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An Analysis of the Distinction Between Voluntary and Involuntary Behaviour in Psychology.

being a Thesis submitted for the Degree of

Doctor of Philosophy

by

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ABSTRACT.

Psychology, as a separate scientific discipline, was derived from philosophy and physiology and, in part, adopted their concepts and language. Initially psychology perceived its subject matter to be volition, among other mental constructs. In response to internal tensions, involving methodology, more intense interest was given to the study of behaviour. Behaviouristic psychology proposed the abolition of mental constructs, and sought to interpret behaviour in mechanistic terms. Two powerful methods were developed to study behaviour objectively; the classical and instrumental conditioning procedures. The use of the two conditioning procedures generated much controversy concerning the classification of behaviour as well as the necessary and sufficient conditions for learning.

However, the behavioural taxonomy generated by its scientific study has been inadequately formulated and there have been fundamental confusions about the concept of behaviour itself. These confusions have been highlighted by the recent experimental data from two important areas of research in the experimental study of learning; (i) autoshaping (ii) the operant conditioning of autonomic responses. These data challenge the widely held view that all behaviour may be classified, after Skinner, as operants or respondents.

Conventional psychological wisdom has conflated the concepts of 'voluntary' and 'involuntary' with the concepts of 'operant' and 'respondent', respectively. 'Respondents' by definition have specifiable antecedents, whereas 'operants' do not. The inability to note specific antecedents to instrumental behaviour is reflected in the original studies using animals by Thorndike. Instrumental (operant) behaviour was seen as

'impulsive', 'emitted' or 'spontaneous' - terms which have traditionally been associated with voluntary behaviour. Inadvertently, under the influence of Skinner, the vitalistic connotations of the operant were hidden from view and protected from criticism. Concomitant with these developments, the role of the central nervous system in the production and control of movement is being re-interpreted by neurophysiologists. In this field mentalistic and vitalistic accounts of behaviour have emerged at the highest levels. Although physical accounts of behaviour do not have logical priority over mental accounts, the former have the advantage of being more open to direct experimental investigation. The apparent paradox of a so-called mechanistic, physicalistic psychology and physiology accounting for behaviour in terms of vitalistic and mentalistic concepts prompted this analysis of the distinction between voluntary and involuntary behaviour.

An historical approach is adopted which draws on both primary and secondary sources in psychology, physiology, philosophy and medicine. References to voluntary and involuntary processes from the early Greeks to the present day, are summarized and their relationship with the broader intellectual issues is broached. The distinction between voluntary and involuntary behaviours arose early in western intellectual history and the concept of 'voluntary behaviour' was discussed, largely within the context of moral responsibility. At various times the mentalistic concepts of soul, mind and free-will were proposed as its source.

The idea that voluntary movement issued from the 'free-will' received its greatest support from Christian theology. Ecclesiastical monopoly of educated thought ensured that this interpretation of behaviour was firmly established in the institutions of western culture. With the rise of western science, the language of this view and its connotations intruded into the language of the disciplines of modern philosophy and physiology, among others.

The term 'voluntary', referring to behaviour, has undergone numerous and subtle changes in meaning, and the separation of voluntary and involuntary behaviour parallels several other important conceptual dichotomies. Two of these are the 'mind-body problem' and the 'mechanism vs vitalism' debate. Contemporary literature in the fields of psychology, physiology and philosophy reflects the fact that these conceptual issues have not been resolved, as once was thought; but are active points of debate.

Psychology is presently changing its understanding of behaviour, and today the voluntary-involuntary distinction may be maintained by the operational definition of a voluntary response being an 'instructed response'. Instructed responses as voluntary responses have been extensively used in both experimental and clinical studies of behaviour. This operational definition, in contrast to others, has brought the voluntary response under direct experimental scrutiny and deprived it of its 'uncaused' attribute. Its use has produced much needed empirical data concerning the metric parameters of movement.

No one method of study or theoretical model is likely to explain behaviour in the near future, and such an explanation will not be derived from experimental evidence alone. It is suggested that future interpretations of behaviour will use concepts derived from such technical fields as engineering and cybernetics as well as from psychology and physiology. Perhaps no current conceptual analysis can give us even partial insight into the future development of self-regulating machines; the future development of such machines, however may shed light onto our current concepts.

CONTENTS

INTRODUCTION

This thesis arose out of consideration of the theoretical-conceptual problems that surrounded the experimental work in which the author was engaged. These experiments were designed to investigate the relationship between cardiovascular responses and skeletal muscular activity within the context of the operant conditioning paradigm. It was assumed that such relationships could be described in terms of 'mechanisms', either conceptual or concrete. Further, responses under operant control i.e. established by the operant conditioning procedure, were tacitly assumed to be under 'voluntary' control. The seemingly successful operant conditioning of autonomic responses greatly expanded the domain of 'voluntary' responses at the expense of 'involuntary' ones. As the term 'voluntary' was linked to the operantly conditioned response, apparently most behaviour could be construed in some sense as voluntary, at least in principle. Furthermore voluntary responses were conscious and looked upon as the 'least automatic' of all responses.

But, a widely accepted view in both psychology and physiology was that most behaviour, including learned responses, proceeded in an automatic and unconscious fashion. This conceptual confusion was due, in part, to the fact that operant behaviour was explicitly defined by Skinner as behaviour which had no discernible antecedents. Therefore, the 'uncaused' attribute of operant behaviour increasingly became a major conceptual stumbling block in the explanation of behaviour.

This conceptual difficulty was made more acute by the publication of The Self and its Brain (1977) by Karl Popper and John Eccles, in which it was asserted, by Eccles, that voluntary responses were a product of the 'self-conscious mind' which exerted its influence through the cortical neural machinary. Moreover, Eccles held that the 'self-conscious mind' was not subject to the known laws of physics. Such a position is usually labelled 'vitalistic'; a view which maintains that behaviour is 'something more' than the physico-chemical processes that underlie it. Thus vitalism asserts that behaviour can never be completely explained by such processes, in contrast to the mechanistic viewpoint. However, vitalism has been eschewed by psychology and physiology, especially since the 19th century, because of its experimental sterility.

The emergence of these events in psychology and physiology and the fact that the operant conditioning of autonomic responses helped to highlight the problems implicit in the classification of behaviours into voluntary and involuntary categories. Therefore it was felt that an analysis of the distinction between voluntary and involuntary behaviours in psychology was justified.

Often this distinction is discussed within the context of the broader 'mechanist-vitalist' debate with which the voluntary-involuntary dichotomy has traditionally been associated. This is appropriate as such a debate is receiving increasing attention . For the sake of orientation it should be stated that mechanistic rather than vitalistic explanations of behaviour are preferred by the author as they are open to experimental attack, and therefore are more likely to generate a coherent scientific statement.

From its inception, psychology struggled to decide its legitimate domain of study, It was generally accepted that it should be an experimental discipline. However, the subject matter and the methods of experimentation represented points of disagreement. Some thought that psychologists should study mental events by the method of introspection. Others believed that psychology would gain greater credence as a science if it emulated physics and dealt with objectively observable events that could be submitted to experimental study and replication. The latter view led to the perception that the study of overt behaviour was the proper domain of psychology. This perception became known as behaviourism and it developed two major methods to experimentally study behaviour; the classical and the instrumental conditioning procedures.

Early behaviourists such as John Watson rejected volition and all other mental events as unimportant in the explanation of behaviour, and embraced the Pavlovian physiological concept of the 'conditioned reflex' to account for orderly behaviour change. Therefore if one followed Watson there was no need to classify behaviour as voluntary or involuntary, for ultimately all behaviour was involuntary. However, not all behaviourists were as extreme as Watson and some felt the need to address the problem of voluntary activity. Two representatives of this group were Walter S. Hunter and Helen Peak.

Hunter and Hudgins (1934) set out three criteria by which voluntary behaviour can be distinguished. For them, voluntary action: (i) was "acquired" (ii) implied "some specific type of control of this activity" (iii) possessed "peculiarities in the latency and form of the response" (Hunter,W.S., and Hudgins,C., 1934, p.200). Hunter and Hudgins ended their paper by inferring that the above criteria could be used to classify behaviour in general, instead of the traditional voluntary-involuntary categories, and by offering the hypothesis that "voluntary behaviour is essentially a conditioned response... under the control of self-excited receptor processes." (Hunter & Hudgins, 1934, p.204).

As with Hunter and Hudgins, Peak (1933) cited three possible differentiating criteria for distinguishing a voluntary from an involuntary response. These included differentiation on the basis of : (i) such features as "the latency, extent, direction, form or behaviour, (ii) its antecedents and consequents" (iii) differences in "... functional relations" between responses and their antecedents. (Peak, H., 1933, pp. 71 - 89). Peak rejected (i) and (ii) as well as the criteria of Hunter and Hudgins as possible grounds for classifying responses, but accepted (iii). Thus, a voluntary response would have a different functional relationship with its antecedent than involuntary response, and she called for an empirical program to derive such relationships. It should be pointed out that Peak conceived that both voluntary and involuntary responses had antecedent stimuli. The conjectures of Hunter and Peak relected some of the confusion in the behaviourists' camp in generating a behavioural taxonomy. A resolution of these issues was attempted by B.F. Skinner.

Skinner is much more important to us than either Hunter or Peak because it was his opinions that became the dominant force in behaviouristic psychology. His resolution involved the classification of behaviours as 'operants' and 'respondents'. Each class of behaviours was defined by the conditioning procedure used to study it. Those behaviours studied by the instrumental conditioning procedure were termed 'operants' whereas 'respondents' were studied by the classical conditioning procedures. Skinner cited Peak's third 'criterion' as closely paralleling his own operant-respondent distinction (Skinner, B.F., 1938).

B.F. Skinner gave the voluntary-involuntary distinction its definitive contemporary formulation. This formulation was actually a secondary event in Skinner's effort to establish operant conditioning as a major laboratory procedure in the study of behavioural change. Of great interest to us is the fact that Skinner, as an experimental expedient, was willing to perceive of great ranges of behaviour as 'emitted' and 'spontaneous'. These responses had no identifiable antecedent stimuli. Conceptually they were uncaused. Thus 'operants' were very similar to Hunter's 'self-excited receptor processes'. They were conceived as "self-initiated acts" (Hilgard, E. & Marquis, D., 1940, p.66).

Under Skinner, the two powerful procedures, operant and respondent conditioning, became identified in a broad sense with the skeletal and smooth musculature (an idea rejected by Hunter and Peak). The argument was further extended to include the parts of the nervous system which subserved the two types of muscle. Thus the central nervous system was viewed as controlling the movement of the skeletal muscles and was open to modification by the operant (instrumental) conditioning procedure. However, the smooth muscles were subserved by the autonomic nervous system and could be modified only by the respondent classical (Pavlovian) conditioning procedure. Therefore Skinner, on procedural grounds, inadvertently gave the voluntary response a home and allowed it to retain its vitalistic connotations.

However, in the analysis that is to follow, data will be presented that suggests that Skinner's 'procedural distinction' is no longer tenable, and as a scheme to classify behaviour it is misleading in that it appears to give a scientific account of volition. Further, the analysis suggests that the longevity of the voluntary-involuntary dichotomy in large part can be accounted for by the inability to build machines capable of purposive, self-adaptive movement. This inability has greatly retarded a convincing mechanistic explanation of behaviour. It is also conjectured that the development of scientific knowledge in psychology and physiology, in itself, is unlikely to resolve the problem. For example, Figs. 1 and 2 portray over 200 years of study of the nervous system ; both figures contain domains of mystery. Fig. 1 is Rene Descartes' conception of the relation of a sensory impression and a motor impulse. The letter 'H' represents the pineal gland,which the visual image enters at point 'b'. The movement in the nerve is initiated at point 'c'. The relation between b and c is the unsolved mystery. Fig. 2 is a diagram from a late 19th century textbook on physiology. The relation between point D and point E parallels the 'unknown' aspects of Fig. 1. The progress in neuroanatomy and neurophysiology has made it possible to fill in these areas somewhat.

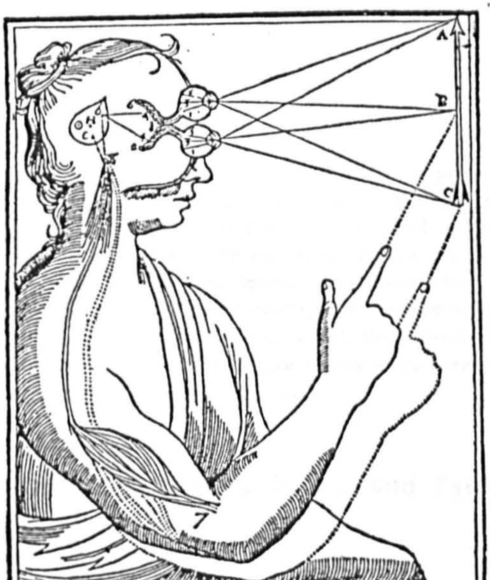
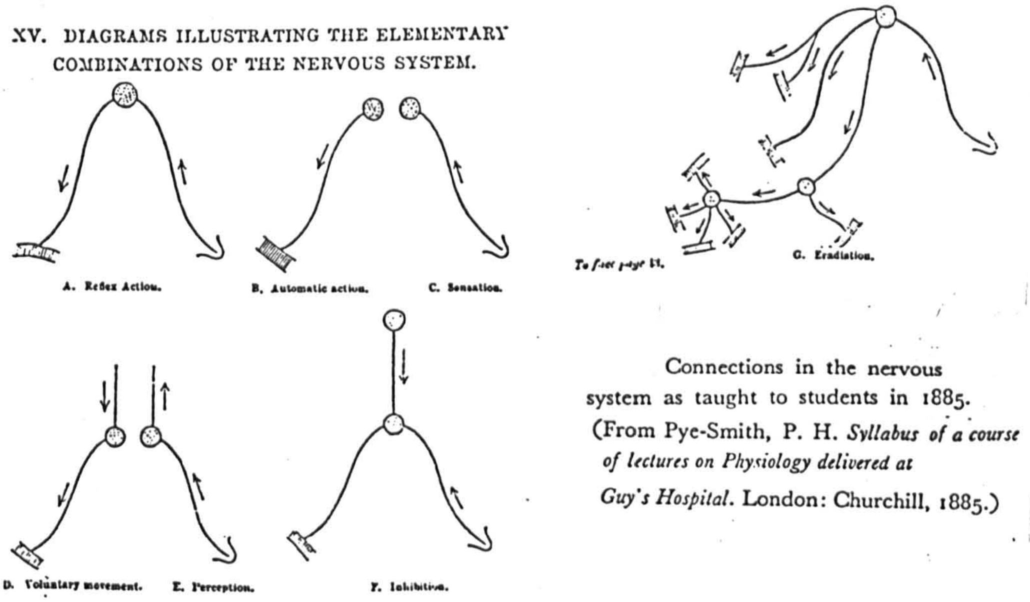


Figure 93

Many of the drawings in Descartes' book, *De homine* (1662) and its French version of 1664, are diagrammatic in form. This one[5] demonstrates his mechanistic theory of brain function. Light from the object (ABC) enters the eyes and forms visual images (135) on the retina which is connected to the walls of the ventricle by hollow tubes representing the optic nerve. The circular open ends of the tubes can be seen and 246 is the incoming or sensory stimulus. From the tubes the message goes through the ventricles by way of the animal spirits and reaches the pear-shaped pineal (H) which initiates the motor stimulus. Thus animal spirits from the ventricles are sent by way of the opening 8 into the nerve to the arm muscle which it inflates, producing motion. This, of course, is the basis of the reflex, and the modern theory of reflex action begins with Descartes' primitive concept of afferent and efferent components.[6]

Fig. 1 Clarke,E., and Dewhurst,K., 1972, p.69.

XV. DIAGRAMS ILLUSTRATING THE ELEMENTARY COMBINATIONS OF THE NERVOUS SYSTEM.



Connections in the nervous system as taught to students in 1885. (From Pye-Smith, P. H. *Syllabus of a course of lectures on Physiology delivered at Guy's Hospital*. London: Churchill, 1885.)

Fig. 2 Brazier, M.A.B., 1959, p.38.

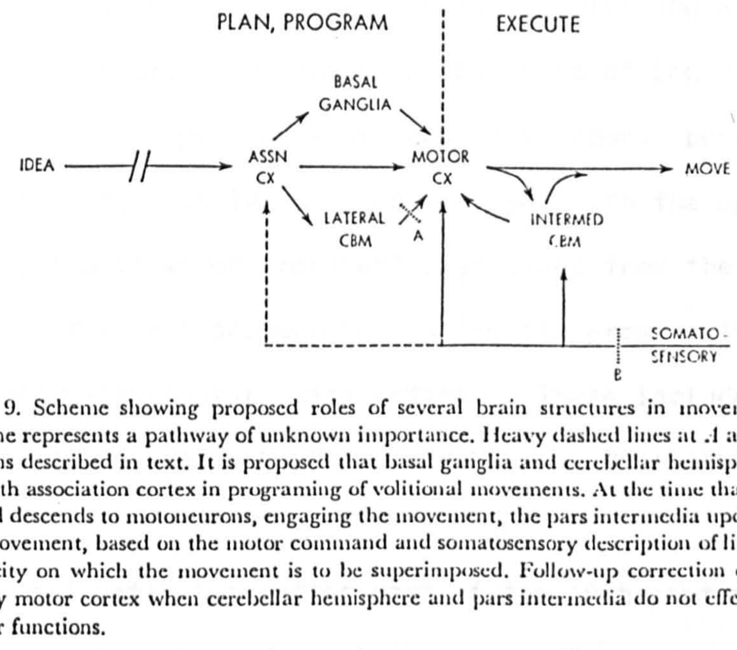


FIG. 9. Scheme showing proposed roles of several brain structures in movement. Thin dashed line represents a pathway of unknown importance. Heavy dashed lines at *A* and *B* represent lesions described in text. It is proposed that basal ganglia and cerebellar hemisphere are involved with association cortex in programing of volitional movements. At the time that the motor command descends to motoneurons, engaging the movement, the pars intermedia updates the intended movement, based on the motor command and somatosensory description of limb position and velocity on which the movement is to be superimposed. Follow-up correction can be performed by motor cortex when cerebellar hemisphere and pars intermedia do not effectively perform their functions.

Fig. 3 Allen, G.I., and Tsukahara,N., 1974, p.992.

Fig. 3 is a modern conception of how the central nervous system produces and controls movement. It was presented by Allen and Tsukahara (1974) and the Plan-Program-Execute sequence apparently has been robust enough to be useful to a great many researchers. However, it will be noted that this figure contains an area marked 'idea'. At present this area is as unexplained as the gap between points b and c or D and E. Hence after 500 years of investigation of the nervous system there are still prominent conceptual gaps in our knowledge of how movement is produced. The argument is further developed as follows.

Chapter 1 is a history of the distinction between voluntary and involuntary behaviour, beginning with the early Greek intellectual endeavour and proceeding through to the neurophysiological opinions of C.S. Sherrington. The writings of Rene Descartes are given a place of prominence for they are the foundation of modern philosophy, and the source of contemporary attempts to maintain that mental events do not obey the same natural laws as physical events.

The Cartesian view of man is contrasted with the account of the empiricists, particularly as found in the works of Locke, Hume and Hartley in which the appearance of seemingly orderly behavioural change was closely tied to experience. Concomitant with the opinions of philosophers, the views of prominent physicians from the 16th century to the 18th century are adduced to confirm the great cultural appeal of the voluntary-involuntary distinction. These include Thomas Willis, Robert Whytt, Julien de la Mattrie, and Hermann Boerhaave among others.

It was not until the latter part of the 19th century that psychology emerged from philosophy and physiology as a discipline in its own right. The work of many of the almost legendary figures of physiology are discussed: Johannes Muller, Claude Bernard, Hermann von Helmholtz and Karl Ludwig among others. In the discussion of the 19th century an attempt will be made to demonstrate that the concepts of voluntary and involuntary were, and still are, associated with certain brain structures and that this idea grew out of research into the structural-functional relationship of the nervous system which characterized 19th century neuroanatomy and physiology. The impact of broader intellectual currents such as evolutionism, materialism, vitalism and mechanism, on the image of man and his behaviour are also broached.

Chapter 2 concerns itself with the influence of behaviouristic thought on the traditional voluntary-involuntary distinction. This was most dramatically felt in the fields of philosophy and psychology. Both areas are discussed. Philosophical behaviourism is presented through the writings of the most influential and vigorous single English-speaking philosophical 'movement' in the 20th century; logical positivism. When addressing the science of psychology, logical positivism assumed a strong physicalist, materialistic position. It did not deny the existence of mental events but held that they could be described in the language of physics. Thus, statements concerning a mental event, volition for example, could be 'translated' into statements about physical events (behaviour). The form of philosophical behaviourism as represented by Rudolf Carnap's famous statement,'psychology is Physics', was the one most influential in psychology.

The latter part of chapter 2 addresses psychological behaviourism. It is treated as a brief survey of the experimental study of learning, for it is in this area that behaviourism has had its most obvious impact. The survey begins with a discussion of associationism, because all major contemporary theories of learning are associative in nature, and the investigation of psychological behaviourism is subsumed under Conditioning. It begins with a description of the classical conditioning procedure and a presentation of Ivan Pavlov's views of 'voluntary'and 'involuntary' behaviour. The impact of Pavlovian thought on 'American behaviourism' is discussed through the assertions and opinions of John Watson, Karl Lashley and Edwin Guthrie. Instrumental conditioning is addressed by way of the studies of Edward Thorndike, E.C. Tolman, J.R. Kantor, Clark Hull and finally B.F. Skinner.

Chapter 3 presents data from two areas of research in the experimental study of learning ; autoshaping and the operant conditioning of autonomic responses. These experimental data suggest that the classification of behaviour by the conditioning procedures used to study it is not a tenable basis for a behavioural taxonomy, and if the voluntary-involuntary categories are to be maintained it must be done on other grounds. Under 'autoshaping' the experiments of Brown and Jenkins (1968) and Williams and Williams (1969) are discussed. When addressing the operant conditioning of autonomic responses the studies of Neal Miller, particularly those with Leo DiCara, are used as a convenient point of departure. The chapter closes with the presentation of experiments in which the author collaborated.

Chapter 4 summarizes several major neurophysiological models which account for the 'voluntary response' in their theoretical framework. These models draw heavily on the terminology and concepts generally associated with the discipline of cybernetics. The models are grouped by the concepts which they use to account for voluntary behaviour. These are :

(i) the use of 'images', under which the theories of William James, I.S. Beritoff, N. Bernstein, Karl Pribram and Eric von Holst are discussed ;

(ii) the use of 'mind', this consists of a detailed description of the views of Sir John Eccles and Wilder Penfield ;

(iii) the use of 'goal direction', the opinions of Pagnar Granit, Walter Hess, Hans Kornhuber and Gordon Mogenson.

It is indicated that even such 'mechanistic' models as these contain conceptual analogies to the 'voluntary' and 'involuntary' dichotomy.

The Concluding Discussion, Chapter 5, examines the definition of voluntary behaviour in contemporary psychology. A voluntary response is presently defined 'operationally' as an 'instructed response'. Thus, if a subject (man or animal) performs a movement in response to an instruction or signal, then the movement is deemed 'voluntary'. Such a view of the voluntary response invites the use of cybernetic concepts in the interpretation of experimental results in studies designed to investigate the 'instructed response'. This theme is carried over to experimental studies that have attempted to identify events within the central nervous system which immediately preceed the onset of movement.

Moreover, there is a brief survey of some of the major opinions concerned with the 'mind-brain' dichotomy, which - like the mechanism-vitalism dichotomy - has been closely associated with the separation of behaviour into 'voluntary' and 'involuntary' categories. The discussion closes with the suggestion that mechanistic explanations of behaviour are in the process of receiving support which may lead to a non-trivial advances in the plausibility of such explanations at the expense of vitalistic ones.

All Figures are presented with their original captions and there is a separate bibliography of the sources. The figures of Chapter One are meant to complement the text, not replace it ; each can be examined separately. All other figures relate directly to the text. Appendix A consists of experiments in which the author collaborated and Appendix B is provided to aid the reader with terminology associated with the brain.

CHAPTER I

The Greeks and Alexandrians: Aristotle to Galen

Historically it is impossible to establish when man began to speculate upon the relationship between his own bodily processes and his feelings, thoughts and sensations and, by extension, their relationship to the external environment. In the earliest endeavours these speculations were embedded in larger currents of intellectual thought concerning the nature of things, their origin and development. Because of the dependence of psychological thought on philosophical doctrine and their long and close association, an acquaintance with the main philosophical trends, even if superficial, is in order.

Beginning with Plato and Aristotle one receives a history of philosophy as well as an account of the various subjects under consideration. Aristotle classified those who had preceded him into two broad categories: One group, the theologi, attempted to describe and explain the world by myths and supernatural causes, while the other, the physici or physiologi, pursued natural explanations in their account of the universe (Guthrie, W.C.K., vol. I, 1962).

The physici/physiologi attempted the monumental task of finding the universal principles which would be the key to all nature. Their attempts ranged from hypothesizing about the basic element(s) of the universe and its origins, to man's place therein. The mode of thought was speculative, but in the fields of medicine, anatomy and physiology, observation and, in the odd case, experimentation began to be used. These men have been called the pre-Socratic philosophers. They included Thales, Anaximander and Anaximenes.

Aristotle stated that Thales was the earliest of the physici and thus was one of the first to attempt to remove external personal agents (gods) from theoretical constructs of nature. He postulated that the changes of the world were initiated by the way the universe was constructed. The concept of 'arche' emerged as a central feature in the thought ot Thales as well as other early Greek philosophers. 'Arche' was conceived to be the basic 'stuff' of the universe. In it, matter and motion, structure and function were not clearly separated. For Thales 'arche' was water. Anaximander, introduced the idea of 'arche' as being a non-preceptable explanatory principle, apeiron (the boundless), which was the origin of, and controlling influence over, all things (Heidel, W.A., 1912; Guthrie, vol. I, 1962).

Anaximander's younger contemporary, Anaximenes, postulated 'arche' as air, highlighting the Greek's interest in 'the Pneuma'(breath) as an explanatory concept. The 'pneuma' theory became closely associated with biological and psychological functions, and had a long and influential history. Anaximenes (circa 545 B.C.) was looking for regularity in the world and from him to the atomists, Democrates and Epicurus, a general explanatory principle of the universe was sought as were rules which controlled or influenced human behaviour (Guthrie, vol. I, 1962).

Meanwhile, other pre-Socratics were making their influence felt. For example, Heraclitus saw all nature as continuous flux and change, whereas Parmenides perceived change as being only an illusion. With these two diametrically opposed views the focus of inquiry broadened to include an explanation for movement and action.

Guthrie puts this point forcefully:

> "By bringing the world to a full stop, as it were, Parmenides drove home the lesson that motion was a phenomenon in need of its own explanation, and in the later pre-Socratics we see, not only the change from a unity to a plurality of physical elements, but also the emergence of a moving cause beside and apart from the moving elements themselves."
>
> (Guthrie, vol. I, p.6, 1962)

Hence the problem of motion became acutely difficult when Parmenides, on logical grounds, had contended that movement and change were impossible. Thus the 'Eleatics', as the followers of Parmenides were called, brought the problem of motion into sharper focus (Guthrie, W.C.K., Vol. II, 1965).

Aristotle thought that the pre-Socratics failed to appreciate the whole problem of the moving cause. Indeed, it is in Aristotle that we find the 'unmoved mover' as the ultimate cause of motion and the important separation of 'substance' and 'attribute' (two terms introduced by him). Aristotle's 'arche' resolved into such concepts as matter, cause, motive and force.

The concept of motion, therefore, played an important part in Aristotle's natural philosophy, for he thought that natures was the principle of movement or change. Causally, every motion originates in another motion, hence in order to prevent an infinite regress, he postulated his 'unmoved mover'. Organisms which are animate are the only ones to possess an inherent power to move (Guthrie, W.C.K., Vol. VI, 1981).

In the inanimate world, Aristotle thought external forces caused movement, but he did not reduce qualitative differences to quantitative relations of size and position, as would occur today. Indeed, Greek mathematics in Aristotle's time were incapable of providing a precise definition of such concepts as acceleration and velocity (Heath, T., 1949; Apostle, H.L., 1952).

Aristotle's notions on movement were heavily influenced by his observations in biology. These focused on embryonic development which led him to think that movement was ultimately directed towards some end or goal. This was his 'teleos', his final cause, and for him, the most important. For science, teleos would turn out to have a retarding effect which was most prominent in biology and psychology.

Aristotle considered psychology among one of his first interests and defined it as 'the study of the soul'. He meant the soul to be something which could receive knowledge and he saw knowledge as something that was derived from the senses. In doing so, he was reacting to Plato's position that knowledge would not be obtained through the senses. For Plato, all our 'knowledge' was derived from remembrances of things learned in the world of Forms, which he asserted was true reality. Plato's psycho-physical dualism and his vigorous advocacy of rationalism was seen as erroneous by Aristotle (Brett, G.S., 1965).

To go into great detail concerning Aristotle's thinking would be out of place here. In his works he discussed the nature and properties of the soul, as well as reviewing the opinions of others who wrote of the soul before him. In such previous accounts the soul was viewed as being, in part, the source of movement. The Homeric Greeks closely associated respiration (pneuma) with the soul, which they conceived of as being essential for life. It later acquired expanded responsibilities, until by Aristotle's time it was able to both think and sense. It was usually thought of as being immortal, leaving the body at death. Plato taught that the soulwas trapped in the body, like a prisoner in a dungeon, and although it could move the body, it was totally separate from it.

Aristotle undoubtedly gave Plato's view of the soul deepest consideration, for apparently he was the only person to sit through his master's entire lecture on the subject (Durant, W.J., and Durant, A., 1967, Vol. 2). Plato put the soul and intelligence in the head because it is the most spherical and therefore 'perfect' shape. In Aristotle's scheme the soul and intelligence were placed in the heart. His reasoning was logical: life began with the beating of the heart and ended when it ceased, its rate varied with different emotions and this fact indicated to him that it was the source of emotions. For him, the brain was a cooling device for the blood, as were the lungs (Doby, T., 1963). This is coupled with Aristotle's idea that heat could possibly be a physical basis for the soul. For clarity, it should be stated that Aristotle postulated three souls; one for plants, two for animals and three for humans and that his views on the soulchanged from time to time as his thought evolved (Singer, C., 1944).

David J. Furley has recently gone back to the original Greek texts and has presented his interpretation of Aristotle's views on animal and human movement. These are briefly summarised below:

(i) There is no break in the chain of causation from stimulus to response, concerning animal movement.

(ii) Animal movement can be attributed to two broad 'causes': (a) thought, (b) desire;

(iii) 'Images' can account for the initiation of movement, the chain of causation being as follows; a stimulus evokes an image, the image evokes a desire, the desire evokes a movement;

(iv) A similar sequence of events can account for human movement. Thus thought or sense perception produces an 'image'; the image produces desire; desire, feeling, and the feeling produces movement.

(v) Concerning human voluntary movement, the sequence in (iv) is wedded to the disposition to behave, The disposition to behave is the outcome of the experiences of the organism.

(Furley, D.J., 1967, pp.215-225).

Therefore, in Aristotle we do not find the need to evoke a 'disembodied mind' or 'free will' to account for behaviour. Voluntary movement was not of a spontaneous or 'uncaused' type, independent of natural laws.

Aristotle wrote prolifically on ethics as did most other early Greek philosophers. In the distinction between voluntary and involuntary movement, moral sanctions applied only to the former. However, the focus of his distinction was on "... the way in which ... habits of behaviour are formed". (Furley, 1967, p.225) and not on immaterial immortal entity. For Aristotle voluntary behaviour, as a class of behaviours, was necessary on ethical grounds only (Furley, 1967; Guthrie, vol. VI, 1981).

In addition to the conceptual advances made by Aristotle, the Greek physicians developed a more sophisticated view of the role of the brain's function than any others until the modern period. For example, Hippocrates (circa 420 B.C.), the 'father' of medicine, in his observation of epileptic patients, claimed that the brain was the seat of both emotions and intellect. His theme was also emphasized by Herophilus of Chalcedon (circa 300 B.C.), the 'father' of anatomy, and Erasistratus of Chios (circa 290 B.C.), the 'father' of physiology, both of whom tried to explain how the brain was the centre of intelligence. In contrast, the prevailing view of the early Egyptians, described by Herodotus (circa 484-425 B.C.).held that the brain was an unimportant organ and that the heart and liver were the seats of human emotion, as did Aristotle (Walker, K., 1955).

The Hippocratic School may have derived some of its ideas on brain function from Alcmaeon of Croton (circa late 6th century B.C.)(Watson, 1971). Sir William Osler cites Alcmaeon as the first to put forth the idea of "the brain as the organ of the mind". (Osler, W., 1935, p.39). In doing so, he challenged ideas previously asserted by the Egyptians that the seat of intellectual life was in the heart. Apparently he was one of the first to perform anatomical dissections and distinguish between veins and arteries (Castiglioni, A., 1947). He further noted that each sense has its own particular sense organ. His work was perpetuated in the efforts of scholars of the city of Alexandria, notably Herophilus and Erasistratus (Watson, 1971).

Herophilus of Chalcedon (circa 300 B.C.) was an extremely important Alexandrian physician and the grandson of Aristotle (Doby, 1963). The nerves, tendons and blood vessels were first separated by him (these were often confused by the Hippocratic School) and he differentiated between sensation and movement, believing that both were conveyed by the nerves (Franklin, K.J., 1949; Singer, 1944; Watson, 1971). He also described the cerebellum and the cerebrum and distinguished the cranial from the spinal nerves. (Durant and Durant, 1967, II).

In addition, he was the first to describe the 'rete mirable' (marvellous net), an anatomical feature found in some species but not in others, including man. This feature was to become central to the more speculative principle of 'pneuma', which is found throughout Ancient Greek medical, biological and philosophical thought (Woolam, D.H.M., 1958). Herophilus gave a role to the ventricles of the brain by placing the 'soul' in the fourth one, thus giving rise (via the writings of Galen and St. Augustine) to the 'cell doctrine' of brain function which prevailed during the Medieval Period. (Clarke, E., and O'Malley, C.D., 1968).

Erasistratus of Chios (circa 290 B.C.) was a younger contemporary and student of Herophilus (Kantor, J.R., I, 1963). Like Aristotle, he was the son of a court physician. He was taught medicine by Methrodorus, the husband of Aristotle's daughter, and at the Hippocratic School at Cos (Doby, 1963). According to Franklin, Erasistratus <u>correctly</u> distinguished between movement and sensation, that is, he attributed the former to the anterior spinal roots and the latter to the posterior ones, thus anticipating Bell and Magendie by two thousand years. In addition, he advanced the idea that the complexity of the cerebral convolutions was related to intelligence in man and animals (Franklin, 1949).

Although Herophilus and Erasistratus are never cited as having explicitly differentiated between voluntary and involuntary behaviours, this distinction was implicit in the pneumatic scheme of the latter. For example, Osler (1935) in discussing Erasistratus' contributions, stated that:

> "... a great division was made between the two functions of the body and two sets of organs: in the vascular system, the heart and arteries and abdominal organs, life was controlled by the vital spirits; on the other hand, in the nervous system were elaborated the animal spirits, controlling motion, sensation and the various special senses."
>
> (Osler, 1935, p.74).

Further, the idea must have been extant in Alexandrian medicine, for both Watson and Fearing draw upon a "Syrian" Book of Medicine, by an unknown author, (English translation by E.A. Wallis Budge). In this, voluntary "powers" are separated from involuntary or 'natural' ones in such a way as to lead both authors to claim that the view presented definitely anticipated the concept of reflex action (Fearing, 1964; Watson, 1971).

Fearing gives a quotation from this interesting book concerning the nervous system and movement:

> "... for the nerves, beside the natural powers, they possess also the power of performing the wish of the soul, which they effect by means of various motions of the body, and because of this injuries that happen to them sometimes bring to naught the voluntary functions and sometimes the natural functions also."
>
> (Fearing, 1964, p.12)

Hence the role of the nervous system in the production of movement was apparently widely recognized.

Guthrie (1965) has speculated on a direct connection between the Lyceum of Aristotle and the great Museum and Library of Alexandria. Apparently, Demetrius of Phaleron, upon his exile from Athens, suggested the idea of a library to Ptolemy I (Soter) of Egypt. Demetrius was a friend of Theophrastus, Aristotle's successor at the Lyceum, and also his student. Further, Strato, another of Aristotle's students, became tutor to the Ptolemaic household (Guthrie, W.C.K., Vol., II, 1965). Therefore the organisation of the museum and library showed the clear stamp of Aristotle's influence.

This great intellectual enterprise developed under the Ptolemies, with Ptolemy III requiring that all manuscripts brought into the city be placed in the Library where a copy would be made. The owner would be given the copy and the Library would keep the original. This attitude made Alexandria the intellectual capital of the Greek world. Indeed, Marc Anthony gave the contents of Perganum, the second largest library of the Greek Antiquity, to Cleopatra, as part replacement for the burned Alexandrian library (Durant & Durant, 1967, II). These two intellectual centres were further bound together by the figure of the greatest physician of the ancient world, Galen of Perganum. Born at Perganum and educated at Alexandria, he was the pinnacle of ancient medical thought. His word concerning anatomy and physiology remained

FIG. 24.—Portrait of Galen. No bust of Galen has survived from antiquity. The only ancient representation of him is to be found in the so-called Juliana Anicia Manuscript. This magnificent illustrated codex is now in what was once the Royal Library at Vienna. It was written in the year A.D. 487 (? 512), and presented as a wedding gift to Juliana Anicia, the daughter of Anicius Olybrius, Emperor of the West in 472, and of his wife Placidia, daughter of Valentinian III. It contains a number of descriptions and paintings of herbs and a valuable text of the herbalist Dioscorides (flourished about A.D. 60). The portrait of Galen occurs on folio 3 verso and is greatly deteriorated, much of the paint being scaled off. The figure here reproduced has been prepared for this volume by Mr. T. L. Poulton, artist to the Anatomical Department at University College. Mr. Poulton has worked on enlarged photographs, has reproduced the original line by line, and has finally filled in missing details.

FIG. 4 from Singer, C., 1925, p.46.

undisputed until Vesalius and Harvey.

Claudius Galen (129-199 A.D.) rose in the Western medical world to become personal physician to the Roman Emperors, especially Marcus Aurelius. In this capacity he had the opportunity to study the effects of trauma on the human body, contracted through gladiatorial and charioteering contests (Bettmann, O.L., 1972). However, he was forbidden from actually dissecting the human body, by Roman custom, and therefore most of his observations were confined to animals. These consisted mainly of pigs, dogs, goats and oxen with some additional dissections of Barbary Apes (Pick, J., 1970; Marti-Ibanez, F., 1962; Guthrie, D., 1946).

Galen believed that direct observation and handling structures were the only means of appreciating their form and relationships. He introduced a crude experimental method (e.g. his transverse sectioning of the spinal cord) and correlated anatomical finding with physiological observations. Following the Alexandrians, Herophilus and Erasistratus, he identified motor and sensory nerves, tracing the former to the cerebellum and the latter to the cerebrum. In studying the nervous system, he concluded that the brain was the source of the nerves and recognized that it connected various parts of the body. He propounded the concept of 'consent' or 'sympathy' between such parts (Brett, 1965). One doesn't need an overactive imagination to recognise the similarity between Galen's idea of 'sympathy' and the concept of the "internal milieu" of Claude Bernard in the 19th century and Walter Cannon's "homeostasis" in the 20th. In all three concepts, the unity of the body is held in a tense harmony of equilibrium by the interrelated functioning of its parts in which disease is conceptualized as an interruption of this "steady state".

Galen was a very prolific writer (traditionally dictating to several scribes simultaneously) and contributed much to our knowledge concerning medicine, anatomy and physiology. Possibly of more importance than the actual number of his works was the force with which they were projected. For example, medical historians often state that when Galen was questioned about a certain aspect of a subject, he would refer the inquirer to one of his numerous works. His magnificent self-confidence added to the undoubted brilliance of his synthesis concerning ancient medical knowledge. The sheer volume of his output makes him central to any history of a psychological concept concerning human behaviour (Castiglioni, 1947) among others.

Galen's general theory of human bodily function, incorporating the idea of 'pneuma' was an eclectic version, based in part on Aristotle, in part on the Alexandrians and in part on his own observation. Its longevity has been truly amazing, lasting in one form or another into the 19th century where it became manifest in the "vitalist vs. materialist" argument. We shall make a brief excursion into Galen's treatment of pneuma, for not only was it a valiant attempt to give a physical basis to the control of human behaviour, but it reveals what was known of the cardiovascular system at that time:

Simply put, the 'vital spirits' were produced in the ventricles of the heart and distributed to all parts of the body. The blood reached the cranial area by way of the internal carotid arteries whereupon it entered the rete mirabile, an extensive network of fine vessels at the base of the brain (Brazier, M.A.B., 1959). Here, the 'vital spirits' underwent an ill-explained transformation into 'animal spirits' which were regarded as the life force (the word 'animal' being used in the sense of animus, the spiritual principle of life). Although an attempt at clarification was made, the actual physical forms of the 'spirits' were never made clear. These 'spirits' were stored in the ventricles of the brain and from there they entered the nerves (thought to be hollow) where they mediated both movement and sensation (Singer, 1944; Doby, 1963).

Regardless of The vitalistic features of the animal spirits, Galen perceived of their functioning in a mechanical fashion. In his view, man was seen as an organism regulated in its operations by a definite organ, the brain.

Embedded in Galen's grand scheme was his concept of voluntary and involuntary responses:

> "He distinguished between voluntary and involuntary motion and included under the latter such integrated movements as the motion of the arteries and heart and those of the stomach and intestine."
>
> (Fearing, 1964, p.12).

Although this statement doesn't explicitly reveal the nature of voluntary motion we can safely assume- by exclusion- that such movement would concern the skeletal musculature.

Osler (1935) in describing Galen's knowledge of the cardiovascular system, was amazed that he had not realised that blood moved in a circular fashion, rather than ebbing and flowing. But, apparently Galen could not, or would not, see where his researches were leading him.

Unfortunately, in the Middle Ages it was wrongly assumed that Galen had described the anatomy of man and his authority continued to be firm, due in part to his view being accepted by the church. Therefore, although few human dissections were performed (it was forbidden by the

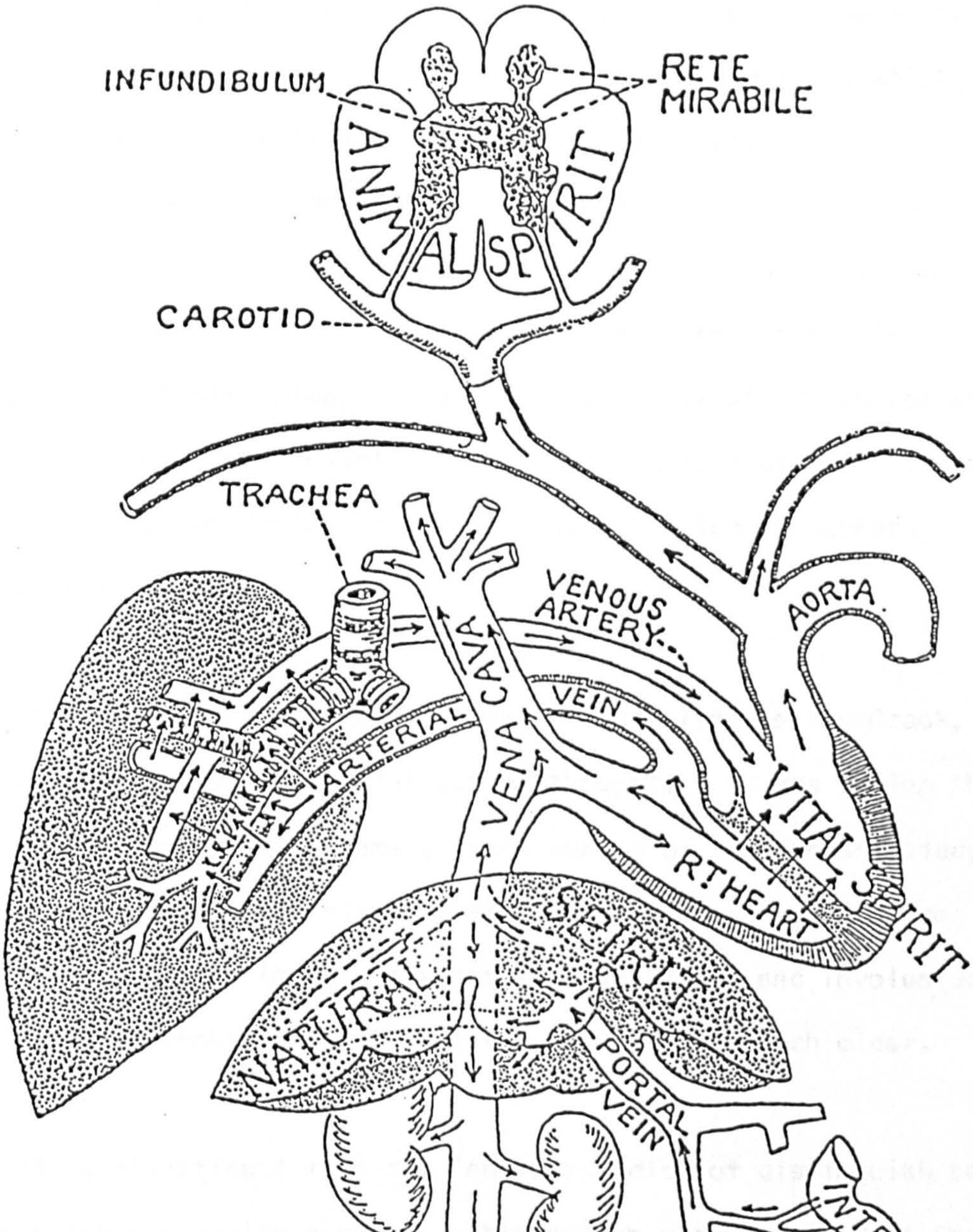


Diagram of Galen's physiological system

FIG. 5 from Singer, C., 1952, p.XIX.

church as it had been by Roman Law) if Galen's descriptions were contradicted, they were considered atypical. A prime example of this concerns the anatomical entity, the 'rete mirabile', which, as stated before, was central to Galen's pneuma theory. This "marvellous net" of blood vessels was found at the base of the brain in ungulates and carnivores, but never in monkeys, rodents or man. It was taken as a reality in the latter species until it was firmly dispelled by the eminent English physician, Thomas Willis. This structure was of unknown purpose until recently. It now appears that it is fundamental to temperature regulation of such animals in which it appears (Baker, M.A., 1979).

