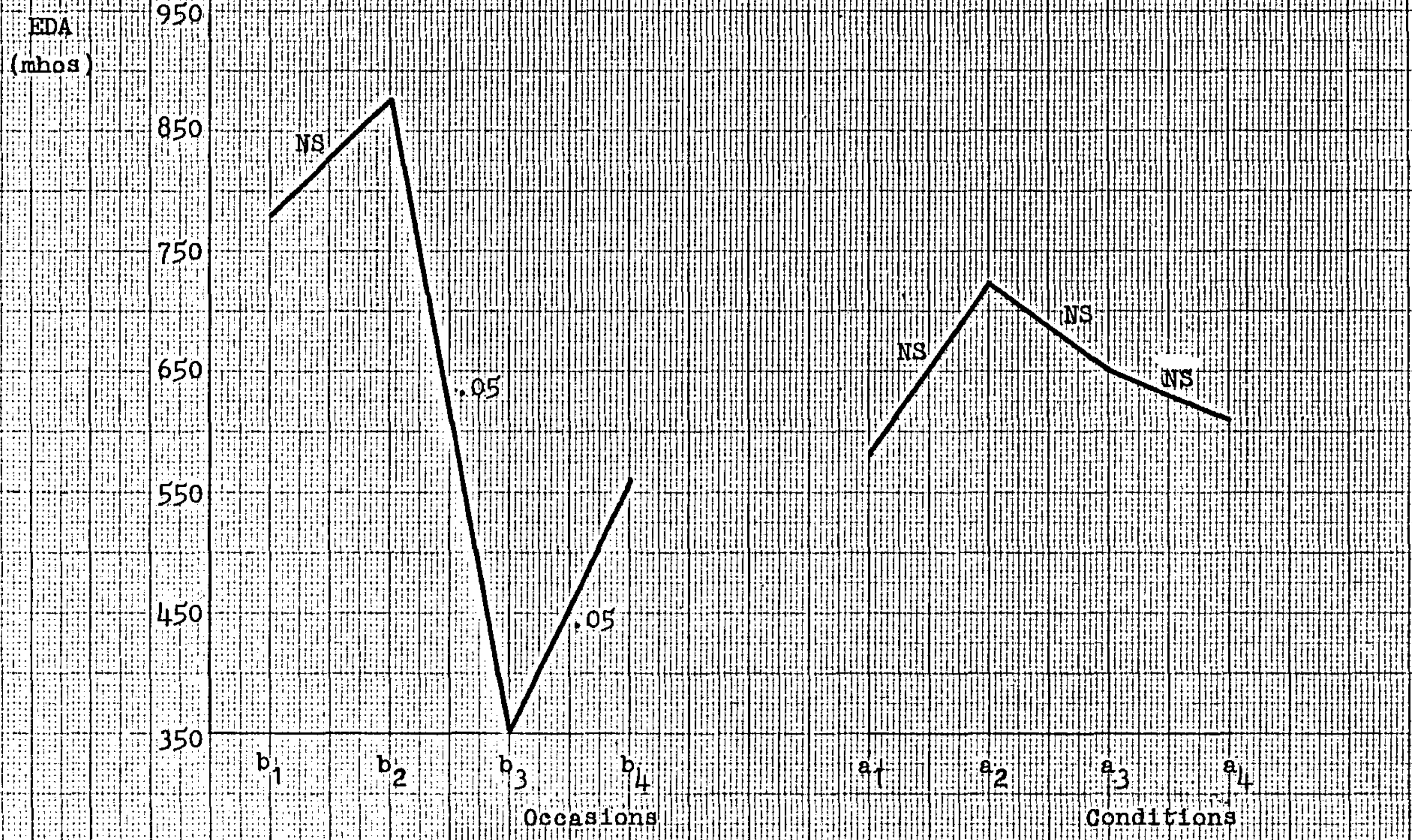


Figure 2.7 Significant differences in mean values by Tukey's HSD for EDA for mental task.

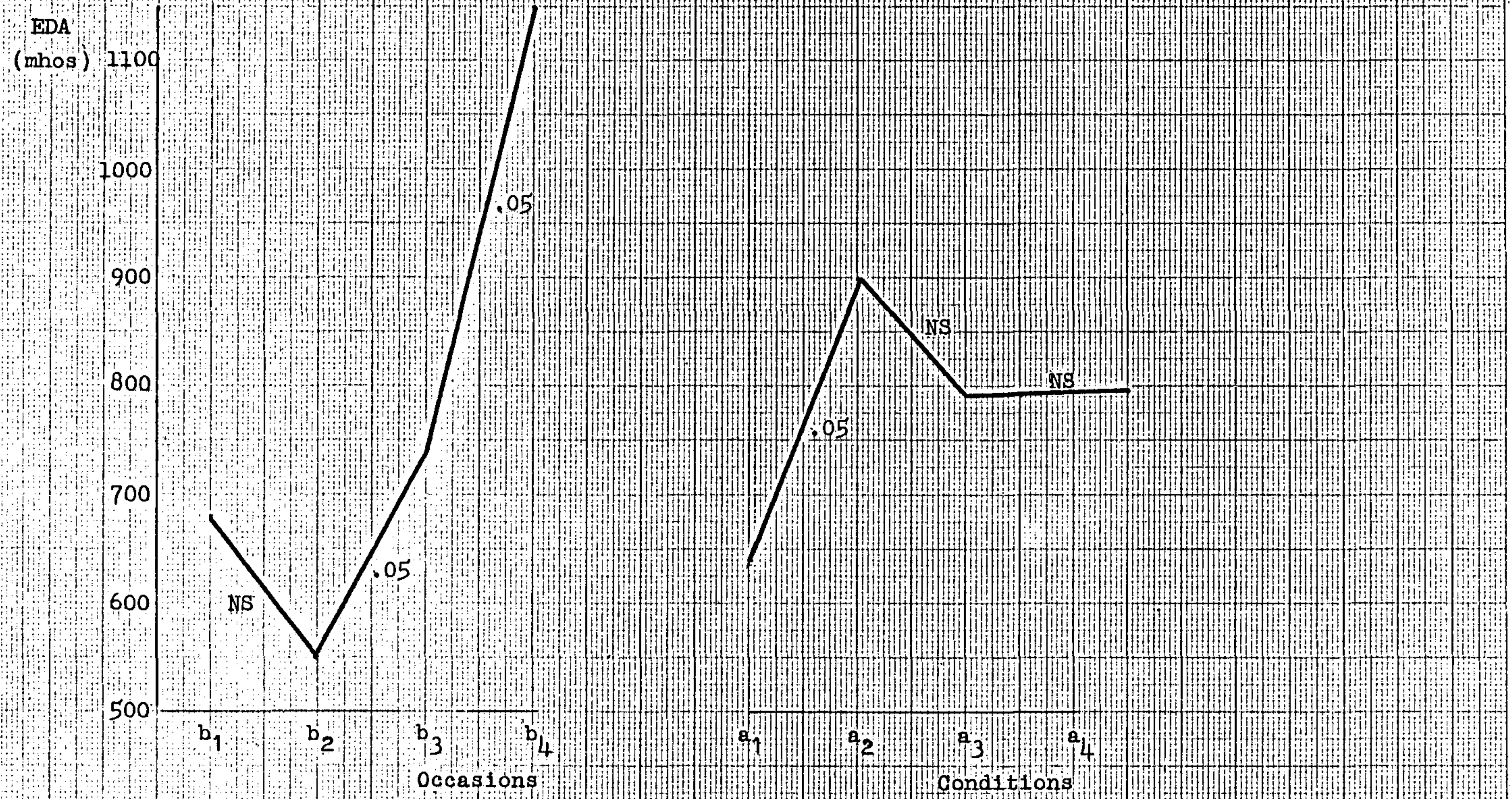


Figure 2.8 Significant differences in mean values by Tukey's HSD for EDA for physical tasks.

The EDA over the four occasions showed a significant increase after occasion two, which then continued into occasion four. This suggests no habituation had occurred over the four occasions which was a contrary result from that suggested with the EDA changes during the mental condition. This implies that there are differences in habituation dependent on the task, and should be considered when using EDA as a measure of arousal. The fact that EDA continues to rise during the second part of the recovery period (b_4 from b_3) for both mental and physical tasks is interesting. It may indicate that the subjects were not able to continue relaxing during the second half of the recovery period and were showing discomfort. This prompted later experiments to reduce the recovery period to less than 15 minutes.

It would be severe to exclude this apparently unreliable measure of autonomic activity without a full examination of the potential reasons for these results. As the same subjects were used for each occasion, the anatomical characteristics can be assumed to have remained constant. Procedural differences were minimised by keeping the time of day, temperature of room, location of electrodes, etc., the same on each occasion. However, even under identical methodologies, the occasions could have been interpreted physiologically as being different.

The results permit the following statement:

"The tonic skin conductance level is influenced by a number of factors which include the level of acetylcholine release at the post ganglionic terminal nerve fibres, the degree of excitatory or inhibitory involvement of the reticular activating system and the extent of cortical restraint. As these factors will be modified by psychological involvement and influences from other biological systems, any changes due to independent stimuli must be considered in relation to the state of the total organism at the time of the experiment."

EDA is a robust and valid measure of autonomic activity. Its reliability is dependent upon other aspects such as the influence of higher nervous structures. This means that experimental procedures must account for potential sources of variance. It will require a control on the influencing variables or an examination of the organism immediately before the experiment. A measurement of the change from the individual's pre-treatment state would be necessary.

2.2.3 Mean heart rate

The interbeat interval was recorded by measuring the distance between successive peaks of the predominant component of the ECG, the 'R' wave. The use of a micrometer screwgauge attached to draughtsman's dividers (British Indicators Ltd. - see Figure 2.9) achieved accuracy to 0.1 mm. This method was extremely tedious and errors may have been caused by observer fatigue. The interbeat intervals for 15 consecutive R-waves were recorded from the oscillograph trace for each minute. The interbeat intervals were converted into a heart rate per minute. Individual differences were shown in the results, so the data were re-examined on a randomised block factorial design. This assessed the contribution that the subjects made to the total variance. Table 2.5 summarises the F ratios for the three components of the analysis of variance.

Table 2.5 - Summary of contribution of subjects, conditions and occasions to the analysis of variance for mean heart rate.

	F Ratio SUBJECTS	F Ratio CONDITIONS	F Ratio OCCASIONS	Interaction
Mental	83.5***	1.2	0.7	0.2
Physical	6.0***	302.1***	17.4***	3.7***

*** $p < .01$

The above table shows that the differences between subjects was the only significant component of the mental occasions. All components contributed on the physical occasions, but the significant interaction effect means that a test of main effects is not appropriate. An examination of the ANOVA revealed that the conditions accounted for 88% of the total variance. This was to be expected as the task criterion involved a change in heart rate. There was no significant effect during the mental conditions. This suggested that the mental load may not have been

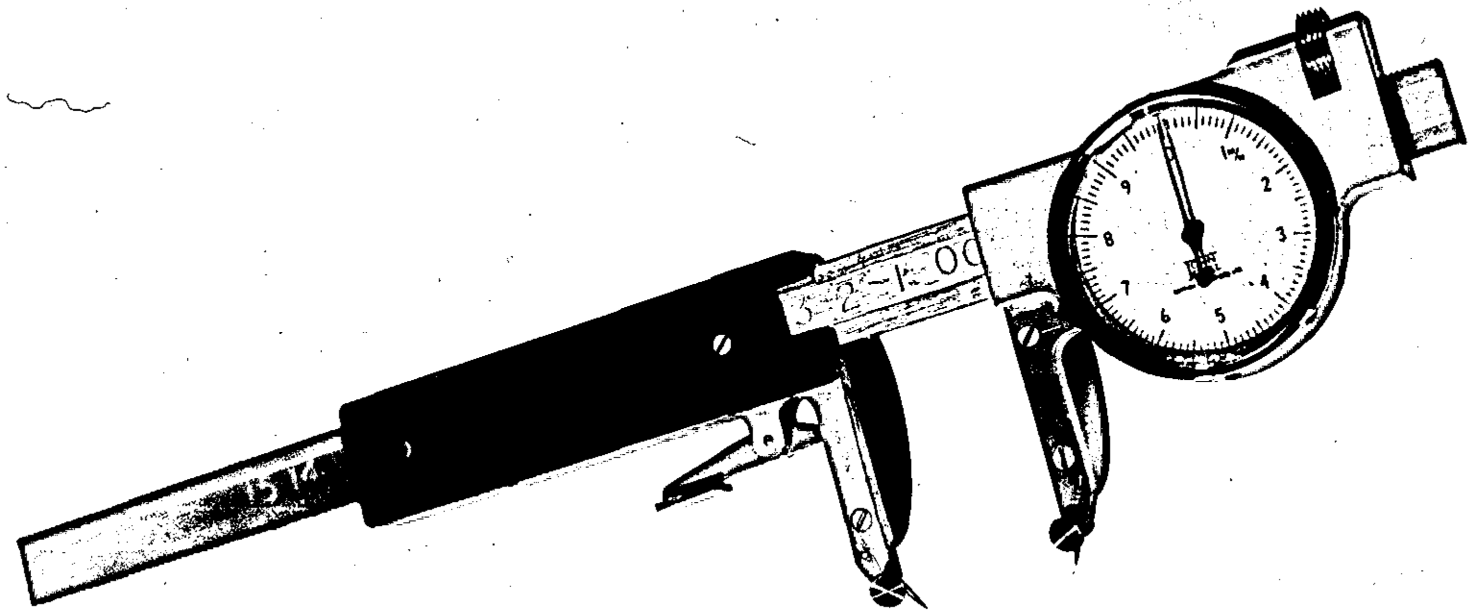


Figure 2.9 - Micrometer screwgauge attached to draughtsman's dividers.

sufficiently demanding to produce an effect. Alternatively, the mean heart rate may be insensitive or simply unaffected by this type of activity.

2.2.4 Heart rate variability (HRV)

The mean, variance and mean square successive difference were calculated for each minute using two separate programs on a Programma 101 desk top calculator (Olivetti Ltd.). This method was laborious, so a semi-automated method was sought. A D-mac analog-to-digital converter was built which produced a voltage proportional to the movement of a cursor in the x or y axis. The machine (P.C.D. X-Y Plotter) was calibrated by moving the x and y axes a known distance and making the necessary computation. The output voltage was displayed on a digital voltmeter (Micro 6051A) and certain statistics were calculated using specially written programs on a 600/14 desk top computer (Wang Ltd.). The statistics calculated were:

Mean heart rate (H_f)
Variance (s^2)
Mean square successive difference (d^2)
Second differential ($\Delta^2 HR\ (\Delta t^2) - 1$)
Ratio of d^2 to s^2 (d^2/s^2)

The reliability of this system was examined by measuring a series of R-R intervals on two occasions. The difference between the means at a heart rate of 60 beats. min^{-1} was only observable at the second decimal place. The accuracy of this method was assessed by measuring a known distance on repeated occasions. The standard deviation was ± 0.2 for measuring a distance equivalent to a heart rate of 60 beats min^{-1}. This dispersion was considered so small that it was not considered as an error term. Most of this error would be caused by the operator positioning the cursor inaccurately. The cursor had a double cross engraved on plastic at a vertical displacement of 1 cm. This reduced paralax errors by the operator.

The four statistically derived measures of HRV were examined by a two way ANOVA to establish the differences between conditions and occasions for each subject. As with most of the other measures, large inter-subject differences were observed so the randomised block factorial design was instituted to take account of these differences.

Table 2.6 - Summary of analyses of variance showing contribution of subjects, conditions and occasions for heart rate variability data.

	F ratio SUBJECTS	F Ratio CONDITIONS	F ratio OCCASIONS	Interaction
Mental d^2	9.3***	0.9	0.8	0.7
Mental s^2	10.7***	0.6	0.4	0.6
Mental 2nd Differential	5.3**	0.4	0.6	0.5
Mental d^2/s^2	4.4**	2.2	1.2	1.2
Physical d^2	14.4***	0.4	2.4	1.8
Physical s^2	14.3***	3.9**	1.0	1.1
Physical 2nd Differential	19.1***	1.3	1.9	0.9
Physical d^2/s^2	1.8	44.0***	1.4	1.4

*** $p < .01$

** $p < .05$

Table 2.6 showed that, once again, the greatest effect was due to the subjects. None of the parameters showed an occasions effect which demonstrated the good reliability of these measures. Two of the parameters (s^2 and d^2/s^2) showed effects between the physical conditions. The measure d^2/s^2 demonstrated the ideal response characteristics of a dependent variable, namely no inter-subject effect, no inter-occasion effect, no interaction, but a significant condition effect. It was responsive to change in condition (basal, experimental, and recovery) but not to anything else. It was interesting to note that d^2/s^2 under the mental conditions, although not quite achieving a level of significance, contributed only 4%

less variance to these conditions than to the significant subjects effect. The test of simple main effects gave support for d^2/s^2 as a measure of condition specificity. Figure 2.10 is a graph of the differences between the pairs of means. It was only the two recovery conditions (a_3 and a_4) which showed no differences. The measure d^2/s^2 thus appeared to show a monotonic change which clearly responded to the experimental treatment. The lack of statistical difference between the conditions a_1 (basal) and a_3 (first recovery) shows that d^2/s^2 returned to its original level after physical exercise. The measure d^2/s^2 does not have the significant interaction effect shown by H_r. This index of HRV, therefore, is measuring a distinct dimension from mean heart rate.

The chief difference between the variance (s^2) and the mean square successive difference (d^2) is that d^2 does not include the effect of any trend which may be shifting the mean of the population, Brodie and Graveling (1974). Thus s^2 <u>per se</u>, which is simply a measure of dispersion about a mean, provides different information from d^2 which looks at the time intervals between successive RR intervals. Heart rate variability measures provide additional information for the understanding of human response systems. This first experiment has indicated valid and reliable HRV measures which should be included in future work. Different mathematical transformations of the RR intervals give different information. It is therefore desirable to extend the range of transformations to get more information about the arousal responses.

The mean heart rate remains static but the variability is reduced. This means that there must be some mechanism which increases the constancy of SA firing. The form of control is uncertain but may involve a negative feedback loop from other related biological systems such as blood pressure and respiration. This will be examined in later experiments.

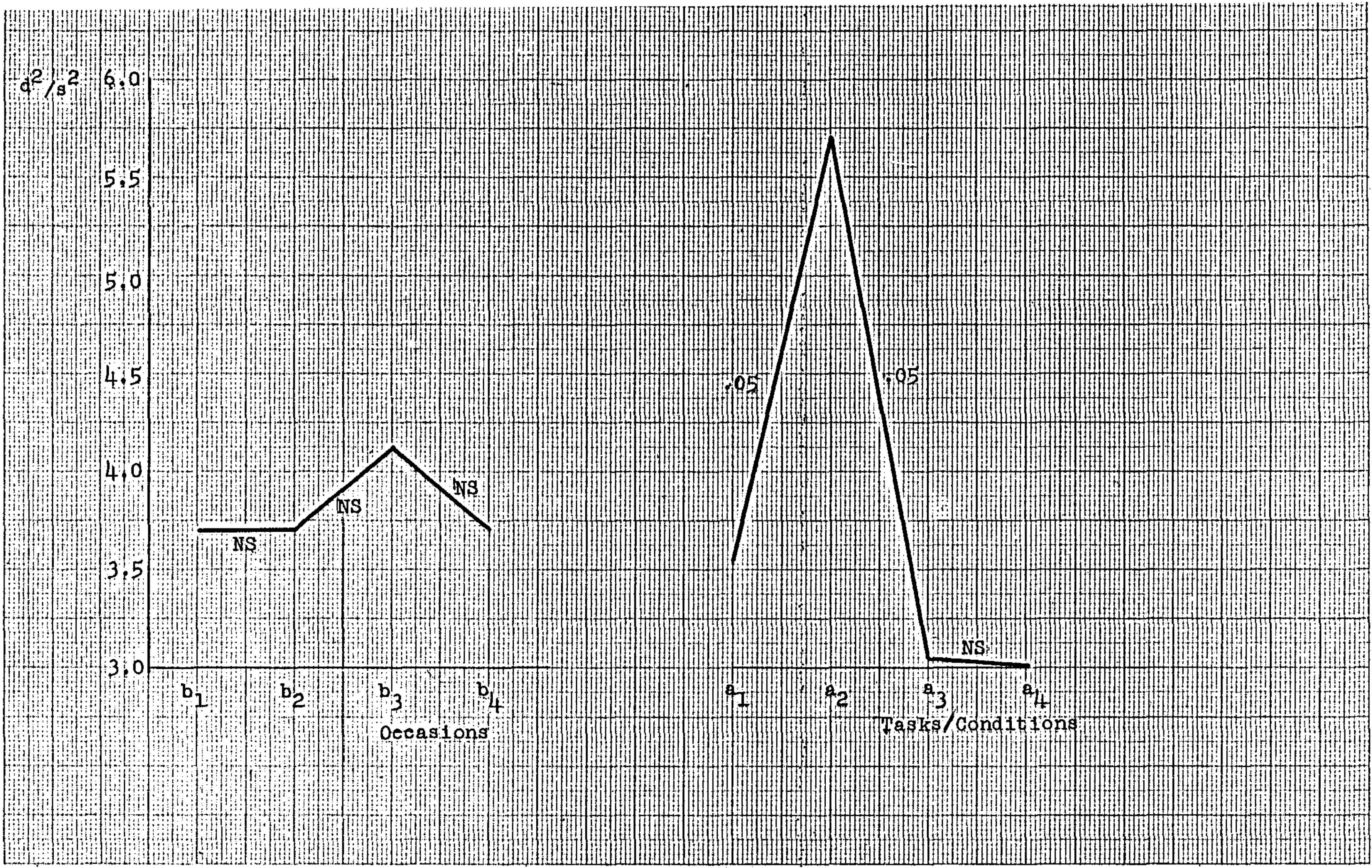


Figure 2.10 Significant differences in mean values by Tukey's HSD for d^2/s^2 for physical tasks.

2.2.5 Temperature

The mean of the four temperature readings for each minute was used in the statistical analysis.

The analysis of variance showed significant differences between the occasions and the conditions for each subject, ($p<.01$). The occasions effect suggested a lack of reliability for this measure. The method of recording temperature was potentially inaccurate because of the frequent changes of scales on the temperature meter. The temperature of the skin was in the region of 20° which was the upper limit of one scale and the lower limit of the next. The compatibility of temperature readings during scale changes was not known, so this could have contributed to the poor reliability. A more satisfactory procedure would have been to establish the range of likely readings and to have chosen an appropriate meter and scale. This may have resulted in a less sensitive reading, but would have eliminated the possibility of artifacts due to scale changes. It was not known, therefore, whether the results of the temperature readings were caused by procedural limitations so the method was changed for subsequent experiments.

One reason for the measurement of temperature at this stage in the study was to examine its relationship with electrodermal activity. The EDA mechanism in response to psychological stimuli involves the excretory duct of the eccrine sweat gland. The thermoregulatory mechanism, which also expels sweat, may interfere with the psychological function and cause a misinterpretation of the psychophysiological data. This would particularly apply under treatment conditions requiring the subject to engage in prolonged physical work. A Pearson product moment correlation revealed no significant relationship between temperature and EDA. This means that there is no specific association between the thermoregulatory mechanism and the psychological response.

Eccrine glands show regional differences in response to both psychological and thermal stimulation. The glands of the palm and sole, for example, respond rapidly to psychological stimuli, but require an intense and sustained stimulus to elicit a thermal response.

Electrodermal activity reflects changes in the autonomic nervous system provided a site is chosen of high eccrine gland density and a physical stimulus does not invoke the thermoregulatory mechanism. A site of high apocrine gland density such as the axilla should be chosen to measure temperature.

The finger temperature per se has been shown to be influenced by level of arousal, Mittelmann & Wolff (1939), Flecker (1951). The ANOVA in this experiment supported this over the four conditions of the experiment ($p<.01$). However the occasions effect was also significant ($p<.01$). This suggested that skin temperature, although a valid measure of response to different stimuli, also lacked reliability.

A temperature measure related more closely to arousal would be a more useful index of human response. This was the reason for using Teichner's "thermal arousal index" (1962) in the next stage of the study.

In summary, the following conclusions may be drawn:

It is both statistically acceptable and parsimonious to use mean values to represent a response level for the autonomic measures of EDA, H_f, HRV and temperature during mental and physical work lasting 10 minutes.

Electrodermal activity lacks day-to-day reliability without some appropriate transformation. It is however, due partly to lack of parasympathetic constraint, a sensitive measure and a suitable change score should be used in future experiments.

Most subjects stop relaxing after approximately 15 minutes of laboratory conditions. This has implications for the length of the recovery period following demanding work and such information will be used in the design of subsequent experiments.

A sequence of heart periods can only be described adequately by two independent dimensions, heart rate and heart rate variability. An association between these two dimensions was shown by Speisman, Osborn and Lazarus (1961) under strong arousal conditions. This study could not support the association for demanding physical work, which suggests that the description of cardiac responses is stimulus specific.

Doubt is expressed over the value of temperature as an independent response measure during demanding mental work. Its involvement in cardiovascular control does merit its inclusion in an overall response profile.

Concern over the potential interference between different types of sweat gland was unfounded. A site of high eccrine gland density will not be influenced by thermoregulatory mechanisms.

SECTION THREE

EXPERIMENTAL STAGE TWO - RESPONSES TO DEMANDING MENTAL WORK DURING INCREASING PHYSICAL LOAD

The psychophysiological measures used previously require modification before they can be considered reliable responses to demanding tasks. The modifications include making allowances for resting levels, expressing the data in alternative ways and developing new forms of analysis.

As stimulus similarity may be limiting the interpretation of the responses, the next experiment involves a graduation in metabolic load. This also provides a progression from cholinergic to adrenergic influence which may explain the differences between the arousal subsystems.

The dominant feature of the first experiment was the individual differences between subjects. The prediction of psychophysiological responses requires a description of both the unique and consistent features of the measures. This requires a further examination of individual differences by including a larger number of subjects and examining their response patterns.

The literature suggests that one such response pattern involves a cardiac-somatic relationship, but this has not been established over a variety of tasks. The progressive increase in metabolic load will provide situations which may clarify the relationship.

3.1 Methods and Materials

3.1.1 Experimental procedure

The experiment was designed to examine the response characteristics (autonomic, physiological and performance) during demanding mental work involving a perceptual-motor task. Physical work was also incorporated at four different loads, by varying the metabolic requirement of the task. Two control occasions completed the procedure, one involving no mental task or physical work, and the other involving no mental task but the highest intensity of physical work. Prior to these 6 experimental conditions, each subject completed 2 occasions to allow for habituation and learning as this was indicated as necessary from the previous experiment. These first 2 occasions were not considered in the subsequent analysis of results. Thus in total, each subject (N = 13) attended the laboratory for a period of one hour on 8 occasions spaced at weekly intervals. The subjects attended the laboratory at the same time each week to minimise diurnal variations.

3.1.2 Perceptual-motor task (P-M)

As this task is basic to all the experimental conditions, it is described separately before the details of the experiment are given in the following section. The subject was required to keep the tip of a photo-electric probe above the moving light spot of a pursuit rotor (Forth Instruments). The light spot followed a star shaped path at a rate of 20 revolutions per minute. A glass cover enabled the subject to locate the probe in a horizontal plane. The importance of achieving good results on this task was emphasised. The time in seconds during which the tip of the probe was above the light spot was displayed in digital form every 20 seconds and recorded by the experimenter without reference to the subject.

3.1.3 Experimental conditions

Each subject was assigned to each of the 6 experimental conditions in a random manner. Details of the 6 conditions follow and involve four intensities of physical work and two control conditions.

(a) No physical load (Intensity 1)

This experimental condition was designed to ensure that the subject attended to the task but made minimal movements. He was required to watch the light spot and to press a microswitch whenever the spot touched two designated positions on its track. These positions were clearly shown to the subject and corresponded to opposite points on two 'arms' of the star at a maximum distance from the centre of the figure. The intention of this task was to retain the characteristics of the perceptual motor task but to involve minimal physical work. This was designated the "no load" condition.

(b) Light physical load (Intensity 2)

This required the subject to operate the pursuit rotor in the normal manner as described in section 3.1.2. This was designated the "light load" condition.

(c) Moderate physical load (Intensity 3)

This required the subject to operate the pursuit rotor normally, but a 2 kg weight was attached to the subject's right lower arm. The attachment was by means of a comfortable light padded strapping. The intention of this task was to induce a limited amount of local muscular fatigue and was designated the "moderate load" condition.

(d) Heavy load (Intensity 4)

This condition involved the same mental task (pursuit rotor) but the subject increased his work load by pedalling a bicycle ergometer (Muller Ltd.), Figure 3.1, at a power of 100 watts. The saddle height was adjusted (109% inside leg measurement) to allow for the heights of various subjects. This condition was designated the "heavy load" condition.

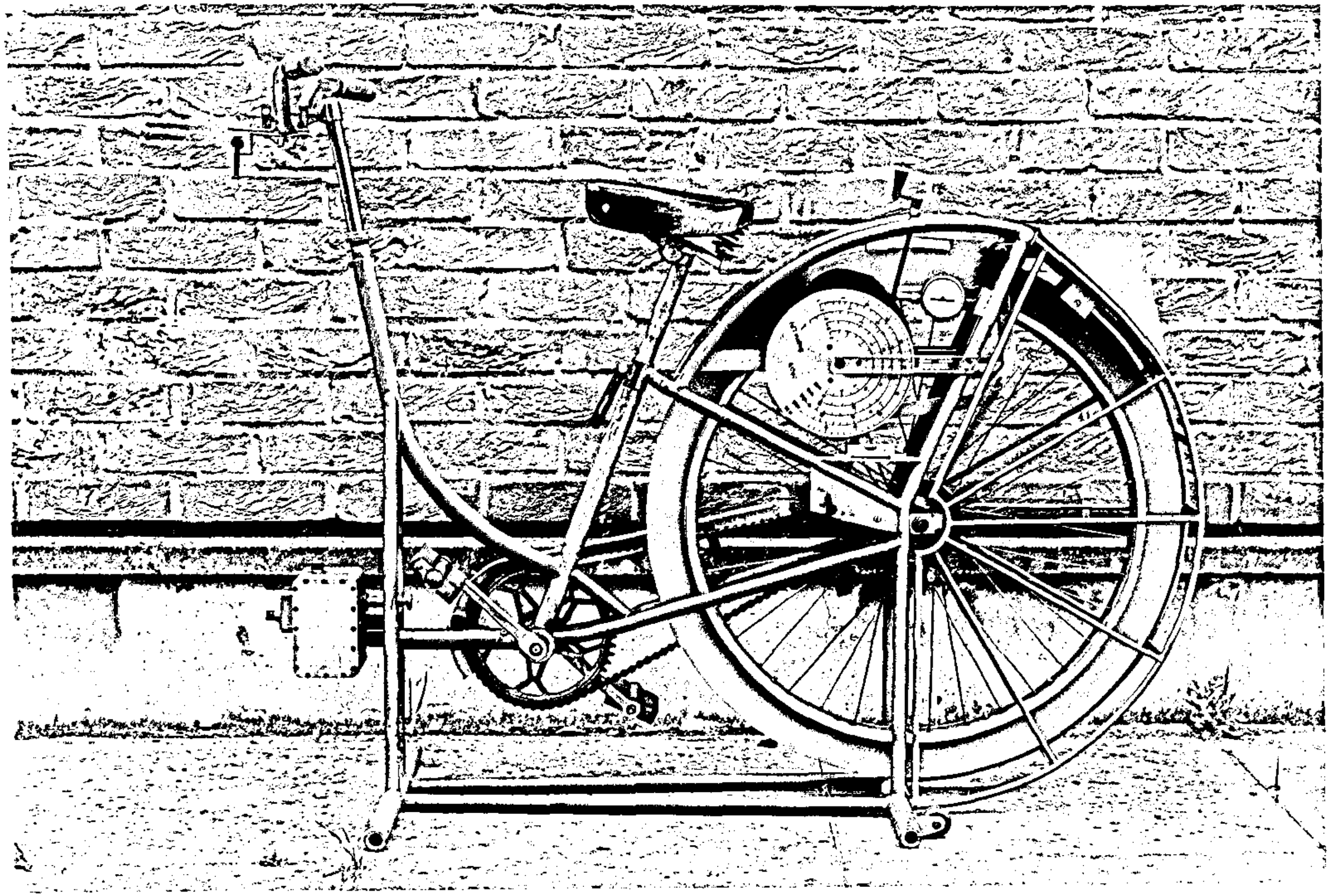


Figure 3.1 - Bicycle ergometer used to produce the physical work load.

(e) Control

The effect of involvement in the task situation and change levels were examined by comparison with a control condition. In this condition the subject simply sat resting. This was designated the "<u>control</u>" condition.

(f) Heavy load control

This was incorporated to examine the effects of the psycho-physiological variables during heavy work, regardless of the mental task. The subjects completed the "heavy load" condition but did not participate in the perceptual motor task. This was designated the "<u>heavy load control</u>" condition.

Figure 3.2 summarises the experimental conditions.

Each experimental condition was divided into 3 parts consisting of a resting, experimental and recovery stage.

The purpose of the resting stage was so that basal levels for each subject on each occasion could be established. Each subject sat in a comfortable position for a period of 10 minutes during which he was instructed to relax. The experimental stage has been described earlier and lasted for a further 10 minutes. The recovery stage was for a further 10 minutes.

NO PHYSICAL LOAD	LIGHT LOAD	MODERATE LOAD	HEAVY LOAD	CONTROL	HEAVY LOAD CONTROL
Intensity 1	Intensity 2	Intensity 3	Intensity 4	No physical load	Cycling
Attending to P-M Task	Normal P-M Task	Weighted arm P-M Task	Cycling + P-M Task	No P-M Task	No P-M Task

Figure 3.2 - Diagram of the experimental conditions

3.1.4 Subjects

Volunteer male subjects of age range 19-32 years and median age 20 took part in the experiment. They were all in normal health and were either students or technical staff of the City of Leeds and Carnegie College, Leeds, England.

3.1.5 Measures

(a) Electrodermal activity

The subjects were prepared as in section 2.1.3 and EDA was recorded once every 20 seconds after the equipment had been calibrated as stated earlier. The mean of the EDA scores for each minute was used for the statistical computations.

(b) ECG

The subjects were prepared as in section 2.1.3 and the ECG recorded continuously on the oscillograph at a paper speed of 2.5 mm sec^{-1}. The ECG data was also recorded on FM tape at a tape speed of $3\frac{3}{4}$ in. min^{-1}. This offered the opportunity for data transportation and data analysis by alternative methods. To ensure that the data was being satisfactorily recorded on the FM tape recorder (Elliott Tandberg Data Recorder Type 64E2) the output mode was connected to a two channel oscilloscope (Solartron Ltd.) and a continuous display was observed.

The recording of a large quantity of continuous data in an efficient manner and with limited resources required a high degree of organisation. For subsequent analysis three essential prerequisites had to be considered. First the location of the magnetic tape on the tape recorder spool had to be highly reproducible. This was essential to ensure that any data recorded elsewhere was synchronised with the tape. This was achieved by tagging the tape and ensuring that the tag was located at exactly the same point on the recorder. The digital counter was then zeroed and the tape moved to a known position as indicated on the counter. Secondly an exact coding procedure had to be adopted so that each experimental condition for each subject on each occasion was known. This was assisted by using a separate, new tape for each subject, but required accurate recording of the details of tape position, etc. In addition the tape was always played through the oscilloscope prior to an experiment to check that the tape had run past all previous recordings. Thirdly the tape speed accuracy had to be established. The manufacturers claimed a relative accuracy of ±0.2% and an absolute accuracy of ± 1%. This was checked by recording a 1 Hz signal simultaneously with an oscillograph trace, and replaying on to the oscillograph. The difference between the record and replay modes was immeasurable at 25 mm sec^{-1}. As the number of cardiac interbeat intervals exceeded 250,000 during this experiment it was desirable to develop an automated system of measurement. Computing facilities were not available near the experimental laboratory so the storage of ECG data on to the FM tape recorder made it possible to transport the information to a computer. The initial computer was a Minic (Micro Computers Ltd.) which was located in the Dept. of Electrical and Communication Engineering, Leeds Polytechnic. The computer acted essentially as a data logger, converting the analog signal into a digital series of R-R time intervals. This procedure took a period of about 12 months to solve satisfactorily. The first approach to the problem was to develop hardware to process the analog signal so that the 'R' wave of the ECG was amplified and re-shaped. This would then be in a form suitable for a timing device to be operated such as a Schmitt trigger and the time measured between successive pulses. Although this met with some success and was a preliminary procedure that is recommended for other workers, it was considered that the Minic computer was ideally suited to the development of software which would replace this data pretreatment. Mr. D. Trevena of the Department of Electrical and Communication Engineering, Leeds Polytechnic, wrote a program which received the analog signal in the FM replay mode, isolated the 'R' wave from the other components of the ECG, and compared this signal with a millisecond pulse. A flow diagram of the system is shown in Figure 3.3.

As no two biological analog signals are identical, it was necessary to have a series of program variables which were set prior to each computational run (Appendix 3.1). The most important of these variables was the height of the 'R' wave. If the program voltage threshold value was set too low, the 'T' wave of the ECG was likely to trigger a false reading, and if the voltage threshold value was too high the 'R' wave would not initate the timing mechanism. Subsequently a short piece of

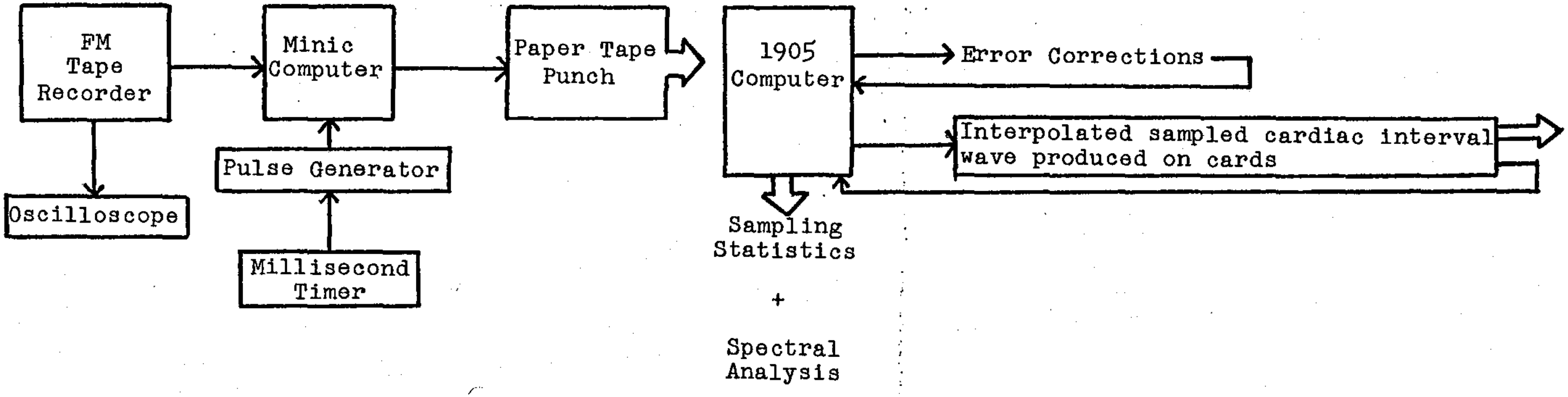


Figure 3.3 - Flow diagram of ECG computer processing system

each recording was played through an oscilloscope and the amplitude of the 'R' wave was recorded in millivolts. The program variable was then set to the appropriate level and each 'R' wave initiated a new timing sequence.

It was also necessary to ensure that the millisecond pulse generator was operating at exactly 1000 Hz. This was essential as the eventual output of the computer produced a series of millisecond times in which the pulse generator was acting as a comparator. The pulse generator (Griffin and George Ltd.) was connected to a millisecond timer (Panax Ltd.) and the pulse generator frequency adjusted until an exact 1000 Hz signal was produced.

The tape was replayed into the computer at real time speed as any accelerated playback would reduce the sensitivity of the interval timings. The computing process was initiated externally so that the exact position of the start of the run could be recorded from the digital counter. The end of the run could be predetermined by one of the program variables but was consistently 300 seconds from the start.

The timed R-R interval sequences wave was then displayed on a line printer and the results were scrutinised for major computing errors. Once errors had been checked and eliminated by re-running the recording with alternative program variables, the digitised date was dumped on to paper tape using a high speed tape punch (Facit Ltd.). All paper tapes were coded to correspond to the subject name and experimental condition.

The reliability of this method of computing the R-R interval distance was established by running a series of tapes through the system on two occasions. The maximum difference between any two readings was ± 8 milliseconds which over an average heart interval time of 400 milliseconds is equivalent to an error of ± 2%. This error is compounded from tape speed accuracy, tape stretch and the reliability of the comparator (millisecond pulse generator). This indicated that when the

R-R interval series is examined, a variation of less than ± 10 milliseconds can not be considered a reliable physiological effect.

The next stage was to 'clean up' the digitised paper tapes so that all the interval times were exact reproductions of the actual analog series. Fortunately the extent of this operation was not large although certain operational decisions had to be made in the programming of the computer as no interactive facilities were available. The most common error, although relatively speaking it was rare with an occurence rate of about 1%, was the triggering of the timing mechanism by the T wave. This was seen quite clearly as a very short interval period relative to the others. Although this T wave is part of the previous ECG complex the time interval has to be added to the subsequent R-R interval to nullify the error. A suitable program was written on the Leeds Polytechnic ICl 1905 computer to correct this error, and the printout confirmed all corrections. This program also calculated a series of descriptive and time series statistics on the interval times.

The statistics were as follows:-

(1) Average length in milliseconds of the computed sequence of R-R intervals (Heart Rate)

(2) Variance in milliseconds of the computed sequence of R-R intervals (Variance or s^2)

(3) Sum of the absolute differences between successive R-R intervals (SABS)

(4) Frequency of relative maximal and minimal heart beats or the number of reversal points (AM2)

(5) Sum of the absolute differences divided by the number of reversal points (SABS/AM2)

(6) Mean square successive difference (MSSD or d^2)

In addition to these heart rate variability measures the ECG data were examined by time series analysis for the frequency patterns of successive 'RR' intervals. The initial assumption for any measurement of heart rate variability from a series of electrocardiograph (ECG) complexes is that there exists a constant interval between the 'P' and 'R' waves of the ECG complex. The location of interest is the sino-artrial (SA) node which is where the neural activity influencing the heart is terminated. The normal ECG indicates SA node activity by the 'P' wave, but it is normal practice to use the R - wave series because the fluctuations in P - R intervals are small relative to the advantages gained by using R waves to detect heart beat intervals by electronic means.

The method of obtaining the RR interval time in milliseconds for each cardiac interbeat interval was as described above. The series of RR intervals were presented on paper tape in digital form and manually transferred to the ICL 1905 computer at Leeds Polytechnic.

In the present study, an interpolation procedure was developed in conjunction with Mr. J. Webster of the School of Mathematics and Computing, Leeds Polytechnic. The intention was to reconstitute a waveform which was amenable to spectrum analysis but retained the characteristics of the original heart rate variability.

The process adopted is illustrated in Figure 3.4. The first stage involved taking the heart interval series in milliseconds (Fig.3.4 (a)) and erecting a series of vertical pulses which were equivalent to the heart period in height and horizontal distance to the next pulse (Fig. 3.4 (b)).

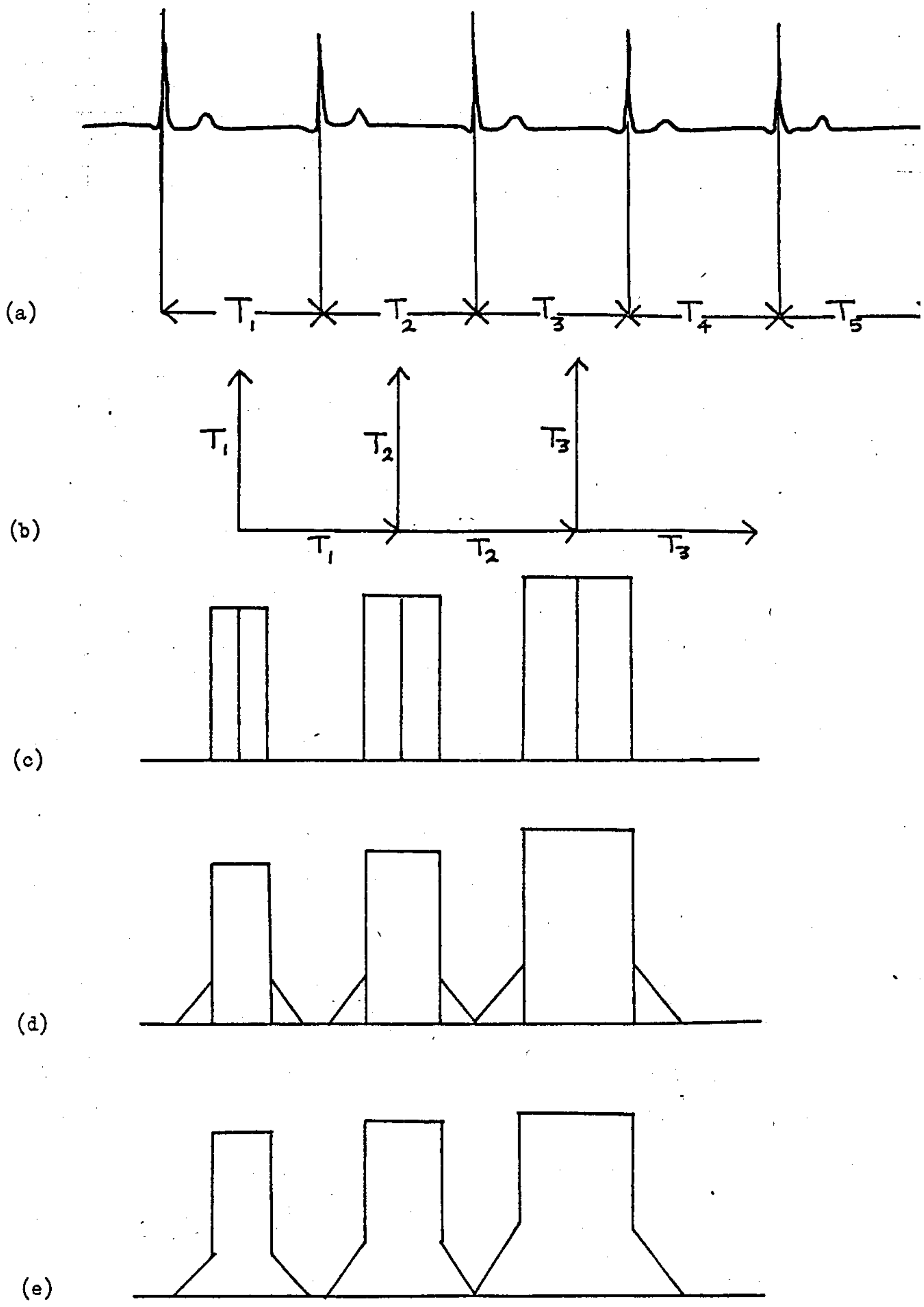


Figure 3.4 - Interpolation of heart interval series

The second stage (Fig. 3.4 (c)) was to convert this series of vertical pulses into a series of rectangles and thirdly to add a triangle to each side of the rectangle to produce a wave-like constitution (Fig. 3.4 (d)). The product was thus a reconstituted wave in which each heart interval contributed to the wave in a manner which was roughly proportional to it's individual influence on the wave (Fig. 3.4 (e)). This was considered to be an improvement on a linear interpolation and approximated to the 'delta function' method of interpolation recommended by Kitney (1975).

The reconstituted waveform was sampled at a rate of 5 Hz and dumped on 80 column cards. The Fourier analysis was performed on the 1905 S computer using a standard package and the spectrum analysis was presented as amplitudes corresponding to harmonic numbers (see Appendix 3.2). Unfortunately the Leeds Polytechnic computer does not offer graph plotting routines so the variation in the amplitudes and the frequencies relative to treatment condition could not be examined by visual inspection of a graph.

It was necessary to convert the amplitude corresponding to a given harmonic to an amplitude corresponding to a given frequency. This procedure would not have been so necessary had each series of data been of equal length. However, each series of data varied in length so the harmonics corresponded to the harmonics of the complete length of data. To derive the frequency, corresponding to each harmonic, the following procedure was adopted.

1. Divide the total number of datum points by 5 to give the number of seconds duration of the datum under consideration (sampling frequency of 5 Hz).
2. Divide the devised time (sec) by the harmonic number to give the frequency of that harmonic in seconds.
3. Reciprocate the frequency in seconds to produce the frequency in Hz. An example of this procedure would be:
   1. 1459 datum points ÷ 5 = 291.8 sec.

2. 291.8 ÷ 10 = 29.18 sec = frequency of 10th harmonic
3. 1 ÷ 29.18 = 0.03 Hz = frequency of 10th harmonic

This procedure was completed and a number of graphs of the amplitude spectra were plotted by hand. As spectrum analysis is potentially more useful in qualitative terms than quantitatively it was important to obtain a graphical representation from the raw amplitudes at each harmonic. For this purpose the spectrum analysis was completed separately using the 1906A computer at Leeds University. On this occasion graph plotting routines were employed as illustrated in Figure 3.5.

Several runs were required to establish a suitable resolution and smoothing. An example of the spectrum eventually produced is shown in Figure 3.6. The algorithm for producing the graph plot of the spectrum analysis involved several stages as shown in Appendix 3.3.

(c) Respiration

The respiratory frequency could be measured by two methods. The first was to strap an elasticated tube around the chest which detected thoracic movement. The output voltage was proportional to the stretching of the tube. The transducer (Sanei Ltd.) was amplified and connected to a Mingograph 34 ink-jet oscillograph (Siemens Ltd.). The excursion of the trace indicated the respiratory frequency and the extent of the thoracic movement.

The alternative method was to clip a thermistor to the inside of the subject's nostril. This, although sounding uncomfortable, was non-intrusive. No subjects reported any degree of discomfort. The thermistor responded to the change in the temperature in the nostril caused by inhalation and exhalation. An earlier pilot study had confirmed that no statistically significant differences existed between the two methods in terms of respiratory frequency ($p<.001$), although

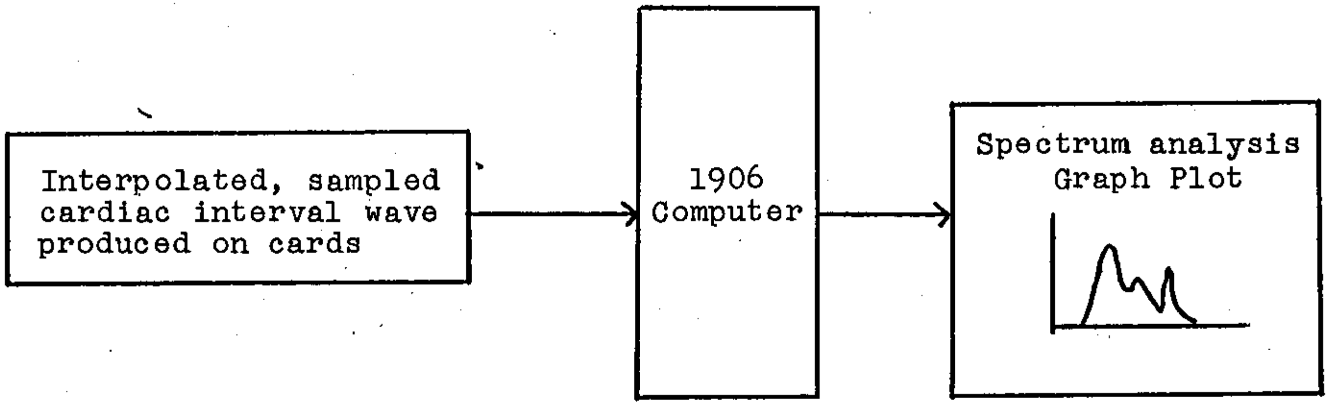


Figure 3.5 - Production of spectrum analysis graphs

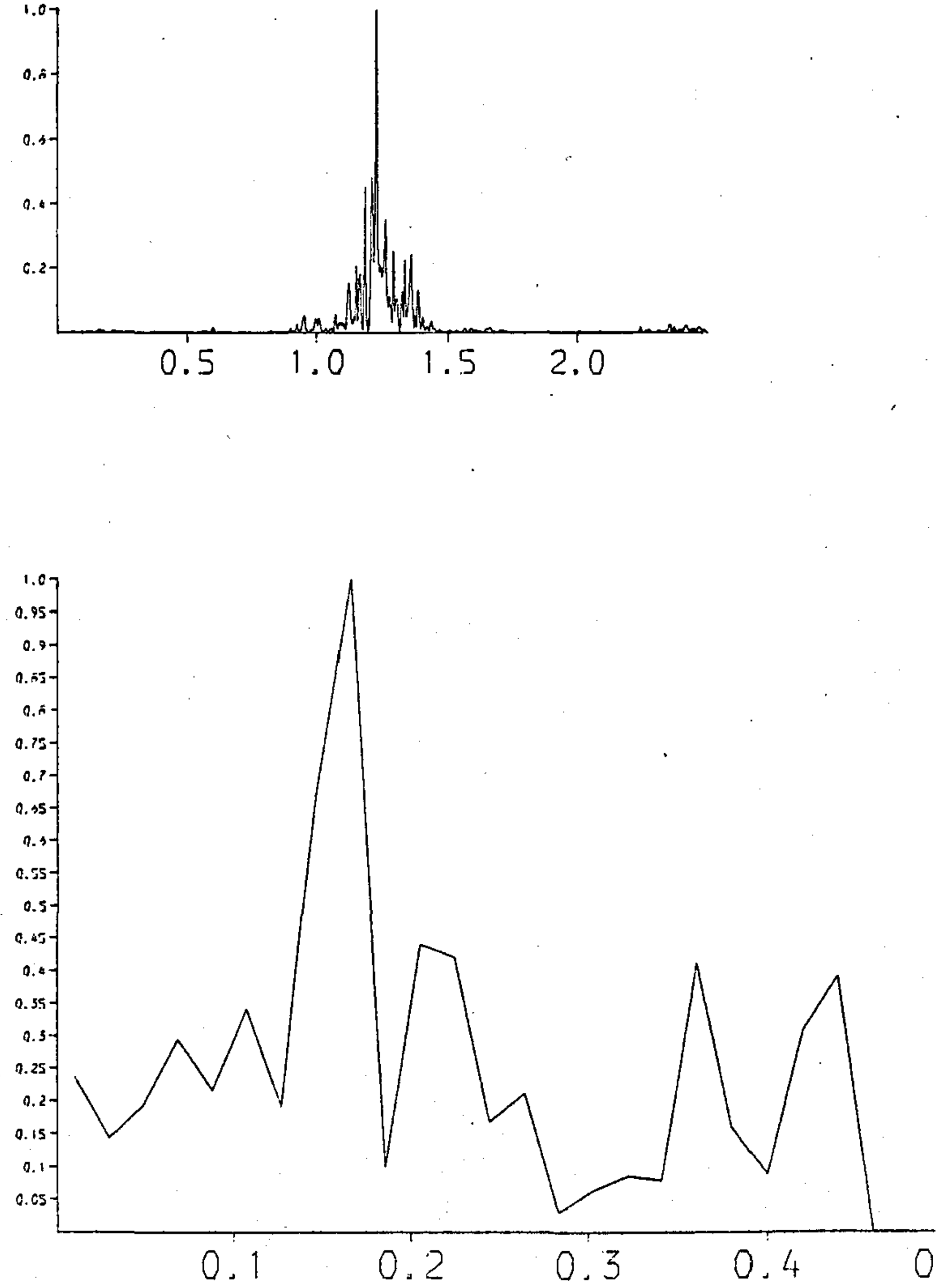


Figure 3.6 - Spectrum analysis of cardiac intervals.

the latter method gave no indication of respiratory depth. As respiratory depth was a potentially useful measure, the method which measured thoracic movement was adopted. Respiration was recorded continuously on the oscillograph at a paper speed of 2.5 mm $\sec^{-1}$ and on the FM recorder at a tape speed of 3¾ in. $\min^{-1}$. The respiratory waveform required no interpolation as it was in a continuous form and could therefore be analysed directly in analog form. This was undertaken by using a Hewlett-Packard Fourier Analyser (HP 5451 A) which involved a two stage process. The first was to decide on an appropriate scanning time and rate of digitization to obtain a good resolution. This was based on the highest possible physiological frequency through which the time series respiratory rate may oscillate. In practice it is necessary to multiply this minimum scanning frequency by a factor appropriate to accuracy. A scanning frequency of 5 Hz was chosen which gave a maximum band width of 2.5 Hz. This was digitized into 1024 values of spectra amplitudes to produce good resolution. The tapes were then replayed into the Fourier Analyser for a running time of 3 minutes at 7½ in. $\sec^{-1}$, digitized and stored on magnetic tape.

The second stage of the process was to recall the digitized data, complete the Fourier analysis and present the power spectrum in a graphical form as shown in Figure 3.7.

(d) Temperature

The three temperature measurements were body temperature, skin temperature and air temperature. These were recorded so that Teichner's "thermal arousal index" (1962) could be investigated. One thermistor was placed in the mouth, one taped on the forearm and one allowed to hang free in the air 1 metre from the subject. These were connected to a battery operated meter from which the temperature was read directly by switching between thermistors. The temperatures were read

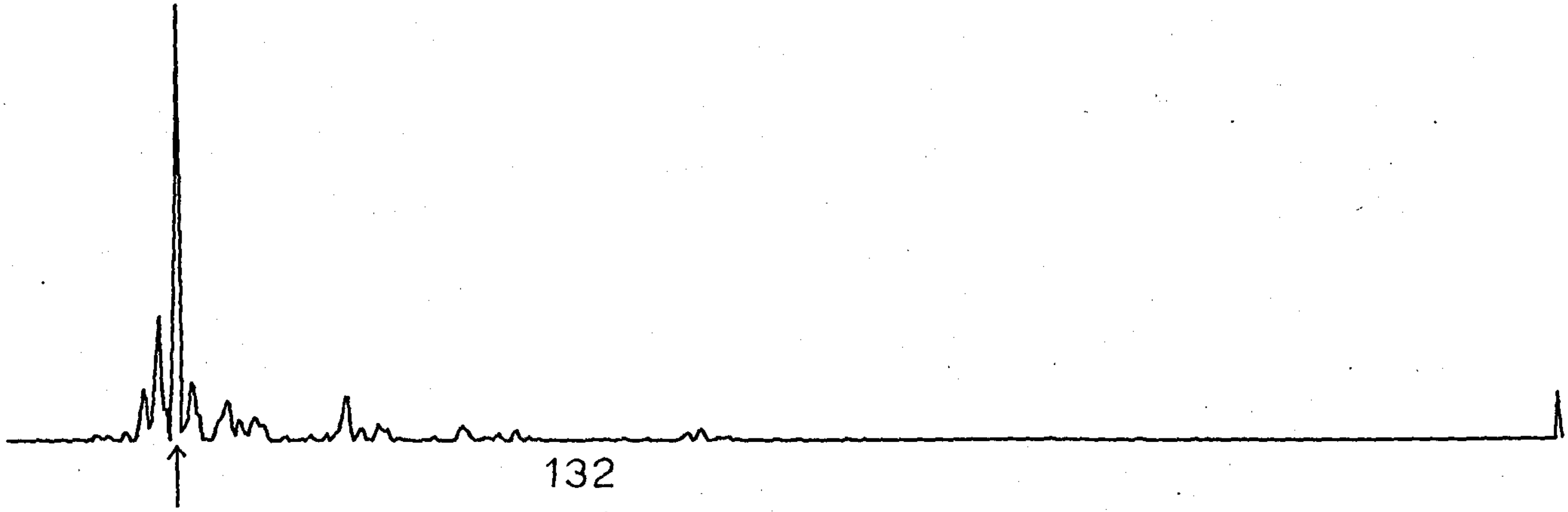


Figure 3.7 - Spectrum analysis of respiratory waveform

to an accuracy of 0.1°C. Calibration was as described in section 2.1.3 and temperature was recorded at the beginning, after 3 minutes, after 6 minutes and after 9 minutes of each stage of the experimental condition. The temperature recordings were converted to an "arousal index", Teichner (1962) as reported in Greenfield and Sternbach (1972).

(e) Simple reaction time (SRT)

The stimulus was a 1 KHz tone adjusted for each subject to a volume level which was comfortable yet distinct. It was produced by the experimenter closing a microswitch which completed the circuit producing the tone from a signal generator (Griffin and George Ltd.) and presented to the subject through stereo headphones (Biofeedback Ltd.). Completion of the circuit also started a millisecond timer with digital display (Panax Ltd.). The subject kept his left index finger on a microswitch throughout the experiment and depressed it on hearing the tone. This depression of the microswitch stopped the millisecond timer and thus gave the time interval between the initiation of the stimulus and the mechanical response. Two demonstrations of the SRT procedure were given to the subject and inspection revealed that millisecond times in the expected range were being produced on each occasion. SRT was recorded during the last 5 seconds of every minute. No warning signal was given as it could have acted as an additional stimulus to the ANS. SRT was only recorded during the experimental stage of each condition and not during the resting and recovery stages.

(f) Other measures

Five additional experimental variables were recorded which have been considered to influence physiological results, (Wenger 1968). These were time of testing, initial room temperature, external temperature at time of testing, relative humidity and barometric pressure.

Figure 3.8 summarises the measures taken during each experimental condition and Figure 3.9 summarises the testing procedure for one subject.

Experimental Condition		Stage	Measures						
			EDA	ECG	R_f	T	SRT	Ors.	P Roto
(a)	No Physical Load	Resting	✓	✓	✓	✓		✓	
		Experimental	✓	✓	✓	✓	✓	✓	
		Recovery	✓	✓	✓	✓		✓	
(b)	Light Physical Load	Resting	✓	✓	✓	✓		✓	
		Experimental	✓	✓	✓	✓	✓	✓	✓
		Recovery	✓	✓	✓	✓		✓	
(c)	Moderate Physical Load	Resting	✓	✓	✓	✓		✓	
		Experimental	✓	✓	✓	✓	✓	✓	✓
		Recovery	✓	✓	✓	✓		✓	
(d)	Heavy Load	Resting	✓	✓	✓	✓		✓	
		Experimental	✓	✓	✓	✓	✓	✓	✓
		Recovery	✓	✓	✓	✓		✓	
(e)	Control	Resting	✓	✓	✓	✓		✓	
		Experimental	✓	✓	✓	✓	✓	✓	
		Recovery	✓	✓	✓	✓		✓	
(f)	Heavy Load Control	Resting	✓	✓	✓	✓		✓	
		Experimental	✓	✓	✓	✓	✓	✓	
		Recovery	✓	✓	✓	✓		✓	

Figure 3.8 - The measures recorded during each stage of the experimental conditions

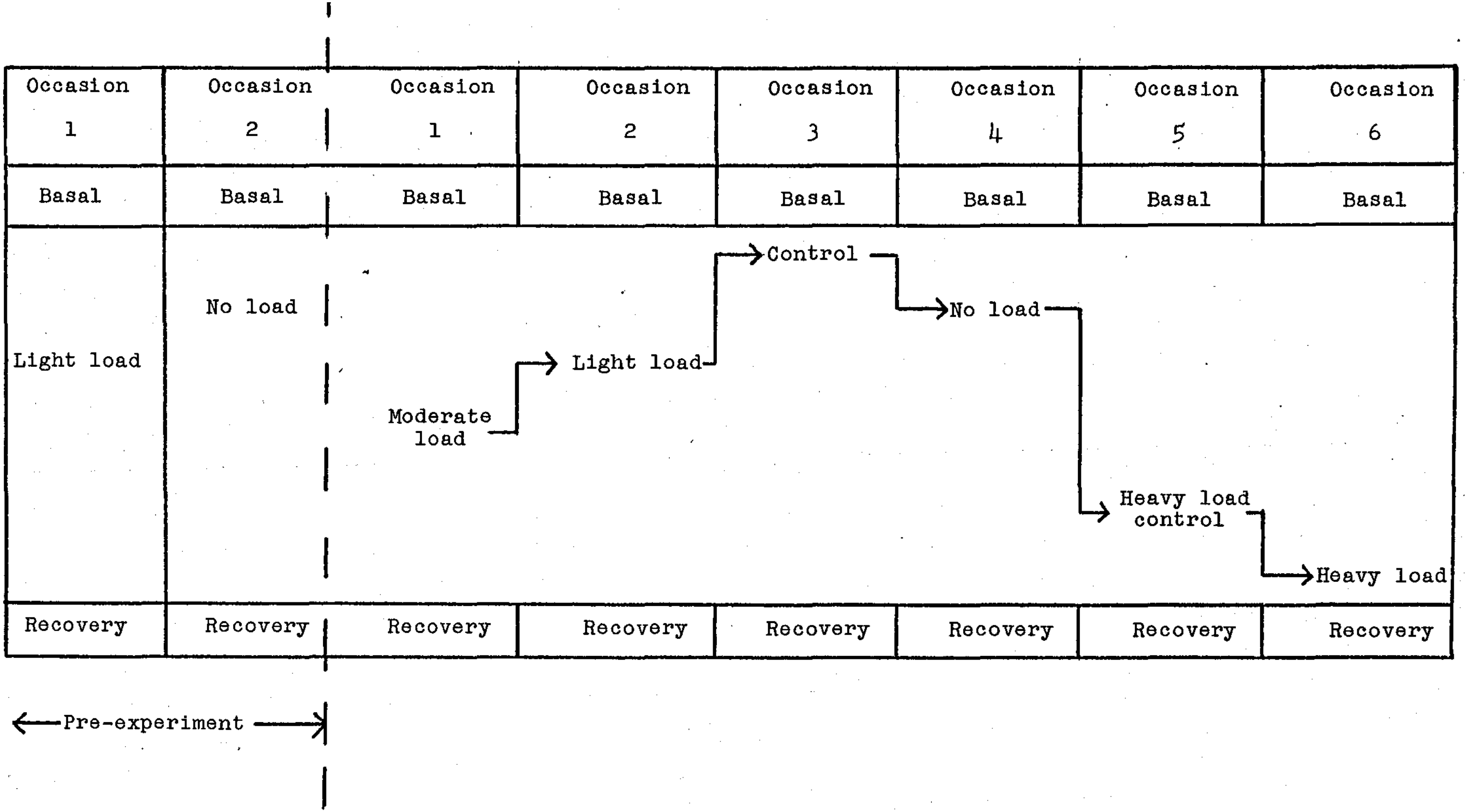


Figure 3.9 - Summary of testing procedure for one subject

3.2 Results and Statistical Analysis

As in section 2.2, the first 5 minutes of any condition was not used in the statistical analysis. The mean value for each measure was used in the calculations because this has been shown in section 2.2.1 to be statistically acceptable. The data were examined by a randomised block design ANOVA (Kirk, p 132) to test the statistical hypothesis that all the condition means and subject means are equal. The ANOVAs were completed separately for each of the stages resting, experimental and recovery.

3.2.1 Electrodermal activity

The following table, Table 3.1 summarises the F ratios for occasions and subjects at each of the three stages, resting, experimental and recovery.

Table 3.1 - F ratio for occasions and subjects at each stage for EDA.

Resting		Experimental		Recovery	
Occasions	Subjects	Occasions	Subjects	Occasions	Subjects
0.28	2.58**	1.30	2.33*	1.18	1.88

** $p < .05$
 * $p < .10$

The results under resting conditions indicated stability of the EDA measure on each occasion the subject came into the laboratory. Although this suggests reliability, the same results in the experimental stage suggests that there was not sufficient change in EDA for the measure to differentiate between the stimuli.

The transformation of skin conductance to a log conductance change as recommended by Haggard (1948) improved the occasions effect somewhat but EDA was still not sufficiently sensitive to differentiate between experimental occasions except when the physical activity was high. Thermal sweating does not influence the EDA results. This suggests that the high metabolic activity causes the change in EDA by sympathetic activity. This is only shown after an appropriate change score transformation has accounted for the effects of resting level.

These results may suggest that EDA is an invalid measure of stimulus change. An alternative explanation for its lack of sensitivity may be deduced from its nervous supply. EDA is innervated by sympathetic fibres alone and therefore lacks the parasympathetic restraint of most autonomic measures. This means that it may respond totally to a stimulus and may not show the more normal graduated response. The experimental situation itself may have produced an EDA response, whereas additional stimuli during the experiment failed to influence EDA further.

3.2.2. Cardiac measures

As described in section 3.1.5, the analysis of the ECG was by two main techniques. One was by using sampling statistics to examine the mean heart rate and heart rate variability and the other involved time series analysis to examine heart rate variability alone. As these two techniques are based on different principles they will be considered separately, starting with sampling statistics.

Table 3.2 summarises the F ratios for occasions and subjects for the resting, experimental and recovery stages.

Table 3.2 - F ratios for occasions and subjects at each stage for cardiac measures.

Measure	Resting stage		Experimental stage		Recovery stage	
	Occs.	Subs.	Occs.	Subs.	Occs.	Subs.
Heart Rate (H_f)	0.32	7.96***	57.26***	5.58***	3.52***	10.39***
Variance (s^2)	0.71	4.54***	7.85***	3.81***	3.01**	7.37***
MSSD (d^2)	1.12	5.54***	8.31***	8.25***	1.81	4.94***
SABS/AM2	3.95***	20.69***	22.33***	4.64***	4.24***	4.99***
SABS	3.25**	33.70***	13.86***	8.01***	2.93**	8.63***
AM2	2.41	2.48**	34.08***	0.24	2.18	2.32**
d^2/s^2	1.37	12.7***	7.22***	2.89**	1.51	7.47***

*** $p < .01$
** $p < .05$

Table 3.2 showed that in the resting stage the only heart rate variability measures to produce an occasions effect were the sum of the absolute differences between successive RR intervals (SABS) and SABS/AM2. This suggested that these two measures lack reliability, but an examination of the source of these effects revealed otherwise. In the case of SABS/AM2, it only showed a significant effect because of an unusually high reading of one subject on one occasion. With the SABS parameter, the significance was caused because one result on one occasion showed a significant mean difference by a very small margin (by Tukey's HSD).

During the experimental stage occasions effects became significant in all cases, supporting the efficacy of these measures to distinguish between tasks. It was then necessary, having established an overall effect due to the tasks, to examine the date for the source of these effects. Tukey's HSD test was used on each measure and the results presented graphically in Figures 3.10 and 3.11.

Figure 3.10 (a) shows the mean heart rate for each of the tasks. The clear trend can be observed of increasing mean heart rate as the physical load is increased. However, the mean heart rate failed to differentiate between any of the lower physical load intensities and only showed significant mean differences between the heavy load tasks and the others. Figure 3.10 (b) which was the variance measure showed a similar pattern. Figure 3.10 (c) (mean square successive difference) demonstrated the same trend, but with this measure the moderate load was also sufficient to produce a significant difference from tasks of lower load. The frequency of relative maximal and minimal heart beats (AM2) score of heart rate variability showed similar trends, Figure 3.11. Significant differences were not shown in any other value until the intensity was that of the heavy load. In the two measures ratio (SABS/AM2) and sum of the absolute differences (SABS), a quite different pattern emerged, (see Figure 3.11 (a) and (b)). These measures both show a significant difference between the "control" and the "no load" occasions with reductions in the scores in both cases. However, an increase in the physical load resulted in the scores increasing again until the high load when a significant decrease was observed. This suggested that some form of attentional state produced a significant effect which was not sustained when the subject started to become involved in the physical demands of the task. The d^2/s^2 measure of variability, as illustrated in Figure 3.10 (d) also failed to show a monotonic trend. In this case, however, the highest

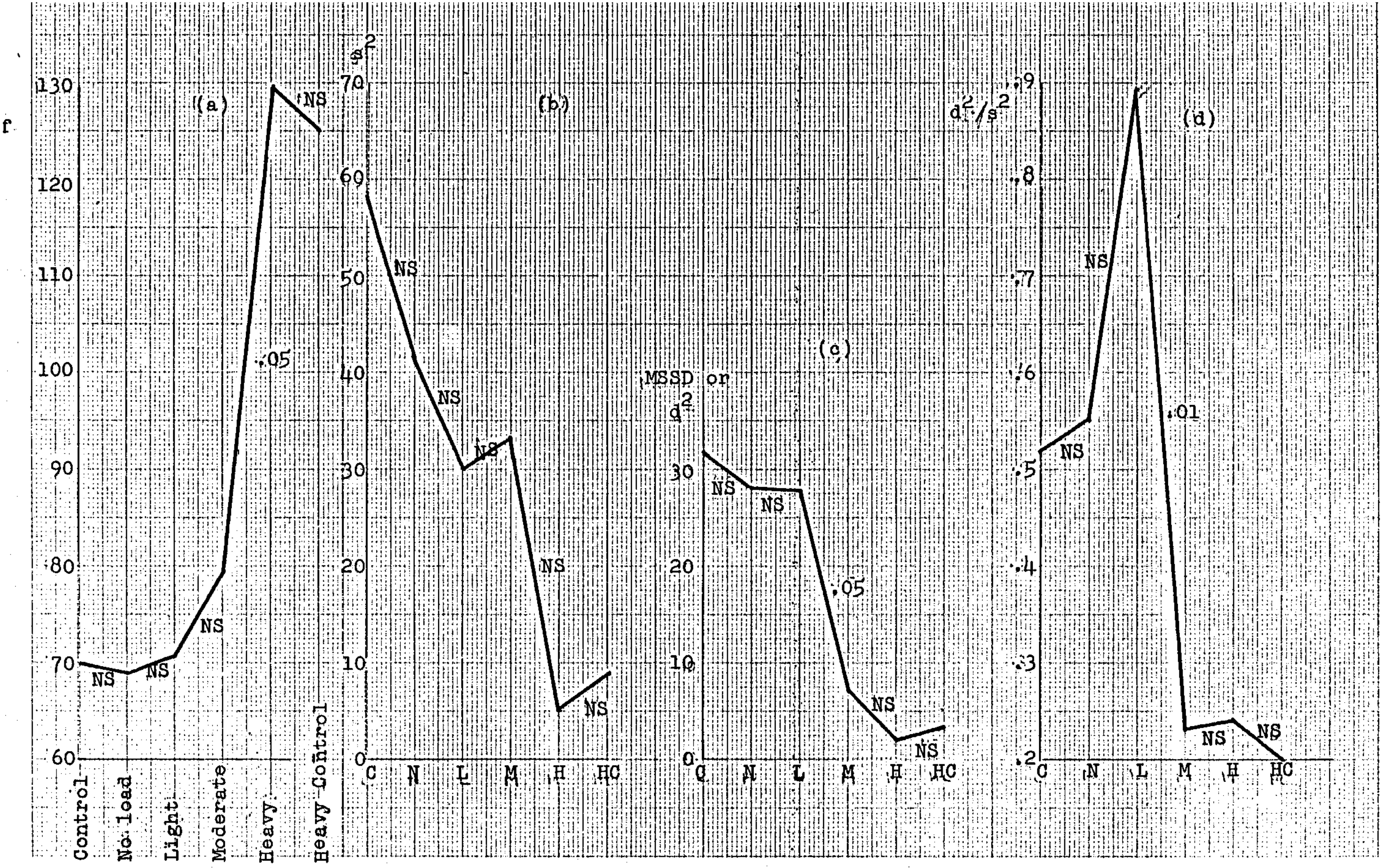


Figure 3.10 - Mean cardiac values on the 6 different occasions

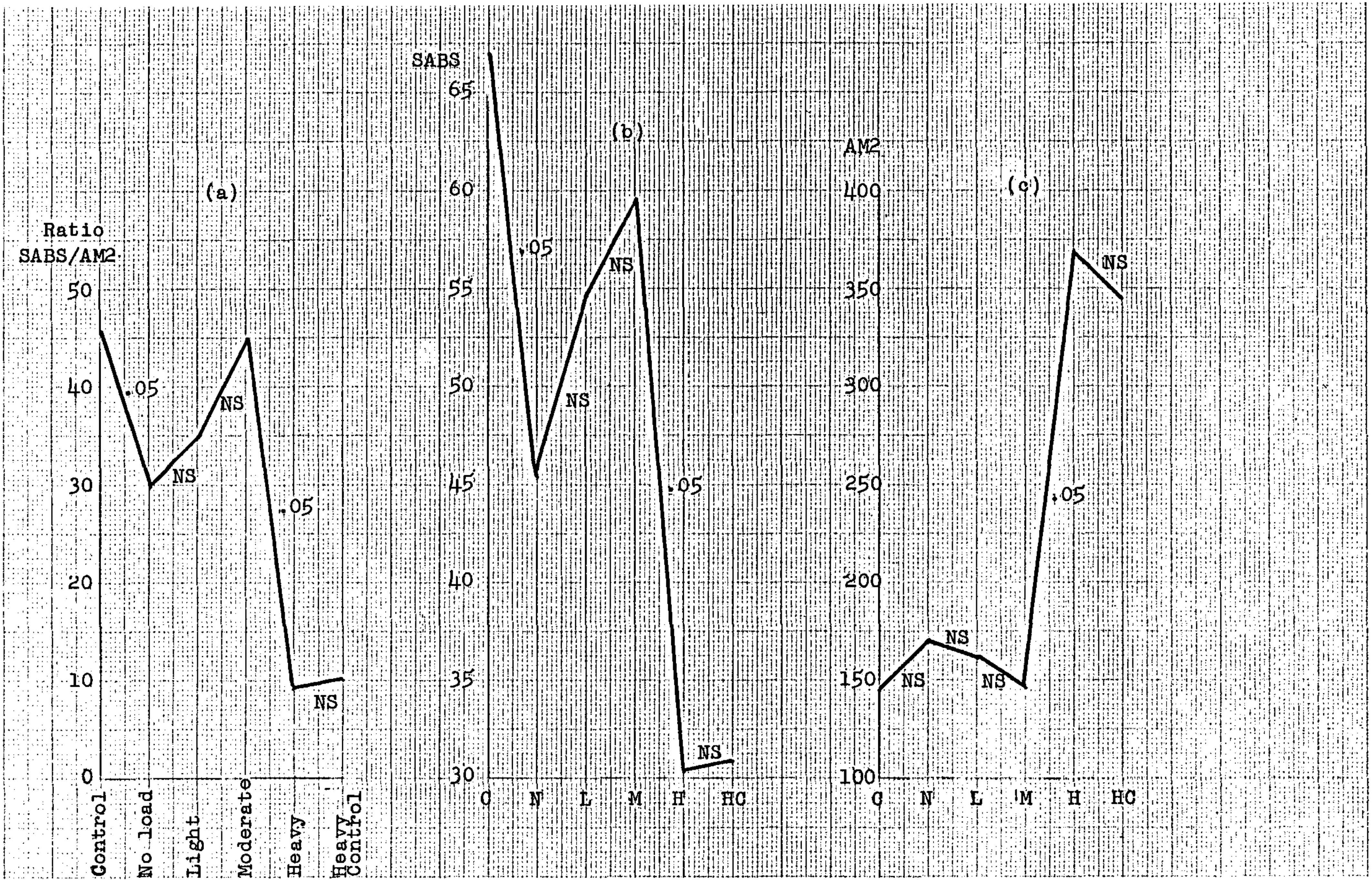


Figure 3.11 - Mean cardiac values on the 6 different occasions.

reading was observed during the "low load" occasion. The significant difference between this low load occasion and all others was the only one that satisfied the test of main effects. Thus the d^2/s^2 ratio was only capable of differentiating between attention to the perceptual motor task alone and the others, not between each task on the continuum. The contribution to the total variance rose from 4% in the resting stage to 34% which indicated the increased importance of the tasks during the experimental stage.

The recovery stage showed that in the case of mean square successive difference (MSSD) and AM2 no occasions effect was present. This suggested that these two measures had recovered rapidly from the experimental stage and a stable physiological state had been restored. In the case of the other measures the occasions effect was still retained. This indicated that homeostasis had not been regained and the latent effects of the experimental stage were still apparent. An examination of the source of these effects (Tukey's HSD test) revealed that in each case (heart rate, s^2, SABS/AM2, and SABS) it was the recovery from the "high load control" occasion which produced the overall significant effect. Thus it was only the effect of "high load control" (cycling) which showed no recovery from the change in heart rate variability incurred during the task. This was of particular interest because the "high physical load" task showed no occasions effect in the recovery stage. Thus the subjects recovered better after doing the task which included both perceptual-motor and cycling activities than just the cycling.

A sensitive index of task specificity would show no occasion or task effects during the resting stage, show no occasion or task effects during the recovery stage and show a monotonic trend with statistically significant differences between each task during the experimental stage.

None of the cardiac parameters fulfil these criteria exactly, but AM2 and MSSD were very close. They both fulfilled the first two criteria of being reliable measures during resting and recovery stages. They both showed significant differences between certain of the experimental tasks and MSSD in clearly monotonic (Figure 3.10 (c)).

This statistic has particular application for continuous response data where the mean level is varying over time, Leiderman & Shapiro (1962). It provides a description of variability between successive points of a continuously changing function, and its great merit is that unlike other measurements of dispersion such as variance, it takes account of the changing base level. This measure is thus particularly applicable to time series data collected over extended periods which is so often the case in psychophysiological research.

As an alternative, the cardiac parameters were examined by plotting the percentage of the total variance attributed to the occasions and the subjects at each stage. Figure 3.12 (a) shows the percentage variance for the occasions and Figure 3.12 (b) shows that for the subjects. It was clear that the percentage of the total variance accounted for by the tasks went up during the experimental stage in every measure. In the cases of AM2, HR and SABS/AM2 it accounted for well over 50% of the variance, yet in the basal and recovery stages they accounted for less than 20%. With the exception of MSSD (d^2) the percentage of the total variance accounted for by the subjects dropped markedly during the experimental stage. In the case of AM2 the decrease was sufficient for the subjects to have no significant effect on the analysis of variance during the experimental stage.

The significant subjects effects in every other stage was very noticeable. This demonstrated the inherent problems of inter-subject comparisons and emphasised the importance of recording resting states as a pre-requisite of any experimental tasks. The communality between subjects in psychophysiological terms appeared limited, although distinct condition effects can be recorded. These results emphasise the importance of considering individual differences in psychophysiological research.

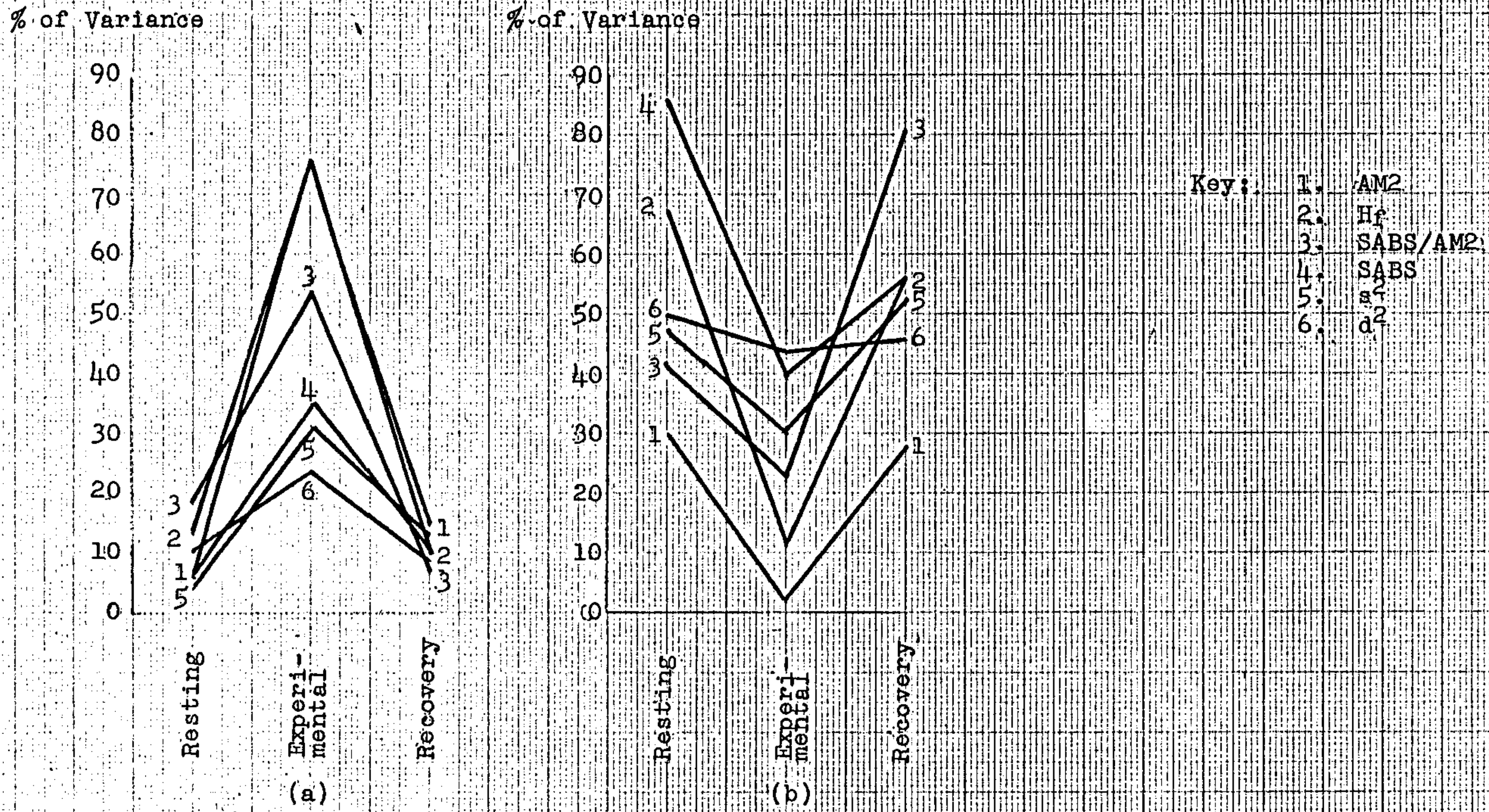


Figure 3.12 - Change in contribution of total variance due to stages (a) for occasions and (b) for subjects.

The time series analysis of heart intervals involved the technique of spectrum analysis. The interpretation of the spectrum analysis was based on the underlying assumption that a series of rhythmic impulses of a non-cardiac origin could be influencing the heart rate variability. Any analysis of the results was primarily to produce evidence of such rhythms. It was only then possible to look for changes in the frequencies of these rhythms during different tasks, and finally to ascribe some quantitative value to any changes. Figure 3.13 shows in the upper graph the total power spectrum for the cardiac interbeat intervals. The power was all concentrated at the 1.5 Hz frequency which was the frequency of the heart beat itself (90 beats min^{-1}). As this rhythm was known and can be established from other less complicated methods, the rhythms which influenced the heart rate variability were of more specific interest. However the power of the heart frequency was of such magnitude that all lesser rhythms were reduced to a level that was not detectable on the total power spectrum.

It was therefore necessary to filter the spectrum at a frequency that would retain the information of importance and reject the remainder. A frequency of 0.5 Hz was chosen because this was considered to be the upper limit of the likely respiratory frequency. A frequency of 0.5 Hz represented a rate of 30 min^{-1} which was unlikely to be exceeded even under demanding physical work. Figure 3.13 lower trace shows the spectrum analysis with a 0.5 Hz filter. Two predominant frequency peaks were shown. One was at about 0.15 Hz and the other at 0.3 Hz. These frequencies were likely to correspond to the blood pressure frequency (0.15 Hz) and the respiratory frequency (0.3 Hz). These spectra have thus produced evidence of alternative physiological rhythms acting upon the sinus node to produce alterations in heart rate variability.

No attempt has been made to apply statistical analyses to the results of the power spectra because it is basically a qualitative technique. The literature cites only one paper,

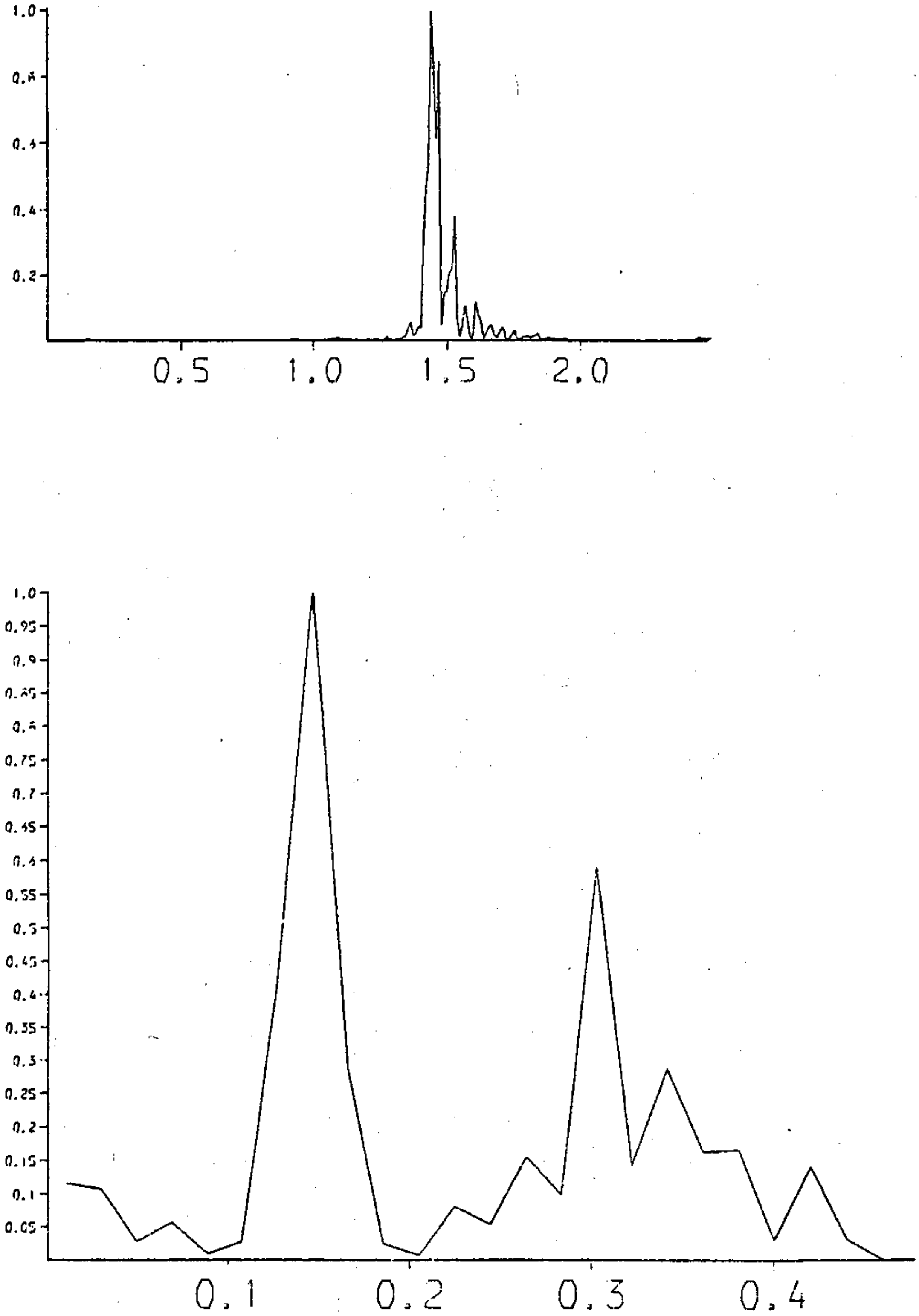


Figure 3.13 - Spectrum analysis of cardiac interval series.

Hyndman and Gregory (1975) in which statistical rigour was applied to the technique. They attempted to divide the spectra into discrete wavebands and to compare treatment conditions for each waveband, but met with no success. Such an attempt would be scientifically unacceptable until a recognised technique of producing the spectra is accepted internationally, and more than anything else illustrates the state of the art which is still highly experimental. However the results appear to have consensus validity because the spectra do show characteristic frequencies which correspond to known biological phenomena. Thus the technique has revealed a method of indicating the biological control mechanisms acting upon the heart. The power of the spectrum at each frequency will give some indication of the importance each control system is having upon the heart. This technique is particularly useful because it is not intrusive, and therefore has a potentially important place as an analytical tool in psychophysiology.

The results in each case showed a clear trend. Under the control and no load conditions the peaks at frequencies corresponding to the known biological signals of respiration, blood pressure and temperature control were present. Under the low and medium load conditions a few subjects were departing from this clarity of frequency peaks and at high load and high control conditions most subjects failed to show clear peaks corresponding with known biological phenomenon.

3.2.3 Respiration

Respiratory frequency (R_f) produced F ratios for occasions and subjects for each stage as in Table 3.3.

Table 3.3. - F ratios for occasions and subjects for each stage

Resting		Experimental		Recovery	
Occasions	Subjects	Occasions	Subjects	Occasions	Subjects
1.0.	6.47***	27.94***	2.20**	0.83	8.60***

*** $p < .01$

** $p < .05$

The significant subjects effect was present, but the occasions effect was only established in the experimental stage. This effect was due solely to those tasks which involved high physical activity ("high load" and "high load control"). The occasions effect showed that respiratory frequency was reliable for the resting and recovery stages. Respiratory frequency showed no significant differences between tasks of lower physical load or between "control" and other task occasions.

The spectrum analysis of the waveforms gave more detailed information of the respiratory pattern. A series of rhythmic processes could be present in what is generally seen as a simple oscillation. The simple oscillation is the respiratory frequency, but superimposed on that may be other, additional frequencies.

The initial data processing for the spectrum analysis of the respiratory waveform produced a graph as in Figure 3.14. The amplitude is in arbitrary units but was scaled from the calibration marker at the right hand end of the graph.

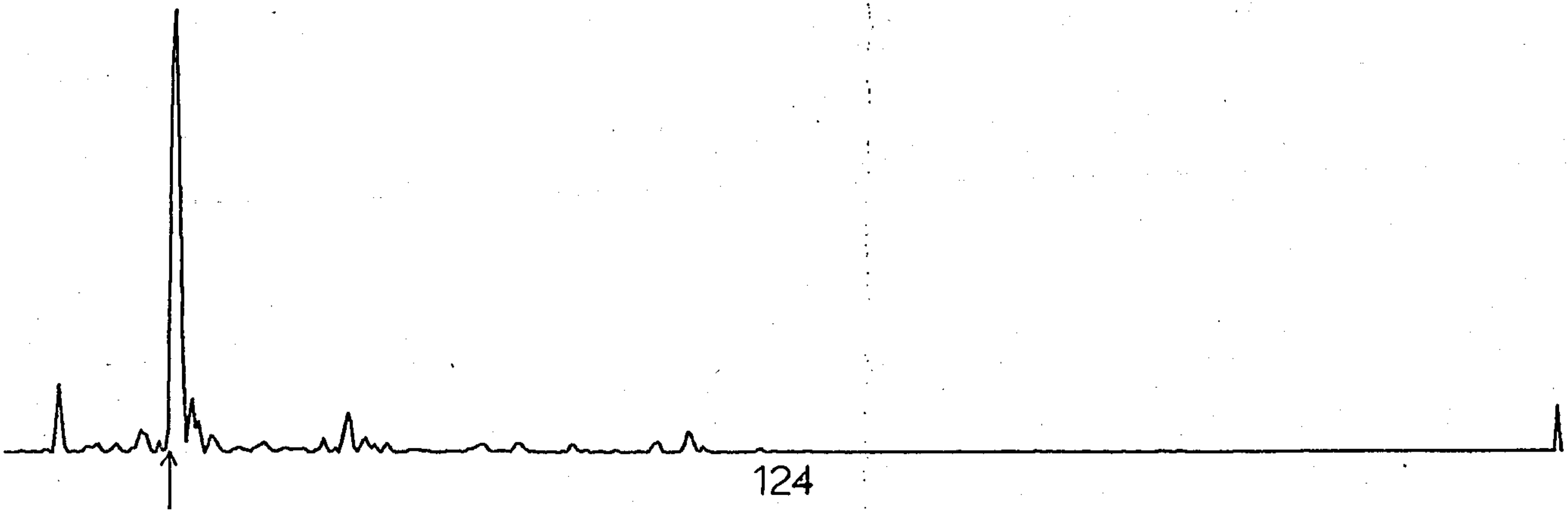


Figure 3.14 - Spectrum analysis of respiratory waveform.

Any qualitative description of the spectrum analysis for each condition involves combining the results from each subject on to one graph. This was achieved by re-drawing each of the 200 graphs on to an overlay of acetate sheet. These individual acetate sheets then gave the opportunity to look at inter-subject or inter-treatment comparisons. The inter-treatment comparison was achieved by overlaying the acetate sheets and making a master graph. The slight individual differences in the predominant frequency gave the impression of larger variations than was actually the case. It was thus decided to standardise the graphs by overlaying each one at the position of the respiratory frequency. This was undertaken by establishing the respiratory frequency from the respiratory waveform (Figure 3.15) and marking each spectrum analysis with an arrow at that frequency. Each graph was then overlayed on the arrow and the master graphs produced (Figures 3.16 - 3.18). In all cases most of the power was at the major respiratory frequency of 0.25 - 0.30 Hz. The distribution of the power around this predominant frequency varied considerably under different experimental conditions. Figure 3.16 (a) showed the wide dispersion of the power over a range from 0.15 - 0.75 Hz covering two predominant peaks at 0.25 Hz and 0.6 Hz. In the "no load" condition, when the subject was attending to the pursuit rotor task without moving, (Figure 3.16 (b)) the range of the power was similar but without the same consistently high amplitude. When the subjects were completing the perceptual motor task ("low load", Fig. 3.16 (c)) a much more limited range was observed with most of the power concentrated at the predominant respiratory frequency of 0.25 Hz. This suggested that the respiratory pattern was showing far more consistency in this condition. This trend was continued in the "moderate load" condition (Fig. 3.17 (a)) and even more so in the two "heavy load" conditions (Figs. 3.17 (b) and (c)). The recovery conditions (Fig. 3.18) showed a high degree of similarity, each one being composed of a major peak at the predominant respiratory frequency and a minor peak at a higher frequency.