Thus between Galen the Alexandrian and Aristotle the Greek, we have an unbroken line of intellectual thought. It was during this period that 'movement' became a topic worthy of independent study. It was also during this period that we have documented evidence concerning a separation of movement into voluntary and involuntary categories, although this distinction was possibly much older.

It is significant that the 'Ancients' did not distinguish between being alive and having a soul. This notion was conceived in various ways but it was always associated with the organisation and control of the body. Detailed biological knowledge was excluded from their intellectual realm by the lack of instrumentation: for example, the absence of optical microscopes prevented the concept of the living cell from emerging. Life was given by the soul, both in animals and plants. The difference between the living and non-living was less marked, and early thinkers tended to assume that all matter possessed power and mobility and was at least quasi-alive.

The early biological conceptions apparently originated in pre-philosophical reflection upon everyday experience. Much information was derived from such endeavours as husbandry, hunting and stock-breeding, nutrition, medicines, poisons and the poignant aspects of childbirth and dying. However, these ideas did not acquire precision until philosophical argument sharpened them. Both medicine and agricultural pursuits were conducted by traditional rules of thumb. The early philosophers used these endeavours to illustrate and justify their own cosmological arguments and thereby evolved biological theories. These were then taken over by the agricultural and medical writers (especially those of the Hippocratic school).

The theoretical influence, therefore, ran mostly from philosophy to biology rather than vice versa. Biology and botany were not separated from cosmology until Aristotle departmentalized the sciences. However, he did not set up autonomous principles in biology, but applied a conceptual framework from his general philosophy. The earlier biological theories, therefore, need to be understood in the context of more comprehensive physical theories.

After Aristotle, the concept of pneuma spread widely, with different applications according to different philosophical positions. Among medical writers it was the legatee of unattributed functions, psychic and sensory. The Stoics equated it with the divine logos that permeates all nature, identifying pneuma and aether. Even the followers of Democratus, the atomists, posited a special kind of atom to account for the soul (Furley, 1967).

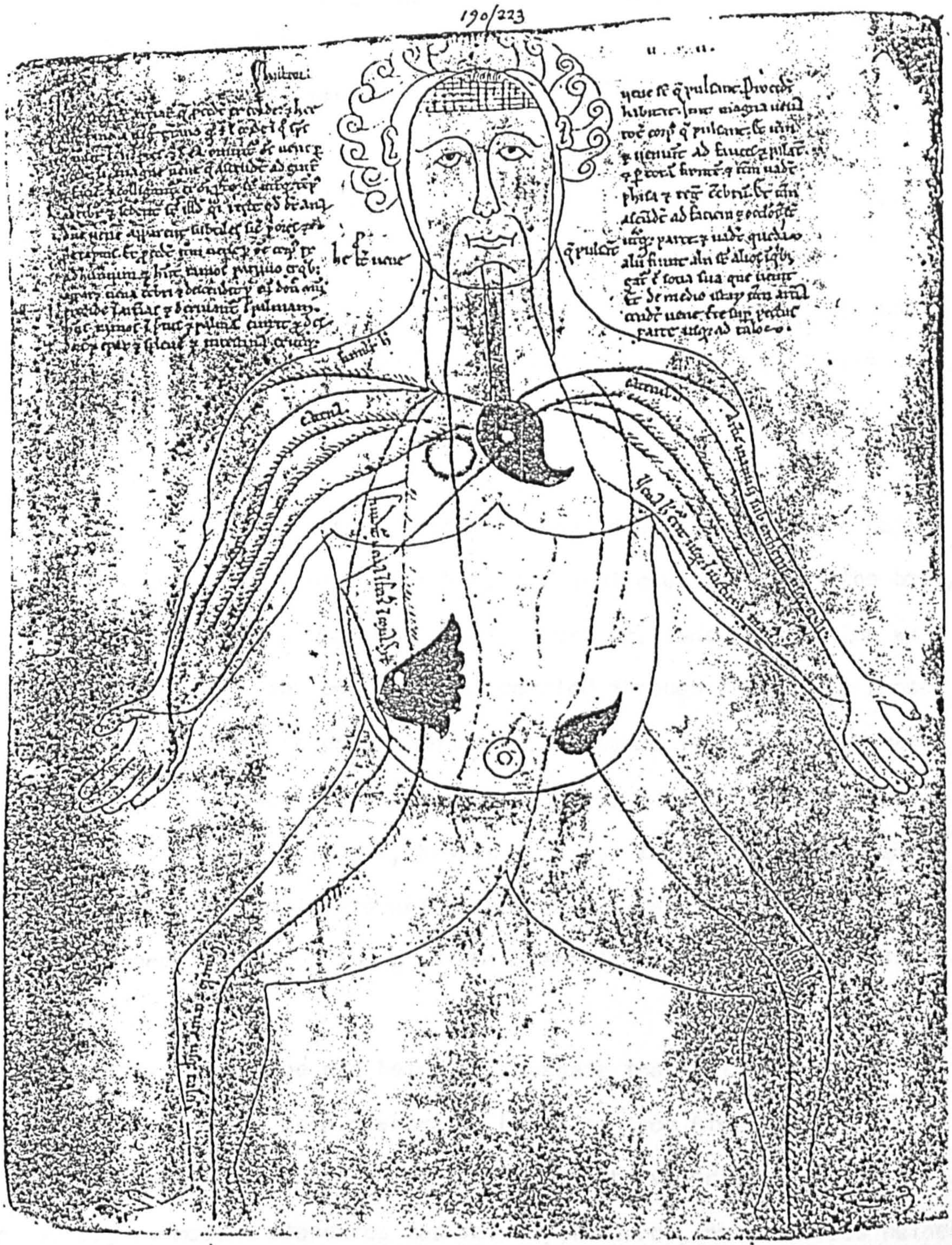
The views of Democratus are considered to be an early form of 'materialism', i.e. a system that defines aspects of the universe, both animate and inanimate, as "nothing-but" matter and the movement of matter. Two further materialistic systems were Stoicism and Epicureanism. Both were largely concerned with ethics but they did bring to attention 'motives' and processes of human action. However, the major feature of these materialistic systems was abandonment of the incorporeal mind with the 'soul' acting on the body through processes that were totally physical. Broadly speaking they foreshadowed thought that would emerge 2,000 years later which would conceive of human behaviour as being environmentally related and concept formation deriving from sense data. But these early attempts embracing 'materialism' and 'behaviourism' were totally abandoned with the rise of Christianity (Furley, 1967).

During the Middle Ages the dominant concern of the influential ecclesiastical forces was the eternal salvation of the soul. The human soul was held by Christian doctrine to be immortal, composed of an immaterial substance and capable of being separated from the body. Such a view of man eclipsed and suppresed alternative conceptions. Moreover, there was a general acceptance of the doctrine of an immaterial principle integrating animal movement independent of physical structure. This may have been responsible for the long delay between early descriptions of movement and much later attempts to correlate structure with function.

As intimated earlier, Greek physicians did not understand the nature of the structures involved in voluntary and involuntary action. Their concepts of the soul, mind, intellect, spirit and will were vague and never concisely defined. In Continental Europe, this confusion is echoed by the fact that linguistically, both soul and mind are the same word 'l'aine' in French, and 'sele' in German (Boring, E.G., 1950).

It is important to realize that Aristotle, Galen and the Epicurians came very close to establishing a mechanistic view of man, albeit in an embryonic state. However, such a concept of man was to fall into abeyance for a period of almost twelve hundred years, as the reigning Christian theology checked or suppressed whatever in the 'pagan' philosophical heritage could not be assimilated into its own position. The mechanistic conception of human nature was, of course, incompatible with theological dogmas affirming the spirituality and immortality of the 'soul' and picturing man as a creature of God, endowed with 'free will'.

But while early mechanistic views were a viable alternative to the concept of supernatural powers, presumed to control human destiny, ancient technology could not convincingly simulate animal or human behaviour by mechanical means. Its major efforts were directed towards building machines that would lift or pull heavy weights, engines of war or simple 'geared' devices such as olive presses. The closest mechanical analogies to animated movement were hydraulic and pneumatic contrivances such as water clocks, fountains and pumps. Indeed, a crude hydraulic pneumatic model was used in the description of animated movement. This reflected in part the popularity of the 'pneuma' concept of the soul. Nevertheless, it would be the sixteenth century before these repudiated aspects of Greek thought witnessed a revival and a naturalistic view of man became reinstated.



The text of this manuscript, composed in the early 13th century, is illustrated by a number of crude drawings, including an Alexandrian Series (see p.5). This one of the arterial system is of interest here because the two arteries running to the cranium, presumably the internal carotids, terminate in a criss-cross area representing the *rete mirabile*. The picture typifies medieval anatomy, for teachers unquestioningly accepted the animal studies of Galen and applied them directly to man, without carrying out any confirmatory practical investigation. As is usually the case with medieval drawings, animal structures and functions were crudely and schematically drawn and superimposed on an outline of the human body. Similar representations of the *rete* are to be found in other manuscripts of the period.[21]

FIG. 6 from Clarke, E. and Dewhurst, K., 1972, p.6.

The Middle Ages: The Fall of Independent Investigation

With the decline of the Alexandrian intellectual effort and the death of Galen, knowledge based upon direct observation and, to a lesser extent, experimentation, went into abeyance. All fields of learning suffered from the great political and social upheavals that accompanied the decline and fall of the Roman Empire. The speculative philosophy of the 'neo-platonists' came to dominate Western thinking, being espoused by Plotinus, the last of the great pagans, and introduced into Christianity by the influential Augustine of Hippo (A.D. 354 340).

It is impractical to do more than indicate some of Augustine's major doctrines concerning the soul. For him, the soul could act upon the body, but the body could not act upon the soul. Further, sense perception was a function of the soul, but one that was carried through the bodily sense organs. The way Brett presented Augustine, he seems to have made a vague separation of voluntary and involuntary responses. However, in general, he exemplified what was to follow, by his interest in the spiritual nature of the soul and its possible eternal salvation, any biological interpretation of human behaviour being out of place in his works (Brett, 1965).

Nonetheless, Augustine did help to propagate the 'cell theory' of brain function which had been elaborated by Galen from Alexandrian thought. This idea that mental processes were located in the ventricles of the brain, which, by modern standards was totally in error, nevertheless helped focus attention on the integrative aspects of brain function(Magoun, H., 1958). Along with Augustine's notions of brain function, his penetrating self-analysis, his views of the reality of the self (anticipating Descartes), his assertion that God was the source of ideas and his emphasis on the soul being an immaterial entity would be integrated into and accepted by Western thought over the next thousand years (Watson, 1971).

Augustine represented educated thought within the Church and education outside the Church was vigorously suppressed. As Guthrie makes clear "learning was no longer held in high esteem, experiment was discouraged, and originality was a dangerous asset" (Guthrie, 1946, p.84). Systematic medical education, under which much of the subject matter of psychology at the time could be subsumed, collapsed. Sir William Osler held the same opinion. He noted that "... a desolation came upon the civilized world in which the light of learning burned low, flickering almost to extinction".(Osler, 1935, p.84). Osler went on to identify 'three channels' by which scientific medicine and thus anatomy and physiology were kept alive during the Middle Ages. These included the monastic schools of southern Italy, Byzantine medicine and Arabian medicine (Osler, 1935). It would be out of place here to go into the contributions of Byzantine and Arabian medicine except to say that they were translators, compilors, preservers and commentators, rather than original thinkers.

One institution which kept learning alive during those turbulent times was the medical school at Salerno. The date of its establishment is not known for sure, but it was functioning at least by the ninth century. This school especially flourished under the patronage of Frederick II (1194-1253) of the Holy Roman Empire, in which a prescribed course of study was given and ended in, what passed for, a 'degree' (Doby, 1963; Castiglioni, 1947).

It was during this century, the thirteenth, that St. Thomas Aquinas (1225-1274) succeeded in bringing the works of Aristotle into the Christian fold (Brett, 1965). It was also this century that saw the establishment of the Universities throughout Europe (Osler, 1935). Eventually, the University at Padua would eclipse all others in the study of the human body, producing the two men who would revolutionize anatomy and physiology;

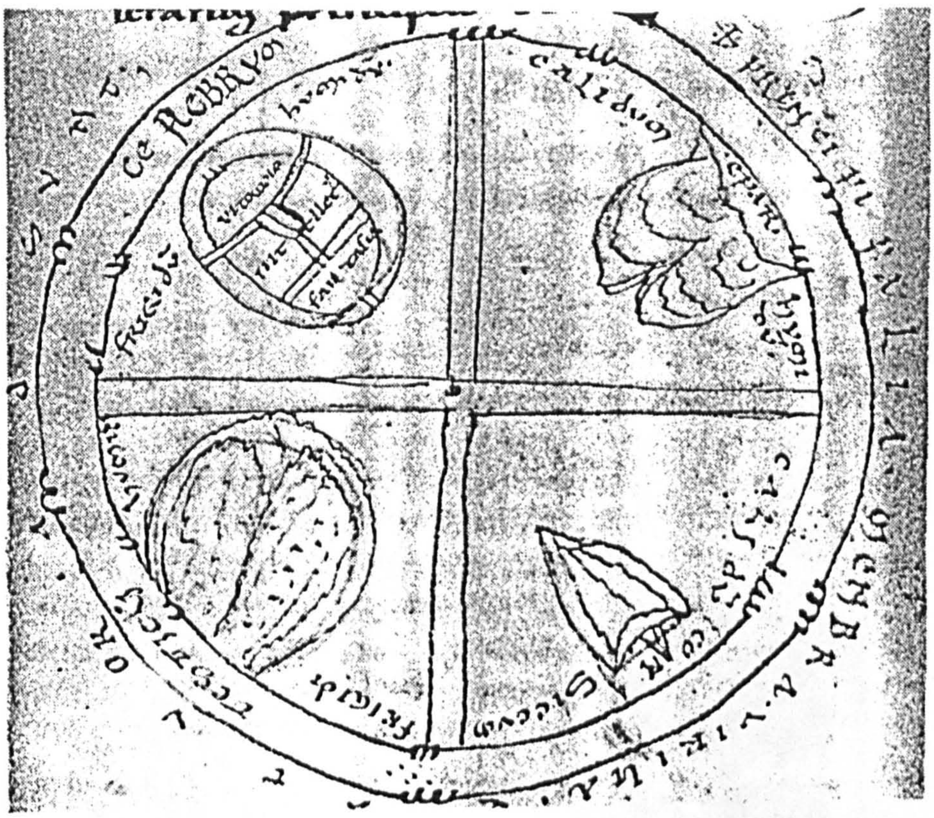


Figure 3[3]

This is from an 11th-century manuscript and is, therefore, the earliest known Western illustration of brain function. The design is reminiscent of the Celtic stone cross found in Anglo-Saxon diagrams, such as the Circle of Pythagoras, the Circle of Columcille,[4] and others of contemporary date. Around the circle is written, "There are present four principal human members", which are, in clockwise sequence from 12 o'clock, liver, heart, testes, and brain ("cerebrum"). The last is, in fact, a drawing of the skull facing inwards and seen from above, with the coronal, sagittal, and lamdoid sutures represented by double lines.[5] The mental faculties inscribed on it centrifugally are, "fantasia" (imagination), "intellectus" (reasoning), and "memoria" (memory). In accordance with the Ancient Greek theory of qualities, the brain is labelled cold and moist, whereas the heart is the opposite, hot and dry; these designations were given great prominence by Aristotle and his followers. The picture, therefore, transmits traditional Greek ideas as well as the concept of the ventricular localization of mental functions.

FIG. 7 from Clarke, E. and Dewhurst, K., 1972, p.10.

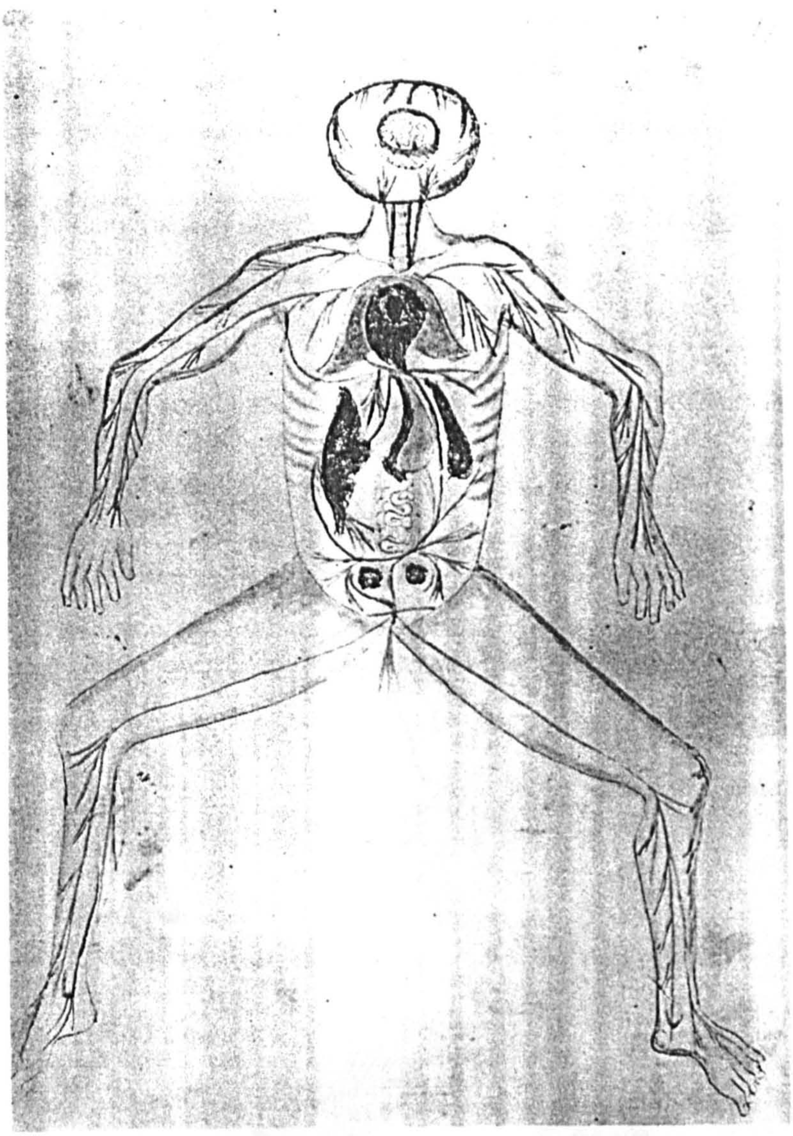


Figure 2 [22] ▷

This is a unique drawing of around 1250 which, according to Sudhoff, may have originated in Salerno.[23] It is part of an Alexandrian Series and depicts the venous system. While two vessels enter the cranial cavity from below, others dip in from the periphery. In the centre is an oval shape consisting of three wavy structures, the significance of which is impossible to elucidate from the drawing alone. The text, written in Catalan, describes three chambers in the brain, thus referring to the Cell Doctrine of ventricular localization of mental functions (see Chapter 3), although it is not readily apparent where these are sited other than possibly between the worm-like structures.

FIG. 8 from Clarke, E. and Dewhurst, K., 1972, p.7.

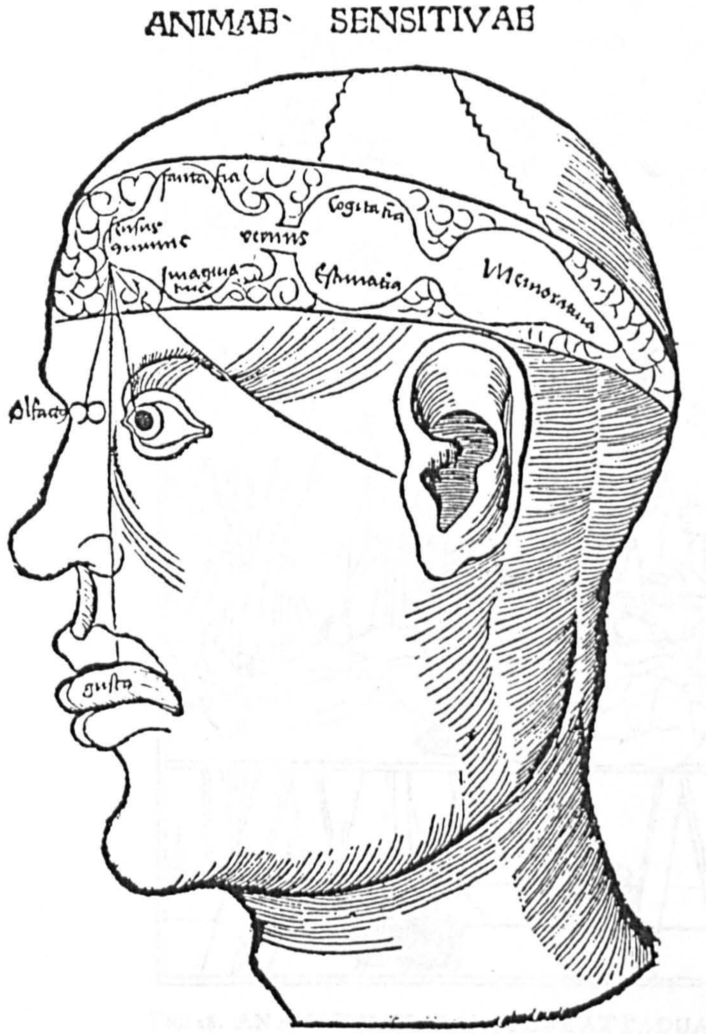


FIG. 47. The scheme of physiological psychology generally accepted in the Middle Ages. It is a diagram of the organs of the 'sensitive soul' (*anima sensitiva*) from Gregor Reisch, *Margarita philosophica*, Freiburg, 1503. Vesalius discusses this very figure on p. 5.

Messages from the organs of hearing, sight, taste (*gustus*), and smell (*olfactus*) unite in the 'Common Sense' (*sensus communis*) in the fore-part of the front ventricle. There fancy (*fantasia*) and imagination (*facultas imaginativa*) are born. Passage from the front ventricle to mid ventricle is guarded by a red worm (*vermis*), a misinterpretation of the chorioid plexus. In the mid ventricle dwell the faculties of thought (*facultas cogitativa*) and judgement (*estimativa*). The hind ventricle is the storehouse of memory (*memorativa*).

FIG. 9 from Singer, 1952, p.139.

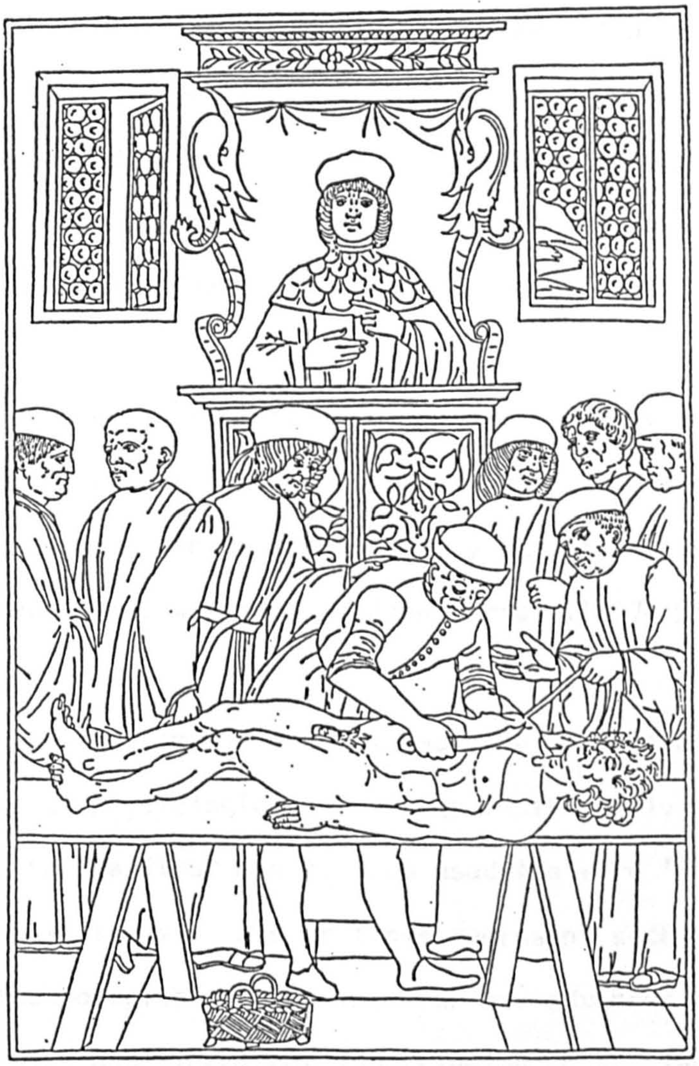


FIG. 28. AN ANATOMICAL LECTURE AT PADUA in the fifteenth century, from a contemporary Italian woodcut. See note opposite.

Description of Fig. 28

The professor stands in his 'chair', a great pulpit or 'cathedra', reading from his book—hence the English academic titles 'Reader' and 'Lecturer' or 'Lector' (that is, 'one who reads'). The body is dissected by a menial, whose work is guided by an assistant, who, with wand, points out (Latin *demonstrat*, hence our modern title *Demonstrator*) the lines of incision. Students in academic dress stand around, but do not themselves dissect.

FIG. 10 from Singer, C., 1928, pp. 74/75.

Vesalius and Harvey. Why Padua? One can speculate, but the Durants may give us a hint: "In nearly all universities except Padua teachers and students were required to accept the official religion ..." (Durant & Durant 1967, Vol. 5, p.583). It seems that eventually this condition fell on the great university, although it went to extreme lengths to avoid it (Guthrie, 1946). Although Padua was the most fertile area as far as medicine and anatomy were concerned, other great contemporary humanists were producing similar works elsewhere.

In the Middle Ages, the study of integrated animal movement as distinct from the mechanisms responsible for bringing it about, led to a broad distinction between voluntary and involuntary action. Such a distinction is represented in the writings of Jean Fernel (1497-1558).

Charles Scott Sherrington, himself a Nobel Laureate of Physiology, paints him as the epitome of physiological knowledge in the early sixteenth century. He is said to be the first man to have used the word 'physiology' in the sense that we know it today. His writings represent such knowledge at the limits of a non-technological education; further advances had to wait for the aid of chemistry and microscopy (Sherrington, C.S., 1946). Fernel was Professor of Medicine in Paris and physician to Henry II and Catherine de Medici (Marti-Ibanez, 1962). His great work Universa Medicina (1554) introduced the terms pathology as well as physiology (Castiglioni, 1947; Brazier, 1959). Indeed Brazier maintains that despite its shortcomings:

> "Fernel's physiology nevertheless shows dawning recognition of some of the automatic movements which we now know to be reflexly initiated for, although only the voluntary muscles were known to him, he realized that sometimes they moved independently of the will."
>
> (Brazier, 1959, p.2)

As well as recognising that some muscular movements were beyond the control of the will, he was the first to describe the central canal of the spinal cord (Franklin, 1949).

Fernal lived during that period of history known as the Renaissance or Rebirth. It was the rebirth of the acquisition of knowledge, a rebirth of the appreciation of human value, a rebirth of man's perception of the world of reality. With the sacking of Constantinople by the Turks in 1453, many Greek scholars and artisans fled west, mainly into southern Europe. They brought with them stunning treasures of art and a point of view which emphasised a humanistic interpretation of reality. The idea of a revolutionary new view of truth was in the air. The notion that human reason had the power to know the truth, to know reality, without the aid of transcendental, divine revelation, was to completely overturn what had been unquestioningly accepted during the Middle Ages.

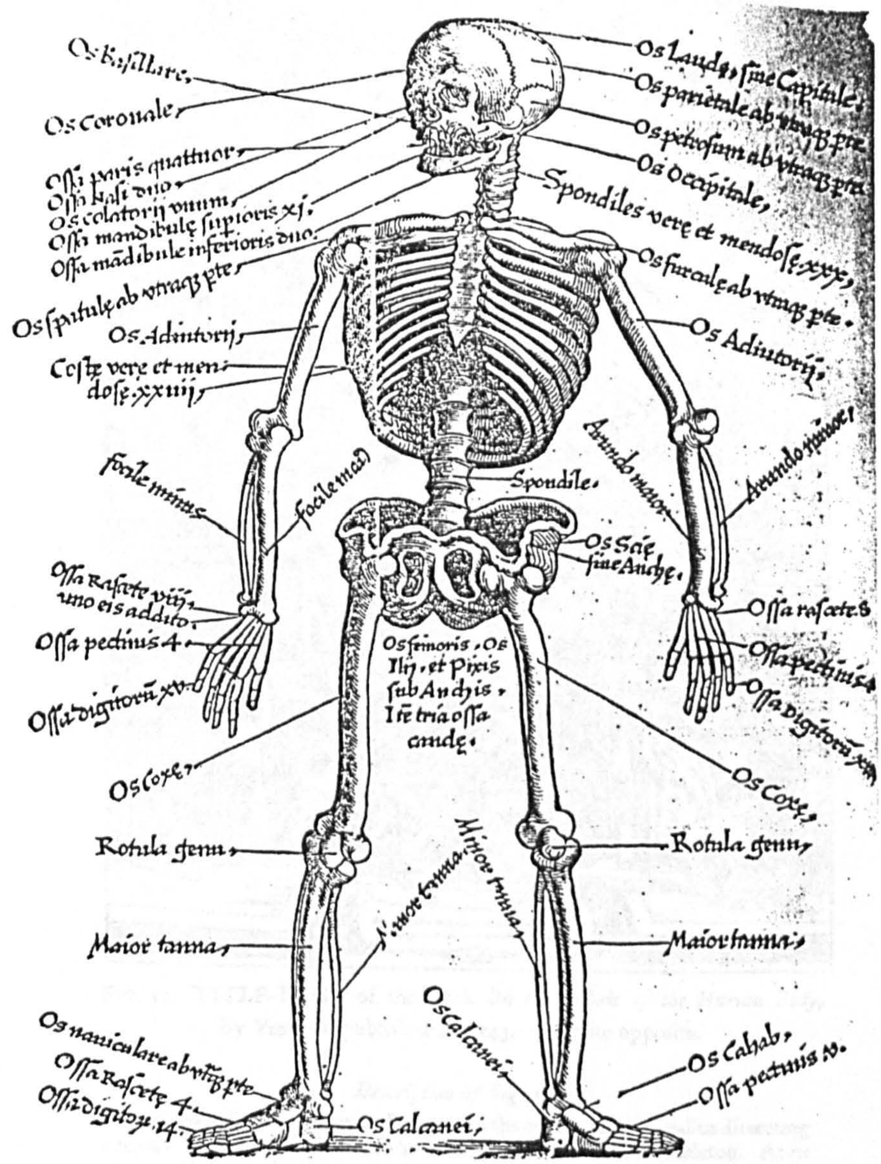
The fifteenth and sixteenth centuries were periods of great discovery; an all-water route to India was found around the Cape of Good Hope, Columbus discovered large land masses to the west which were not oriental, Magellan's expedition circumnavigated the globe - all these enlivened the imagination. However, the advancement of the helio-centric theory of the universe, by the Polish astronomer Nicolus Copernicus, in 1542, was the momentous event of the age, for it challenged Ptolemy's geo-centric theory which had prevailed for fourteen centuries (from the second through the sixteenth) and which had been accepted by the church. By stating that the earth rotated on its own axis and revolved around the sun instead of the sun revolving around the earth, Copernicus was able to account for the new astronomical observations with mathematical calculations more simple than those required by Ptolemaic epicycles. This was a reversal of accepted 'truth' of the first magnitude, so much so that since the sixteenth century, any drastic change in thought is likened to the 'Copernican Revolution'. One year after Copernicus' announcement concerning astronomy, the greatest biological publication of the sixteenth century appeared.

In 1543, Andreas Vesalius (1514-1564) published his 'Structure of the Human Body', thus giving the Galenist Scheme its decisive challenge. This book, illustrated with the help of Titian and his pupil, Jan Stephan of Calcar, corrected some 200 Galenic errors of human anatomy (Marti-Ibanez, 1962).

Marti-Ibanez describes Vesalius, the son of the apothecary to Charles V, stealing corpses from the Cemetery of the Innocents, whilst still a student in Paris, and dissecting them by candlelight, to later produce, as Professor of Surgery in Padua, the 'greatest book in medicine' (Marti-Ibanez, 1962). Later he had to flee Padua, where incidentally he shared the same house as John Caius (later 2nd president of the Royal College of Physicians), to seek the protection of Charles V in Spain because of opposition from strong ecclesiastical influences as well as from orthodox anatomy (Osler, 1935). However, the quality of his work was simply unsurpassed, and it is unfortunate that after having so much to say about the structure of the human body, he had so little to relate concerning its function. Apart from saying that he upheld the "animal spirits" theory in claiming, as was common, that they acted through the brain and nerves to govern bodily movement, he would speculate no further. It is thought by some medical historians that it was ecclesiastical forces that quieted his voice. This view may have had much to offer, for they eventually, indirectly at least, succeeded. Vesalius died on an enforced pilgrimage, leaving only a cloak as his 'estate' (Doby, 1963).

171. *Portrait of Vesalius.*
Woodcut by Stephen Calcar in the first edition of the Fabrica.

FIG. 11 from Castiglioni, A., 1947, p. 426.



A pre-Vesalian skeleton clearly indicating traditional, nonhuman, and even imaginary osteology. The terminology is medieval.

FIG. 12 from O'Malley, C.D., 1964, facing p.81.

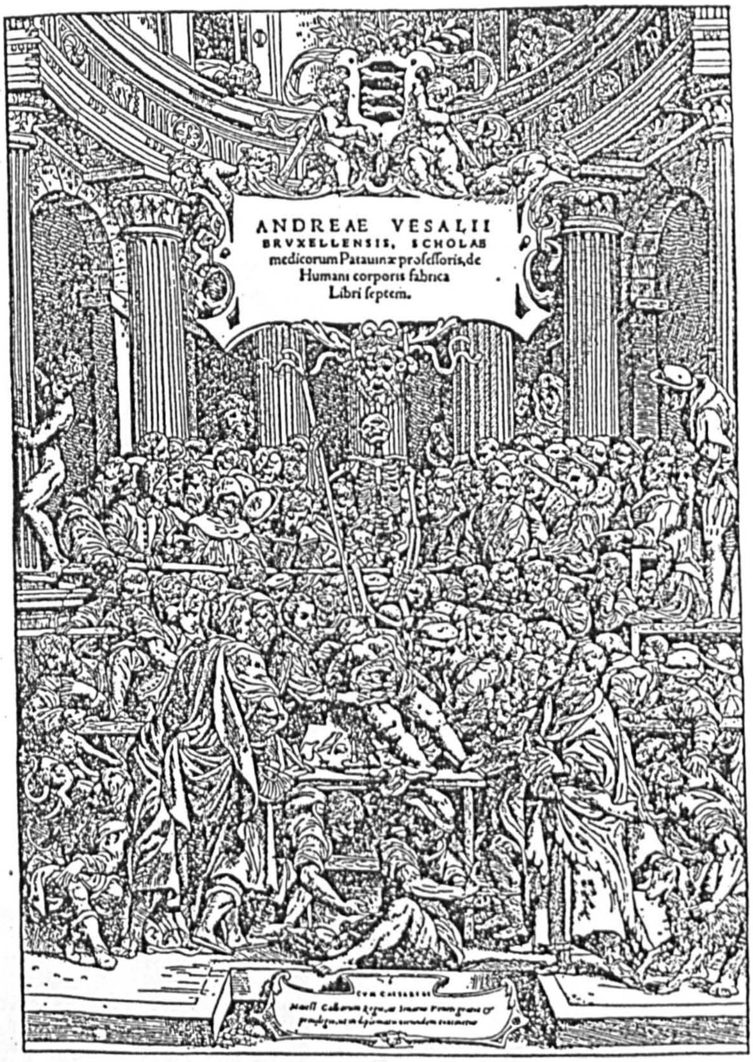


FIG. 31. TITLE-PAGE of the work *On the Fabric of the Human Body*, by Vesalius, published in 1543. See note opposite.

Description of Fig. 31.

It shows a dissection scene at Padua. In the centre stands Vesalius dissecting a female body. At the head of the table stands an articulated skeleton. At its foot are dissecting instruments. Eager students throng around. In the foreground attendants are squabbling. On one side an attendant holds a monkey, one on the other a dog, for Vesalius had often to resort to animal in lieu of human anatomy. Shut off by a bar are members of the lay public. Gallants, grey-bearded scholars, monks, and an enthusiastic bookworm may be discerned among them. Other observers crowd in from every vantage point, even from the windows in the roof. The naked man to the left has been used by Vesalius to demonstrate the surface markings of the underlying organs. The whole scene is busy and vigorous in the extreme. It should be contrasted with the academic calm of Fig. 28 drawn fifty years earlier.

FIG. 13 from Singer, 1928, pp. 86/87.

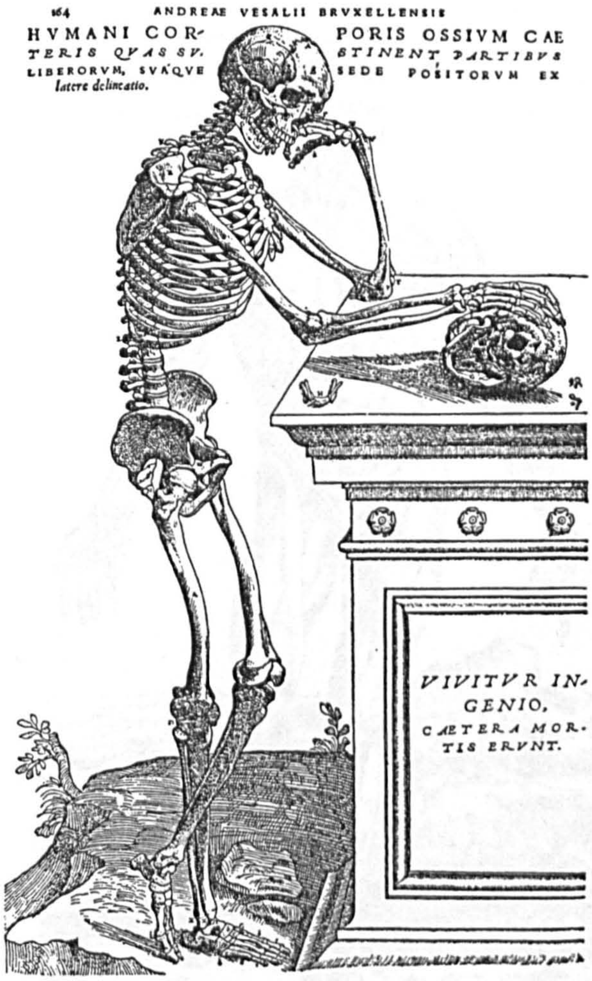


FIG. 103.—Second Skeleton from *Fabrica*.

FIG. 14 from Singer, 1925, p.181.

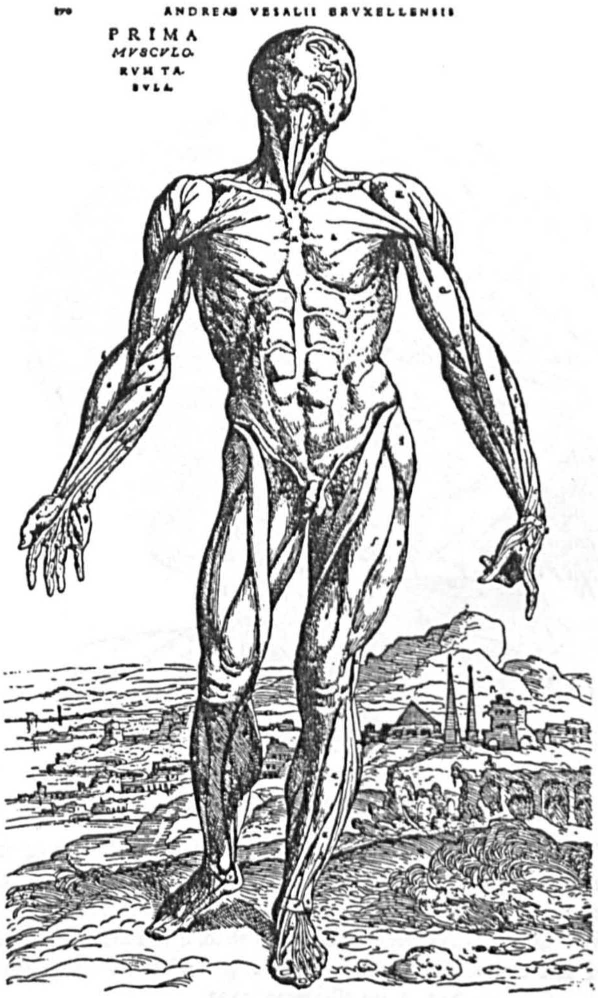


FIG. 105.—First Muscle Tabula from *Fabrica*.

FIG. 15 from Singer, 1925, p.193.

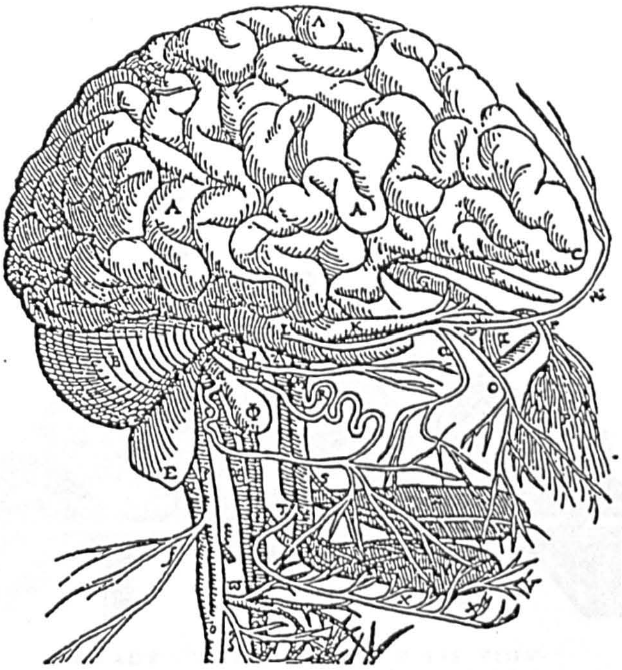
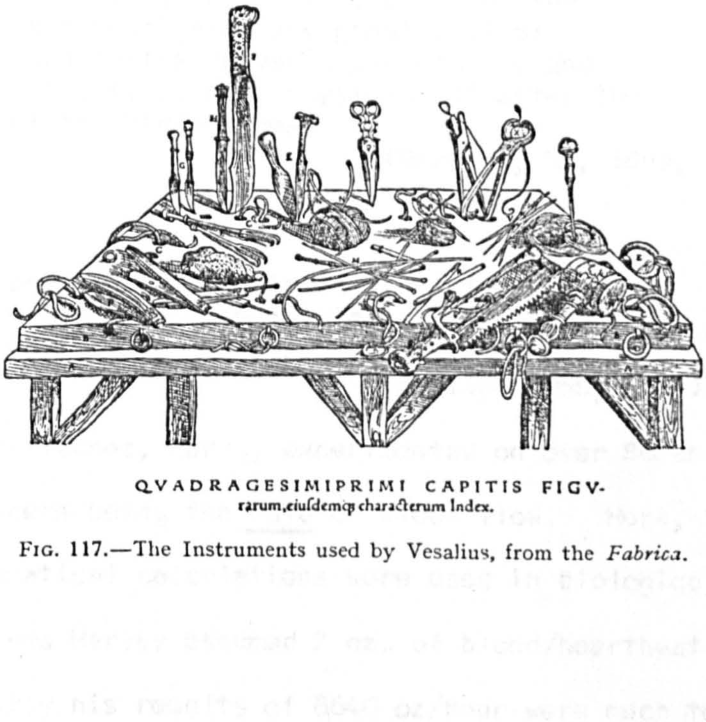


Figure 25

Upper part of diagram of cranial nerves from *Fabrica*, p. 319. The letters F,G,I,K, *a,c,d*, Φ represent the same structures as in Fig. 24. The masses Z and Y represent palate and tongue respectively. The identification of the nerve-roots is discussed by Professors J. B. de C. M. Saunders and C. D. O'Malley in their *Illustrations from the Works of Andreas Vesalius*, Cleveland and New York, 1950, especially on p. 146.