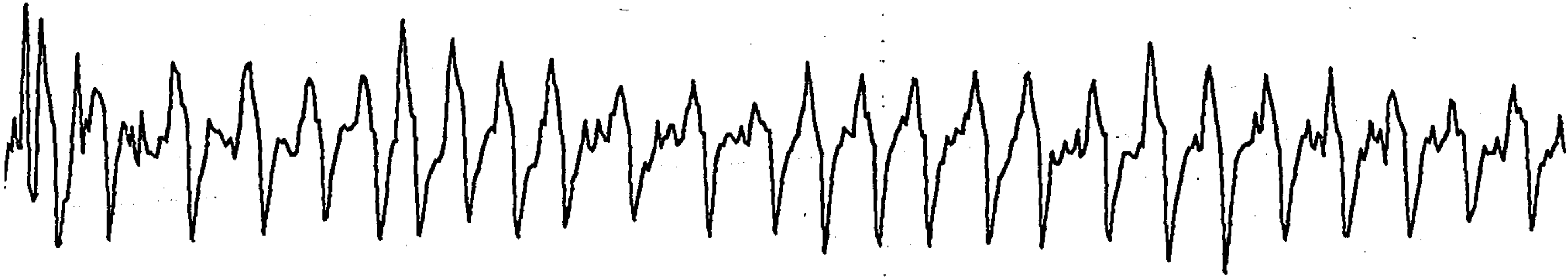
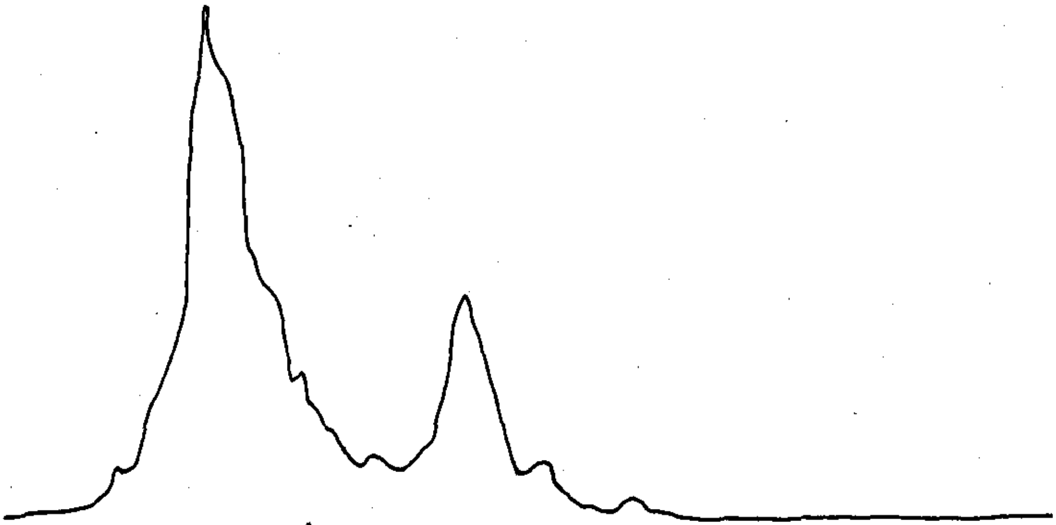
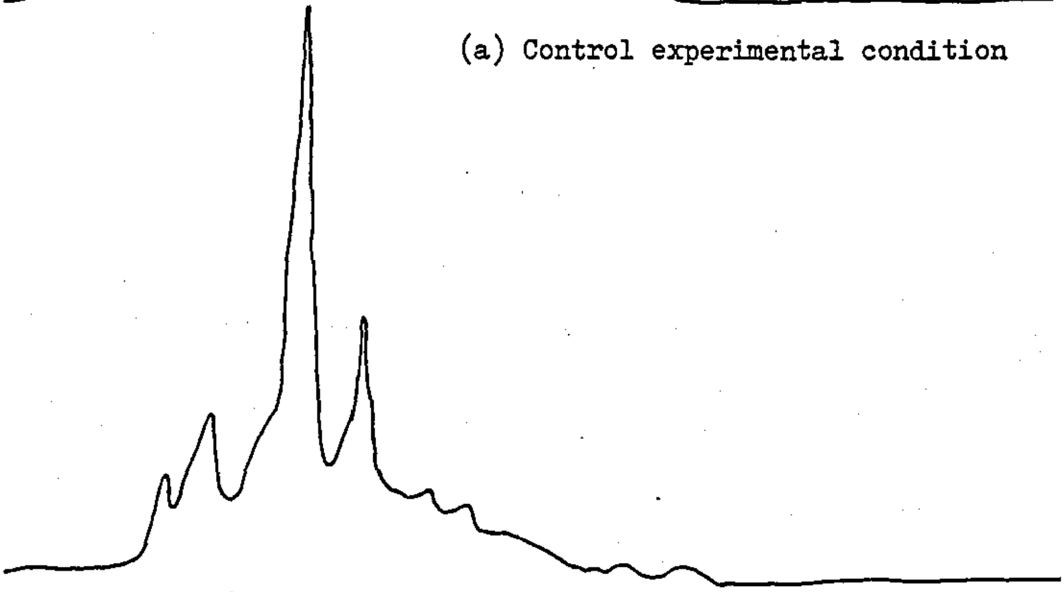


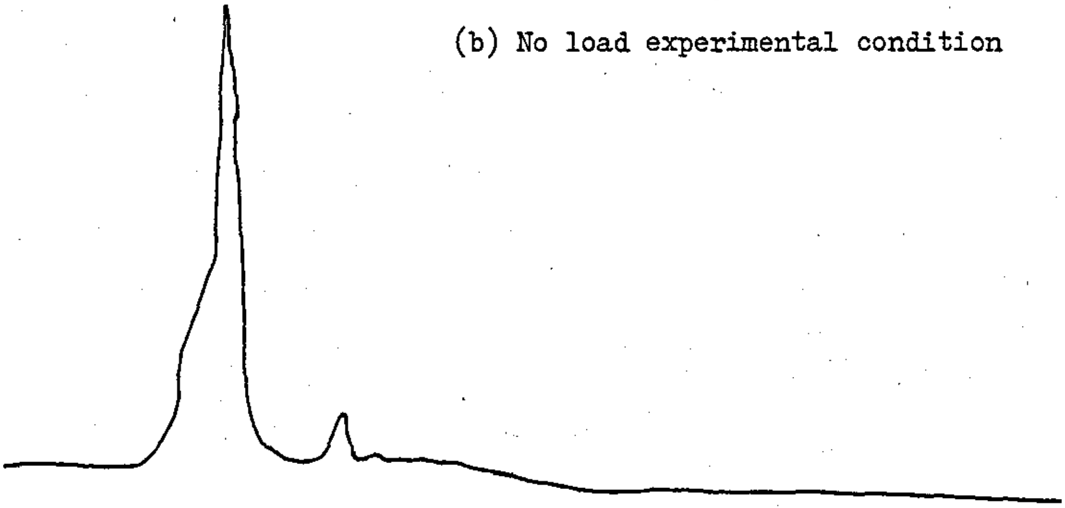
Figure 3.15 - Computer reconstituted respiratory waveform.



(a) Control experimental condition

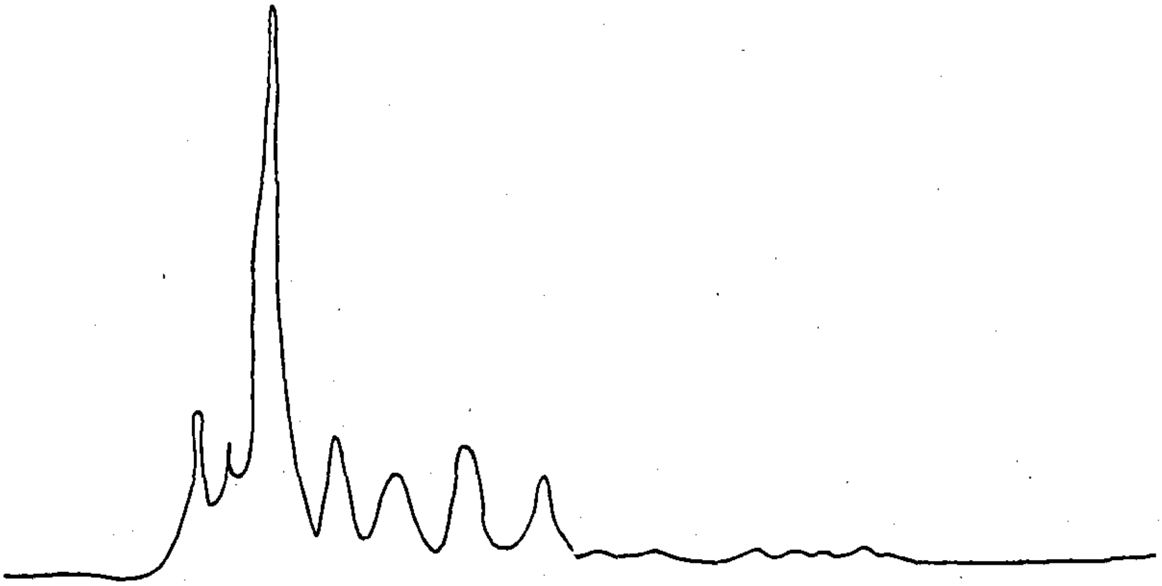


(b) No load experimental condition

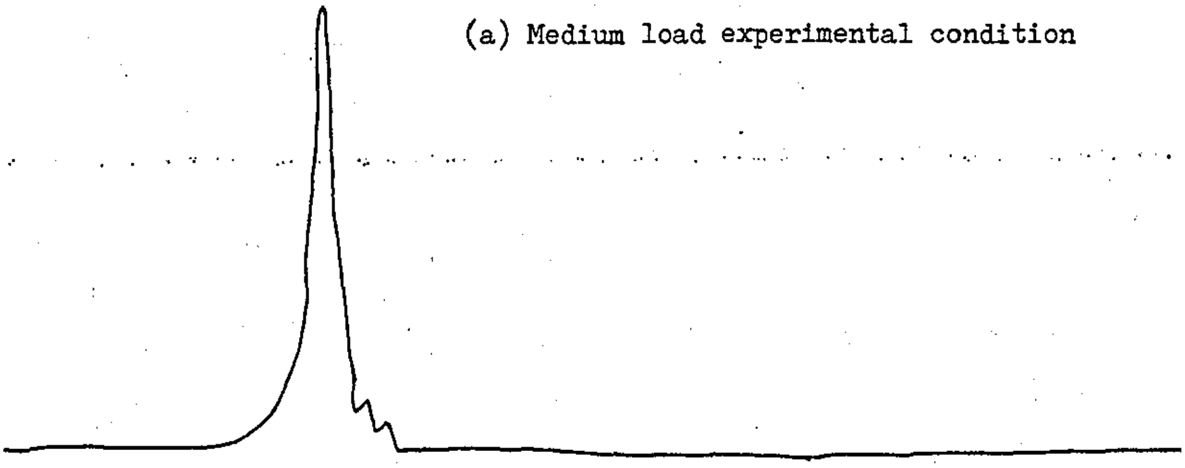


(c) Low load experimental condition

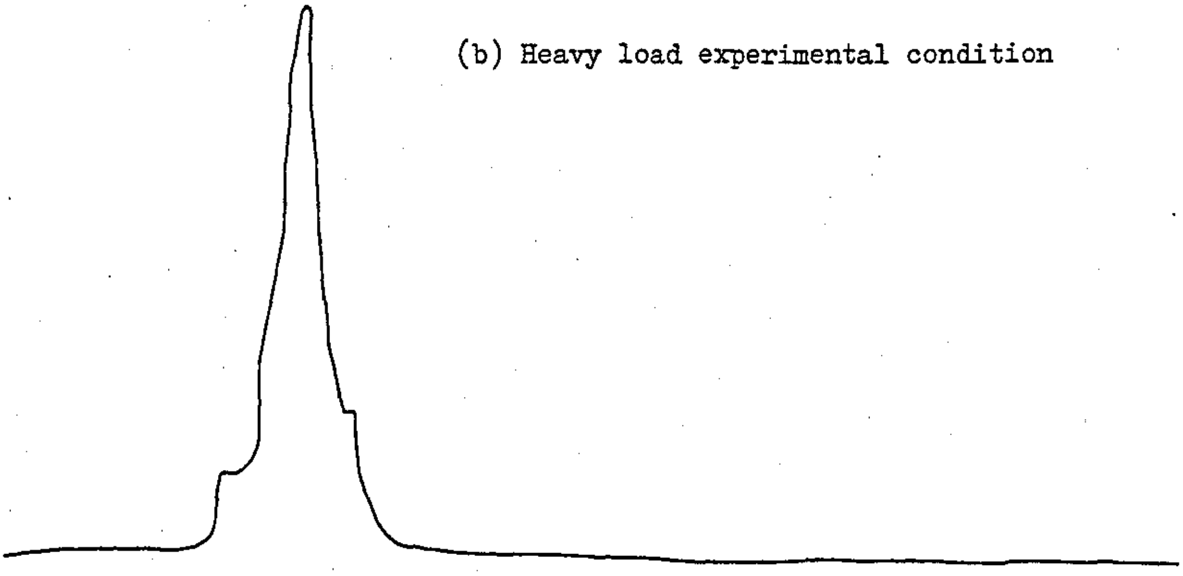
Figure 3.16 - Spectrum analysis for respiration during (a) control, (b) no load and (c) low load experimental conditions.



(a) Medium load experimental condition

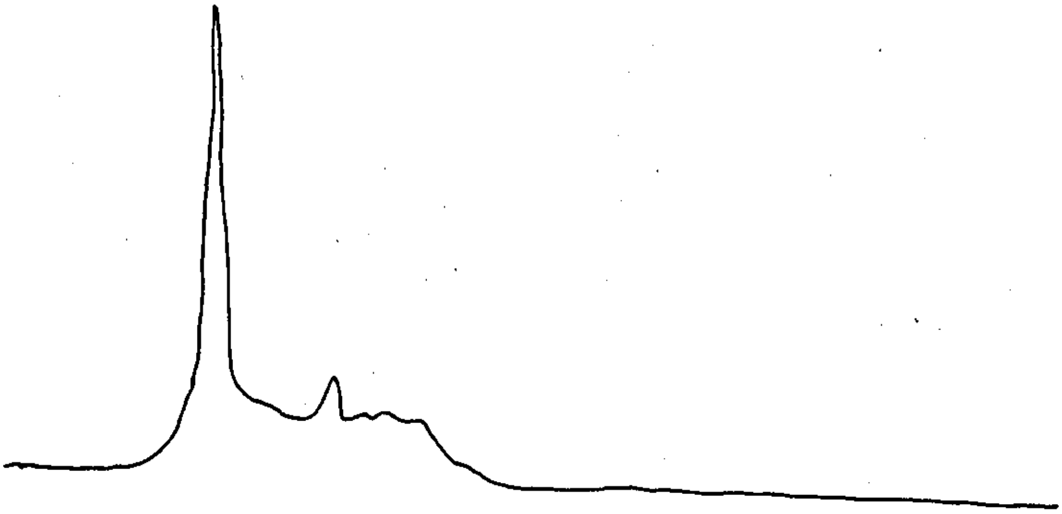


(b) Heavy load experimental condition

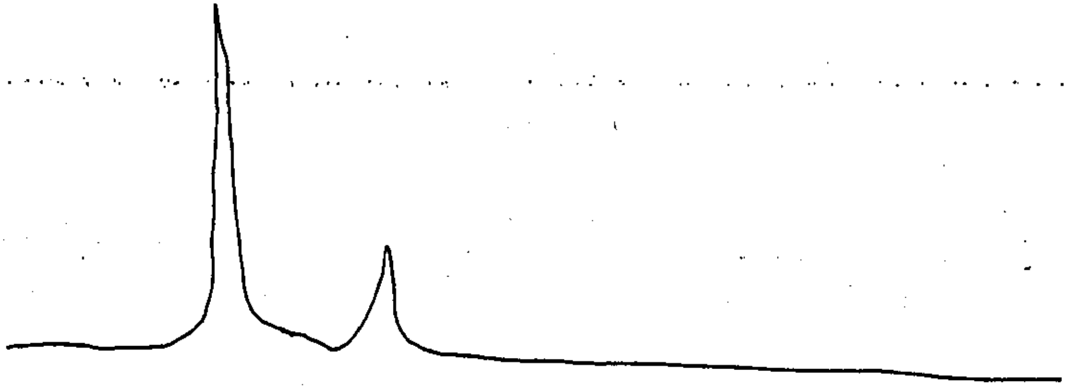


(c) Heavy load control, experimental conditic

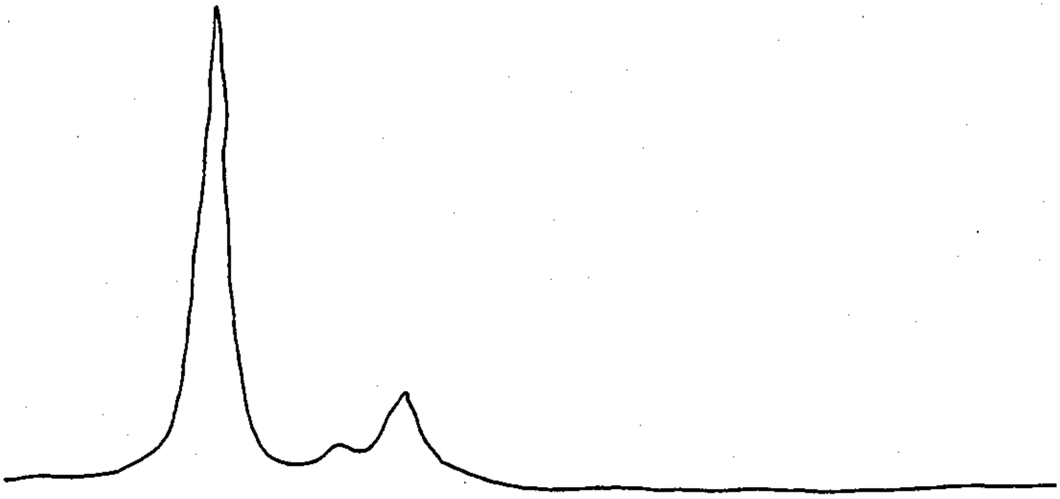
Figure 3.17 - Spectrum analysis for respiration during (a) moderate load, (b) heavy load and (c) heavy load control experimental conditions.



(a) Low load, recovery condition



(b) Medium load, recovery condition



(c) High load, recovery condition

Figure 3.18 - Spectrum analysis for respiration during (a) low load, (b) moderate load, and (c) high load recovery conditions.

In addition to examining the qualitative aspects of the spectrum analysis, an attempt was made to make some quantitative comparisons between treatments. The quantity selected was the maximum amplitude in arbitrary units of the predominant respiratory peak. These were corrected for each graph by the necessary scaling factor.

Table 3.4 summarises the F values between the occasions and subjects for each of the three stages, resting, experimental and recovery.

Table 3.4 - F ratios for occasions and subjects at each stage for maximum amplitude of respiratory spectrum analysis.

Resting		Experimental		Recovery	
Occasions	Subjects	Occasions	Subjects	Occasions	Subjects
1.24	2.08	10.22***	1.43	1.24	2.08

*** $p < .01$

This measure indicated reliability between occasions or tasks in the resting and recovery conditions. The significant effect in the experimental condition suggested that this measure revealed a discriminative task effect. The source of the variance (Tukey's HSD) established that it was the "high load" condition producing the effect (see Fig. 3.19). This measure also discriminated between the "high load" condition and the "high load control" condition. No other autonomic measure examined in this overall experiment has been capable of differentiating between these conditions. Thus the maximum power from the spectrum analysis showed significant differences between cycling whilst undertaking a perceptual motor task and cycling alone. The other notable factor in Table 3.4 was the lack of any subject effect in all conditions. This was contrary to other autonomic measures and demonstrated that the spectrum analysis was a potential measure for inter-subject comparisons.

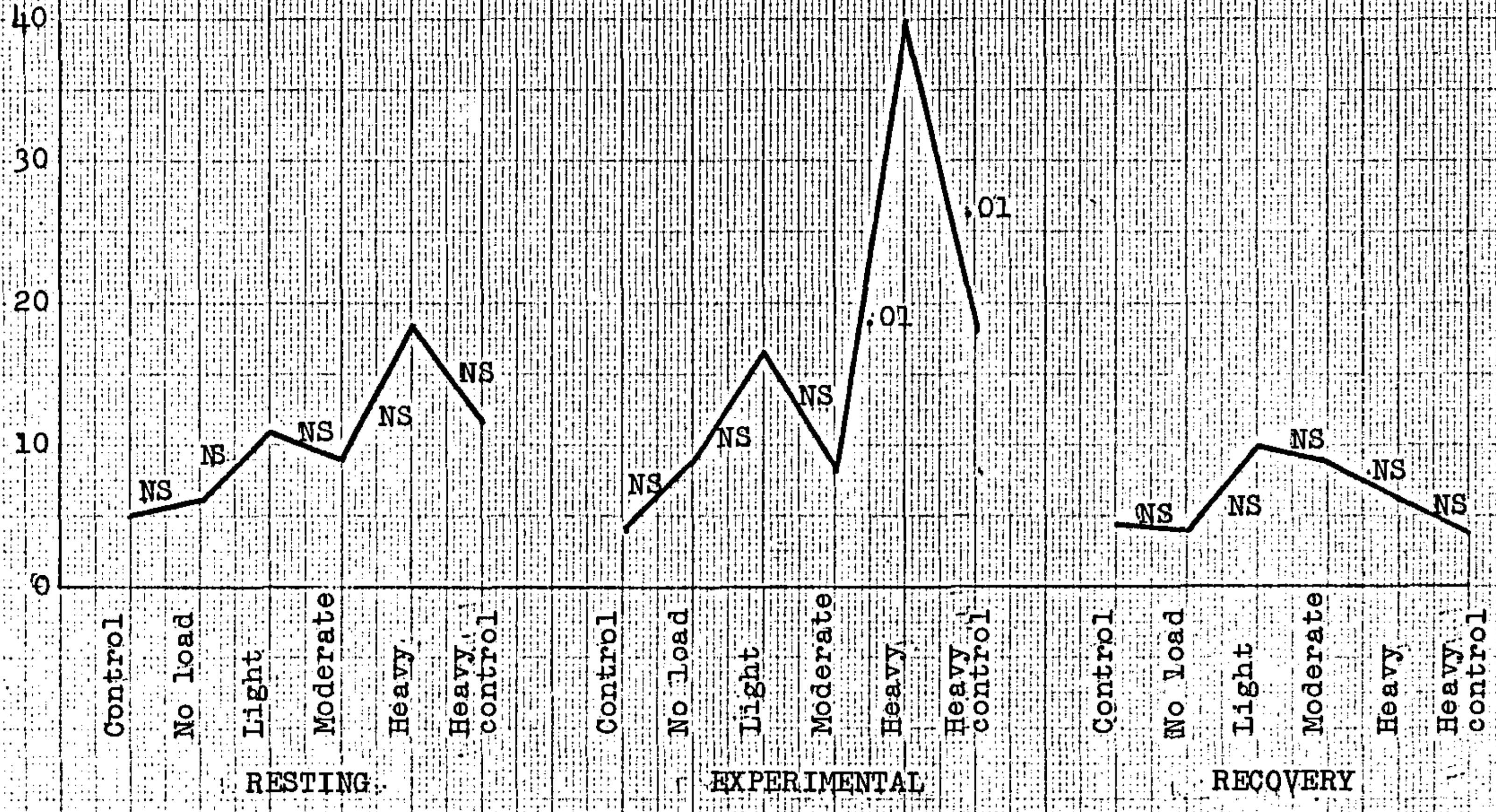


Figure 3.19 - Mean values of amplitude of spectrum analysis for respiratory waveform.

3.2.4 Temperature

Teichner's "thermal arousal index" was calculated for each subject, on each occasion during each stage of the experiment. It was the "ratio of the difference between body and skin temperature to the difference between skin and air temperature". Teichner (1962) considered that "values of the ratio that are greater than 1.00 are said to reflect most, if not all, other physiological changes that are indicators of arousal". The present study failed to find any ratios in excess of 1.00. This was not surprising as it would have required a greater temperature gradient to have occurred from core to skin than from skin to air. This is most unlikely, except when air temperature is above 30°C, a situation unlikely in most laboratories, or a skin temperature of 5°C less than normal. However, the "thermal arousal index" was computed and examined by a two way ANOVA to examine the differences between tasks. Table 3.5 shows the results.

Table 3.5 - F ratios of subjects and occasions from the resting, experimental and recovery stages.

Resting		Experimental		Recovery	
Occasions	Subjects	Occasions	Subjects	Occasions	Subjects
2.92**	9.27***	4.89***	8.32***	2.47**	5.92***

** $p < .05$ *** $p < .01$

The increase in the F ratio from 2.92 in the basal condition to 4.89 in the experimental stage only represented an increase in the variance of 6% of the total. The significant occasions effect in both the recovery and the resting stages suggested that this measure lacked any discriminative value.

The principle of the thermal arousal index is not clear but is presumably based upon massive peripheral blood flow clampdown. This phenomenon is indeed possible and personal experience of attempted intravenous catheterisation being thwarted by peripheral clampdown bears testomony to the fact.

The temperature regulating mechanism affects skin temperature by controlling peripheral blood flow. This is achieved by altering the flow resistance in the peripheral vessels, an adrenergic function which does not have a cholinergic equivalent. Thus the idea of a sympathetic arousal index based largely on skin temperature changes is theoretically reasonable, but not reproduced in practice in this experiment. Extremes of emotion may produce such a response but most common arousal situations would be unlikely to cause such an extreme reaction.

Thermal arousal index as a measure of arousal would therefore require a large temperature gradient between the core and the skin temperature. The inclusion of air temperature in the calculation is a further source of variability. A regression equation which excluded air temperature and was based on the core/surface gradient alone may substantiate the relationship between arousal and temperature.

3.2.5 Simple reaction time (SRT)

This measure was only recorded during the experimental condition. The analysis of variance produced a significant ($p < .01$) occasions and subjects effect. The source of the variance (Tukey's HSD test) was entirely attributable to the "no load" condition, Figure 3.20, but the reaction time was significantly slower, not faster as one might have expected. The subjects therefore appeared to be unable to respond rapidly when concentrating on the perceptual motor task alone. They were capable of attending to the primary task and responding quickly to the SRT stimulus when movement or physical load was involved.

The explanation for this could be either selective attention or the influence of raised activity in the reticular formation.

The first explanation is that when the subject considers the perceptual motor task (pursuit rotor) alone, he projects a high proportion of his attentional capacity on that task. The result is that an irregular, additional task (SRT) commands only a limited attention, and the response is slower.

The second explanation has a similar neurophysiological basis. It is proposed that the fast SRT in the other conditions is an accelerated response caused by increased neural activation. A number of studies, Baust et al (1968), Podvoll and Goodman (1967), support the association between increased arousal and greater neuronal activity in the brain stem reticular cells. It is suggested by Cooper (1973) that metabolic activity causes feedback to the brain via cardiovascular and blood pressure afferents. In addition to these, the somatic afferents have connections in the reticular neurones. It is somatic activity which alters when changing from the no load conditions to others, so it is highly probable that such a mechanism could be causing increased neuronal activation. A sequence of neural activity

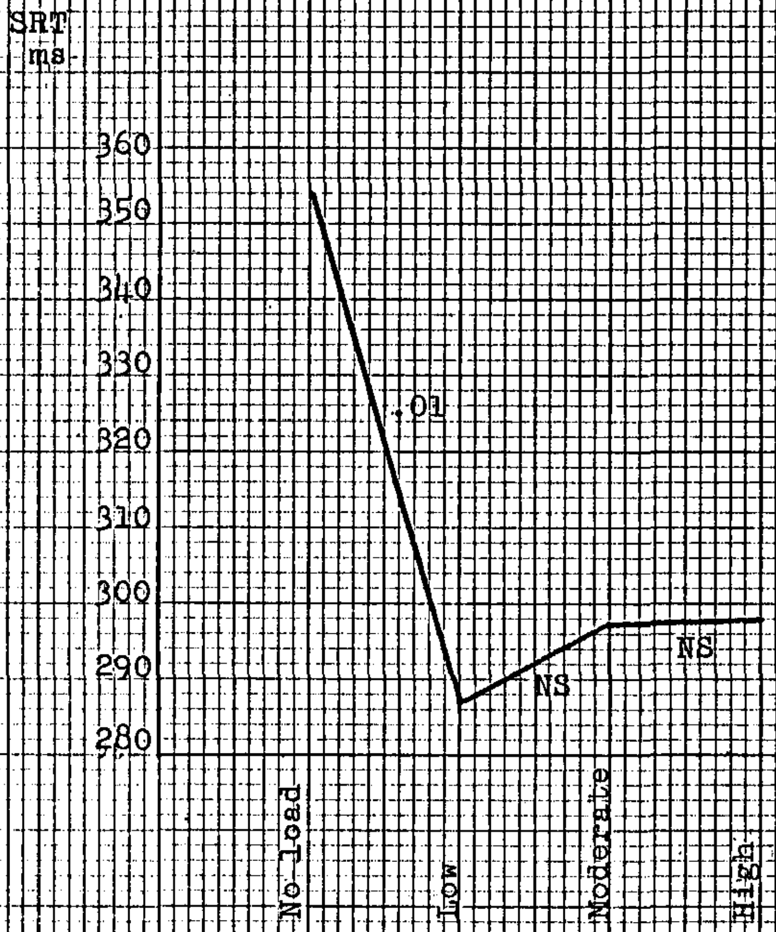


Figure 3.20 - Mean SRT values showing differences between pairs by Tukey's HSD test.

within the brian cells will involve a series of synaptic connections. The level of excitation must be near to the firing threshold for the synaptic connections to fire. These will influence other groups of neurones, some of which may have thresholds with high excitation levels. The optimum number of synaptic links must be at the correct threshold for the complete sequence of neural activity to operate at maximum speed. 'Optimum' is a critical term in this context, because a number of synaptic links, in addition to those required for the neural sequence, may be near the excitability threshold. These may fire extraneously and decrease the efficient passage of nervous connections. The SRT therefore requires the optimum conditions of synaptic links for maximum speed, and this may be a function of the number of excitability thresholds. It is hypothesised that the increased metabolic load makes more synaptic links reach optimum thresholds and subsequently decreases the SRT. This would explain the results of the experiment.

3.2.6 Perceptual - motor task

The results from the pursuit rotor task showed significant subject differences ($p < .01$), but revealed no differences between occasions. The differences in metabolic load failed, therefore, to influence the performance on the pursuit rotor.

This suggested that the subjects were treating the perceptual-motor task correctly as the primary task, and giving it a high proportion of their information processing capacity. The consistent level of performance implies that the metabolic changes were not influencing the neurophysiological processes. This assumes that a change in neurophysiological processes would be reflected in the performance of the task. The task may be insensitive to such changes, but experience in other contexts (e.g. motivational or competitive experiments), suggests that the pursuit rotor is a sensitive task. The cause of the consistence performance in this experiment is probably the involvement of motor control. The motor pathways would recruit a larger neural network than with SRT. This would decrease the sensitivity of response and give the observed results.

In summary, the following conclusions may be drawn:

The exclusive sympathetic innervation of EDA probably causes such a large response to each experimental situation that it cannot be used to differentiate between each occasion.

The transformation of electrodermal activity to log conductance change did not increase the sensitivity of the measure to show differences between experimental occasions.

Cardiac information which has been based on sequential intervals (time series data) is better able to distinguish arousal levels than data based on dispersion around a mean.

The investigation of cardiac intervals by spectrum analysis techniques provides a potent, non-intrusive method of investigation. The most apparent periodicities are those associated with respiratory, thermoregulatory and blood pressure inputs.

The spectrum analysis has revealed that the temperature regulating mechanism has an influence upon blood pressure and cardiac control. However, the measurement of core, shell and air temperature appears to lack sensitivity and it is recommended that plethysmographic techniques are employed to examine the involvement of the temperature control.

Qualitative differences in respiratory pattern were shown between the stages of progressive metabolic load. A quantitative measure based on the respiratory spectrum analysis did not show the individual differences normally observed with autonomic measures.

Teichner's "thermal arousal index" although theoretically feasible was not shown in practice to be a valid response to demanding work.

A slower reaction time was attributed to either selective attention or alteration in the thresholds for synaptic connections.

The perceptual-motor task showed no differences in results between occasions. The involvement of motor pathways may have decreased the sensitivity of the response.

SECTION FOUR

EXPERIMENTAL STAGE THREE - RESPONSES TO INCREASING INTENSITY OF MENTAL AND PHYSICAL LOAD.

The previous experiment has given further support for each arousal subsystem to be considered independently. The influence of stimulus similarity has not been resolved and the present experiment has been designed to examine this further. The intensities of both the mental and physical loads were progressively increased producing conditions of high stimulus similarity. The comparison between mental and physical work was the condition of low stimulus similarity.

The design will also permit a further examination of the relationships between the cholinergic/adrenergic influences and metabolic load. This experiment accounts for individual differences by basing the intensity on the pre-treatment working ability. In the case of the physical work, the adjustment was on the basis of measured maximum oxygen uptake ($\dot{V}_{O_2}$ max.) or aerobic capacity. The work intensities were then set at given percentage values of this capacity. In the case of mental work such fine adjustment was not possible, but each subject was pre-tested and the range of mental intensities selected for the experiment was based on individual response scores during the pre-test.

Respiration has been shown to have a potent influence on the cardiac system but the extent to which this is related to somatic activity requires further investigation.

Oxygen consumption has been used as a measure of gross cellular metabolism previously, but the measurement of the small changes associated with mentally demanding tasks was technically difficult. In a summary of studies by Obrist et al (1974) on the relationship between somatic and cardiovascular processes, only 1 out of 19 studies used V_{O_2} as the somatic measure. The intrusive nature of measuring V_{O_2} has also contributed to its lack of use, although the ventilated hood technique, De Looy (1974) has removed this objection. The recent development of an oxygen consumption meter which offers a continuous reading, Brodie, Humphrey and de Looy (1978) facilitated this measurement. Although a face mask is still necessary and may be considered slightly intrusive, the two habituation periods gave sufficient time for the subjects to become familiar with the apparatus, and none reported any discomfort.

An additional reason for including this measure has been the suggestion, Venables (1977), that the heart rate in excess of metabolic requirement could be a valid measure of stress. This, combined with metabolic requirement being so fundamental to many of the more commonly used psychophysiological measures, illustrates the basis for measuring $\dot{V}_{O_2}$.

The development of novel analytical techniques for the cardiac and respiratory measures showed that useful information can be obtained by data manipulation. This will be consolidated in the third experiment with the technique of spectrum analysis being more fully evaluated.

Certain individuals have shown a distinctive, autonomic response and this may partly be caused by subjects perceiving the tasks differently. This final experiment includes measures which will indicate the perception of the task. In an attempt to understand the individual differences more fully, a range of additional measures could be included. One measure, however, which particularly merits inclusion is that of personality. This is because of its strong association with the central processing of afferent information, particularly under different arousal conditions. This justifies an assessment of personality within the final experiment.

4.1 Methods and Materials

4.1.1 Experimental procedure

Each subject attended the laboratory on five occasions. The first two occasions were used to habituate the subject and to establish the basal performance levels. The third and fourth occasion involved the measurement of responses to increasing intensities of physical and mental work. The personality questionnaire was completed on the final occasion.

(a) Occasion 1

Each subject listened to a series of pre-recorded digits through stereo headphones. The digits were presented sequentially in random order. The subject responded to every "odd-even-odd" sequence of digits. This task was chosen because it required minimal response movement and has been found by earlier workers, (Brown and Poulton, 1971, Davey, 1973) to be demanding in nature. The subject was instructed in the procedure before the experiment. He was told to listen for any "odd-even-odd" sequence of numbers and respond by depressing the microswitch. Any two odd numbers which were identical in the sequence e.g. 1-4-1 did not require a response as this was considered too easy. The subjects were reminded that the digit "0" is an even number and that the final odd digit in a sequence of three could be initiating a second sequence of three, e.g. 1-4-3-2-7. No practice time was considered necessary as the whole occasion was an habituation period.

The final amplifier on the physiograph (Minograph 34, Siemens Ltd.) was shortcircuited by pressing the microswitch held in the left hand. This gave a short baseline deflection. The physiograph was running continuously during the experiment (0.25 mm sec^{-1}) so it was possible to determine the exact time of the response. The timing of each "odd-even-odd" sequence was known for each digit presentation and thus an error score could be established from the physiograph recording.

Each subject listened to the recording for a period of 5 minutes, responding as appropriate. There were four recordings available at digit presentation rates of:

Once per 3 seconds
Once per 2 seconds
Once per 1½ seconds
Once per 1 second

The decrease in time interval represented an increase in mental load.

Each subject listened to each recording which was presented in random sequence. Baseline levels on the measures were established over a five minute period prior to every recorded presentation (see Figure 4.1).

The purpose of Occasion 1 was mainly one of habituation. It was necessary, however, to gauge the mental load of the task. The mental load could not be altered so that it influenced each subject by an equivalent amount but it was possible to ensure that each subject was responding in a characteristic fashion and in a similar hierarchical manner. It was assumed that an increase in digit presentation rate would cause an increase in psychological load. Physiological responses could not be employed to test this assumption because the subjects had not become habituated. It was considered acceptable, however, to employ the perceived exertion scale, Borg (1962), for this purpose. A few subjects showed little differentiation between the presentation rates of once per 1½ seconds and once per 2 seconds, but generally the perceived exertion followed a hierarchial order with once per 1 second being the most demanding and once per 3 seconds being the least demanding ($p<.001$).

Condition	Time
Basal Period	5 min.
Digit Presentation 1 (one per 3 sec)	5 min.
Digit Presentation 2 (one per 1 sec)	5 min.
Digit Presentation 3 (one per $1\frac{1}{2}$ sec)	5 min.
Digit Presentation 4 (one per 2 sec)	5 min.

Fig. 4.1 - Experimental design for Occasion 1

(b) Occasion 2

Each subject was required to ride a cycle ergometer (Muller), see Fig. 3.1, at a progressively increasing load. This form of work was used in the determination of maximum oxygen consumption ($\dot{V}O_2$ max.). The reason for measuring $\dot{V}_{O_2}$ max. was that each subject could then be matched in terms of a percentage of his individual physical work capacity.

$\dot{V}_{O_2}$ max. was measured using the open circuit method (see Fig. 4.2). The subject breathed in and out of a Triple - J high flow rate valve (Warren Collins) with the expired air passing through elephant tubing to a dry gas meter (Parkinson Cowan). The volume of expired air (V_E) was measured with the dry gas meter and the air was then passed through a two-way tap to a 200 ℓ Douglas bag. The fraction of oxygen in expired air (F_{E,O_2}) was determined by passing a sample of air from the Douglas bag via a Higginson syringe and a drying agent to an oxygen analyser (Servomex E2500). This was calibrated from standard gases before each experiment.

The work loads started at 50 watts and involved step wise increases of 50 watts with each load being held until respiratory steady state and for a minimum of 4 minutes. Respiratory steady state was monitored by recording V_E every minute. The air was collected in the Douglas bag for one minute when two consecutive readings were within 5 litres.

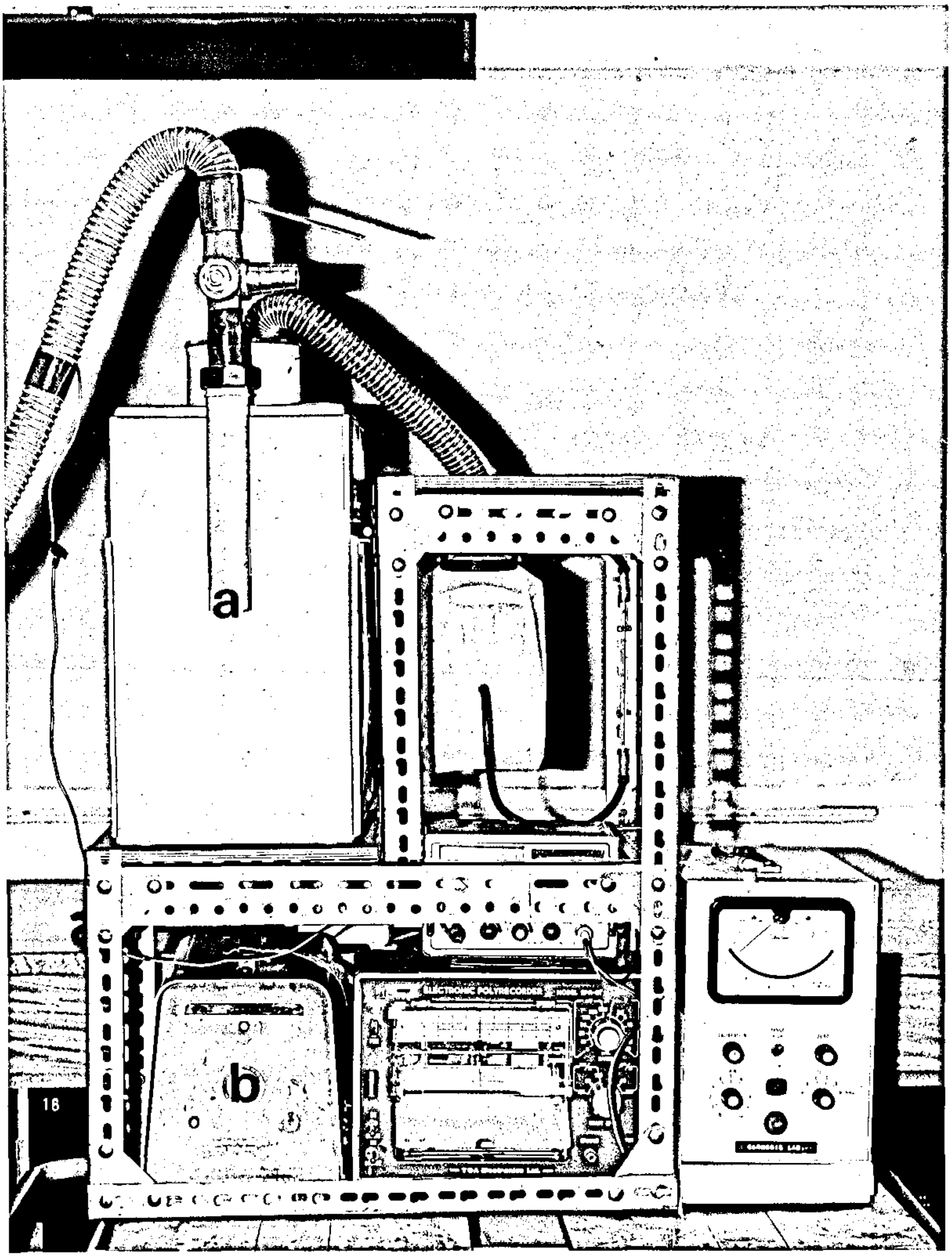


Figure 4.2 - Equipment for open circuit method of measuring oxygen consumption showing (a) dry gas meter and (b) oxygen analyser.

$\dot{V}_{O_2}$ was calculated from V_E and F_{E,O_2} and was corrected to STDP. Laboratory temperature, barometric pressure and relative humidity were measured prior to each experiment. The temperature of V_E was measured during the one minute collection period using a thermometer placed in the neck of the gas meter.

Each subject was given the standard verbal warning about feeling of discomfort, pains in the chest and left arm, giddiness and nausea and was then requested to cycle the ergometer at the progressively increasing loads. The loads were increased until the subject became exhausted. Exhaustion was defined as the inability to maintain the correct pedalling frequency. The subject established the correct pedalling frequency by keeping the pointer on a large dial placed in front of the ergometer stationary. The saddle height was adjusted individually to 109% inside leg measurement, Hamley & Thomas (1967).

A reading for $\dot{V}_{O_2}$, corrected to STDP, was made for the final minute at each workload and the highest reading taken as the $\dot{V}_{O_2}$ max. In theory the $\dot{V}_{O_2}$/ work load relationship should plateau at the $\dot{V}_{O_2}$ max. even during further increases in work load. This was only evident in half the cases, but this is a common limitation of using the cycle ergometer because local muscular fatigue in the legs causes exhaustion before the occurence of metabolic insufficiency. The figure attained of $\dot{V}_{O_2}$ max. <u>at or before exhaustion</u> is confidently accepted as being sufficiently near to the <u>actual</u> $\dot{V}_{O_2}$ max. for the purpose of this experiment. A graph was plotted for each subject relating $\dot{V}_{O_2}$ to work load. This graph was used to interpolate a reading in watts for 30%, 50% and 70% of attained $\dot{V}_{O_2}$ max. These readings were used to set the cycle ergometer workloads for Occasion 4.

Heart rate was measured from the ECG record during the final minute of each workload. A rating of perceived exertion was established immediately after each workload by the Borg scale. This indicated whether subjects were perceiving the increments in work load in an hierarchical manner. Two subjects rated the perceived exertion between two of the workloads at the same level, but otherwise the perceived exertion score increased as the load became more demanding.

(c) Occasion 3

This was the measurement of responses to increasing mental load. The experimental design is shown in Figure 4.3.

Baseline psychophysiological measures were established during a five minute period before the digit presentation. The sequence was:

One per 3 seconds

One per 2 seconds

One per 1 second

with a 10 minute recovery period following each digit presentation which was itself 10 minutes in length. The measures used on this occasion are explained in section 4.1.3.

(d) Occasion 4.

This was the measurement of responses to increasing physical load. The experimental design is shown in Figure 4.4.

A five minute period prior to the series of physical loads allowed baseline levels on the measures to be established. The sequence of physical load was:

30% $\dot{V}_{O_2}$ max.

50% $\dot{V}_{O_2}$ max.

70% $\dot{V}_{O_2}$ max.

with a 10 minute recovery period following each load. Each

CONDITIONS

	Basal		Digit Presentation 1 One per 3 seconds		Recovery 1		Digit Presentation 2 One per 2 seconds		Recovery 2		Digit Presentation 3 One per 1 Second		Recovery	
Time	5 min		10 min		10 min		10 min		10 min		10 min		10 min	
Measures	HR	PF	HR	PE	HR	PF	HR	PE	HR	PF	HR	PE	HR	PF
	f		f		f		f		f		f		f	
	V_I		V_I		V_I		V_I		V_I		V_I		V_I	
	$\dot{V}_{O_2}$		$\dot{V}_{O_2}$		$\dot{V}_{O_2}$		$\dot{V}_{O_2}$		$\dot{V}_{O_2}$		$\dot{V}_{O_2}$		$\dot{V}_{O_2}$	
	RT		RT		RT		RT		RT		RT		RT	
	EDA		EDA		EDA		EDA		EDA		EDA		EDA	
			Digit Response				Digit Response				Digit Response			

Figure 4.3 - Design of Occasion 3 - Responses to Increasing Mental Load.

CONDITIONS

	Basal		30% $\dot{V}O_2$ max		Recovery 1		50% $\dot{V}O_2$ max		Recovery 2		70% $\dot{V}O_2$ max		Recovery 3	
Time	5 min		5 min		10 min		5 min		10 min		5 min		10 min	
Measures	HR	PF	HR	PE	HR	PF	HR	PE	HR	PF	HR	PE	HR	PF
	f		f		f		f		f		f		f	
	V_I		V_I		V_I		V_I		V_I		V_I		V_I	
	$\dot{V}O_2$		$\dot{V}O_2$		$\dot{V}O_2$		$\dot{V}O_2$		$\dot{V}O_2$		$\dot{V}O_2$		$\dot{V}O_2$	
	RT		RT		RT		RT		RT		RT		RT	
	EDA		EDA		EDA		EDA		EDA		EDA		EDA	

Figure 4.4 - Design of Occasion 4 - Responses to Increasing Physical Load.

physical load period was 5 minutes in length. The levels of physical load were chosen to correspond approximately to the working demands of recreational physical activities. Thus the lowest level (30% $\dot{V}_{O_2}$ max.) approximated to mild physical activity and the highest level to strenuous physical activity.

All the psychophysiological measures were recorded as in Occasion 3 with the exception of the response to digit presentation which did not apply on this occasion.

(e) Occasion 5

Each subject was required to complete a personality questionnaire. More personality dimensions were available using the Cattell 16 PF than the Eysenck EPI so this was selected. Each subject was instructed carefully in the procedure and completed form C.

4.1.2 Subjects

The subjects were male students and laboratory technicians (N=24) from Leeds Polytechnic, England with a modal age 19 years (range 18-34). They were in good health and were originally invited to participate in the experiment on the basis of whether or not they regularly participated in demanding physical activities. Half of the sample were regular participants and the other half not, the intention being to examine whether levels of physical fitness made any contribution to the between-subject variance.

4.1.3 Measures

(a) Electrodermal activity

The transducer preparation and recording of EDA was as in the previous experimental stage and described fully in section 2.1.3. A recording was made every minute and the mean value of each treatment condition used in the statistical analysis.

(b) Electrocardiography

The transducer preparation was as used previously and described fully in section 2.1.3.

The ECG recording was entirely different from the previous experiments. This was because (a) the FM recorder was no longer available, and (b) an alternative method was developed to facilitate heart interval data to be recorded in an inexpensive and more flexible manner.

A modification was made to a Childerhouse 'R' wave cardiac monitor (Figure 4.5) so that the internal loudspeaker was disconnected and the leads to the loudspeakers reconnected to two 4 mm sockets. Two 4 mm jack plugs were then inserted into these sockets and leads connected to the final amplifier of the Mingograph physiograph. Thus for every heart beat as triggered on the 'R' wave of the ECG an electrical signal of short duration and high amplitude was recorded on the physiograph. The signal was then fed from the physiograph to a domestic cassette recorder (Philips Ltd.) and an audio tone recorded on cassette tape (see Figure 4.6). Although this system does not allow for ECG waveform analysis, it does present a method for heart rate and heart rate variability assessment without the requirement of an FM tape recorder - a very expensive piece of equipment. The sequence of recorded audio tones did need a specialized electronic circuit to filter 50 Hz noise and make the tones accessible by computer, but this did not add appreciably to the cost. The cassette tapes were then transfered to Bradford University Computer Control Laboratory and the system that follows was developed to analyse the audio tones present on the tapes. The system is based on (1) an electronic hardware link between the cassette recorder and the computer, (2) a Ferranti 700E real time computer, and (3) a Hewlett Packard 2100A computer with associated hard copy facilities.

(1) Electronic hardware.

The audio tones on magnetic tape required initial

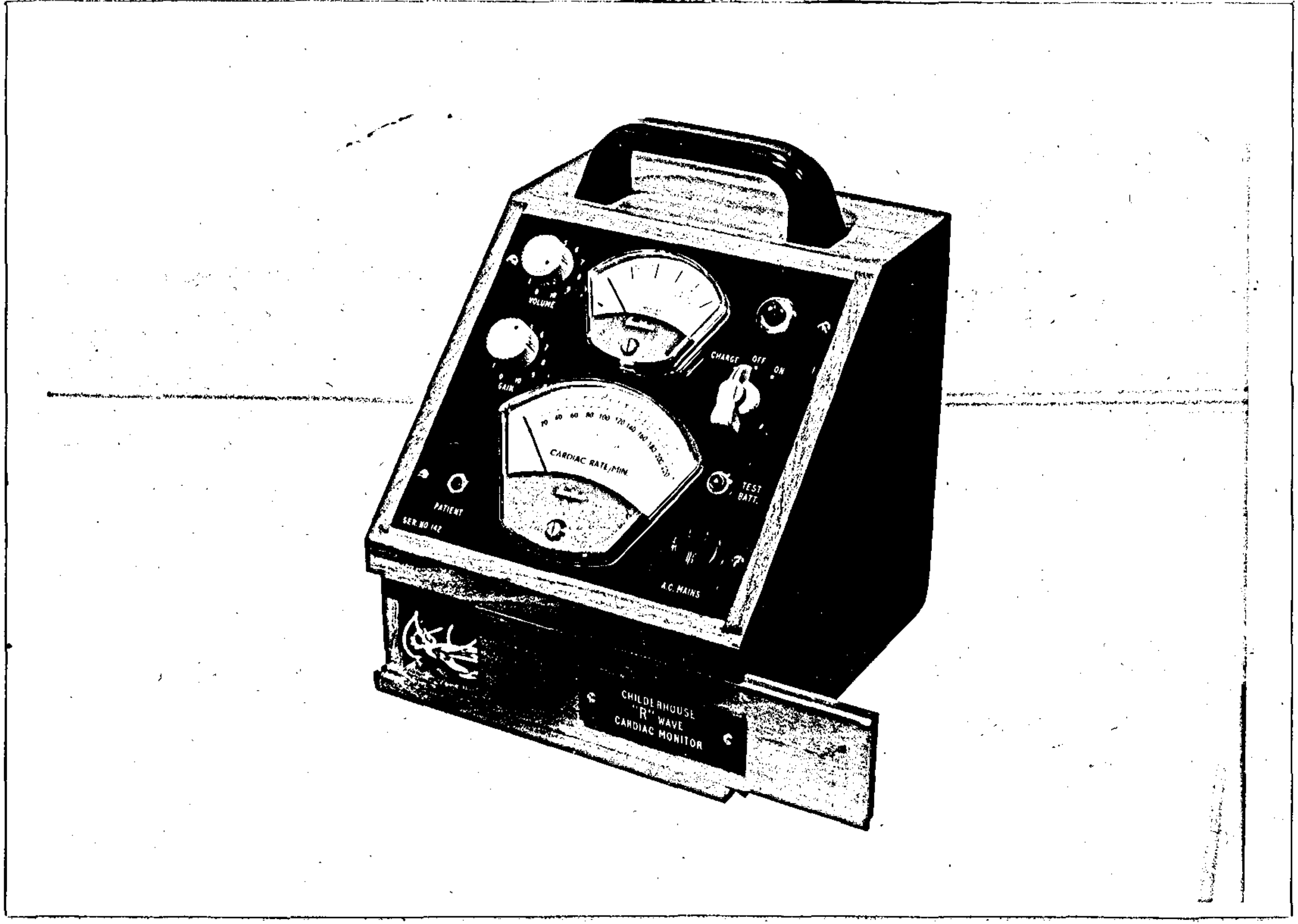


Figure 4.5 - Childerhouse 'R' wave cardiac monitor

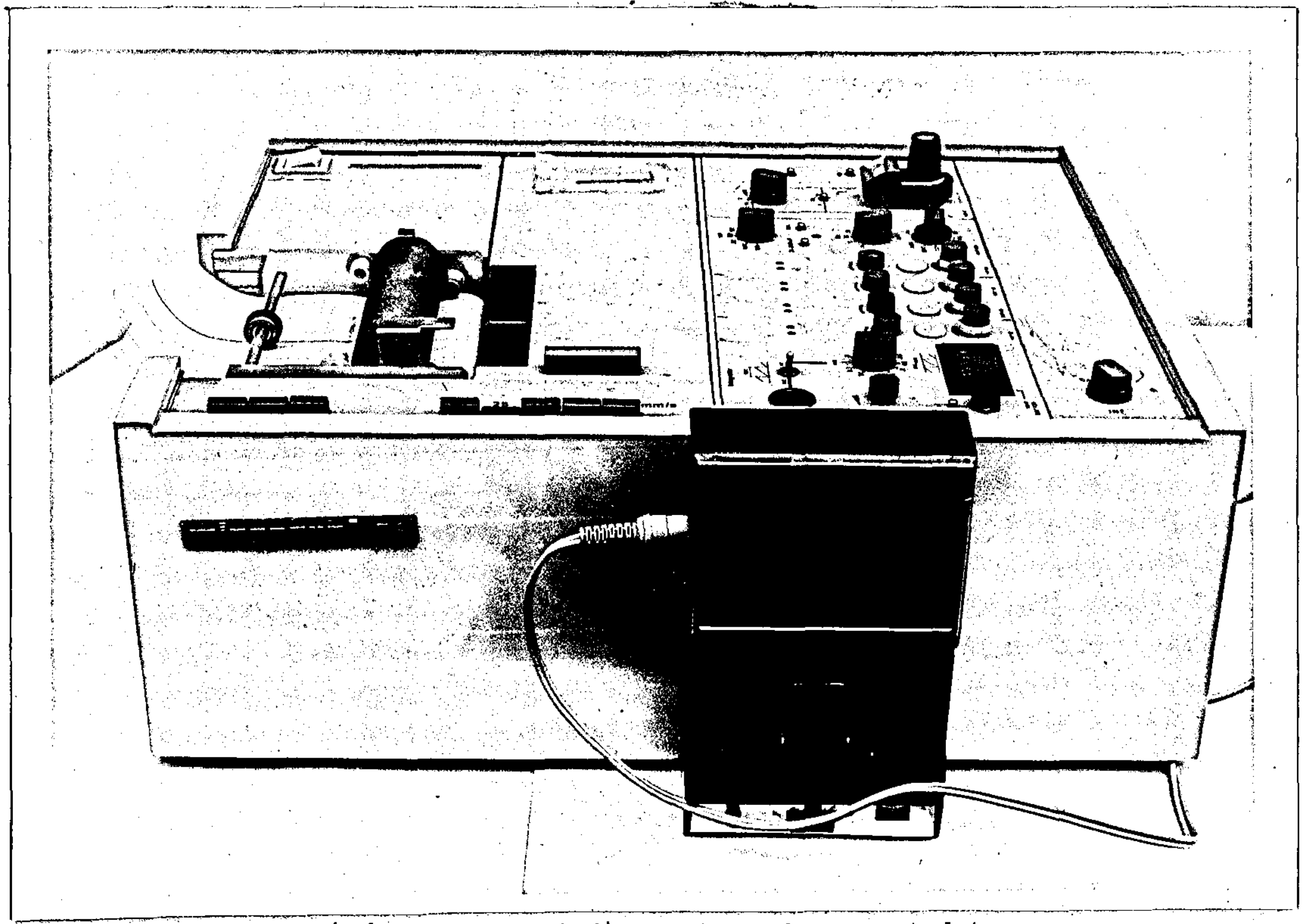


Figure 4.6 - Mingograph 34 physiograph connected to domestic cassette recorder.

processing to improve the signal to noise ratio and to make the leading edge of the tone sufficiently distinct to operate the Schmitt Trigger. This signal was then coupled to the Schmitt Trigger via a transformer. The Schmitt Trigger and associated monostable closes the gate of a counter, fires a transformed and reset mechanism which also re-opens the gate. This gives the R-R interval which is displayed in digital form on four light emitting diodes as milliseconds. A block diagram of this hardware is given in Fig. 4.7. The R-R interval is transferred from the buffer registers to the Ferranti 700E after the interrupt has been generated.

(ii) Ferranti 700E

On receiving the appropriate interrupt the 700E reads the counter buffer. The sequence of the R-R intervals is stored until the magnetic tape is stopped. A videodisplay unit (VDU) presented the total number of R-R intervals every 10 seconds. This meant that the experimenter could tell how many R-R intervals had been stored in the 700E and stop the magnetic tape accordingly. It was decided to analyse 256 R-R intervals, so to allow for spurious information arising in the process of sampling and recording, a number in the region of 275-300 R-R intervals was stored for each condition. The programs for the 700E are time shared with other real time experiments and written in ICOL, a language developed by Butts and Gough (1978).

An interval of more than 10 seconds (usually obtained by stopping the magnetic tape) caused the generation of the sequence of R-R intervals in milliseconds to be displayed on:

Paper tape,
teletype, and
line printer.

The paper tape was then labelled and transferred for analysis by the Hewlett Packard 2100A.

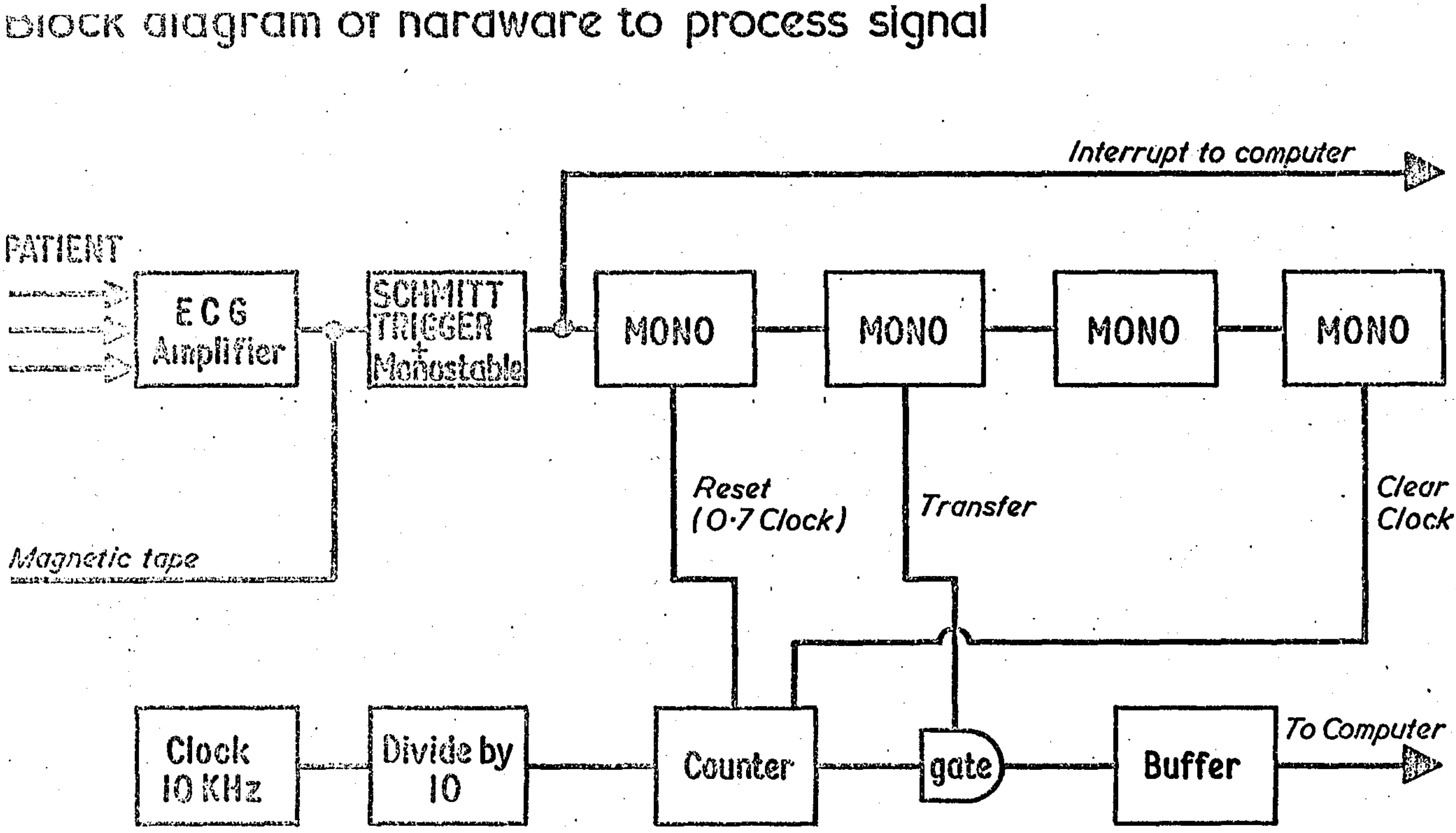


Figure 4.7 - Block diagram of hardware to process signal

(iii) Hewlett Packard 2100A

The first operation was the removal of spurious information and limiting the data to a standard 256 data points. The computer was programmed to remove any data that lay outside 2 standard deviations either side of the mean R-R interval time. Although these limits were arbitrary, they successfully removed any spurious data. This was checked by comparing the R-R interval printout from the 700E with the Hewlett Packard VDU display. It was only rarely that spurious information existed in the original magnetic tape but a noisy burst such as that caused by electrode slippage or electronic interference was easily removed by this procedure.

After elimination of outliers, the remaining data were plotted against time on a Tektronix 4101 visual display unit using a linear interpolation between successive data points. Maximal and minimal values were also noted and it was possible to code each graph. It was possible to display up to four graphs on each VDU display, but 2 were chosen as the optimum number to allow comparisons to be made, yet not reduce the size too greatly. A hard copy of each graph was made on a Tektronix Hard Copy Unit as shown in Fig. 4.8.

After the graph plot had been displayed and copied the computer produced an R-R interval frequency distribution curve with a suitable class interval (bin size) as illustrated in Fig. 4.9. The bin size in this case is 25 ms. The computed frequency was expressed as a percentage of the total to allow for a varying number of data points. A hard copy was also made of this. The computer also produced a frequency distribution curve for the R-R interval difference which is shown in Fig. 4.10. This calculated the difference between successive R-R intervals and plotted the appropriate histogram. The advantage of the former curve is it gives an indication of the changing mean heart rate under different treatments, (Fig. 4.9) whereas the latter histogram gives a much clearer picture of the variability itself (Fig. 4.10).

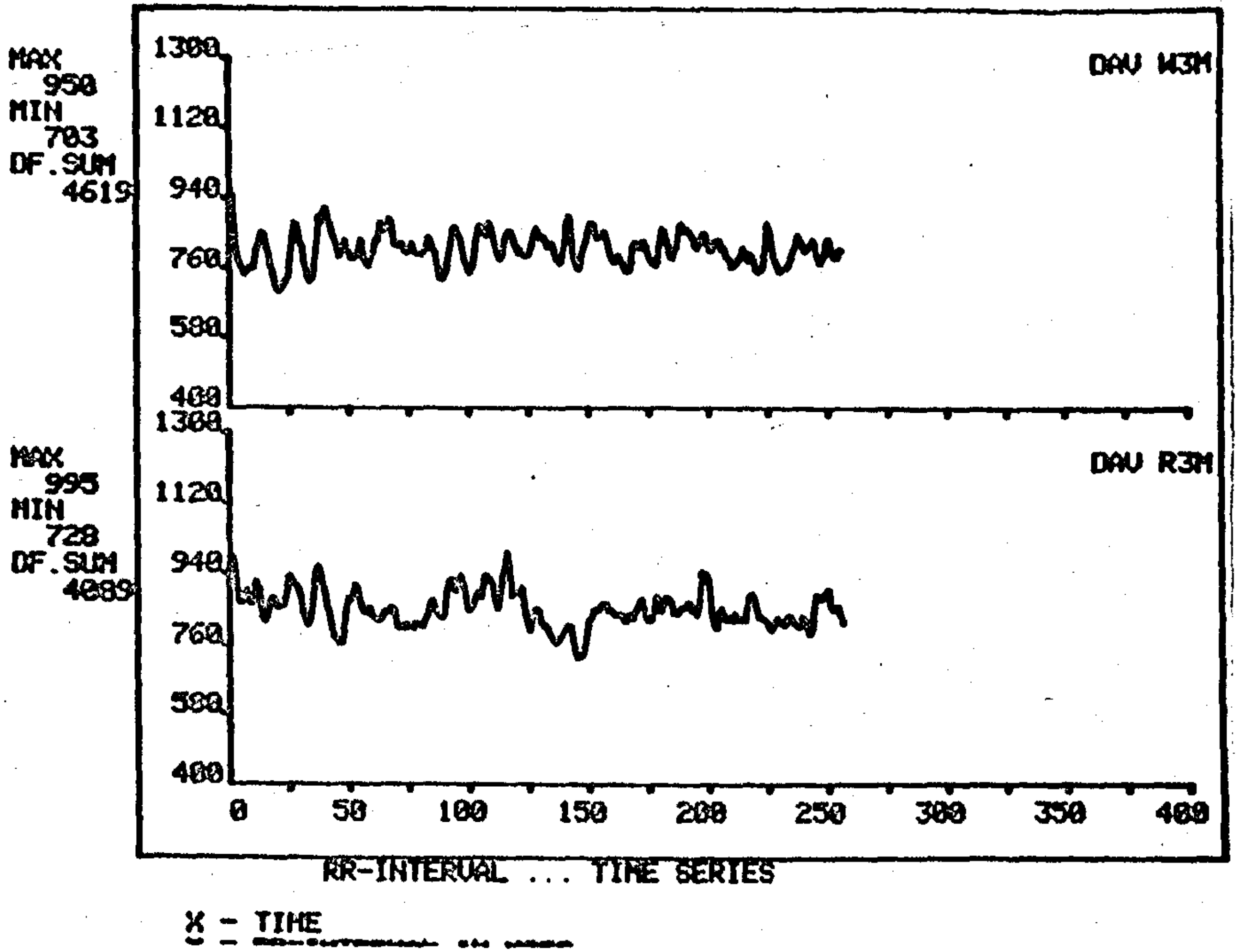


Figure 4.8 - Graphs of the RR interval time series produced on the Hewlett Packard 2100 computer.

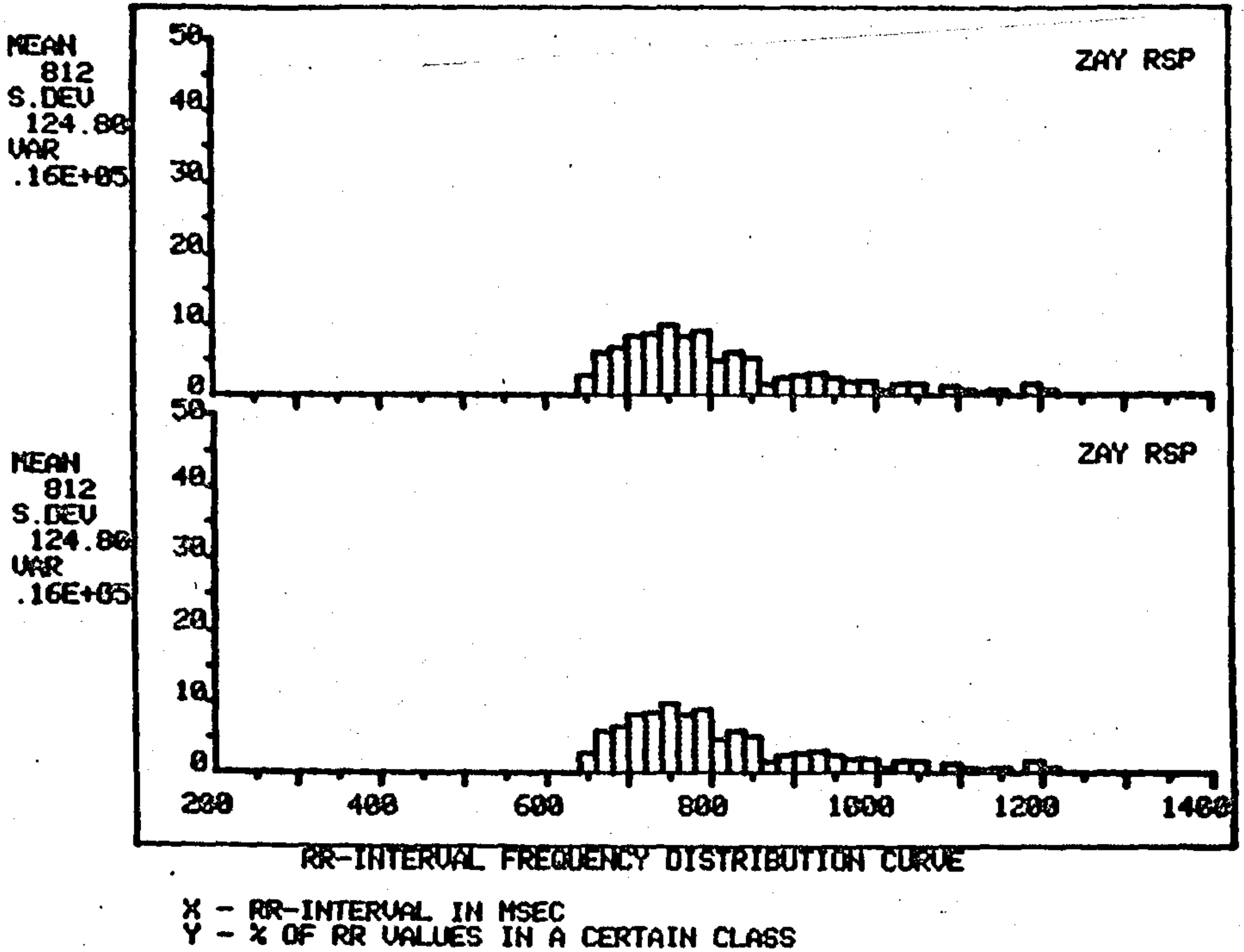


Figure 4.9 - Graphs of RR interval frequency distribution curves.

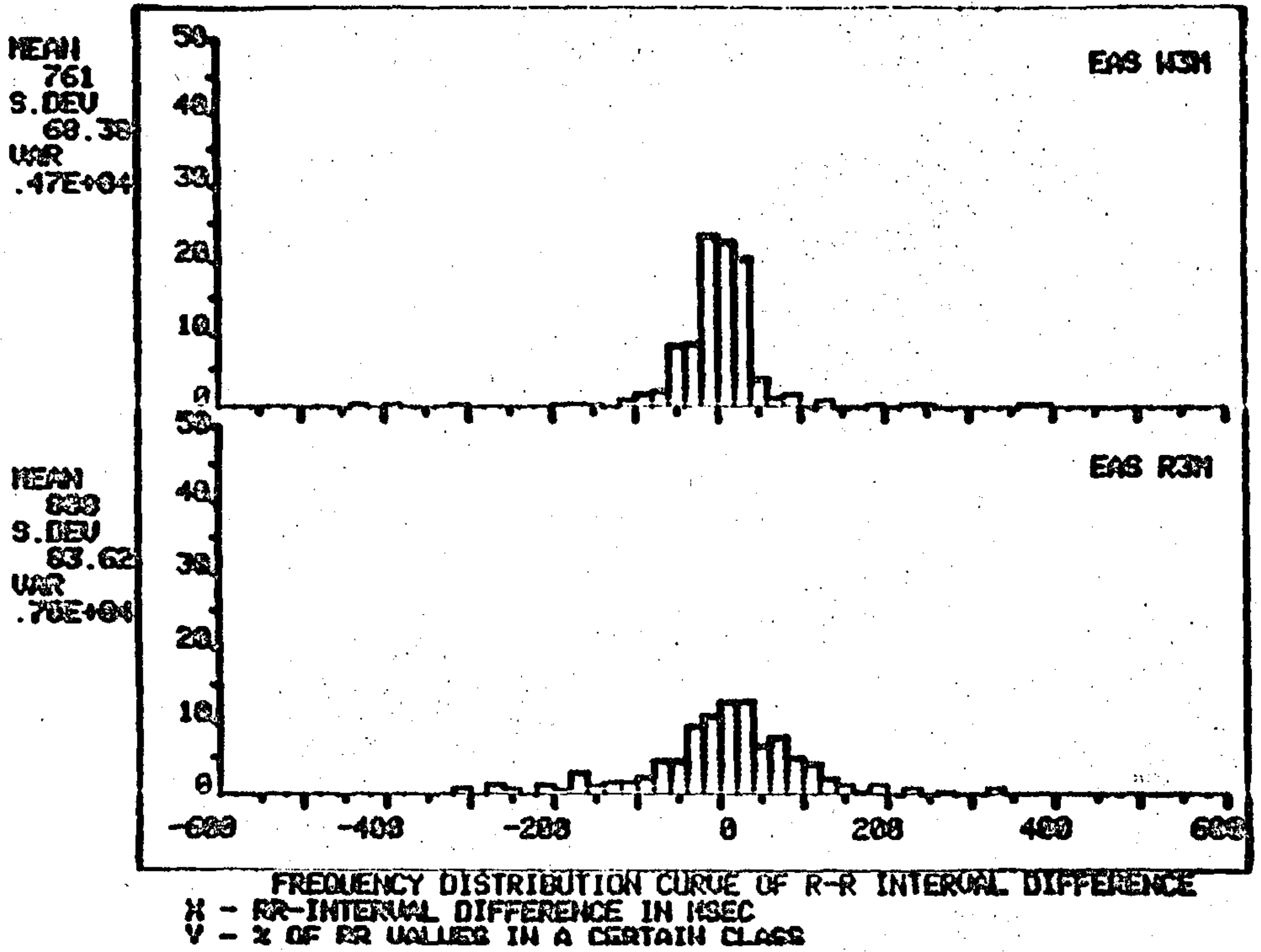


Figure 4.10 - Graphs of RR interval frequency distribution curves.

A series of heart rate variability statistics were then computed, displayed and presented on a teletype. These were:-

1. Mean
2. Standard deviation
3. Variance
4. Frequency of maximal beats
5. Frequency of minimal beats
6. Number of reversal points
7. Sum of absolute differences
8. Ratio of 7 and 6
9. First difference mean
10. Second difference mean
11. Square of the successive differences.

Although the previous experiment indicated that a more limited selection of measurements may be appropriate, it was considered that an experimental design which was to examine stimulus intensity instead of stimulus type would benefit from a larger number of variability measures. Those listed above were indeed selected from over 30 HRV measures and were the ones recommended most consistently in the literature.

A block diagram of the complete R-R interval processing system is shown in Figure 4.11.

The reliability of the system was assessed by repeatedly playing the same cassette recording through the system. It was found that the R-R intervals did not vary by more than 2 ms, a figure which demonstrates very high replicability, particularly when dealing with a motor driven system and magnetic tape which has inherent errors such as tape stretch.

(c) Respiration

The transducer preparation was as described in section

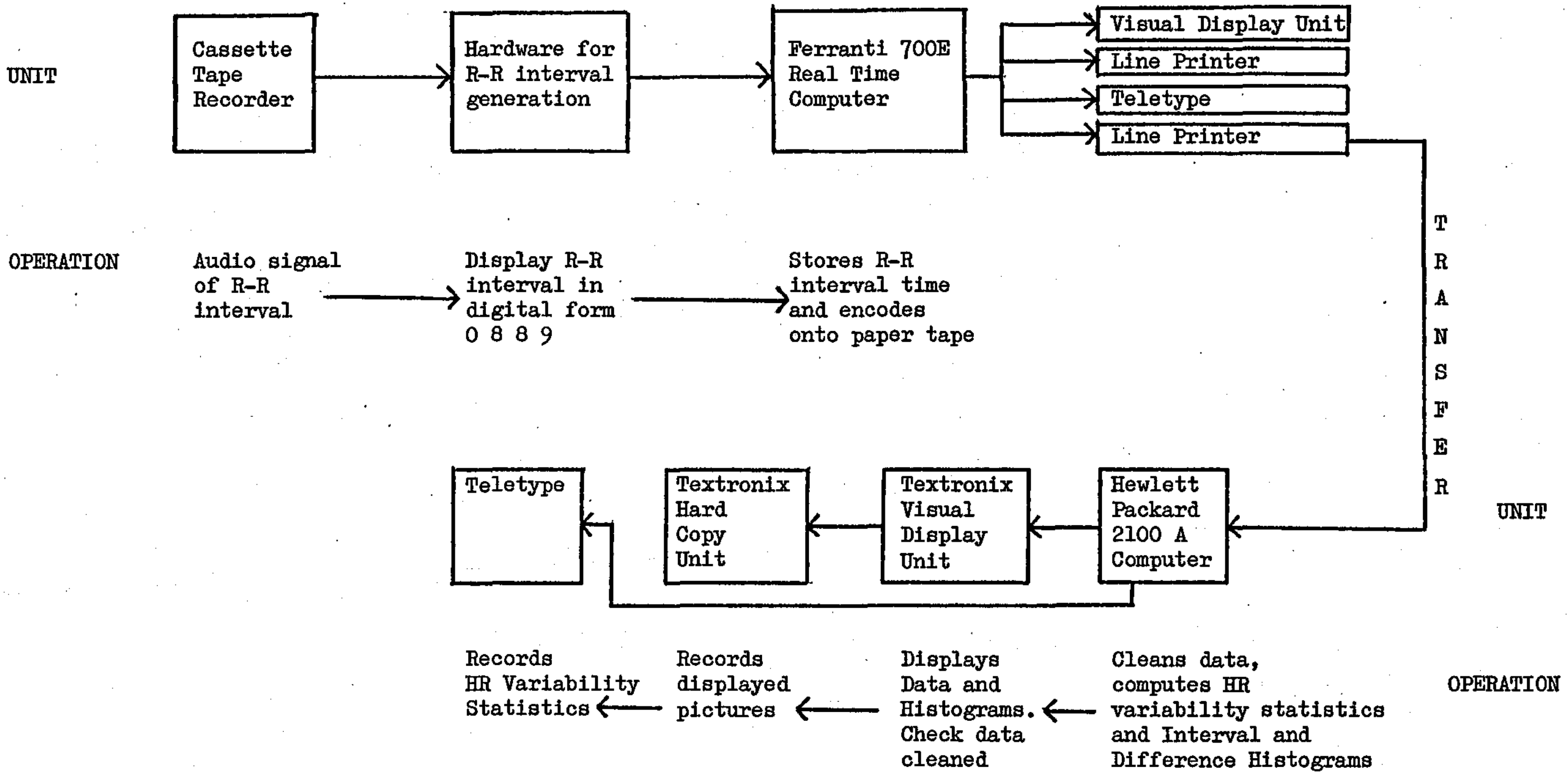


Figure 4.11 Block Diagram of R-R Interval Processing System

3.1.5 as was the recording. The respiratory frequency was measured from the oscillograph trace with the value for every minute recorded for the statistical analysis.

(d) Simple reaction time.

Each subject was required to attend to a small electric bulb which was placed at chest height three feet in front of the subject. When the bulb came on the subject was requested to respond as rapidly as possible by depressing a microswitch held in the right hand. It was explained that a measure of reaction time was being taken and the importance of a rapid response was emphasised. A simple electronic circuit was designed so that the experimenter switched on the bulb and a millisecond electronic timer simultaneously, with the depression of the microswitch stopping the timer. The timer (Pannax Ltd.) recorded to 0.0001 sec. but each recording was corrected to give a reaction time in milliseconds.

(e) Metabolic measures

The primary measure used to indicate metabolic activity was oxygen consumption ($\dot{V}_{O_2}$). It was recorded continuously using a hitherto unavailable piece of equipment, the Oxylog (P.K. Morgan The Oxylog (see Fig 4.12) was validated by Brodie, Humphrey and de Looy (1978) and incorporated a flow rate transducer based on a rotating vane interrupting a photoelectric light source. The electrical signal from the rate transducer was proportional to the volume of inspired air (V_I) and was held internally for one minute. The oxygen fraction in atmospheric air (F_{I,O_2}) was being compared constantly with the oxygen fraction in expired air (F_{E,O_2}) by means of a polarographic oxygen sensor and the electronic circuitry facilitated a digital display of $\dot{V}_{O_2}$ every minute. An alternative display mode was a DC pulse of approximatel 3 volts for every 100 ml of oxygen consumed. To display this pulse on the physiograph it had to be rectified and a small electronic circuit was designed for this purpose. The subject

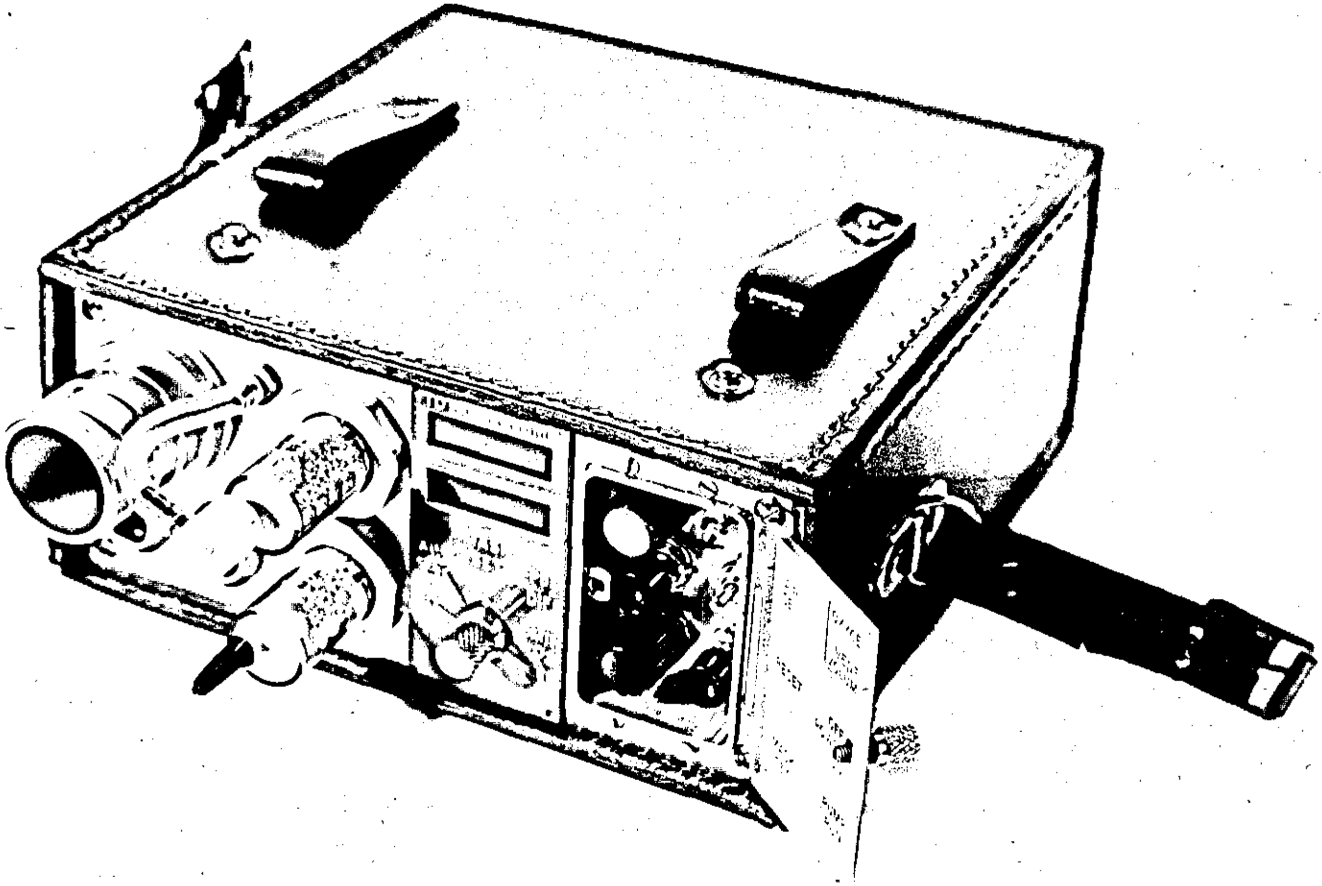


Figure 4.12 - The Oxylog portable oxygen consumption meter.

was required to wear a face mask to measure V_I and F_{E,O_2}. This was slightly intrusive, but it was considered worthwhile because of the potential advantages of this information. The two habituation periods prior to the experiment allowed adequate time for the subjects to become familiar with the face mask and no-one reported any discomfort.

A modification to the equipment allowed $\dot{V}_I$ to be recorded. This measure is related to $\dot{V}_{O_2}$ by the formula:

$$\dot{V}_{O_2} = V_I \times F_{E,O_2},$$

so it allows F_{E,O_2} to be calculated.

V_I was therefore included as it gave more detailed information about the way that the body responded to metabolic requirements. It also has the additional advantage of giving more information about the respiratory manoeuvres. To date only respiratory frequency (R_f) was being measured, but the inclusion of V_I meant that the mean volume of air per breath (V_T) could be calculated.

Figure 4.13 summarises the data recording systems for measures (a) to (e) above.

(f) Perceived exertion, (PE)

The individual differences shown in the previous experiment suggested that additional behavioural measures may be required to understand psychophysiological integration better. Perception of the situation may be involved in the response mechanism, so it was included in this experimental state. The Borg scale of perceived exertion, Borg (1962) was used. The Borg scale has not been related to mental load previously but correlates well with measures of physical load such as H_f and $\dot{V}_{O_2}$, Borg (1962), Borg (1970), Ulmer et al (1978) and Edwards et al (1972). Each subject rated his perceived exertion from the 15 point scale (Fig. 4.14) which was presented in the

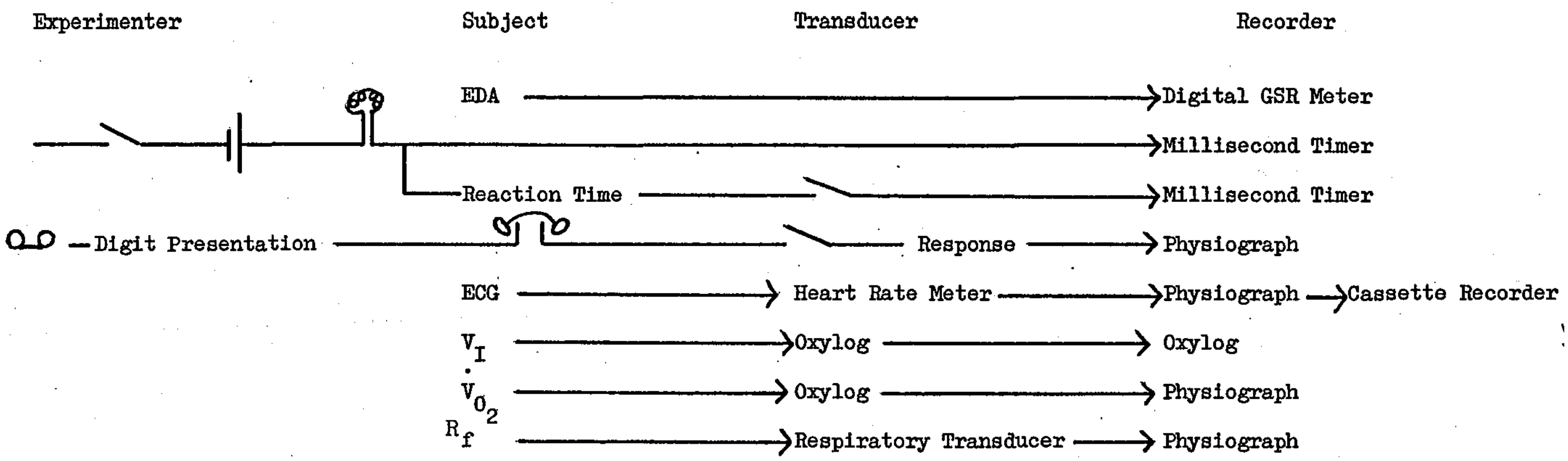


Figure 4.13. Psychophysiological data recording system

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

Figure 4.14 - Borg scale of perceived exertion

form of an A4 sized card with the numerals and legend a minimum of 8 mm in height. The timing of the rating of perceived exertion was immediately following the presentation of the digits (mental task) or the workload (physical task).

(g) Perceived feeling, (PF)

The development of any model on individual differences may require some assessment of personal feeling. The "feeling of well being" is anecdotally, reported in many situations and the measure of 'perceived feeling' was an attempt to give an empirical basis to the subjective stage. Although any such statement will be a conglomeration of contributing factors such as degree of physiological disequilibrium, psychological load, and recent experiences, it may still give an insight into another aspect of perception. Perceived exertion indicates the significance of an applied stimulus to the organism, whereas perceived feeling integrates the complex internal states of the individual and indicates the overall perception without involving a specific stimulus. It is appreciated that one channel of this internal perception of feelings could easily become pre-eminent and mask others. Such would be the case if an individual had a heavy cold or had just received a telegram containing disturbing news.

Perceived feeling (PF) was administered in the form of a short questionnaire at the end of the resting period and each recovery period. The questions were of a semantic differential nature and are shown in Appendix 4.1. The questionnaire was a modification of the Spielberger Self-Evaluation Questionnaire, Spielberger, Gorsuch and Lushene (1970), with seven positive statements and seven negative statements of personal feeling. The semantic differential scale was later reorganised so that each positive statement (good feeling) scored high and each negative statement scored low irrespective of the manner in which the question was asked in the original form. This resulted in the total score for each of the 14 statements giving a higher score if there was a good feeling and a low score if there was a poor feeling. None of the procedures normally adopted to validate the scale were implemented. However, it was felt that the inclusion of this questionnaire, although of limited scientific rigour, may produce information of value and relevance to the total psychophysiological integration.

(h) Personality

It is possible that differences in perceiving afferent stimuli will be seen as differences in personality. Eysenck in developing his personality theory proposed that,

> "Individuals in whom (CNS) excitatory potential is generated slowly and in whom excitatory potentials so generated are relatively weak, are thereby predisposed to extraverted patterns of behaviour......(as are)...... individuals in whom reactive inhibition is developed quickly, in whom strong reactive inhibitions are generated and in whom reactive inhibition is dissipated slowly......"
>
> Eysenck (1957) p.114

The association of extraversion and the ascending reticular formation, Eysenck (1963) gives a further reason for testing the relationship between psychophysiological responses and personality. An identification of personality traits was made by Cattell (1947) and used to construct the 16 personality factor index (16 PFI). The results from form C were scored using the stencil key. As the four second order factors, Q_I, Q_{II}, Q_{III} and Q_{IV} were likely to be of most interest, these were calculated by the method described in the Manual for the 16 PF (1972) pp.23-28. Second-order factors are more easily derived from sten scores so these were produced for the population in question. This was implemented because although the population was composed predominantly of students, there were also some technical staff. This meant that the pre-prepared sten scores based on student norms would not have been satisfactory. It was also considered desirable to generate sten scores for the specific population because this would improve the homogeneity of the results and thus made exceptions more evident. The procedure as described in Cattell and Eber (1957) was adopted to calculate the sten scores.

(i) Suprametabolic Index

It has been suggested, Blix et al (1974), Stromme et al (1977), that if in any situation, heart rate exceeds the value obtained at the same oxygen uptake during physical work, then the "additional heart rate" is likely to be due to some kind of psychological activation. This relationship would also give further information concerning the cardiac-somatic coupling by indicating the extent to which H_f is associated or dissociated with V_{O_2}. It was thus decided to calculate the ratio of H_f to V_{O_2} as both measures were being recorded as part of the experiment. The ratio $H_f \div V_{O_2}$ was calculated for every minute and was called the suprametabolic index.

4.2 Results and Statistical Analysis

4.2.1 Statistical design and results

The results were subjected to four types of analysis.

The first was univariate and involved an Analysis of Variance (ANOVA) to test the statistical hypothesis that there is no difference between the seven treatment conditions (basal, intensities 1-3 and recoveries 1-3) for both mental and physical tasks.

The second was multivariate and attempted to show individual differences between mental and physical work for:

(a) patterns of response,
(b) individual measures.

The third was also multivariate and employed a factor analysis design to show the 'orderly simplification', Burt (1940) of a number of interrelated measures. This involved a correlation matrix as the basis for the factor analysis so the relationship between measures was also examined.

The fourth type of analysis was specific to the heart rate variability measure and was the spectrum analysis described in section 4.1.3.

4.2.2. Analyses of variance results.

An analysis of variance program ANVAR 1 from the Time Sharing Library of the Honeywell 66 series computer in Leeds Polytechnic was used. On-line terminal facilities enabled the data to be typed in at the terminal with results of the analysis being presented back at the terminal in hard copy form almost immediately. This procedure removed the errors inherent in batch processing data but was tedious, time consuming and expensive in terms of computing time.

A typical analysis of variance result is shown in Table 4.1. The program enabled an *a posteriori* test of the significant differences between means to be undertaken. Unlike experimental stage 2 of this study which used Tukey's HSD test, the differences between means were examined to see if they exceeded the confidence interval at a pre-selected significance level. The program enabled the experimenter to set the level of significance at will and thus it was possible to report the highest level of significance that the difference exceeded between each pair of means.

This procedure which involved 40 ANOVAs with up to 21 *a posteriori* tests of differences between means for each ANOVA is shown in Tables 4.2 and 4.3. Column 1 gives the measure involved, columns 2-8 give the mean values, column 9 gives the level of significance of the 'F' ratio and columns 10-30 give the levels of significance of the differences between means.

Table 4.1 - Typical ANOVA results using Honeywell Statistics Package ANVAR 1.

Group 1 = Basal
Group 2 = Mental Intensity 1
Group 3 = Mental Intensity 2
Group 4 = Mental Intensity 3
Group 5 = Mental Recovery 1
Group 6 = Mental Recovery 2
Group 7 = Mental Recovery 3

EDA SOURCE	DF	SS	MS	F RATIO	P
BETWEEN GROUPS	6	1.1078346E 05	1.8463909E 04	1.5662643E 00	N.S.
RESIDUAL	161	1.8979488E 06	1.1788502E 04		
TOTAL	167	2.0087323E 06			

OVERALL MEAN = 2.0671428E 02

CONFIDENCE LEVEL FOR MEANS
= .95

GROUP	MEAN	SD	CONFIDENCE
1	0.22220833E 03	0.10687258E 03	0.43647805E 02
2	0.16391667E 03	0.81279824E 02	0.43647805E 02
3	0.18125000E 03	0.86726222E 02	0.43647805E 02
4	0.20462500E 03	0.13709085E 03	0.43647805E 02
5	0.20629167E 03	0.94657487E 02	0.43647805E 02
6	0.22087500E 03	0.99617733E 02	0.43647805E 02
7	0.24783333E 03	0.12591256E 03	0.43647805E 02

Difference exceeds .95 Confidence Interval in groups 2 :7
and 3 : 7

Table 4.2 - ANOVA and significant differences between means for basal, mental intensities and recoveries.

	Basal	Int. 1	Int. 2	Int. 3	Rec. 1	Rec. 2	Rec. 3	Level of Signif. of 'F' Value	Bas: I_1	Bas: I_2	Bas: I_3	Bas: R_1	Bas: R_2	Bas: R_3	I_1 : I_2	I_1 : I_3	I_1 : R_1	I_1 : R_2	I_1 : R_3	I_2 : I_3	I_2 : R_1	I_2 : R_2	I_2 : R_3	I_3 : R_1	I_3 : R_2	I_3 : R_3	R_1 : R_2	R_1 : R_3	R_2 : R_3
Measure			Mean Values						Differences between means exceed stated confidence interval																				
EDA	222	163	181	204	206	220	247	NS											.95				.95						
HEART RATE	68	69	70	68	67	67	65	NS																					
OXYGEN UPTAKE	.24	.26	.25	.25	.23	.23	.23	.05									.95	.95	.95			.90	.95			.95			
RESP. FREQUENCY	14	15	16	17	14	13	13	.01			.95							.95	.95			.95	.95	.95	.95	.95			
S.M. INDEX	2.9	2.7	2.7	2.7	2.9	2.9	2.9	NS																					
REACTION TIME	249	459	454	458	258	278	256	.01	.95	.95	.95						.95	.95	.95		.95	.95	.95	.95	.95	.95			
PERC. EXERTION		10.4	11.7	14.6				.01							.95	.95				.95									
PERC. FEELING	90				82	76	72	.01					.95	.95														.95	
ERROR		5.5	6.4	12.0				.01								.99				.99									
INSPIRED VOLUME	7.1	7.5	7.6	7.6	6.6	7.1	7.1	NS																					
HI. MEAN	854	845	846	854	867	871	883	NS																					
HI. STAN. DEV	72	64	71	77	76	90	102	.1						.95					.95				.95						
HRV MAX BEATS	65	62	63	63	68	66	64	NS																					
HRV MIN BEATS	52	61	60	64	57	58	57	NS																					
HRV REVERSALS	118	123	124	128	125	125	121	NS																					
HRV SABS	.13	.12	.12	.13	.13	.14	.15	NS																					
HRV RATIO	119	99	98	105	102	115	129	NS																					
HRV FIRST DIFF	51	49	48	52	50	57	60	NS																					
HRV SECOND DIFF	44	39	39	43	89	88	90	.01					.95	.95	.95		.99	.99	.99			.99	.99	.95	.95	.95			
HRV SUCC DIFF^2	.19	.13	.17	.20	.16	.21	.24	NS																					
1	2	3	4	4	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Table 4.3 - ANOVA and significant differences between basal physical intensities and recoveries.