FIG. 16 from Singer, 1952, p.124.



QVADRAGESIMIPRIMI CAPITIS FIGV-
rarum,eiusdemq; characterum Index.

FIG. 117.—The Instruments used by Vesalius, from the *Fabrica*.

FIG. 17 from Singer, 1925, p.205.

Vesalius, almost single-handedly, totally transformed anatomy as it was known before his time. His accurate description of the human body was to be the foundation for the study of its functions, which was to follow in the next three centuries. Among his followers in Padua were Falloplus and Fabricius ab Aquapendente, teacher of William Harvey. Harvey (1578-1657) contributed to physiology what Vesalius did for anatomy: he revolutionised the field. As stated by Max Verworn:

> "Harvey, by his brilliant discovery, raised the experimental method again to an honourable position in physiology, after it had remained in complete oblivion for 13 centuries. The spirit of the conscientious investigator and great logical acuteness characterise Harvey's personality and stamp him as the first real physiologist after the long night of the Middle Ages."
>
> (Verworn, M., 1899, p.13).

Boring concurs;

> "Harvey's discovery of the circulation of blood is dated 1628, the first item of biological science which we cite for the new age."
>
> (Boring, 1950, p.50).

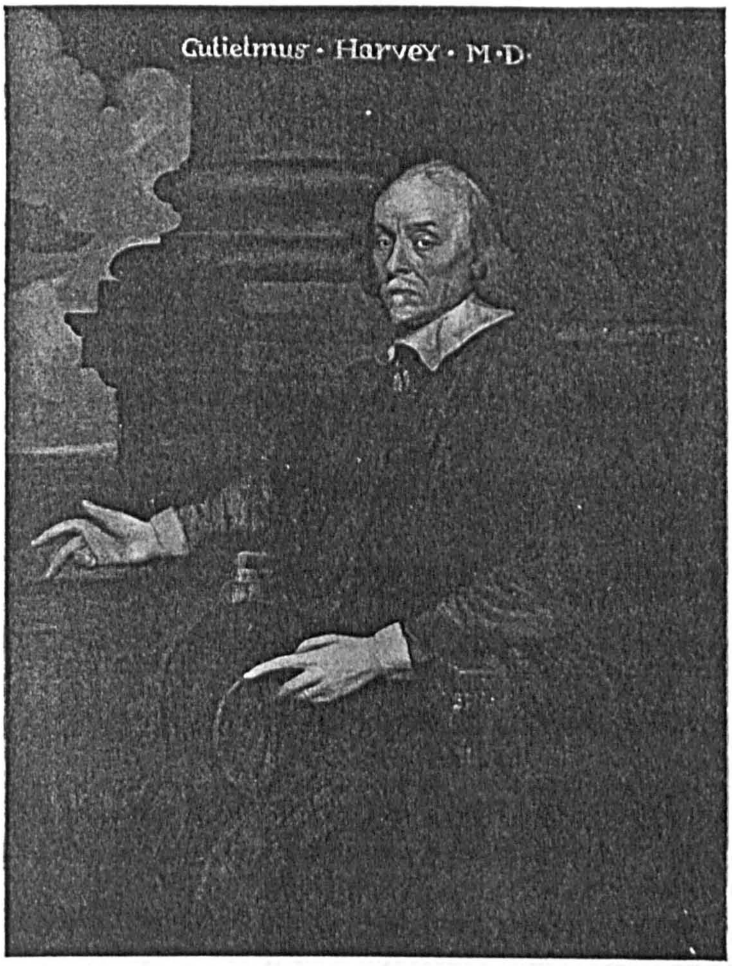
According to Marti-Ibanez, Harvey experimented on over 80 animal species, with his main concern being the <u>rate</u> of blood flow. Here, for the first time, mathematical calculations were used in biological investigation. For his calculations Harvey assumed 2 oz. of blood/heartbeat and 72 beats/minute. Apparently his results of 8640 oz/hour were much too high for the blood to come from food or tissue storage, his conclusion was that the blood circulated from the heart to the arteries to the veins and back to the heart (Marti-Ibanez, 1962).

Harvey's first announcement of his epoch-making discovery went virtually unnoticed for twelve years, until it was published in Frankfurt in 1628. After this, it received widespread acceptance, although it was not without its critics: for example, he was attacked by the Paris Faculty of Medicine, led by Guy Patin (1601-1672), who called his theory 'absurd' and 'harmful' among other things (Castiglioni, 1947). But it was destined to become the fundamental concept, upon which was built the relatively rapid advances in the scientific knowledge of the human body and how it functions, over the following three centuries. Unfortunately, Harvey, like Vesalius, ventured little speculation about the influenced of the nervous system upon bodily action, except to emphasize the mechanical or physical processes of such.

As an epilogue, it should be said that Harvey's concept necessitated a physical connection between the arteries and veins. This connection was demonstrated in 1661 by Marcello Malpighi, pioneer in microscopic anatomy and regarded by many as the founder of histology, through his description of capillaries in the lungs of frogs. Both men also advanced the science of embryology, with Malpighi extending Harvey's idea that 'all life comes from an egg'. With Harvey, the methods of observation and experimentation became firmly-established principles in biology. His concept of circulation destroyed the Galenist idea that blood ebbed and flowed through invisible pores in the intra-ventricular septum and therefore struck at the basis of the 'animal spirit' theory of movement and muscular contraction, although this was not fully recognised for another two centuries (Franklin, 1949).

The efforts of Harvey and Vesalius were extremely important in creating an intellectual climate that would promote a mechanistic view of man. Vesalius' De Fabrica familiarized the sixteenth century mind with the image of the human body as a co-ordinated assemblage of related structures. An analogy developed between the internal organization of the body and that of the clock, which was perhaps the most intricate mechanism of the day. Harvey's discovery of the circulation of the blood became a pivotal theme in the perception of the body as a hydraulic machine.

PLATE XVIII



WILLIAM HARVEY 1578-16
From the painting by CORNELIUS JANSSEN in the Royal College of Physicians of London.

FIG. 18 from Singer, 1925, facing p.180.

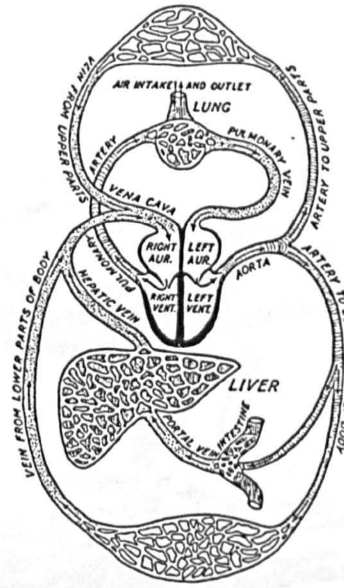


FIG. 43. DIAGRAM TO ILLUSTRATE THE NATURE OF THE CIRCULATION OF THE BLOOD. Leaving the *left ventricle*, when the walls of that cavity contract, the blood is forced through the valves into the great artery known as the *aorta*. From the aorta it passes into smaller and ever smaller arteries, finally reaching the *systemic capillaries* or the *portal capillaries*. After travelling through one or other capillary network it enters a vein. Thence it passes into larger and ever larger veins, until it ultimately enters the great vein known as the *vena cava* that opens into the *right auricle*. It has now completed the Greater Circulation. As the right auricle contracts the blood passes through the valves between the right auricle and right ventricle into the *right ventricle*. From there it enters the Lesser Circulation, passing into the great *pulmonary artery*, which conducts it to the lung. In the lung the pulmonary artery breaks up into branches and finally into capillaries. Through these the blood travels until it reaches a tributary of the *pulmonary vein* and finally the pulmonary vein itself. The pulmonary vein empties its blood into the *left auricle*. From the left auricle the blood passes at last into the left ventricle from which it started, having traversed both the Greater and the Lesser Circulations.

To understand the change which Harvey wrought in the conception of the workings of the body, this description and diagram should be compared with the description and diagram on pages 56–59.

3383 I

FIG. 19 from Singer, 1928, p.113.

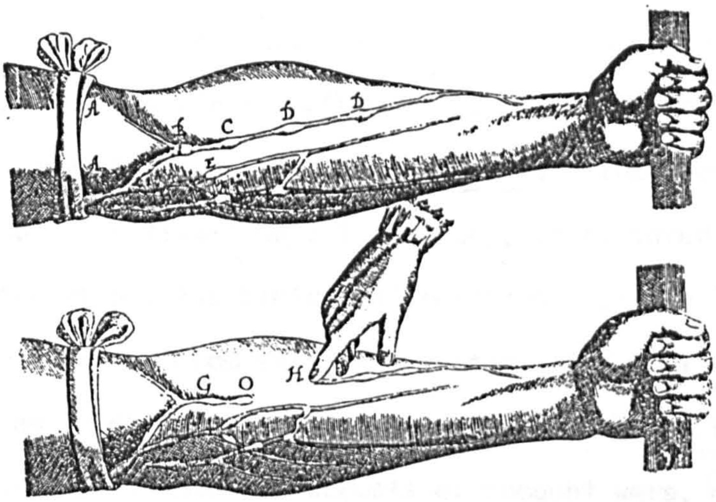


FIG. 44. THE VALVES in the superficial veins as seen in the bandaged arms of living men, from William Harvey's great work on the *Circulation of the Blood*, printed in 1628. The bandage is seen on the upper arm in each case, and the valves are indicated, as in life, by nodes or swellings in the veins. If a finger is pressed along the vein from one valve to another as from node O to node H in a direction away from the heart, the vein from O to H will be emptied of blood. It will remain empty, since the valve at O does not permit the passage of blood away from the heart, but only towards it. This observation was Harvey's starting point for his great discovery.

FIG. 20 from Singer, 1928, p.114.

Hence the heart could be viewed as the 'mainspring' which drove the clockwork body.

The 17th century witnessed a seemingly irresistible passion to interpret the functions of the body, both human and animal, in terms of mechanical and physical concepts without reference to a non-material cause, such as the soul. This could be understood as an outgrowth of Copernican theory. The earth is dethroned as the centre of the Universe. Man's importance is diminished, except to himself. The fact that man himself had become a legitimate object of study, represented a major shift of scientific interest and the biological sciences took the form by which we recognise them today. From this same century, two conflicting schools of thought arose as to what the method used by the emerging sciences was going to be. These philosophical schools of thought were, of course, rationalism and empiricism. The latter was largely an English enterprise, whilst the former has been associated with France and, to a lesser extent, Germany.

It is felt that a digression into broader issues is in order here: the 17th century opened with the burning at the stake of Giordano Bruno for being an atheist and a Copernican. Later it saw the publications of Kepler, Descartes, Harvey, Galileo, Newton and Locke. One could say, without being misleading, that during the 17th century the Universe, including man, became mechanised. Indeed, Galileo founded kinetics, the subject matter of which comprises the causal expression of the Laws of Motion (Born, M., 1962). His work, based on the publications of Kepler, which is looked upon today as proof of Copernican theory, was in his own time denounced as heresy. It was a century in which men of great intellect would struggle to ascertain exactly what was meant by the 'scientific' method. In doing so they would greatly advance all sciences, not only astronomy and mathematics, but biology as well. Thus the structure and function of the nervous system and its role in the control of behaviour, started to receive long-awaited attention.

Two schools of thought emerged in the medical community which attempted to explain bodily processes by different methods; the so-called iatrophysical and iatrochemical views. The former maintained that all vital phenomena could be explained in mechanical terms whereas the latter held to a chemical explanation. Of course both were partly correct, but the distinction was more sharply viewed at that time. The iatrophysical position was put forth forcefully by the great Giovani Alfonso Borelli (1608-1679) who applied mathematical analysis to muscular movements. Borelli was a student of Galileo and one of the teachers of Malphighi and is important because he advocated the idea that living organisms were subject to physical laws in the Newtonian sense (Castiglioni, 1947).

The other broad view, the iatrochemical school, was led by Francis de la Boe (Sylvius)(1614-1672) who not only advocated the role of chemistry in bodily processes, but showed great interest in the nervous system. The gross morphological feature of the brain called the Sylvian Fissure was named after him (Guthrie, 1946). Also it may well have been Sylvius' interest in the brain that inspired one of his students at Leyden, Thomas Willis, to raise the knowledge of it to a new and higher standard (Marti-Ibanez, 1962).

A younger contemporary of Harvey, Descartes and Swammerdam, the English physician Willis (1621-1675), distinguished himself with the publication of his <u>Cerebric Anatome</u> in 1664 which is widely recognized as

Portrait of Thomas Willis. As it appears in Collected Works. Amsterdam 1682–After an engraving by David Loggan (1666). – Institute of the History of Medicine, Zürich.

FIG. 21 from Isler, H., 1968, facing title page.

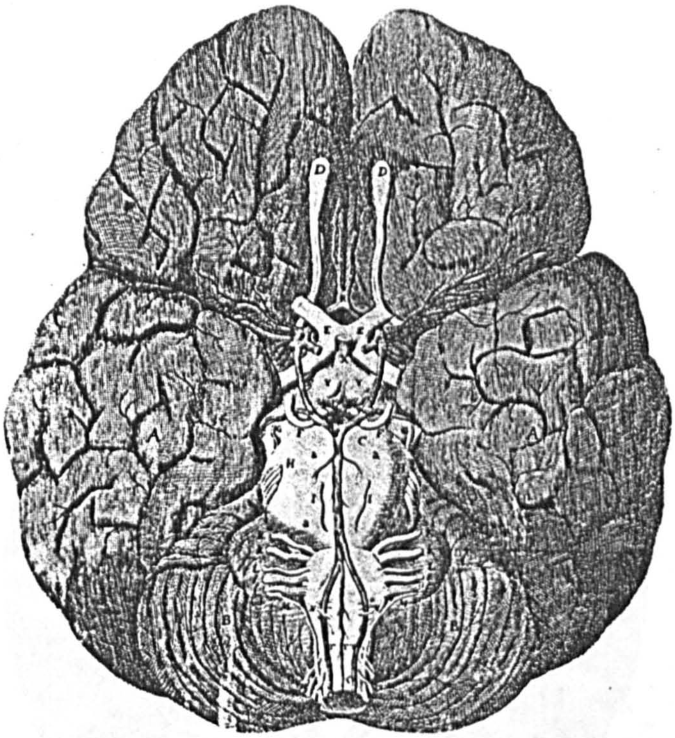


Figure 96

Although in this illustration, Willis's drawing of the surface of the brain was not of a high standard, other details of structures at the base of the brain were accurately depicted. Indeed, Steno substantiates this opinion when he wrote in his essay (see p.70) "the best figures of the brain up to the present are those presented to us by Willis", although he went on to state that they were by no means perfect.[22]

Figure 96[23] is probably the most famous 17th century brain illustration. It was drawn, together with others of Willis's plates, by Christopher Wren, and depicts elegantly the complete circle of Willis (cf. Figure 91) and the cranial nerves.[24] Willis acknowledges his indebtedness to Wren, who was "frequently present at our Dissection, to confer and reason out the use of the Parts". "... Dr Wren, on account of his singular humanity, wherewith he abounds," wrote Willis, "was pleased to delineate with his own most skilful hands many figures of the Brain and Skull so that the work could be more exact."[25][26]

The cerebral convolutions receive much less adequate treatment, however, but it could be argued that this is because they are merely a background to the basal structures, which the artist wished to high-light. The gyri are sketched in with equal vagueness in the rest of Willis's illustrations of the human brain. Blood vessels emerging from gyri are shown.

FIG. 22 from Clarke and Dewhurst, 1972, p.71.

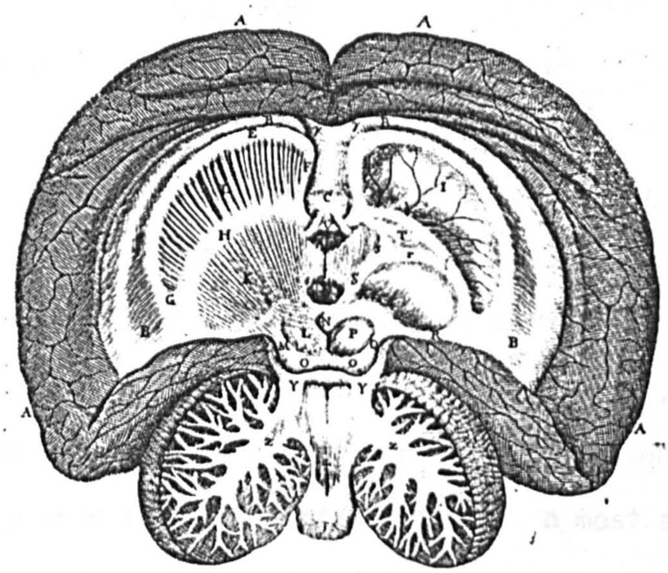


Figure 98

Willis put an end to ventricular localization of brain function and proposed three areas in the brain itself: the corpus striatum, corpus callosum, and the cerebral cortex. These mediated "sensus communis", imagination, and memory, respectively. This plate is from Willis's *De anima brutorum* of 1672[30] showing the basal structures cut coronally. The main structures are: BBBB, corpus callosum; C, fornix; D, I, corpus striatum; K, thalamus; N, pineal; LPOO, quadrigeminal bodies. Interestingly enough, in none of Willis's plates was the cerebral cortex depicted in section and here the convolutions have the same flat and lifeless appearance as in his other drawings (Figures 96, 97).[31]

FIG. 23 from Clarke and Dewhurst, 1972, p.72.

the most comprehensive work on the nervous system up to its date (Fearing, 1964). As Sedleian Professor of Natural Philosophy at Oxford, he was in a position to put forth his views in a forceful manner. His friends and colleagues, Richard Lower and Christopher Wren, helped him greatly, with Wren executing the illustrations and Lower doing many of the dissections (Franklin, 1949). These three men were all to become original members of the Royal Society (1663). Pick credits Willis with great contributions to neurophysiology in that he distinguished for the first time "'involuntary' and 'volitional' movements" and goes on to say that he, "laid the foundation of what we call today the vegetative and somatic functions of the nervous system" (Pick, 1970, p.6). More explicitly, he considered the cerebellum or 'lower centre' to be the seat of involuntary movements whereas the cerebrum or 'higher centre' served voluntary motions (Brazier, 1959). Fearing (1964) also points out that Willis formulated his idea in such a way that they would be open to experimental attack: a most admirable endeavour, in any age. In addition, the 'circle of Willis' abolished once and for all, Galen's 'rete mirable' in man. Willis was to achieve greater importance in the next century when his ideas were accepted by Boerhaave and his views that, functionally, the sympathetic ganglia were autonomous centres of nervous control were extended by Jacques Benigne Winslow (1669-1760) (Pick, 1970).

After the thirty years war, the intellectual vigour of Europe gradually marched toward the religious tolerance of the north, particularly Holland. This country attracted many great figures, the most important of which was the brilliant French philosopher Rene Descartes. He epitomises the fact that man himself had become a legitimate object of study, and although his physiology was largely imaginative and speculative, his philosophy profoundly influenced man's view of himself.

The Cartesian View of Man

With Rene Descartes (1596-1650) one reaches the beginning of the modern age in philosophy, physiology, and psychology. He is recognised as the father of modern dualistic thinking and modern reflexology. Also he introduced interactionism into mind-body theory. Descartes' intellectual stature has been noted as follows:

> "Not since Aristotle had a philosopher constructed a new and influential system of thought that took into account the sum of knowledge which in two thousand years had grown significantly."
>
> (Herrnstein and Boring, 1965, p.58)

Wilson reiterates this point in his recent defence of physicalistic explanations of mental phenomena.

> "The Cartesian formulation of psycho-physical dualism remains essentially unchallenged to the present .... the Cartesian dualist model of persons and their behaviour can be taken in toto as the root metaphysical model of the prevailing orthodoxy. In recent time the dualism has been construed as a linguistic, conceptual, logical or phenomenological one, rather than a substantial one, but the distinctions drawn are still along the same lines as those drawn by Descartes."
>
> (Wilson, E., 1979, p.46)

Fancher emphasises the great appeal of Descartes' ideas on Western culture:

> "Whatever its faults, his (Descartes) interactive dualism captured the Western imagination to such an extent that it became accepted almost as a matter of course. Few theories, in any discipline, can claim equal success."
>
> (Fancher, 1979, p.37).

With such accolades it would serve us well to pause and discuss Descartes' views in more depth than those of the previously mentioned individuals.

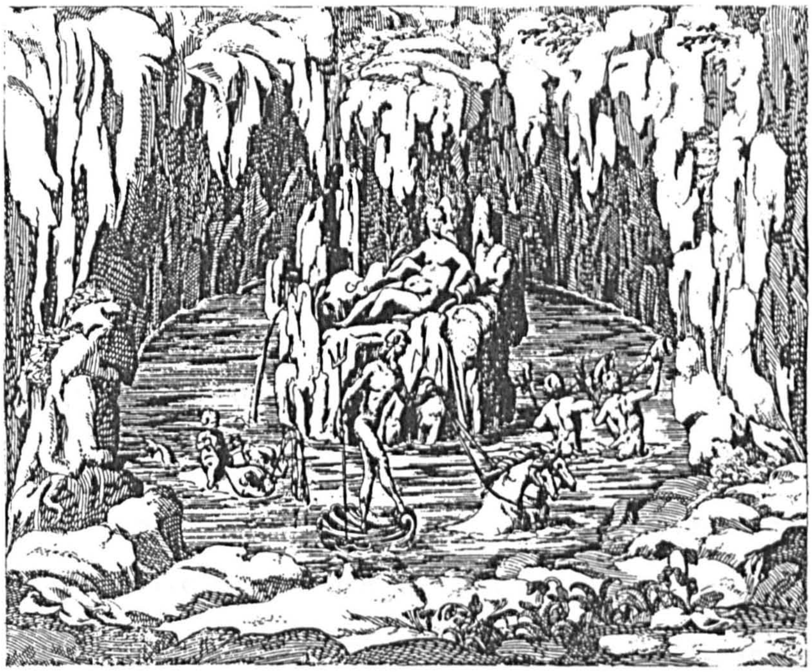
Descartes was a rationalist and for him reason had primacy, it was the most important source and test of truth. In all areas in which knowledge is sought, Descartes thought one begins with clear and distinct, self-evident and true axioms, from which other truths can be deduced, constructing a deductive, logical system of truths. He was also concerned with mathematics, a field in which he was somewhat gifted. Apparently, the key to analytical geometry was revealed to him in a dream: the story goes that he was snowed in on the banks of the Danube whilst in the service (1619) of the Duke of Bavaria, a Protestant. In this condition he took refuge in a warm room, fell asleep and had a dream. This dream not only revealed to him the basis of a marvellous new science, but also his vocation, which was to entrench dualistic thought into Western philosophy, from his own time to the present day. Interestingly, he was so impressed by this experience that he vowed to make a pilgrimage to the shrine of Our Lady of Lorette which he eventually fulfilled on foot (Maritain, J., 1944).

The most striking feature of reality as described by Descartes' philosophy is that a barrier is erected between two different kinds of reality. based upon substances and their attributes, i.e. between mental, spiritual, thinking substance on the one hand, and on the other physically, spatially extended substances. Descartes presents us with the classical case of psychophysical dualism. Dualism is the name for any theory which claims that there are two ultimate and irreducible components to be explained within the subject, whatever it may be.

Psychophysical dualism may be defined as the doctrine that reality has two kinds of attributes; the mental and the physical, and that one kind of reality can never be a form of or be reduced to the other. So for psychophysical dualism, mind can never be shown to be derived from, or a form of, or a function of, or reducible to matter. Cartesian psychophysical dualism formulates its doctrine in terms of substances. Since, for Descartes, attributes such as mental or physical cannot exist except as the attributes of substances. This is how Descartes proved that one's being conscious of the attribute of thinking, showed <u>necessarily</u> that one exists as a thinking substance, ie. a substance in which thinking is going on. This led him to his famous cogito proof, 'Cogito Ergo Sum',

III René Descartes

FIG. 24 from Whitteridge, G., 1971, p.64.



Automated garden figures and main driving mechanism in the grottoes of the royal gardens at Saint-Germain-en-Laye. From engravings in Salomon de Caus, *Les raisons des forces mouvantes avec diverses machines tant utilles que plaisantes ausquelles sont adjoints plusieurs desseings de grotes et fontaines*, Frankfurt, J. Norton, 1615. This grotto is described by Descartes on page 13 of the French text.

XVIII

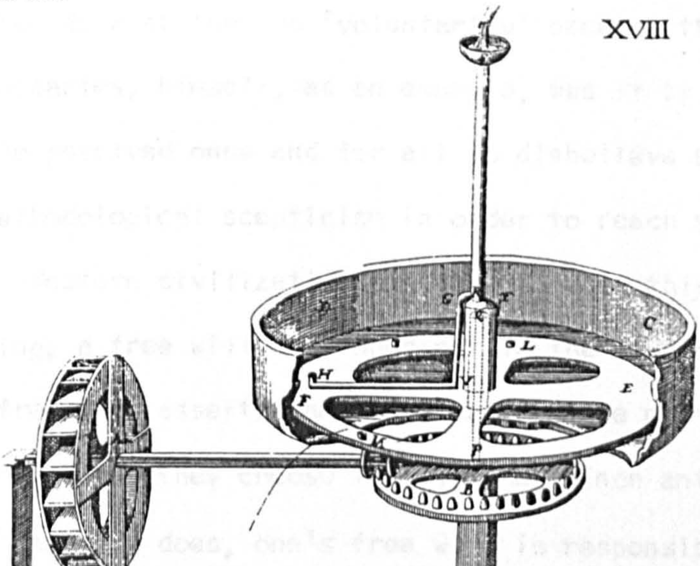


FIG. 25 from Hall, T.S., 1972, facing title page.

(I think, therefore I am,) one of the most singularly famous lines in all philosophy, the proof, the rock of his philosophy. Cartesian rationalism is as bold a statement for human reason as has ever been made, for it claims that the structure of the world correspondes to the structure of our own reason, of our rational ideas (Alanen, L., 1982).

One can see how extreme his position is, by considering its impact on the individual human being. For here, each person is split in two: on the one hand, the body obeys the laws of mechanics; it performs its functions in orderly, lawful ways; it follows causal necessity. On the other hand, the mind exhibits free will and is not subject to the laws of Newton's deterministic world machine; it is free to choose. This point is of major importance to society today, especially in the areas of criminal psychiatry and jurisprudence, with implications for the treatment of law-breakers. Human beings are looked upon as being responsible for their actions, they do what they do 'voluntarily' because they choose to do so. Using Descartes, himself, as an example, was it by mechanical clock-work that he resolved once and for all to disbelieve everything and attempt to use methodological scepticism in order to reach an absolutely certain belief? Western civilization has come to view this as a triumph of a thinking thing, a free will, not obedient to the laws of mechanics. The doctrine of free will asserts that human beings are not determined by antecedent causes in what they choose to do. And since antecedent causes do not determine what one does, one's free will is responsible for one's actions. In contrast the doctrine of determinism claims that one is not responsible, that one's action is the inevitable and necessary result of a host of prior causes.

For completeness we must now turn to perhaps the weakest aspect of Descartes' philosophy, his theory of interaction between the mind and the body. It has long been recognised that Descartes was attempting to formulate a compromise between the church and the rising new sciences, but the problem has continued to disturb psychology down to the present day. Descartes' attempt at interaction failed, as critics deemed the recent effort by Karl Popper and Sir John Eccles, a failure.

The reason is common-sensical; almost every human being realises, during his life, that the body affects the mind and vice versa. If one imbibes a large amount of alcohol or a small amount of a narcotic, one soon knows that the mind has been affected. And the mind can affect the body; if one crosses a picket line, calls one's dog or waves to another human being, one does so because one 'wills' it so. Interaction fails in Descartes' case because of the way in which he formulated his doctrine (i.e. substances). How can an immaterial, non-extended, motionless substance, subject only to free will, influence a spatially extended substance, obeying the laws of mechanics and motion?

Descartes used the pineal body of the brain as the focal point where the mind interacts with the body. In his time it was thought that this body was the only single structure in the brain, the rest being paired in bilateral symmetry. Today it would be a great surprise to neurophysiologists and neuroanatomists for it to be revealed that the pineal body was the seat of volition. Anatomically part of the epithalamus, its function isn't definitively known, although it is thought to affect, either in a direct or indirect fashion, the function of the gonads. Moreover the pineal hormone, melatonin, may be a neurohumour, as are acetylcholine and noradrenaline. Parenthetically, it may be mentioned that the pineal body is penetrated by "autonomic nerve cells" in the primate and sub-primate. In the rat the fibres have their origin in the superior cervical ganglion, but these relations in man are not yet clear (Crosby, E.L., Humphrey, T. and Lauer, E.W., 1962). So even Descartes' pineal device doesn't save him. Descartes, having started with the self, (his cogito proof) found it difficult to pass from mind to body. And his difficulty has been a dilemma for psychology to the present day. Walter B. Weimer, in his essay 'Manifestations of Mind' succinctly reflects current opinion.

> "Mind cannot cause matter, nor vice versa. Classic, emergent interactionism, which postulates that the interaction is causal, cannot be correct."
>
> (Weimar, W., 1976, p.25)

However, his psychological contributions were many: eg. mechanical conception of the body, mind-body interactionism, doctrine of innate ideas, locating the mind's functions in the brain and the concept of the reflex in terms of sensory input and motor output. Importantly for us, he recognised 'unclulato reflexa' or involuntary action which was beyond the control of the will as well as behaviours which are under the supervision of the free will (Schultze, 1946; Boring, 1950).

Descartes' most important contributions to psychophysiology came in his 'Traite de l'homme', published posthumously, in 1662. Fearing regards this work as:

> "..... probably the first attempt to present systematically, a coherent description of bodily responses in terms of actual - or by hypothetical - neuromuscular structure."
>
> (Fearing, 1964, p.19)

Fearing's study of Descartes is instructive because he includes many direct quotes from the great philosopher and also credits him with the first descriptive statement of involuntary action which bears a recognisable resemblance to the modern concept of reflex action.

Thus, Descartes made the distinction between voluntary and involuntary behaviours in the human being. In animals, all behaviours were reflexive and therefore involuntary. Animals, having no will, could not be expected to exhibit voluntary behaviour. Animals, having no will or soul, cannot be rational, cannot think in the reflective human sense and are not immortal. As Brett has stated:

> "..... there can be no doubt that Henry More hit the mark when he said that the whole idea arose from the prejudice against giving animals a claim to immortality."
>
> (Brett, 1965, p.373).

The extent of Descartes' influence can be seen in Pavlov's citing of Descartes' concepts of reflex action as the input to the development of his own concept of conditioned reflexes (Pavlov, I.P., 1927). At Kotuvsky Biological Station (now Pavlovo) 'the new seat of Soviet physiology', "on a green lawn laid down by Pavlov's own hands" three bronze busts were erected: they are of Mendel, Descartes and Sechenov (Frolov, Y.P., 1937).

Further, the great English physiologist, Sir Charles Scott Sherrington, in the foreword of his The Integrative Action of the Nervous System , 1947 edition, claims that his decerebrated animals were Cartesian models. Thus the decerebrated animal:

> "..... is found to be a Cartesian puppet: it can execute certain acts, but is devoid of mind. That it is devoid of mind may seem a dogmatic statement. Exhaustive tests, however, bear the assertion out. Thoughts, feelings, memory, percepts, conation etc. of these, no evidence is forthcoming or to be elicited. Yet the animal remains a motor mechanism, which can be touched into action in certain ways, to exhibit pieces of its behaviour."
>
> (Sherrington, C.S., 1947, p.xiv-xv).

For Descartes animals were automata and subject to the doctrine of determinism. He likened their movement to the hydraulically operated automata in the royal gardens of Saint-Germain. He also used this analogy to account for the effects of sense perception on the brain, in humans as well as animals (Descartes, R., 1972). This mechanical emphasis in Cartesian physiology threatened to undermine his psycho-physical parallelistic position by inviting similar criteria for humans as well as animals. This is intimated in the closing statement of his Treatise of Man:

> "I desire you to consider, further, that all the functions that I have attributed to this machine, such as (a) the digestion of food; (b) the beating of the heart and arteries; (c) the nourishment and growth of the members; (d) respiration; (e) waking and sleeping; (f) the reception by the external sense organs of light, sounds, smells, tastes, heat, and all other such qualities; (g) the imprinting of the ideas of these qualities in the organ of common sense and imagination; (h) the retention or imprint of these ideas in the memory; (i) the internal movements of the appetites and passions; and finally (j), the external movements of all the members that so properly follow both the actions of objects presented to the senses and the passions and impressions which are entailed in the memory - I desire you to consider, I say, that these functions imitate those of a real man as perfectly as possible and that they follow naturally in this machine entirely from the disposition of the organs - no more nor less than do the movements of a clock or other automaton, from the arrangement of its counterweights and wheels. Wherefore it is not necessary, on their account, to conceive of any vegetative or sensitive soul or any other principle of movement and life than its blood and its spirits, agitated by the heat of the fire which burns continually in its heart and which is of no other nature than all those fires that occur in inanimate bodies."

(Descartes, R., 1972 , p.113).

The implications of Descartes' statements were perceived in his own time and gave rise to objections against him by various critics. Thus in "the Sixth Set of Objections" to his Meditations on First Philosphy, a group of theologians pointed out that a mechanistic view of animals could lead to the conclusion that the differences between man and animals was attributable simply to machines of different levels of complexity (Haldane, E.S., and Ross, G.R.T., 1912). Indeed this was exactly what happened with La Mettrie following the ascendancy of Newtonian thought.

Finally, Mary Brazier lists Descartes' contributions to neurophysiology as:

> "... the concept of the body as a machine, energized, not by an immaterial anima, but by the external world impinging on it, that perhaps some of these actions lay outside the control of the will ..... and what was later to be known as the reciprocal innervation of antagonistic muscles."
>
> (Brazier, 1959, p.6-7).

This last feature was seized upon by a young contemporary of Descartes, the talented and eccentric Jan Swammerdam (1637-1680), as the definitive criterion for voluntary action; i.e. voluntary movement wasn't possible without antagonistic innervation. Fearing (1964) goes into some detail in describing Swammerdam's contributions in nerve-muscle physiology, voluntary action and experimental method. Suffice it to say that his contributions were many and his insight into the problems of neural physiology was well ahead of his time. It is clear from his direct quotes of Swammerdam that the latter understood postural tonus, various involuntary actions as well as voluntary ones, and that his explanations were always in mechanical terms. He never resorted to metaphysical 'causes' (Fearing, 1964).

Swammerdam's Bible of Nature has been considered 'priceless' (Singer, 1944) and Brazier describes an experiment by Swammerdam that was probably the first ever conducted in electrophysiology (Brazier, p.13). This would be at least 100 years before Galvani. Figures illustrating his nerve-muscle experiments are presented in Fearing (p.47), Brazier (p.13) and Singer (p.123). This experiment destroyed the long-held idea that muscles inflated like a balloon (due to the influx of animal spirits) upon contraction, anticipating, by many years, Francis Glisson's similar demonstration. In this experiment he described the response of the muscle to nerve stimulation and his technique was a prototype of future plethysmography (as was Glisson's) (Franklin, 1949).

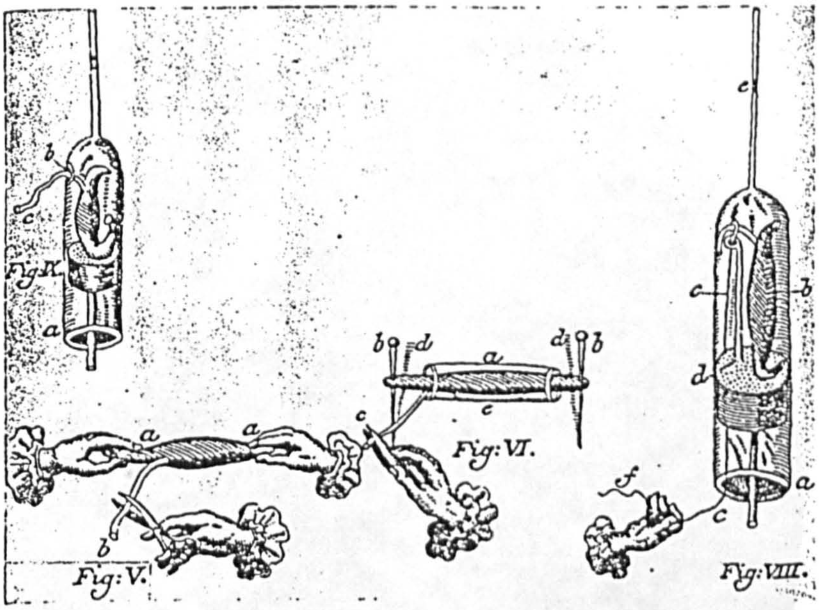


FIG. 8. Swammerdam's experiments including the one by which he proved that muscles were no swollen by an influx of nervous fluid when they contracted. *Fig. V* is of an experiment to show the change in shape of a muscle when stimulated by pinching its nerve. *Fig. VI* illustrates the pulling together of the pins holding the tendons when the muscle contracts. *Fig. VIII* is the crucial one in which a drop of water is imprisoned in the narrow tube projecting from the vessel enclosing the muscle. Swammerdam found that when he stimulated the nerve by pulling it down by a wire, the muscle contracted but the drop of water did not move. He concluded that the volume of the muscle did not expand on contraction. It is the fact that the wire was made of silver (filium argenteum) and the loop of copper (filium aeneum) that has credited Swammerdam with the use of bimetallic electricity as a stimulus to nerve. Some authors however interpret the action in this experiment as the mechanical pull on the nerve. Some originals of Swammerdam's plates can be seen at the National Museum of the History of Science in Leiden. (From *Biblia Naturae*. Amsterdam, 1738).

FIG. 26 from Brazier, M.A.B., 1959, p.13.

Herman Boerhaave
Portrait of c. 1723 by Aert de Gelder
(The Royal Picture Gallery (Mauritshuis), The Hague)

FIG. 27 from Lindeboom, G.A., 1968, facing title page.

For our purposes his importance has been summarized by Fearing:

> "He discussed voluntary action from an objective and comparative point of view, rather than as a problem in metaphysics ..... He attempted to bring both the phenomena of voluntary and involuntary action under a single neuro-muscular principle. He pointed out that both were determined by some previous event or stimulus."
>
> (Fearing, 1964, p.53)

Swammerdam's work was published posthumously by his fellow countryman, the great Dutch teacher Hermann Boerhaave in 1739. Boerhaave (1668-1738) was apparently a teacher of extraordinary ability. According to Walker "... his reputation as a man and as a teacher of medicine was such that his name was known as far afield as China." (Walker, 1955, p.151). This dramatic statement is substantiated by Otto Bettman:

> "A Chinese mandarin is supposed to have addressed a letter to 'Boerhaave of Europe' and it reached him promptly."
>
> (Bettmann, p.185)

It was Boerhaave that made it possible for Leyden University to eclipse the University of Padua in the teaching of medicine. He believed that medical knowledge was for all mankind and firmly established its international character, which it still possesses. Boerhaave's Elementa chemiae, published in 1732, has been called "the most learned and luminous treatise that the world had seen on the subject." His Institutiones medical of 1708 was the most popular text on physiology for the first half of the 18th century (Franklin, 1949). Boerhaave made the distinction between voluntary and involuntary responses as well as following Willis' conception of cerebellar and cerebral functions, i.e. the former supervised involuntary actions while the latter was associated with voluntary behaviour (Fearing, 1964).

Singer (1944), claims that Boerhaave was the greatest physician of modern times . This is primarily due to the impact which he had on both colleagues and students. He attracted Bernard Seigfried Albinus (1797-1870) to Leyden, whose Anatomical Plates of the Muscles of Man published in 1747, are considered "... the most beautiful and among the most accurate anatomical figures ever published"; it is still in use today (Singer, 1944, p.140-141). Brett (1965) asserts that Leyden's major merit was its focus on the study of the nervous system and its theories were the fountain-head of eighteenth century psychological and medical thought. So Boerhaave's acceptance of Willis' theories and his distinction between voluntary and involuntary are of paramount importance. For example, Singer (1944) claims that British medicine owes him an incalculable debt and cites him as the real founder of the Edinburgh Medical School.

Brazier (1959) indirectly supports Singer's statement by listing a few of Boerhaave's some four-hundred odd students: Von Hall, van Swieten, Monro, Cullen and Pringle. Albrecht von Haller, became the greatest physiologist of the age. Gerard van Swieten revived the Vienna School along the lines of Leyden (Marti-Ibanez, 1962), and three of the above were Scots: John Pringle became president of the Royal Society, reformed army hygiene and introduced the word 'antiseptic'. Monro (Primus) advanced anatomy and with William Cullen established Edinburgh as a great clinical training centre for pupils of both the Old and New Worlds (Bettmann, 1972).

For example, William Shippen, Benjamin Rush and John Morgan, all of Philadelphia, were educated at Edinburgh. Although Rush became the first American to gain international stature as a physician, it was John Morgan's idea of medical education which prevailed at Philadelphia's College of Physics. This was to become the first School of Medicine in the New World. Pennsylvania Hospital, the oldest in the United States, also accepted his principles and became an institution of great educational importance (Bettmann, 1972). Walker (1955) considers Morgan as the founder of all medical education in the United States.

It should be noted that while Boerhaave was at the height of his power, William Porterfield was appointed to a chair of the Institutes of Medicine at Edinburgh in 1724 and with this appointment physiology as a discipline became recognised in Great Britain (Franklin, 1949). Interestingly, Porterfield put forth the view that all bodily movements are under control of the will and that vital motions are at first under voluntary control but can recede from consciousness through habit (Fearing, 1964).

In this he was directly challenged by Robert Whytt (1714-1766), Professor of Medicine at the University of Edinburgh and one of its most brilliant early figures. He attended both Edinburgh and Leyden Universities, but received his medical degree from Rheims. In his major scientific publication, mainly based upon experimental studies, _An Essay on the Vital and other Involuntary Motions of Animals_ (1751), he recognised three types of muscular contraction; natural, voluntary and involuntary. Natural would be classified today as muscle tonus, voluntary movements followed from the 'will' and involuntary motions were dependent upon an eliciting stimulus. His classification of animal movements as differentiated from types of muscular contraction included voluntary, involuntary and mixed. By appealing to mixed movements and habits, Whytt recognised that actions can go from being voluntary to involuntary as well as from involuntary to voluntary. To complete his scheme, he used 'habit' to forge a connection between voluntary and involuntary movement (Whytt, R., 1978).

Whytt also anticipated the 'conditional reflex' of Pavlov but he did not investigate it experimentally. . However, he clearly developed another idea that has been attached to voluntary and involuntary responses in psychology to the present day. It is the view that the length of the interval between stimulation and response can be used to determine if a response is voluntary or involuntary. Usually the shorter the interval the more likely a given response will be deemed involuntary or reflexive (Fearing, 1964; Boring, 1950).

In addition, Whytt's classification of muscular contractions and movement was based upon his interpretation of results derived from animal experiments. This was unlike Hartley's method, whose views were largely speculative. In using observation and experimentation to substantiate his ideas, Whytt was following the empiricist's interpretation of how science should be, an interpretation which was, at that time, being persuasively presented in the British Isles.

<u>The Empirical response to Cartesianism</u>

Thirty-seven years after the death of Descartes, the British physician Isaac Newton (1642-1727) published his <u>Mathematical Principle of Natural Philosophy</u>. This work became the centrepiece and most esteemed of all scientific achievements to come from the so-called Age of Enlightenment, that is, the period roughly between the death of Descartes (1650) to the death of Hume (1776). This period was marked by self-confidence and optimism in philosophy and progressive acceptance of science against waning ecclesiastical pressure. Newton rapidly became

Figure 12 Newton investigating the nature of light, engraving after J. A. Houston (Mansell Collection).