Measure	Basal	Int. 1	Int. 2	Int. 3	Rec. 1	Rec. 2	Rec. 3	Signif. of 'F' Value	Bas : I_1	Bas : I_2	Bas : I_3	Bas : R_1	Bas : R_2	Bas : R_3	I_1 : I_2	I_1 : I_3	I_1 : R_1	I_1 : R_2	I_1 : R_3	I_2 : I_3	I_2 : R_1	I_2 : R_2	I_2 : R_3	I_3 : R_1	I_3 : R_2	I_3 : R_3	R_1 : R_2	R_1 : R_3	R_2 : R_3
			Mean Values						Differences between means exceed stated confidence intervals																				
EDA	175	114	98	92	150	143	129	.1	.95	.95	.95													.95					
S.M. INDEX	3.2	1.2	0.9	0.7	2.3	2.1	1.8	.01	.99	.99	.99	.99	.99	.99			.99	.99	.99		.99		.99	.99	.99	.99			
HEART RATE	73	98	117	137	75	78	87	.01	.99	.99	.99			.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99		.99	.99
OXYGEN UPTAKE	.25	.86	1.36	1.91	.34	.37	4.7	.01	.99	.99	.99			.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99			
RESP. FREQUENCY	13	17	19	22	14	15	15	.01	.99	.99	.99					.99	.99				.99	.99	.99	.99	.99	.99			
REACTION TIME	241	333	329	332	224	245	232	.01	.99	.99	.99						.99	.99	.99		.99	.99	.99	.99	.99	.99			
PERC. EXERTION		8.9	11.7	13.6				.01							.99	.99				.99									
PERC. FEELING	86				79	79	76	.25						.95															
INSPIRED VOLUME	8.6	22.3	9.2	33.7	9.6	47.3	11.6	.01	.99	.99	.99				.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99			
HI. MEAN	794	603	510	431	776	738	658	.01	.99	.99	.99			.99		.99	.99	.99			.99	.99	.99	.99	.99	.99		.99	
HI. STAN. DEV	70	26	25	25	66	53	55	.01	.99	.99	.99						.99	.99	.99		.99	.99	.99	.99	.99	.99			
HRV MAX BEATS	69	64	40	35	63	63	66	.01		.99	.99				.99	.99			.99		.99	.99	.99		.99	.99			
HRV MIN BEATS	47	47	59	67	52	50	47	.01			.99					.99								.99	.99	.99			
HRV REVERSALS	118	111	100	97	115	114	113	.01		.99	.99					.99					.99	.99	.99	.99	.99	.99			
HRV SABS	.91	.30	.28	.16	.81	.67	.56	.01	.99	.99	.99	.99					.99				.99			.99	.99				
HRV RATIO	77	26	27	16	69	57	48	.01	.99	.99	.99						.99				.99			.99	.95				
HRV FIRST DIFF.	35	11	10	6.0	31	26	21	.01	.99	.99	.99						.99				.99			.99	.99				
HRV SECOND DIFF.	29	11	12	.5	38	35	23	.01			.99						.99	.99			.99			.99	.99				
HRV SUCC DIFF^2	.89	.20	.19	.10	.82	.54	.50	.05	.95	.95	.95						.95				.95			.95					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

(a) Mental Intensities

Perceived exertion was the only psychophysiological measure to show a significant, monotonic difference between the 3 mental intensities (Figure 4.15). This demonstrated that in terms of general, subjective, bodily feeling, the mental tasks were perceived as progressive increments. This was expected from the structure of the experiment and a different result would have questioned whether the stimulus intensities were suitable.

The autonomic measures did not demonstrate sufficient sensitivity to distinguish the three levels of intensity. The reasons for this may have been the complex interaction of the various arousal subsystems. The resultant effect of interaction between a variety of changing measures was a regression towards the mean. A change was observed, but the sensitivity of each individual measure making up the overall change was reduced.

An alternative explanation is that a finite autonomic change occurs irrespective of the stimulus intensity. This "all-or-none" interpretation may be speculative, but is replicated by 17 measures from 5 different autonomic channels. The whole response system appears to "switch on" once arousal reaches a specific level, and then shows only limited, non-significant, variation. This occurs below the lowest mental intensity chosen for the study. The inclusion of a rating of perceived exertion makes it possible to state that:

"within the limitations of the experiment, mental tasks perceived on the Borg scale above a score of 10 cause similar autonomic responses".

Column 9 on table 4.2 shows that only the measures of Oxygen Uptake, Respiratory Frequency, Reaction Time and HRV Second Differential show significant differences between the mental work and the basal or recovery levels. Respiratory Frequency alone shows a difference between the basal levels and

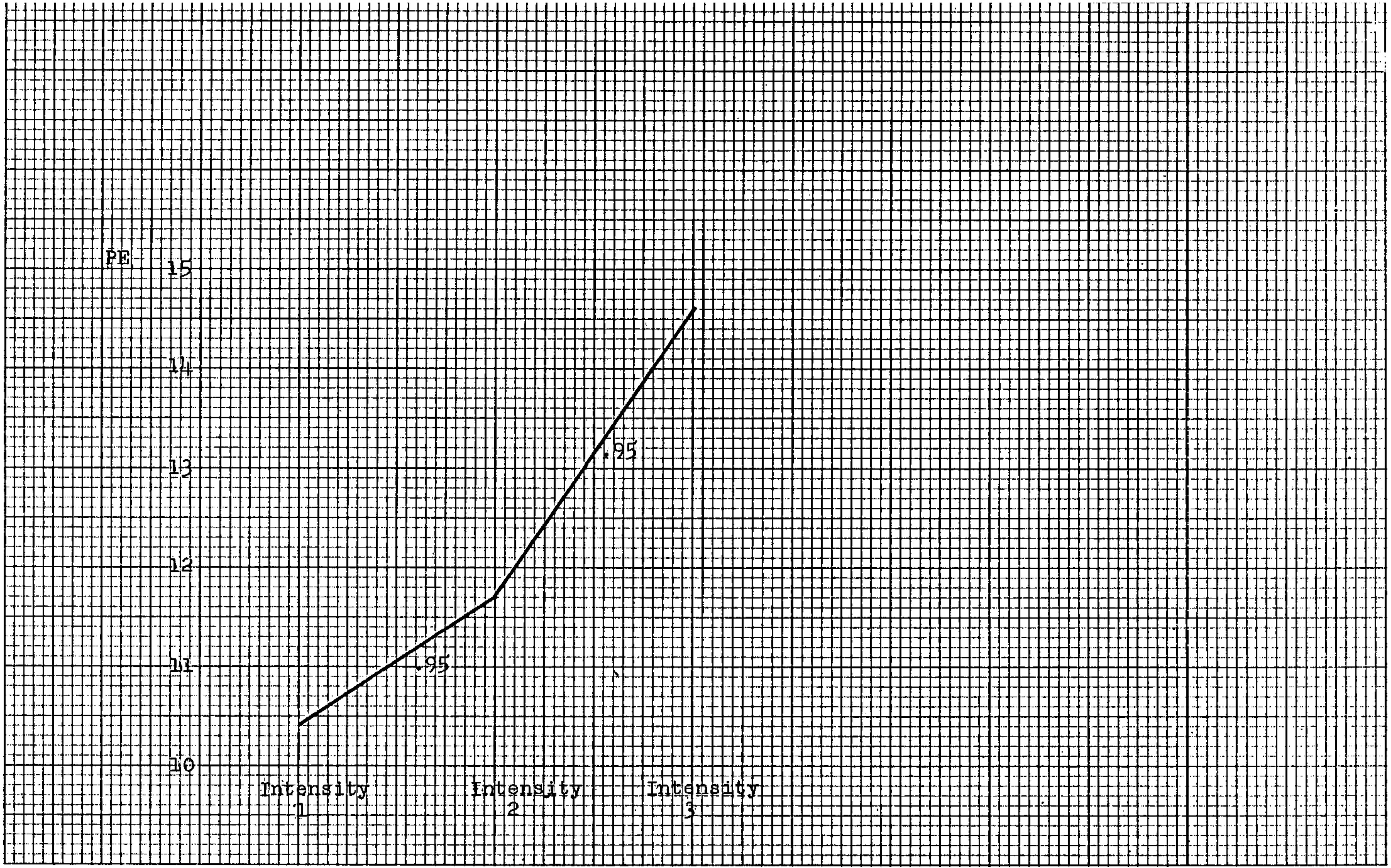


Figure 4.15 - The significant differences between intensities of mental load for the measure of perceived exertion.

the mental work. The other differences (see Fig. 4.16) only occur during the recovery period.

The reason that oxygen uptake and HRV second differential did not show differences between basal and mental intensity levels is not clear, but the results suggest that the anticipation of the task was having an arousing effect. This caused the basal levels to produce a slight autonomic response and, with the exception of respiratory frequency, showed no distinction from the mental intensity. The results question the validity of EDA and Heart Rate as sensitive measures of mental load and yet point to the usefulness of measures hitherto considered very little.

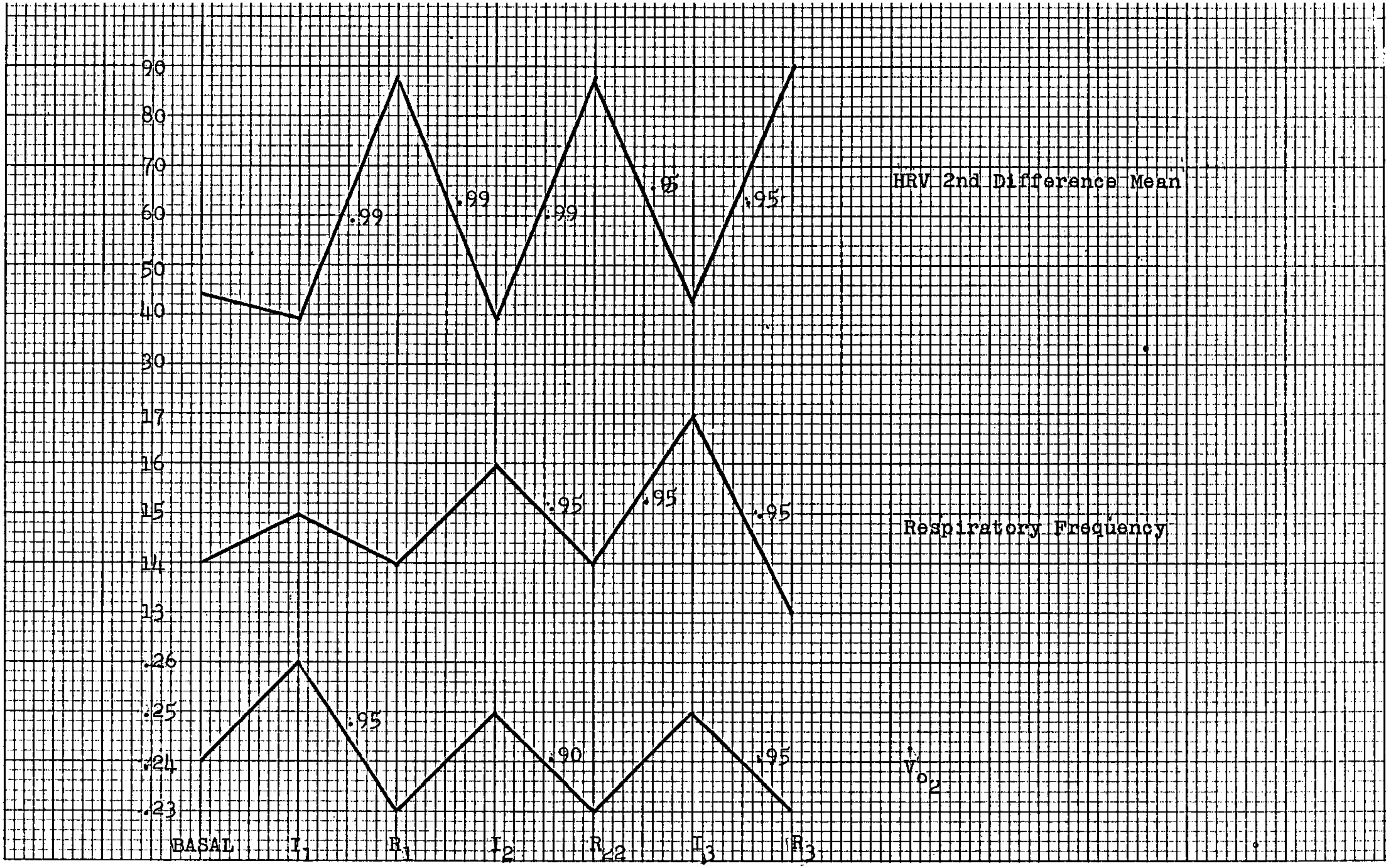


Figure 4.16 - Measures showing significant differences between mental loads and recoveries.

(b) Physical Intensities

Table 4.3 shows different results from the mental intensities, with many measures exceeding the 0.99 level of significance between means. This would be expected as the psychophysiological measures are likely to respond to changes of 30%, 50% and 70% of each subject's V_{O_2} max.

Electrodermal activity showed significant differences between basal levels and physical intensity levels but did not drop sufficiently during the 10 minute recovery period to show mean differences. This was probably caused by slow dissipation of the response in combination with some interference from the thermoregulatory mechanisms. The production of sweat for the purpose of heat control may have maintained the high electrodermal levels. The results suggest that EDA should be used cautiously, particularly during recovery after exercise.

The requirements of a measure to show valid responses to increasing physical intensities involve:-

1. a significant difference between basal and intensity levels.
2. a significant difference between the three intensity levels.
3. a significant difference between intensity and recovery levels.
4. no further significant differences.

These requirements are rigorous and for physical intensity levels which are only varying by 20% of V_{O_2} max, the measure would have to show a combination of sensitivity and stability.

The measures of heart rate (H_f), oxygen consumption (V_{O_2})and inspired volume (V_I) do combine sensitivity and stability related directly to metabolic changes. The measures related to respiration and heart rate variability do not discriminate between physical intensity levels. This indicates the interdependence of HRV measures from mean heart rate. The increase in heart rate may cause such a reduction in heart rate variability at the lowest physical intensity, that any further increase in physical intensity has no effect. This illustrates the specificity of HRV as a measure. It is sensitive to mental load without a commensurate increase in heart rate, but an increase in heart rate due to metabolic demand causes no change. The importance of this observation in terms of human responses is that two independent arousal systems are operating which have a close physiological relationship.

4.2.3 Individual differences between mental and physical work

Several methods were used to examine the individual differences between mental and physical work but they all produced qualitative results. It was thus necessary to develop a procedure which gave quantitative results but accounted for the range of results inherent in a variety of measures. In consultation with Dr. Petit of the Department of Mathematics, University of Loughborough, the following procedures were adopted.

(a) Patterns of response.

The responses for each intensity level were rank ordered for each subject. The same applied for each recovery level and for the (intensity-recovery) levels to show changes in responses. Appendix 4.2 gives an example of one of the measures, EDA.

To establish the 'normal' pattern of response a modal ranking for each measure was established.

Rankings were denoted			
	123	by	A
	132		B
	213		C
	231		D
	312		E
	321		F

For ties, 1 2= 2= was denoted by ½A, ½B

Thus Mental Intensity for EDA was:

	A	B	C	D	E	F
	111½11 111½	1111 1111	½1½	1	1½	11½
Total =	9	8	2	1	1½	2½

Therefore normal is either A or B, with A being the modal ranking.

Each subject is then rated as to whether he is similar or dissimilar from the modal ranking, over the 5 measures of EDA, H_f, $\dot{V}_{O2}$, R_f, and SRT.

Thus Mental Intensity Ranking from the 5 measures, with 1 if similar and 0 if dissimilar, produces the following table, Table 4.4.

Table 4.4 - Similarity/Dissimilarity ratings produced from modal rankings for 5 measures from mental intensities.

Subject	EDA	H_f	$\dot{V}_{O_2}$	R_f	SRT
GRIF	1	0	1	1	0
MUN	1	1	1	0	0
FIR	0	1	0	0	0
PYE	1	0	0	0	1
PIL	0	1	0	1	0
WOOD	0	1	0	0	1
DAN	0	0	0	0	0
STAD	1	1	0	0	0
ZAY	1	1	1	0	0
GREG	0	0	1	0	0
FEN	0	0	0	0	0
BUT	0	0	0	0	0
CLEM	0	0	1	1	0
PORT	1	0	0	1	1
EAST	0	0	0	0	0
BROD	0	1	1	1	0
COOK	1	0	1	1	1
PHEL	0	1	0	0	1
PRIC	0	1	0	1	1
TOML	0	1	0	1	0
DAVI	0	0	1	1	0
TOMA	1	0	1	1	1
JONE	0	1	0	0	1
WORR	1	1	1	0	1
NORMAL	1	1	1	1	1

So MUN = ZAY

DAN = FEN = BUT

PIL = TOML , etc.

A dissimilarity matrix was then constructed which consisted of the number of different elements between each pair of subjects. So that GRIF and MUN would have, from Table 4.4, 2 different elements (H_f and R_f).

If the elements for GRIF are (Z_1, Z_2...... Z_5), those for MUN are (Y_1, Y_2.......Y_5), then

$$\text{diss (GRIF, MUN)} = \sum_{i=1}^{5} (Z_i - Y_i)$$

The matrix for mental recoveries is as in table 4.5.

The dissimilarity matrices can be interpreted in the form of a crude cluster analysis. These would show the similarities between subjects for the way in which they respond (patterns) to different intensities of task. Although this would give a sound visual interpretation of similarities, it was considered that a statistical basis to the similarities would be preferable. Thus the sum of all the differences between all subjects was calculated and this was designated a "dissimilarity score". The dissimilarity score was therefore a global measure of the extent one individual differed from another individual in response pattern. A correlation matrix, Figure 4.17, was produced to show the relationships between the 6 different conditions:

mental intensity
mental recovery
mental (intensity - recovery)
physical intensity
physical recovery
physical (intensity - recovery)

Table 4.5 - Dissimilarity matrix for mental recoveries.

	GRIF	MUN	FIR	PYE	PIL	WOOD	DAN	STAD	ZAY	GREG	FEN	BUT	CLEM	PORT	EAST	BROD	COOK	PHEL	PRIC	TOML	DAVI	TOMA	JONE	WORR	NORM.
GRIF	-																								
MUN	2	-																							
FIR	1	1	-																						
PYE	2	0	1	-																					
PIL	2	2	1	2	-																				
WOOD	4	2	3	2	1	-																			
DAN	3	1	2	1	1	3	-																		
STAD	3	1	2	1	1	3	0	-																	
ZAY	2	2	1	2	2	2	3	3	-																
GREG	5	3	3	3	3	1	2	2	3	-															
FEN	4	4	3	4	2	2	3	3	2	1	-														
BUT	3	3	4	3	5	1	4	4	3	2	3	-													
CLEM	3	1	2	2	2	3	0	0	3	2	2	4	-												
PORT	1	1	2	1	3	3	2	2	2	3	5	2	2	-											
EAST	2	2	3	2	2	4	1	1	4	3	4	3	1	1	-										
BROD	3	3	4	3	3	3	2	2	3	2	3	2	2	2	1	-									
COOK	2	2	3	2	4	2	3	3	4	3	4	1	3	1	2	3	-								
PHEL	2	0	1	0	2	2	1	1	2	3	4	3	1	1	2	3	2	-							
PRIC	3	3	4	3	5	1	4	4	4	2	3	0	4	2	3	2	1	3	-						
TOML	5	3	4	3	3	1	2	2	4	0	1	2	2	4	4	2	3	3	2	-					
DAVI	2	2	3	2	4	2	3	3	3	2	4	1	3	1	2	2	2	2	1	3	-				
TOMA	3	1	3	2	3	1	2	2	3	2	3	2	2	2	3	4	1	1	2	2	3	-			
JONE	4	2	3	2	4	0	3	3	2	1	2	1	3	3	4	3	2	2	1	1	2	1	-		
WORR	2	0	1	0	2	2	1	3	2	3	4	3	1	1	2	3	2	0	3	3	2	1	2	-	
NORMAL	1	3	3	3	1	5	2	2	3	4	3	4	2	2	2	2	3	3	4	4	3	4	5	3	-
$\Sigma =$	63	41	55	43	59	48	47	49	61	54	70	59	48	47	56	60	55	41	60	59	54	49	51	43	71

	Mental Intensity	Mental Recovery	Mental (Intensity -Recovery)	Physical Intensity	Physical Recovery	Physical (Intensity -Recovery)
Mental Intensity	1					
Mental Recovery	-.23	1				
Mental (Intensity - Recovery)	.31	.11	1			
Physical Intensity	.17	-.03	.19	1		
Physical Recovery	-.07	-.09	.03	.14	1	
Physical (Intensity -Recovery)	-.03	-.17	-.15	.44*	.42*	1

* $p < .05$

Figure 4.17 - Correlation matrix of dissimilarity scores.

It can be seen from the above figure that the overall response patterns between the 6 conditions showed only a poor relationship ($p < .05$) between two of the measures. This indicates that groupings of individuals vary between the 6 conditions. Individuals who respond with a particular pattern to mental intensity or mental recovery do not replicate this pattern during physical intensity or recovery. This clearly suggests that stability of response pattern does not occur for different types of stimuli.

(b) Individual measures

For a given subject and measure let:

D_{MI} = average over the 3 mental intensities

D_{PI} = average over the 3 physical intensities

D_{MR} = average over the 3 mental recoveries

D_{PR} = average over the 3 physical recoveries

$\bar{D}_M$ = D_{MI} - basal level for mental

$\bar{D}_P$ = D_{PI} - basal level for physical

These were analysed by a product moment correlation using the time sharing library program ANVAR 1 of the Leeds Polytechnic Honeywell 66 series computer.

The correlation between D_{MI} and D_{PI} will give the association between the level of response to physical and mental stimuli. A significant correlation will suggest that high responders to mental stimuli also respond highly to physical activity.

Similarly the correlation between D_{MR} and D_{PR} will show the association between the recoveries from the mental and physical stimuli. The correlation between $\bar{D}_M$ and $\bar{D}_P$ will show the association between the change in the measure for mental and physical stimuli.

The correlation matrices for each measure have been placed in Appendix 4.5. Figure 4.18 summarises the relevant results, and shows the correlations between the mental and physical tasks for the intensity condition, the recovery condition and the change from the baseline condition. Figure 4.18 shows that certain autonomic responses are similar irrespective of the situation, whereas other autonomic measures show poor response consistency.

	Mental/Physical Intensities	Mental/Physical Recoveries	Mental/Physical Change from Baseline
EDA	.82***	.82***	.32
H_f	.23	.41*	-.08
$\dot{V}O_2$	.42*	.38	-.06
R_f	.58**	.78***	.54**
SRT	.37	.54**	-.10

*** $p<.001$ **$p<.01$ * $p<.05$

Figure 4.18 - Correlations and p values between mental and physical responses for different measures.

The measures most clearly associated with response consistency are those of respiratory frequency and EDA, whereas heart rate and oxygen uptake give a maximum 'r' value which corresponds to only 16% of the variance. The response variables showing greatest consistency are those commonly associated with emotional response, whereas the least consistent reflect metabolic involvement. This suggests a division of response chaannels into two; the autonomic responses normally governed by psychological aspects, and those involved in metabolism.

This gives the opportunity for an extension of Lacey's autonomic response specificity principle, Lacey (1950). In its original form it stated

> "for a given set of autonomic functions, individuals tend to respond with a pattern of autonomic activation in which maximum activation will be shown by the same physiological function, whatever the stress".

The extension of this principle is that

> "when the (stress) situations are sufficiently distinct as to vary from mental to physical tasks, maximum consistency of autonomic response is seen to graduate from those responses normally associated with mental stimuli to those responses normally associated with physical stimuli."

Responses such as heart rate and oxygen uptake were unable to maintain their level of activation across such disparate stimulus situations as mental and physical work. This was most probably associated with the metabolic demands of the physical stimulus. When physical activity is used as the stimulus situation (e.g. Davey 1973), the demand of the activity upon the organism's metabolic resources is large and response consistency cannot be maintained.

4.2.4 Factor analysis results

The potential number of measurements to be included in the analysis would be:

6 dissimilarity scores;

4 second order personality scores (16 PF);

EDA, H_f, $\dot{V}_{O_2}$, R_f, SRT, V_I

for the conditions of basal, intensities and recoveries for both mental and physical treatments;

Perceived exertion and perceived feeling scores for mental and physical treatments;

Error score for mental treatments;

Measurement of fitness;

9 measurements of heart rate variability by sampling statistics for the conditions of basal, intensities and recoveries for both mental and physical treatments.

This totals 105 measurements which would not only involve an unweildy analysis but be of limited analytical value.

The measures were thus divided into groups so that interactions between relevant variables could be studied. The object was to reduce the size of the statement needed to describe any integration between the measures. Accordingly the multivariate procedure of factor analysis was appropriate and the groups selected were based on the natural divisions of the experiment. These were:

Mental Basal
Mental Intensity
Mental Recovery
Physical Basal
Physical Intensity
Physical Recovery

These were subdivided into two factor analyses, each one containing slightly different measures. In general the first factor analysis of each pair included the heart rate variability measures, whereas the second run excluded them. It was decided to exclude these HRV measures in the second run because they were all calculated from the same raw data (R-R intervals) and could potentially weight the factors.

In addition to these, one further factor analysis was examined which took a wider selection of measures than those related to the specific divisions of the experiment. This was called an "overall" factor analysis.

The factor analyses examined and the measures included in each one are shown in Table 4.6.

In all cases the direct method used was the principal components analysis. The criterion for deciding on the number of factors to be extracted was Kaiser's criterion with all factors with an eigen value exceeding unity being retained. Although this criterion may extract a conservative number of factors if the number of variables is less than 20, this was considered acceptable as Kaiser's criterion is "particularly useful for principal components design", Child (1970).

The criterion for choosing the significant loadings in each factor was not the arbitrary figure of 0.3 as often considered acceptable but a more stringent criterion by applying the Burt-Banks formula, Burt and Banks (1947).

The rotation method adopted was the Varimax method.

The program employed was the FACTAN program from the Time Sharing Library on the Leeds Polytechnic Honeywell 66 series computer.

Table 4.6 - Measures included in the factor analysis.

Measures	Physical Basal 1	Physical Basal 2	Mental Basal 1	Mental Basal 2	Physical Intensity 1	Physical Intensity 2	Physical Recovery 1	Physical Recovery 2	Mental Intensity 1	Mental Intensity 2	Mental Recovery 1	Mental Recovery 2	Overall
Q_I	X	X	X	X	X	X	X	X	X	X	X	X	X
Q_{II}	X	X	X	X	X	X	X	X	X	X	X	X	X
Q_{III}	X	X	X	X	X	X	X	X	X	X	X	X	X
Q_{IV}	X	X	X	X	X	X	X	X	X	X	X	X	X
Dissimilarity					X	X	X	X	X	X	X	X	
EDA	X	X	X	X	X	X	X	X	X	X	X	X	
H_f	X	X	X	X	X	X	X	X	X	X	X	X	
$\dot{V}O_2$	X	X	X	X	X	X	X	X	X	X	X	X	
R_f	X	X	X	X	X	X	X	X	X	X	X	X	
SRT	X	X	X	X	X	X	X	X	X	X	X	X	
Perceived Exertion					X	X			X	X			
H.Interval Stand. Dev.	X		X		X		X		X		X		
HRV Reversals	X		X		X		X		X		X		
HRV SABS	X		X		X		X		X		X		
HRV 2nd Difference	X		X		X		X		X		X		
Perceived Feeling	X	X	X	X	X		X				X		
Error Score									X	X			
Fitness													X
All Dissimilarity Scores													X
EDA Intensities Mental													X
H_f Intensities Mental													X
$\dot{V}O_2$ Intensities Mental													X
R_f Intensities Mental													X
SRT Intensities Mental													X
EDA Intensities Physical													X
H_f Intensities Physical													X
$\dot{V}O_2$ Intensities Physical													X
R_f Intensities Physical													X
SRT Intensities Physical													X

Appendices 4.3 and 4.4 give a specimen factor analysis with details of the correlation coefficients, the common factor loadings from the principal components matrix and the rotated factor loadings from the varimax analysis. In summarising the 13 factor analyses produced, only those factor loadings which exceeded the 1% significance level have been included. On this basis, the following tables, 4.7 - 4.13 summarise the statements which can be made about the factor analyses.

In assigning a name to factors it is appropriate to distinguish between those factors which have positive and negative loadings and those which do not. The former are called 'bipolar' factors because the factor embodies contrasting groups of variables. In cases such as this the factor name includes a slash (/) to designate the bipolar configuration.

Table 4.7 - Summary of factor statements for physical basal conditions.

Analysis Name	Factor No.	% Variance	Factor Name	Measures with signif. loadings 1%	Loadings
Physical Basal 1	I	43.6	Cardiac-Cortical/metabolic-perception	HR	-.95
				SRT	-.94
				HRV 2nd Diff	.92
				Perceived Feeling	.89
				V_{O_2}	.88
	II	17.8	Variability - anxiety	H. Int. S.D.	.93
				Q_{II}	.84
	III	14.8	Variability - arousal	HRV SABS	.97
				EDA	.80
	IV	9.6	Respiration	Resp. frequency	.93
	V	7.2	Tough poise	Q_{III}	.87
Physical Basal 2	I	24.9	Anxiety/Independence cardiac	Q_{II}	-.80
				Q_{IV}	.78
				HR	-.54
	II	16.6	Cortical-arousal	Reaction time	.70
				Resp. frequency	.65
				EDA	.58
	III	12.3	Extraversion tough poise	Q_{III}	.78
				Q_{I}	.69

Table 4.8 - Summary of factor statements for mental basal conditions.

Analysis name	Factor No.	% Variance	Factor Name	Measures with signif. loadings above 1%	Loadings
Mental Basal 1	I	30.6	Cardiac	HRV 2nd Difference	.91
				HRV SABS	.91
				H.Interval S.D.	.91
				HR	-.82
	II	15.8	Cortical-Respiration-Extraversion	SRT	.85
				Resp. frequency	.79
				Q_I	.76
	III	12.9	Arousal/ Anxiety	Perceived feeling	.91
				EDA	.70
				Q_{II}	-.67
	IV	11.0	Reversals	HRV Reversals	.95
	V	8.8	Independence	Q_{IV}	.86
	VI	7.1	Metabolic	V_{O_2}	.92

Analysis name	Factor No.	% Variance	Factor Name	Measures with signif. loadings above 1%	Loadings
Mental Basal 2	I	23.2	Cortical-metabolic-extraversion	SRT	.74
				V_{O_2}	.64
				Q_I	.61
				Resp. frequency	.59
	II	20.2	Anxiety/ Independence	Q_{II}	-.82
				Q_{IV}	.80
	III	15.6	Tough poise - cardiac	Q_{III}	.73
				HR	.72

Table 4.9 - Summary of factor statements for physical intensity conditions.

Analysis Name	Factor No.	% Variance	Factor name	Measures with signif. loadings 1%	Loadings
Physical Intensity 1	I	26.7	Cardiac variability - metabolic	HRV, SABS	.97
				HRV, 2nd Diff.	.97
				Heart Interval, . S. Dev.	.81
				$\dot{V}_{O_2}$	.69
	II	15.1	Reversals	HRV, Reversals	.93
	III	13.4	Physiological	Resp. frequency	.90
				Heart rate	.69
	IV	12.2	Anxiety	Q_{II}	.85
	V	10.6	Extraversion/ Perception	Q_{I}	-.89
				Perceived Exertion	.79
	VI	7.3	Independence	Q_{IV}	.91
Physical Intensity 2	I	20.3	Bodily load	SRT	.95
				Perceived Exertion	-.87
				$\dot{V}_{O_2}$	-.60
	II	18.8	Anxiety/ Independence	Q_{II}	-.88
				Q_{IV}	.78
	III	15.6	Physiological	Heart rate	.85
				Resp. frequency	.77
	IV	13.5	Isolate/ Arousal	Dissimilarity	.85
				EDA	-.70
	V	9.6	Extraversion-tough poise	Q_{III}	83
				Q_{I}	71

Table 4.10 - Summary of factor statements for physical recovery conditions.

Analysis Name	Factor No.	% Variance	Factor Name	Measures with signif. loadings 1%	Loadings
Physical Recovery 1	I	33.4	Cardiovascular -independence	Heart rate	-.90
				Q_{IV}	.89
				HRV Reversals	.86
	II	21.1	Similarity-Perception-Arousal	Perceived feeling	.85
				Dissimilarity	-.83
				EDA	.77
	III	10.7	Tough poise	Q_{III}	.90
	IV	10.1	Respiratory frequency	Resp. frequency	.93
	V	8.6	Anxiety	Q_{II}	.97
	VI	8.2	R.T./oxygen consumption	SRT	-.94
				$\dot{V}O_2$	.83
Physical Recovery 2	I	26.5	Anxiety/ Independence - metabolic	Q_{IV}	.82
				Q_{II}	-.80
				$\dot{V}O_2$	.77
	II	15.6	Arousal- tough poise - similarity	EDA	.78
				Q_{III}	.74
				Dissimilarity	-.65
	III	13.5	Extraversion/ RT	Q_I	.78
				SRT	-.72
	IV	11.3	Heart rate	Heart rate	.88
	V	10.2	Resp. frequency	Resp. frequency	-.92

Table 4.11 - Summary of factor statements for mental intensity conditions.

Analysis Name	Factor No.	% Variance	Factor Name	Measures with signif. loadings 1%	Loadings
Mental Intensity 1	I	31.3	Cardiac	HRV SABS	.95
				HRV 2nd Difference	.95
				H. Interval S.D.	.93
				Heart Rate	-.71
	II	17.8	Isolate/ Performance	Dissimilarity	.83
				Error	-.81
	III	11.0	Cortical/ Metabolic	SRT	-.84
				Q_{II}	-.79
				V_{O_2}	.75
	IV	8.3	Extraversion/ Perception	Q_{I}	.87
				Perceived exertion	-.76
	V	5.1	Cardio-respiratory	HRV Reversals	.92
Mental Intensity 2	I	21.3	Physiological perception	Heart rate	-.77
				Perceived exertion	-.69
				EDA	.57
	II	16.2	Isolate/ Performance	Error	-.86
				Dissimilarity	.78
	III	13.9	Metabolic	$\dot{V}_{O_2}$	-.75
				Resp. frequency	.66
	IV	11.7	Tough poise	Q_{III}	-.90
	V	9.5	Independence	Q_{IV}	-.90

Table 4.12 - Summary of factor statements for mental recovery conditions

Analysis Name	Factor No.	% Variance	Factor Name	Measures with signif. loadings 1%	Loadings
Mental Recovery 1	I	27.6	Cardiac	HRV 2nd Diff.	.98
				H. Int. S.D.	.98
				HRV SABS	.93
	II	19.1	Arousal	EDA	-.86
				Q_I	.77
				Q_{III}	.71
	III	17.2	Anxiety/ metabolic	H.R.	-.80
				Q_{II}	-.78
				V_{O_2}	.68
	IV	13.5	Respiration-Perception	Resp. frequency	-.91
				Perceived feeling	-.76
	V	7.9	Isolate	Dissimilarity	.92

Analysis Name	Factor No.	% Variance	Factor Name	Measures with signif. loadings 1%	Loadings
Mental Recovery 2	I	23.0	Independence-Anxiety	Q_{IV}	.86
				Q_{II}	-.69
	II	19.2	Extravert-isolate	Dissimilarity	-.76
				Q_I	.73
				V_{O_2}	.72
				Q_{III}	.62
	III	14.9	Reaction - respiration	SRT	.79
				Resp. frequency	.68
	IV	11.6	Arousal	EDA	.88
				HR	-.63

Table 4.13 - Summary of factor statements for overall conditions

Analysis Name	Factor No.	% Variance	Factor Name	Measures with signif. loadings 1%	Loadings
Overall	I	17.2	Anxiety/ Independence	Q_{IV}	-.85
				Q_{II}	.78
	II	14.0	Isolate Physical Recovery	Dissimilarity-Physical Recovery	-.77
				Dissimilarity-Physical (I-R)	-.57
	III	11.7	Respiration	Resp. Mental Intensity	.91
				Resp. Physical Intensity	.72
	IV	9.9	Personality-metabolic	Dissimilarity Mental Recov.	.72
				Q_{III}	-.69
				Q_{I}	-.58
				VO_2 Mental Intensity	-.63
	V	8.2		EDA Mental	.93
				Heart Rate Physical	.60
	VI	7.6		Reaction Time Physical	.86
				VO_2 Physical	-.75
				Dissimilarity Mental Intensity	-.69
	VII	6.0		Dissimilarity Physical Intensity	-.82
				Heart Rate Mental	-.66
	VIII	4.8	Isolate Mental Change	Dissimilarity Mental (I-R)	.88

One of the most important aspects of the factor analysis was the manner in which the measures form the same or different factors under the changing experimental stages. This was best established by summarising Tables 4.7 - 4.13 in the form of Figures 4.19 and 4.20. These figures show the variables which load significantly on each factor and in brackets the percentage of the total variance.

As this study is concerned with the human responses to mental and physical work, the model presented as Figure 4.21 focusses on the manner in which the measures either remain stable (stabiles) or change (labiles) during work. The stabiles will have retained the same relationship before, during and after the work period. The labiles will have been independent before the work task, have become integrated during the work and lose their integration during the recovery.

	Basal	Work	Recovery
Physical	H_f, SRT, HRV 2nd Diff, Perceived feeling, $\dot{V}_{O_2}$ (43.6) H. Int. S.D., Q_{II} (17.8) HRV SABS, EDA (14.8) Resp. frequency (9.6) Q_{III} (7.2)	HRV SABS, HRV 2nd Diff, H.Int. S.D., $\dot{V}_{O_2}$ (26.7) HRV Reversals (15.1) Resp. f. HR (13.4) Q_{II} (12.2) Q_I, Perc. Ex. (10.6) Q_{IV} (7.3)	H_f, Q_{IV}, HRV Reversals (33.4) Perceived feeling, Dissimilarity, EDA (21.1) Q_{III} (10.7) Resp. f. (10.1) Q_{II} (8.6) SRT, $\dot{V}_{O_2}$ (8.2)
Mental	HRV, 2nd Diff., HRV SABS, H.I. S.D., HR (30.6) SRT, Resp. f., Q_I (15.8) Perceived feeling, EDA, Q_{II} (12.9) HRV, Reversals (11.0) Q_{IV} (8.8) $\dot{V}_{O_2}$ (7.1)	HRV SABS, HRV 2nd Diff., H.Int. S.D., H_f (31.3) Dissim., Error (16.2) SRT, Q_{II}, $\dot{V}_{O_2}$ (11.0) Q_I, P.E., (8.3) HRV Reversals (5.1)	HRV 2nd Diff., H.Int. S.D., HRV SABS (27.6) EDA, Q_I, Q_{III} (19.1) H_f, Q_{II}, $\dot{V}_{O_2}$ (17.2) Resp. f., Perceived feeling (13.5) Dissimilarity (7.9)

Figure 4.19 - Summary of factor analyses including HRV measures.

	Basal	Work	Recovery
Physical	I Q_{II}, Q_{IV}, H_f (24.9) II SRT, Resp. frequency (16.6) III Q_{III}, Q_I (12.3)	I SRT, Perceived Ex., $\dot{V}_{o_2}$ (20.3) II Q_{II}, Q_{IV} (18.8) III H_f, Resp. f. (15.6) IV Dissimilarity, EDA (13.5) V Q_{III}, Q_I (9.6)	I Q_{IV}, Q_{II}, $\dot{V}_{o_2}$ (26.5) II EDA, Q_{III}, Dissimilarity (15.6) III Q_I, SRT (13.5) IV Heart Rate (11.3) V Resp. frequency (10.2)
Mental	I SRT, $\dot{V}_{o_2}$, Q_I, Resp. f. (23.2) II Q_{II}, Q_{IV} (20.2) III Q_{III}, H_f (15.6)	I Heart Rate, Perceived Ex., EDA (21.3) II Error, Dissimilarity (16.2) III $\dot{V}_{o_2}$, Resp. frequency (13.9) IV Q_{III} (11.7) V Q_{IV} (9.5)	I Q_{IV}, Q_{II} (23.0) II Dissimilarity, $\dot{V}_{o_2}$, Q_I, Q_{III} (19.2) III SRT, Resp. frequency (14.9) IV EDA, H_f (11.6

Figure 4.20 - Summary of factor analyses excluding HRV measures.

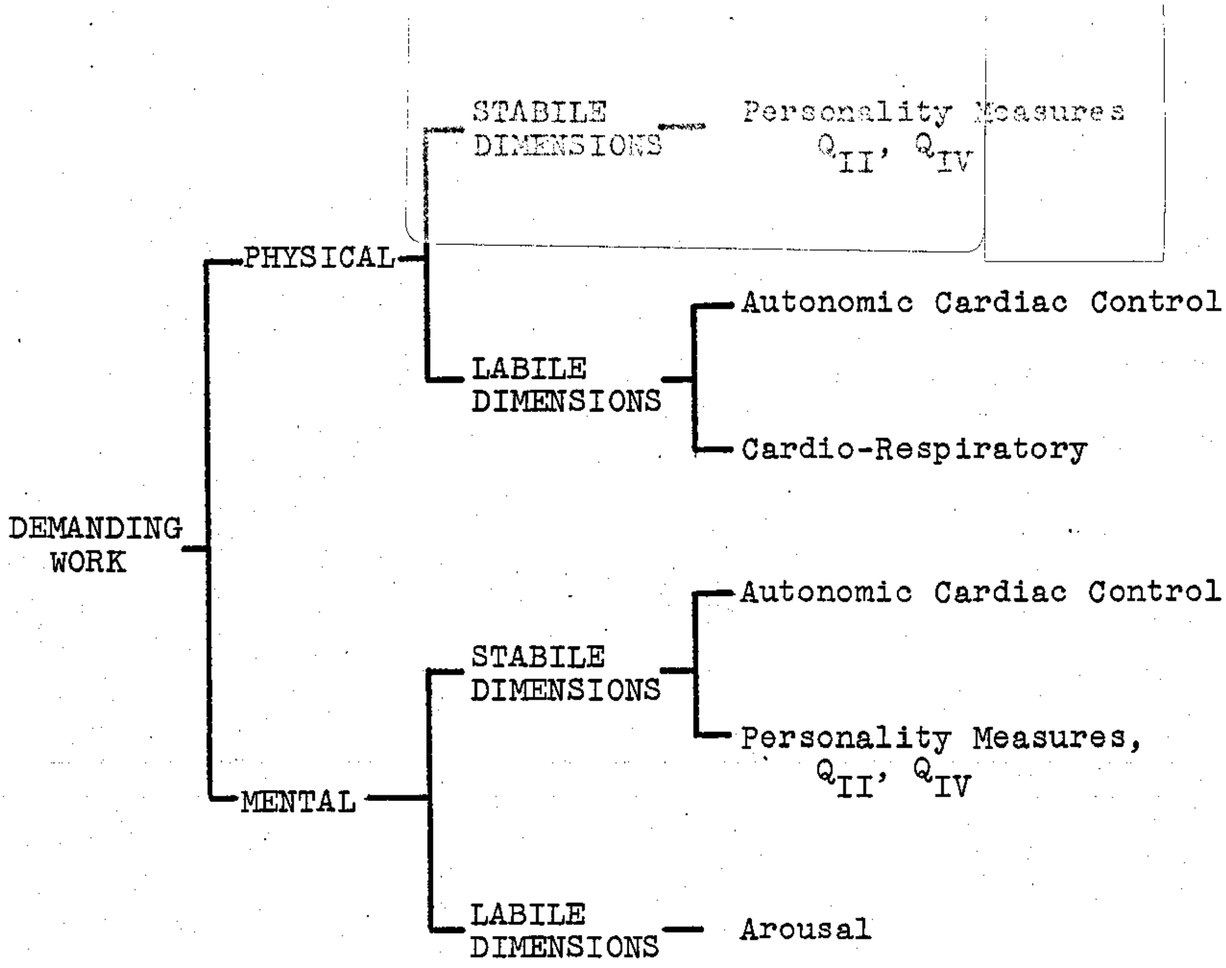


Figure 4.21 - A model based on factor analysis of certain human responses to demanding work.

(a) Responses to Physical Work

Summary Figures 4.19 and 4.20 show:

The important relationship between HRV measures and V_{O_2}, with all of them except HRV Reversals loading together in the first factor.

HRV Reversals is separated from other HRV measures, forming an independent factor.

Mean heart rate forms a clear relationship with respiratory frequency. This is not shown either before the task when they both load on other factors or during recovery when they form independent factors.

The model, Figure 4.21, shows that during physical work only the personality measures Q_{II} and Q_{IV} (anxiety/independence) remain stable, whereas two major dimensions can be identified as showing integration. These dimensions are a combination of factors and include measures that are not apparent before or after physical work and are thus dependent upon the act of working. The two dimensions are those of:

(i) Autonomic Cardiac Control, and
(ii) Cardio-Respiratory

Autonomic Cardiac Control is based on the factors which include all the HRV measures. In the resting and recovery states these measures are dispersed over several factors. During physical work they all load on 2 factors, accounting for about 35% of the variance.

(b) Responses to Mental Work

Summary Figures 4.19 and 4.20 show:

The HRV/HR measures all retain their relationship and factor position (Factor I) during the mental load, the only difference being a 0.7% change in % variance.

HRV Reversals remains separate from the other HRV measures and forms a separate factor.

Two factors contain measures related to arousal. Heart Rate and EDA load in Factor I, and V_{O_2} and Respiratory frequency load together in Factor III.

The model, Figure 4.21, shows that during mental work the dimension to show lability was Arousal which is equivalent to the first factor in summary Figure 4.20. This factor includes the measures of heart rate, perceived exertion and EDA. The emergence of EDA as an important measure is emphasised and its relationship with heart rate and perception of the task is shown. It would suggest that a common mechanism initiates these autonomic responses and shows that a generalised response is sometimes possible, and that the arousal subsystems do not always show poor correlations.

(c) Mental and Physical Work

The results of the more comprehensive overall factor analysis (Table 4.13) revealed eight significant factors and of these three were distinctive because they contained closely related measures and all contributed to over 10% of the variance.

The loading of the personality measures Q_{II} and Q_{IV} reinforces the concern about the independence of these two second-order personality factors.

Two dissimilarity measures formed a clear factor. This suggests that people recover from physical activity in a manner which is distinctive, causing their overall pattern to show dissimilarities from others. The third distinctive factor was associated with respiration. The high correlation ($p<.01$) during mental and physical work confirms respiration as being an arousal subsystem which has a stereotyped response irrespective of the stimulus and as such deserves more attention by psychophysiologists. The highest correlation in the matrix is between the oxygen uptake and SRT during physical work ($p<.01$). This can be explained by the increased metabolic demands of the body causing more afferent stimuli. This would increase the sensitivity of the neural system resulting in more efficient processing. Whether this trend would reverse with a physical work load above 70% of $\dot{V}_{O_2}$ max. is unknown, but one suspects that the point where the system becomes physiologically 'noisy' would cause the SRT to become slower.

This overall factor analysis permits a further model to be constructed, Figure 4.22, which identifies the response dimensions discussed above.

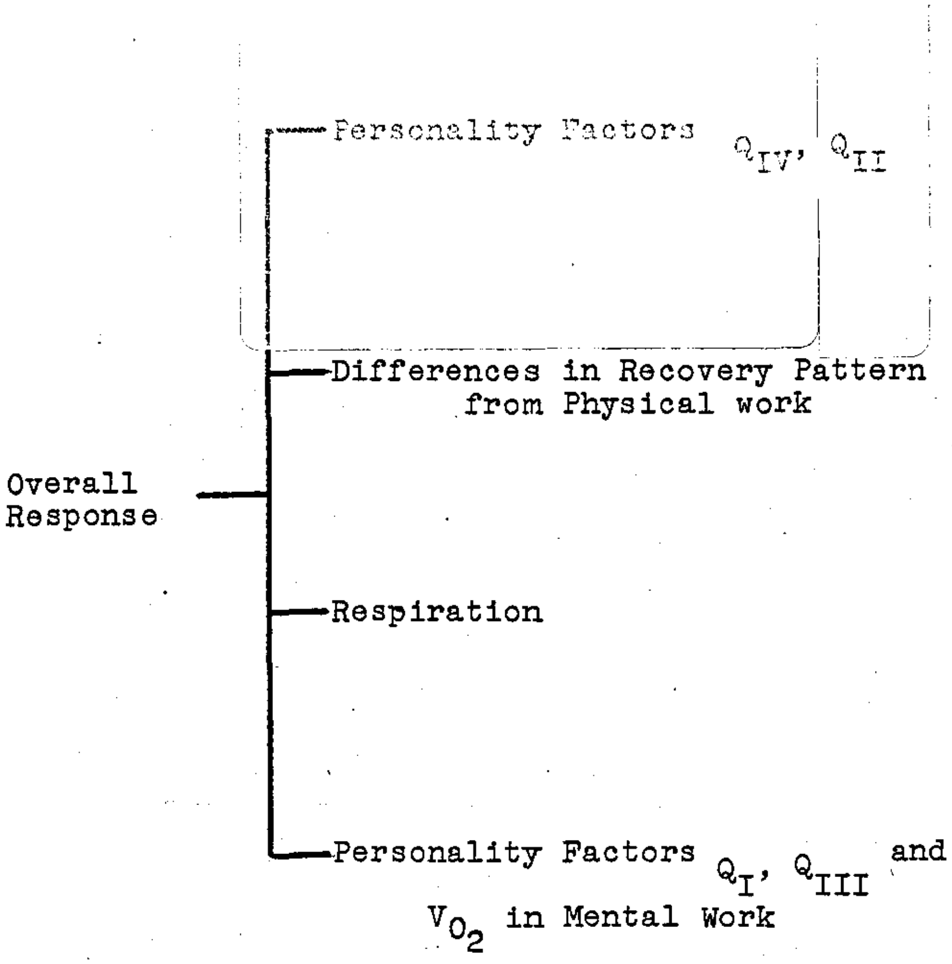


Figure 4.22 - Response dimensions for both mental and physical work.

4.2.5 Spectrum analysis results

The time series analysis of cardiac data is presented in two forms. The first is a listing of the power amplitude at frequencies between 0 and 0.5 Hz and this is followed by a graph plot of the spectrum with the vertical axis showing the amplitude and the horizontal axis showing the frequency. As each graph is scaled to fit the video display unit, the maximum amplitude is printed so that the scaling factor can be applied. The process of making a hard copy from the VDU removed the bottom line of the printout which meant that no scale for the horizontal axis was printed. To obtain the maximum information from the data, the amplitudes and frequencies were recorded from the listing for each peak value. The listing was scanned and each time a peak amplitude was observed, both the frequency of that peak and the amplitude was recorded. In almost every case this peak corresponded to one of the three known biological frequencies. This information revealed:

(1) the changes in frequencies due to mental and physical work,

(2) the changes in power at the biological frequencies,

(3) the changes in the number of peaks. (i.e. whether or not certain biological imputs continue to influence the cardiac signal.)

In subjects at rest the spectrum analysis obtained from the interbeat interval shows 3 main frequency components at approximately 0.03 Hz, 0.1 Hz and 0.25 Hz. Figure 4.23 shows a spectrum analysis of a subject at rest and Figure 4.24 is a spectrum analysis of the same subject under demanding mental work.

During mental work the frequency component attributed to the respiration, moved approximately from 0.25 Hz to 0.3 Hz. This increased frequency was observed in all subjects. In the less demanding test (one digit per three seconds) the shift was from 0.25 to 0.28 Hz on average. During the recovery periods the respiratory component slowly returned to the

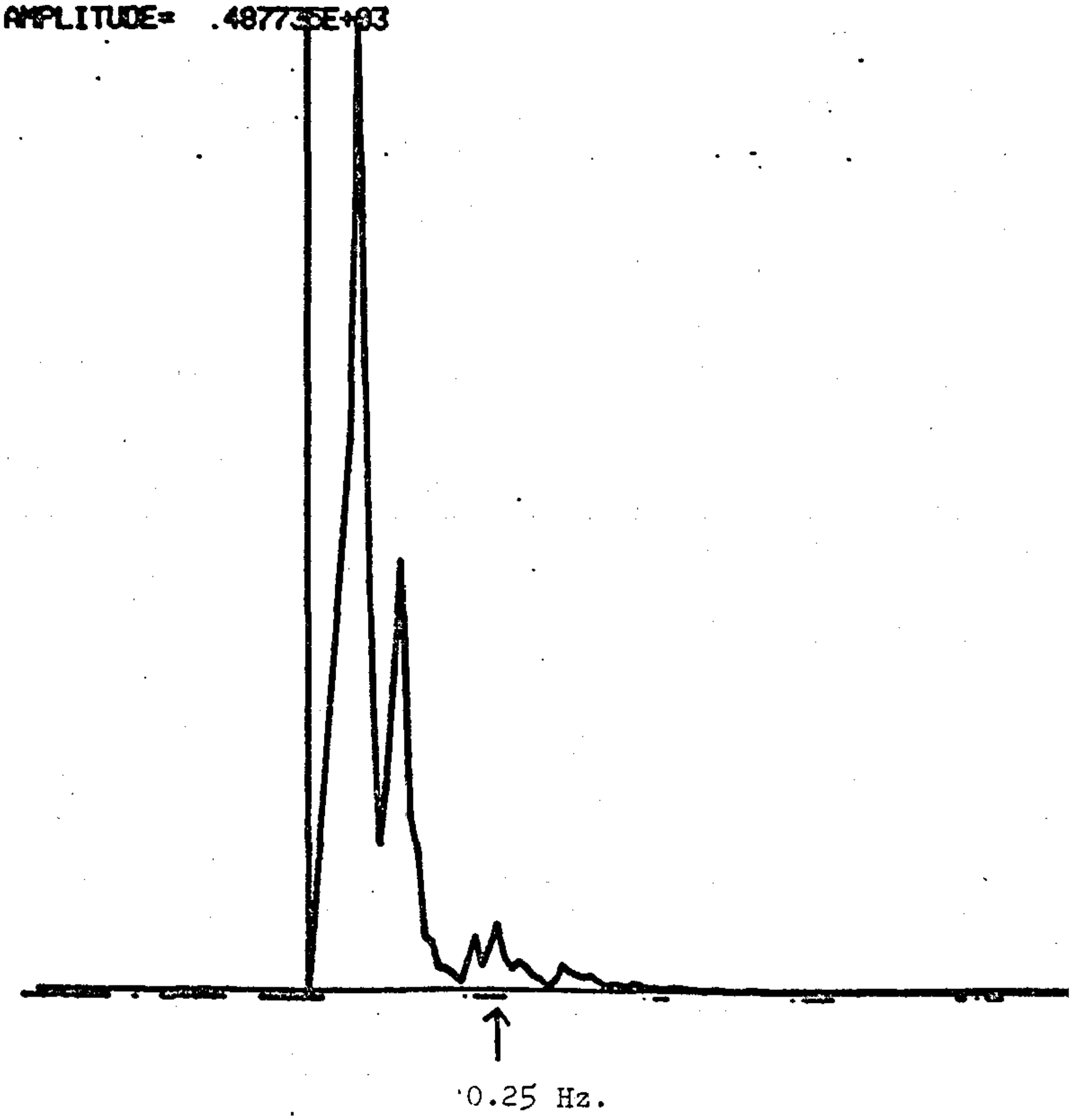


Figure 4.23 - Spectrum analysis of subject at rest

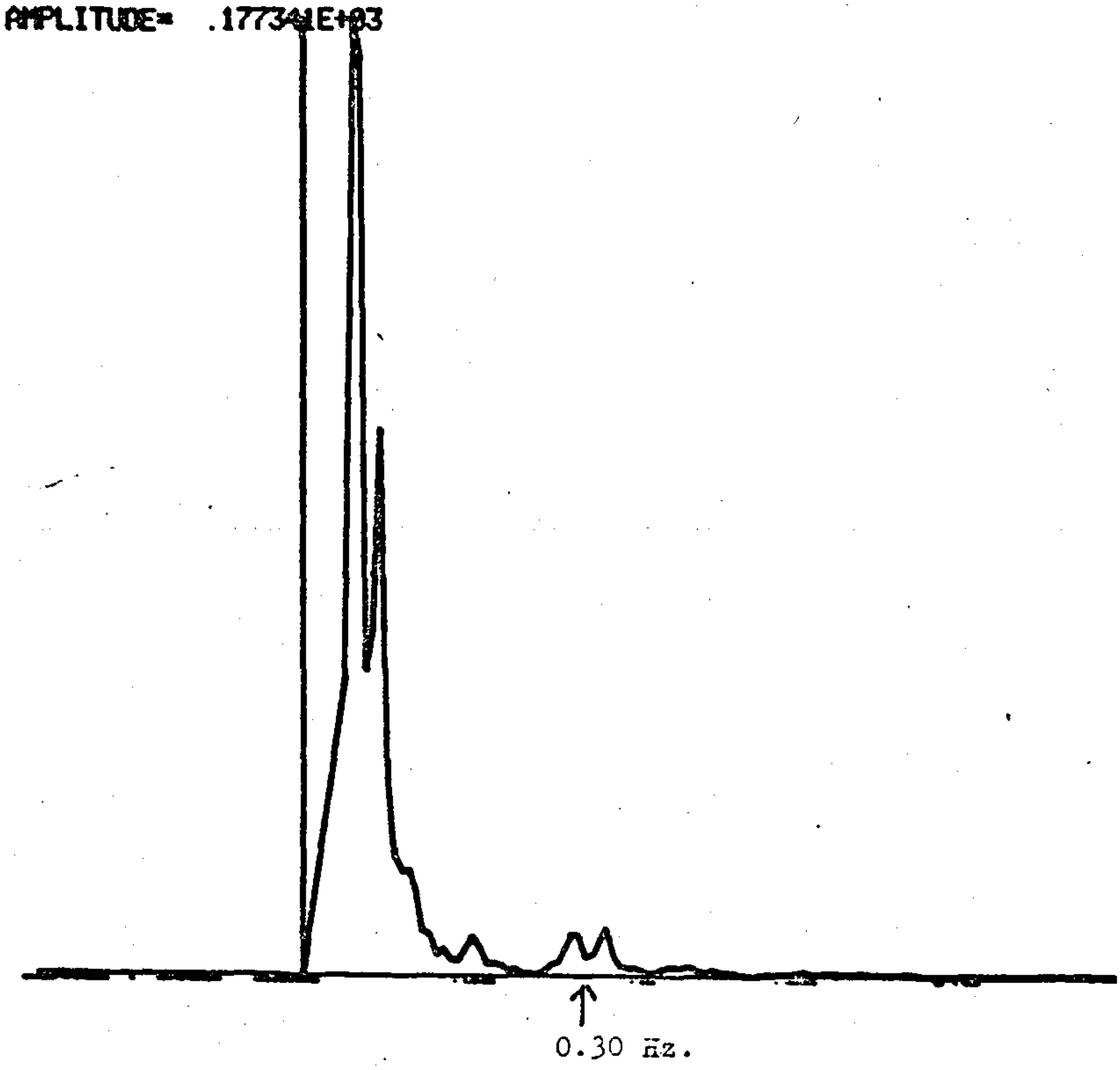
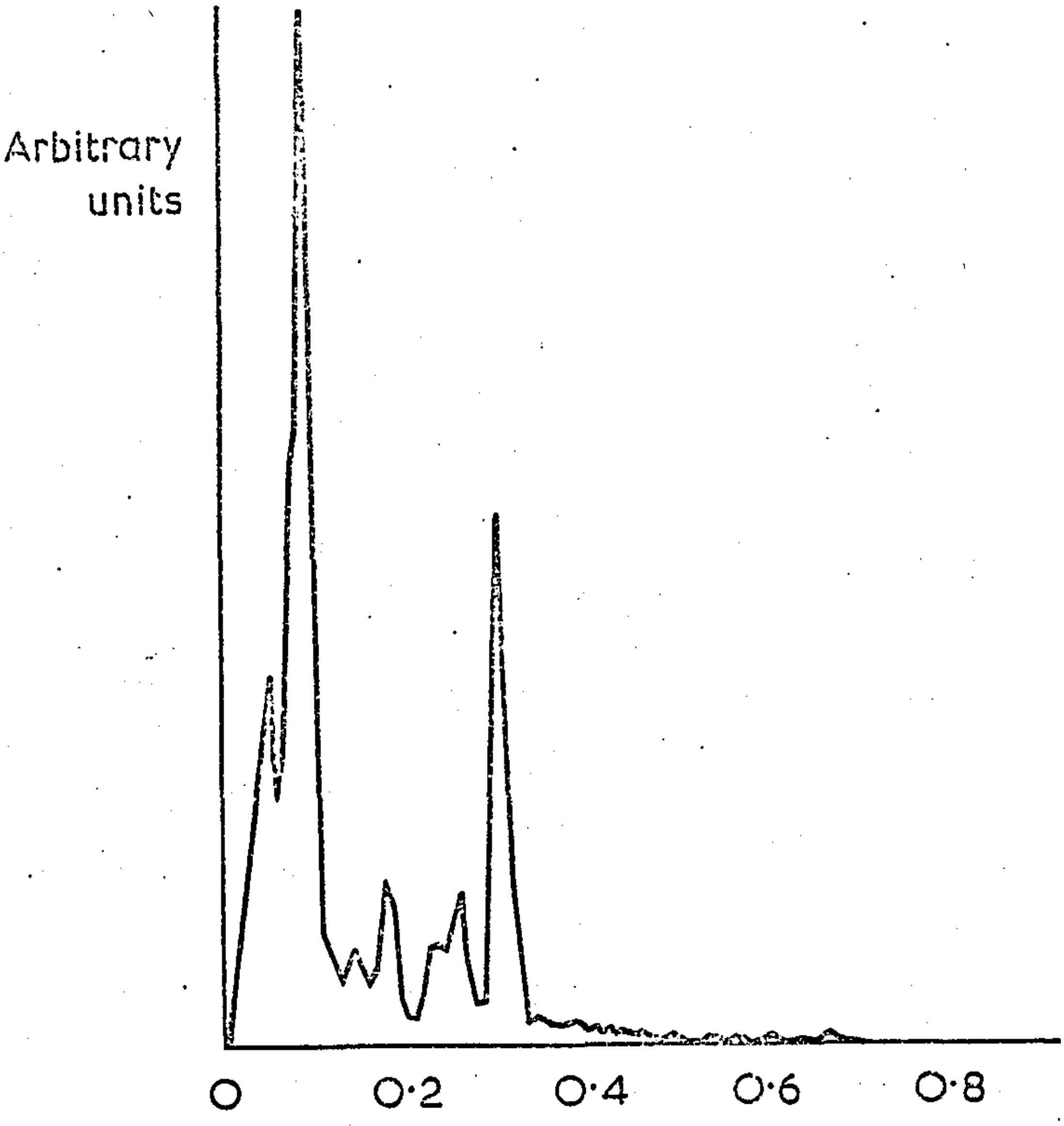


Figure 4.24 - Spectrum analysis of subject under demanding mental work

original frequency. The more demanding the test, the more the shift of the respiratory component. This was true for all subjects.

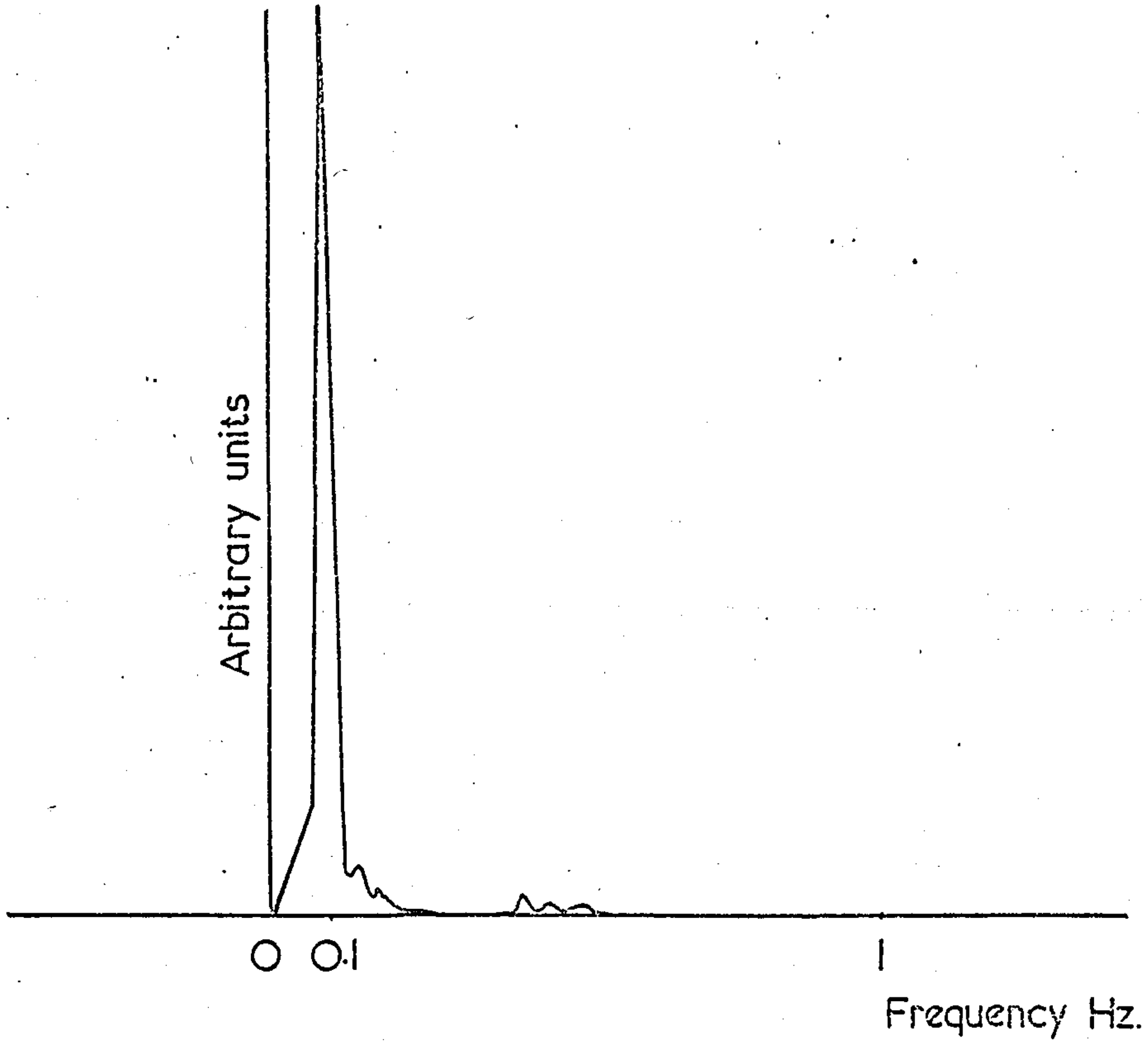
60% of the subjects had the total power of the spectrum contained at two frequencies, namely, the blood pressure (0.1 Hz) and respiration frequencies (0.25 Hz) during the mental tasks, as can be seen from Figure 4.25.

During the physical activity the blood pressure component at 0.1 Hz increased in amplitude and the respiration component moved to a higher frequency and decreased amplitude. During the physical work of highest intensity, the blood pressure component was the only component present in most subjects, with only very few having a temperature component present, and none of them having a respiration component. However during the recovery periods the temperature component became dominant due to the cooling mechanism of the body, and in some subjects this was the only component present in the first five minutes of the recovery period. The respiration component then began to reappear. Figures 4.26 and 4.27 show the power spectra of one subject during and after the physical work tasks.



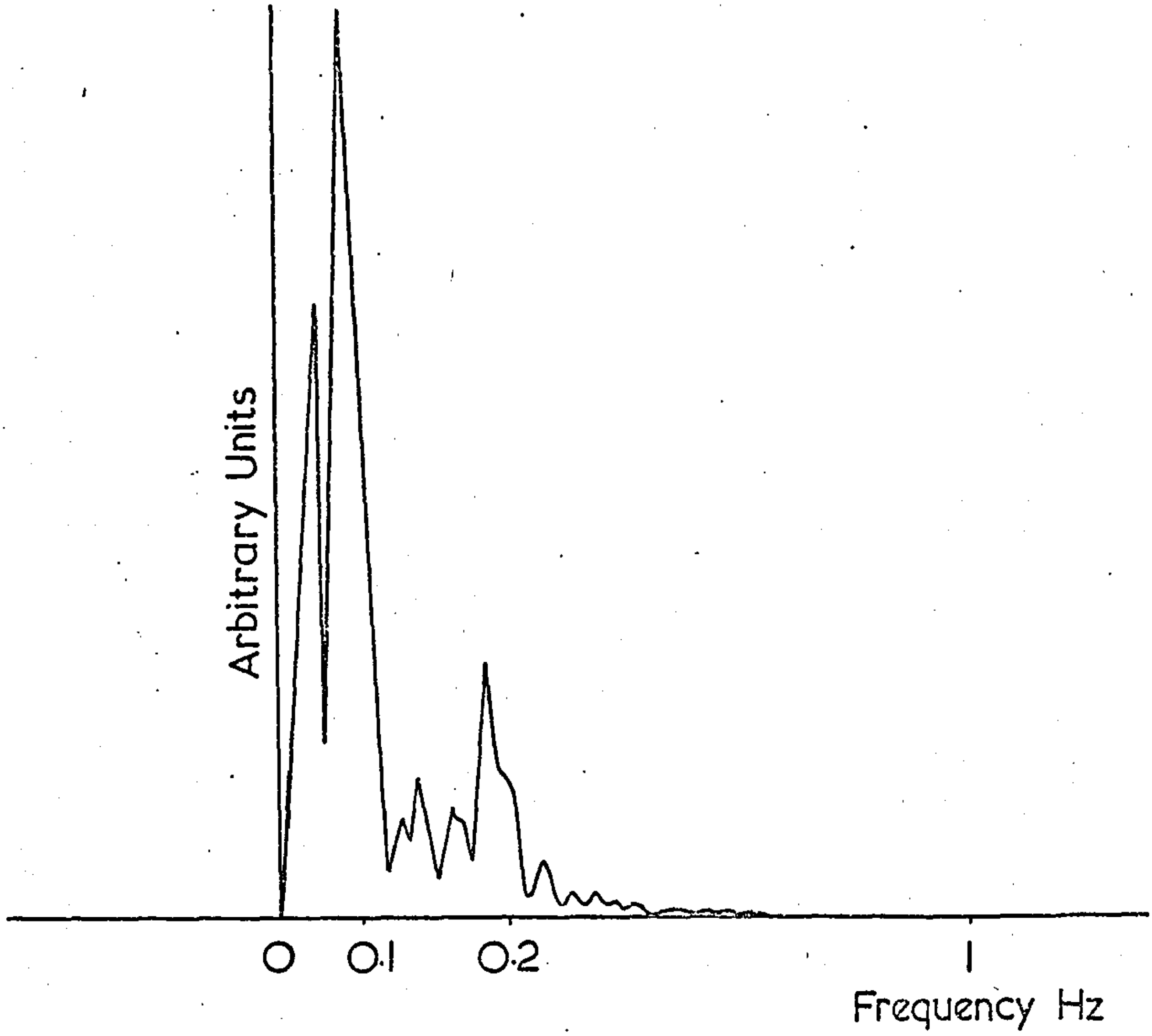
Fourier analysis of the irregular heart beat of subject under mental loading

Figure 4.25 - (taken from Hitchen, Brodie & Harness, 1979



Fourier analysis of the irregular heartbeat interval in subject during physical loading

Figure 4.26 - (taken from Brodie,Harness, Hitchen, Murarka,1979



Fourier analysis of the irregular heartbeat interval in subject after physical loading

Figure 4.27 - (taken from Brodie, Harness, Hitchen & Murarka, 1979)

In summary, the following conclusions may be drawn:

Perception is a subjective measure, but its discriminatory ability is greater than any individual autonomic response. This suggests that the ability of the individual to integrate his internal processes is an important facility. It may indicate with some precision the degree of disequilibrium within the total system.

Newly developed techniques for measuring oxygen consumption offer valuable information about metabolic changes in mental work. Oxygen consumption can be considered as a viable alternative to other methods of measuring somatic activity.

The heart rate variability of up to 40 beats $\min^{-1}$ in successive cardiac intervals indicates the limitation of heart rate as a correlate with total metabolic activity during resting conditions. Heart rate is a better representation of metabolic requirement during physical work because it is more closely representative of cardiac output.

The variability of cardiac intervals is a sensitive measure of mental load even when no commensurate increase in heart rate is observed. This indicates that a response system in which all the autonomic measures move in a sympathetic-like direction simultaneously cannot be accepted. Two independent arousal systems are operating which are both concerned with cardiac control.

Response patterns show variations between mental and physical work which indicates that a stable response pattern does not occur for distinctive types of stimuli.

Examination of mental and physical work shows differences between individual psychophysiological measures. Those that show the greatest consistency are related to emotional responses whereas the least consistent are involved more directly with metabolism.

The results of the factor analysis showed that the psychophysiological measures could be divided into stabile or labile dimensions. During physical work a 'cardio-respiratory' dimension becomes important. This would be anticipated because of the increased metabolic requirement. Measures associated with heart periodicity form a specific dimension during physical work, yet during mental work they remain unaltered compared with the resting and recovery states. Psychophysiological measures which have less involvement in metabolic requirement are well integrated during mental work. This demonstrates a clear dissociation of responses to different forms of demanding work.

The independence of the Q_{II} and Q_{IV} second order personality factors requires reconsideration as a consistent factorial relationship has been shown between them.

Respiration has a fundamental regulatory function and its influence upon the blood pressure and cardiac control systems was emphasised. It is recommended that respiration is considered in the interpretation of many autonomic responses.

SECTION FIVE

DISCUSSION AND CONCLUSIONS

The results of this study have shown consistently that individual differences exist for most of the psychophysiological measures. Each subject was showing an individual, autonomic interpretation of the stimuli. There were a number of intrinsic aspects which could all have contributed to the observed individual differences. These included the subject's perception of the stimulus and the way in which personality influenced the responses. Additionally, the genetic constitution of each person may have caused differences in neural thresholds. The response pattern which is a consequence of these many influences can be explained in terms of autonomic specificity. A subject may be responding maximally and consistently in one autonomic channel, say EDA, whereas other subjects show a similar magnitude of response for a completely different autonomic channel.

Apart from explaining the variations in response patterns this proposal questions the notion of a 'typical' response. It may be inappropriate to consider that any response can be 'typical' unless it is compared with an established, consistent response for a given individual. This implies that experiments which examine atypical individual responses require highly controlled conditions and rigorous statistical treatment. Psychophysiological laboratories must allow minimal interference from the environment, and the design of the experiments must establish normal states before any stimuli are imposed. This would apply particularly in interpreting the autonomic responses of subjects with a stressful life-style.

The overall response patterns for the group varied between the different experiments. Closer examination revealed that when the stimuli were similar (Table 4.2), the response patterns were often the same. When the stimuli varied, either in intensity (Table 4.3), or type (Appendix 4.5), the patterns varied. It was only when the stimuli moved out of the confines of "pure" psychological stimuli or "pure" physical stimuli that some of these differences became evident. This suggests that any statements of response consistency were based on a very limited range of stimuli and were in fact a consequence of stimulus similarity.

Lacey's principle of response stereotypy could only have been formulated on a restricted range of stimuli which predominantly involved mental work. Lacey's principle should thus be modified to state that

"some individuals respond to different stimuli with a fixed patterning or hierarchy of autonomic activation _when the stimuli are primarily of psychological origin and do not involve high metabolic activity_."

The results have shown the error of extrapolating the response patterns from one situation to another when the stimuli are substantially different. This supports Lacey's principle of situational stereotypy (1967) and indicates the importance of the stimulus situation to the overall response. It is not appropriate to consider an individual as a response "type" showing an expected response pattern irrespective of the situation. The context of the situation becomes a critical aspect of the manner of response because unlike the stimulus _per se_ it implies the nature of the subject's involvement. This adds another aspect to individual differences, the degree to which each person considers the tasks to be situationally different. There are many factors which may contribute to a person's interpretation of a situation. One of these factors is the value of the situation to an individual, Duffy (1957). This implies a purposeful interaction between the outcome of the response and the response itself. Lacey (1967) proposed another factor, the intention of the organism in a given situation. The intention will most probably have been modified by the person's competence to master the situation. This was re-stated by Sells (1970) who suggested that the consequence of failure to meet the demand must be regarded as important before stress will occur. Hermann (1966) also considered that stress was a consequence of perceiving a situation as thwarting or potentially thwarting, and this theme is included in McGrath's (1970) definition of stress:

> "occuring when there is substantial imbalance between environmental demand and the response capability of the focal organism."

Thus stress is directly linked to the stimulus situation. A given stimulus may be interpreted differently by the creation of an individual stimulus situation. To some, a stimulus is interpreted as a threat and therefore becomes a stressful stimulus situation. To others the stimulus is perceived as lacking significance and the situation is of little consequence. These observations re-inforce the importance of examining individual responses to given states and suggest caution in placing too much emphasis on traits alone. Although traits have certain descriptive value, their predictive capacity has limitations when the stimulus situations or states show much variation.

In sporting, domestic and occupational contexts the stimulus situation will often vary dramatically on a day to day or even a minute by minute basis. This has implications for the sports coach, the marriage guidance counsellor or the ergonomist. Each must be aware of the influence of the context, be able to provide situations so that experiences can be gained, and be capable of subsequent analysis. Much modern rehabilatitive work for maladjusted children is based on experience therapy where such people are placed in simulations of experiences and have to work out their solution often in a traumatic manner. Similarly the sports coach will use pressure drills which provide a situation common to the game but presented in a demanding manner so that the players become conditioned to the appropriate response. In another context, many industrial trainees are subjected to close scrutiny during outward bound courses financed by their companies. The reason for this is the belief that people placed in physically demanding situations may indicate the management potential required in industry. This study shows that it is erroneous to expect responses from one context to predict the outcome of another. A person may have very good qualities which are never evident under the rigours of demanding physical activities because his attention is directed towards other aspects such as his personal survival. If the job requirement, such as deep sea diving, involves personal survival then an individual's response to physical load may be of predictive value. However, the hypothesis that one can predict the response characteristics of an individual by placing him in a dissimilar situation has not been supported here. In certain jobs there may be some value in simulation exercises and indeed certain skills such as flying are taught initially in simulators. A similar trend is seen in management training when business 'games' are used. The training of personnel by using situations related to the requirements of the job is a valid exercise, but should not be extrapolated to situations bearing little relevance to the occupation in question or to activities which need not utilise the availability of pavlovian conditioned reflexes.

Another situation in which individual differences become apparent is that of sport, yet many people are the antithesis of their normal selves when placed in sporting contexts. Some very gentle and humane people become aggressive and almost inhuman under the guise of sport. It may be postulated that those people who do not have an acceptable channel for their emotions are more at risk from autonomically-related diseases. Competitive sport was not included as a stimulus situation in Wenger's (1966) extensive review on autonomic balance and the influence of cathartic activities such as sport should be studied. The extent that autonomic balance is changed by sporting experiences may give exercise credibility as a 'relaxation' activity. This thesis has shown that simple measurement techniques such as perceived exertion could be used as the basis of a practicable study of the effectiveness of physical activity as an antidote to stress.

The term 'strength of the nervous system' has been considered earlier and was specified by Nebylitsyn (1972) as a prolonged maintenance of characteristic levels of response. Its value as a single dimension requires assessment if the term is to be used in describing responses to demanding work.

The factorial relationship between the personality dimension Q_I (introversion - extroversion) and the measure of perceived exertion (see Figure 4.19) suggests some support for the notion of a trait similar to "strength of the nervous system". It was particularly interesting that the two measures of perceived exertion and Q_I loaded together on the same factor in both mental and physical work. As it was a bipolar factor it suggests that subjects high in extroversion do not perceive the task to be as demanding as subjects lower in extroversion. One implication is that personality may need to be considered in situations when mental and physical work loads have to be tolerated with precision. This could apply to many occupational activities including air traffic control, the construction industry and also to sport. The selection procedures for jobs in which the tolerance of physical work involves human life also may need to consider personality factors. Such jobs could include the armed forces, the lifeboat service and the security forces. Future experimentation should select distinctive populations by personality traits and then compare their mental and physical work perception. If the present findings are confirmed it may be necessary to modify some of Borg's (1962) work on perceived exertion by the inclusion of an appropriate weighting for personality.

Personality was also considered by Gray (1972) who suggested that the introvert has a "weak nervous system" which is characterised by low thresholds and high reactivity. The organism integrates these neural characteristics in such a manner that the stimulus is perceived as being of greater magnitude than the same stimulus would be perceived by the extrovert. The factorial relationship shown in Figure 4.19 demonstrates that the introvert quantifies the stimulus as high in perceived exertion and this supports Gray's conclusion. Although "strength of the nervous system" is adequate to explain certain observations, it remains a composite term. It incorporates sensory threshold levels, the activity of the RAS and the level of the effector output. There is a close parallel between these differences and perception of pain tolerance described by Petrie (1960). Petrie used the terms augmenters and reducers to indicate the tendency to enlarge or reduce the perceived intensity of sensations respectively. It may be concluded that although this thesis supports the concept of "strength of the nervous system", it has limited value as a single dimension. It would be far preferable to determine the component parts of the concept and then replace the term with a more adequate and precise expression.

The stabile dimension of the personality measures Q_{II} (anxiety) and Q_{IV} (independence) were of interest because of the extent to which they related one with another (see Figure 4.21). These two measures consistently load on the same factor suggesting that they may not be as independent as originally considered by Cattell. This relationship indicates that the process of calculating second-order factors may be devaluing the contribution made by Cattell with his sixteen primary factors. It may be preferable for the practitioner to employ an alternative psychological test to derive the same or similar information.

Although the extensive study by Saville and Blinkhorn (1976) did not use factor analysis, it did show a significant correlation between the second order factors Q_{III} (tough poise) and Q_I (extroversion). A factorial relationship was observed in the present study between the personality measures Q_{III} and Q_I (Table 4.13) and this once again questions the extent to which they are distinct. It can be seen from Table 4.13 that the same personality measures (Q_I and Q_{III}) also have "V_{O_2} during mental work" loading on the same factor. This would suggest that the extroverted - tough poise personality type expends more energy during mental tasks. This observation may explain the range of mannerisms associated with mental work. Some people are very passive and hardly seem to breath while engaged in mental work, whereas others seem to be continuously involved in non-productive activities such as scratching, doodling, paper sorting and fiddling with pens. It may be that these activities reflect cellular metabolism related to the particular extroverted - tough poise personality type. If so, then this suggests that there is not only a neurological basis to personality but also considerable metabolic involvement.

One can conclude for this part of the discussion that although "strength of the nervous system" may be an adequate term to describe a trait relating the Q_I personality dimension with perception of the task, its value as a single dimension is limited. This has implications in certain occupations. Another conclusion is that a review of the independence of certain second order personality dimensions is necessary.

The results presented in this thesis seriously question the usefulness of mean heart rate as a satisfactory measure of psychological load. Elsewhere heart rate changes have been quoted when psychological load was expected to increase, but many of the conditions also required a slight increase in somatic involvement. Examples of this would be the increased heart rate during the landing of an aeroplane at an airport and the comparison between using inter-city rail travel and driving a car, as used in a recent British Rail advertisement. In both these examples the implication was clearly one of relating increased mental load with increased heart rate. The possibility that increased bodily activity could have caused the heart rate increase was not considered. This thesis has shown (Table 4.2) that when movement was restricted, heart rate is unsatisfactory as a measure of involvement and is better used as a measure of metabolism in its classical form. As an indication of mental load, mean heart rate is only a convenient, coarse measure of cardiac output. Mean heart rate may mask some valuable information which the variation in interbeat intervals would reveal about cardiac filling. Support for this statement comes from the clear distinction between mean heart rate and heart rate variability measures which was a consistent finding of this thesis and is shown in Section 2 page 76, Figures 3.10 and 3.11, and Table 4.2. This indicates that the integral of successive beats over time (H_f) produces different information from cardiac measures which are dependent upon the organisation of successive heart intervals. (HRV). The distinctive HRV measure in the third experiment was 'second differential'. This measure can be usefully compared with another measure of HRV, that of the 'first differential'. In the case of the first differential the dispersion is relative to a changing mean, whereas the second differential is relative to a zero baseline. This is analagous to the differences between an RR interval frequency distribution curve (Fig. 5.1 (a)) and an RR interval difference frequency distribution curve (Fig. 5.1 (b)).

The HRV first differential, which did not show significant differences between occasions, is still largely under the influence of a changing mean heart rate value. The second differential on the other hand, is measuring the difference between these several differences and as such moves a stage further from mean heart rate. In physiological terms it could be viewed as a move away from the combined effects of the parasympathetic and sympathetic influences on the sinus node and towards a measure of the organisation of the heart interval series irrespective of the overall rate. The existence of these distinctive cardiac response systems justifies the method of spectrum analysis to examine the multiple feedback loops which influence the heart's rhythmicity. Indeed spectrum analysis is required to give a quantitative basis to the periodicity of heart intervals. Spectrum analysis has shown

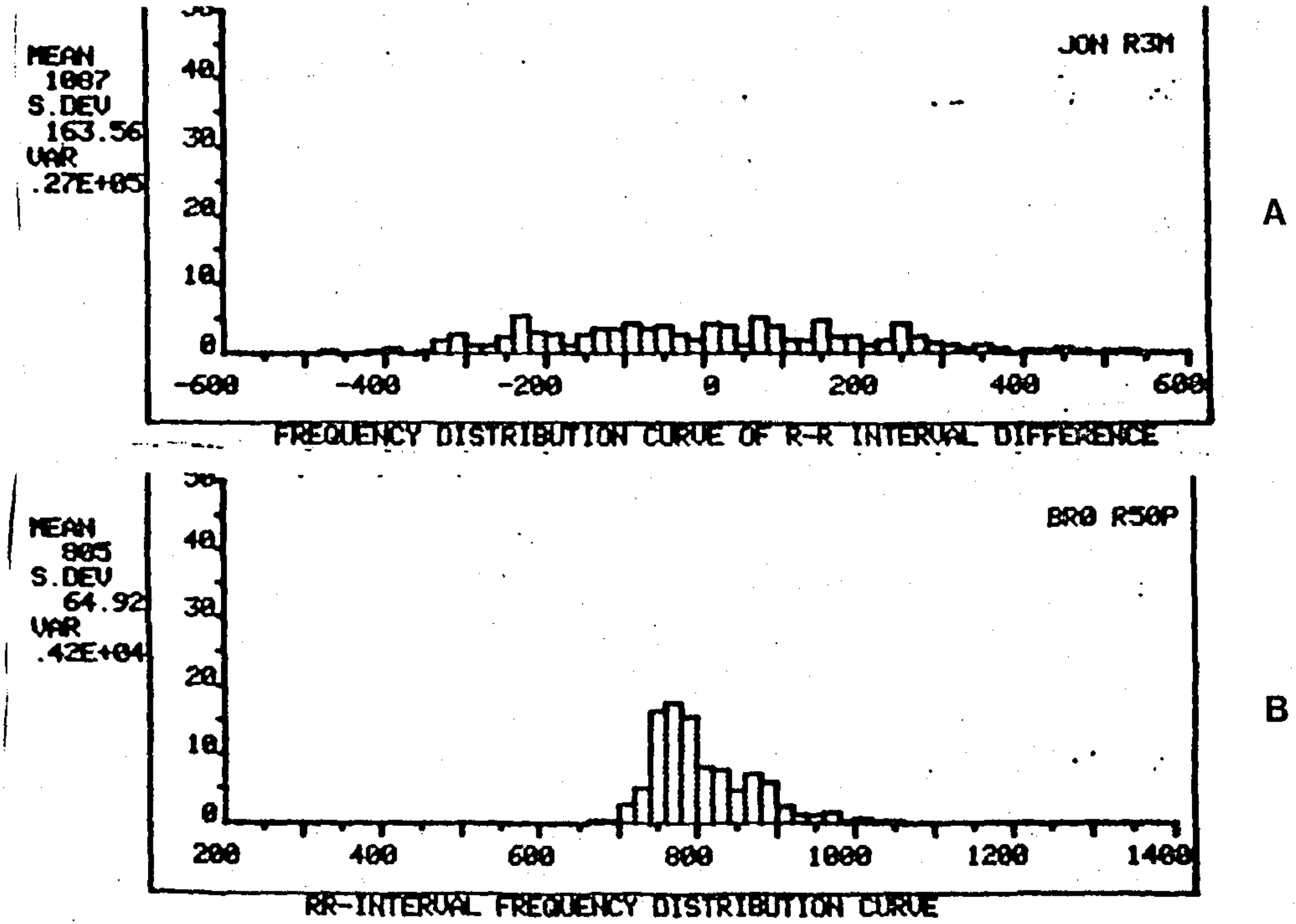


Fig. 5.1 - (a) RR interval frequency distribution wave, and (b) RR interval difference frequency distribution wave.

the variability of the heart interval (see Figure 4.23) to be caused by the Hering - Breuer reflexes involving a respiratory input with a periodicity of about 0.25 Hz, a blood pressure input at about 0.1 Hz and a thermo-regulatory input at about 0.025 Hz.

It can be concluded that the organisation of successive heart intervals is an important aspect of the human cardiac response system.

The present results (Figures 4.26 and 4.27) suggest that the various inputs upon the SA node are making their greatest individual impact at the lower levels of metabolic load. The three inputs are influencing the periodicity of the SA node quite individually. They are not being integrated with each other or with other controlling factors. When the metabolic load increases, the clear peaks at frequencies corresponding to the known biological signals are lost and the power is dispersed over the full range of the spectrum (see page116). This suggests that at higher metabolic loads the feedback loops are integrated and they no longer remain as distinct periodic influences.

One way to clarify the cholinergic/adrenergic influences upon the heart is to vary the neural input directly by surgery or pharmacological agents. Although this procedure is not appropriate for humans, Chess, Tam and Calaresu (1975) studied the spectrum analyses of cats under these conditions. Three principal rhythms were identified under the control condition. Chess et al recognised the respiratory frequency. The other two rhythms based on their frequencies, were almost certainly those of thermoregulation and arterial blood pressure. It was clear from the experiment, that these were an intrinsic feature of the regulation of the heart period by the vagus system. The effect of the sympathetic activity was a tendency to reduce the amplitudes of the thermoregulatory and blood pressure components of the spectrum. This was observed in the present study during the higher metabolic loads (Section 3.2.2), and this may give a clue to the relative contribution of the cholinergic and adrenergic influences on the heart. A "cross over point" between loss of vagal tone and initiation of sympathetic activity occurs during an increase in metabolic load and this is shown as a change in the power spectrum. The present study indicated that such a postulated "cross over point" could have occurred at some point between the medium load and high load conditions used in the experiment.

An understanding of heart rate variability requires knowledge of the primary function of the cardiovascular system. This is an adequate movement of blood in the vasculature. The many controlling responses, although having individuality, are often subservient to this primary function. The vascular movement of the blood is directly influenced by the cardiac output. Throughout the normal physiological range of habitual activity, the cardiac output is proportional to the heart rate. This, in itself, is within the control of the frequency of vagal efferent discharge. The vascular system maintains a certain blood pressure which is monitored by the baroreceptors in the carotid sinus and the aortic arch. These baroreceptors influence the frequency of afferent nerve discharge which acts on the vasomotor centre. The other input to the vasomotor centre is from higher centres of the brain. This model is shown in Figure 5.2.

The spectrum analysis technique has revealed a periodicity associated with respiration which suggests a respiratory influence upon the heart rate. An experiment by Miyawaki, Takahashi and Takemura (1965) in which the respiratory frequency was varied, revealed that most gain in the heart period fluctuations occurred when the rate was in the order of 6 cycles min^{-1} or 0.1 Hz. This is the naturally occuring blood pressure frequency indicating that the respiratory frequency entrains the blood pressure fluctuation. The baroreceptor stretch can be influenced by pressure in the thoracic cavity because of the elastic nature of the arteries. Breathing has a very real influence on the thoracic blood vessesl by altering intra-pleural pressure. These observations require the respiratory disturbance to be added to the model as an external signal influencing the baroreceptors (Fig. 5.2). The frequency of this external signal (respiration) could be in phase with the heart rate and cause entrainment, or be out of phase and cause a reduction in the heart rate periodicity. Therefore, it can be seen that the respiratory frequency can have a marked influence on cardiac variability via the blood

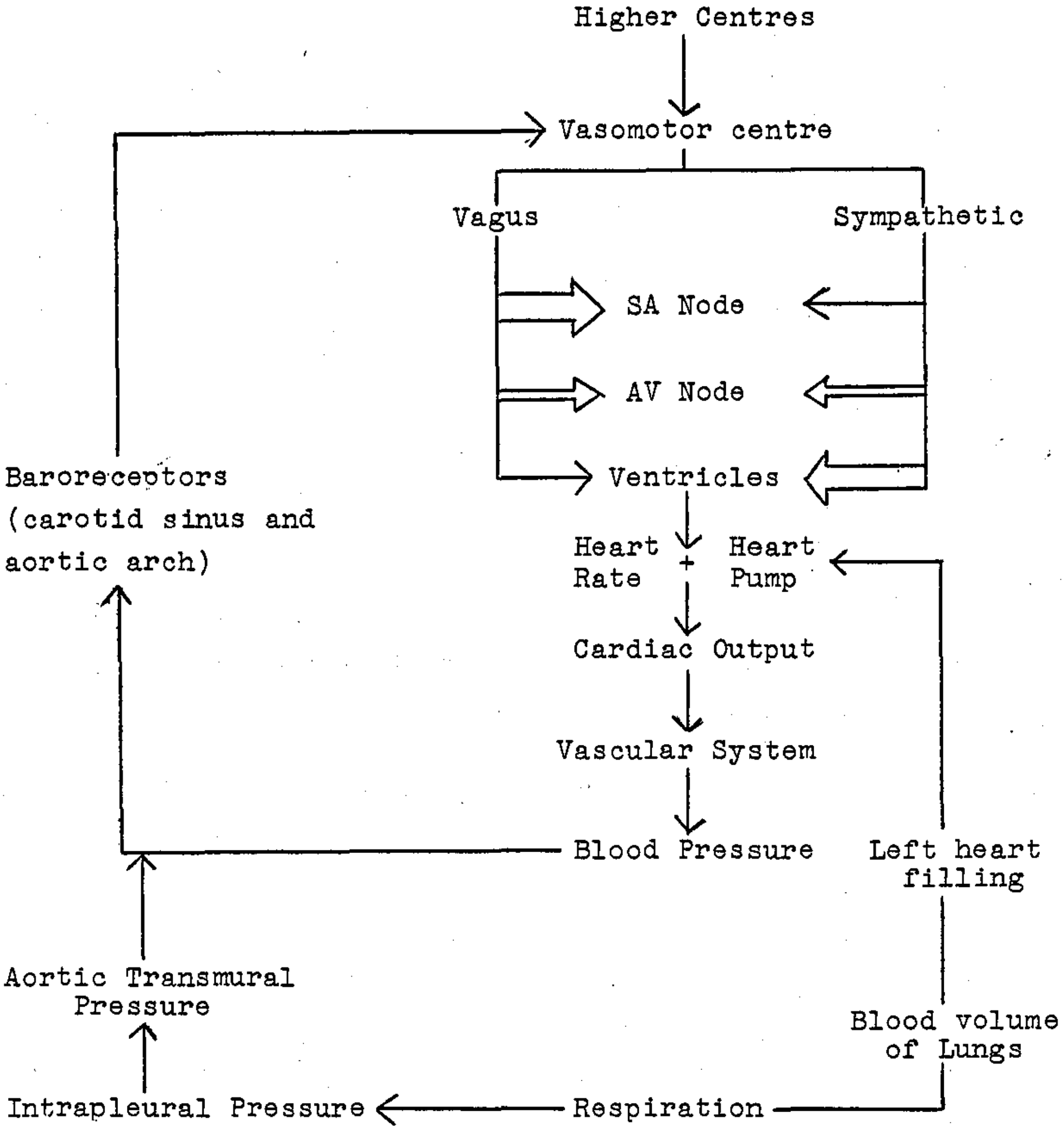


Figure 5.2 - Model of control of heart rate variability.

pressure control system. At lower metabolic loads the system described in Figure 5.2 applies. The vasomotor centre can satisfactorily translate the incoming efferent information from the baroreceptors (reflecting blood pressure and respiratory inputs) into vagal efferent discharges which retain these periodicities at the SA node. Figure 5.2 would be incomplete without reference to the respiratory influence on the left heart volume. During inspiration there is an inhibited blood return which causes a lower arterial blood pressure and output. In expiration, the augmented blood return causes an increased output and blood pressure. These statements are based on the laws of the heart, Bainbridge (1915), Starling (1918) and particularly the earlier work of Hering and Breuer (1868).

It is at higher metabolic loads that the SA node does not appear to maintain its periodicity, and as has been suggested earlier, it is probably a function of sympathetic activity. When sympathetic activity becomes greater the SA node integrates both cholinergic and adrenergic transmitter substances with the result that it loses its innate periodicity. Sympathetic activity may provide less influence on the SA node and more on the force of ventricular contraction. This could cause the barorecptor feedback to the SA node to be more closely associated with the blood pressure control system. The observed result would be an increase in the power associated with the blood pressure frequency which is consistent with the results of this study, Figure 4.26. The full extent to which the sympathetic nerve fibres are separate for their chronotropic (rate) or inotropic (force) effects is unknown, Heymans and Neil (1958), but even if the innervation to the SA node and atria and ventricles were from the same postganglionic fibres, the effect of increased cardiac force due to sympathetic involvement would still apply.