FIG. 28 from The Open University, 1974, p. 14

1. John Locke (1672) by John Greenhill.
(By kind permission of the National Portrait Gallery.)

FIG. 29 from Dewhurst, K., 1972, facing title page.

the very symbol of the Enlightenment and the manifestation of the ability of human reason to understand the laws which govern the physical universe. His universe was mechanical, a 'world machine' and causal in all its workings. Newton's universe was a system of causes and their necessary effects, such a system is called deterministic. Everything that happens in a deterministic system is necessary and the inevitable results of antecedent, prior causes. Nothing can be other than what it is. All things are the way they are by causal necessity. No material body can be free from this intrinsic, causal determinism (Lowry, 1971).

Under the influence of Newton, the 18th century enlightened philosophers began to ask if physical nature is governed by necessary laws that reason can discover, then why is this not also true of human nature? Is not the human sphere also part of nature? Is it not also governed by orderly, natural laws? In England John Locke asserted, in 1690, that indeed there was a law of human nature. For Locke a law of nature was "... something that we, being ignorant of, may attain to the knowledge of, by the use and due application of our natural faculties" (Locke, J., 1894, Vol. I p.78), This position grew out of his denial of the Cartesian doctrine of innate ideas.

John Locke (1632-1704) greatly enlarged the influence of the point of view known as empiricism, although he had a fore-runner in Thomas Hobbes. Empiricism claimed that the only reliable knowledge is that which comes to us by sensory experience with emphasis laid on observation and experimentation (Schultz, 1972). Therefore, at its roots, empiricism was a theory of knowledge. A theory of knowledge which, like Descartes' rational doctrine, proposed to found all knowledge on clear, distinct and certain ideas. For Descartes the rationalist, these types of ideas were innate and guaranteed by God and included such ones as God, substance, cause and effect, together with the rational principles of geometry and logic. Locke attacked Descartes' theory of innate ideas in his "An Essay Concerning Human Understanding" (1690). For Locke, the empiricist, men begin to have ideas when they begin to have sensations. Patterns of sensations give rise to simple ideas which, through the principles of associationism, are made more and more complex - see Chapter two (Locke, J., 1894, Vol. I).

The empiricist's emphasis on environmental stimuli and associationistic principles also appeared in 20th Century psychological behaviourism. However in behaviourism stimulus and response are connected by association instead of ideas, as in empiricism, and whereas behaviourism accounted for behaviour exclusive of mental events, Locke made great use of them. For example Locke maintained that any action which is consequent to an "... order or command of the mind, is called voluntary, and whatsoever action is performed without such a thought of the mind is called involuntary" (Locke, 1894, Vol. I, p.314). Elsewhere, in an apparent nod to Newton's deterministic universe, Locke explicitly classified movement as 'voluntary' or 'involuntary' as distinct from 'voluntary' or 'necessary' and used heart-beat and convulsions as examples of involuntary action. Moreover when discussing 'our complex ideas of substances' he takes on a familiar Aristotelian tone, "Another idea we have of body is, the power of communication of motion by impulse; and of our souls, the power of exciting motion by thought. These ideas, the one of body, the other of our minds, every day's experience clearly furnishes us with; but if here again we imagine how this is done, we are equally in the dark." (Locke, 1894, Vol. I, p. 413).

indeed he thought that if an adequate account could be given for voluntary behaviour, then only one great mystery would remain - the explanation of creation. Equally mystified by the apparent ability of the 'will' to control bodily movements was another great empiricist, David Hume. Empiricism went on to reach maturity with Hume (1711-1776) and with him one is well and truly in the 18th century. He was educated at Edinburgh and was a contemporary of Hartley, Whytt, Unzer and La Mettrie.

For Hume the 'will' was

> "... the internal impression we feel and are conscious of, when we knowingly give rise to any new motion of our body, or new perception of our mind."
>
> (Hume, D., 1896, p.399).

This 'internal impression' was one which was learned through experience. Hume dealt with the problem of the will causing bodily movements in much the same way as he approached the problem of cause and effect among external objects. Both problems seemed to be necessarily connected but in fact both were internal impressions generated by experience, and subject to the associationistic principles of contiguity and succession. Through experience

> "... we acquire the idea of power and energy ... which is exercised by will, both over the organs of the body and the faculties of the soul ... But the means by which this is effected; the energy by which the will performs so extraordinary an operation; of this we are so far from being immediately conscious, that it must for ever escape our most diligent enquiry."
>
> (Hume, D., 1927, pp 64-65).

Thus with Hume we see a concern with the 'source of energy' when accounting for voluntary movement, a concern which became acute in the mid-19th century with the formulation of the law of the conservation of energy.

Hume further asked the question, "Why has the will an influence over the tongue and fingers, not over the heart and liver?" (Hume, 1927, p.65).

But he has no ready answer to such a question. He simply stated that experience teaches us that this seems to be so. Hume didn't dichotomize movements into voluntary and involuntary categories since for him volition was created by the association of impressions. Indeed, in the Treatise he wrote,

> "Any thing may produce any thing. Creation, annihilation, motion, reason, volition; all these may arise from one another, or from any other object we can imagine."
> (Hume, 1896, p.173).

Hence in Hume's view, if one entertained the possibility of mental events producing bodily movement, one can equally entertain the possibility of bodily movement producing mental events. For example, he asserted later in the Treatise that

> "... we may certainly conclude, that motion may be, and actually is, the cause of thought and perception."
> (Hume, 1896, p.248).

This idea, as did other empirical notions, also emerged in 20th century behaviourism (e.g. Watson, Guthrie and Wheeler among others), although Hume never used the terms 'movement produced stimuli' or 'kinesthetic sensation' as did the psychologists.

To continue this point, Hume made one other proclamation of which we should take note. Conceptually it has great import for us. In his Enquiries he asked "Is it more difficult to conceive that motion may arise from impulse than that it may arise from volition?" and he went on to honestly answer "All we know is our profound ignorance in both cases." (Hume, 1927, p.73). Thus for Hume, these cases assumed a conceptual equivalence. Such a conceptual equivalence would arise in the experimental studies of behaviour of E.L.Thorndike and more importantly of B.F. Skinner. In each case, the terms 'impulse' and 'voluntary' imply categories of behaviour which are ultimately unaccounted for.

Through Hume the idea of any substance, either mental or physical, was destroyed, together with the concept of the existence of a 'self'. The doctrine of cause and effect was in doubt, being replaced entirely by the association of 'impressions' and 'ideas', his two sources of knowledge (Warren, H.C., 1967). Hume, who most consistently carried out the epistemological analysis of empiricism, has also been associated with positivism (which also emphasized sense perception) and was to replace it in the following century (Schultz, 1969).

However, it was to be up to David Hartley (1705-1757) "to extend the principle of association systematically to all classes of mental phenomena." (Warren, 1967, p.15). Hartley used the principle of contiguity and Newton's idea of "vibrations" to explain all behaviour, mental and physical. The principle of contiguity was not new (it was at least as old as Aristotle), but the concept of "vibrations" was. Newton had invented it along with the concept of "ether", to account for the enigmas which emerged from his physical theories on motion. Also, "vibrations" was the physical principle upon which Hartley's associationism was based (Lowry, 1971). Hartley's views did not achieve widespread recognition when published as "Observations on Man, His Frame, His Duty and His Expectations" (1749). The book was edited by Joseph Priestly and became more widely known, in a truncated version. Its influence was assured when it was broadly adapted by James Mill in his propagation of associationism in the 19th century (Watson, 1971). Moreover, Hartley has been cited by many as being the first, or one of the first, 'physiological psychologists' (Boring, 1950; Brett, 1965).

Hartley put forth a strong, materialistic argument for the physical basis of mind and body, without realizing the extremity of his position. Hartley was almost 'a man of the cloth' but went into medicine instead (Schultz, 1969; Brett, 1965). When he expounded his views, he separated "psychology" from "physiology", but also maintained that there was a parallelism between the 'mental' and 'physical' events. Thus his position was broadly similar to that of Descartes.

In Hartley's scheme, the environmental events gave rise to "vibrations" in the nervous system. These are the basis, not only of sensation, but of higher psychological functions, such as memory and understanding, as well as overt behaviour. Not unexpectedly, he proposed two broad classifications of behaviour; the 'automatic' and the 'voluntary'. The latter derives from ideas and affections, whilst the former is directly related to sensation (Fearing, 1964). Hartley believed that involuntary responses can become voluntary and vice versa. This was much the same view as his contemporary, Richard Whytt. However, Hartley emphasized association to account for their ability to change (Watson, 1971). The ideas of these two men are also similar in that Hartley uses the concept of automatism much as Whytt employed 'habits'. These were acts that had become 'automatic' by the repetition of 'associations'.

To sum up, Hartley is of fundamental importance because his interests have become the characteristic subject matter of subsequent physiological psychology, i.e. his localization of mental functions in the brain, his juxtaposition of psychological and physiological events, and his proposing physiological substrates of mental processes together with his approval of the comparative method. As previously stated, his greatest achievement was the consistent manner with which he applied the concept of association to all psychological events. He was able to demonstrate more convincingly than others, the usefulness of association for psychology and its potential role as the fundamental psychological law. It would be in the field of learning that the effects of this line of thought were most extensively felt.

A younger contemporary of Hartley and Hume was Immanuel Kant (1724-1804). Kant claimed that Hume awakened him from his "dogmatic slumbers" and his great contribution to psychology was the view that the 'mind' is an active object which is structured in such a way that it imposes its way of knowing upon its objects. Thus by its very nature, the mind actively organises our experiences.

Kant advanced his "critical philosophy" as a reconciliation of rationalism and empiricism. He rejected the notion of the empiricists that what is called mind could be explained as a product of ideas arising out of experience and arranging themselves according to the laws of association. But neither did he accept the doctrine of innate ideas of the rationalist nor did he mean that the mind creates objects. Kant maintained that the mind must be regarded as a structure regulated by principles of its own activities. Thus it is objects that conform to the operations of the mind and not the other way around. Further, for Kant these principles could not be arrived at empirically for they were presupposed by any empirical investigation, including psychological empiricism (Brett, 1965).

For him, these principles could only be arrived at by critical philosophy which would look into the presuppositions which seemed to make experience possible. In this, he postulated his antinomies or contradictory propositions; one of which was that "... freedom of action must occur along with caused action, and yet all action is surely caused." (Boring, 1950, p.249). Kant thought he could resolve this seeming contradiction by taking the position of the active mind. He held that human action was a product of human reason and, insofar as reason is involved, human behaviour cannot be explained in terms of the mechanical laws of nature. Thus Kant, in emphasizing the concept of will and rational action resembled Descartes and both men addressed a crucial problem for the development of psychology to which no satisfactory answer has yet been given (Wolff, R.P., 1963).

The philosophy of Kant closed the 18th century which had been a time of significant advance for science and its methods. Whereas Bruno had been burned at the stake at the beginning of the 17th century for his atheistic and Copernican beliefs, Hume, the God denier, was widely praised within his own lifetime and died a peaceful death (1776).

Lowry (1971) has characterized the 18th century as one in which 'nature' was considered of paramount importance and man was viewed as product of his environment. Thus he emphasized the empirical spirit of the age as represented particularly by the writings of Hume but reflected in Whytt and Hartley as well. Kant's view formed a counterpoint to such attitudes. Kant's idea that the mind actively synthesized sensory experience opposed the empiricist position that the mind received such experience passively. Kant's mind did not create objects, nor did it possess innate ideas, but was structured in such a way as to impose its way of knowing upon its objects. If one substitutes brain for mind then Kant's point of view is distinctly modern. Nevertheless he avoided complete committment to the position that human reason was governed by the laws of nature by linking divine reason with human reason. But the important feature of Kant's position was that human thought itself proceeded in accordance with the natural structure of mind.

Another Cartesian critic who held views in marked contrast to the Kant and the British Empiricists was Nicolas Malebranche (1638-1715). Nicolas Malebranche did not find an interactionism, such as Descartes, necessary for his explanation of physical and mental events. Malebranche epitomised the so-called 'occasionalists' position in post-Cartesian philosophy. That is, the occasionalists maintained that the cause of the occurrence of an appropriate physical event, on the occasion of a mental one, was the intervention of God. It should be pointed out that Malebranche retained Descartes' dualist distinction between the physical (extension) and the mental (thought) and this perpetuated parallelism of such events (Malebranche, N., 1923).

Following the same approach Gottfried von Leibniz assumed a 'pre-established harmony' which served the same function in his philosophy as God had in Malebranche's. Leibniz' two clock analogy is well known. In this the mental and the physical were separate events which always behaved in a similar manner due to pre-established harmony (Rescher, N., 1979). His argument may appear weak and possibly redundant today, but Leibniz was recognised as an intellect of uncommon stature and his opinion carried great weight in the educated community. His 'psychophysical parallelism' found widespread acceptance among the fledgling psychologists of the 19th century (Esper, E., 1964).

One who rejected Descartes' dualistic ideas altogether was Baruch Spinoza (1632-1677). In his own lifetime Spinoza did not enjoy the prestige of Leibniz, nor did he speak from an institutional theological platform as Malebranche had done. His philosophy went into abeyance after his death with the rise of empiricism. But Spinoza postulated an important feature concerned with the mind-body problem. His solution was monistic as compared with the dualistic ones of Descartes, Malebranche and Leibniz. This solution is his 'dual-aspect theory' in which mental and physical events are different aspects of one and the same thing. Thus the conceptions of thought and extension are two different descriptions of the same thing. Further, Spinoza insisted that both mental and physical events were determined, and thought that one cannot speak in a meaningful manner about the voluntary action of human beings. Not surprisingly, Spinoza's views have found greater acceptance among those inclined to advocate a 'physical' basis of mentality (Allison, H.E., 1975).

Such a person was Julien Offray de la Mettrie (1709-1751). La Mettrie was educated as a physician under Herman Boerhaave whose 'ratiomechanistic' doctrines were embraced by him. Although a noted physician in his own time - La Mettrie was personal physician to Frederick the Great - his wider fame rests on the strength with which he put forth a mechanistic view of man. His most succinct statement came at the end of his Man a Machine (1747). He asserted:

> "Let us then conclude boldly that man is a machine, and that in the whole universe there is but a single substance differently modified."
> (La Mettrie, J., 1927, p.69).

This work is generally viewed as being a heuristic hypothesis for the scientific study of behaviour as well as being anti-metaphysical and atheistic in tone.

La Mettrie thought that the transition from animal to man was a gradual one. For him:

> "... throughout the animal kingdom the same aims are pursued and accomplished by an infinite number of different mechanisms, all of them, however, exactly geometrical."
> (La Mettrie, 1927, p.43).

Moreover he not only viewed man as being 'mechanistic' in nature, but also as a purposively dynamic, self-moving and self-sufficient machine. He noted:

FIG. 6. Albrecht von Haller, the greatest physiologist of the eighteenth century, and de La Mettrie whose treatise *L'homme machine*, addressed to Haller, caused a controversy that highlighted the question as to whether the soul lay in the province of the physiologist. The portrait of Haller is from the frontispiece of his *Elementa Physiologiae* and is an engraving by Tardieu; that of de La Mettrie is from an engraving in the Bibliothèque Nationale (reproduced here with permission), the original painting being a pastel by Maurice Quentin La Tour.

FIG. 30 from Brazier, 1959, p.11.

> "The body is but a watch, whose watchmaker is the new chyle. Nature's first care, when the chyle enters the blood, is to excite in it a kind of fever which the chemists, who dream only of retorts, must take for fermentation. This fever produces a greater filtration of spirits, which mechanically animate the muscles and the heart, as if they had been sent there by order of the will".
>
> (La Mettrie, 1927, p.56).

He thought that a machine as complicated as man was impossible to define, and in order to avoid using the 'soul' as an explanation of certain behaviours, La Mettrie accepted the doctrine that motion was an intrinsic feature of matter.

> "Grant only that organized matter is endowed with a principle of motion, which alone differentiates it from the inorganic ... and that among animals ... everything depends upon the diversity of this organization: these admissions suffice for guessing the riddle of substances and of man. It (thus) appears that there is but one (type of organization) in the universe, and that man is the most perfect (example)".
>
> (La Mettrie, 1927, p.61).

Paradoxically this feature of La Mettrie's thought has led to him being accused of being a 'vitalist' which he most certainly was not (Lange, F.A., 1925, pp. 49-92).

La Mettrie maintained that differences among animal species could be attributed to differences in organization. Thus the differences among species was one of degree and not of kind, a position based, in part at least, on the ability of craftsmen to build complicated, behaviour-simulating machines. For example Jacques de Vaucauson (1709-1782) assembled several mechanical contrivances which profoundly impressed La Mettrie. Vaucauson's 'asp' could hiss before it bit Cleopatra's breast, his 'duck' could swim, eat and digest food, while his 'flute-player' was so life-like that it aroused speculation of demonology. Vaucauson's ability was such that La Mettrie was convinced that the building of a mechanical man was really a matter of skill.

He proclaimed:

> "... Vaucauson, who needed more skill for making his flute-player than for making his duck, would have needed still more to make a talking man, a mechanism no longer to be regarded as impossible, especially in the hands of another Prometheus".
>
> (La Mettrie, 1927, p.61).

Interestingly, La Mettrie's views are in line with the contemporary 'cybernetic' view of man, of which he may well have approved.

Perhaps above all La Mettrie's mechanistic position was an affirmation of scientific faith. It asserted the ultimate fruitfulness of the mechanistic method in bridging the gap between the living and non-living, between the conscious and the unconscious and, by extension, between the 'voluntary' and 'involuntary': all of these being aspects of a presumably unitary nature.

As empiricism was the dominant spirit of the 17th and 18th centuries, positivism played this part in the 19th century. This term was introduced by Auguste Comte (1798-1857) who attempted a systematic survey of all knowledge. To make this ambition manageable, he limited his work to only those facts that were true beyond question (as Descartes had wished to do). For Comte, this meant facts ascertained by the methods of science, i.e. sensory data. It was empiricism, positivism as well as materialism (the view that consciousness can be explained in physico-chemical terms and therefore focuses on the anatomical and physiological aspects of the brain) that were the philosophical bases of the emerging 'psychology' (Schultz, 1969). However, in spite of the assertion of such views, the classification of movement had undergone little, if any, change. This can be seen in the opening statement of John Newport Langley's <u>The Autonomic Nervous System</u> .

> "In the early part of the 18th century the movements of the various parts of the body were commonly divided into three classes, viz. (1) voluntary movements (2) involuntary movements which could also be produced by the will, such as movements of the respiratory muscles in sleep and instinctive movements, (3) involuntary movements over which the will had little or no control, such as the movements of the heart and intestines; the form of involuntary movement was called vital or natural movement".
>
> (Langley, J.N., 1925, p.1)

Interestingly, in 1764, Johnstone advanced our knowledge of the sympathetic system by recognizing that it, in part at least, arose from the spinal cord and was not of cerebral origin as Willis had maintained (Franklin, 1949). He also attempted to use the sympathetic ganglia as an agent to "convert voluntary into involuntary movements" (Pick, 1970, p.10). However, it was during the 19th century when the knowledge of the anatomy and physiology of the human body and the elucidation of the relationship of the nervous system to the rest of the body exploded.

The role of physiology in the emancipation of psychology from philosophy as well as serving to orient the 'new' science can be made evident by a review of the great progress and numerous discoveries of this discipline in the 19th century. With psychology being a child of physiology and philosophy, it should not be unexpected that the great problems of sensation and motion inherent in the latter discipline would find their way into the former. The background for psychologists' interest in the study of the nervous system in the 19th century had already been well laid: Descartes had located the point of interaction between soul and body in the brain and the associationists had attempted to correlate cerebral events with psychological processes. Further, for emphasis and clarity, (and this point cannot be overstressed) it should be stated that the great names of general physiology: Muller, Bernard and Ludwig, finally committed their science to be founded upon physics and chemistry with a strong experimental bias.

Thus by the last quarter of the century, the studies which had made constant progress in new areas of knowledge had prepared the intellectual climate for the acceptance of a scientific psychology based on biology. These included the microscopic description of the body, the specific nervous energy, the reflex arc, the finite quality of the speed of the nervous impulse and the proposed role of certain localized cerebral structures in the control of behaviour.

The Advent of Mechanistic Physiology

The 19th century opened with Marie Francois Xavier Bichat (1771-1802) proposing his views on somatic and visceral function. The latter was subserved by the lateral sympathetic ganglionic chain which he maintained was completely free of influence from the brain or spinal cord and controlled the 'inner world' of man that was concerned with bodily maintenance. The former was based on the activity of the brain and spinal cord directing sense perception and volitional movement related to the 'outer world' of man (Pick, 1970). Gaskell (1916) tells us that Bichat's views were predominant when he undertook his elucidation of the morphology of the 'involuntary nervous system' (1885).

Besides the views of Bichat, another crucial presentation was made by Sir Charles Bell (1774-1842) of Scotland and Francois Magendie (1783-1855) of France. Although at the time there was a great controversy as to priority of publication, for us it has been resolved by the title of the Bell-Magendie Law. It concerned the input and output relations of the nervous system and was a rediscovery of the opinion of Erasistratus, viz: the posteripr (dorsal) roots of the spinal cord carry the sensory input to the nervous system while the anterior (ventral) roots carry its motor output. This concept was of great importance, for it would give future generations of researchers an anatomical basis for the 'reflex arc' which itself became a basic unit of behaviour (Castiglioni, 1947; Franklin, 1949; Brazier, 1959).

Fearing had no doubts as to the importance of this concept:

> "The so-called Bell-Magendie Law is as significant to the development of the knowledge of neural action as the discovery of the circulation was to the physiology of the blood".
>
> (Fearing, 1964, p.117).

FIG. 20. The protagonists in the Bell-Magendie controversy. Bell (*left*) and Magendie (*right*) as young men. The portrait of Bell was painted by Antony Stewart of Edinburgh in 1804; that of Magendie (attributed to Guérin) is at the Collège de France.

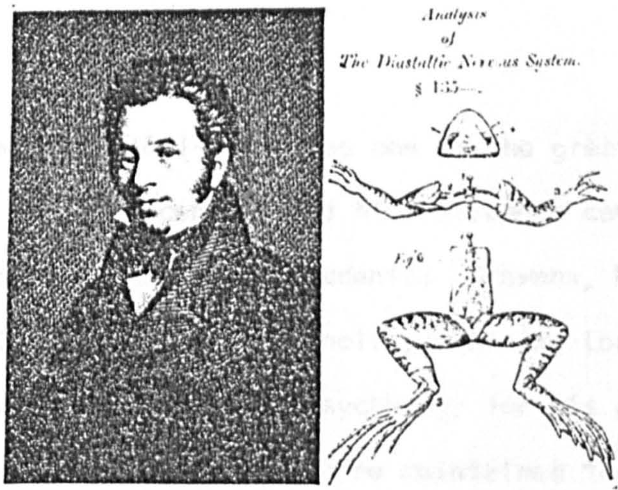


FIG. 22. *Left:* Marshall Hall. *Right:* one of his experiments to demonstrate the three parts of the reflex arc. The arc was broken by any of the following procedures: *a*) skinning the extremity (at *3*) (the 'esodic' nerves); *b*) sectioning of the "brachial or the lumbar or femoral nerve leading to the point irritated" (i.e. the 'exodic nerve' at *2*); or *c*) removing the spinal marrow (the 'spinal centre'). (From Hall, M. *Synopsis of the Diastaltic Nervous System:* being outlines of the Croonian Lectures delivered at the Royal College of Physicians in April 1850.)

FIG. 31 from Brazier, 1959, top p.29; bottom p.34.

A researcher who utilized the concept to great advantage and compared the importance of his own work with that of Harvey was the brilliant and combative English physician Marshall Hall (1790-1857).

Hall himself was embroiled in controversy as to priority of ideas in his own lifetime. But today he is recognised as having definitely formulated the concept of the 'reflex arc' (Boring, 1950). Apparently he anticipated Sherrington in stating that spinal reflexes had a suprasegmental character. Although he separated spinal responses (his excito-motory system) from voluntary (cerebral) ones, in the end he conceded that "The true spinal system (excito-motory) is susceptible to modification by volition ..." (Hall, M., 1978, p.245). Hall's idea gained greater credibility with their general acceptance by Johannes Muller.

Johannes Muller (1801-1858) was one of the greatest teachers of physiology in the 19th century and his influence can be understood by briefly enumerating some of his students: Schwann, Henle, Kolliker, Virchow, Du Bois-Reymond, Von Helmholtz, Wundt and Ludwig (Castiglioni, 1947). Muller is best known in psychology for his doctrine of the specific energy of nerves in which he maintained that each sensory nerve subserved a specific sensation no matter how it was stimulated. In other words, it was the characteristics of the stimulated nerve that determined the sensation and not the stimulating object. Although he was in two minds as to where the specificity arose, the nerve or the brain, he finally decided (erroneously) in favour of the nerve (Watson, 1971). He was also noted for the statement "Every psychologist must first be a physiologist", thus further emphasizing the close links between psychology and physiology (Verworn, 1899, p.21).

In general, Muller is most famous for his Handbook of Human Physiology, a systematic and exhaustive study of all that was known of physiology to that date. Boring (1950) states that it was divided into eight books, half of which discussed subject matter familiar to psychologists today e.g. physiology of nerves (III), muscular movement (IV), sensory physiology (V) and higher mental functions: memory, association, thought etc. (VI). In retrospect, only one criticism is usually levelled at Muller and that concerns him being the last great physiologist who had a shadow of vitalism in his thinking (Esper, 1964; Fancher, 1979; Boring, 1950; Watson, 1971). Vitalism is "the doctrine or theory that the origin and phenomena of life are due to or produced by a vital principle as distinct from a purely chemical or physical force" (The Compact Edition of the Oxford English Dictionary, Vol. II, 'V', p.26). Fancher (1979) goes on to add that this 'principle' is not analyzable by scientific methods. In contrast to this, in biology at least, is the concept of mechanism which is embedded within the broader concept of materialism.

The theory of materialism claims that nothing exists except matter and its movements. As a corollary to this it is maintained that material agencies are responsible for the phenomena of consciousness and will (C.E.O.E.D. Vol. I, 'M', p.230). In biology this argument assumed the form called 'mechanistic' and was based upon the disciplines of physics and chemistry. The mechanistic interpretation of nature received great impetus in 1845 when four students of Johannes Muller sought to put the mechanistic position on firm footing. They proposed to demonstrate that no other forces than common physical and chemical ones are active within the organism. These four were (I) Carl Ludwig, believed by some to have eclipsed his master as a teacher of physiology; (II) Emil du Bois-Reymond, who greatly improved instrumentation to measure

PLATE I

Emil Du Bois-Reymond (1818–1896)
who first demonstrated the action potential of nerve

'If I do not greatly deceive myself', he said, 'I have succeeded in realising in full actuality (albeit under a slightly different aspect) the hundred-years' dream of physicists and physiologists, to wit, the identity of the nervous principle with electricity.'

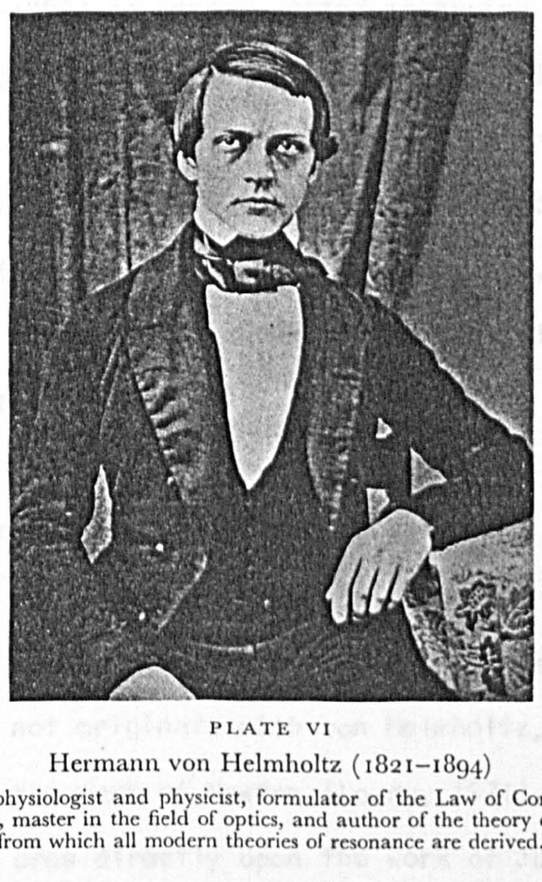


PLATE VI

Hermann von Helmholtz (1821–1894)

Brilliant physiologist and physicist, formulator of the Law of Conservation of Energy, master in the field of optics, and author of the theory of hearing from which all modern theories of resonance are derived.

FIG. 32 from Brazier, M.A.D., 1968, top facing p.48; bottom facing p.241.

the 'negative variation' (the nerve impulse); (iii) Ernst Brucke, future teacher of Sigmund Freud and (iv) the incomparable Herman von Helmholtz, a truly universal genius whose studies were important not only to psychology but all science (Fancher, 1979). These men were young at the time of their avowal of mechanism and had to combat formidable opponents. One such opponent was Justus von Liebig (1803-1873), one of the greatest chemists of the 19th century and an advocate of vitalism, who stated in 1842 that:

> "... if (the vital force) alters the direction of chemical forces in such wise, that the elements of constituents of food arrange themselves in another form ... it causes the new compounds to assume form altogether different from those which are the result of the attraction of cohesion when acting freely, that is, without resistance ..."
>
> (Lowry, 1971, p.76)

Against this evidence mounted indicating that the distinction between the inorganic and organic worlds was more illusory than real. Friedrich Wohler (1800-1882) is usually cited as having performed the first synthesis of an organic compound from inorganic elements i.e. urea from lead cyanate and ammonia (Esper, 1964). Franklin (1949) denied that Wohler's procedure was a 'true' synthesis, but goes on to say that Liebig himself synthesized lactic acid in 1850. In any case, Liebig and Wohler were important in establishing physiological chemistry in the 19th century (Castiglioni, 1947).

However, it was in 1847 that vitalism received its decisive challenge at the hands of Hermann Ludwig Ferdinand von Helmholtz (1821-1894). The challenge was in the form of the Law of the Conservation of Energy. This law did not originate with von Helmholtz, but had been slowly developing from the work of Newton (Lowry, 1971). As a matter of fact, von Helmholtz drew directly upon the work of Julius Robert Mayer. Mayer's study of animal physiology indicated to him that the processes of digestion and metabolism could adequately account for the production of heat and energy exhibited by animals (Franklin, 1949). Von Helmholtz' great contribution was his rigorous mathematical expression of this principle. It was a compelling description that demonstrated that energy could and did change its quality (form) but could not and did not change its quantity (amount). Indeed, this argument was so compelling that recently Hans Kornhuber (1978) used it when discussing various theories of the mind-body relationship. He pointed out to his audience, which consisted of some of the world's most distinguished brain researchers, that "It will suffice to remind you that the assumption of some non-physical (spiritual) event causing some physical event contradicts the law of the conservation of energy." (Kornhuber, 1978, p.321). Von Helmholtz's formulation laid the foundation of the science of thermo-dynamics. However, more significantly, this formulation would apply to the organic as well as the inorganic worlds and render less plausible any claims that living and non-living systems could not possibly be comprehended in one theory (Esper, 1964; Fancher, 1979; Boring, 1950; Lowry, 1971).

Of equal significance to psychology and physiology was his measurement of the speed of the nervous impulse. Some physiologists had previously thought that this feat was impossible (Muller) while others had estimated that it moved faster than the speed of light. Helmholtz's values were relatively low (no more than one hundred feet per second). This indicated to him that the propagation of the impulse was more than just electrical conductance, therefore other features, probably chemical ones, must be involved (Boring, 1950).

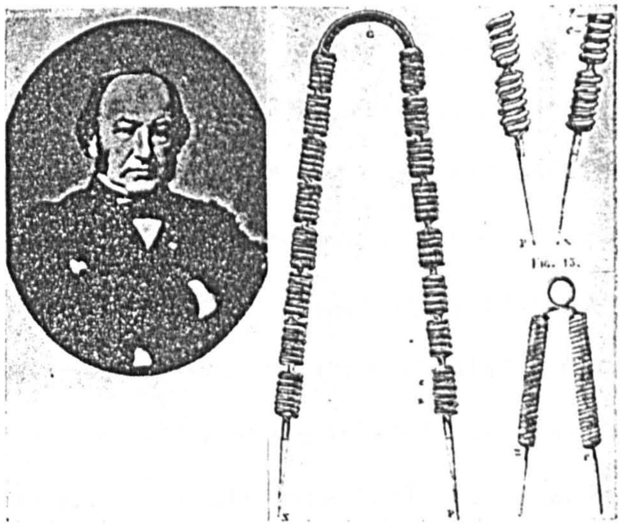


FIG. 16. Claude Bernard at the age of 53, and the ingenious stimulators he used in his electrophysiological studies of nerve. They were miniature voltaic piles built up of alternate discs of copper and zinc. Just before use they were moistened with vinegar. Such devices were made obsolete by the du Bois-Reymond induction coil and it is rather surprising to find Bernard still advocating them in his day. Although adequate for nerve stimulation, they gave too feeble a current to stimulate a muscle directly; from this Bernard concluded that the nervous effect on muscle could not be electrical.

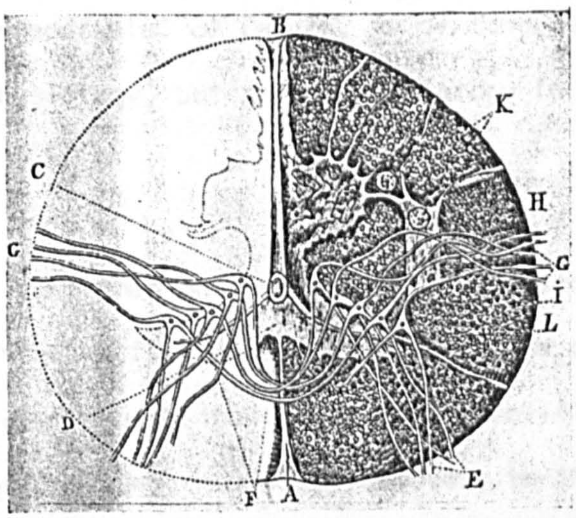


FIG. 24. *Above:* Schema of the connections between the posterior and anterior roots of the spinal cord as taught to students in the days before the neuron doctrine and the theory of the synapse. [From Bernard, C. *Leçons sur la Physiologie et la Pathologie du Système Nerveux.* Paris: Ballière, 1858.)

FIG. 33 from Brazier, 1959, top p.21;
bottom p.38.

Another distinguished physiologist who came to the same conclusion was Claude Bernard of France (1813-1878). Bernard used the exotic poison from South America called curare. Curare will be discussed in a later chapter, but essentially its action blocks the effect of nervous impulses on skeletal muscle, thus causing paralysis. His work on vascular reflexes and on the regulatory role of the sympathetic system added great strength to a mechanistic explanation of bodily functions. He demonstrated experimentally that the viscera, by direct and indirect connections with the brain, were able to produce bodily changes which influenced emotion, motivation and thinking. Bernard also introduced the concept of the 'milieu interieur' or internal environment which involved the co-ordinated efforts of all internal organs to maintain a stable state of affairs (Bernard, C., 1944, p.viii). In this, the nervous system was viewed as being essential for the stable condition to be maintained. Today the direct conceptual descendent of this view, the 'homeostasis' of Cannon, is of fundamental importance, not only to psychophysiology, but animal physiology in general (Castiglioni, 1947).

In addition, Bernard was a confirmed anti-vitalist, thus following his mentor, Magendie, who had attacked the concept earlier in the century. Thus, in principle, he did not distinguish the use of the scientific method as applied to organic and inorganic matter. However, he thought that due to the far greater complexity of living entities they were more difficult to study than non-living ones. Bernard further maintained that there was a fundamental unity among all life forms. The higher ones were distinguished by their greater independence of the external environment and a correspondingly greater dependence on their internal environment. Above all, he agreed with the idea that complex phenomena observed in the organic world were ultimately reducible to physiochemical processes (Bernard, 1944).

Twelve years after von Helmholtz presented his mathematical treatment of the principle of energy conservation, Charles Darwin published his Origin of Species (1859) and followed it in 1871 with the Descent of Man. These two works provided a coherent and empirically founded case for the materialistic position in two respects: the first is that the organisation of living things into forms admirably suited for survival and reproduction entails an explanation without appeal to transcendental concepts; secondly man is part and product of natural environmental events. Of course, the Darwinian view of man was not without its critics. The idea of systems changing through time was applied not only to the biological world, but to the physical one as well. There was revolt amongst the members of the intellectual community who did not find mechanistic and materialistic notions attractive.

One of the most influential and articulate of Darwin's critics and spokesman for a vitalistic evolution was the Frenchman Henri Bergson (1859-1941). Bergson contended that the Darwinian view was inadequate to account for evolutionary phenomena: His Creative Evolution (1911) was an ingenious but speculative work in which he held that such phenomena became more intelligible if they were regarded as consequences of the action of a vital impulse. This impulse works purposively to sustain organisms in the short run, but does not pursue any final goal. Finally, it is a "current of consciousness" which has found expression in human intelligence as a result of "a sudden leap from animal to man" (Bergson, H. 1911, p.195).

Bergson notwithstanding, the triumphant progress in the twentieth century of a materialistic biology has almost completely eliminated vitalistic notions and supernatural views of life. Thus the situation of ages has been reversed; it now seems implausible to maintain that the vital functions of living organisms are different in kind from chemical and ultimately physical processes. Therefore, in the attempt to demonstrate that something other than matter exists, it is on mind, rather than life, that those opposed to materialism now rely. In addition, since Einstein has related energy and matter, the extreme materialistic position has been weakened, but the basic tenets are still intact, as energy together with matter can be quantified.

The last great physiologist of the 19th century agreed with the above view and introduced instrumentation (the kymograph) to measure and record physiological phenomena for permanent record (the graphic method). Descendents of both the instrument and method are absolutely necessary to produce work of quality in any psychophysiology laboratory in the world today (Verworn, 1899; Franklin, 1947). He, of course, was Karl Friedrich Wilhelm Ludwig (1816-1895), a true master of his discipline. Ludwig's primary interest was in the physiology of circulation but his ability as a teacher was so effective that he came to dominate European physiology in the latter portion of the 19th century (Castiglioni, 1947). E.F.Adolph (1968) cites his work with E.von Cyon (Pavlov's future teacher) as being one of the seven great discoveries in the physiological regulation of bodily processes. More specifically it concerned the influence of the nervous system in regulating heart rate and arterial blood pressure. Von Cyon soon won the annual prize in experimental physiology from the Paris Academy for Science (1868), Claude Bernard presiding. Ludwig achieved greater influence through his students who are too numerous to mention here except the most notable, Bowditch, Kronecker, Stirling, von Kries, Burdon Sanderson, Sechenov, Pavlov and Gaskell (Boring, 1950; Gaskell, 1915).

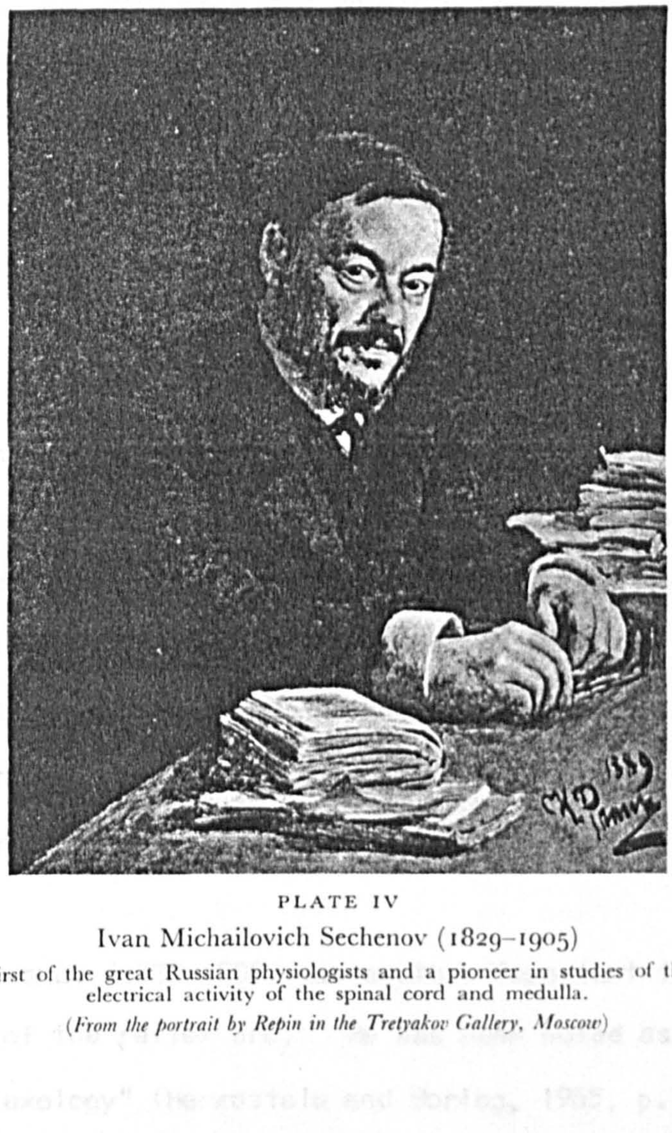


PLATE IV

Ivan Michailovich Sechenov (1829–1905)

First of the great Russian physiologists and a pioneer in studies of the electrical activity of the spinal cord and medulla.

(*From the portrait by Repin in the Tretyakov Gallery, Moscow*)

FIG. 34 from Brazier, 1968, facing p.65.

Henry Bowditch did research on heart muscle (discovering the all-or-none phenomena), established physiology at Harvard University and was the teacher of Walter Cannon and Harvey Cushing (Magoun, 1958; Thomson, E.H., 1950). Karl Hugo Kronecker also worked with von Helmholtz and Du Bois-Reymond, and was interested in muscle fatigue. He demonstrated that heart muscle doesn't tetanize, and discovered, with William Stirling, the refractory phase of the heart. He also taught physiology to Harvey Cushing. (Cushing was the first American to achieve international pre-eminence as a neurosurgeon and was a close colleague of C.S. Sherrington and J.F. Fulton) (Castiglioni, 1947; Thomson, 1950). Johannes von Kries worked with von Helmholtz and published mainly in the field of sensory physiology (vision) relating rods with night sight and cones with day vision (Boring, 1950). J. S. Burdon Sanderson, together with Page, measured the electrical nature of the heart (work that culminated with that of Einthoven) and succeeded to the first chair of physiology in Great Britain at University College, London in 1874 (Franklin, 1947). Whilst this work was important for an understand of psychophysiology, that of Sechenov is of more direct significance to us.

Ivan M. Sechenov (1829-1905) was another important figure who made great use of the reflex arc. He has been noted as "the father of Russian reflexology" (Herrnstein and Boring, 1965, p.308) as well as the founder of Russian neurophysiology (Brazier, 1959). He had an extensive education, studying under the giants of Western European physiology: Muller, Bernard and Ludwig, not to mention von Helmholtz and Du Bois-Reymond. His most important publication, Reflexes of the Brain (1863) aroused the disapproval of the Csarist authorities and was not fully appreciated in the West until well into the 20th century. In this work, Sechenov expanded the concept of the reflex to encompass all movement, voluntary and involuntary as well as psychological processes as complex as thinking. Indeed the original title of his work was "An Attempt Physiologically to Explain the Origin of Psychical Phenomena" and in it Sechenov presented a strong materialistic point of view. Thus he was the focus of much criticism in mid-nineteenth century Russia although Pavlov was later to call his Reflexes of the Brain "a sublime achievement of Russian science" (Brazier 1959, p.145).

For us Sechenov's experimental evidence that the central nervous system could inhibit the motion of the skeletal musculature in decapitated animals (frogs) is important (Sechenov, I.M. 1965). Before him, the conventional view was that the 'will' controlled the movement of skeletal muscles. In addition, earlier work on inhibition of responses was at the periphery; for example, Weber's demonstration that stimulation of the vagus nerve inhibited heartbeat (1849), and Rosenthal's sectioning of the same nerve resulting in the slowing of respiration (1864). However, Sechenov focused on the central aspects of inhibition (Sechenov, 1965).

In Sechenov's scheme involuntary responses could be excited (containing an emotional ingredient) or inhibited or could be 'reflexes' such as those exhibited by decapitated animals. Voluntary responses received a lengthy discussion, but their hallmarks, among other criteria, were; the absence of 'perceptible sensory excitation' and the fact that such responses were 'always conscious'. He was unremitting in his application of the reflex arc concept, which in the final analysis led him to maintain that thinking itself was the total inhibition of the motor component of the arc, whereas willed action lacked the sensory component (Sechenov, 1965).

The implications of Sechenov's ideas are viewed as another anticipation of Pavlov's "conditioned reflex". Indeed Sechenov had a profound influence on Pavlov and all of Russian physiology. Moreover he formulated his doctrine of nervous system activity in such a way as to anticipate both Pavlovian and Sherringtonian views that such activity reflected the balance of excitation and inhibition.