The most convincing result from the spectrum analysis during mental work was the change in the frequency of the respiratory component (see Figure 4.23 and 4.24). This clearly demonstrates that the pattern of interbeat interval is being influenced directly by the rate of breathing. It has been known for some time that the respiratory frequency influences the interbeat interval, but it has not been demonstrated previously that mental work increases the control upon the heart via the respiratory frequency. The finding that most of the subjects showed only two frequency peaks (Figure 4.25) negates the suggestion of Charnock and Manenica (1978) that respiratory frequency is unimportant. During mental work many subjects lost all power corresponding to the thermoregulatory frequency. This meant that the temperature control failed to influence the heart's variability and the other components will dominate the feedback to the SA node. Spectrum analysis revealed that during mental work the primary influences upon the heart were from the respiratory and blood pressure inputs

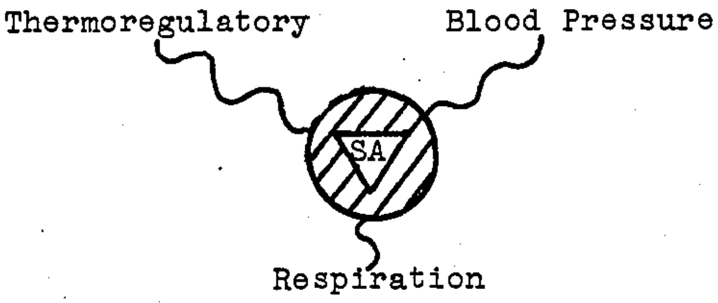
(Figure 4.25). A shift in the power from three to two frequencies for normal, healthy, young subjects would probably be of little consequence. However, mental work in combination with an aperiodic respiratory frequency, could cause all the power to be established at the blood pressure frequency. The effect on a diseased heart could prove fatal with the primary influence now coming from the blood pressure control alone. Arteriosclerosis could cause a loss in the responsiveness of the blood pressure component, and with a widely fluctuating respiratory input, the periodicity of the heart could be changed with fatal consequences. This hypothesis has not been tested but there is some evidence that subjects who show wide variations in respiratory pattern (even stop breathing for as long as a minute whilst sleeping), are predisposed to myocardial infarction, Dunn (1979).

The combined effect of all feedback mechanisms on the heart is to modulate the influence of each one acting separately. A single, predominant input will decrease the overall modulation and this has been observed in various entrainment experiments. Increased activity from all three inputs will reduce the degree of change in rhythm and is observed as decreased heart rate variability.

Figure 5.3 gives a crude model of the influences upon the SA node during four different states. The shaded areas represent the degree of control that each input to the heart is having over the SA node. It is an attempt to summarise the foregoing discussion in a diagrammatic form.

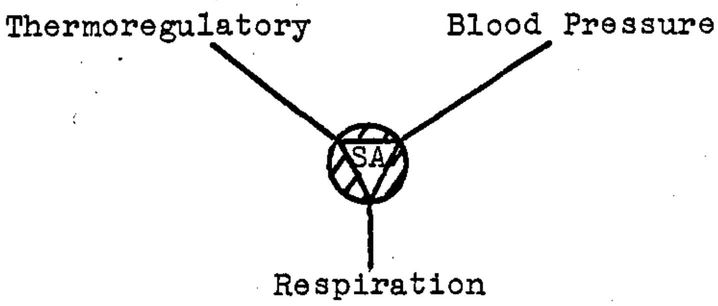
The blood pressure component of the spectrum analysis during physical work became dominant at first and then exclusive as the intensity became greater (Figure 4.26). The increased respiratory rate and respiratory depth which accompanies physical work, although essential for greater tissue oxygenation, does not appear to be reflected in cardiac control. The reason for this may be that during conditions of high cardiac output, the regular surging of blood through the

1.



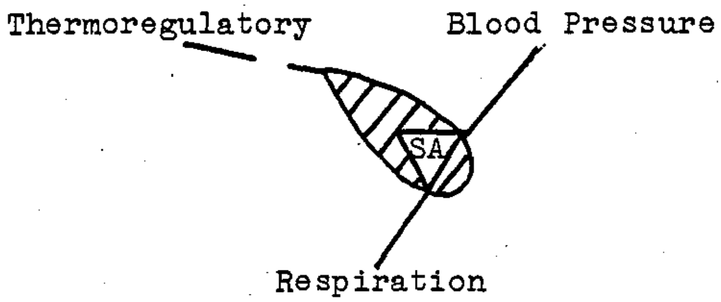
Resting Condition
High Variability

2.



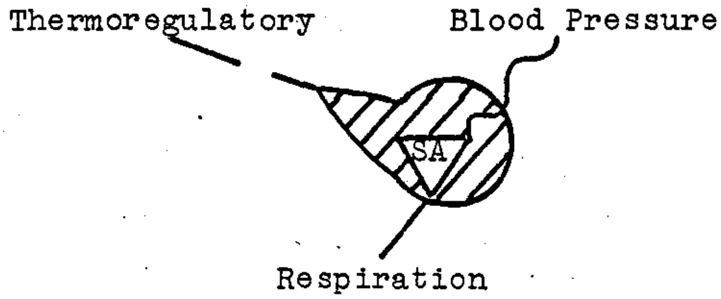
Moderate Arousal
Low Variability

3.



Mental Load
Indistinct Variability

4.



Mental Load and Limited
Control in one system
Aperiodic Heart Intervals
tendency towards cardiac
insufficiency.

Figure 5.3 - Model of major control systems on the SA node during different conditions.

vasculature will be so great relative to the changes of intra-pleural pressure in the thoracic cavity, that most of the power will be seen in the blood pressure frequency. At rest, respiration influences the baroreceptors via the thoracic blood vessels, but under physical work the greater blood flow dominates this mechanism. The temperature component was observed in a few subjects during physical work. This demonstrated that the temperature control mechanism was sufficiently powerful still to exert an influence upon cardiac control. When exercise stopped, the temperature control mechanism became the dominant power in the spectrum, showing the manner in which the organism apparently switches all its resources into the cooling mechanism. When the body cooled further, the respiratory component returned and the normal control mechanisms on the heart were re-established. Further experimentation would be required to determine whether there is any significance in the time it takes for the respiratory component to re-appear or whether there is any relationship with fitness or cardiac efficiency. This proposed respiratory influence involves systemic and peripheral blood pressure control. It is thus associated with blood pressure factors on left heart filling. The pulmonary arterial baroreceptor and intrathoracic air pressure control by thoracic posture is a distinctly different source of variability. This latter system is inherently cyclic and is the one most influenced by both body position and mental activity. Thus respiratory influences offer two entries to the CNS and can provide considerable variability on the cardiac system. Figure 5.4 is based on the spectrum analysis results and summarises the dominance of inputs to the SA node, with the sizes of the boxes indicating the extent of the dominance.

Once again the speculative link with cardiac insufficiency can be considered. The normal controls may lose their sensitivity and cause cardiac arrest when the dominant input to the SA node is changing and when artificial or unusual conditions are encountered such as drugs, sudden changes in temperature or abnormal breathing patterns. The cases of

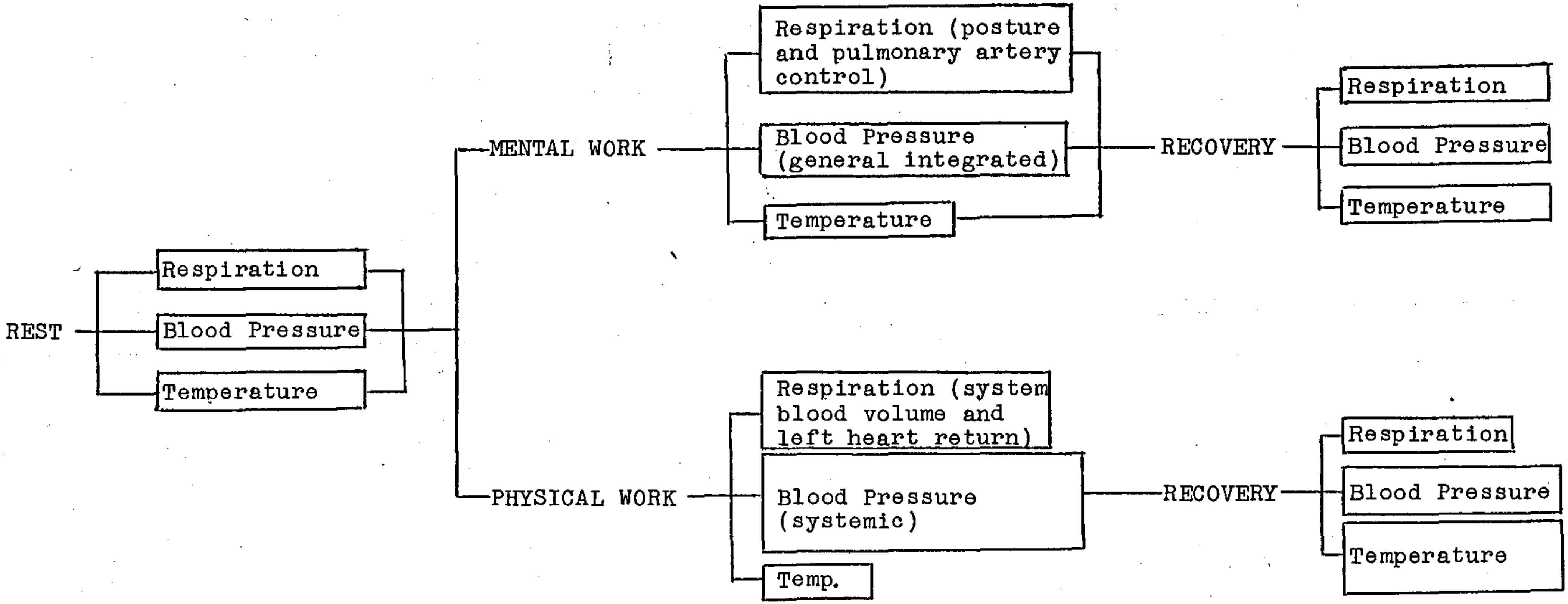


Figure 5.4 - Model of dominance of inputs on SA node during rest, work and recovery all taken from the results of spectrum analysis.

cardiac arrest during such situations, although based on non-empirical evidence, do leave many unanswered questions which could well be explained by the use of spectrum analysis techniques. The development of an on-line spectrum analyser for cardiac intervals, Brodie, Harness and Mearns (1979) for use in an intensive care unit may clarify some of these unanswered questions.

The conclusion one reaches in this discussion is that cardiac control must be considered as two distinctive systems. One, heart rate variability, is sensitive to the three major inputs of the SA node, whereas the other, mean heart rate, is an integral measure reflecting cardiac output more closely. The cardiac responses to increased metabolic load can be modelled to show the lack of integration between feedback loops to the SA node and a switch from vagal to sympathetic innervation This corresponds to the series of Hering - Breuer reflexes controlling the overall cardiovascular response.

Three findings from the present study all combine to indicate the importance of respiration in the control of other human psychophysiological responses.

The first of these is the increase in respiratory frequency during mental tasks without a statistically significant increase in inspired volume (V_I) as shown in Table 4.2. This suggests that the tidal volume must have dropped during the mental taks. This change to a shallower, more rapid type of breathing has not been reported in the literature as a response to mental load and may be important when considering the relationship between the many arousal subsystems. The observation of a rapid, shallow breathing pattern is confirmed from the findings of the spectrum analysis (Figures 4.23 and 4.24).

The second finding was a clear change in the pattern of the respiration (Figures 3.16 and 3.17) irrespective of respiratory frequency changes. The results suggest that as the metabolic load increases, the variability in the respiratory waveform decreases. The intercostal muscles, having a limited range of contraction and relaxation, will show less variation with deeper breathing than with shallower breathing. This is because the full capacity of the lungs is not being used during shallower breathing and therefore the opportunity always exists for a deeper breath. The metabolic demands associated with deep breathing are less likely to permit many shallow breaths.

The third finding is the relationship between respiratory frequency and cardiac measures. The factor analysis suggested such a relationship, but the more important evidence was found in the spectrum analysis which showed the direct method of association. The spectrum analysis of the cardiac interbeat interval showed an involvement with the respiratory mechanisms under all conditions producing the phenomenon of respiratory sinus arrhythmia (RSA). RSA was originally observed by Hering and Breuer (1868) in connection with respiratory stretch fibres, but its association with cardiac frequency is more likely to include blood flow distribution changes within the pulmonary circuit and the aortic baroreceptors on the left side of the heart. The respiratory drive is a mechanism which maintains cardiac output homeostasis without depending solely upon the feedback from the cardiovascular system. It maintains a degree of control within a distinct range by imposing a regular, oscillating impulse. The evidence for this distinctive range is that the maximum RSA occurs when the respiratory frequency entrains the blood pressure system (5 - 7 cycles per minute or 0.1 Hz). The entrained blood pressure control system causes minimum afferent impulse to the RAS and reduces levels of arousal. The control of arousal is therefore influenced by respiratory pattern and frequency. Specific breathing patterns may reduce high adrenergic involvement. Acute cardiac distress may prove to be less dangerous if patients are trained to breathe in a manner which causes a lowering of adrenergic influences. Support for this hypothesis comes from Eriksson's (1975) observation of a low HRV as a risk factor in future death from ischaemic heart disease.

Breathing pattern is also a characteristic of maternal relaxation training in prenatal clinics and is considered of great importance during birth. There are undoubtedly other psychophysiological reasons for such a practice, but the calming influence may be caused by the process described above. Breathing control is characteristically used in autogenic relaxation techniques and is necessary for the correct intonation of the 'mantra' used in transcendental meditation. Both of these procedures require a breathing rate of about 6 cycles per minute which is the same frequency as the maximum blood pressure entrainment. The information gained from the spectrum analysis techniques used in this study presents a physiological basis for a decrease in arousal and explains the necessity for controlled breathing in certain relaxation practices.

A further application of the relationship between HRV and breathing pattern is to indicate the state of the autonomic nervous system in certain diseases. Young diabetics have different HRV characteristics from normals, Murray et al (1975). This is considered to be caused by vagal denervation of the heart, but this study had limitations because time series analysis was not used to describe HRV. A viable screening device for the early stages of autonomic neuropathy could be developed by altering the respiratory pattern and noting the change in HRV. Work has already started on continuous monitoring systems of HRV by spectrum analysis in the form of a single-patient microprocessor for use in an intensive care unit. The computer-aided analysis of the cardiac rate signal is described by Brodie et al (1979, 1980) and shown in Appendix 5.1. Thermal entrainment procedures have similarly been used for cardiovascular investigations, Hitchen, Harness and Mearns (1980).

Respiration and thermal entrainment procedures have numerous applications. They may be used to test the integration of the autonomic nervous system, (a) in the deterioration of diabetics by periodic screening, (b) in the different diagnosis of postural hypertension, and (c) for clinical estimation of dose response for anti-hypertensive agents, particularly ganglion blocking drugs. They can also be used to establish the normal responses of temperature control. Entrainment procedures have a place in intensive care to test the adequacy of blood volume replacement and cardiac output. They can also be used to study thermoregulation during work in both industrial and sporting contexts. The extent of hypothermia and related conditions such as immersion-foot and frostbite could be assessed using these techniques. The most important application may be in the quantification of congenital heart disease including central shunts, atrial and ventricular septal defects. Other heart diseases such as acquired pulmonary venous hypertension and cyanotic diseases could be examined similarly. A further application of respiratory and thermal entrainment procedures is to test the many drugs said to improve peripheral circulation. Peripheral vascular disease, particularly microangiopathy (Raynaud's disease) would be typical of the conditions treated by such drugs. An alternative discipline which could utilise these entrainment procedures is psychology. The psychological aspects of concentration and attention may benefit from a greater understanding of the physiological changes associated with respiration and thermoregulation.

This section of the study has shown the inadequacy of drawing detailed conclusions from heart rate variability measures without a full assessment of respiratory involvement. The results have shown how the information content of a simple signal (Figures 3.15 and 3.16) can be greater than originally considered. The development of on-line microprocessing systems will produce a new generation of patient monitoring techniques which should be an invaluable support to medical personnel.

This thesis has shown that psychophysiological measures intercorrelate poorly during conditions of high arousal. This may be explained by examining autonomic innervation. Adrenergic changes mobilise bodily resources and supply energy to the organs in greatest need. The response effectors which have parasympathetic involvement (e.g. heart rate) are more directly involved in energy metabolism. Those which contribute least to metabolic control (sweat glands, cutaneous blood vessels) are exclusively sympathetically innervated. The importance of the variation in autonomic innervation has been expressed by Dykman et al (1963) who suggested that "the level of sympathetic functioning might well determine the limits of parasympathetic variation". This means that response systems which have no cholinergic constraints tend to lack sensitive changes to increased arousal. The response systems that have high cholinergic constraints show normal adrenergic changes but usually increase their response to a further demanding stimulus. This would explain the high initial readings of EDA in the present study (no parasympathetic control), the graduated respiratory frequency results (limited cholinergic control) and the insignificant differences shown in the heart rate readings (substantial cholinergic control), Table 4.2. Arousal determines the level of body function, but the pattern of the sympathetic and parasympathetic nerve tuning will determine the specific regulatory actions. This can be illustrated particularly well by examining mean heart rate which is under the dual innervation of the adrenergic and cholinergic (vagal) divisions of the ANS. This innervation of the SA node is rarely of equal magnitude. Robinson et al (1966) and Power (1975) agree that the cholinergic influence on mean HR is dominant at rest. The increase in HR during mild exercise is caused mainly by a decrease in parasympathetic activity. Cardiac acceleration at higher work levels also involves sympathetic stimulation. Robinson et al (1966) have shown that baroreceptor sensitivity remained unaltered during exercise. The responsiveness of the parasympathetic nerves must therefore be influenced by the CNS. This means that heart rate is increased under exercise conditions by a progressive change from vagal and cholinergic dominance to adrenergic dominance.

The autonomic influences on HR and HRV are more complex during mental work because the metabolic requirement is not so pronounced. The alterations in HR appear to be vagally mediated when there is a close relationship between HR and somatic activity, Obrist et al (1975). The non-vagal influences on the heart become predominant when this cardiac/somatic relationship breaks down. An invaluable index of the association between psychological stress and sympathetic nerve action could be the cardiac/somatic independence. Figure 5.5 illustrates this relationship. Sympathetic nerve activity increases more during mental exertion in subjects with a low initial level than in controls, Blohmke, Schaefer and Stelzer (1967). This indicates that resting level influences sympathetic nerve action. The low resting heart rates characteristic of athletes is caused by reduced adrenergic and increased cholinergic activity, Ekblom, Kilblom and Soltysiak (1973). These statements support the suggestion that the breakdown in the cardiac/somatic relationship may be a useful indication of sympathetic activity.

In conclusion, certain arousal sub-systems have in-built controls (parasympathetics) which give the system sensitivity. This allows an extreme stimulus to produce an appropriate response due to the response capacity not being exceeded previously. With mental work the cardiac/somatic relationship is more important in modelling the cholinergic/adrenergic balance.

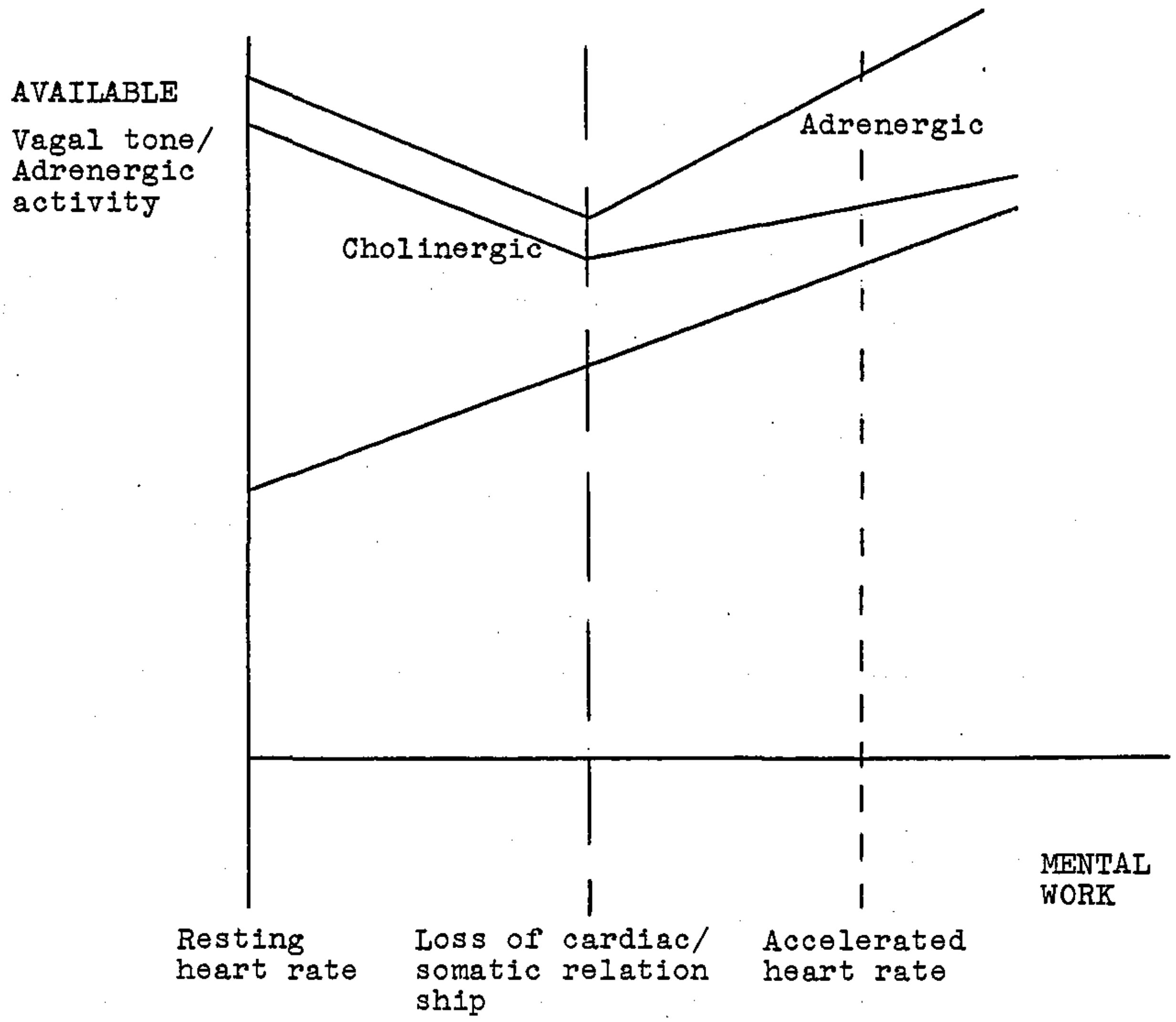


Figure 5.5 - The relationship of cholinergic/adrenergic influence during mental work.

The increase in oxygen utilisation during mental tasks (see Table 4.2) was an original finding of this study. Obrist (1976) clearly respects the potential of this measure to support his cardiac-somatic model. He states that "even if we were able to measure oxygen consumption, I am not sure that our technology is sufficiently advanced to detect what would have to be very minute changes in V_{O_2}." The replacement of the open circuit systems by methods of continuous analysis, Brodie et al (1978) and the development of micro-electronic techniques, Brodie, Humphrey and de Looy (1978), advanced the technology to a state where changes in V_{O_2} became significant. Somatic involvement was assessed before these recent developments by measurements of general activity, eye blink rate and chin EMG, Obrist et al (1974). Oxygen consumption provides a more direct measure of somatic activity than those methods used by many psychophysiological workers. Increased oxygen consumption during high levels of arousal suggests greater striated muscular activity. A further cause for an increase in oxygen utilisation however, is the requirement of the RAS and the CNS in general. The total oxygen consumption of the brain is about 50 ml min^{-1} which if expressed in terms of blood flow per 100g, substantially exceeds that of powerfully contracting muscle, Keele and Neil (1965). This makes the metabolic rate of nerve cells extremely high. The cerebral blood flow is almost identical (600-900 ml per minute) with the total skeletal muscle blood flow at rest. Venous blood leaving the brain is more extensively reduced than elsewhere in the resting body, thus the cerebral blood demands as much or more of the available oxygen than the striated musculature. This being so, the brian and musculature could both be expected to receive a proportion of the increased oxygen consumption. This increased oxygen utilisation during high arousal levels is compatible with Howard and Scott's (1965) conclusions. They considered that failure to master psychological problems used more energy than would have been the case if mastery had been achieved. Excessive energy utilisation thus occurs in the conflict situation which is often the hallmark of stress. Change of habits can also cause increased oxygen utilisation. This was observed in stressed rats as increased grooming and postural changes. Excessive pacing up and down before an important meeting may be the equivalent in humans. The present study was designed to eliminate increased movement during the mental tasks by ensuring that the subjects pressed the microswitches randomly during the basal and recovery conditions. More detail concerning oxygen utilisation can be deduced from a further measure, that of inspired volume, V_I. Inspired volume did not contribute to the increased V_{O_2}, and therefore the percentage oxygen in expired air (F_{E,O_2}) must have caused the difference. It would be difficult to state whether changes were occuring at cellular, vascular or alveolar levels without sampling blood P_{O_2}, but it is not caused by adjustments in external respiration.

The two measures of heart rate (H_f) and respiratory frequency (R_f) were isolated on one factor during physical work, Figures 4.19 and 4.20. The body provides chemoreceptors to monitor the bicarbonate values in the blood. The available carbon dioxide and V_{O_2} would therefore be expected to have a fairly close relationship with the other two measures (H_f and R_f) involved in the control of oxygen transportation. V_{O_2}, however, never loads on the same factor as H_f and R_f. This dissociation suggests that under certain conditions the increased oxygen utilisation has its own <u>modus operandi</u> which is not associated with other aspects of the oxygen transportation system. This is a further example of independence between arousal subsystems.

The measurement of oxygen consumption gives an opportunity to consider further the cardiac-somatic relationship for demanding physical and mental tasks. Obrist (1963) considers that the cardiovascular and somatic musculature can be so finely tuned or coupled that the least alteration in somatic activity will be accompanied by an equally discrete alteration in heart rate. Elliot (1974) even suggests that "the heart provides in one muscle a picture of the total somatic involvement at any given time." These simplistic statements would only apply over a limited physiological range and require substantial modification to concur with the present results. Obrist (1976) modified his earlier conclusion to state that

> "when the heart is under vagal control it is directionally linked with somatic activity. When under greater sympathetic control it is directionally independent of concomitant somatic activity."

This now acknowledges the existence of cardiac-somatic uncoupling under certain conditions. The literature on uncoupling shows a consistently higher heart rate during conditions of extreme arousal than would be expected from V_{O_2} measurements, Blix et al (1974), Stromme et al (1977), Cohen (1973) and Hahn and Slaughter (1971). The results of this study during the mental work showed the opposite relationship. Oxygen uptake increased whereas heart rate remained the same.

The first explanation for this is that the level of metabolic changes, even though showing statistically significant differences, are still so near baseline values that the mechanism which causes the discrepancy between H_f and V_{O_2} does not operate. The expected mechanism would involve an increase in sympathetic or decrease in parasympathetic innervation. The autonomic nervous system produces a heart rate in excess of somatic requirements at high levels of arousal. The lack of heart rate increase during the present experimental conditions suggests limited autonomic involvement. The observed metabolic adjustments must have required some form of circulatory adaptation during the mental load, particularly as the response continued over the full 10 minute experimental period, (Table 4.2). An alternative explanation is that the adrenergic action on the heart is maintained, but the sympathetics are having their influence on the contractile force of the heart by acting primarily on the AV node and the Purkinje fibres. The cardiac output could be increased in this way to supply the needs of the musculature without a change in heart rate.

The implications of this proposition particularly apply to cardiac rhythm. Any dramatic change of adrenergic influence may cause the AV node to dominate the heart rhythm. This will alter conduction time which is normally measured on the electrocardiogram as the interval between the top of the P wave (AV node excitation) and the beginning of the QRS complex (start of the invasion of the ventricles). A shortened P-R interval may indicate that the impulse has arisen in the AV node. The ventricles would contract sooner than normal causing the heart to become inefficient. Such a condition may well be associated with cardiac failure. This contention is supported by the many instances of heart attack during situations of high sympathetic involvement.

Figure 5.6 summarises the proposed mechanisms. Stage 1 is the observation of the present study. The V_{O_2} exceeds that expected from the normal H_f/V_{O_2} relationship during psychological load and at low heart rates. It is suggested that this is a response to a metabolic demand in which an increased contractile force produces the required cardiac output. Stage 2 is the cardiac-somatic relationship in which H_f/V_{O_2} ratio is in accord, and Stage 3 is when the parasympathetic restraint is lifted and H_f increases disproportionately. The point at which cellular metabolism and cardiovascular adjustments are closely linked, (Stage 2, Figure 5.6) could indicate internal organisation in which performance is at an optimum. The disequilibrium caused by cardiac-somatic uncoupling (Stages 1 and 3, Figure 5.6) produces 'noise' as the body attempts to restore homeostasis. The result is an inefficient use of available energy with a consequent diminution in performance. The involvement of the metabolism could be an alternative explanation for the proposals of Cooper (1973) who considered the 'signal to noise' ratio as the basis for changes in performance during arousal. Future investigation should examine performance in the context of the heart rate/oxygen consumption ratio. Performance levels during these "additional heart rate" conditions become important when life or expensive equipment is involved. Human error during

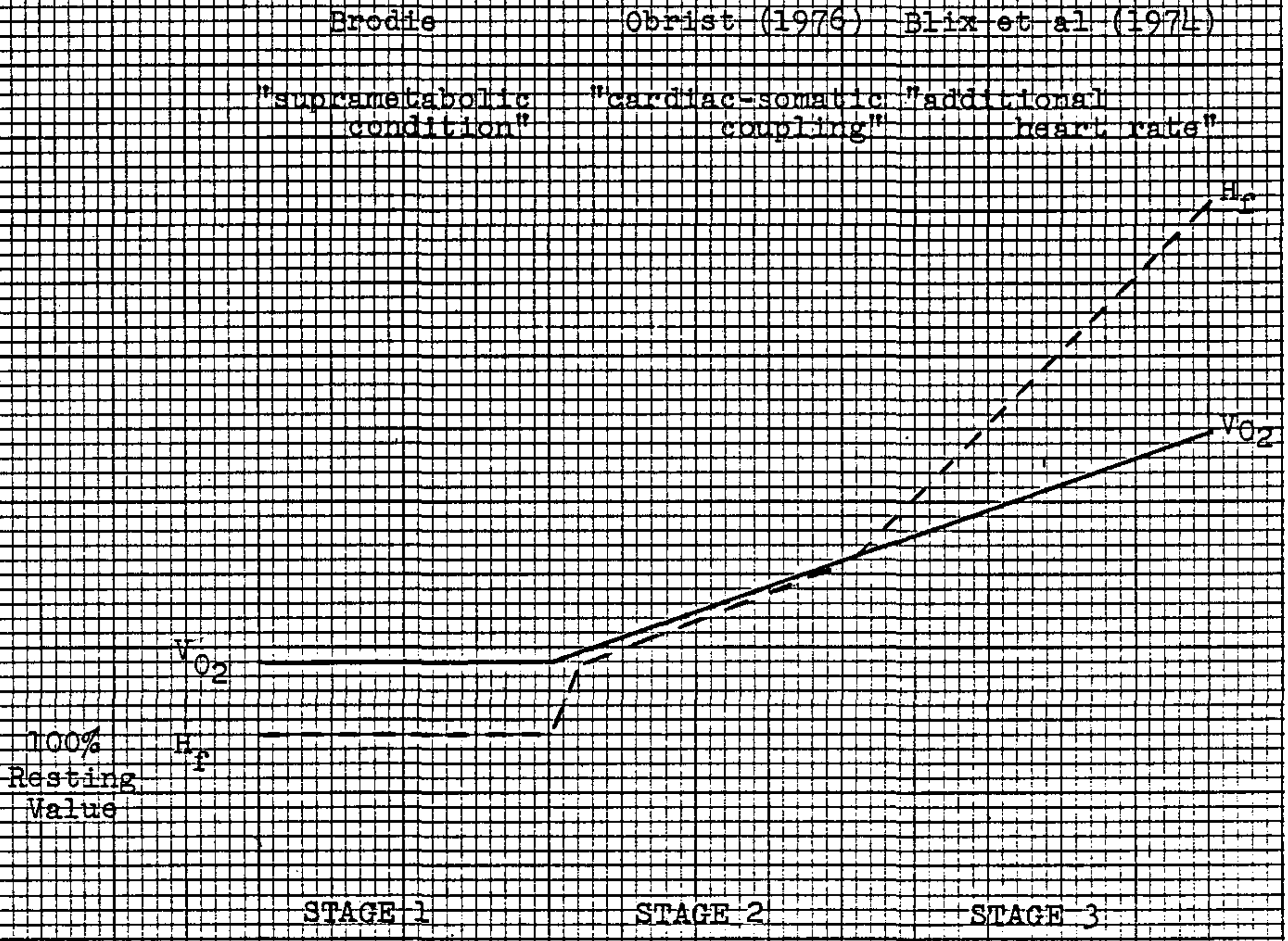


Figure 5.6 - A summary of the mechanisms relating H_f to V_{O_2} during mental work.

activities such as piloting aircraft or deep sea diving may be linked with specific physiological episodes. A subject may be considered at risk when the heart rate is in excess of that required for metabolism. The stress stimulus should then be reduced. The consequence of human error is so severe in certain jobs, that an investigation into the physiological stress responses associated with cardiac failure would be well worthwhile.

The conclusions to be drawn from this part of the discussion involve the relationships between oxygen consumption and mental and physical work. Hitherto it may have been reasonable to consider oxygen consumption was related directly to somatic activity, and that it reflected other correlates of metabolism such as mean heart rate and respiratory frequency. This thesis has shown that there are situations when neither of these statements are true. The change in oxygen consumption during mental work is closely associated with internal respiration. The alteration in the cardiac/somatic relationship involves the sympathetic nervous system and this has implications for arousal thresholds and the potentiality for human error in skilled tasks.

Individual differences are a dominant feature of this study and may indicate the way people use their energy stores. It is proposed that at low levels of arousal, energy is mainly in the form of potential energy. Metabolic processes are minimal and kinetic energy is only sufficient for basic requirements. The variability of response at low levels of arousal will be influenced by the capacity of individuals to store energy. Individual physiological mechanisms may use the available energy uniquely and this will cause the different responses of the arousal subsystems. The resevoir of potential energy will be converted into kinetic energy as the stimuli become more demanding. This will reduce the variability of the responses. This model complements the ideas of Welford (1973) and Cooper (1973) concerning the lowering of synaptic resistancies. The limited availability of kinetic energy at lower arousal levels means that few cells exceed the threshold levels required for a co-ordinated neuronal activity pattern. Adequate supplies of kinetic energy are available at higher arousal levels; more synaptic connections are made and the neuronal activity patterns are improved. The system is swamped with kinetic energy at the highest arousal levels and this causes a reduced efficiency in the brain with a consequent reduction in performance.

The different responses of individual measures can also be explained in terms of their homeostatic requirements. The importance of homeostasis was recognised by Cannon (1939) and by Freeman (1948) who considered that:

> "in psychophysiological assays the most important feature of the organism is its tendency to maintain dynamic equilibrium."

The response may be minimal at lower levels of arousal because homeostasis is largely unaffected. The response will aim to reduce or remove the effect of the stimulus at higher levels of arousal. The different arousal subsystems must be considered relative to their importance in maintaining homeostasis. This suggests the possibility of a response hierarchy, with certain measures responding in an ordered manner, reflecting homeostatic needs. A measure that has little influence on metabolism would respond early in the hierarchy (Table 4.2), when the levels of arousal were low and metabolic requirements minimal. One of these "early responders" in the response hierarchy would be EDA. The place of EDA in the response hierarchy is supported by Epstein, Boudreau and Kling (1975) who have shown that EDA is more sensitive to cognitive demands than motor demands. EDA responds before a commitment to restore homeostasis is required. Those measures which reflect homeostatic adjustments operate more significantly as arousal levels increase. The observed lack of relationship between the different arousal subsystems (Figure 4.18), was the net result of this response hierarchy based on homeostatic needs.

The implications of this postulate is that each individual requires a specific profile based on homeostatic responses to a range of stimuli. Such a profile would be a valuable diagnostic tool, and useful in assessing the severity of a stress stimulus or the implications of a stress response. Sport scientists often compare psychophysiological responses during pre- and post- competitive states without normative values on their individual athletes. A more productive strategy might be to establish psychophysiological measures under basal conditions and then involve the sports coach in both simulation and real competitive situations. This fundamental ethos of "knowing your subject" would apply equally to the clinician's approach to a psychosomatic patient and to the industrial psychologist dealing with an executive displaying symptoms of stress.

Conditions of persistent, high mental and physical load are not necessarily harmful, although many studies imply that this is the case. Certain people find great satisfaction in work which involves regular, demanding challenges. The satisfaction may be related to the physiological changes associated with catecholamine release. Such people develop a lifestyle in which their bodies demand autonomic disequilibrium on a regular basis. A change in lifestyle may cause 'withdrawal symptoms' which produce more problems than the conditions of apparent stress to which they had adapted. Support for this hypothesis comes from the life expectancy figures at retirement. Those individuals who replace work with few challenging alternatives die earlier than those who find employment or simply do not retire. The normal research strategy is for people with mentally demanding occupations to be studied during their work. A more profitable alternative for future research may be to examine such people when they are prevented from working. The heart surgeon or television news producer who thrives on the challenges of his job may suffer dramatically from not obtaining a regular increase in catecholamine excretion. The consequences of this would be important when faced with re-employment, redundancy or retirement. An alternative method of providing the required autonomic disequilibrium may be physical activity. Future research needs to investigate the appropriate 'replacement therapy' for people in most need.

The experimental work in this study has demonstrated repeatedly the limitations of a generalised arousal response. This is supported by the independence of the cardiac measures of rate and variability, and the variety of relationships shown in the factor analysis. The consistent occurence of individual differences for each measure also shows that a generalised arousal system has limited validity. The reasons for the independence of arousal subsystems have already been discussed. They include differing degrees of cholinergic/ adrenergic control, the requirements of the organism to restore homeostasis and the availability of potential and kinetic energy. The combined effect will be for individuals to trigger an appropriate arousal subsystem response at different times. An alteration in stimulus characteristics, both between and within mental and physical work, also causes different parts of the total system to operate. There are a number of other factors which contribute to the individuality of the organism irrespective of the stimulus. A convenient division is into extrinsic and intrinsic factors.

Extrinsic factors are not innate characteristics of the organism but influence the stimulus situation from the environment. They include the climatic environment, present events, social norms and external motivation. Intrinsic factors involve the human organism and represent more innate characteristics. Some may have been accquired through experience, learning and because of past events. Genetic endowment, the sensory processes, the intention of the organism, Blatt (1961), internal motivation, and the perception of threat, Lazarus and Baker (1956) are all examples of intrinsic factors. Intrinsic factors are analogous to a 'trait', whereas extrinsic factors will cause a specific 'state'. An important intrinsic factor is the personality of the individual. Personality represents a common characteristic of intrinsic factors, namely direct action upon both the stimulus situation and the other stages of the total system. Both extrinsic and intrinsic factors dictate the context of the stimulus for a given individual. The stimulus situation is the first major stage in developing a model to describe human responses to demanding mental and physical work, and is shown in Figure 5.7.

The next stage in the system is that of perception. The organism, by constant reference to intrinsic factors ((i) on Figure 5.7), perceives the stimulus situation in a particular manner and the result is an appropriate response strategy. A further influence upon the perception stage in the total system is the level of arousal, which is dependent upon RAS activation and cortical tuning. Teichner (1968) has

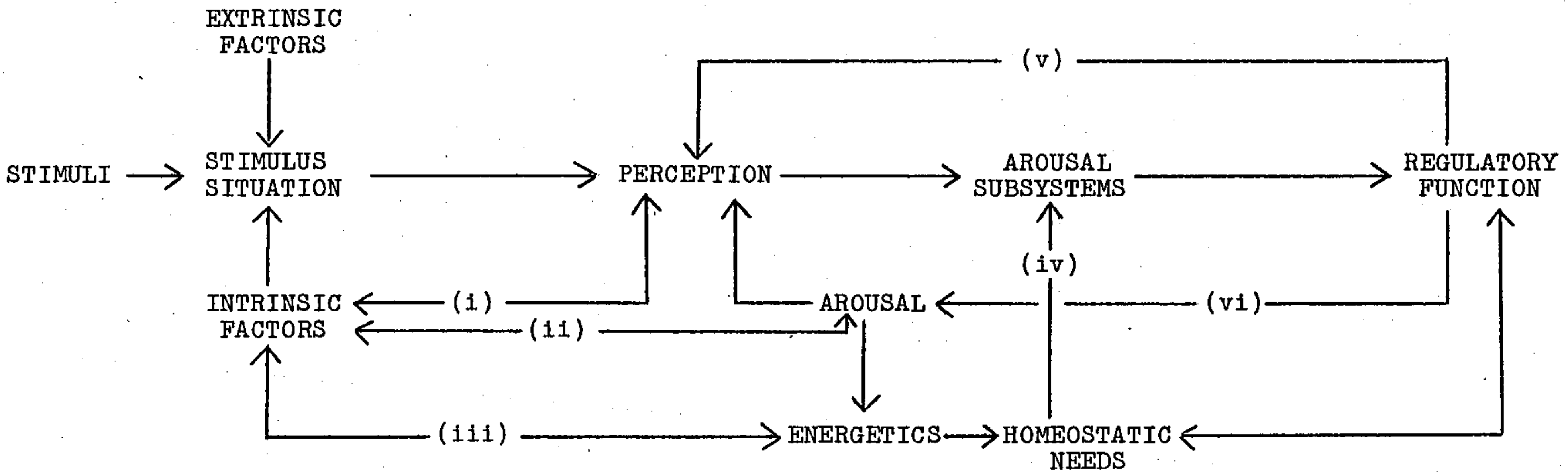


Figure 5.7 - A model of human responses to specific stimuli

suggested that cortical tuning is influenced by certain intrinsic factors such as genetic endowment and learning, so it is necessary to place a feedback loop between these elements of the model as (ii) in Figure 5.7. The level of arousal influences the <u>energetics</u> balance which is also related to personality, Freeman (1948). This is included in the model as a further feedback loop to the intrinsic factors, ((iii) in Figure 5.7). Energetics is a key feature of the system with its relationship to the homeostatic needs of the organism of major importance.

Human responses involve the triggering of <u>arousal subsystems</u>, each one having specific features. The different response latencies and response limits, the different degree to which they are subservient to homeostatic needs, the different way that each individual perceives the stimulus situation, all cause confusion if they are used interchangeably. Psychophysiological responses have a <u>regulatory function</u> to maintain homeostasis, or should the stimulus be sufficiently demanding, to restore homeostasis. This regulatory function means that the response is not necessarily the end point in the system, but is involved in the control of other stages. This is clearly the case when respiration, blood pressure and temperature influence cardiac variability. Heart rate is an independent arousal subsystem which has a regulatory function upon cardiac output and is also involved in the maintenance of adequate blood pressure. The changes in metabolism which were shown during mental work similarly support the notion of different arousal subsystems acting in a regulatory manner. This is because the capacity of a single subsystem such as oxygen absorbtion at the alveolar interface, may not be adequate to bring about the required change. This has been shown in the model as a by-pass loop between homeostatic needs and the regulatory function.

The relationship of the arousal subsystems to homeostatic needs is included in the model ((iv) in Figure 5.7), as is feedback from the regulatory functions to perception, ((v) in Figure 5.7). Excessive sweating and loud, rapid heartbeats would be examples of a regulatory function acting on individual perception. Doctor et al (1964) and Lacey (1967) state that autonomic afferents from heart rate changes feed back to the RAS producing modulation of activation level. A further feedback loop ((vi) in Figure 5.7) accomodates this evidence.

The association between homeostatic needs and the perception of a stimulus situation is critical. The coping mechanism of the arousal subsystem response may not be adequate if a great disparity exists. An imbalance between the perception of the stimulus situation and the appropriate coping strategy is the condition commonly called stress. Figure 5.7 shows that the intrinsic factors, the level of arousal, and the regulation of the arousal subsystems may all contribute to the potential imbalance. These factors have made stress an elusive concept, and it may be better to consider stress in the fractionated manner proposed in the model.

This study has shown that a generalised response to changing levels of arousal can be considered only at a superficial level. The search for a single measure which could indicate some specific level of arousal should cease. The direction of future study should be to develop knowledge of the relationships between the several arousal subsystems. This knowledge could be applied to stress induced diseases and stimulus situations involving large excretion of catecholamines. The relationship between such conditions and heart attacks requires further research and would have special relevance in preventative medicine and the study of psychosomatic illness.

The final conclusions from this thesis relate to the integration of psychological and physiological domains. The complex relationships that exist between the arousal subsystems produce clear individual differences in psychophysiological response patterns. The information gained in this study of human regulatory systems and processes explains how inconsistencies and ambiguities have arisen in previous work. This thesis has shown that certain psychophysiological measures have been used previously to support psychological postulates without sufficient scrutiny of the underlying physiology. The use of a cardiovascular measure as an index of both performance and involvement is an example of this inadequacy. Human responses to demanding mental and physical work are complex, and although this thesis has partially established the unique properties of the different psychophysiological arousal subsystems, further study will be required to predict human action with better precision. The notion of a stimulus situation is of benefit in understanding human responses, as are the factors which influence the stimulus situation in the proposed model. It is clear that future work on human psychology and physiology must benefit from a close interaction between both disciplines.

Perhaps the following statement implies the necessity for such interaction:-

"No enquiry that begins or ends in the intellect is worth treating seriously"

Leonardo da Vinci,
(1452 - 1519)

and the important relationship between physical and mental activity is undoubtedly considered in the quotation:-

"Walking to and fro stimulates the mind"

Herodotus
(484 - 409 B.C.)

SECTION SIX

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SECTION SEVEN

THE APPENDICES

Appendix 1.1

Electrophysiological responses in the stress process

Date	Researcher(s)	Response
1973	Laurig	Mean Heart rate, heart rate variability
1971	Peake and Leonard	Mean heart rate
1972	Levi	Mean heart rate, ECG
1970	Danev and Wartna	Mean heart rate, heart rate variability
1964	Haida and Popper	Mean heart rate
1970	Craig and Wood	Mean heart rate
1959	Deane	Mean heart rate
1971	Janis	Heart rate variability
1968	Kalsbeek	Heart rate variability
1964	Fenz	Electrodermal activity
1964	Fenz and Epstein	Electrodermal activity
1970	Danev and Wartna	Electrodermal activity
1940	Freeman	Electrodermal activity
1971	Janis	Electrodermal activity
1967	Taylor and Epstein	EDA and mean heart rate
1969	Glass, Singer and Friedman	Electrodermal activity
1969	Manigault, Valentin and Tarriere	Electroencephalography
1970	Kelly, Brown and Schaffer	Electromyography
1967	Blohmke et al	Electrocardiography
1967	Blohmke, Schaefer and Stelzer	Electrocardiography

Appendix 1.2

Behavioural responses in the stress process

Date	Researcher(s)	Response
1969	Fitts and Posner	Reaction Time, tracking tasks, learning tasks
1957	Broadhurst	Rats learning maze
1953	Deese, Lazarus and Keenan	Learning curves
1964	Kalsbeek	Errors on multiple tasks
1970	Danev and Wartna	Errors on multiple tasks
1956	Davidson, Andrews and Ross	Errors of ommission
1967	Diamond	Circle filling and transposition of symbols
1970	Martenuik and Wenger	Pursuit rotor
1961	Ryan	Stabilometer performance
1968	Carron	Stabilometer performance
1962	Berkun et al	Radio repair
1955	Castaneda and Palermo	Choice reaction time
1950	Mackworth	Vigilance tasks
1957	Ulrich and Burke	Gross mechanical efficienc

Appendix 1.3

Metabolic responses in the stress process

Date	Researcher(s)	Response
1972	Carlson, Levi and Oro	Mobilisation of free fatty acids
1956	Board, Persky and Hamburg	Hypertrophy of adrenal cortex
1971	Levine	Increase in ACTH production
1972	Levi	Increase in adrenaline excretion
1962	Berkun et al	17-hydroxycortico-steroid increase
1949	Brody	Protein bound iodine
1952	Hertzel, de la Haba and Hinkle	Protein bound iodine

Appendix 1.4 The use of EDA as a measure of autonomic activity

Author(s)	Date	Electrodermal Measure	Independent Variable	Comments
Craig	1968	SC	Imagines, vicarious and	SC could not distinguish between different types of stress although an increase in conductance was observed.
Bowers	1971	GSR	High/low shock	? usefulness and ethics of electric shock treatment for extrapolation to non-laboratory situations. Also potential intrusion of shock to underlying electrophysiological measure.
Brodsky	1969	GSR	Socio-economic status	Complex sociological factors make any causal explanation doubtful.
Bernal & Miller	1971	GSR	Variety of sensory stimuli	Comparison of normals v schizophrenics with greater responsivity of normals to early trials.
Wallace & Fehur	1970	SR	Distraction condition	Small subject number (n=10) No counterbalanced design.
Volavka, Matousek & Roubicek	1966	GSR	Mental arithmetic and eye opening	No rationale given for GSR 'as a monitor of the general level of activation'.
Tizzard	1968	SPR	Response to sounds in normals and subnormals	SPR used as a measure of responsiveness. Relationship between EDA and responsiveness assumed and only considered in terms of habituation.
Stennett	1956	SC	Tracking tasks at various intensities	Rationale based on previous work suggesting relationships of arousal to conductance level.
Shaw & McLachlan	1968	Log Conductance	Sensory Tasks	EDA assumed to be related to arousal; no rationale given.
Ryan & Ranseen	1944	SR	Muscular activity	Restricted by early equipment. That EDA indicates changes in the functional response of the sympathetic system not proven.

Appendix 1 (cont)

Author(s)	Date	Electrodermal Measure	Independent Variable	Comments
Fenz & Craig	1972	SC	Sleep deprivation	Expected relationship discussed inadequately.
Epstein & Rouperian	1970	SC	Induced anxiety	No rationale for EDA, but examined the aspect of individual coping strategies.
Eason, Bearshall & Jaffee	1965	SC	Vigilance task	Relationship of EDA to activity level of sympathetic branch of the ANS assumed and performances during task related directly to the activation level.
Doctor, Kasway & Nakamura	1964	Spontaneous GSR	Motor Performance	No relationship reported. No account of respiratory pattern influence, although apparently aware of the potential artefact.
Church	1962	SC	Competition	Used as a 'motivational level', but no causal relationship considered.
Burdick	1966	GSR	Neuroticism	Equates various EDA measures with ANS activity without any attempt to justify it.

Appendix 1 (cont)

Author(s)	Date	Electrodermal Measure	Independent Variable	Comments
Roessler, Burch & Childers	1966	Basal slim resistance GSR	Sound and light stimuli	Showed relationship of GSR amplitudes to intensity of stimulation. Failed to show difference between basal and stress condition.
Milosevic	1975	SR	Auditory vigilance	EDA used to measure activation hypothesis with the rationale given for using the measure.
McDaniel, et al	1968	GSR	Cold pressor and reation time	EDA changes commensurate with increased sympathetic activity but with no rationale.
Levinsohson	1955	GSR	Cold pressor and failure stress	Stress responses on EDA observed but used abnormal populations.
Lakie	1967	GSR	Task difficulty	Use of hand contraction considered to produce abnormal results due to increased muscle tension.
Katkin	1965	GSR SR	Threat of shock	Unqualified statement that GSR measures ANS activity.
Hustmyer & Burdick	1965	GSR	Repeat testing	Refers to GSR as a measure of ANS spontaneity in other studies.
Harding, Stevens & Marston	1972	SC	Rate of information processing	Used as autonomic response without qualification.
Glass, Singer & Friedman	1969	SC	Noise	No physiological explanation of habituation.
Frankenhauser et al	1967	SC	Perceptual conflict tasks	Clear relationship between EDA and 'stress', with no reference to the ANS, but simply a physiological index of activation.

Appendix 2.1 - Analysis of variance table from Salford Univeristy Statistical Package NWD5

```
  RESULTS FOR DATA SET NUMBER  1


 ANALYSIS OF VARIANCE

   SOURCE    DF  SUM OF SQUARES    MEAN SQUARE    F

 TREATMENTS  9.     118.117        13.1242       0.109
 ERROR      30.     3625.93        120.864
 ****************************
 TOTAL      39.     3744.05
```

Appendix 3.1 - Program variables used to convert analog signals to digital heart intervals.

TM	(0)	Time of run (secs)
TX	(4000)	max. period without pulse (ms)
TC	(1)	Time constant (sec/½s)
TS	(10)	min. pulse length (ms)
I	(4)	no. of initialising pulses (no.)
VH	(800)	high pulse level (mV)
VL	(80)	low pulse level (mV)

Appendix 3.2 - Spectral analysis of cardiac intervals showing amplitudes corresponding to harmonic numbers

```
                 10/26/10    10/02/77     ICL  1900 STATISTICAL ANALYSIS    XDS3/17

             FOURIER ANALYSIS

  MATRIX      TS1           VARIABLE      CN0001

          COSINE VALUES              SINE VALUES                    AMPLITUDES                   ARC TAN VALUES
  0         .614021E  3
  1         .207155E  1              .126172E  1                    .242554E  1                  .102373E  1
  2         .285696E  1             -.170401E  1                    .332654E  1                 -.103300E  1
  3         .107688E  1             -.123602E  1                    .163934E  1                 -.716701E  0
  4        -.195253E  1             -.602580E  0                    .204340E  1                  .127146E  1
  5         .129091E  1              .291106E  1                    .318445E  1                  .417394E  0
  6         .244210E  1              .148399E  1                    .285764E  1                  .102475E  1
  7        -.373119E  1             -.161806E  0                    .373469E  1                  .152746E  1
  8         .485805E  0             -.983604E  0                    .109703E  1                 -.458758E  0
  9        -.503426E  0              .921404E  0                    .104996E  1                 -.500051E  0
 10         .142592E  1              .163675E  1                    .217076E  1                  .716668E  0
 11        -.239351E  0             -.202504E  1                    .203914E  1                  .117650E  0
 12         .391474E  1              .113643E  0                    .391639E  1                  .154178E  1
 13         .197517E  1             -.298351E  1                    .357808E  1                 -.584756E  0
 14         .139429E  1             -.276812E  1                    .309944E  1                 -.466600E  0
 15         .276168E  1              .239443E  1                    .367029E  1                  .660075E  0
 16        -.131175E  1              .130046E  1                    .184713E  1                 -.789722E  0
 17         .637539E  0              .162158E  1                    .174240E  1                  .374596E  0
 18        -.697231E  0             -.448393E  0                    .828967E  0                  .999283E  0
 19        -.206971E  1             -.505564E  1                    .545290E  1                  .385571E  0
 20         .197456E  1             -.228128E  1                    .301714E  1                 -.713452E  0
 21         .984613E  0             -.424294E  1                    .435569E  1                 -.228023E  0
 22         .731175E  0             -.652518E  0                    .979998E  0                 -.842182E  0
 23        -.557530E  0             -.896487E  0                    .105571E  1                  .556371E  0
 24        -.464070E  0             -.341442E  1                    .344581E  1                 -.135087E  0
 25        -.163426E  0             -.184211E- 1                    .164461E  0                  .145855E  1
```

Appendix 3.3 - Stages involved in producing a spectrum analysis graph plotalgorithm.

(1) Read in data
(2) Set constants
(3) Form real numbers from integers
(4) Remove DC component
(5) Rescale and form root mean square value
(6) Fast fourier transform subroutine
(7) Power spectral density values
(8) Draw raw power spectral density (PSD)
(9) Obtain smoothed array
(10) Additional smoothing if required
(11) Form sum of PSD components
(12) Set values for drawing smoothed PSD
(13) Written output
(14) Draw smoothed PSD

Appendix 4.1 - Self evaluation questionnaire of perceived feeling.

Name Date Time

Directions: A number of statements which people have used to describe themselves are given below. Read each statement and then put a circle around the appropriate number to the right of the statement to indicate how you feel right now, that is, at this moment. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	NOT AT ALL	VERY SLIGHTLY	SOMEWHAT	FAIRLY	MODERATELY SO	QUITE DEFINITELY	VERY MUCH SO	COMPLETELY
1. I feel good								
2. I feel under pressure								
3. I feel unhappy								
4. I feel rested								
5. I feel uncomfortable								
6. I am relaxed								
7. I feel unpleasant								
8. I am tense								
9. I am content								
10. I feel lively								
11. I feel uneasy								
12. I feel fine								
13. I feel unwell								
14. I feel cheerful								

Appendix 4.2 - Rank order for each subject for intensities, recoveries and (intensity-recovery) for mental and physical conditions for EDA.

	MENTAL									PHYSICAL								
	INTENSITIES			RECOVERIES			INT-RECOV			INTENSITIES			RECOVERIES			INT-REC		
GRIF	1	2	3	1	2	3	2	1	3	1	2=	2=	2	3	1	3	2	1
MUN	1	2	3	1	2	3	3	1=	1=	3	1	2	1	3	2	1	3	2
FIR	1	3	2	1	2	3	2	1	3	2	3	1	2	3	1	2	1	3
PYE	1	2	3	1	2	3	1=	1=	3	3	2	1	2=	1	2=	1=	1=	3
PIL	1	3	2	1	2	3	2	1	3	3	2	1	3	2	1	3	1	2
WOOD	1	3	2	2	3	1	3	2	1	3	2	1	2	3	1	1	3	2
DAN	1=	1=	3	1	2	3	1	2	3	2=	2=	1	1	2	3	1	2	3
STAD	1	2	3	1	2	3	3	1	2	3	1	2	2=	1	2=	1=	1=	1
ZAY	1	2	3	1	3	2	2	3	1	1	2	3	3	1	2	2	1	3
GREG	3	2	1	3	1	2	3	1	2	1	3	2	3	1=	1=	3	1	2
FEN	3	2	1	3	1	2	3	1	2	3	2	1	3	2	1	3	1	2
BUT	1	3	2	2	1	3	3	1	2	3	1	2	1	3	2	1	3	2
CLEM	1	3	2	1	2=	2=	1=	1=	3	3	2	1	1	2	3	1	2	3
PORT	1	2	3	1	2	3	1	3	2	3	2	1	3	2	1	2	3	1
EAST	3	1	2	1	2	3	1	2	3	3	2	1	3	2	1	3	2	1
BROD	1	3	2	2	1	3	2=	1	2=	3	2	1	3	2	1	3	2	
COOK	1	2	3	1	2	3	2	1	3	3	2	1	3	2	1	3	2	1
PHEL	3	1=	1=	1	2	3	1	2	3	1	3	2	3	1	2	3	1	2
PRIC	1	3	2	1	3	2	1	2	3	3	2	1	3	2	1	3	2	1
TOML	2	1	3	3	2	1	3	2	1	3	2	1	1	2	3	1	2	3
DAVI	1	3	2	1	3	2	1	3	2	2=	2=	1	2	1	3	2	1	3
TOMA	1=	1=	3	1	2	3	1	2	3	3	2	1	3	2	1	3	2	1
JONE	2	3	1	2=	2=	1	2	1	3	3	2	1	3	2	1	3	2	1
WORR	1	2	3	1	2	3	3	1=	1=	3	1	2	1	2	3	1	2=	2
X̄	1	2	3	1	2	3	2=	1	2=	3	2	1	3	2	1	1=	3	1
	Intensity 1	Intensity 2	Intensity 3	Recovery 1	Recovery 2	Recovery 3	Int1-Recov 1	Int 2 - Recov 2	Int 3 - Recov 3	Intensity 1	Intensity 2	Intensity 3	Recovery 1	Recovery 2	Recovery 3	Int 1 - Recov 1	Int 2 - Recov 2	Int 3 - Recov 3
= X̄ pattern			9			14			15			15			10			6

Appendix 4.3 - Specimen factor analysis from Honeywell FACTAN program showing the correlation matrix, eigenvalues and the proportion of the total variance.

```
THE CORRELATION MATRIX IS

   1.000000   -0.199037    0.310344    0.221424    0.031456   -0.401530
   0.154279    0.037357   -0.094060

  -0.199037    1.000000   -0.053308   -0.516877   -0.253266    0.27765
  -0.139232   -0.009378   -0.049755

   0.310344   -0.053308    1.000000    0.143880    0.193374   -0.067721
   0.071615   -0.077520    0.016431

   0.221424   -0.516877    0.143880    1.000000    0.098233   -0.27497
   0.169563   -0.015929    0.134143

   0.031456   -0.253266    0.193374    P.098233    1.000000   -0.29567
  -0.047930    0.180192    0.216994

  -0.401530    0.277655   -0.067721   -0.274978   -0.295673    1.00000
  -0.209116    0.209632    0.123565

   0.154279   -0.139232    0.071615    0.169563   -0.047930   -0.20911
   1.000000   -0.081222   -0.056181

   0.037357   -0.009378   -0.077520   -0.015929    0.180192    0.20963
  -0.081222    1.000000    0.215948

  -0.094060   -0.049755    0.016431    0.134143    0.216994    0.12356
  -0.056181    0.215948    1.000000


 EIGENVALUES ARE
   2.238691    1.495471    1.105320    0.965584    0.892736    0.84524
   0.694076    0.459922    0.302953


 PROPORTIONS OF TOTAL VARIANCE ARE
   0.248743    0.166163    0.122813    0.107287    0.099193    0.09391
   0.077120    0.051102    0.033661
```

Appendix 4.4. - Specimen factor analysis from Honeywell FACTAN program showing the factor loadings and the rotated loadings.

```
THE FIRST   3 FACTORS ARE CONSIDERED SIGNIFICANT

HOW MANY FACTORS DO YOU WISH TO ROTATE ?
=3


FACTOR LOADING    1 IS
   0.604776   -0.679619    0.389354    0.679069    0.413030   -0.69328
   0.372450   -0.085908    0.031406


FACTOR LOADING    2 IS
  -0.215497   -0.198123   -0.016505    0.143635    0.542933    0.24680
  -0.309308    0.650595    0.717106


FACTOR LOADING    3 IS
   0.396008    0.411414    0.696706   -0.387839    0.270727   -0.02605
  -0.232347    0.105601   -0.065638


INPUT ERROR CRITERION
=.0001


THE VARIMAX CRITERION =
  0.33564446E 02


THE VARIMAX CRITERION =
  0.34404962E 02


THE VARIMAX CRITERION =
  0.34405285E 02


THE VARIMAX CRITERION =
  0.34405286E 02


THE ROTATED LOADINGS ARE

   0.255164   -0.800281   -0.085404    0.783853    0.204156   -0.539523
   0.424352   -0.102678    0.094724

  -0.139918   -0.169313    0.087688    0.118315    0.588392    0.215025
  -0.322230    0.655045    0.703445

   0.695937   -0.035759    0.788851    0.061339    0.388301   -0.452677
   0.066856   -0.046678   -0.125413
```

Appendix 4.5 The correlation matrices between mental and and physical conditions for the measures of EDA, Heart Rate, Oxygen Consumption, Respiratory Frequency and Simple Reaction Time.

	D_{MI}	D_{PI}	D_{MR}	D_{PR}	$\bar{D}_M$	$\bar{D}_P$
D_{MI}	1					
D_{PI}	.82***	1				
D_{MR}	.94***	.79***	1			
D_{PR}	.78***	.93***	.82***	1		
$\bar{D}_M$	.20	.36	.16	.32	1	
$\bar{D}_P$	.01	-.01	.00	-.09	.32	1

*** p<.001

Correlation matrix showing similarities between mental and physical responses for EDA

	D_{MI}	D_{PI}	D_{MR}	D_{PR}	$\bar{D}_M$	$\bar{D}_P$
D_{MI}	1					
D_{PI}	.23	1				
D_{MR}	.72***	.22	1			
D_{PR}	.44*	.74***	.41*	1		
$\bar{D}_M$	-.42*	-.46*	-.34	-.48*	1	
$\bar{D}_P$	-.53**	.10	-.54**	-.39*	-.08	1

*** p<.001

** p<.01

* p<.05

Correlation matrix showing similarities between mental and physical responses to heart rate.

	D_{MI}	D_{PI}	D_{MR}	D_{PR}	$\bar{D}_M$	$\bar{D}_P$
D_{MI}	1					
D_{PI}	.42*	1				
D_{MR}	.91***	.43*	1			
D_{PR}	.45*	.41*	.38	1		
$\bar{D}_M$	.09	-.01	.14	.32	1	
$\bar{D}_P$	.36	.95***	.39	.27	-.06	1

*** $p<.001$
* $p<.05$

Correlation matrix showing similarities between mental and physical responses to oxygen consumption

	D_{MI}	D_{PI}	D_{MR}	D_{PR}	$\bar{D}_M$	$\bar{D}_P$
D_{MI}	1					
D_{PI}	.58***	1				
D_{MR}	.82***	.67	1			
D_{PR}	.63***	.77***	.78***	1		
$\bar{D}_M$	.20	.18	-.07	.01	1	
$\bar{D}_P$	.07	.67***	.07	.32	.54**	1

***$p<.001$
*$p<.01$

Correlation matrix showing similarities beetween mental and physical responses to respiratory frequency.

	D_{MI}	D_{PI}	D_{MR}	D_{PR}	$\bar{D}_M$	$\bar{D}_P$
D_{MI}	1					
D_{PI}	.37	1				
D_{MR}	.69***	.63***	1			
D_{PR}	.47*	.45*	.54	1		
$\bar{D}_M$	.79***	.15	.24	.23	1	
$\bar{D}_P$	-.25	.49*	-.09	-.25	-.10	1

*** $p<.001$
** $p<.01$
* $p<.05$

Correlation matrix showing similarities between mental and physical responses to simple reaction time.

Appendix 5 - Published papers by author concerning this thesis.

5.1 Preprint from Ergonomics (1980)

Cardiac responses to demanding mental load

By M. HITCHEN,* D. A. BRODIE,† J. B. HARNESS‡

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The interbeat interval, peripheral blood flow and respiration waveform of 14 subjects were measured during three mental tests of different intensity and during 10 min recovery time after each test. The signals were analysed using a general statistical package and a spectrum analysis procedure. It was shown that the respiration frequency component moved to a higher frequency during mental tests and returned to its original frequency during the recovery periods. The mean heart rate increased by 15% during the tasks and the heart rate variability decreased.

1. Introduction

Several workers (Kalsbeek and Ettema 1963, Luczak and Laurig 1973, Mulder and van der Meulen 1973, Hyndman and Gregory 1975, Hyndman 1978, Charnock and Manenica 1978) have looked at the effect of mental loading on cardiac rate variability. They have shown that increasing mental load decreases heart rate variability. Charnock and Manenica (1978) looked at the power spectra obtained from the heart interbeat intervals measured under different work conditions. These results show that the frequency component attributed to the respiration rate is small and of no significance. Hyndman (1978) shows that during mental tests the power in the respiratory range moves from approximately 0·25 Hz to 0·35 Hz. This paper reports a study of human responses to demanding mental work and several physiological variables are measured, namely, peripheral blood flow, the electrocardiogram (ECG) and the respiration waveform. The work shows the correlation between the signals and discusses the importance of the respiratory frequency during mental loading and during recovery from the tests.

2. Methods

The experiments were carried out on 14 healthy subjects. These subjects were students and laboratory technicians from Leeds Polytechnic and Bradford University with a modal age of 19 y and a range of 18–24 y.

2.1. *Mental task*

On two occasions each subject was habituated to the experimental situation by participating in similar experiments. On the third occasion the subjects listened to a series of pre-recorded digits through stereo headphones. The digits were presented sequentially in random order. The subject was required to listen for a specific 'odd-even-odd' sequence and on hearing this sequence depressed a microswitch which was held in the left hand. This task was chosen because it requires minimal response movement. The task devised by Brown and Poulton (1961) is demanding but not one that previous experience would assist or inhibit or one in which learning would substantially affect performance during successive repetitions.

Prior to the experiment, the subjects were instructed in the procedure. They were reminded that the digit '0' is an even number and that the final odd digit in a sequence of three could be initiating a second series of three, e.g. 1-4-3-2-7 and requires two responses.

A five minute period prior to the presentation of the recorded digits allowed the subjects to acclimatise to the surroundings. The digits were presented at a rate of one per three seconds for ten minutes then a ten minute recovery period followed. The experiment was repeated with the digits being presented at one per two seconds and finally after another ten minute recovery period, one per second.

2.2. *Collection of data*

The subjects' ECG, peripheral blood flow and respiratory waveforms were recorded on magnetic tape, and the respiration waveform also recorded on paper tape. The peripheral blood flow was measured using a *finger plethysmograph* and the respiratory waveform was measured using a *nasal myograph*. Alternatively an inexpensive method of recording the interbeat interval onto a cassette recorder may be used as ECG waveform analysis is not required. For this, modifications were made to a *Childerhouse heart rate meter* so that the internal loudspeaker was disconnected and the leads to the loudspeaker re-connected to 4 mm sockets. Leads were taken from this to the final amplifier of a *Mingograph 34 recorder*. Thus for every heart beat, as triggered on the 'R' wave of the ECG, an electrical signal of short duration and high amplitude was recorded on the recorder. The signal was then fed from the recorder to a simple domestic cassette recorder and an audio tone recorded on cassette. The sequence of audio tones was filtered to remove 50 Hz noise.

2.3. *Processing the results*

Before the results can be numerically analysed they are processed using the real time computer, namely, a *Ferranti Argus 700E computer*. The computation of the interbeat interval using the real time computer is described by Hitchen, Harness and Mearr (1979). The intervals were then analysed using a *Hewlett Packard 2000E computer*. The sampling of the peripheral blood flow and the respiration waveforms was also executed in a similar manner.

2.4. *Statistical analysis of the interbeat intervals*

The interbeat intervals were displayed both against time and in histogram form using a visual display unit (VDU) connected to the Hewlett Packard. Several statistical properties, e.g. mean, standard deviation, variance, number of reversal points, were also calculated. A full description of these is given by Brodie *et al.* (1979).

2.5. *Spectrum analysis using the fast Fourier transform*

Spectrum analysis is a very commonly used way of analysing signals and the Fast Fourier Transform (FFT) is now widely used to effect spectrum analysis where fine frequency resolution is required. For the method to be used accurately on heart rate values, some method of interpolation must be performed to provide a wave which can be sampled regularly; Luczak *et al.* (1973) explains three commonly used methods. Sayers (1973) derived the spectrum without using any interpolation method and where the variation in heart rate is small, this derivation presents little error. However, the representation is generally incorrect as the data is monotonic but not linear. Hyndman *et al.* (1975) devised a method which depends on the use of low pass filtering of the individual delta pulses representing the cardiac events through a hanning window filter. Chess *et al.* (1973) fitted Chebyshev polynomials to the interval series to remove the slow trends from the data which he felt would dominate the answers and mask the rhythmic variations of interest. Galloway *et al.* (1969) tried Lagrange interpolations of different orders with the effect that the main low frequency peaks remained unaltered and the high frequency band had lower amplitudes. As any sequence of intervals is only a statistical sample drawn out of a hypothetical sequence of infinite extent, the resulting spectrum obtained by analysing a sequence by any interpolation method is a statistical estimate and the errors that are thereby created are unavoidable and greater than the deviation between the results of the different interpolation methods. In view of this it was decided to use one of the less complex methods and the linear interpolation method derived from control theory was chosen and is described by Luczak *et al.* (1973) and shown in figure 1. Under resting conditions the heart beats at about 75 times per minute, so to reach this frequency by spectrum analysis the heart rate variability signal must be sampled at 2·5 Hz or once every 400 ms. Luczak *et al.* (1973) sampled once every 200 ms to take into account the fact that the Nyquist criteria holds only for a sine wave of infinite length. Both Galloway *et al.* (1969) and Mulder *et al.* (1973) decided this to be unnecessary and hence a sampling frequency of 2·5 Hz was chosen.

In practice there can only be a finite amount of data collected. Outside this range of collected data everything is considered to be zero, this is called 'fitting a rectangular window' as it multiplies everything inside by one and everything outside by zero. Other windows simply multiply sections of the series by differing weights, a description of several commonly used windows is given by Ackroyd (1973). The windows have spectra shown in figure 2. Galloway *et al.* (1969) used the hanning or triangular window which

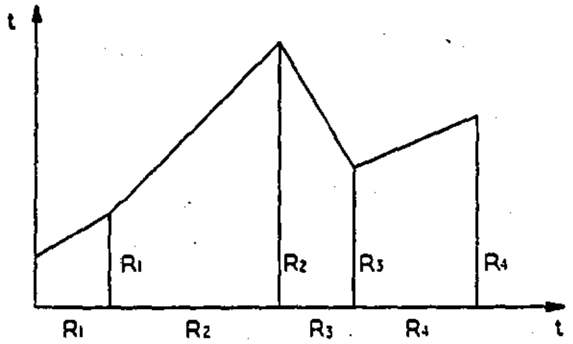

Figure 1. Linear interpolation of the irregular heart beat.

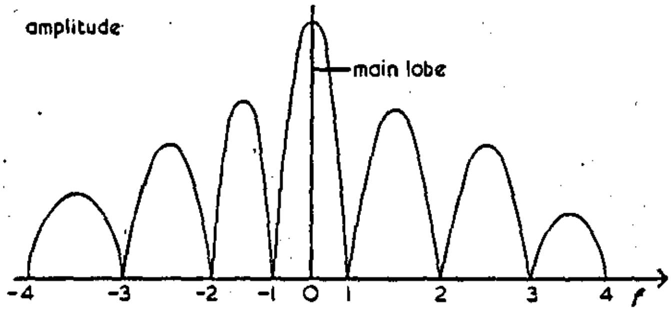

Figure 2. Spectra of windows.

is simple and gave similar results as more complex windows, so it was decided to apply the hanning window to the real and imaginary parts of the Fourier series which proved satisfactory.

3. Results

Although Mulder and van der Meulen (1973) found that there was a large difference between subjects, many of the results presented here are common for all subjects.

3.1. *The histograms and statistical properties*

During mental loading the histograms were less broad because of the decrease in heart rate variability. This is clearly seen in figures 3 (a) and (b) which shows a histogram of a subject at rest and a histogram of that same subject during mental loading.

The mean heart rate of a subject during largest mental loading increased on average by 15% which concurs with the work of Hyndman (1978). An *analysis of variance* was carried out on the variance of the interbeat interval and this was found to be significant during the most demanding task only, i.e. one digit s^{-1}.

3.2. *The power spectra*

In a subject at rest the power spectrum obtained from the interbeat interval shows 3 main frequency components. These were attributed by Sayers (1973) to the temperature mechanism, blood pressure and respiration frequencies. These frequency components occur at approximately 0·03 Hz, 0·1 Hz and 0·25 Hz respectively. Figure 4 (a) shows a power spectrum of a subject at rest and figure 4 (b) is a power spectrum of the same subject under mental loading.

During mental loading the frequency component attributed to the respiration moved approximately from 0·25 Hz to 0·3 Hz. In all subjects this increased frequency was obtained. In the less demanding test (one digit $3\,s^{-1}$) the shift was from 0·25 to 0·28 Hz on average. During the recovery periods the respiratory component slowly returned to the original frequency. The more demanding the test, the more the shift of the respiratory component; this was true for all subjects. On examination of the results obtained by Hyndman (1978) it can be seen that he also found a shift in the respiration frequency component. However, Hyndman (1978) could not tell to what frequency the respiration component moved as he only looked at the relative power in 0·05 Hz spectral bands. This meant that during mental loading there was a shift of power from one spectral band to a higher spectral band but this could not be directly attributed to a change in the respiration. Hyndman (1978) was primarily concerned with recovery from mental tasks and not variations in respiration patterns during tasks of different intensities. Sixty per cent of the subjects had the total power of the spectrum contained at two frequencies, namely, the blood pressure and respiration frequencies during the tests, as can be seen from figure 4 (b). This negates the theory of Charnock and Manenica (1978) which states the respiratory frequency to be unimportant.

The power spectra obtained from the peripheral blood flow signal contained the same information as that of the interbeat interval so it would seem unnecessary to measure both signals unless a cross spectrum is required.

The respiration waveform does not contain all of the information contained in the other two signals, but gives one large peak at the respiration frequency only. This however confirmed that the increased frequency during mental loading is due to a

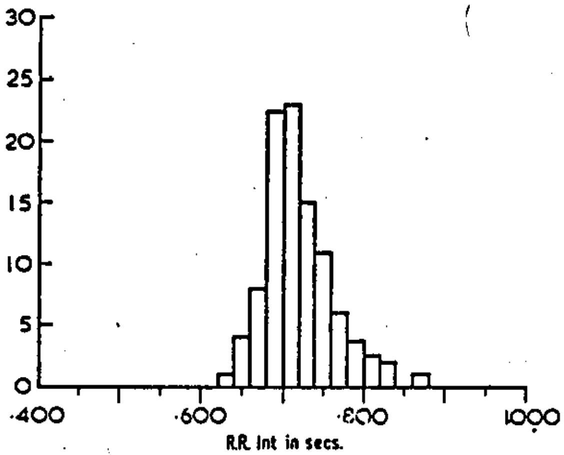

Figure 3(a). Histogram of subject at rest.

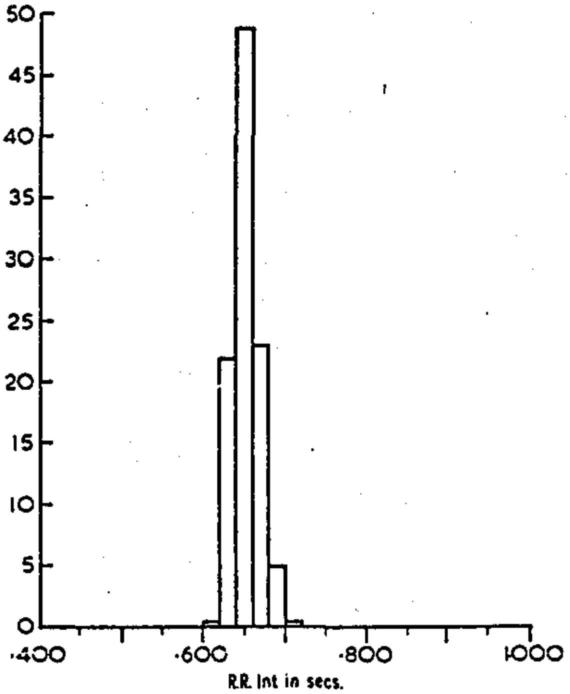

Figure 3(b). Histogram of subject during mental loading.

respiration increase and not due to any other extraneous factors. Hyndman (1978) did not measure or analyse any respiration waveforms so he could not be certain that the peak he was obtaining at 0·3 Hz was due to an increase in respiration rate.

One subject switched off during the most demanding test. During the two less demanding tests the subject produced an increased respiratory frequency but during the most demanding test the respiration rate started to rise then quite rapidly returned to that under no mental load. On examination of the histogram and mean heart rate after the switch off it was seen that both of these were identical to the results of the

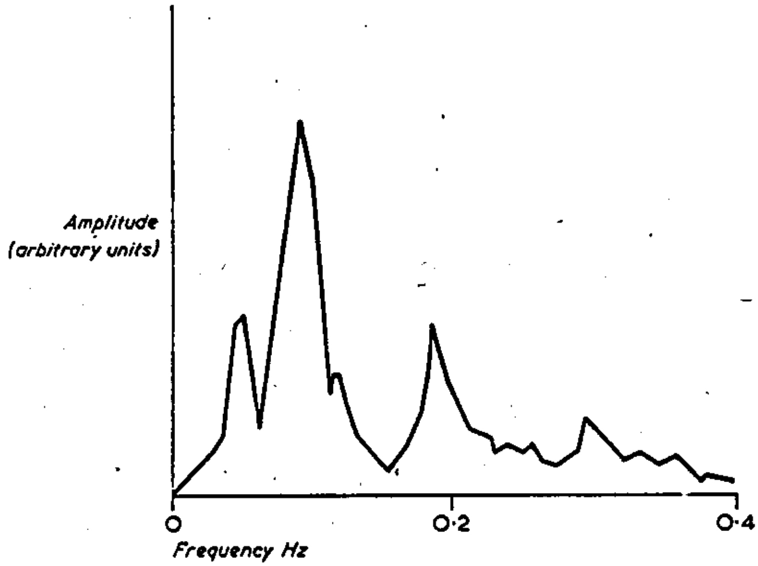

Figure 4(a). Fourier analysis of the irregular heart beat intervals.

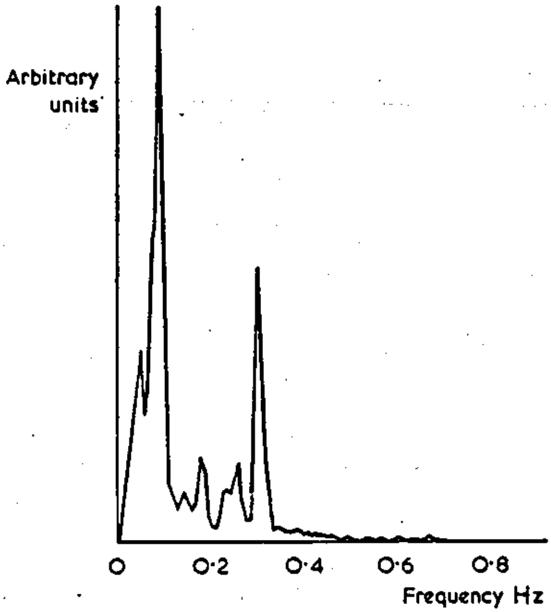

Figure 4(b). Fourier analysis of the irregular heart beat of subject under mental loading.

subject at rest; also it was noted that the responses to the test were mainly incorrect. It was concluded therefore that the subject had ceased to concentrate during the final test, although the subject did not admit to this.

4. Discussion

It has been shown that in spite of large differences between individual patients, some conclusions may be reached for all subjects. Clearly the respiratory frequency increases with mental load. More work could be done to discover the time taken for the respiratory component to return to its original frequency. In addition, it would be interesting to do more studies to discover how much the respiratory frequency component can be moved and if that could hence be used as a measure for the level of stress induced by certain tasks and be used also as an indication of how much stress is placed on different individuals doing the same task. The technique could also indicate if a subject is concentrating fully on a task or not as was shown by one of the subjects in the experiment.

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5.2 Preprint from Journal of Physiology, 1980.

D. 3

Apparatus for the continuous measurement of respiratory volume and oxygen uptake

By D. A. Brodie and T. Salmons* (introduced by M. H. Harrison). *Carnegie School of Physical Education and Human Movement Studies, Leeds Polytechnic, Leeds LS6 3QS, and * Bioscience, Sheerness, Kent ME12 1RZ*

A system incorporating an air-flow transducer, an oxygen analyser and a valve coupler will be demonstrated. It is accurate and reliable though simple in design, of low weight and is relatively inexpensive.

Inspired air passing through the flow transducer causes vanes to revolve. One complete revolution is attained by a flow of 3·08 ml. The revolutions are detected by an optical system with the output accepted by an electronic counter.

Information derived from this transducer can be displayed as a breath-by-breath respiratory volume by resetting the counter system automatically when no pulses are present or as a rising d.c. level resetting when a pre-determined volume has been reached. The reset levels can be either 5 or 10 l.

Another option is to hold a level during a predetermined period so that it is always indicating the volume of inspired air over the previous 20 sec.

The cross sectional area of the flow path is 549 mm^2 with an outside diameter for input and output ports of 22 mm. Flow resistance is 1·2 cm H_2O l.$^{-1}$ sec^{-1} rising to 10 cm H_2O at 3 l. sec^{-1}. The flow transducer has a minimum flow rate of 2 l. min^{-1} and a weight of 200 g.

The measurement of oxygen percentage in the expired air (F_{E,O_2}) uses a micro fuel cell of the general fast-response type. It has a linearity error (0–100 % O_2) of less than 0·5 % with a typical response time of 90 % of change in 7 sec. It is housed such that a baffle allows 10 % of the expirate to be directed over the cell, with the remainder vented to the atmosphere.

The interfacing circuits allow the cell to be connected via a d.c. coupler to an oscillograph. A normal sensitivity is a 5 mm pen deflexion for a 1 % reduction in oxygen content of the air at the surface of the cell, but the sensitivity may be doubled if required.

The valve coupling system is based upon an MSA face mask containing rubber valves of 22 mm diameter with a measured flow resistance of 2 cm water at 2 l. sec^{-1}. The dead space depends on the size of the subject's face, but is less than 100 ml.

The two components of the system were calibrated with a dry gas meter (Parkinson Cowan) and an oxygen analyser (Servomex). From 80 trials ranging in flow rates from 1·4 to 150 l. min^{-1} (obtained during cycle ergometry) the mean difference was 3·3 % (s.d. ± 1·1 %). The F_{E,O_2} values gave a mean difference of 1·5 % (s.d. ± 1·2 %).

5.3 Copy from The Lancet, 2nd July, 1977.

HEART-RATE VARIABILITY

SIR,—The differences in heart-rate variability found by the several workers referred to by Dr Jennett (April 16, p. 860) are implicit in their methods. Autocorrelation and cross-correlation techniques would reveal relationships between heart-rate variability and intracranial pressure, if they exist. Fourier analysis would demonstrate the distribution of power of the various frequencies contained in each record.

Visual examination of the records of Dr Lowensohn and his colleagues (March 19, p. 626) shows that not only the mean and range of heart-rate variability changed; there was also a difference in the rapidity of rate of change (i.e., there is more power present at the higher frequencies in the later record).

Fourier analysis of reconstituted R-R interval wave form was developed by Sayers[1] and refined by Rompelman and Kitney.[2] They have demonstrated standard frequencies at 0·25 Hz (respiratory control), 0·1 Hz (blood-pressure control), and 0·03 Hz (temperature control) (figs 1 and 2). Firm entrainment of heart rate by cyclical thermal stimuli has been shown by Kitney and Rompelman,[3] and by varying respiratory-rates by Campbell.[4] Entrainment experiments are limited by heart-rate and are difficult to demonstrate above 110 beats/min; this probably reflects the law of initial value.[5] These techniques using entrainment stimuli introduce principles of systems analysis to the assessment of the integrity of nervous control.

We support Dr Jennett in her criticism of the paper by Lowensohn et al., particularly in her statement that heart-rate variability must not be assessed without due note of mean rate and of respiratory pattern. We would also suggest that some record be made of the patient's thermoregulatory condition, particularly the core/peripheral gradient.

Time-series analysis offers solutions to many vexed questions of heart-rate variability and its relationship to respiration, blood-pressure, and thermoregulation.

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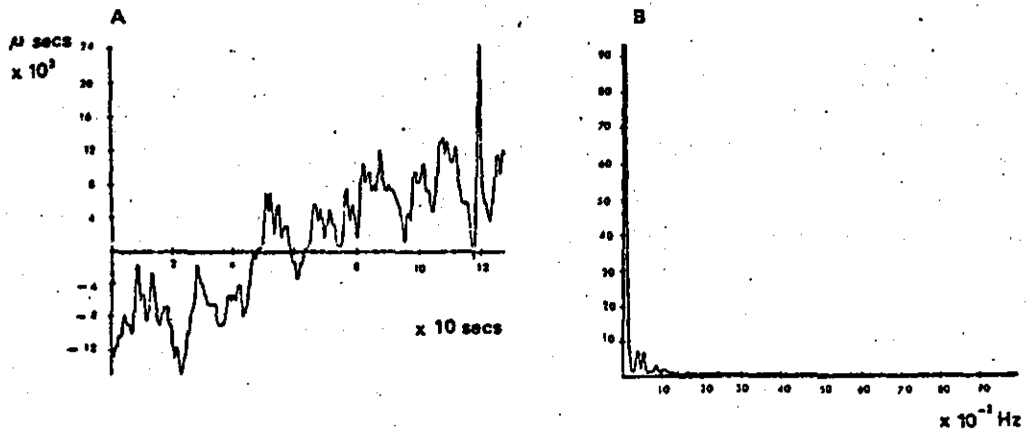

Fig. 1—Early postoperative period after aortic-valve replacement.

Core temperature 36°C, toe temperature 28°C. Ventilated 12/min (0·2 Hz). Mean heart-rate 80/min, sinus rhythm.
(A) R-R interval wave-form variability about the mean (scale exaggerated to show how little variation there is).
(B) Fourier transform showing minimal power above the D.C. frequency.

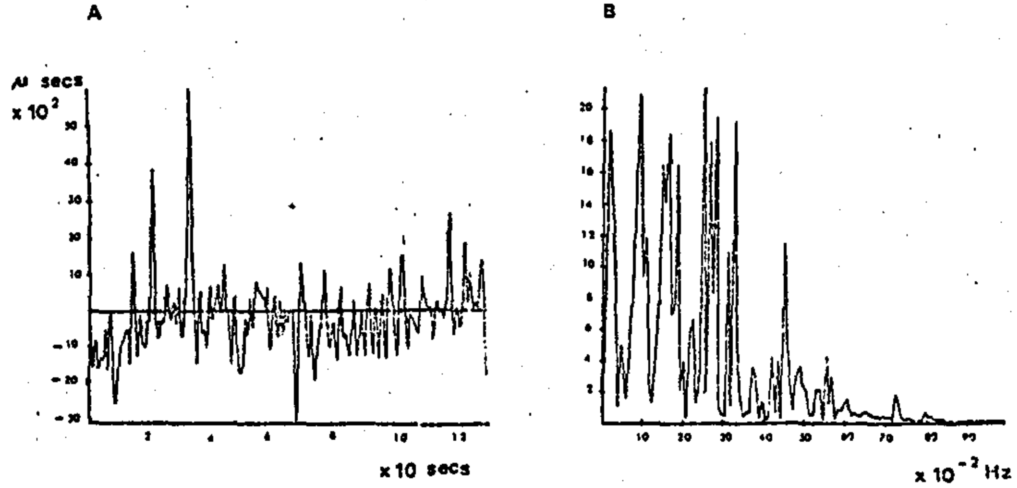

Fig. 2—Same patient, 24 h later.

Spontaneous respiration 15/min. Blood-pressure normal. Core temperature 37·5°C, toe temperature 35°C. Power is demonstrated at the respiratory frequency (0·25 Hz), blood-pressure-control frequency (0·1 Hz), and at temperature-control frequency (0·03 Hz). The vertical scales have been emphasised in the Fourier transform (fig. 2B) to demonstrate power.

5.4 Offprint from Research Papers in Physical Education, 1978, 3(4) : 34-36

Research Papers in Physical Education 1978 3 (4) : 34-36

The Oxylog — an oxygen consumption meter for use with ambulatory subjects

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Introduction

The measurement of oxygen consumption yields valuable information for the human biologist, nutritionist, physical educationalist and clinician. The relationship of oxygen consumption to energy expenditure is the *prima facie* reason for such an interest but measurement of maximal aerobic capacity and the prediction of cardiac output are also facilitated by its measurement.

Until recently one of the limiting factors in the measurement of oxygen consumption has been the weight and size of the measuring equipment. Closed or open circuit techniques for measuring oxygen uptake are either non portable, or heavily dependant on laboratory based analysis of respiratory gases. For these and other reasons the Kofranyi-Michaelis meter, (Kofranyi and Michaelis 1949), the Integrating Motor Pneumotachograph (Fletcher and Wolff 1964) and the Miser (Eley, Goldsmith, Layman and Wright 1976) impose certain limitations.

Humphrey and Wolff (1977) described the development of a new piece of equipment which made possible the immediate measurement of oxygen consumed by the subject. The Oxylog gives a direct reading of oxygen uptake in units of 100 cubic millilitres.

Staff at Leeds Polytechnic were invited to examine the Prototype Oxylog and investigate its reliability and validity particularly in the higher flowrate range.

Materials and Methods

The Protoytpe Oxylog is shown in Figure 1. It measures 8.5 x 12 x 20.5 cm without case, and weighs 1.8 kg. The subject wears a face mask with inspiratory and expiratory values to which is attached a flow meter to measure inspiratory volume. Expired air passes through a flexible pipe connected to the instrument. The P_{O_2} difference between the inspired and expired air is measured in the instrument and the volume of oxygen extracted from the air breathed is calculated and displayed on a counter.

The apparatus used for calibration purposes is shown at B in Figure 1 and was removed before the machine is used. The production model has been designed to incorporate the calibration unit and is shown in Figure 2.

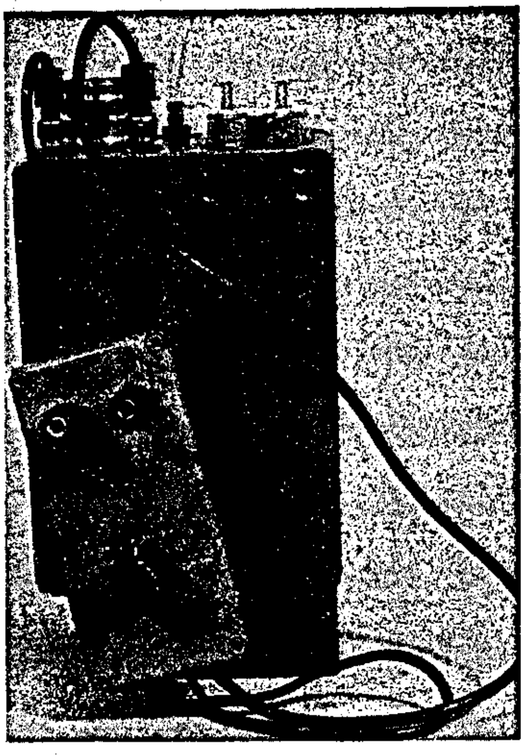


Figure 1 *The prototype Oxy-log*

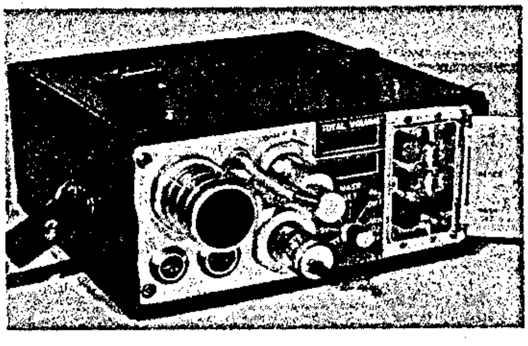


Figure 2 *Oxylog Production Model*

Photo: G. Wilcock

5.4 Offprint from Research Papers in Physical Education, 1978, 3(4) : 34-36

To assess the value for oxygen uptake given by the Oxylog a conventional open circuit indirect calorimetry system was used. The Oxylog was placed in series (Figure 3) so that measurements of oxygen consumption could be made concurrently.

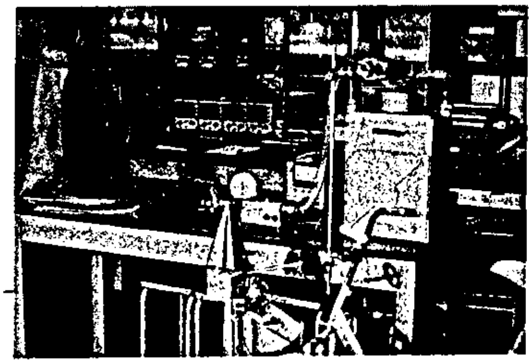


Figure 3 *Oxy-log placed in series with open circuit measurement of oxygen consumption.*

Nine subjects, members of staff and students from Leeds Polytechnic, volunteered to ride a bicycle ergometer (Muller) at a variety of work intensities. Each subject cycled for a six minute period at each work intensity. The oxygen consumption (Vo_2) was recorded by both methods over the final minute of each exercise.

The respiratory volume (V_E) had been recorded during every minute of the exercise to ensure that the subject had reached respiratory steady state. The Oxylog was also run continuously throughout the six minute period to allow the instrument to accommodate. The digital display was zeroed at the start of the fifth minute. At the end of the sixth minute a reading was taken from the Oxylog and compared with the results from the open circuit method.

There was a mean difference between the Oxylog and open circuit system of ±4.07% with a range of −5.5% to +11.8%. The correlation coefficient between the two methods was 0.87 (p>0.001).

The difference between the Oxylog value for oxygen consumed and that given by the traditional open circuit system was not related to changes in respiratory volume.

Discussion

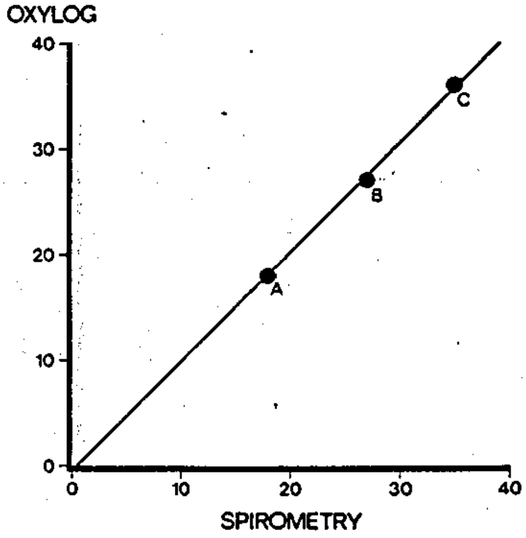
In any system there are potential sources of error including leakage from the mask and valves, deadspace in the tubing between pieces of apparatus and inaccuracies in sampling. However precautions were taken to ensure that these errors were minimized. The system was flushed with expired air before sampling was commenced in the last and final minute of each test period and if leaks were suspected around the mask it was physically held onto the subject. But a possible source of error could arise from the different techniques used by the two systems in recording. The Oxylog is dependent upon inspiratory volume measurement, whereas the open circuit method gives a value from expiratory volumes. Changes in R.Q. or nitrogen volumes could contribute to potential discrepancies.

The short length of the sampling period could have contributed to errors as the prototype Oxylog is only capable of reading to 100 cc of oxygen consumed. The length of sampling period was dictated by the capacity of the Douglas bags relative to the work intensity.

In an attempt to examine the accuracy of the Oxylog over longer sampling periods, the machine was compared with a closed circuit spirometry system at the Cardio-thoracic Unit, Killingbeck Hospital, Leeds. Figure 4 summarises the differences and testifies to the linear relationship of the two systems.

OXYGEN DIFFERENCE BY OXYLOG

AND SPIROMETRY



Mean flow for 5 min. A 39.6 litres
B 70.36 ··
C 90.3 ··

Figure 4

Conclusion

Within the spacial and physical limitations of the open circuit system used the error between the two values obtained was 4% which was not related to ventilation volume per minute i.e. this relationship holds even at high flow rates in excess of 50 l. min^{-1}. This error is probably acceptable to workers in the field when the advantages of a totally portable system is realised.

The Oxylog system was found to be comfortable, and the results were sufficiently encouraging for field trials to be considered.