The Spinal Soul

In order to draw upon the scientific pregnancy of the 19th century a little repetition must be permitted. While Muller, Bernard and Ludwig were molding physiology on a grand scale, many other lesser lights were struggling with what the new advancements in the knowledge of the nervous system and its interrelationship with the other systems of the body, meant to the developing new psychology. For example, a direct consequence of the work of Marshall Hall was an intense interest in the functions of the spinal cord. An extension of this fascination precipitated the so-called Pfluger-Lotze Controversy. This debate reflected the dilemma that many in the European intellectual community perceived to confront them.

Eduard Pfluger (1829-1910), a physiologist, represented the position which assumed that every function of the nervous system was part of the mind, therefore, how could reflexes, which were under the control of the nervous system, be looked upon as being unconscious? On the other hand, Rodolph Lotze (1817-1881), a man of more philosophical and religious learnings, postulated that the spinal cord was unconsciousness, that the brain was the only "organ of consciousness" and that the apparent purposefulness of 'spinal' animals was due to the plasticity of the nervous system (Boring, 1950). Today this controversy is looked upon as a 'pseudo-problem' and often neglected. For example, G. Stanley

Hall (1924) in his lengthy treatment of Lotze, does not even mention Pfluger's name. Nonetheless, at that time (mid 19th century) it was the confluence of many streams of thought that gave rise to much-needed experimental research.

The immediate problem revolved around the concept of collating 'sensation' with 'consciousness'; the circumscription of the latter and the degree to which consciousness influenced reflexes, particularly spinal ones. Much of the experimental evidence which led the debate involved the apparent 'purposive' behaviour of decapitated animals in response to external stimuli. The net result was confusion concerning the function of different parts of the nervous system. The question concerned whether consciousness and volition were only in the brain or whether they were also located in the spinal cord (Brazier, 1959).

Philosophers, physiologists and future psychologists entered the fray e.g. Lewes, Gotz, Ferrier, Maudsley, Foster and Sherrington, to name a few. Further, this controversy, which lasted into the 20th century, illustrated the great importance to psychology of findings that can be considered strictly physiological in nature. The discovery of neural activity independent of the brain; involuntary, seemingly machine-like and yet purposive, presented a real challenge for any psychological theory. In fact, the general elucidation, since the 19th century, of the varieties of reflex mechanism, together with the turn of the century findings of Pavlov and his 'conditioned reflex' has demonstrated how far specific forms of conscious activity proceed from the integrated autonomic interplay of the central nervous system.

Charles Scott Sherrington discussed this issue in the opening statement of his seventh Silliman lecture:

> "It is, of course, as impossible to disprove as to prove that psychical events accompany, or that they do not accompany, the nervous reactions of the 'spinal' animal. It is significant, however, that the best known controversy (Pfluger, Lotze) as to the psychical powers of the spinal cord, occurred prior to the advent of Darwinian theory of evolution. This latter suggests how purposive neural mechanisms may arise. It furnishes a key to the genesis and development of adapted reactions and among these latter, reflexes".
>
> (Sherrington, 1947, p.236).

Indeed a decisive element in the acceptance of the mechanistic view of the human being was Darwinian biology and the new orientations that it provoked in psychology. The idea that man had evolved from simpler life forms perceptively weakened any presumption that postulated man as a spiritual creature with a transcendent nature (Lowry, 1971). Although this position was achieved only after great difficulty, once established, it permitted all human characteristics to be viewed as natural phenomena open to natural explanation. Thus the continuity, established by Darwin, between man and other animal species was an invitation to interested parties to study humans by the same behavioural criteria that were to be used in the study of animals (Schultz, 1972). This intellectual impetus would be of great use to Pavlov and Thorndike in developing laboratory procedures to study animal behaviour that directly or indirectly has dominated the experimental psychology of learning to the present day.

Thus, the image of man was in a state of transition. It goes without saying that the concepts of consciousness and unconsciousness had usually been closely bound to the concepts of voluntary and involuntary respectively and it was during this era that the clarification

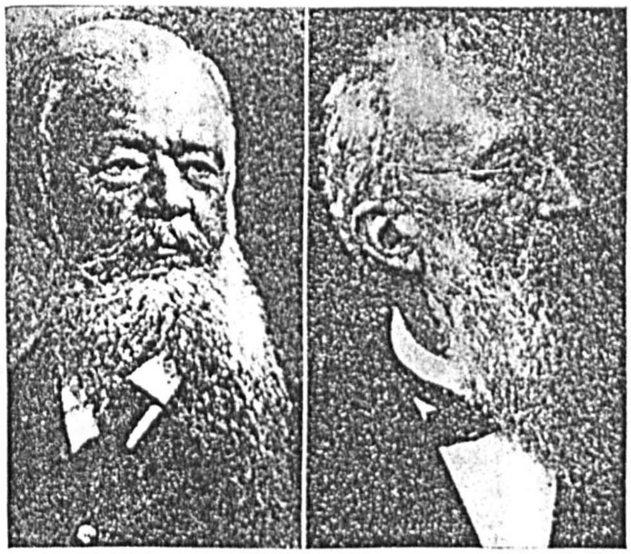


FIG. 34. Gustav Fritsch and Edouard Hitzig. (Photographs reproduced by kind permission of Dr. A. E. Walker, for whom Professor Stender of Berlin obtained the picture of Hitzig.)

FIG. 31. Goltz and one of his decorticate dogs. (Studio portraits of man and dog are reproduced here by the kind permission of Dr. Paul Dell.)

FIG. 35 from Brazier, 1959, top p.48;
bottom p.46.

of the neural substrates of such functioning came under vigorous experimental attack. This came about due to the growing expertise of the researchers in the methods which they used. These included ablation (old) and the electrical stimulation of nervous tissue (new). This area of special interest has been called 'localization of function' within the nervous system and the major obstacle to progress area was the skill of the researcher.

Localisation of Function

Apparently one of the better earlier surgeons was Pierre Flourens (1794-1867) who was Professor of Comparative Anatomy at Paris. He was able to keep his decorticated pigeons alive longer than most others and concluded that the nervous system could be broadly differentiated functionally; the cerebrum was responsible for volition, perception, sensation and intellectual functions, the cerebellum co-ordinated muscular movement, while the medulla was concerned with visceral functions. In addition the medulla "orders the sensations before they are perceived, to bring together the volitions before they are executived in movement" (Boring, 1950, p.62-63). Flouren's work on the cerebral cortex led him to conclude that, at least as far as volition and intelligence are concerned, the structure was 'equipotential', thus anticipating Lashley by a century (Tizard, B., 1959). The 'equipotentiality' refers to the ability of any intact cortical area to perform the functions of other parts of the cortex.

This concept went into abeyance in the mid-century but was resurrected by Friedrich Leopold Goltz (1834-1902) who was by far the most accomplished of those who represented this point of view (Brett, 1965). The surgical skill of Goltz, who was Professor of Physiology at Strasburg and a pupil of von Helmholtz, was confirmed by his dogs living from several weeks to many months after being decorticated.

They were not very spontaneous, but they did react to stimulation (Fearing, 1964). His theoretical bias notwithstanding, he described 'sham rage' in animals with frontal lobe lesions and diminished spontaneity in those with posterior ones, as well as conceding a clearly defined visual area (Esper, 1964).

In addition to the experimental studies of Flourens and Goltz, clinical evidence also began to accumulate support for the concept that speech was cerebrally controlled. This concerned clinical syndromes called aphasias "difficulties in ideational elaboration of speech as distinguished from defective verbal articulations" (Penfield, W., and Roberts, L., 1959, p.198). An area was found in the posterior portion of the frontal lobe of the left hemisphere by Paul Broca (Broca's area) while another was identified in the first and second convolution of the temporal lobe (same hemisphere) by Karl Wernicke (Wernicke's area) (Penfield and Roberts, 1959). The importance of this work lay in the implication that if there were areas devoted to such complex behaviours as speech, then maybe other areas could be discovered which would subserve other behaviours.

Another clinician subscribing to this thesis was the English neurologist John Hughlings Jackson (1835-1911). He was mainly concerned with epilepsy caused by traumatic injury; a type that became known as Jacksonian epilepsy. Somewhat influenced by the evolutionary philosophy of Herbert Spencer, Jackson surmised from clinical observation, that the nervous system was arranged in a hierarchical fashion and that voluntary movement proceeded from the cerebral cortex (Young, R.M. 1970).

Jackson divided his hierarchy into three broad divisions. The 'lowest' section governed movement whose form was considered the least complicated. Structurally this involved, not surprisingly, the spinal cord and the medulla oblongata. His second or 'middle' division involved the pre-central gyrus or motor cortex, and lastly the frontal cortex was viewed as the repository of the highest and most distinctly human intellectual capacities, and an area which elaborated movement (Jackson, J.H., 1873). However, since Hebb's criticism, this argument has been greatly weakened (Hebb, D.O., 1945).

Nonetheless, dramatic support for Jackson's clinical studies came in 1870 with publications by Gustav Fritsch (1838-1891) and Edouard Hitzig (1838-1907). Their results revolutionized concepts of brain function and directly challenged the view of Flourens and Goltz. By electrically stimulating the cortex of dogs they elicited leg movements on the opposite side of the body, thus simultaneously demonstrating the cortex to be electrically excitable and identifying what is now called the motor cortex.

Soon after the publication of Fritsch and Hitzig, David Ferrier (1843-1928) greatly refined the location of focal points on the 'motor strip' in the cerebral cortex of vertebrates, particularly monkeys.. Sherrington, in his Royal Society Obituary for Ferrier, states that:

> "He established the localization of the motor cortex very much as we know it, ... He pointed out that its extent was greater and its character more detailed in the ape than in any of the types less near to men. He showed that its focal movements were obtainable with such definition and precision that 'the experimenter can predict with certainty the results of (electrical) stimulation of a given region'."
>
> (Sherrington, 1928, p.viii)

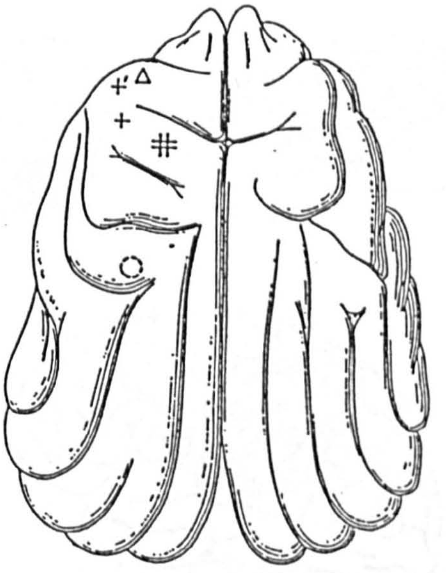


FIG. 2.1. Fritsch and Hitzig's (1870) historic map of galvanic stimulation of the dog's brain. Δ, 'Centre for the neck muscles'; +', 'centre for the extensors and adductors of the forelimb'; +, 'centres for the flexion and rotation of the limb'; #, 'centre for the hind leg'; ◌, 'facial'. 'We did not always succeed in setting the neck muscles in action. . . . The muscles of the back, tail and abdomen we have often enough excited to contraction from points lying between those marked, but no circumscribed point from which they could be individually stimulated could be satisfactorily determined. The whole of the convexity lying behind the facial centre we found absolutely unexcitable, even with altogether disproportionate intensity of current.' (David Ferrier's translation.)

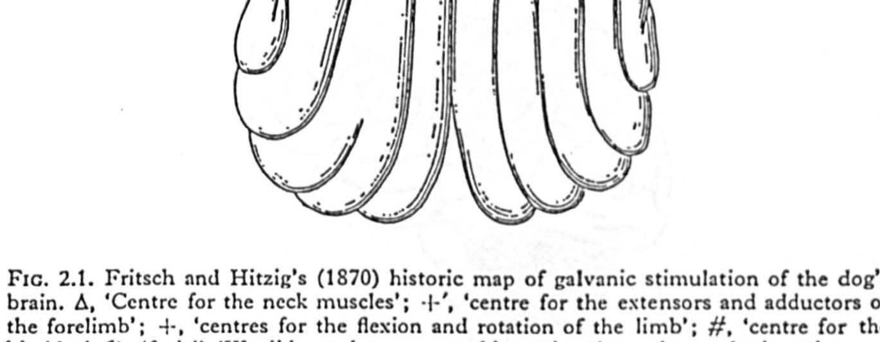


FIG. 2.3. 'Motor zone' of monkey's brain: dorsolateral aspect (left) and medial aspect (right), based on the experiments of Victor Horsley with C. E. Beevor and E. A. Schäfer (Schäfer, 1900).

FIG. 36 from Phillips, C.G. and Porter, R., 1977, top p.23; bottom p.28.

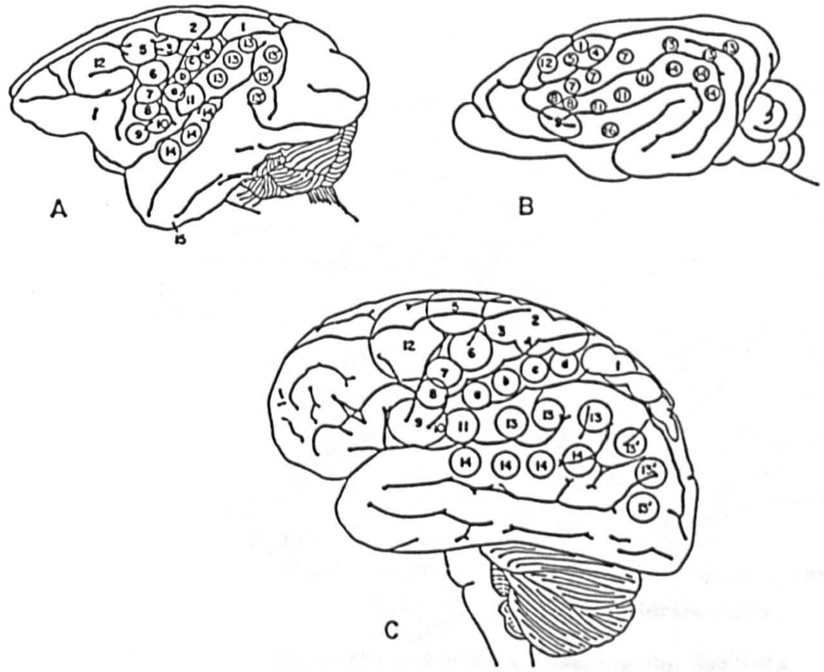


FIG. 2.2. A. David Ferrier's historic map of faradic stimulation of the monkey's brain (1875). 1, 'The opposite hind limb is advanced as in walking. . . .' 2, 'Flexion with outward rotation of the thigh, rotation inwards of the leg, with flexion of the toes—the action being such as is seen when a monkey makes a grasping movement, or scratches its chest or abdomen with its foot. . . . The action is similar to that caused by stimulation of the sixth lumbar root of the crural plexus. . . .' 3, As for 1 and 2—'In some cases also the tail is moved. I have not been able to dissociate the movements of the tail from those of the trunk and hind limb.' 4, 'The opposite arm is adducted, extended, and retracted, the hand pronated . . . almost exactly in the same way as occurs on stimulation of the seventh cervical root of the brachial plexus . . . if the hand were the fixed point . . . would . . . raise the body upwards and forwards, as in climbing a trapeze.' 5, 'Extension forwards of the opposite arm, as if the animal tried to reach or touch something in front'. a, b, c, d, 'Clenching of the fist. With slight stimulation the action begins in the thumb and index finger, followed on longer stimulation by flexion of all the fingers and firm clenching of the fist. With the closure of the fist is associated the synergic action of the extensors of the wrist and fingers, but centres for the individual flexors and extensors could not be differentiated.' 6, 'Flexion and supination of the forearm—the completed action bringing the hand up to the mouth. The movement is essentially the same as that which occurs on stimulation of the sixth cervical root of the brachial plexus.' 7, 'Retraction and elevation of the angle of the mouth.' 8, 'Elevation of the ala of the nose and upper lip.' 9 and 10, 'Opening of the mouth, with protrusion (9) and retraction (10) of the tongue.' 11, 'Retraction of the angle of the mouth.' 12, 'The eyes open widely, the pupils dilate, and head and eyes turn to the opposite side.' 13 and 13′, 'The eyes move to opposite side, with an upward' (13) 'or downward deviation' (13′) . . . 'Sometimes the head turns with the eyes.' 14, 'Pricking of the opposite ear, head and eyes turn to the opposite side, pupils dilate widely.' 15, 'On the anterior and inner aspect of the uncinate gyrus . . . Torsion of the lip and semiclosure of the nostril on the same side, as when the interior of the nostril is irritated by some pungent odour.' At lower extremity of middle temporosphenoidal convolution: 'movements of the tongue, cheek pouches and jaws . . . very like those which are characteristic of tasting'.

B. Ferrier's map of the dog's brain. The numbers refers to responses resembling those recorded by the same numbers in the monkey map. 'They do not pretend to indicate more than approximate physiological homologies, certain individual peculiarities being observable in different animals which scarcely admit of strict comparison with each other.' (Ferrier, 1876.)

C. Ferrier's (1876) transfer of his monkey centres to an outline of the human brain.

FIG. 37 from Phillips and Porter, 1977, pp.24/25.

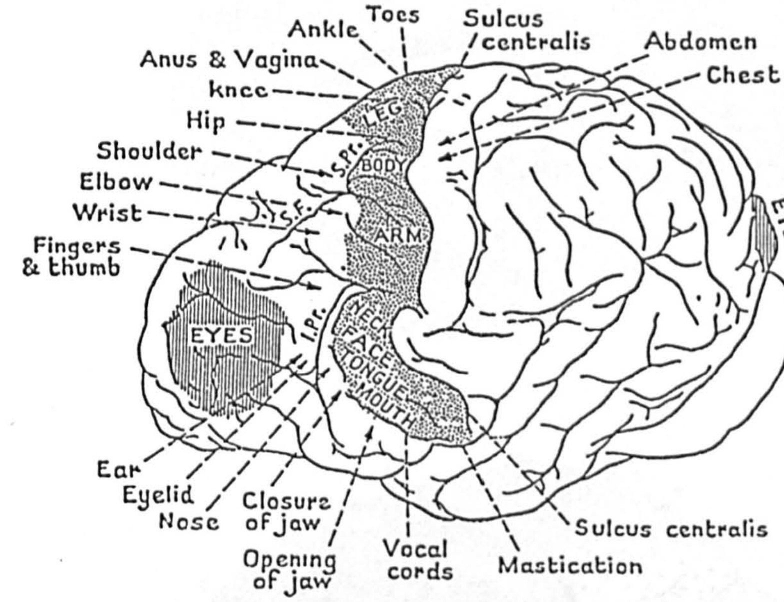


Fig. 72 (from Grünbaum & Sherrington). Brain of a chimpanzee (*Troglodytes niger*)

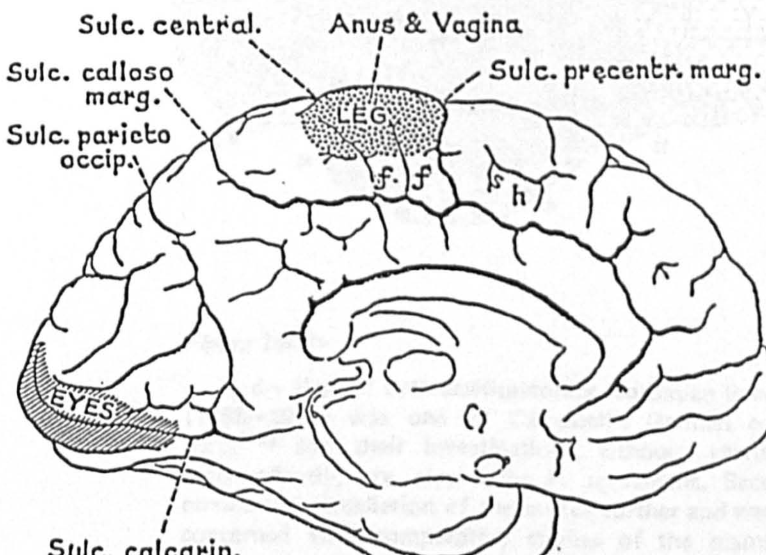


Fig. 73 (from Grünbaum & Sherrington). Brain of a chimpanzee (*Troglodytes niger*)

FIG. 38 from Sherrington, C.S., 1906, top p.274; bottom p.275.

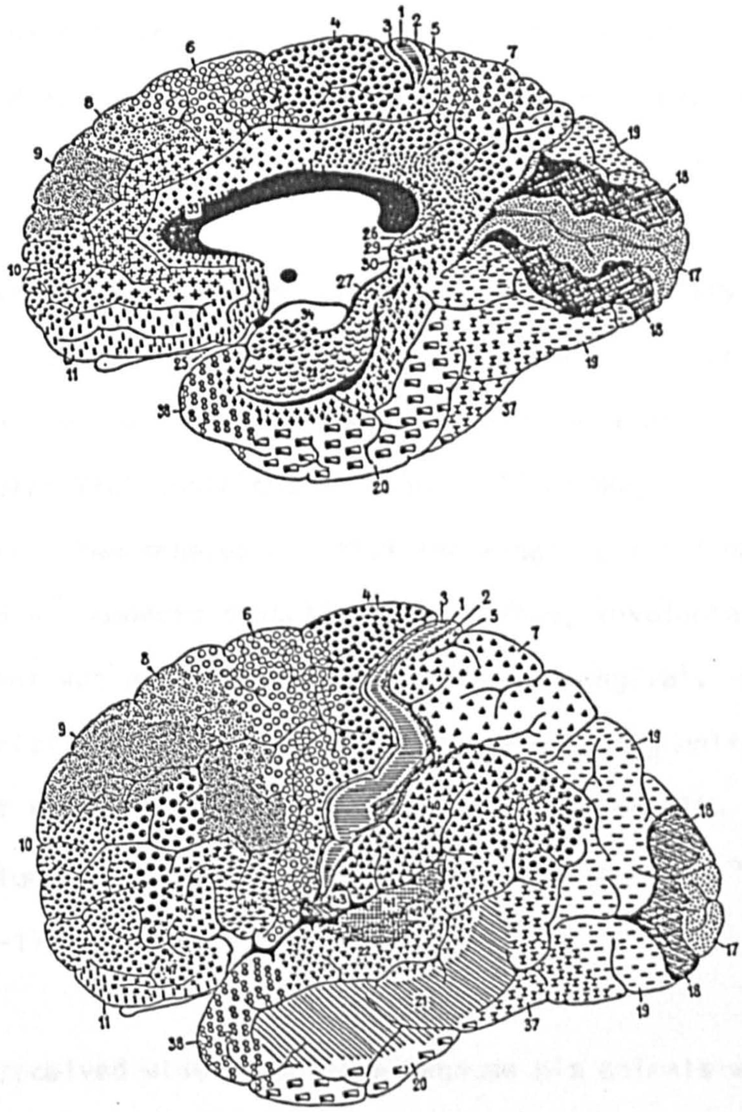


Figure 144 ▷

In the field of cyto-architectonics Korbinian Brodmann (1868–1918) was one of Campbell's German counterparts[42] and their investigations, although carried out independently, are essentially in agreement. Brodmann carried the parcellation of the cortex further and was more concerned with comparative studies of the mammalian cortex; his work forms the basis of this modern science.

FIG. 39 from Clarke and Dewhurst, 1972, p.121.

Ferrier also ablated discrete areas of the motor cortex which results in either paralysis of a single limb (monoplegia) or an entire side of the body (hemiplegia) depending on the extent of the lesion (Sherrington, 1928).

Fancher (1979) claims that these ablations prevented voluntary limb movements but also states that the affected limb could respond to stimulation.. In doing so, he was following Ferrier's own lead. Ferrier agreed with Lotze that consciousness and volition were subserved by the cerebral hemispheres and that the adaptive reactions of the spinal cord did not connote consciousness. Thus, involuntary and unconscious movement was associated with the 'lower ganglia'. However it was not strictly machine-like in the sense of being uniform and unchangeable, "but rather a mode of reaction which varies with the intensity of stimulation and the vital conditions of the organism." (Fearing, 1964, p.173-174).

Ferrier's views received wide acceptance because his animals were able to survive the operations, like those of Flourens and Goltz whose opinions he eclipsed. Indeed, Cajal was deeply impressed by Ferrier's surgical dexterity, especially in the way in which he controlled the loss of blood (Cannon, D.F., 1949).

The work of Flourens, Goltz, Broca, Wernicke, Jackson, Fritsch, Hitzig and Ferrier among others had significant clinical overtones. The reason being that if there were cirumscribed cerebral areas representing specific neurological functions then lesions could be localized in corresponding regions by means of their clinical manifestations. This type of research was necessary for the important field of brain surgery to develop, although it should be said that the electrical stimulation studies performed on the cerebrum of humans between 1874 and 1914, often yielded equivocal results at best (Scarff, J.E., 1940).

However, the mounting evidence was such that it led Victor Horsley (1857-1916) of the University College Hospital, London, to perform surgery on the cerebral cortex in man as early as 1886. These early attempts, as well as his experimental work with Charles Beevor, have resulted in Horsley "being called the founder of neurosurgery" (Thomson, 1950, p.194-195). The Beevor-Horsley studies extended the work of Ferrier, with the subjects being monkeys and orangutangs. These led to "the description of the pre-central gyrus as predominantly motor in function and the post-central as sensory" (Brazier, 1959, p.48). Horsley also worked with Robert Henry Clarke at University College, London. Clarke had developed a stereotaxic instrument to study the cerebellum of animal brains. This instrument allowed an animal's head to be immobilized within a three-dimensional metal frame. There are metric calibrations along each dimension of the frame with adjustment screws to make possible movement in each direction. Thus, any point within an animal's brain can be precisely located. Stephen Walter Ranson would make this instrument an absolute necessity in the study of the structure and function of the nervous system, in the United States.

After Ferrier and Horsley and Beevor, a third British series of experiments on cortical localization, especially of motor activity, came from the Cambridge School of Physiology. These were conducted by C.S. Sherrington (1857-1952) and A.S.F. Grunbaum (1869-1921) in the opening decade of the 20th century. Sherrington thought that these studies confirmed the earlier work of Hitzig, i.e. that the 'motor cortex' was, in large measure, confined to the pre-central gyrus (Sherrington, 1947). Thus, their work was used by others as a basis for the opinion that there was a pre-central motor mechanism which was independent of post-central participation (Penfield, W. and Rasmussen, T., 1950). However, Sherrington clearly warned that:

> "Our examination of the anthropoid brains we have worked through, convinces us that not only do the fissures of the frontal region not mark any physiological boundaries, but that they are not closely reliable even as landmarks of the functional topography."
>
> (Sherrington, 1947, p.276).

Sherrington's warning as to function, notwithstanding, anatomists meanwhile were discovering great variety in the structure of the components which make up the nervous system.

While distinguished physicians and physiologists were attempting to determine the function of the nervous system, the anatomists were increasingly identifying and classifying its structure. Many competent workers participated in this enterprise, but only two shall be mentioned here because of their overshadowing importance. Their contributions were widely recognized and they jointly received the Nobel Prize for Medicine and Physiology in 1906. It was Camillo Golgi (1843-1926) who applied the chrome-silver-nitrate stain (the Golgi Stain) to the central nervous system. Although this stain did not impregnate every cell (if it did, it would be useless due to the high cell density of the CNS), the ones that were coloured could be seen with unprecedented clarity and detail. It was in the hands of Santiago Ramon y Cajal (1852-1934) that an improvement on this staining technique showed its true potential. It was Cajal's meticulous exploration of almost the entire nervous system that formed the sound and yet unchallenged view that it was composed of innumerable individual cells, now called neurones (Castiglioni, 1947; Boring, 1950).

The work of Ramon y Cajal has been the cornerstone of all modern thinking on the structure and function of the nervous system. Through his perseverence he was able to use the Golgi Stain where others had failed and he presented his results to the German Anatomical Society in Berlin in 1889. Among those present were Wilhelm His, Wilhelm Waldeyer and most important of all Albrecht von Kolliker (Muller's pupil). The latter was "the eagle among the sparrows" and "knew more about the microscopic structure of animal tissue than anyone who ever lived."(Williams, 1954, p.129).

Before that conference the conventional wisdom among students of the nervous system (including Kolliker himself) was the so-called reticular 6r network theory, which had been promulgated by Joseph von Gerlach. This theory stated that nerve cells (gray matter) and nerve fibres (white matter) were independent but connected entities within the nervous system. Further, these formed physically interconnected links which could conduct impulses in any direction (Fearing, 1964; Cannon, 1949).

In contrast, the neurone theory maintained that the nervous system was composed of innumerable, individually separate cells in a variety of sizes and shapes. The nerve fibres were not separate units but extended processes of the nerve cells and these cells were not actual continuations of one another but there was very close physical contact between them. In other words, the nerve cells form close contiguity with one another but not continuity. They were separated by very small spaces. This functional junction between nerve cells was called a 'synapse' by Sherrington. It should be added that Wilhelm His and Auguste Forel had earlier proposed a weak neurone theory but it lacked any clear microscopic observations and that Wilhelm Waldeyer's 1891 formulation was actually a summary of Cajal's work and nothing more (Cannon, 1949).

Later Cajal was to give a summary of his own work in the 1894 Croonian lecture. While in England he was the personal guest of Michael Foster and Charles Scott Sherrington and was brought into intimate contact with the increasingly influential Cambridge School of Physiology. Further, he and Golgi were jointly awarded the 1906 Nobel Prize for Medicine and Physiology. Incidentally, Kollicker, the most influential histologist in Europe, showed true greatness by rejecting the previously accepted reticular theory and accepting the neuron doctrine on the basis of elegantly presented scientific evidence. However, Golgi never rose to the occasion and defended the network concept to the last, even in his Nobel acceptance speech. Of course, Cajal's address presented evidence that the neuron doctrine rested on the strength of research capable of maintaining it to the present day. Sherrington in "A Memoir of Dr. Cajal" writes:

> "He solved at a stroke the great question of the direction of the nerve currents in their travel through brain and spinal cord. He showed, for instance, that each nerve path is always a line of one-way traffic only, and that the direction of that traffic is at all times irreversibly the same. The so-called nerve-network with unfixed direction of travel he swept away".
>
> (Sherrington, C.S., 1949, p.xii).

In addition to the fundamental work of Cajal, other efforts also addressed the structural-functional relationships within the nervous system. Many of these studies focused on man's most prominent neurological feature - the cerebral cortex. Therefore, in the attempt to associate structure with function it was viewed as the most likely area for the origin of voluntary acts.

Among the first to recognise regional structural differences within the cerebral cortex was Theodore Meymert (1833-1892) (Brett, 1965). He related thse structural differences with differences in function and advanced an early "cellular" theory of memory in which "Each new impression meets a new, still vacant cell" (Luria, A.R., 1966, p.12). He was followed by Paul Emil Flechsig (1847-1929) who used the method of myelogenesis to relate structure and function. Myelogenesis involves the development of a fatty sheath around the axon of the nerve cell. He observed the progressive appearance of myelin in the sub-cortical white matter of human foetuses and infants. Based on these observations, he concluded that the cortex could be divided into regions of projection subserving sensory and motor functions and others of 'association' correlated with intellectual activity. In this he thought that the parieto-temporo-occipital areas were most important to cognitive functions (Esper, 1964).

In addition to myelogenesis another method called architectonics was used to study the representation of function in the cerebral cortex. This approach concerns itself with the microscopical study of the sizes and shapes of nerve cells (cytoarchitectonics). The pioneering work done in this area was that of Campbell, Brodmann and the Vogts (Haymaker, W. and Schiller, F., 1970).

A. Walter Campbell in his Histological Studies of the Localization of Cerebral Function (1905) identified distinct architectonical regions but was broadly conservative in his interpretation of their function (Luria, 1966). Later Korbinian Brodman (1868-1918) independently of Campbell, carried out comparative studies of the mammalian cortex (Haymaker and Schiller, 1970). His mentors, Oskar and Cecile Vogt, carried the divisions of the cerebral cortex to the almost obsessional dimensions of the phrenologists by specifying more than a hundred different areas in the brain of the long tail monkey (Haymaker, W., 1951).

Early in this field of research, there was a tendency, especially with the Vogts, to consider each function as acting independently of one another. As techniques have improved there has been a deviation from the idea that very precise cortical areas subserved very specific functions and that these functions could operate independently. Indeed, those actions seemingly most human, such as learning and memory which form important links in the execution of voluntary action, have been the ones most refractory to revealing an exact locus or structure which would subserve them. A later trend has been to view the nervous system as an integrating unit. It processes information from the environment and translates, in the case of humans at least, it into thought and/or action. Sherrington had elegantly described the integrative functions of the nervous system as early as 1906.

Neurophysiological synthesis: Sherrington

Charles Scott Sherrington (1857-1952) received his higher education at the Cambridge School of Physiology which was established under the directorship of Michael Foster. This great institution not only would become central to significant advancements in physiology but in all the biological sciences. Some of these researchers would leave the school to establish "Cambridge Physiology" elsewhere in the world. For example, H. Newell Martin became the first professor of biology at the now (pre-eminent) American University, Johns Hopkins, continuing the superb effort begun at Cambridge. In the Cambridge School, with help later on from Oxford, he made English biological sciences the standard by which the rest of the world's biological sciences would be measured. (Incidentally, Sherrington began his career at Cambridge and ended at Oxford with an extended sojourn at Liverpool). That this

Portrait by R. G. Eves, 1927, in the Sherrington Room,
Woodward Library, University of British Columbia

Portrait of C.S. Sherrington

FIG. 40 from Eccles, J.C. and Gibson, W.C., 1979, facing title page.

trend continues today is demonstrated by the fact that the Medical Research Council's Unit for the study of Molecular Basis of Biological Systems has produced six Nobel Prizewinners in recent years.

Sherrington studied directly under Gaskell and Langley, whose work on the autonomic nervous system is mentioned in a later chapter. His first paper was published in collaboration with Langley and his opinion concerning neurophysiology has become the most potent one of the twentieth century. Sherrington's greatest contribution was the synthesis of a large body of data devoted to the structure and function of the nervous system, especially the spinal cord. His work, produced largely, but not entirely, around the turn of the century or soon thereafter, has withstood, in large part, experimental assault throughout this century. For example, his The Integrative Action of the Nervous System (1906) was so advanced for its time that it required little revision in the 1947 (5th) edition. F.M.R. Walshe, in reviewing the 1947 edition, compared its importance in physiology with that of Newton's Mathematical Principles of Natural Philosophy in physics (Walshe, F.M.R., 1947). Given its importance and the fact that the ideas presented therein have been in the main substantiated or modified rather than overthrown, it will be often quoted when discussing his views on the influence of voluntary control of reflex responses.

This seminal work summarized such concepts as integrative action of the nervous system (pp. 308-353), the final common path (pp. 117-151), proprioception (p.130, pp132-135, pp.205-206, pp.335-344), and reciprocal innervation (inhibition) (pp. 83-113, pp. 280-299) and throughout makes great use of excitatory and inhibitory states of central origin as Sechenov and Pavlov had done. As intimated earlier, Sherrington did not avoid or ignore the role of volitional control in the function of the nervous system and by extension, behaviour, and, as Pavlov, he attempted to relate nervous system activity to muscular movement. He believed that "No exposition of the integrative action of the nervous system is complete, even in outline, if this control is left without consideration" (Sherrington, 1947, p.386). Further, when he addressed the problem of volition, he states:

> "Pure reflexes are admirably adapted to certain ends ... theirs is of itself a machine-like fatality ... (but) the reactions of reflex-arcs are controllable by mechanisms to whose activity consciousness is adjunct. By these higher centers, this or that reflex can be checked, or released, or modified in its action with such variety and seeming independence of external stimuli that the existence of a sponteneous internal process expressed as "will" is the naive inference drawn".
>
> (Sherrington, 1947, pp. 385-386.

In addition he recognised that reflexes (involuntary responses) could, with training, be brought under voluntary control and that voluntary responses could become involuntary, as with overlearned motor responses. Thus, Sherrington like other researchers, in the final analysis, did not make the distinction between voluntary and involuntary responses clear or rigid. Of great interest to us is the fact that Sherrington repeats several times in so many words that while the control of reflexes is often unconscious "consciousness is adjunct to centers which exert the control" (Sherrington, 1947, p.387). In its general form, this idea has also arisen in the work of Penfield, Eccles and Kornhuber.

Sherrington had matured during the highly invigorating intellectual debates that followed Darwin's introduction of a theory of evolution. At the same time there were struggles to define what science "is" and the methods that it should use. In England the new psychology (psycho-physiology) had great moral implications, for it was perceived that a scientific psychology (scientific at that time was viewed as being synonymous with being mechanistic, reductionistic, deterministic and empirical) would directly conflict with traditional concepts about a self-moving agent which acted under the influence of free-will. Henry Sidwick of Cambridge (1874) apparently stated the dilemma clearly:

> "The belief that events are determinately related to the state of things immediately preceding them is now held by all competent thinkers in respect to all kinds of occurrences except human volitions".
>
> (Daston, L., 1978, p.193-194).

Scientific law, that is, those propositions about specific sequences of phenomena that can be relied upon to the same degree as the law of causation, is not a distinction applicable to human behaviour. Opinion ranged from that of T.H. Green (Oxford) who believed that a science of man was not possible, to Henry Maudsley who advocated the immediate adopting by psychology of methods used in the other (natural) sciences. Further, Maudsley accepted a "reflexive" explanation of voluntary behaviour which was close to Sechenov's position. This meant adaptation of the empiricist proposal of observation and experiment, as well as the use of the logical processes of induction and (to a lesser extent) deduction. Although John Stuart Mill had a great deal to say about inductive reasoning and scientific explanation, as did William Whewell, they, along with other philosophers of science, could not agree upon a single methodology that constitutes the 'scientific method' (Daston, L., 1978).

Thus, psychology was born as a separate discipline in an atmosphere in which all science was seeking to clarify that which constituted scientific evidence and method. Hence during the nineteenth century emerged the first generations of full-time professional scientists, the term being introduced by Whewell in 1836.

For psychology a most important event took place in 1886 with the publication of the 9th edition of the Encyclopedia Britannica. In it, James Ward presented his definition of a psychology that was scientific and through it, eclipsed other current opinions. James Ward (1843-1925) was influenced by the idealistic philosophy of Rudolf Lotze but also received physiological training under Carl Ludwig and Michael Foster. Eventually he was elected to the Chair of Logic and Mental Philosophy at Cambridge (1897). For psychology to be scientific, Ward contended it must be empirical, which meant studying mental events, with volition and self-consciousness being central to his approach. Psychology could not be, or use the methods of, the natural sciences, it must define its own subject matter and methods and for him this meant phenomena and introspection respectively. This gave Ward's view a dualistic slant. Such a slant could have affected Sherrington when he addressed mental events in his work. But Sherrington did recognise the thorny problem which has always stung the interactionalist-dualist position that is the problem of 'how'?

Sherrington presented a great deal of experimental data in which the graphic method of Ludwig (i.e. the kymograph) was used with great effectiveness. Usually he surgically isolated the spinal cord from the brain, thus producing a 'spinal' animal. Drawing on his experimental efforts, he proposed that the reflex was the elemental unit of behaviour and that all co-ordinated forms of action were constructed of these. His view of reflexes was not the Cartesian mirror-like reflection of activity but was based on the concept of the reflex arc (i.e. afferent input, interconnecting and interconnected neurons and efferent output). Sherringtonian reflexes could operate simultaneously (lecture V) or in sequence (lecture VI) and could serve a common purpose. Complex behaviour was a compound of simpler 'allied' and 'antagonistic' reflexes. Further, a reflex reaction, even a simple spinal one, was always a reaction conditioned by many reflex arcs. Thus a major problem in nervous co-ordination became the compounding together of reflexes (Sherrington, 1947).

In discussing the interaction between reflexes, Sherrington put forth one of his most important principles concerning the integrative action of the nervous system, that of the 'final common path'. In this he maintains that reflex arcs, some allied, some antagonistic, form interconnected paths (neuronal inter-connections) which may be common to more than one reflex arc and these in turn must compete with one another for access to the 'final common path', through which this or that reflex achieves overt expression. Moreover, he includes the 'motor unit' (i.e. the motor neuron and the muscle fibres it innervates) as an extension of this terminal path. Therefore by using the final common path, different reflexes can involve the same muscles with the distinguishing feature of any given reflex being its pattern of motor neuron activity in space and time (Sherrington, 1947).

In Lecture VI Sherrington discussed the successive combination of reflexes which was viewed as sequences of reflexes. This was his version of the 'chaining' of reflexes, which has been used throughout the 20th century to account for long sequences of orderly movement illustrative of the inverted "outward behaviour of animals" (Sherrington, 1947, p.83). Chaining of reflexes be a major feature of theories concerned with the experimental study of learning, e.g. those of Pavlov, Hull and Skinner.

Late in his life Sherrington published a broad 'philosophical' work entitled Man on His Nature (1941) in which he covered many of the same topics he had addressed in the experimentally oriented

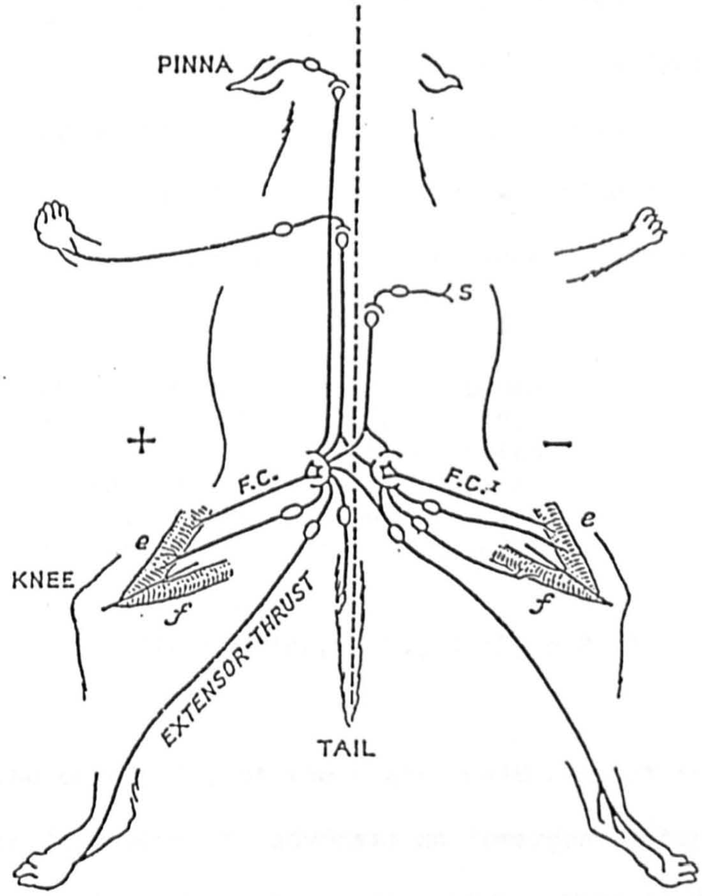


Fig. 44. Explanation mainly in text

s stands for scratch-receptor, *e* and *f* are extensor and flexor muscles of knee respectively.

The final common path is therefore an instrument passive in the hands of certain groups of reflex-paths. I have attempted to depict this very simply in Fig. 44. There certain type-reflexes are indicated by lines representing their paths. The final common path (*FC*) selected is the motor neurone of the vasto-crureus of the dog or cat. Reflexes that act as 'allied reflexes' on *FC* are represented as having their terminals joined together next to the final common path. Reflexes with excitatory effect (+sign) are brought together on the left, those with inhibitory (−sign) on the right. Of the reflex pairs formed by the two reflexes which two symmetrical receptive points, one right and one left, yield in regard to the final common path, one of the pair only is represented, in order to simplify the diagram. To have a further indication of the reflexes playing upon *FC*, all that is required is to add to the reflexes indicated in the diagram for *FC*, a set of reflexes similar to those given in the diagram for *FC*^{1}, for they *must* be added if the remaining members of the right and left reflex pairs from various parts of the body be taken into account. It is noteworthy that in many instances the end-effect of a spinal reflex initiated from a surface point on one side is bilateral and takes effect at symmetrical parts, but is opposite in kind at those two parts, e.g. is inhibition at one of them, excitation at the other. Hence reflexes initiated from points corresponding one with the other in the two halves of the body are commonly antagonistic.

FIG. 41 from Sherrington, 1906, p.146.

Integrative Action. In this later work he discussed 'recognisable mind' at length. For him, 'recognisable mind' was a feature of complex nervous systems and arose in close connection with motor behaviour. Thus the voluntary act, as derived from mind, was tied to the motor act. Therefore, mind and motor behaviour evolved together in a progressive manner.

> "The connexion of the brain with mind seems to rest on the organization of the brain, and that organization is cell-organization. An observer's only means of inferring mind, other than his own which he experiences not, is behaviour; motricity is the behaviour he can observe."
>
> (Sherrington, C.S., 1955, p.217)

For him, the complexity of the brain could account for 'recognisable mind'. Sherrington seemed to advocate an 'emergent' theory of mental development, although he did not use the word. When he takes 'a liberty with our subject' he proposes two types of processes which influence the overt expression of behaviour, intrinsic and extrinsic processes. The former arises 'intrinsically' from the roof-brain (cerebrum) and are more complex than the extrinsic processes that arise 'outside' from sensory processes. Normal motor behaviour is a product of both intrinsic and extrinsic processes working in 'harmonious' concert. However, these processes can, at times, control motor behaviour independently of one another. In this, when extrinsic processes act alone, the motor behaviour is reflexive, and when intrinsic processes function in an independent manner the motor behaviour is 'willed' (Sherrington, 1955).

Moreover, for Sherrington, 'willed' behaviour was a culmination of processes of attention which in turn was 'the climax of mental integration'. He drew a parallel between attention and a skilled act. Attention was to 'mental integration' what skilled motor behaviour was to 'motor integration' (Sherrington, 1947).

Nonetheless, when he expanded on the topic of the mind *per se*, he stated:

> "Mind, for anything perception can compass, goes therefore in our spatial world more ghostly than a ghost. Invisible, intangible, it is a thing not even of outline; it is not a 'thing'. It remains without sensual confirmation, and remains without it for ever."
>
> (Sherrington, 1955, p.264).

Despite the intangibility of the mind, Sherrington insisted there was interaction between mental and physical events. He noted:

> "..... that in the sequence of events a step is reached where a physical situation in the brain leads to a psychical, which however contains no hint of the brain or any other bodily part .... The supposition has to be, it would seem, two continuous series of events, one physico-chemical, the other psychical, and at times interaction between them."
>
> (Sherrington, 1947, p.xvii)

In closing with Sherrington we have the climax of 19th century neurophysiology. But a neurophysiology whose thinking ended in dualism. A dualism which had not advanced conceptually in the 350 years since Descartes and with the distinction between voluntary and involuntary responses drawn essentially along the lines of those proposed by him. Therefore, although there has been an enormous expansion in the knowledge of the role of the central nervous system in the production of movement, the impact of this knowledge on the concepts by which man perceives himself, was limited and vitalistic notions were still very powerful.

Be this as it may, the 19th century witnessed a concerted re-emergence of mechanistic doctrine. This doctrine saw the body as an enormously complex self-adaptive system which could be analysed as physico-chemical processes but for which no faithful analogue among artificial machines was available. Therefore the mechanistic view affirmed only that the dynamics of the organism could ultimately be governed by the same laws that governed mechanical systems.

Nevertheless, both mechanistic and vitalistic views were presented with the same problem; how do mental events influence physical events and vice versa?

Sherrington's solution was the 'liaison brain':

> "In all those types of organism in which the physical and the psychical co-exist, each of the two achieves its aim only by reason of a contact utile between them. And this liaison can rank as the final and supreme integration completing its individual. But the problem of how that liaison is effected remains unsolved; it remains where Aristotle left it more than 2,000 years ago."
>
> (Sherrington, 1947, p.xix).

One way to deal with the problem of "how" would be to ignore it. Indeed this is exactly what the powerful psychological movement of behaviourism did. Launched in 1913 by J.B. Watson, this 'school' was an attempt to circumvent the metaphysical implications of 'mind'. Watson thought this concept to be totally devoid of explanatory power. For him, if one wished to understand the activities of animals, including man, all one had to do was to study the organism's response to stimuli, in other words, its behaviour.

In Europe, including Great Britain, this vied with two other influential approaches, Gestalt Psychology and Ethology. The former emphasized the wholeness of experience focusing mainly on perceptional problems, whilst the latter studied animal behaviour in a natural setting and made important discoveries concerning the influence of genetics or 'instincts' on behaviour. In the United States, however, behaviourism became the dominant force although it was not without its internal debates. For example, Tolman, who was firmly in the behaviourists' camp, advocated a 'cognitive behaviourism' as close to Gestalt psychology as behaviourism.

However, the events taking place in physiology and psychology did not occur in isolation as the advances taking place in physics would demonstrate.

CHAPTER 2

Behaviourism

The family of ideas known as behaviourism emerged with great prominence in the early 20th century. However, its basic tenets have been closely associated with materialism, i.e. that mental states can be interpreted in terms of matter in motion. In its most general form, behaviourism has attempted to use laws and/or theories to explain the behaviour of animals and men. However, it should be pointed out that behaviourism is so historically rooted in such different concerns that it is very difficult to put forth a single account that reviews all its forms. Therefore an attempt will be made to explore the two most influential types of behaviourism - philosophical and psychological - and the effect that these have had on the classification of behaviours.

To begin, 20th century philosophy has been, in large part, a revolt against 19th century metaphysics, particularly that of Hegel, while 20th century psychological behaviourism has been a reaction against the use of the method of "introspection" to study mental events which was stressed by the 'founder' of experimental psychology, Wilhelm Wundt. Therefore, we shall discuss behaviouristic thought as philosophical behaviourism and psychological behaviourism. These forms have not developed independently, but have interacted with, and have been influenced by, one another. Their sweeping, common element is the conviction that 'behaviour' is, or should be, of central importance in the study of human beings and other animals. Although it may be difficult to persuade the various types of behaviourists to draw the compass of behaviour in the same manner, it is not misleading to state that the general thrust of behaviourism has been to restrict the scope of 'behaviour' to those things which are overt, observable and measurable; therefore opening behaviour to experimental manipulation and measurement. This restriction is maintained in an effort to be scientific, even though the objective study of behaviour always involves a prior decision of some sort. Thus it is difficult to know what behaviour 'is' because at some point, a decision must be made about what to observe and what to ignore; what to count and what not to count. Therefore, in the end, behaviourism becomes an article of faith or a policy statement as much as a strictly justified, arguable thesis. Nonetheless, behaviourism has advanced psychology, both as a biological and experimental science, while in philosophy it has sharpened arguments concerning the separation of mental and physical events (i.e. the mind-body problem).

Behaviourism is one of the closest links psychology has with other natural sciences. It emulates, or appears to reflect, the science of physics in stressing observation and experimentation. This is less true for philosophical behaviourism than for psychological behaviourism. Nonetheless we shall treat the former first.

Philosophical behaviourism has been part of a larger movement in philosophy which sought to unify all the sciences, with the discipline of physics being the final arbiter. The proponents of this movement, the logical positivists, were either educated in mathematics and physics or deeply impressed by the advances therein, particularly the relativity theories of Albert Einstein. Although logical positivism received widespread support throughout the English-speaking world, its driving force centred around the University of Vienna during the first decade of the 20th century. Its formation can be traced to the appointment of Mortiz Schlick to the chair of Philosophy of the Inductive Sciences at the University of Vienna.

Schlick, educated under Max Planck and a personal friend of Einstein, was well-versed in philosophy as well as physics. In fact, much more so than those whom he succeeded at Vienna, Ernst Mach and Ludwig Boltzmann. Among those attracted to Schlick were Rudolf Carnap, Herbert Feigl, Otto Neurath, Hans Hahn, and F. Waismann, among others. One who made his presente felt, although he did not attend the 'circle's' meetings, was Ludwig Wittgenstein (Joergensen, J., 1970).

The talented Schlick had a profound respect for Wittgenstein and through him, Wittgenstein's views received considerable attention. He called Wittgenstein's Tractatus Logico-Philosophicus (1919) the decisive publication in contemporary philosophy. Schlick and Wittgenstein were attempting to adapt to the broad implications of Einstein's Theory of Relativity and their writings reflect this concern. Such concern was also seen in philosophical movements in Germany and Great Britain, represented respectively by Hans Reichenback of the 'Berlin Society for for Empirical Philosophy' and the analytical philosophers, Bertrand Russell and A.J. Ayer. Schlick was on intimate terms with Einstein and Planck and Reichenbach wrote a paper which explicitly addressed "The Philosophical Significance of the Theory of Relativity" (Reichenbach, H., 1953). The essay was an attack on Kantian and Newtonian ideas on 'absolute' space and/or time and closes with:

> "It does not happen very often that physical systems of such philosophical signficance are presented to us: Einstein's predecessor was Newton. It is a privilege of our generation that we have among us a physicist whose work occupies the same rank as that of the man who determined the philosophy of space and time for two centuries."
>
> (Reichenbach, H., 1953, p.211)

Thus Reichenbach, and by extension, contemporary empiricistic thinking, views Einsteinian physics with a respect which parallels that of the 'enlightenment philosophers' for the accomplishments of Newton.

Einstein's Special Theory of Relativity (1905) was the outcome of his considerations of Clarke Maxwell's electromagnetic equations and the repudication of the Newtonian conception of simultaneity. These concepts were basic to early 20th century physics' view of the universe, the former was a brilliant mathematical synthesis of electrical and magnetic phenomena and the latter, an underlying assumption of the Newtonian view of space and time. Einstein used Maxwell's equations as the impetus to a more comprehensive and accurate picture of the universe than that of Newton (Einstein, A., 1953).

Besides his 'relativity' paper, he also published two other works in 1905, one of which concerned a kinetic-molecular account of Brownian Movement, while the other demonstrated the photo-electric effect and speculated on the characteristics of the photon. Shortly thereafter he presented his best-known principle, the mass equivalence of energy; $E = mc^2$. Hence mass is 'condensed energy' and a small amount of mass is equivalent to a large amount of energy. For Einstein, it was largely a matter of taste how one worded the relationship. Thus, whether (i) matter is a form of energy, (ii) matter is energy, or (iii) matter is destroyed and energy created, were equivalent statements. Therefore the principle of mass-energy equivalence united the 'independent' laws of the conservation of matter and the conservation of energy. Although it superceded them, it has nonetheless confirmed them (Bondi, H., 1964).

Strictly speaking, Einstein's General Theory of Relativity (1916), which dealt with the concept of gravitation, and which was ignored by the 'special theory', was a mathematical expression of the behaviour of the entire universe. Therefore any experiment designed to test the predictions of this theory could not be performed - strictly speaking.

However, 'approximate' experiments can, and have, been executed. For the most part, these studies are concerned with the effects of gravity on the propagation of electromagnetic radiation, particularly light as well as the gravitational interaction of closely adjacent massive bodies such as a star and its planetary system. In this approximate sense the theory of relativity has been partially continued. For example, light has been observed to be 'bent' by the intense gravitational field of a star; the advance of the peri-helion of the planet Mercury around the sun was accurately described, and frequency shifts in the wavelengths of light emitted by a massive body accounted for. Moreover, the latter phenomenon also occurs in rapidly rotating objects (pulsars).

The key assumption in all this was that the speed of light was invariant. Of all 'things' that move, light is the quickest, but even it has a finite, measurable, upper limit. However, as one approaches this upper limit the bizarre world of relativity becomes more obvious and less commonsensical. Time dilates and matter contracts in proportion to one's velocity. Further mathematical development of Einstein's equations by Schwartzchild described perhaps the strangest physical 'object' of all; the so-called 'black-holes'.

These are objects so massive that their gravitational pull does not permit even energetic light to escape from their surfaces. The term 'surface' may be out of place here, for the 'black hole' has an 'event horizon', not a surface. Since it does not emit light, it is invisible, but can be seen as a 'black hole' superimposed on the star field. However, the most likely way of identifying a black hole in contemporary astronomy is not by visual confirmation, but in the detection of its gravitational effects on the physical bodies in the adjacent areas.

Regardless of the exterior effects of its gravity, it is the interior effects that really strain the human imagination: here an object with a mass several times larger than the sun, is collapsed into singularity - singularity being a point with no physical dimensions in the traditional sense, but nonetheless exhibiting enormous gravitational 'tidal forces'. Inside the event horizon of a black hole the laws of physics (including relativistic physics) become altered in an unknown and, indeed, unknowable manner (Gribbin, J., 1983).

A similar condition has also arisen in the micro-level of investigation. Quantum theory attempts to describe the world of the very, very small and it, like relativity theory, has helped dissolve the strict deterministic universe of Newton. Instead of the determinism of classical physics, modern physics offers a problematic universe based on statistical laws. Following von Helmholtz, Gibbs and Boltzmann gave a mathematical treatment of the thermodynamics of systems which indicated that the concept of temperature was an index of our lack of knowledge of a particular system. Thus "temperature is a physical concept which can only be applied to an object when our knowledge of the object is incomplete" and "can only be used meaningfully when the system is not fully known and we wish to derive statistical conclusions from our incomplete knowledge" (Heisenberg, W., 1958, p.38).

While, in thermodynamics incomplete knowledge must be taken into account, in quantum theory it is essential. This feature is most forcefully brought forth by Heisenberg's 'uncertainty principle' which states it is "impossible to describe simultaneously both the position and the velocity of an atomic particle with any prescribed degree of accuracy"(Heisenberg, 1958, p.39). The consequence of this principle is that the laws governing the behaviour of atoms must be formulated as statistical laws and in modern physics 'pure' determinism has been abandoned. Hence it appears that limits are placed on our ability to 'understand' the universe around us. However, for Heisenberg, the 'uncertainty principle' indicated an intrinsic randomness in the universe and suggested that the act of observation itself altered the experimental results (Heisenberg, 1958).

Therefore developments in physics have cast attempts to deal with the 'unknowable' mental phenomena in a different light. If psychology can be reduced to physics and physics uses statistical laws and 'uncertainty relations' to describe physical events, what of mental events? Under these circumstances mental states seem to enter the class of events called 'ignorabimus' by Emile du Bois Raymond.- according to Du Bois Raymond, writing in the 1880s, 'ignorabimus' was a category of events which could not be explained by natural science, mental events fell into this category (Pavlov, I.P., 1955, p.653). Indeed, some 20th century psychologists have followed Du Bois Raymond's lead and have used Heisenberg's uncertainty principle to emphasize the 'unknown' quality of mental events as well as physical events (Sperry, R., 1980).

Given this state of affairs in the scientific enterprise, certain members of the philosophical community attempted to generate a standard which would clarify scientific statements and by which such statements could be declared meaningful. The result was the verification principle. Under it, a statement can be classified as meaningful or meaningless depending on whether or not it is verifiable. "This view was then summed up in the famous slogan that the meaning of a proposition is its method of verification" (Ayer, A.J., 1946, p.13.).

For logical positivism, this meant either empirical or analytical verification. The former was to be based on 'sense data' while the latter indicated that verification was, at least, logically possible. The aim was to produce statements that would have 'cognitive meaning', that is, statements which are true or false, or are a possible subject of knowledge. With the verification principle as their 'criterion of meaning', the logical positivists hoped not only to demolish the metaphysical edifice of traditional philosophy, but to construct propositions in such a way that there could be, in principle at least, an answer to every question. Therefore, if a question concerning a particular problem is stated in such a way that there is no answer which can be formulated in the manner of a proposition capable of verification, then it is a pseudo-problem, i.e. the question isn't meaningful and the problem is not genuine. Wittgenstein, in his Tractatus proposed that:

> "Most of the propositions and questions to be found in philosophical works are not false but non-sensical. Consequently we cannot give any answers to questions of this kind, but can only establish that they are non-sensical. Most of the propositions and questions of philosophers arise from our failure to understand the logic of our language."
>
> (Wittgenstein, L., 1969, p.37)

Wittgenstein had, immediately before, discussed the interplay of logic, language and thought, concluding that 'language disguised thought' (Wittgenstein, 1969, p.37). But language could be used in such a way as to produce clear thoughts. "Everything that can be thought at all can be thought clearly. Everything that can be put into words can be put clearly." (Wittgenstein, 1969, p.51).

Thus a significant contribution of logical positivism was to put forth an empirical philosophy that formulated a theory of meaning which would allow anyone to distinguish a meaningful sentence from a meaningless one. This theory was directed with particular vigour toward the 'mind/body' issue.

The positivists claimed that the mind/body problem, a fundamental philosophical issue, was in reality, a pseudo-problem. Moritz Schlick addressed the subject directly in a paper discussing the relationship between psychological and physical concepts. He rejected the Cartesian concept of two substances, the mental and the physical and asked "the harmless question of how, in general, we have come by our physical and psychological concepts" (Schlick, M., 1949, p.393). He then clarified his view by maintaining that the 'mental' (mind) and the 'physical' (body) are but "two different representational modes by which the data of experience are ordered; they are different ways of describing reality" (Schlick, 1949, p.403).

A.J. Ayer held similar views in his Language, Truth and Logic in which he also rejected Cartesian psychophysical dualism. He claimed the mind/body problem was "fictitious" because it arose "out of the senseless metaphysical conception of mind and matter or minds and material things as 'substances' " (Ayer, 1946, p.124). For us, these discussions are of import because volition (a mental event) and, by extension, the voluntary response, is subsumed, under 'mind', whereas involuntary responses are bodily events and are subsumed under the 'body' category.

The members of the 'Circle' solved (or thought they solved) the mind/body problem by collapsing the mental into the physical. The influential Rudolf Carnap did this by a variety of interpretations. Carnap thought that the language of mental events could be reformulated in the language of physical events. Moreover, Carnap advocated that psychology was a branch of physics and proposed that "every sentence of psychology may be formulated in physical language" (Carnap, R., 1959 p.165). Further, he stated that:

> "... the statements of an experimental subject are not, in principle, to be interpreted differently from his other voluntary and involuntary movements though his speech movements may, under favourable circumstances, be regarded as especially informative."
>
> (Carnap, 1959, p.195).

Carnap argued that the movements of animals, the movement of the needle of a voltmeter as well as the voluntary and involuntary movements of humans could, in principle, be studied in the same manner.

> "In all these cases, the issue is basically the same: from a specific physical sentence, other sentences can be inferred by a causal argument, i.e. with the help of general physical formulae - the so-called natural laws."
>
> (Carnap, 1959, p.195).

Carnap's writings are one of the few references where voluntary and involuntary movements are mentioned explicitly by the positivists. As stated previously, these movements, and those of a voltmeter, could be examined in a similar manner. Thus he held the same position that John Watson, the founder of psychological behaviourism held, that is, psychology is ultimately physics. However, an important point to remember is that Carnap and the other philosophical behaviourists were primarily concerned with the logical analysis of language - in this case psychological language - while psychological behaviourists attempted to give a scientific explanation of psychological phenomena.

The orientation of philosophical behaviourism and the related notions of operationalism, physicalism, reductionism and the verification principle, have reflected, in the 20th century, efforts to make psychology a natural science. A major thrust of logical positivism, with a particularly strong impetus from Otto Neurath, was to unify all the sciences and to give them all one language - that of physics. Further, the logical positivists have occasionally altered their verifiability theory of meaning. For example, Carl Hempel in "The Logical Analysis of Psychology" argues that mentalistic terms, instead of being totally 'reduced' to physical terms, can be viewed as a convenient short-hand in the description of long and involved material test conditions (Hempel, C.G., 1949). Furthermore, what has been called philosophical behaviourism Hempel has termed 'logical behaviourism' as has Gustav Bergmann. Moreover:

> "Logical behaviourism does not identify itself either with physiological nor with any molar behaviourism, or with any special psychological theory at all. It does not offer anything but logical criteria and formal methodological schemes and is not able to take sides between various theoretical approaches within a science, provided that all these approaches comply with its purely formal requirements."
>
> (Bergmann, G., 1953, p.628)

Thus logical positivism has adopted the view that meaningful statements about the mind are only those which refer to its outwardly observable properties and can, therefore, be tested. This epistemological form of materialism has in turn promoted a behaviouristic analysis of mind, the general effect of which has been to construe 'mentalistic' propositions as 'physicalistic'. The discipline of psychology also embraced a similar conceptual framework.

The adherents of psychological behaviourism draw heavily on the theoretical reflections of the logical positivists and their conception of science. This is especially so concerning the attempts to define concepts by the method of observation. That is, certain ranges of concepts fall within the realism of 'observation' and other concepts are given meaning in terms of the observables, e.g. the well-known 'operational definition'. A 'definition' which is distinguished by its insistence that the crucial data of behaviour theory must be measurable.

Psychological behaviourism has been an extension of philosophical behaviourism in that both attempt to use laws to explain the behaviour of men and animals. Philosophical behaviourism was a reaction against, and an alternative to, the psychophysical dualism of Descartes. Descartes recognised both mental and physical states and conceived them to be two causally unrelated substances. The former is private, and self-observation (introspection) is the only way an individual can ascertain one's own internal (mental) state. The latter, physical states, are overt and public, and can be discovered independently of a given individual. Behaviourism, philosophical and psychological, denies the 'two substance' position of Descartes.

One of the most important 20th century criticisms of Descartes' dualism has come from the Oxford philosopher, Gilbert Ryle. Ryle has been most noted for his so-called 'dogma of the ghost in the machine' (Ryle, G., 1949). In his The Concept of Mind (1949), he takes as his central thesis, that Cartesian psychophysical dualism is a 'category mistake'. This mistake occurs when something is taken to belong to a different category from its true one. The dualism, Ryle maintains, is only the illusion of mutually exclusive categories and for him, the failure to understand this is attributed to conceptual confusion. Indeed, Ryle's writings have been a refinement of the view that philosophy is the activity of removing fundamental conceptual confusions by logical and/or linguistic analysis. The source of this confusion is the propensity to construe grammatical similarities and differences as indicative of logical similarities and differences. Such a conception of philosophy is similar to that of the Cambridgeite, Ludwig Wittgenstein.

Unjustly, Ryle's philosophical argument can only be examined in the briefest summary fashion here. Essentially Ryle's discussion moves successively through various types of mental terms. In each case, he refutes what is commonsensical to most of humanity, that is, that mental events exist and that mental terms are required to refer to such events. For Ryle, mental terms do not refer to mental events but to 'dispositions to behave'. Therefore, in Ryle's analysis, mental terms become behavioural terms. Thus when we speak of mental and physical (bodily) activities, grammatical similarities mislead us into thinking that they are independent and simultaneous events - the category mistake.

Regardless of how successful one considers his attempt to eliminate the mind/body problem as a fundamental philosophical issue, The Concept of Mind is a modern classic. His effort has had important implications for the distinction between the categories of voluntary and involuntary responses.

Ryle's opinions notwithstanding, psychological behaviourism has received its fullest expression in the experimental psychology of learning in the 20th century. Furthermore, the theories which have been developed to account for learning are almost universally associationistic in nature. The two great laboratory procedures - classical and instrumental conditioning - used to study learning experimentally, are explicitly associationistic. This being the case, it is felt that a discussion of associationism would be in place at this time.

Associationism

Associationism is one of the most ancient and important doctrines still extant in psychology today. Aristotle, in developing his theory of knowledge, used it to explain how memories were formed and related. His formulation of this doctrine embodied features which are now looked upon as the three Primary Laws of Associationism (Hernstein, and Boring, 1965). For Aristotle, events which coexisted - occurred together or almost together in space and/or time - become 'connected' or associated in the mind. Such events were said to be contiguous and the principle of contiguity was the more important element of Aristotle's associationism. Of those events which are contiguous, the ones which were similar were more easily and reliably connected. Similarly, the connection between events was enhanced if the events were in contrast to one another. Moreover, if contiguous events are repeatedly contiguous, the bond between them is strengthened by the process of repetition (Rachlin, H., 1976).

Associationism became the vehicle by which experience seemingly produced orderly change. Later, in the eighteenth century, it became closely tied to empiricism, in that each emphasized sensory experience as the basis of knowledge acquisition. In psychology, associationism became a potent explanatory concept in the attempts to understand the phenomena of learning. This paralleled its role in philosophy for it was used with great utility by the British Empricists in their attack, led by John Locke, on the Cartesian concept of innate ideas.

Howard Warren (1967) has written the most comprehensive history of the doctrine of Associationism in psychology and the following summary draws on his account.

Locke, along with Thomas Hobbes who preceded him, and Hume, who followed, were classified as 'precursors' by Warren because they used 'association psychology' to further their epistemological concerns. Locke used the principles of associationism to explain how ideas were acquired through experience. David Hume extended associationism to include the fundamental concept of causality, the perception of which, for him, was based upon observation and experience. However, it was With David Hartley that associationism assumed "the role of psychological doctrine and school in Great Britain" (Warren, H.C., 1967, p.15). It was Hartley who attempted to apply the principles of Newtonian mechanics in a comprehensive manner to the physiology of the nervous system. With great impetus from Locke, Hume and Hartley among others, associationism received its fullest expression in the 19th century.

Early in the century (1820) Thomas Brown (1778-1820) published his secondary laws of association. However he preferred the word 'suggestion' to association; a term which he had borrowed from Hobbes. For him, mental phenomena were not united by association but were linked in a successive fashion. Thus, one idea suggested another successively (Warren, 1967).

Brown accepted the principles of contiguity, similarity and contrast, as the Primary Laws of Associationism, and further postulated nine secondary laws which he thought could affect the development of associations. Brown's propositions are now recognised as the most complete expression of a doctrine of associationism. For this reason his secondary laws of association - or suggestion - are presented in their entirety. The list was derived from the original sources by Howard Warren (1967). Brown's secondary laws were modifying conditions of the primary ones and purported to explain why one association was formed instead of another. They are as follows:

"1. The relative duration of the original sensations: "The longer we dwell on objects, the more fully do we rely on our future remembrance of them."

2. Their relative liveliness: "The parts of a train appear to be more closely and firmly associated as the original feelings have been more lively."

3. Relative frequency: "The parts of any train are more readily suggested in proportion as they have been more frequently renewed."

4. Relative recency: "Events which happened a few hours before are remembered when there is a total forgetfulness of what happened a few days before."

5. Their coexistence in the past with fewer alternative associates: "The song which we have never heard but from on person can scarcely be heard again by us without recalling that person to our memory."

6. Constitutional differences between individuals modify the primary laws: They give "greater proportional vigor to one set of tendencies of suggestion than to another."

7. Variations in the same individual, "according to the varying emotion of the hour."

8. "Temporary diversities of state," as in intoxication, delirium, or ill-health."

9. Prior habits of life and thought - the influence of inground tendencies upon any given situation, however new or irrelevant the experience may be. "

(Warren, 1967, p.73)

Brown's views were not significantly improved upon by those who followed him, therefore his position is viewed as one of classical associationism. Importantly, his views were pursued, in general outline, by the Mills. They, like Brown, did not perceive, or did not emphasize, links between physiology and psychology, as Hartly had done.

The Mills represent a pair of distinguished intellects who produced extensive writings on a variety of topics. Their works are characterized by exceptional logical rigour which fall into the pre-scientific period of psychology. Although their relationship was father-son, there was a sharp contrast between them concerning the doctrine of associationism.

James Mill (1773-1836), the elder, held that complex ideas were groups of simpler ideas held together in a mechanistic fashion by the adhesive qualities of association. Complex ideas were compounds of simple ideas, but the whole did not exceed the sum of its parts. In contrast, John Stuart Mill (1806-1873) proposed a 'mental chemistry' in which simple ideas came together to form new 'compounds' or complex ideas. Therefore complex ideas were transformations of simple ideas. In other words, in his view, the whole exceeded the sum of its parts and complex ideas were new entities. Of further importance was J.S. Mill's recognition of the significance of attention in the acquisition of voluntary movement (Warren, 1967). This argument would be sharpened into the important problem of discrimination by Bain.

Alexander Bain (1818-1903) was not only an associationist, but a strong empiricist as well. He was deeply influenced by the Mills, but did not blindly follow them. Unlike them, he abandoned introspection and insisted that psychology should be a science based on observation and experimentation, i.e. an empirical science. Bain, like Hartley before him, emphasized the role of the nervous system in mental phenomena (Herrnstein and Boring, 1965). However, despite his clear recognition of the importance of nervous system physiology, he took the position of psychological parallelism. Bain's version of this position resembles what is now called 'double aspect' theory. In this, the mental and the physical are "as individual twins" and thus "we have always a two-sided course" (Herrnstein and Boring, 1965, p.544). This 'course' can be viewed as mind or matter and can be studied subjectively or objectively, respectively.

Bain was a pivotal, albeit transitional, figure in psychology and his influence is often underrated. For example, his Mental and Moral Science (1868) was a highly regarded textbook for almost half a century in Great Britain. Nor was Bain ignored in America, for he anticipated by several decades Thorndike's Law of Effect as well as trial and error learning. In general, his effort was an attempt to integrate physiology and psychology with special attention given to sensory physiology (Esper, 1964).

Further, he extended the principles of associationism to new problems of psychology, such as movement, habit and will. He went on to question how the sensations that are associated, reach the status of "sensation" in the first place, as all sensations are not remembered or associated. Therefore, to explain the selection of those features of the environment that became associated, Bain raised the problem of discrimination for the first time (Kimmel, H.D., 1976).

Bain's thought reflected the dominant features of the then current psychological climate of opinion. It was associationistic and empirical and leant towards parallelism of mental and physical events. Furthermore he was interested in behaviour and emphasized the role of movement in learning. His advocacy of sensation giving rise to movement allowed associationism to become very influential in the development of physiological study of the nervous system, for it linked stimulus and response. This is especially so concerning the "reflex arc" which was being used to explain more and more behaviour until ultimately, with Sechenov, all behaviour was viewed as 'reflexes' including thought. This added energy to the trend of thought that considered the physiology of reflexes (especially modifiable reflexes) and the psychology of learning as one topic of research.

Contemporaneously with Bain, Herbert Spencer (1820-1903) introduced his "synthetic philosophy". By this, he introduced evolutionary thought into psychology. In this philosophy, psychology was subsumed under the science of biology, thus giving it the status of a natrual science. He further maintained that those who would be psychologists should give special attention to the structure and function of the nervous system (Warren, 1967).

Spencer's physiological approach to psychology was influenced by three great streams of thought; (i) the theory of evolution, (ii) the concepts of differentiation and integration which were developed in embryology; and (iii) associationism, particularly the principles of contiguity, similarity and repetition. He wove these ideas into an evolutionary fabric which he thought could cover all states of being, both mental and physical.

For Spencer, the process by which various parts of a complex organism interacted in a harmonious manner to enhance the organism's adaptability to the environment, (i.e. integration), was the very essence of evolution. His 'evolutionary associationism' was the vehicle he employed for propagating acceptance of the Lamarckian idea of the inheritance of acquired characteristics. Using the principle of repetition, Spencer claimed that ontological experiences could achieve phylogenetic dimensions. In other words, what would be a learned response in an organism of one generation could become an instinct in another, descendent, organism.

Despite such a view, Spencer was known as 'our philosopher' by the Darwinian camp. Moreover, he helped to legitimise the study of animal behaviour in which he emphasized the adaptive qualities, both mental and physical, or the organism and its relationship with the environment (Schultz, 1969; Boring, 1950).

Mainly through the influence of Spencer and Bain, associationistic views entered psychology from its very birth. With the recognition of the problem of learning and the expansion of experimentation, two procedures developed that have dominated such inquiry to the present day. These are, of course, instrumental and classical conditioning. The former emerged in America through the work of E.L. Thorndike, and the latter was developed by I.P. Pavlov in Russia.

Classical Conditioning: I.P. Pavlov

Classical, respondent or Pavlovian conditioning was developed by Ivan Petrovich Pavlov (1849-1936) as an outgrowth of an observation in his laboratory during his work on digestion. Pavlov, for his efforts in digestion, became the first physiologist and the first Russian to receive the Nobel Prize (1904). The award-winning studies were summarized in his The Work of the Digestive Glands (1897) and were essentially a demonstration of 'unconditioned reflexes'. Thus Pavlov was well placed for the pursuit of research regarding the relationship of the activity of the autonomic nervous system (A.N.S.) and the various behaviours exhibited by the internal (visceral) organs. During his career Pavlov and his associates studied every organ innervated by the A.N.S. Pavlov himself studied the cardiovascular system before turning his attention to digestion (Schultz, 1969).

Moreover, concerning his techniques, he preferred the chronic experiment to the acute one. In the latter, the animal is anaesthetized, the organ of interest removed and quickly studied with the experiment ending with the death of the animal. Chronic experiments require the animal to be kept alive and as healthy as possible, not anaesthetized and available for repeated and careful observation. This type of experiment was advantageous while studying Claude Bernard's "milieu interne". Pavlov embraced Bernard's assertion that an internal equilibrium was necessary for the existence of organisms and his digestive studies convinced him that the unconditioned reflexes which he observed were the mechanism by which the equilibrium could be maintainted.

His concept of the 'reflex' was derived directly from Descartes in which stimulation was 'reflected' as a response. Thus external or internal 'agents' excite nervous receptors which pass the excitation to the central nervous system via nerve fibres where established nervous connections transmit it to nerve fibres of the working organ "... where it is transformed into a special activity of the cells of this organ." (Pavlov, I.P., 1955, p.179). For Pavlov the reflex was a purely mechanical process which ensured an organism could adapt to and be in equilibrium with its environment. Hence:

> "The more complex the organisms, the more delicate and manifold are its elements of equilibration. The analysers and the mechanisms of constant as well as of temporary connections, serve for this purpose, they establish the most precise relations between the smallest elements of the environment and the finest reactions of the animal organism. In this way then is all life, from that of the simplest to the most complex organism, including man, a long series of more and more complicated equilibrations with the outer world".
>
> (Pavlov, I.P., 1927, p.129)

Pavlov accounted for all the behaviour of an organism in terms of unconditioned and conditioned responses. He viewed the unconditioned response as an evolutionary adaptation to the normal environment, whereas responses considered 'conditioned' were looked upon as 'associational adaptations' to the idiosyncratic features of a particular organism's unique environment (Pavlov, I.P., 1957).

Of greater importance, Pavlov came to recognize the significance of 'psychic secretions' to digestion. These secretions appeared not only in response to food but also to environmental effects contiguous with the presentation of food. For example, secretions could appear at the sight or sound (footsteps) of a laboratory assistant who regularly delivered food to the animal.. (Pavlov, 1955). Furthermore after having been impressed with this observation, Pavlov went on to develop a procedure that gave him and his associates fruitful results. Pavlov already had a large data base, concerning the relationship between 'unconditioned stimuli' and 'unconditioned responses', from his previous work on digestion. Thus, the key elements of a Pavlovian conditioning experiment are as follows:

1) The unconditioned stimulus (UCS) has the ability to elicit a response which is chosen for investigation. In other words, the response follows the UCS in a very reliable manner.
2) The unconditioned response (UCR) is the response which is elicited by the UCS.
3) The conditioned stimulus (CS) is a stimulus which initially does not elicit the UCR.
4) The conditioned response (CR) is the response elicited by the CS after repeated pairings (associations) with the UCS.

The term 'conditioning' is used to denote the process by which the CS acquires the ability to elicit the CR. Plainly the Pavlovian procedure incorporates two principles of associationistic thought (i) the CS and the UCS must occur in temporal contiguity, and (ii) this must be done repeatedly. The characteristics of the unconditioned response were permanence and stability, presumably derived from its innateness. Conditioned responses are temporary and unstable compared with unconditioned responses. Further the UCS is usually produced by direct stimulation (touching, taste) whereas the CS usually activates distance receptors (sight, hearing, smell).

Pavlov viewed the nervous system as functioning under the influence of so-called 'waves' of excitation and inhibition, much as did Sechenov. When Pavlov studied conditioned responses he perceived it as a study of higher nervous system functions and as a distinctly physiological enterprise. For him "one of the functional laws of the entire central nervous system" was that "both the excitatory and inhibitory processes arising in the cerebral hemispheres, first spread over them or irradiate and then concentrate in the point of origin ..." (Pavlov, I.P., 1957, p.255).

In addition to the processes of excitation and inhibition, the cerebral hemispheres contained mechanisms called analysers. An analyser was a neural apparatus, the purpose of which was to:

> "... decompose the complexity of the external workd into separate elements; for example, the eye analyser consists of the peripheral part - the retina, of the optic nerve and, finally, of the cerebral cells in which this nerve ends. The union of all these into a single mechanism ... is called (an) analyser".

Moreover,

> "... in addition to the above-mentioned analysers relating to the external world, the existence of special analysers in the cerebral hemispheres must be recognized, whose function is to decompose the enormous complexity of the internal phenomena arising within the organism itself."

(Pavlov 1955, p.292)

Although these 'cortical analysers' were perceived to have discrete locations within the central nervous system, Pavlov maintained that there was considerable overlap among them - a feature which would apparently facilitate the formation of temporary connections between them.

Pavlov used the idea of temporary connections between cortical analysers and the concept of irradiating excitation and inhibition to describe the process by which a conditioned response is established. The details of his theory need not concern us here. However, his speculation as to 'what is learned?' is of importance for it formed one of the two camps into which later learning theorists would fall.

Therefore Pavlov advocated the stimulus substitution position. In other words, Pavlov thought that the CS became an adequate substitute for the UCS, given a sufficient number of pairings. One stimulus was substituted for another. Of course, this is not true in the strict sense, that is, the animal would not try to eat the CS as it would the

UCS, but in a restricted sense a large body of literature supports this position. In the restricted sense the occurence of the CS signals or predicts the occurence of the UCS. The 'signalling' interpretation arose in part from experimental evidence indicating that 'conditioning' required fewer pairings of the CS and UCS if the CS slightly preceded the UCS. Pavlov saw in the CS

> "... a most perfect mechanism of adaptation ... for maintaining an equilibrium with the surrounding medium."
>
> (Pavlov 1927, p.87).

Pavlov did not classify behaviours into voluntary and involuntary categories nor did he associate 'voluntary' with acquired (conditioned) responses and 'involuntary' with innate (unconditioned) responses. When he addressed 'voluntary movement' he always preceded the term with the words 'so-called' and considered such movement a conditioned process. For example, in his lecture on the "Physiology of the Higher Nervous Activity", he tells us that:

> "Another ordinary phenomenon, reproduced by us also in the laboratory, is the temporary connection established between various external stimuli and passive movements which in response to certain signals evokes definite active movements of the animal. However, it is still not clear whether the connection between the kinesthetic stimulus and the corresponding motor action is of an unconditioned or of a conditioned character. Beyond this extreme point the entire mechanism of volitional movement is a conditioned associative process ..."
>
> (Pavlov, 1955, p.281).

Further in "Physiological Mechanism of the So-Called Voluntary Movements" Pavlov's primary assertation was that 'kinesthetic cells' form connections with other cortical cells which represent both internal and external processes. In this he cited Krasnogorsky's experiment, suggesting that passive movements of the limbs could be used as signals to indidate impending food.

He also cited Miller and Konorski as producing conditioned inhibition of "unconditioned negative reflexes", i.e. prevention of "a painful stimulation of the ear" or "the introduction of acids" into the mouth (Pavlov, 1957, p.306). Therefore if the dog lifted its leg it could either prevent a noxious event or receive food, depending upon the training. This type of training has been called response-contingent reinforcement and was a departure from the traditional Pavlovian procedure of presenting a stimulus and then measuring a response. Conversely, in the response contingent procedure, the response could influence stimulus conditions.

Konorski and Miller were Poles working in Pavlov's laboratory and their experiments were not published in English until about a decade after their initiation. In their paper "On Two Types of Conditioned Reflex" (1937) they presented a procedure, very similar to that which Skinner would call operant conditioning. However, they argued the Pavlovian stimulus substitution theory to explain their experimental results and considered the phenomenon a special case of Pavlovian conditioning. Thus they called their new conditioned reflex Type II to distinguish it from the more traditional conditioned reflex, i.e. Type I.

Methodology and terminology aside, for us the most important assertion came at the end of their presentation. They state:

> "... the conditioned reflex of the new type (our Type II) is confined exclusively to striped muscles, while the classical type has no restrictions laid on effectors and includes among them, besides striped muscles, smooth muscles and glands."
>
> (Konorski, J. & Miller, S., 1937, p.271).

Therefore Konorski and Miller conceived that their response contingent procedure could modify only the skeletal musculature while no restrictions were placed on the traditional Pavlovian procedure. This distinguished their view from that of Skinner, who <u>did</u> place restrictions on the Pavlovian procedure when he developed his own technique.

Importantly, the suggestion that the Pavlovian school interpreted the experimental results of Konorski and Miller's procedure as a special case of classical conditioning and thus asserting the primacy of contiguity over reward has recently been challenged. Herb Kimmel, drawing on L.A. Orbeli's <u>Pavlovskie sredy</u> (Pavlovian Wednesdays) (1949), has asserted that Pavlov recognized the Konorski and Miller procedure as a 'new' type of conditioning which could possibly be "the basis of voluntary behaviour in higher animals" (Kimmel, H.D., 1976, p.555). For example, Pavlov is quoted as saying:

> "If the dog wanted to eat, it performed the movement that preceded the reinforcement."

and that:

> "we can see the entire mechanism of voluntary movement in this, ... the voluntary activity of the animal."
>
> (Kimmel, 1976, p.555).

Kimmel is presently translating into English the text of the Pavlovian Wednesday meetings which have previously appeared in a very truncated form in Pavlov's <u>Selected Works</u> (1955). Such a translation could have important ramifications for the interpretation of Pavlov's theoretical position, with the suggestion that he could have been much closer to Skinner's position than previously appreciated. There is no doubt that Pavlov was impressed by Konorski and Miller's experiments and thought that their results could be assimilated into his theoretical framework.

The behaviours manipulated by these procedures, as with all behaviour, were considered by Pavlov to be overt manifestations of interconnections between cortical cells. Thus he stated:

> "It is this that constitutes the physiological basis of the so-called voluntariness of movements, i.e. of their dependence on the aggregate activity of the cortex."
>
> (Pavlov, 1957, p.308).

Be this as it may, given its importance in the experimental study of learning, a few clarifying statements are perhaps in order concerning the Pavlovian conditioning procedure.

(i) Certain responses of organisms follow, in a very reliable manner, certain antecedent stimuli. Such responses are said to be elicited. Elicited responses occur in an unconditional fashion; they are unconditioned. For example food in the mouth elicits salivation. Salivation is an unconditioned response, provided that the animal is hungry.

(ii) Some stimuli do not usually elicit responses but can acquire the ability to do so if paired with a stimulus which has the 'unconditioned' ability to do so.

(iii) Pavlov always stressed that the associationistic principle of contiguity was a necessary and sufficient condition for a previous ineffective stimulus to acquire the ability to elicit a response.

(iv) An important feature of the Pavlovian conditioning procedure was that the response always followed the presentation of the stimulus.

For Pavlov conditioned or acquired responses were derived from pre-existing, unconditioned, innate responses. Conceptually the organism was a passive element in the conditioning process. The conditioning process was automatic and proceded in a mechanical fashion. The behaviour of Pavlov's organisms was governed by the temporal contiguity of environmental stimuli. Such features in his thought brought him in close affinity with the British Empiricists. However, instead of 'ideas', 'stimuli' were associated. Moreover the works of Cajal and Sherrington had given neurones, within the CNS, experimental foundation. Therefore the association of 'ideas' or 'stimuli', via interconnections, was given an anatomical and physiological parallel by the interconnections of nerves within the central nervous system. Further his emphasis on the interpretation of unconditioned and conditioned responses as processes for adapting to the internal and external environments indicated the widening influence of evolutionary theory; a feature that would emerge in the psychological behaviourism that developed in America. Lastly we have with the Pavlovian conditioning procedure a technique which was used to study both the physiology of the nervous system and the psychology of learning.

Throughout his scientific career, Pavlov did not deviate from the basic teachings of Sechenov. Thus his assertion that conditioned responses are ultimately based on unconditional responses leads to the conclusion that <u>all</u> behaviour is, in the final analysis, involuntary. Although he did not deny the existence of 'the mind', he was adamant on the point that mental events were firmly rooted in physical processes within the central nervous system. Indeed Pavlov saved his most scathing criticism for those who would disagree with him on this position. A major example of this was his dispute with Sherrington;

both Pavlov and Sherrington agreed that the reflexes exhibited by the nervous system were adaptive in nature. However, Sherrington's suggestion that mental events could be independent of physical (brain) events stunned him.

Pavlov's response to Sherrington's dualistic position reveals a great deal about his world view. Concerning Sherrington's assertions he stated

> "... this is not a matter of some kind of misunderstanding, thoughtlessness or misjudgement. I simply suppose that he is ill, although he is only seventy years old, that these are distinct symptoms of old age, of senility".
>
> (Pavlov, 1955, pp.564-565).

Moreover he accused Sherrington of building "... a nest of animism" within English physiology. (Animism was A.E. Stahl's theory that the soul was the vital principle of life and mind). With derision Pavlov compared Sherrington's suggestions with those of Emile du Bois Raymond's "ignorabimus". Thus we see a Pavlov who was violently anti-vitalistic and strongly materialistic and mechanistic.

At the risk of over-quoting Pavlov, but at the same time adding depth to his personality, we shall let the great man speak for himself:

> "About myself I shall add the following. At the beginning of our work and for a long time afterwards we felt the compulsion of habit in explaining our subject by psychological interpretations. Every time the objective investigation met an obstacle, or when it was halted by the complexity of the problem, there arose quite naturally misgivings as to the correctness of our new method. Gradually with the progress of our research these doubts appeared more rarely, and now I am deeply and irrevocably convinced that along this path will be found the final triumph of the human mind over its uttermost and supreme problem - the knowledge of the mechanism and laws of human nature. Only thus may come a full, true and permanent happiness. Let the mind rise from victory to victory over surrounding nature, let it conquer for human life and activity not only the surface of the earth, but all that lies between the depth of the seas

> and the outer limits of the atmosphere, let it command for its service prodigious energy to flow from one part of the universe to the other, let it annihilate space for the transference of its thoughts - yet the same human creature, led by dark powers to wars and revolutions and their horrors, produces for itself incalculable material losses and inexpressible pain and reverts to bestial conditions. Only science, exact science about human nature itself, and the most sincere approach to it by the aid of the omnipotent scientific method, will deliver man from his present gloom, and will purge him from his contemporary shame in the sphere of interhuman relations."
>
> (Pavlov, 1927, p.41)

Such was Ivan Petrovich Pavlov.

Despite the controversies surrounding the interpretation of experimental results of Classical Conditioning, Pavlov has had a very powerful impact on twentieth century psychology. His work was emphatically embraced by early American behaviourists (Watson) and has been the major rival of the 'instrumental conditioning' procedure and theories developed under Thorndike, Hull and Skinner. Moreover, his hard going materialism, and his stressing the point that brain functions must be considered to fully understand behaviour, have been an important counterbalance to the radical behaviourists who thought such functions insignificant.

American Behaviourism

The attempt to define psychology as the study of behaviour is universally recognised as beginning with the writings of John Broadus Watson (1878-1958). However the importance of the objective study of behaviour to psychology was not original with or unique to Watson. For example, Samelson (1981) states that E.B. Holt was teaching "red-hot behaviourism" as early as 1911. Further, William McDougall, in his Introduction to Social Psychology (1908) recognised such study as important, as did W.B. Pillsbury's Elements of Psychology (1911). In the main, they argued that psychology could benefit from the objective study of animal behaviour.

What made Watson's psychological behaviourism distinctive was that he wanted psychology to be only a study of behaviour. In Watsonian behaviourism, all mentalistic terms were to be abolished and introspection as a method of obtaining data was rejected.

John Watson

Always interested in animal behaviour, Watson was a student of James Rowland Angell at the University of Chicago, where he received his Ph.D. in 1903. Therefore Watson was educated in the 'functionalist' school of psychology which dominated Chicago from the mid-1890s to about 1920. This 'school' was a loose collection of learning theorists who emphasized evolutionary theory in the explanation of behaviour and believed that 'mind' could be a useful concept for understanding human behings. A major exponent of functional psychology was John Dewey. His famous paper on the 'reflex arc' (1896) denied the mechanistic, dualistic stimulus-response principle and asserted that organisms were active, not passive, perceivers of stimuli. Thus, for Dewey, behaviour was continuous, and could not be divided discretely into stimuli and responses, but each aspect was blended into the other (Dewey,J., 1896). Interestingly, Watson maintained that he never understood anything Dewey said.

Besides being taught functionalistic psychology, Watson was also exposed to the strong mechanistic physiology of Jacques Loeb. Loeb, famous for his description of tropism in plants and very simple animals, expanded his interest to the comparative study of brain physiology (Rachlin, H., 1976).

He thought that all animal behaviour could and should be explained mechanistically. He had studied under Goltz, as had Sherrington, and compared the tropisms of plants to the reflexes of animals and thought that,

> "It is essential only that there be a protoplasmic bridge between the irritable tissue and the responding mechanism. No specific qualities in the central nervous system are necessary."
>
> (Fearing, 1964, p.280).

This is of great importance in view of the fact that Watson was later to deny that all mental phenomena such as mind and thoughts and to adopt an extreme peripheral S-R position, although he admitted three basic emotions; fear, rage and love (Watson, J.B., 1930).

Watson's main goal was to establish psychology as a natural science. For him the way to do this was to define the subject-matter of psychology in such a way that it could be studied by the methods of observation and measurement. His criticism of introspective psychology was more of a direct frontal assault than a balanced and scholarly analysis. The 'imageless thought' controversy among the introspectionists gave him the opportunity to strike (Angell, J.R., 1911, Woodworth, R.S., 1915).

He proclaimed:

> "Today the behaviorist can safely throw out a real challenge to the subjective psychologist - show us that you have a possible method, indeed that you have a legitimate subject-matter".
>
> (Watson, J. B., 1924, p.17).

When the disarray of the introspective camp was contrasted with the advances being made in the study of animal behaviour, through the impetus of evolutionary theory, Watson's way seemed clear. Psychology would adopt the subject-matter and techniques that were successful in the study of animals. Therefore the behaviourist's "... sole object is to gather facts about behavior - verify his data - subject them both to logic and mathematics (the tools of every scientist)." (Watson, 1924 p.7).

Watson defined behaviour as what the subject was doing. His definition was broad enough to include speech as a datum for it was something that certain animals could do (Watson, 1924). Moreover, in Watson's view, what animals did was to form habits - a concept he had learned under Angell and one which also received support from William James. At first he thought that habits were established by the associationistic principle of recency and frequency. Therefore the response which occurred immediately after a stimulus would form a bond with that stimulus (recency) and the durability of this bond depended on the number of times this event occurred (frequency) (Watson, J.B., 1930). Later after being exposed to the writings of Bekhterev and Pavlov he assimilated the Pavlovian conditioned reflex into his own theory of habit formation (Watson, J.B., 1916).

Thus:

> "The relationship, theoretically, between the simplest cases of the conditioned responses ... and the more complicated, integrated, spaced and timed habit responses we are considering seems to me to be quite simple. It is the relationship, apparently of part

> to whole, that is, the conditioned reflex is the unit out of which the whole habit is formed. In other words, when a complicated habit is completely analysed, each unit of the habit is a conditioned reflex."
>
> (Watson, 1930, p.207).

Hence Watson greatly facilitated the establishment of Pavlovian concepts and techniques in behaviouristic psychology.

Given Watson's obvious importance in the formulation of behaviourism how may we characterise his doctrine? First, it was materialistic, for example he conceived of thought as being sub-vocal speech. Secondly, it was mechanistic, e.g. habits were analogous to conditioned responses and formed in the same intrinsic fashion. Thirdly, it was associationistic, that is at first Watson used the principles of frequency and recency and later that of contiguity. Fourthly, it was extremely peripheralistic, i.e. observable stimuli were linked with observable responses. He considered the characteristics of the central nervous system to be of little or no importance. He was quite content to consider it as a protoplasmic bridge as did Loeb, or as a tabula rasa as did the British Empiricists.

Therefore the historical tendency to categorize behaviour as voluntary and involuntary did not arise. Indeed, given the major thrust of Watson's position, i.e. to model psychology on physics, such a distinction was precluded. Hence his psychological program was very close to the philosophical assertions of the logical positivists, especially Rudolf Carnap.

When Watson proposed that the exclusive scientific data of psychology was behaviour and movements, he was in marked contrast to previous psychological opinion. For example, Buchner had asserted that:

> "The prime condition of psychological study is not to be found in the presentation of mere movements to one's senses".
>
> (Buchner, E.F., 1900, p.502).

According to Buchner the proper subject matter of psychology concerned facts about consciousness with volition being at the very core of any enquiry. Thus he echoed the perception of psychology advanced by James Ward, among others. Regardless of the differences of opinion, Buchner pointed out a conceptual subtlety often overlooked by behaviourists particularly of the radical persuasion. He cogently illustrated that if peripherally stimulated movements were described as 'non-voluntary' then such a characterization necessarily implied the concept of volition (Buchner, E.F. 1900). Despite this tacit vitalistic motion within their conceptual framework, behaviourists increasingly perceived that their explanation of behaviour was mechanistic in nature.

Few of the behaviourists that followed Watson agree with all the points of his extreme position. However, those that were his most immediate contemporaries tended to hold more in common with his bold propositions than did the later followers. Interestingly, one of his most ardent critics and strong supporters was his famous student Karl Lashley.

Karl Lashley

Lashley, unlike his mentor, took a great interest in the mechanisms of the central nervous system and made many distinguished contributions to the field of neurophysiology. His Brain Mechanisms and Intelligence (1929) has long been recognised as a major contribution to the neurophysiological literature and it was begun in order to verify the Watsonian program. For example, Lashley tells us that:

> "I began the study of cerebral function with a definite bias towards such an interpretation of the learning problem. The original program of

> research looked toward the tracing of conditioned-reflex arcs through the cortex, as the spinal paths of simple reflexes seemed to have been traced through the cord."

But he continued with

> "The experimental findings have never fitted into such a scheme."
>
> (Lashley, K.S., 1929, p.14).

Lashley proposed that learning was a function of the total mass of cortical tissue available in any given species. This was his principle of 'mass action'. Another important principle was that of 'equipotentiality' which states that as far as the capacity for learning is concerned, one part of the cerebral cortex is, potentially at least, the same as any other part. Not surprisingly Lashley attacked those psychological positions that proposed theories of simple connections between stimuli and responses, while either ignoring or considering as insignificant the role of the central nervous system in behaviour. Although many behaviourists failed to recognize it at the time, Lashley's rigorous experimental studies of the central nervous system established a firm trend that would create a close collaboration between psychology and neurophysiology in the effort to account for behaviour.

Despite the fact that he thought that "random activity, association, and retention constitute only a small part of the totality of processes underlying the formation of such habit ..." (Lashley, 1929, p.15), he nonetheless held firm to the materialistic features of Watson's position. For example he gave a long defence of behaviourism's ability to account for mental concepts such as consciousness. Lashley asserted that consciousness of all behaviour could be describable in terms of physicochemical processes. He conceived of consciousness as being:

> "... a complex integration and succession of bodily activities which are closely related to or involve the verbal and gestural mechanisms ..."
>
> (Lashley, K.S., 1923, p.341).

He repeatedly attacked the method of introspection and vitalistic notions in general. His chief lament for the behaviourist was "the lack of an adequate physiology upon which to base his science" (Lashley, K.S., 1922, p.351). Another who held equally strong anti-vitalistic views was E.R. Guthrie.

Edwin Guthrie

Guthrie is more important than Lashley from the point of view of learning theory but he was nonetheless close to him in spirit. This can be seen in the introduction to his The Psychology of Learning (1935) in which he states:

> "... the theological or mythological notion of mind as a substance, as a mysterious hidden cause of action, we may dismiss at once. Our interest is scientific, and we are dealing only with observable features of the world about us. Mind must be for us a mode of behavior, namely, that behavior which changes with use or practice - behavior, in other words, that exhibits learning".
>
> (Guthrie, E.R., 1935, p.3).

Edwin Guthrie began his university career by studying philosophy. He was exposed to E.A. Single's paper on "Mind as an Observable Object" in 1910, which suggested that the difficulties encountered in studying 'mind' may be solved by the study of behaviour. When he became persuaded of the efficacy of the experimental method in studying the nature of 'man', he turned to psychology (Guthrie, E.R., 1959). Like Watson, Guthrie avoided physiological speculation and made 'conditioning' virtually synonymous with 'learning', as well as strongly emphasizing environmental events in modifying behaviour. Moreover, he was perhaps the strongest advocate of the primacy of the principle of contiguity as a necessary and sufficient condition for learning. He maintained that "a stimulus pattern gains its full associative strength on the basis of its first pairing with a response" (Guthrie, E.R. 1942, p.30).

For Guthrie, learning or conditioning took place at the molecular level with the association of individual muscular movements and individual stimuli. The habits of Watson were the summation of these associations. Habits in turn were the basis of skilled behaviour. "A skill is not a simple habit, but a large collection of habits that achieve a certain result in many and varied circumstances." (Guthrie, E.R., 1942, p.59). Therefore the descriptions of muscular behaviour made by reinforcement theorists such as Thorndike, Hull and Skinner could not, in his view, be analysed by his basic law of learning, contiguity.

Guthrie's focus on individual muscular movement led him to conjecture about movement-produced stimuli. This important concept was not an original of his but he gave it such great prominence that it is often associated with his name. Today it is usually termed 'kinesthetic feedback' and is a major feature of the cybernetic models of motor control that are appearing in contemporary psychology.

In Guthrie's day, the concept of movement-produced stimuli did not carry the term 'feedback', but the term 'sensation' and 'kinesthetic sensation' were crucial to theories of the will. For example kinesthetic sensation was a key element in William James' ideo-motor theory of voluntary movement. The concept was also decisive for Raymond Wheeler in his paper "Theories of the Will and Kinesthetic Sensations" (1920). In this paper, Wheeler reviewed the theories of the will in the history of psychology, which he perceived to fall into three broad categories:

(i) Those theories which characterized the will as desire

(ii) Those which saw it as a source and cause of action

(iii) Those which brought the will into close relations with feelings. He dismissed the previous theories in favour of an "objective or behavioristic attack". In his perception, the objective position was to be based on the ideo-motor principle and the concept of the reflex-arc. Wheeler ended his presentation with the strong statement that "The unique mental process, we believe, is nothing more than kinesthetic sensation" (Wheeler, R.H., 1920, p.359). It is important to point out that Guthrie's 'muscle-produced stimuli' complicated the S-R criterion of a stimulus, by viewing the response as a stimulus and the stimulus as a response.

Guthrie seemed to have a concept of action similar to William James' ideo-motor theory (discussed in Chapter 4). Both drew heavily on what is now called kinesthetic feedback for their conceptual formulations. Thus Guthrie maintained "Thoughts born in action, paradoxical as that may seem to those who notice how often action depends on thought; but it is possible to doubt, as I do, that we can report any thoughts which are not embodied in movement" (Guthrie, 1935, p.25). In addition, in the same passage he asserted a clear mechanistic position "I am also strongly inclined to believe that the occasion of every thought as well as of every act is to be found in stimuli acting on receptors" (Guthrie, 1935, p.25).

Guthrie, in common with many behaviourists, believed behaviour was determined by environmental events and freely applied animal data to the human level. His emphasis on a single principle of learning, contiguity, confined his classification of behaviour to conditional and unconditional responses. It is not surprising that he did not feel the need to classify behaviuor into the voluntary and involuntary categories. It would be a member of the group of learning theorists who stressed the primacy of reinforcement, that would re-establish such a distinction.

Instrumental Conditioning

With the emergence of evolutionary theory the behaviour of animals became an area of rapidly expanding interest. The focus of this interest was an examination of the Darwinian hypothesis of the continuity between man and animals, in particular the thesis that there was a continuity of intelligence between species. In turn, the importance of learning in animal studies became quickly recognized and there were pioneering efforts by George Romanes and C. Lloyd Morgan in this field. However for behaviouristic psychology the decisive event was the work of E.L. Thorndike (1874-1949).

Edward Thorndike

Pavlov considered Thorndike's studies to be the first "to subject the highest nervous activities of animals to experimental analysis under various specially devised conditions" (Pavlov, 1960, p.6). Thorndike offered a mechanistic theory of animal learning based upon his observations of the learned patterns exhibited by cats to escape from 'puzzle boxes'. This was his trial and error learning which he believed "stamped in" stimulus-response bonds. He rejected the idea that animals learned by reasoning or 'insight'. Instead he suggested that in a given situation animals exhibited a variety of responses and gradually successful responses were 'stamped in' while unsuccessful ones were eliminated.

Thorndike was a student of William James and accepted his biological explanation of learning. In this scheme, repetition of experience physically modified the nervous system so that actions as well as ideas and emotions became associated with one another. James, like Pavlov and the 'later' Watson, stressed on contiguity in learning. Thorndike added the important dimension of what is now called reinforcement. He thought that the consequences of behaviour were the most important feature in predicting learning, although his 'basic unit' of learning continued to be S-R bonds. These consequences were phrased in terms of satisfaction and annoyance, and became the heart of this theory of learning, the Law of Effect. This Law revolved around the idea that a response is more likely to reoccur if it immediately precedes a 'satisfying state of affairs'. Conversely, responses just prior to an 'annoying state of affairs' are more likely not to be repeated (Thorndike, E.L., 1913, p.2). Thus satisfiers 'stamped in' responses while annoyers 'stamped' them out. For Thorndike 'stamping' was a mechanical process and learning was defined in terms of S-R bonds.

Thorndike's terminology is easily seen as subjective even though he stated that mentalistic processes such as consciousness were not necessary for the association of stimulus and response (Thorndike, E.L., 1898). However, he did not convince his critics, and therefore has been accused of producing a 'mentalistic' theory, although this was contrary to his intentions (Schwartz, B., 1978).

Thorndike later altered his law of effect, with the role of 'annoyers' or 'punishers' as 'weakeners' of S-R bond strength being relegated to a minor role. His flexibility in adapting concepts, and his willingness to revise has kept his theory alive through much criticism. The most important point made by his critics has been the fact that the theory seemed to work backwards upon the S-R bonds. This logical impasse has not been effectively resolved even today, but suffice it to say that Thorndike's general contention that behaviour can be explained in terms of its consequences has been empirically established and widely accepted.

More importantly for us, however, is Thorndike's use of the term 'impulse'. We can see that from the very beginning of the scientific study of behaviour there was an element of mystery, of unaccountability about animal movement. Impulsive behaviour in the human being carries the conotation of being 'spontaneous' and spontaneous, possibly impulsive, behaviour is a hallmark of voluntary behaviour. This is of great conceptual importance for similar features emerged with Skinner's concept of the operant. What is important to realize is that behaviouristic psychology, which perceived itself to be most scientific and mechanistic of the psychologies and would purge all mentalistic and vitalistic concepts from its domain, carried deeply buried within its conceptual framework those self-same elements it wished to abolish.

A more detailed description of the behaviour of Thorndike's cats will emphasize this point. He noted that:

> "When put into the box, the cat would show evident signs of discomfort and of an impulse to escape from confinement. It tries to squeeze through any opening; it claws and bites at the bars of wire; it thrust its paws out through any opening and claws at everything it reaches; it continues its efforts when it strikes anything loose and shaky; it may claw at things within the box ... gradually all the other non-successful impulses will be stamped out and the particular impulse leading to the successful act will be stamped in by the resulting pleasure, until, after many trials, the cat will, when put into the box, immediately claw the button or loop in a definite way."
>
> (Thorndike, E.L., 1911, p.35).

Again, the impulse of behaviour was stressed. It was the modification of the various impulsive behaviours that impressed Thorndike. The 'impulsive behaviours' already existed in the animal's behavioural repertoire when they were put into the puzzle-box. While in this experimental situation some behaviours were observed to increase in occurrance whereas others decreased, eventually to the point of disappearance. Thorndike, like Skinner, stressed the role of environmental events in determining behaviour and therefore did not object to the incorporation into his theory of concepts from biology, such as adaptation to the environment.

In a recent important paper, Staddon and Simmelhag (1971) have suggested that Thorndike actually based his theory of learning on an evolutionary model. That is the stamped-out behaviour was the extinction of non-adaptive responses whereas the stamped-in behaviour was adaptive and thus protected from extinction by reinforcement (Staddon, J.E. and Simmelhag, V.L., 1971) A contemporary of Thorndike, Edward Tolman, had also re-interpreted Thorndike's experimental results to fit in with his own ideas of learning.

Edward Tolman

Edward Chace Tolman (1886-1959) was taught psychology by the 'red-hot' behaviourist Edwin Holt. Holt was a strong behaviourist and stressed its mechanistic and materialistic aspects. In his "Materialism and the Criteria of the Psychic" (1937) he proclaimed that:

> "... awareness is created by motor response; that these motor responses are the only genuine criterion of the psychic; and, lastly that an ultra-materialistic psychology is able to account for the epistemological categories of delusion".
>
> (Holt, E.B., 1937, p.53).

Thus Holt treated the 'psychic' much as Guthrie had treated 'thought', i.e. both were based on motor responses. However, Tolman rebelled against 'muscle twitchism' and conceived his own 'purposive behaviourism'.

Tolman's 'purposive behaviourism' was a radical departure from the materialistic orientation of Watson, Lashley, Guthrie, and his mentor Holt. His type of behaviourism was a hybrid which assimilated elements from both the behaviouristc and cognitive camps. For example, Tolman rejected the method of introspection and embraced the behaviourists' ideas about the sort of evidence on which a scientific psychology should be based. He also stressed the influence of environmental events on behaviour and used animal experimentation to develop his theoretical position. On the cognitive side he formulated his notions of learning in such terms as 'means-end-readinesses' and 'expectancies', among others.

In Tolmans' terms, Thorndike was studying docile behaviour, i.e. behaviour which was teachable and which had a goal-object. Tolman borrowed this term from Ralph Perry who had perceived a close affinity between docility and purposiveness (Perry, P.B., 1918). Tolman defined docility as a molar behaviour:

> "... which consists in the fact that, if a given behavior-act in a given environment proves relatively unsuccessful, i.e., does not get to the demanded type of good object at all, or gets there only by a relatively long distance (q.v.), it will, on subsequent occasions, tend to give way to an act or acts which will tend to get the organism to this demanded type of goal-object and will tend to get him to it by a relatively short route".
>
> (Tolman, E.C., 1932, pp.442-443).

Docile behaviour succinctly encapsulates three major points of Tolman's theoretical position. (1) Behaviourists should study molar behaviour, i.e. large segments of behaviour as distinguished from the molecular behaviour studied by Watson and Guthrie. (2) Behaviour was goal-directed or purposive. For Tolman organisms did not form passive habits composed of S-R links but generated "cognitive maps" and "sign-gestalts" of the environment. Thus organisms behaved not because of past specific stimulus-response associations but because they expected a specific outcome at a particular place. (3) Behaviour followed the principle of least effort. Tolman, in characteristic fashion, does not claim originality here but states that the principle:

> "... when applied to the study of behavior would assert that the final choices between alternative means-routes will always tend to occur in the direction of a minimum expenditure of physical energy."
>
> (Tolman, 1932, p.448).

Moreover he proposed that the concept of goal-direction or purpose could not be reduced to smaller elements. He maintained that:

> "... first and foremost, and this is a point which it is important to stress, our task as psychologists, is the collecting and ordering of the molar behavior facts per se, and this task can, in large part, be performed in relative ignorance of both physiology and neurology".
>
> (Tolman, 1932, p.116).

Thus he was clearly opposed to Clark Hull's position that molar behaviour could be deduced from or reduced to molecular behaviour, and Hull's hypothesizing about internal neurological entities.

Nevertheless, Tolman introduced the concept of the intervening variable; a concept which was very important to him for it allowed him to theorise beyond the 'raw' experimental data. However, for him, intervening variables were total abstractions; he did not conceive of them as being possible neurological mechanisms awaiting future discovery as did Hull with his hypothetical constructs. For an explanation of the distinction between the two concepts, see MacCorquodale, K., and Meehl, P.E., (1948).

Although Tolman is considered a 'cognitive theorist' he did not attribute any metaphysical, non-physical characteristics to his cognitive structures. He saw no need to distinguish between voluntary and involuntary responses. For him:

> "Organisms, human and sub-human, are biological entities immersed in environments. To these environments they must, by virtue of their physiological needs, adjust. Their 'mental processes' are functionally defined aspects determining their adjustments. For the behaviorist, all things are open and aboveboard; for him, animal psychology plays into the hands of human psychology."
>
> (Tolman, 1932, p.3).

Tolman viewed behaviour, especially learned behaviour, as adaptation by the organism to the environment. Another who shared Tolman's views in broad outline but who nevertheless classified certain behaviours along the voluntary, volitional and involuntary dimensions, was J.R. Kantor.

Jacob Kantor

Kantor represented a growing willingness of behaviouristic psychologists to expand the domain of their subject matter. He noted that:

> "... when we look upon psychological phenomena as co-ordinations of responses and stimuli the domain of psychological observation is unlimited; we may study any kind of reaction of the person whether it be simple or complex, physical, social, aesthetic or intellectual, whether it be normal or pathological."
>
> (Kantor, J.R., 1922, pp.195-196).

He rarely cited experimental evidence to support his assertions and his form of behaviourism is difficult to understand in that it had a somewhat ephemeral quality when compared to 'hard-nose' S-R behaviourism, e.g. he didn't draw a distinction between the concept of persons and that of responses (Kantor, J.R., 1923). Further, he considered all responses to have a 'psychological' as well as a neurological and physiological dimension. Be this as it may, Kantor considered the data of psychology to be made up of stimulus conditions and definite responses. Indeed he maintained that:

> "To divide an organism's action into mental and physical and to make the data of psychology into anything but responses to stimuli is not a scientific enterprise but a metaphysical one."
>
> (Kantor, 1922, p.510).

From Kantor's point of view, the organism could be human or animal. In either case the organism was perceived as a pattern of reaction systems to specific stimuli.

Kantor's concepts of adjustment stimulus, pre-current reactions and consummatory or final response bear a striking resemblance to Tolman's concepts of goal-object, intervening variable, and goal-directed behaviour respectively. However Kantor, in contrast to Tolman, used his concepts in an attempt to account for such complex behaviours as volition. His "An Objective Analysis of Volitional Behaviour" (1923) is peppered with idiosyncratic terminology and elaborate notions of volition. Nonetheless, his paper was a concerted effort to account for 'volitional' behaviour within the behaviourist conceptual framework. For Kantor behaviours could be classified as 'voluntary' or 'volitional', as 'habit' or 'reflex' depending on how close the 'adjustment stimulus' was to the 'consummatory response' and on how many 'pre-current reactions' took place between the stimulus and response. Here we shall discuss only his volitional class but for his views on reflexes and habits, as well as 'meaning' see Kantor (1922, a, b; 1921).

Kantor began his discussion of volitional behaviour by distinguishing it from voluntary behaviour. Both types of behaviour were considered as response adaptations to an 'adjustment stimulus'. The adjustment stimulus had the conceptual status of a purpose or goal and the response was an 'adjustment' to this stimulus, hence its name. Voluntary behaviour possessed (1) choice responses, (2) deliberative responses and (3) long delays of response that were not seen in volitional behaviour. In contrast volitional behaviour, once initiated, proceeded immediately to completion. Moreover:

> "... a volitional reaction is one in which some other acts besides the definitive response must be performed in order that the definitive response itself can occur..."
>
> (Kantor, J.R., 1923, p.118).

The 'other acts' were called by Kantor 'pre-current reactions'. Pre-current reactions could be attention, perceptual reaction, concepts, images, meanings, and language reactions as well as reactions of the skeletal musculature. Such reactions functioned in an integral manner to guide behaviour, directly or indirectly, to a final consummatory response. Thus, although the final response may be remote in time from the adjustment stimulus, they are nonetheless always connected by the pre-current reactions. Therefore volitional behaviour was durational but not delayed and, in essence, it was the performing of the intervening acts which gave the behaviour its 'volitional' characteristics.

Further Kantor divided volitional behaviour itself into six separate classes. The differentiating features were (1) the extent to which the adjustment stimulus changed due to a shifting stimulus situation and (2) the degree to which the pre-current reactions determined the final response. Therefore, if the adjustment stimulus was complex or remote and the number of pre-current reactions large, volitional behaviour could merge imperceptibly with voluntary behaviour.

Perhaps as an injustice to Kantor we have not gone into the details of his scheme. His articles tended to be long and involved and presented for the most part in his own terminology. As stated before, he did not adduce experimental evidence to support his arguments and therefore his mode of discussion was largely speculative. Nevertheless he is important to us in that he attempted an objective analysis of such sticky topics as meaning and volition. Further, in his confrontations with B.F. Skinner, he forced Skinner to sharpen and possibly harden his (Skinner's) own position (Verplanck, W., 1983). However before we turn to Skinner, we must first recognise Clark Hull without whom any account of behaviouristic psychology would be incomplete.

Clark Hull

Clark L. Hull (1884-1952) has been universally recognised as the grand theoretician in the experimental study of learning. In his elaborate scheme, reinforcement was considered to have primacy in learning. Contiguity, although influential, was secondary to it. Thus he preferred Thorndike as contrasted with Watson and Guthrie. But it was Hull's enthusiastic embracing of Darwinian evolutionary theory that gave his ideas their most distinctive feature. This was, of course, his concept of 'drive reduction'.

It should be stated here that Hull's conception of 'drive' and 'drive-reduction' was based largely on the 'homeostasis' of Walter Cannon. Cannon introduced the term in his classical work The Wisdom of the Body (1932) which was derived from his experimental studies concerning the role played by the sympathetic nervous system in maintaining the internal equilibrium of the body. The concept of homeostasis was a more sophisticated and experimentally verified version of Claude Bernard's milieu interieur. Stability was a key feature of Cannon's concept of homeostasis. If an organism was to survive it must maintain an internal stability or at least maintain a narrow physiological range within the internal environment. In Hull we see 'drive' conceived of as destabilizing the internal environment and as having the ability to precipitate 'drive-reducing' behaviour that would, if successful, re-stabilize the system.

Hull suggested that those who study overt molar behaviour were the Newtons and Galileos of their field. And further, that:

> "It is conceivable that the elaboration of a systematic science of behaviour at a molar level may aid in the development of an adequate neurophysiology and thus lead in the end to a truly molecular theory of behaviour firmly based on physiology."
>
> (Hull, C.L., 1943, p.20).

Thus the study of behaviour at the molar level could contribute to the knowledge of nervous system function without waiting for an exhaustive neurophysiological analysis of what he considered a remarkably 'automatic structure', i.e. the central nervous system (Hull, 1943).

Hull attempted to model this theory of learning on the discipline of physics. Thus his approach has been called hypothetico-deductive. He thought that all scientific theory, including psychological theory, consisted "of a hierarchy of logically deduced propositions which parallel all the observed empirical relationships composing a science" (Hull, 1943, p.381). Therefore, for him "science has no use for unverifiable hypotheses" (Hull, 1943, p.23). Psychology would advance if specific statements were made about the connections between stimuli and responses. From these statements other statements about behaviour would be deduced. All statements were to be supported by experimental evidence i.e. stated in terms of overt behaviour. If the statements failed to be supported by experimental evidence then they would be altered to fit that data. Thus his scheme would be self-correcting in the long run. Further, Hull attempted to produce his laws of behaviour in a strict mathematical form. In the briefest possible terms, his statements were developed in the form of intervening variables which were inferred to mediate between observed stimuli and responses, i.e. independent and dependent variables, respectively. The inferred 'intervening variables' were the core of Hull's theorising. Such variables were called 'hypothetical constructs' if they were thought to have neurological foundations (Hull,1943).

Thus Hull brought to the fore 'internal events' as important determiners of behaviour. Although internal events such as volition or thinking had no place in his grand design. He thought that:

> "It is the primary task of a molar science of behaviour to isolate the basic laws or rules according to which various combinations of stimulation, arising from the state of need on the one hand and the state of the environment on the other, bring about the kind of behaviour characteristics of different organisms."
>
> (Hull, 1943, p.19).

Likewise he maintained that:

> "... man's pre-eminence lies in his capacity for adaptive behaviour. Because of the seemingly unique and remarkable nature of adaptive behaviour, it has long been customary to attribute it to the action of a special agent or substance called 'mind'. "
>
> (Hull, 1937, p.1).

Hull always conceived of behaviour as being mechanistic in character and his emphasis was so strong that he has been compared with that early 'mechanist', Thomas Hobbs (Peters, R.S., and Tajfel, H., 1957).

Indeed Hull attempted to generate 'a mechanical model', a 'mechanical parallel' as well as 'an electro-chemical parallel' of the conditioned reflex which, for a while at least, he thought to be the 'basic unit' of behaviour (Baernstein, H.D., and Hull, C.L., 1931(a); Hull, C.L. and Baernstein, H.D., 1929; Krueger, R.G. and Hull, C.L., 1931(b)). In addition to the efforts of Hull along these lines were those of Thomas Ross.

Ross was concerned with:

> "... research which aims to endow machines with intelligence of the sort possessed by living creatures."
>
> (Ross, T., 1935, p.387).

He described one machine that could thread its way through a simple maze (Ross, T., 1933). Later he presented a design that was supposed to be 'self-conditioning'. This machine consisted of; two sets of solenoids, glass needles, moving sheets of paper and photo-electric cells. One set of solenoids moved the sheets of paper, the other set activated the needles which perforated the paper. In turn light, which passed through the holes, activated the photo-electric cells which again energized the solenoids that moved the paper. The details of Ross's and Hull's designs are not important. What is important is that not only was behaviour perceived of as having mechanical characteristics but efforts were put forth to produce non-living machines that would replicate animated behaviour.

In the behaviourist fashion, Hull did not consider volition *per se*. He stressed adaptation and mechanisms in his account of behaviour and, like Watson, Guthrie, Lashley and even Tolman, he didn't classify behaviour as 'voluntary' or 'involuntary'.

As Hull's theory developed he inserted, in part in response to the ingenious experimentation of Tolman, more and more hypothetical entities between the reception of a stimulus by an organism and the organism's final response. Indeed Peters asserts that Hull's concept of drive-reduction was based on constructs whose existence was so shadowy and whose interrelations were so obscure that it ranks as a prime example of 20th century metaphysics (Peters, R.S., 1958).

Hull's influence upon psychology has been immense. For example, Hilgard and Bower have noted that 40% of all the experimental studies published in the Journal of Comparative and Physiological Psychology and the Journal of Experimental Psychology during the decade of the 1940s "referred either to one or more of Hull's books or papers" and in the same journals 70% of the studies concerned with learning and motivation cited Hull (Hilgard, E.R., and Bower, G.H., 1966, p.189). Nonetheless Hull's grand scheme, while it attracted a large following during his lifetime, rapidly went out of fashion after his death. This permitted the strongly 'peripheralistic' behaviourism of B.F.Skinner to achieve ascendency.

Skinner published his single most important work, Behaviour of Organisms in 1938. In it one finds all the features perceived to be in behaviouristic psychology. For example, Arthur Bills set out the credo of psychology as a science circa 1938. Thus 'psychology as science' was empirical, mechanistic and quantitative: it was nomothetic (concerned with establishing general laws), analytic, and used operational concepts (Bills, A.G., 1938). These elements are found in Skinner's behaviourism. Further C.C. Pratt in a paper called "Psychological Physiology" (1938) stated that although behaviour may ultimately be explained by physiological mechanisms, psychology need not wait for a physiological explanation. He noted that when psychologists speculated in physiological concepts it usually produced "brain <u>mythology</u> rather than brain <u>physiology</u>" (Pratt, C.C., 1938, p.424). He thought that "The uniformities among psychological data are presumably what they are because of their relation to physiological determinants". Therefore psychological data are extensions of physiological data. Thus:

> "If such concepts-by-extension do not leap too far beyond the material properties upon which they are based, their scientific status can hardly be called into serious question, for they amount to little more than a restatement of the initial observations in a different terminology ..."
>
> (Pratt, 1938, p.425).

Such an attitude is also found in the psychology of Skinner.

Lastly and most importantly while the distinction of voluntary and involuntary behaviour did not arise in the writings of such behaviourists as Watson, Guthrie, Tolman and Hull, such a proclivity was seen in Kantor as well as those behaviourists mentioned in the introduction, i.e. Helen Peck and Walter Hunter. Such a proclivity would not only arise in Skinnerian behaviourism, but would become dogmatized.

<u>B.F. Skinner</u>

Burrhus Frederic Skinner (1904-) stood, in the mid 1930s, at the confluence of three important and related streams of modern thought in psychology; behaviourism, operationalism and logical positivism. Behaviourism has attempted to explain the behaviour of men and animals by theories and laws couched in terms which designate only physical things and events. Thus emulation of the physical sciences was supposed to make psychology more scientific. Operationalism was (and still is) an attempt to make scientific statements more precise by defining concepts in terms of corresponding sets of operations which are used to study them. It was set forth by Percy W. Bridgman in his <u>The Logic of</u>

Modern Physics (1927) and achieved rapid, widespread acceptance, not only in physics, but in psychology as well. The idea is to facilitate communication between scientists by the elimination of ambiguous language. Logical empiricism is also concerned with the language and logic of science.

Skinner's version of behaviourism is sometimes called neo-behaviourism to distinguish it from that of Watson, although it is just as extreme. But whereas Watson embraced Pavlovian conditioning and stressed contiguity, Skinner attested instrumental conditioning (which he called operant conditioning) and stressed reinforcement. Skinner's technique involved the exhaustive analysis of the behaviour of one organism (the rat), not a large population. His Ph.D. thesis was such a departure from the mainstream that his supervisor, the great psychological historian Edwin Boring, refused to accept it. Skinner presented it the following year, unchanged, to a committee not chaired by Boring and it was approved (Weigel, J.A., 1977).

In the 'radical' behaviourism of both Watson and Skinner inner events or happenings were passed over and attempts were made to directly relate environmental features and overt (observable) behaviour. As William Verplanck (1954) has stated, when presenting Skinner's views, "'hear', 'feel', 'try', 'need', 'in order to', and 'intention' cannot be included in the data language of a science of behavior...." (p.278). Skinner was also similar to Watson in his willingness to accept certain types of verbal reports as objective behaviour.

Throughout his career Skinner consistently avoided theorizing about inner causes of behaviour. He doesn't claim that such causes do not exist, but he has had a deep-seated faith that the ultimate cause of inner behaviour itself could, in the last analysis, be traced to environmental factors. His final goal was to develop a method by which he could analyse the influence of environmental events in the determination and prediction of behaviour (Skinner, B.F., 1938).

In his Behaviour of Organisms (1938) Skinner defines behaviour as 'the action of the organism upon the outside world' (Skinner, B.F., 1938, p.6). Thereby he focussed the attention of psychology on the study of skeletal movements, thus reducing to secondary importance 'inner' physiological processes, such as those of the viscera. However, when Skinner is pressed to account for verbal behaviour in humans he extends the notion that "it is often desirable to deal with the effect rather than with the movement itself, as in the production of sounds" (Skinner,1938, p.6).

Skinner always advocated objective scientific methodology. He stressed the external variables controlling behaviour and proposed to study them by what he called 'functional analysis'. His objective was the prediction and control of the behavioural variables. Thus the external, environmental variables were viewed as independent variables while the responses (behaviour) of the organism were the dependent variables. He maintained that the study of the relationship between the former and the latter is all that is necessary to build a comprehensive picture of organisms as behaving systems. Therefore Skinner is able to circumvent the postulations of those such as Clark Hull, involving internal mediating variables assumed to exist within the organism.

Skinner recognized the significance of Pavlov's conditioning experiments and postulated the existence of two types of learning. One was based on the procedure of Pavlov, in which the response was perceived as being 'elicited'. The other was based on his own procedure, in which the response was viewed as being spontaneously 'emitted'. The former he called Type S (respondent) conditioning and the latter Type R (operant) conditioning. Type S conditioning was seen by Skinner as the procedure which was important in the modification of the responses of smooth muscle and glands. This was the way that new stimuli elicit emotional or motivational states. However, in Skinner's opinion Type S conditioning of visceral responses was a minor feature of overall behaviour. He felt that his operant conditioning procedure and its modification of the skeletal musculature could account for almost all observed behaviour.

Indeed, Skinner was quite confident that his 'science of behaviour' could handle, not only public events but private ones as well, as he expanded the concept of behaviour to include:

> "... events taking place within the skin of the organism not as physiological mediators of behavior, but as part of behavior itself ..... (and further) ..... The skin is not that important as a boundary. Private and public events have the same kind of physical dimensions."
>
> (Skinner, 1938, p.84).

In his Science and Human Behaviour (1953), Skinner gives a more clear formulation of the status of 'inner states' within his conceptual framework. This statement also reveals a line of reasoning similar to that of C.C. Pratt:

> "The objection to inner states is not that they do not exist, but that they are not relevant in a functional analysis. We cannot account for the behaviour of any system while staying wholly inside it; eventually we must turn to forces operating upon the organism from without. Unless there is a weak spot in our causal chain so that

> the second link is not lawfully determined by the first, or the third by the second, then the first and third links must be lawfully related. If we must always go back beyond the second link for prediction and control, we may avoid many tiresome and exhausting digressions by examining the third link as a function of the first. Valid information about the second link may throw light upon this relationship but can in no way alter it."
>
> (Skinner, B.F., 1953, p.35).

For Skinner, behaviour is a function of external variables and psychology was to be the science of the prediction and control of behaviour. On this point Skinner was in agreement with Hull and Tolman. The emphasis on 'prediction and control' permitted Skinner to ignore origins of behaviour which he assumed to be somewhere in the environment. However, the major concern of Skinnerian behaviourism was not to identify environmental stimuli that would prove to be the ultimate 'cause' of behaviour. His aim was to predictably control behaviour once it occurred. He states:

> "A response which has already occurred cannot, of course, be predicted or controlled. We can only predict that similar responses will occur in the future. The unit of a predictive science is, therefore, not a response but a class of responses. The word 'operant' will be used to describe this class. The term emphasizes the fact that the behaviour operates upon the environment to generate consequences. The consequences define the properties with respect to which responses are called similar."
>
> (Skinner, 1953, 65).

Skinner was empirical in his definition of a reinforcer, for it could be anything that increased the probability of response occurrence. Once he established reinforcement as a central feature and viewed responses as spontaneously emitted, he had avoided Pavlov's problem of stimulus control. He has consistently defended his view for over 40 years and has had great confidence in the power of operant conditioning to shape behaviour much as artisans shape their works.

Skinner further used the Pavlovian literature to his advantage in his concept of 'conditioned reinforcement' which he used to account for long chains of behaviour. In doing so he appeared to make classical conditioning a special case of operant conditioning and thus relegated internal responses to secondary importance. In addition, his use of a discriminative stimulus (Sd) focused attention on the 'discriminated operant'. The former is an environmental event which functions as a signal to the organism that the probability is high that an operant will be reinforced. The latter is the operant which is reinforced.

The discriminative operant usually took the form of a 'molar' response. A molar response is one which is a much more neurophysiologically complex event than the molecular responses which may involve nothing more than a single muscular fibre. Compared to molecular responses, molar responses are large segments of motion. For example, a bar press for food in rats and playing the piano in humans. It should be pointed out that conceptually the discriminative stimulus functions only as a signal to the organism. It does not elicit the operant under study, but serves to inform the organism to emit the operant. This methodology spawned a whole support technology for the counting, graphing and analysing of molar segments of behaviour. One of the chief products of this methodology is the process of shaping. This is done by first rewarding small segments of the required behaviour and then gradually demanding larger and larger segments for reinforcement until the desired behaviour is shaped.

But what is of most importance to us is Skinner's dogmatic separation of respondent and operant behaviours. Interestingly enough, he seems to have done this as an effort to establish the study of operant behaviours as a separate important field of investigation and suggested leaving the study of respondent behaviour to the physiologist (Skinner, B.F., 1938). On this point it is felt that in 1938 when The Behaviour of Organisms was published, Skinner perceived that his most important task was to make operant conditioning the science of behaviour. Other features of his scheme appear to be subordinate to this grand effort. Thus in one paragraph Skinner progresses from "The distinction between types R and S arising from their confinement to operant and respondent behaviour respectively implies a rough topographical separation", to "It is quite possible on the existing evidence that a strict topographical separation of types following the skeletal-autonomic distinction may be made." (Skinner, 1938, p.112).

Skinner continued this 'topographical separation' in Science and Human Behaviour (Skinner, B.F., 1953). The distinction was sanctioned by Hilgard and Marquis in their Conditioning and Learning (1940) and it remained largely unchanged in Kimble's revision of this highly influential textbook in 1961.

As stated previously the operant behaviours of Skinner's rats were conceptually very similar to those impulsive behaviours of Thorndike's cats. Both classes of behaviour had to be 'emitted' before they could be controlled. Both possessed the 'spontaneous' characteristics associated with 'voluntary' behaviour. By using an operational definition to classify behaviour, Skinner dressed the 'operant' in the clothes of respectability in the sense that such a definition was intended to deal objectively with the subject of study.

When he classified behaviours as 'operants' and 'respondents', based on the procedure used to study them, Skinner was attempting a resolution of the issues surrounding the conditionability of responses and their taxonomy.

However, the way Skinner formulated his doctrines proved to be an analogue of the voluntary-involuntary dichotomy. That is, 'respondents', by definition, had specifiable antecedents, whereas 'operants' did not. Through Skinner the operant became a central feature of a psychology which perceived itself to be mechanistic, quantitative, empirical and operational. Under his influence the vitalistic connotations of the operant were retained and conceptual rigor gave way to experimental expediency.

Skinnerian behaviourism promoted the mechanistic view of man in the sense that it limited itself to observing the 'mind' non-subjectively from without, which, interestingly, is the only way in which the behaviour of a machine can be perceived and explained. Thus, to insist on a psychology restricted to the study of only overt behaviour of men and animals, makes psychology analogous to the study of machines.

CHAPTER 3

Contemporary Studies

As seen in the previous chapter, the similarities between the two major conditioning procedures are striking and there have been occasional attempts to consider one procedure to be a special case of the other. (Konorski and Miller, 1937; Skinner, 1937). The decade of the 60s witnessed an unprecedented growth in experimental data and conceptual speculations concerning the classification of responses as voluntary and involuntary on procedural grounds. Also, the discussions which developed invited a reformulation of ideas about the inter-relationships of somato-motor and visceral activities. In passing, it is interesting to note that during the previous decade the great traditional theoreticians had died; for example, Thorndike, in 1949, Clark Hull in 1952, Watson (although no longer effective) in 1958, and Guthrie and Tolman in 1959. Skinner in America was left in charge of the field and he claimed to be atheoretical. This was a period that seemed ripe for change. Therefore, for the sake of clarity it will be helpful at this point to make explicit, in general form, the attributes of the two great response categories: involuntary and voluntary, as recognized by mid-twentieth century psychology.

Involuntary responses were innate, reflexive and unconscious (or sub-conscious). Further, involuntary responses were viewed as being subserved by the ANS and were therefore closely associated with the responses of the smooth and cardiac musculature as well as the responses of both the duct and ductless glands of the body (i.e. the viscera of the body). Therefore, involuntary, autonomic responses were those which maintained the homeostasis of the body. Conscious sensation of these responses (when they were conscious at all) was vague and diffuse although there was firm neuroanatomical evidence of afferent connections between the CNS and the viscera. However, this afference appeared to be relatively meagre compared to that from the skeletal musculature. This feature, coupled with vague or non-existent visceral sensations in conscious man, as well as the profound effects of ANS efferents on the visceral organs led J.N. Langley to view the ANS as primarily, but not exclusively, a motor system (Langley, J.N., 1921).

Langley's physiological investigation of the functions of the ANS established new standards by which they were studied. He was one of a pair of distinguished physiologists, at the Cambridge School, upon whose studies the modern concepts of the ANS and its function are based. The other was Walter Holbart Gaskell, whose detailed anatomical studies of the ANS had set the stage for Langley. Interestingly, while Langley's experiments meant to him that there was a degree, possibly a large degree, of autonomic neural function that was independent of the central nervous system, Gaskell, on morphological grounds, maintained that there was only one nervous system - the 'cerebro-spinal system' (Gaskell, W.H., 1916).

Gaskell's opinion was eclipsed by that of Langley, and in the 20th century Langley's descriptive terminology of the ANS - i.e. the term 'autonomic' itself as well as 'pre and post ganglionic neurones' and the familiar 'sympathetic, parasympathetic nervous systems' - soon entered into psychology.

More recently, however, the concept that the nervous innervations of the skeletal and smooth musculatures are two peripheral manifestations of a single entity, the central nervous system, has re-emerged. This position also gives greater recognition to the numerous central representations of autonomic activities, and stresses CNS regulation of such activities (Pick, 1970).

A voluntary response was conscious, involved the skeletal musculature of the body and was subserved by the CNS. In general, the great variety of responses exhibited by the skeletal musculature were viewed as 'learned', but possibly built upon reflexes, as well as being conscious and dependent upon sensory feedback for their proper execution.

In psychology, the instrumental and classical conditioning procedures became closely associated, but not exclusively associated with the great muscle groups of the body, skeletal and smooth, respectively. These muscle groups had the terms voluntary and involuntary attached to them by physiologists and as such they were accepted into psychology. The general rule of thumb was that the classical conditioning procedure modified smooth muscular movement and the movement was 'involuntary', whereas the operant conditioning procedure modified the movement of skeletal muscles which was 'voluntary'. However, such a conceptual framework was a rule of thumb and most psychologists, when pressed on this point, would probably agree with Hilgard and Marquis (1940), by maintaining that most conditioned responses are 'semi-voluntary'. The term semi-voluntary usually meant in practice that the response topography of a given movement could be altered by instruction.

Kimble, in his 1961 revision of Hilgard and Marquis, recognised that there was not any such thing as 'pure' classical and instrumental learning experiments, and he stressed that it was most important that psychologists generate experiments to clarify the distinctions between the two procedures. This was felt necessary because all the general features present in classical conditioning are also contained in instrumental conditioning. These include discrimination, generalization, extinction and the effects of different temporal characteristics.

Since Kimble's publication this clarification has yet to materialize while there is mounting evidence of a breakdown in the procedural distinction.

This evidence comes from two areas of research; (i) autoshaping; and (ii) the demonstrations of instrumental conditioning of autonomic responses. If the evidence continues to be confirmed, then a plausible case can be presented which asserts that the traditional tendency to erect categories of behaviour, based on the method used to study it, is no longer tenable. Therefore if the separation of behaviour into voluntary and involuntary categories is to be maintained then it must be done on grounds which exclude the classical and operant conditioning procedures.

Autoshaping

Autoshaping is a phenomenon first described by Brown and Jenkins in 1968. Their experiment utilized a standard subject, a pigeon; a standard experimental environment, a "Skinner box", and a standard response, a key peck. In their experiment a key was illuminated for eight seconds within each minute. At the end of the eight second period the key-light was terminated and grain was delivered. Although the pigeon was not required to peck the key for grain delivery, if a key peck occurred the key-light was immediately terminated and grain was delivered into the hopper. The first key peck usually occurred after about forty pairings of key-light termination and grain delivery and thereafter rapidly increased in frequency. In spite of the fact that key pecks produced grain in the hopper, Brown and Jenkins maintained that because the pigeon was not required to peck the key for grain, the procedure was classical conditioning (Brown, P.L. and Jenkins, H.M., 1968).

A subsequent experiment by Williams and Williams(1969)using the auto-shaping paradigm demonstrated that keypecking could be initiated and sustained even when the key-pecking prevented the occurrence of grain delivery. This they called auto-maintenance. Their experiment was the converse of that of Brown and Jenkins. Williams and Williams presented grain immediately after the termination of an illuminated key if no key pecks had occurred during the period that the key was lit. In this procedure, any peck during CS (illuminated key) prevented the grain delivery (UCS) that was otherwise scheduled to occur after CS termination. Despite these negative consequences pigeons continued to peck the illuminated key on a large number of trials (up to 2,000) (Williams, D.R., and Williams, H., 1969).

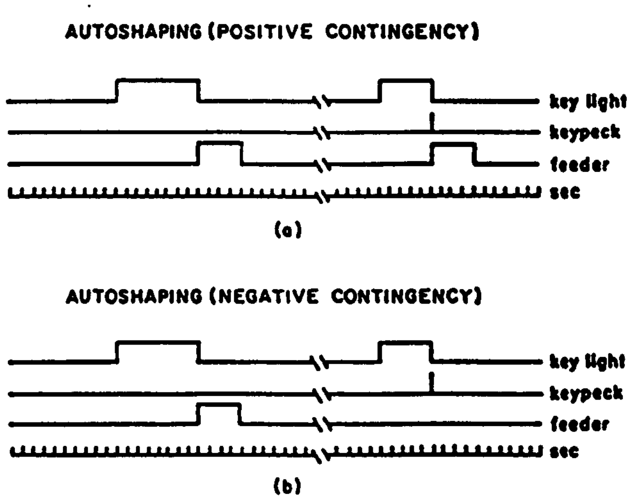


Figure 3.1. Two basic autoshaping procedures. Upward deflection of the line signals the onset of the event labeled at right. With (*a*) a positive contingency, autoshaping involves presentation of the reinforcer after a set period of key exposure or immediately after a key peck response. By contrast, with (*b*) the negative contingency, the reinforcer is presented after a set period of key exposure if there is no peck, but a peck turns off the key, prevents reinforcement, and starts the interval between trials.

FIG. 42 Williams,D.R., 1981, p.57.

An inspection of Figure 42 reveals that both the procedures are confounded. For example, in the 'positive contingency' case (Brown and Jenkins, 1968), although grain was present upon key-light termination without a key peck being required, when a key peck did occur, it terminated the key light and grain was presented. So this procedure seems to be a compound of both classical and instrumental conditioning. In the 'negative contingency' case (Williams and Williams 1969), again key-light termination was followed by grain delivery with pecking not required. But in this case, when a key peck did occur, it produced key light termination but no grain. This is called 'omission training' by Fred Sheffield, a colleague of Williams (Sheffield, F., 1965) from whom Williams borrowed the experimental design. In each case a key peck brought about a systematic 'response' from the environment. To eliminate this feature, Schwartz (1972) conducted an experiment based on the 'negative contingency' procedure. The Schwartz study proceeded in the following manner: 1) A key light was presented and grain was delivered upon key light termination with no key pecks being required for grain delivery. If a key peck occurred during key light presentation the light was not turned off, but stayed on the same length of time as if there were no key peck. Not only did a key peck not turn off the light, but it prevented grain delivery as well. 2) In a further modification of the procedure the key light was left on during grain presentation. Therefore key light termination was not followed by grain delivery (Schwartz, B., 1972). Under both conditions great increases in key-pecks was observed.

The phenomenon is apparently real for it has been demonstrated in a variety of species using a number of different CS's, reinforcers and responses. In further experiments, in which there was not a positive contingency between the illuminated key and grain in the hopper, key pecking was very poor. Therefore, in order to obtain autoshaping, the lighted key must reliably predict grain in the hopper. Hearst and Jenkins (1974) have reviewed the literature concerning this subject and have concluded that the phenomena of autoshaping can be subsumed under the more general concept 'sign-tracking'. Sign tracking refers to those behaviours that are directed either towards or away from a stimulus as a result of the relationship between that stimulus and a reinforcer. The term 'sign' is used to point out the importance of stimulus-reinforcer correlations as contrasted with the Law of Effect. Thus a sign predicts the presence or absence of some other envitonmental event. The term 'tracking' calls attention to the organism's "orientation, approach and contact responses directed toward signs of particular reinforcers"(Hearst, E. and Jenkins, H.M., 1974, p.4). Hearst and Jenkins also extended the concept of sign tracking to situations in which an organism moves away from a stimulus that signals the absence of a reinforcer.

The important feature of this phenomenon is that the sign or CS apparently achieves its capacity to control directed movements of the whole organism via procedures operationally the same as those used in conventional classical conditioning. Therefore there seems to be in autoshaping a method of classically conditioning behaviour that has provided the prime example of operant behaviour. More importantly, these experiments detract from the popular view that the pigeon's key-pecking behaviour is relatively arbitrary (emitted) as proposed in the publication of Ferster and Skinner (1957).

However, more recent evidence suggests that the autoshaping procedure is more complicated than straightforward classical conditioning of an operant. Williams (1981) reviewed in detail the development of autoshaping and came to the conclusion that the pigeon's key peck could be under the influence of both the stimulus-stimulus and the response-stimulus paradigms. He termed such behaviours biconditional and called for the rejection of the use of 'operant' and 'respondent' as categorical concepts, i.e. as mutually exclusive and possible exhaustive 'types' of behaviour to which only S-S or only R-S laws apply. He further proposed that the instrumental and classical conditioning procedures should be 'tools of analysis' in the experimental study of learning (Williams, D.R., 1981).

Schwartz maintains that, after all is said and done, the only way to differentiate between the two conditioning procedures is to distinguish them as relations. He defines classical conditioning as "a relation between two stimuli" and instrumental conditioning as "a relation between a response and a stimulus", but indicated that "both relations may control the same class of behaviour". He ended his discussion of the classical-instrumental distinction much as did Williams, that is, by proposing that the conditioning procedures be viewed as analytical tools and not to classify behaviour (Schwartz, B., 1975).

Textbooks have recently appeared that have given autoshaping prominence as a possible alternative explanation to behaviours that in the past have been interpreted as being operants (Schwartz, 1975, Rachlin, H. 1976.). If the 'sign tracking' and 'autoshaping' experiments as well as those concerning the operant conditioning of visceral response are accepted, it will call for a radical re-evaluation of the domains of operant and respondent behaviours.

The Operant Conditioning of Autonomic Responses

By the 1960's the technical benefits of the achievements made in electrical engineering and related fields made available high grade electronic instrumentation to laboratories with even modest research endowments. To the experimental psychologist, this meant that previously covert responses, i.e. heart rate, blood pressure, electrodermal activity, EEG, etc., could be observed and measured with relative ease.

With the technical expertise at hand, the operant conditioning of autonomic responses began to be scientifically explored by experimental study as well as by pilot clinical efforts. These studies were themselves preceded by reports dealing with human subjects suggesting that operant conditioning effects involving autonomic processes were possible. For example, Gregory Razran's 1957 review of the Russian literature was suggestive of such (Razran, G., 1957). Indeed, the efforts of Soviet psychologists and physiologists have continued to influence researchers in America. This has not only been through scholarly journals but widely cited monographs as well. For example, W.H. Gantt's translation of K.M. Bykov's The Cerebral Cortex and Internal Organs (1957), Chernigovsky's Interoception (1967) and the Hungarian, G. Adam's Introception and Behaviour (1967) among others. These three publications did much to dispel the myth that the ANS has a scanty afferent component and poor representation in the CNS. Indeed, the ANS seems rich in both.

In America there were important pioneering experimental studies which gave scientific feasibility to the idea that autonomic responses could be operantly conditioned. The experiments of Donald Shearn and Herb Kimmel were particularly suggestive: Shearn demonstrated small but distinct accelerations in heart rate (HR) in humans (Shearn, D., 1962), while Kimmel produced evidence for modification of the Galvanic Skin Response GSR in humans using operant conditioning schedules (Fowler, R.L. & Kimmel H.D., 1962; Kimmel, E. & Kimmel H.D., 1963). Significantly Shearn's experiment also revealed a large somatic component, in this case, heart rate increases were highly correlated with increases in respiration.

Shearn's experimental results were similar to those obtained by Abe Black in his early studies with dogs. Black used the Pavlovian procedure to condition heart rate increases in dogs and these increases were found to be closely correlated with skeletal movements, including respiration (Black, A.H., 1959).

It is important to note here that Black was using the classical conditioning procedure, whereas Shearn was utilizing the operant procedure and both obtained similar general results.

Slightly earlier, Kendon Smith had published a much-cited article entitled "Conditioning as an Artifact" (1954). In this article he claimed his major aim was to present a monistic approach in which:

> "every conditioned visceral response is, in reality, an artifact, an innate accompaniment of the skeletal responses inculcated by the conditioning process."
>
> (Smith, K., 1954, p.217).

Although Smith's criticism was aimed at the classical condition of visceral responses, it was later directed at the attempts to operantly condition such responses.

In defending his position, he reviewed the evidence suggesting the conditionability of such autonomic responses as the galvanic skin response (GSR), the salivary response and the pupillary response. He found it very unconvincing that condtioned visceral responses were acquired independently of somatic responses. In each case he argued logically that learned visceral activity was a by-product of somatic behaviour. Therefore, Smith's position pivoted on whether or not somatic activity always occurred in visceral conditioning. If it did, then it could be argued that the conditionable skeletal response was eliciting the involuntary and unconditionable visceral response in a reflexive fashion. Applying Occam's Razor, it was therefore unnecessary to postulate visceral conditioning.

As it seems that one can always argue that some undetected somatic activity can occur, it is logically invulnerable, as Smith admits. Any opponent would have to prove a negative hypothesis, i.e. that something did *not* exist, a notoriously refractory enterprise. It is important to point out that when discussing conditioned GSR, he entertained the idea that the GSR and muscular tension could "arise as parallel events from a common innervation" (Smith, 1954, pp.217-225). This hints at the possibility of central coupling of these two responses, an idea we shall meet again. Thus, Smith's criticism was not new, but it had wide appeal and was held in favour by a large segment of the psychological community. Therefore there was a justified reluctance to acknowledge the operant conditioning of autonomic responses as feasible.

This is not surprising, as influential psychological textbooks were dogmatic on the point. For example, Gregory Kimble's 1961 revision of Hilgard and Marquis' Conditioning and Learning states that:

> "There is good evidence that most (we think all) responses which can be conditioned classically cannot be conditioned instrumentally and vice versa."
>
> (Kimble, G., 1961, p.107.)

But Kimble sounded a word of caution to his readers: in his summary of Chapter 4 (Classical and Instrumental Conditioning Compared) he thought that voluntary factors play an important role in classically conditioned responses. Indeed, there is again 'good evidence' that the classically conditioned response is a combination of voluntary and involuntary processes. "The same state of affairs probably exists in the case of instrumental conditioning" and further, that:

> "the voluntary control over autonomic reaction which suggests that instrumental conditioning of these responses might be possible, probably always requires a mediating response involving the central nervous system."
>
> (Kimble, 1961, p.108)

Thus Kimble's position is close to, but no identical with, that of Smith.

Be this as it may, the possibility that the same central mechanism may control both the somatic and the visceral response, was largely ignored at the time in favour of a direct attack on Smith's somatic mediation hypothesis. Therefore, in order to deal with the problem of mediation, researchers attempted to develop methods which would systematically vary or entirely eliminate somatic responses, so leaving the visceral response system more open to direct study. The most extensively used technique in this endeavour has been that of curarization.

Curare blocks the action of the peripheral nerves on the skeletal musculature, creating a state of flaccid paralysis. However, the skeletal musculature is differentially sensitive to the effects of curare. Therefore some muscles enter a state of paralysis before others, the respiratory muscles being the most resistant to curare.

Thus Smith maintained that there could be skeletal responses which occurred and were not overt (Smith, K., 1964).

To answer this constant criticism, Black and Lang used dogs and recorded electromyographic (EMG) activity from three of the four legs and from the forehead. A delayed classical conditioning procedure was instituted - the CS was a tone (4,000 cycle), the UCS, an electric shock (4 milliamp) of 5 seconds duration, the CS-UCS interval was 10 seconds. They infused d-tubocurarine chloride into the recurrent tarsal vein. Thus, cardiac responses and skeletal activity (EMG) were recorded concomitantly. Their data suggested that cardiac responses could be conditioned without skeletal responding as measured by the EMG (Black, A.H., and Lang, W.M., 1964). Of interest here is the introduction of the operational definition of a skeletal response, i.e. no EMG, no skeletal activity. Such seemed to be necessary to deal with the criticism of Smith. Furthermore, this operational definition of a skeletal response was accepted in the efforts to instrumentally condition autonomic responses and, therefore, there was extensive use of curare in these experiments.

Some of the most dramatic experimental studies using curare were performed by Neal Miller and Leo DiCara. They undertook this series of experiments in order to investigate whether or not instrumental conditioning could modify visceral responses in animals devoid of voluntary somato-motor activities, including voluntary respiration. Thus their attempt addressed the mediation problem spoken of previously. This was an attempt that was to capture the imagination of the psychological community or at least that portion interested in the experimental study of learning.

Miller, unlike most of his colleagues, was already prepared to entertain the idea of the instrumental conditioning of visceral responses. Indeed Miller had previously called for a "Liberalization of Basic S-R Concepts" (1959), a concern which was reflected in the title of his contribution to the outstanding series of psychological writings, Psychology, A Study of a Science, edited by Sigmund Koch. In this paper, Miller, a student of Clark Hull, illustrated what he considered to be the advantages of using intervening variables, such as the 'drives' thirst and hunger, within the S-R theoretical framework. Miller, following Hull, was a 'drive reductionist', that is, he thought that organisms possess innate biological 'drives' that were energizers of behaviour. Behaviours which were successful in 'reducing' a particular drive tended to be perpetuated in the behaviour repertoire of the organism whereas unsuccessful behaviours would be eliminated because their execution did not 'reduce a drive'. In this theory drive-reduction is viewed as essential to the learning process and most of Miller's publications concerned studies directed to this concept. However, by 1961 Miller had proposed a research program that shifted emphasis from drive-reduction to efforts using the instrumental conditioning procedure to study visceral responses (Miller, N., 1961).

First, Miller presented experimental evidence suggesting that salivation in the dog could be modified by the instrumental conditioning procedure (Miller, N.E. & Carmona, A. 1967). Dogs were rewarded by water for periods without salivation as well as for 'spontaneous' bursts of salivation and progressive decreases and increases in salivation respectively were achieved. Miller also paralysed the dogs with curare but found that the drug precipitated a large increase in salivation, making conditioning impossible. He then embarked on a series of experiments with Leo DiCara which appeared to indicate the legitimacy of the operant conditioning of autonomic responses.

In the beginning, Miller and DiCara focused on heart rate as the autonomic response to be subject to the operant conditioning procedure. Their first experiment was essentially a replication of an experiment conducted previously by J.A. Trowill in Miller's laboratory. Trowill had paralysed the skeletal musculature of rats with curare and rewarded both increases and decreases in heart rate with electrical brain stimulation (EBS) to a sub-cortical structure known as the medial forebrain bundle. This structure is anatomically connected with olfaction in the rat and, since the publications of James Olds (1956 a, b), has been recognized as a significant reward centre in the brain. The medial forebrain bundle's reward features are inferred from the high rates of bar-pressing exhibited by rats given the opportunity to self-administer ESB. Trowill's experiment produced distinct, but small, heart rate increases and decreases - in the order of 5% (Trowill, J. A., 1967).

In the experiment of Miller and DiCara, a few changes were introduced, such as an increase in the time allowed for recovery from the effects of ESB, more trials and a longer period of training, but the most important were the use of a discriminative stimulus. A light or a tone marked the discriminative stimulus (SD) period, during which the subjects (rats) received ESB for either increasing or decreasing their heart rate (HR) as the case may be. In this experiment heart rate increases and decreases on the order of 20% were reported, as compared to the 5% changes observed by Trowill. Apparently the introduction of the SD greatly increased the magnitude of the rewarded increases and decreases in heart rate. In addition the criteria for reward could be flexible within the SD period. In other words the number of heart beats required for an ESB could be made progressively more difficult in both the 'increase' and 'decrease' groups. If the criterion level for heart rate was successfully met then a slightly higher criterion could be set thereby demanding a higher heart rate in order to receive ESB and so on. Hence HR levels could be progressively 'shaped' up or down.

Miller and DiCara were quick to point out that their results did not reflect the unconditioned effects of ESB because there was considerable overlap between the number of ESBs delivered in each group. The fact that they conditioned both increases and decreases in HR using the same experimental procedures (the bi-directional design) suggested that HR could be directly influenced by the experimental contingencies. Of course, if confirmed, these experimental results would have important implications for psychology, not only on the conceptual and theoretical side, but on the practical side as well, as exemplified by the potential of such techniques to help treat human visceral pathologies.

The claim, by Miller and DiCara, that the instrumental conditioning of a visceral response had been demonstrated, rested on the fact that they had used a curarized preparation. Therefore the animals had to be artificially respirated. The respiration parameters established by Miller and DiCara in this experiment were used by them in their subsequent studies (Miller and DiCara, 1967). These were to assume great importance when attempts were made to replicate their experiments.

Miller and DiCara followed this with no less than six publications in 1968 alone. These included operantly conditioned heart rate responses as avoidance reactions to electrical shock (DiCara and Miller, 1968a), and suggestions that operantly conditioned heart rate transfers from the curare state to a non-curare state (DiCara and Miller, 1968b). But, the most remarkable feature was the specificity with which a response could be conditioned, with the most startling example provided by a study which claimed to show that rats could differentially control blood flow in the two ears (Dicara and Miller, 1968e). In their review of the literature concerning operantly conditioned autonomic responses, Katkin and Murray (1968) concluded that the curare studies presented the most convincing evidence that autonomic responses could be operantly conditioned "independent of possible mediators" (Katkin, E.S. & Murray, E.N., 1968, p.64).

Given the extraordinary nature of the evidence presented by Miller and Dicara, many efforts were made to confirm their experimental results. Some of these produced positive results (Hothersall, D. and Brener, J., 1969; Banuazizi, A., 1972; Slaughter, J., Hahn, W., and Rinaldi, P., 1970). However, there was a growing body of evidence which was negative (Roberts, L.E., 1978).

In one attempt Brener, Eissenberg and Middaugh rigorously reproduced the methodology of Miller and Dicara, giving particular attention to the respiration parameters. They found that:

> "Our experience in employing these parameters led us to believe that they result in hyperventilation of the curarized rat. Rats respirated by this technique display profound invariant tachycardia at the inception of the session, show a systematic decrease in heart rate throughout the session, and are unresponsive to peripheral stimulation."
>
> (Brener, et al, 1974, p.255).

Brener et al (1974) had varied the respiratory parameters for each animal in order not to have a comatose animal and although they were able to operantly condition heart rate, the magnitude was small compared to the results of Miller and Dicara.

They interpreted the results of their experiment as indicating that skeletal-motor and visceral activity are two manifestations of a centrally integrated motor system. This idea had also been suggested by Black (1967) and Obrist et al (1970). The major features of this study were that it demonstrated the extreme care that must be taken with the curarized preparation.

Eventually Miller himself was unable to replicate the experimental results of his previous studies (Dworkin, B.P., and Miller, N.E., 1977, Miller, N.E., & Dworkin, B.P., 1974). In turn these experimental failures weakened Miller's conjecture that autonomic responses and somato-skeletal responses are controlled by two independent processes within the CNS and strengthened the conjecture that the two seemingly independent processes were centrally integrated. Indeed some of Miller and DiCara's own data could be interpreted to suggest such central coupling of somato-motor and autonomic responses. For example, Dicara and Miller (1969) conditioned heart rate increases and decreases in two separate groups of curarized rats. When tested for retention of the conditioned heart rate responses in the normal (non-curarized) state, the group conditioned for heart rate decreases under curare manifested significantly lower respiratory rate and activity levels than the group that had been conditioned for heart rate increases.

To test this hypothesis further, Goesling and Brener (1972) conducted another 'transfer' experiment, the converse of that of Dicara and Miller. In this study two groups of rats with yoked controls were conditioned to be active (running in a running wheel) or immobile (remaining still in a cage) via a shock avoidance procedure. After the pre-training period, each group was split for heart rate conditioning (increases and decreases) under curare. That is, one half of the active group was conditioned for heart rate increases and one half for decreases. The same procedure held for the immobile group. The results of this experiment demonstrated that performance under curare was a function of the pre-training and not of the contingencies under curare. These results were interpreted as evidence for central linkage of somato-motor and cardiovascular activities. Indeed, the transfer studies as a group provided some of the strongest evidence supporting the hypothesis that visceral conditioning was centrally mediated by structures responsible for skeletal muscular control. Moreover Orville Smith has amassed a large body of evidence indicating that cardiovascular and somatomotor activities are integrated within the CNS, as distinct from regulation and control by peripheral feed-back loops (Smith, O.A., 1974). However, if the 'central mediation' interpretation of the results of experiments attempting to operantly condition autonomic responses was viable, then the curare experiments did not adequately address the problem; curare only blocks nervous activity at its most peripheral point, i.e. at the myoneural junction. Any processes proximal to this junction would not be affected by curare.

Therefore, if it is conjectured that skeletal muscular and autonomic activities are centrally linked and that curare is only preventing the expression of one component of the behavioural gestalt - the skeletal muscular one, then one would expect activity in the motor nerves which innervate the skeletal musculature although the muscles themselves fail to contract. Unfortunately such diract evidence was not obtained in the above cited experiments. However, experiments using curare in a more physiological setting have been performed and offer some strong indirect evidence that such activity does indeed occur. These experiments are important in that they indicate that there are 'coordinating motor centres' within the CNS which are active in the curarized preparation. Hence coordinated central activity, even in paralysed animals, could be causing the observed changes in visceral responses.

Dellagina et al (1975) stimulated the cervical spinal cord in both decerebrated and decapitated cats and measured electrical activity in the muscle nerves gastrocnemius laterals (GL) and tibialis anterior (TA). When the cats were immobilized with Flaxedil, thereby eliminating peripheral feedback, rhythmical activity was detected in GL and TA, evoked by cervical stimulation, an activity that has become known as 'fictive' scratching. The oscillations set up in GL and TA exhibited frequencies, very similar to those of the intact animal (approx. 2-5 cycles/sec.). Since no movement took place, the oscillations measured in the two nerves were deemed to be under the control of a central program. This program seemed to be a spinal mechanism which could control not only oscillations between muscles, but the phase relationships as well (Dellagina, T.G., Feldman, A.G., Gelfand, I.M., Orlovsky, G.N., 1975). The interesting feature here is that in a preparation which was pharmacologically immobilized, electrical activity was occurring in the skeletal motor nerves.

In another experiment Feldman and Orlovsky (1975) studied 'fictive' locomotion in the spinal cat. First Ia interneurons receive input from Ia afferents from the muscle spindle as well as from central structures. The major effects of Ia interneuron discharge are activation of the motor neuron located in the same muscle as the muscle spindle giving input to the Ia interneurons and inhibition of its antagonist. Again, a neural locomotor pattern similar to that of the intact animal was set up in spinal animals that had either been de-afferentated (by cutting the ventral roots) or curarized. This study suggests that a central program can co-ordinate both excitation and inhibition of the alpha and gamma motor-neurons as well as the Ia interneuron without peripheral input. The concept of a central program controlling movement will be expanded in the following chapter, but again at present the important point is that under curare electrical activity does occur in the nerves which innervate the appropriate skeletal musculature (Feldman, A.G. and Orlovsky, G.N., 1975). Such evidence is encouraging; however it can only be used with great caution when drawing conclusions about activity in the skeletal motor nerves of the curarized preparation in the operant conditioning paradigm.

Be this as it may, and despite the problems encountered with the curare preparation, there emerged the point of view that, taken as a whole, the experiments concerned with operantly conditioning autonomic responses demonstrated a real, if frail, phenomenon (Thornton & Van Toller, 1973; Middaugh, Eissenberg, & Brener, 1975; Gliner, Horvath and Wolfe, 1975; Cabanac & Serres, 1976). In addition, these so-called 'autonomic operants' exhibited in a general manner characteristics usually associated with skeletal muscle responses which have been operantly conditioned, e.g. responses could be modified by both positive and negative reinforcement (Miller and Dicara, 1967, Dicara and Miller 1968a) When reinforcement was discontinued, extinction resulted (Hothersall and Brener, 1969; Dicara and Stone, 1970); there was retention of acquired responses (Dicara and Miller, 1968c) as well as acquisition of both increases and decreases in activity (Dicara and Miller, 1968a).

Thus it can be seen that the operant conditioning of autonomic responses and the classical conditioning of skeletal responses (the auto-shaping phenomenon) represent two converging lines of evidence, demonstrating the unviability of the practise of classifying behaviour into two rigid and mutually exclusive categories: operant and respondent, voluntary and involuntary, skeletal and visceral. Furthermore, the hypothesis that behaviour is an integrated response with both central and peripheral components gives a framework for the interpretation of behaviour that is more consonant with recent evidence than with the voluntary-involuntary dichotomy. In order to avoid the problems surrounding the use of curare but nevertheless investigate the influence of instrumental experimental contingencies on both autonomic and skeletal responses, Brener, Phillips and Connally (1977, 1980) conducted experiments which measured both components of the total behavioural gestalt, i.e. the autonomic as well as the skeletal responses, in the intact, freely moving animals.

Several lines of evidence were brought together in this study:
1) In freely moving animals variations in heart rate (HR) - the autonomic component of the behavioural gestalt - are usually highly correlated with variations in somatomotor activity. However, there is evidence suggesting that, in situations of stressful environmental demand, the cardio-somatic gestalt could be disrupted (Obrist, P.A., 1976). These experimental data suggested that the central nervous system has the capacity to differentiate the somatomotor-heart rate gestalt and that this differentiation could be studied using the operant conditioning procedure.
2) It was apparent that HR changes could be conditioned by operant reinforcement contingencies in non-curarized subjects. This had been demonstrated in several species, man (Obrist, P.A. et al, 1974), the monkey (Engel & Gottlieb, 1972), the baboon (Harris, A.H. et al, 1976) and the rat (Black, A.H. et al, 1976). Although the same studies asserted that there was HR-somatomotor dissociation, they had used only discrete and partial indices of somatomotor activities such as eye blinks, E.M.G. recording from selected sites and respiratory rate or amplitude. Thus the nature of the somatomotor variation was clouded

and therefore the evidence for a cardio-specific effect of the contingencies was inadequate.

3) Although gross measures of somatomotor activities - stabilimeter recording - revealed a reliable co-variation between HR and somatic activities (Elliott, R.E., 1974), isometric muscle contractions have also been shown to produce profound disturbances of cardiovascular activity (Goodwin, R.M. et al, 1972). Since these isometric contractions easily escape detection, it would lead to an underestimation of any correlation between cardiac and somatic activities. However, all somatomotor processes involve energy expenditure and the variations in this expenditure is reflected by precisely correlated variations in oxygen consumption (OC). Hence if the operantly conditioned variations in HR are one component of a HR-somatomotor gestalt then they should be positively correlated with variations in OC.

In these studies not only was ambulation recorded but the gross level of somatomotor activity was assessed by continuous monitoring of oxygen consumption (OC) as well. Moreover in the freely moving subject, peripheral processes can account for heart rate skeletal muscle integration.

The reader is referred to the appendix for the full text of these experiments, especially concerning the methods used, the details of the results and their interpretation. Of importance here is the general implication of these experiments.

Brener et al (1977) demonstrated that shock-avoidance reinforced contingencies effectively conditioned discriminated tonic increases and decreases in HR. Furthermore these conditioned HR responses were accompanied by especially significant changes in somatomotor activity measured by both ambulation and OC. The positive covariation of HR and somatomotor activity again strongly suggested a possible central integration of such responses. This suggestion complements other evidence indicating that the combination of somatic and cardiovascular activities is achieved by central neural integration (Gellhorn, E., 1967; Germana, J. 1969; Smith, 1974). Moreover, Obrist et al (1975) demonstrated that, in man, the magnitude of conditioned HR change is inversely related to the degree of somatomotor restraint applied during conditioning. This evidence suggests that conditioned HR changes are more than an accompaniment of somatomotor changes but are an integral component of a generalized cardio-somatic response. If such a hypothesis were valid, one might expect similar behavioural adjustments to result regardless of which response component of an integrated behavioural gestalt is identified as the operant by the reinforcement contingencies.

To pursue this point, Brener et al (1980) used matched signalled shock-avoidance procedures and a running wheel environment. Again, the reader is referred to the appendix for experimental details. One group of rats was reinforced for heart rate (HR) increases, and another group for running. This experiment was more comprehensive than Brener et al (1977) and perhaps the results were more equivocal and difficult to interpret. Nonetheless an important feature emerged: in terms of the reinforcement contingency rules, subjects in the HR group could terminate the warning stimulus and avoid electrical shock independently of ambulating, but in fact their avoidance behaviour was characterized by high ambulation rates. This observation conforms with other results indicating that operantly-conditioned HR variations are learned as one component of non-specific variations in activity.

Thus researchers concerned with the experimental study of learning have arrived at a point of view that conceives of organisms as functional unities, and the observed behaviours of such organisms as the product of integrative activities of the CNS. It is of great interest that similar ideas have concomitantly emerged within the discipline of neurophysiology, particularly from those researchers concerned with the role of the CNS in the production of movement. In a neurophysiological context, such concepts as 'motor programs' and 'motor commands' have been postulated to account for the evidence generated by the study of movement. Moreover the 'central mediation hypothesis' compliments rather than contradicts these concepts, which are, themselves, usually subsumed under the more general topic of 'motor control'.

In closing this chapter, it is felt that a plausible case has been made for the abandonment of the perception that behaviour can be classified into the two great classes: operants and respondents; voluntary and involuntary responses. This is, of course, in the sense that such response categories were classified by the procedures used to study them. The evidence drawn on to support this assertion has been derived from the experimental study of learning, an area of study which has traditionally made extensive use of this dichotomy.

To reiterate, it is asserted that if the voluntary-involuntary distinction is to be maintained, it must be done on grounds other than the use of the classical and operant conditioning procedures. The continuation of such a distinction on these grounds could be potentially counterproductive to future research. For if researchers using these criteria, believe that they have somehow accounted for 'voluntary' behaviour, they will be less likely to pursue an alternative explanation of the observed behaviour.

Also it has been intimated that the term 'voluntary' carries with it vitalist connotations. This is in the sense that a voluntary response has been perceived as having a privileged status. For example, within the conceptual framework of traditional S-R psychology, the voluntary response - the operant- was not, by definition, preceded by an identifiable antecedent event. Skinner claimed this type of response was 'emitted' as distinguished from the 'elicited' involuntary response. Thus the origin of the 'emitted' response was much more mysterious than that of the 'elicited' response. Furthermore, historically voluntary behaviour has been intimately attached to that bastion of vitalism, the mind. Therefore the 'cause' of this type of behaviour has a sense of the incorporeal associated with it. Other sources of voluntary behaviour which have been postulated, such as the concepts of 'soul' and 'spirit', were often considered to be immortal. Hence volition has been speculated to be independent of the principles that appear to govern the natural world.

However, it is possible to define operationally a voluntary response in such a way that metaphysical implications do not arise. That is, if humans could produce or inhibit a response, upon instruction, signal or command, it would be considered a voluntary response. For example, if a human subject was told to raise his arm and did so; arm raising would be a voluntary response. Further, if subjects could increase or decrease their heart rate on instruction; the heart rate could be said to be under voluntary control. Today, the 'instructive' definition of a voluntary response is extensively used in both psychological and neurophysiological studies (see Brener, J., 1977).

In contemporary efforts to explain bodily movement, the concepts emerging in the area of 'motor control' seem to be the most promising. In the past two decades the literature concerning this area of research has grown so rapidly and to such an extent that a discussion drawing the full compass of this area would be well beyond the scope of this thesis. Therefore, in the following chapter, the hypotheses put forth are of a very selective nature. The focus will be on models and experiments attempting to account for voluntary movement, and an effort has been made to present major authorities whose views address the central conceptual features used in the explanation of such movement. It will also be suggested that even in this 'hard-nose' scientific area, the vitalistic attributes of voluntary movement are still very prominent.

CHAPTER 4

Motor Control

In general terms, 'motor control' denotes the study of the role of the CNS in the production and control of movement; one area of research which traditionally has been within the domain of neurophysiology. At present, however, the concepts used to describe and interpret 'motor control' are derived from such disciplines as information (communication) theory, control theory, computer science and electrical engineering; fields subsumed hereafter under the rubric, cybernetics.

In behaviouristic psychology there is a growing awareness that a more coherent explanation of behaviour may be developed if CNS activity is given serious consideration in experimental and/or conceptual schema.. Thus the study of motor control can be seen as a point of convergence of similar but not identical interest held by psychology, physiology and cybernetics; a unifying concern being the prediction and control of movement.

It will be recalled that Skinnerian psychology presented itself as an atheoretical psychology. Skinner maintained that the knowledge of processes within the CNS were unnecessary in accounts of behaviour and the 'laws of behaviour' were to be independent of 'neurological support'. Skinner held that a science of behaviour could provide the most general possible description of CNS activity; the study of behaviour was "regarded as a sort of thermodynamics of the nervous system". (Skinner, 1938, p.432). Hence psychology, as the science of behaviour, would outline a program to which neurophysiology must conform.

As suggested in Chapter 2 the interpretation, by psychology, of the overt, public behaviour of biological organisms in terms of stimulus and response may be seen as analogous to the interpretation of the behaviour of machines in terms of input and output by the engineering sciences. This is an important feature of behaviouristic doctrine for it has permitted psychology to easily assimilate the concepts generated in cybernetics, a field which perceives similarities between mechanical and biological phenomena. Psychology, in turn, has been drawn into closer affinity with the physical sciences. This being the case, an introduction of some of these concepts would be appropriate at this point. Perhaps this can best be accomplished by doing a little backtracking.

In the 1940's Skinnerian psychology was in the ascendancy. World War 2 intervened in the activities of all scientific disciplines however, and Skinner's pigeons for example, were employed to help develop a guidance system for missiles. Another who was drawn into the war effort, and interested in guidance systems, was the philosopher turned mathematician, Nobert Wiener.

Weiner is universally recognized as having introduced the term 'cybernetics', which he considered to be the study of control and communication in animals and machines. His ideas concerning cybernetics were the product of a seminar on the methodology of science given at Harvard University by Arturo Rosenblueth. Immediately before the war Wiener was developing computing machines for the solution of partial differential equations. During the war he worked with Julien Bigelow in an "investigation of the theory of prediction and of the construction of apparatus to embody these theories" (Wiener, N., 1961, p.6).

The practical features of this effort involved the design of automatic systems which would make aircraft-tracking radar data available to computers. The computers calculated the future pathway of the aircraft and controlled the aiming of the anti-aircraft guns. As the task progressed, Wiener and Bigelow came to the important conclusion that the mechanisms responsible for the manipulation of feedback information in self-regulating machines in broad outline, were similar to those used by the CNS to control motor activity.

Wiener and Bigelow speculated that the oscillations seen in their mechanical systems due to improper feedback could have an analogue in the mechanisms which control human motor activity. They approached Rosenblueth with their suggestion and he immediately pointed out that disruptive oscillations occurred in a neurological systematology called 'purpose tremor', a disorder often associated with disturbances to cerebellar function. Patients suffering from this pathological condition overshoot the mark and/or exhibit uncontrolled oscillations when attempting to voluntarily pick up or touch an environmental object such as a pencil or tea cup. This neurological data convinced Wiener of the feasibility of applying the same general concepts - such as feedback - to many research areas.

In 1943, Rosenblueth, Wiener and Bigelow published an article entitled "Behaviour, Purpose and Teleology" in which it was officially suggested that the concept of negative feedback mechanisms was basic to CNS function and, hence, had an important role to play in the explanation of behaviour. This suggestion has come to be called the 'hypothesis of cybernetics' (Mays, W., 1951).

Wiener stated that there was an awareness of the contrast between the essential unity of the set of problems centering about communication, control, and statistical mechanics, whether in the machine or in living tissue and the lack of unity , or absence of common terminology, in the literature concerning these problems. To address this problem, Wiener introduced a new discipline termed cybernetics in 1948 (Wiener, N., 1961, p.19).

Wiener intended cybernetics to be the scientific framework which would describe similar phenomena in the biological as well as mechanical worlds. Importantly, Wiener always stressed the point that logical priority should be given to neither world, a notion often neglected by his followers. The term 'cybernetic' is derived from the Greek word meaning 'steersman or helmsman'. This concept, however, is not to be confused with Plato's 'pilot of the ship'. In the case of cybernetics the 'helmsman' is not concerned with immortality, but with the transmission, processing and control of signals or of information in the formal signals or symbols.

Rosenblueth et al (1943) recognized that the concepts of control and communications were inseparable. Control involved analysis of communication problems which in turn concerned the analysis of messages or signals, in other words, the analysis of information. Wiener contrasted the amount of information in a system with that of entropy. Entropy being a concept from classical thermodynamics which holds that closed systems - those systems independent of external energy sources - tend to experience 'heat death'. This 'death' is a basic feature of closed systems. All closed systems which exhibit temperature differentials can do work (energy transfer). However, with no external energy source such a system gradually reaches a state of equilibrium i.e. it becomes 'iso-thermal' and can no longer work. Wiener viewed 'entropy' as the degree of disorganisation of a system. In contrast, 'information' was a measure of its organisation! However, the 'theory of information' is most closely associated with Wiener's student, Claude Shannon.

The Mathematical Theory of Communication was published by Shannon and Weaver in 1949 and provided a means of ascertaining the amount of information generated by an informational source, real or artificial. It also permitted precise, mathematical definition of the 'capacity' of a communication channel as well as its 'efficiency'. The concepts of 'coding', 'decoding', 'noise' and redundancy are also given mathematical treatment. Shannon's mathematical expression of these concepts is far beyond the scope of this thesis but suffice it to say that 'information theory' is a rigorous brand of probability theory which has been broadly applied to many areas of research; computers, automata, telecommunications and biological systems (McCulloch, W.G., 1949; Ashby, W.R., 1952; Von Neuman, J., 1958).

D.M. Mackay thinks that a theory of communication can bridge the gap between the psychological and physiological levels of discourse of behaviour.

> "Now the language of information and control, in which the theory of automata is framed, is conceptually intermediate between those of psychology and physiology"
>
> (Mackay, 1956, p.31).

Further, advances in the development of computing machines led to the notion that 'intelligent' activity of the brain may be simulated and investigated independent of the study of its 'hardware'. For example, Alan Turing has demonstrated that the organisation of computers may be conceived as an ordered collection of 'logical states' which can be, in principle, at least, completely specified by their relations to each other and to the input and output of the machine, regardless of its physical construction. Thus the 'software' may be independent of the 'hardware' (Turing, A.M., 1950).

Turing also formulated the now famous "Turing test", which was to serve as the criterion to separate machine and human behaviour. Simply put, if a machine can respond appropriately to a series of questions - that is give answers that a human would give - then one could not distinguish between man and machine. Therefore Turing's 'test' took place at the behavioural level. Addressing the behavioural level of discourse, Claude Shannon presented a 'maze-solving machine' in 1951. The machine - with 72 relays for a 'brain', could solve any maze problem within a twenty-five sequence area. This amazed its audience. L.K. Franks stated that its behaviour was "all too human" and H.W. Brosin "George Orwell, the late author of 1984, should have seen this" (Shannon, C., 1952, p.179).

At the same conference where Shannon demonstrated his maze-solver, D.M. Mackay put forth 'The Nomenclature of Information Theory' derived from a Symposium of Information Theory held in London in 1950. Mackay defined information "in the most general sense as that which adds to a representation" (Mackay, D.M., 1952, p.225). A representation was "any structure (pattern, picture, model), whether abstract or concrete, of which the features purport to symbolize or correspond in some sense with those of some other structure" (Mackay, 1952, p.224). Information theory was conceived to be concerned with the generation of 'representation'.

This conception of information, coupled with the seemingly purposive behaviour of self-regulating machines, is complementary to ideas from psychology and physiology which have attempted to account for behaviour in terms of images and goal-direction. Indeed, the terms 'image' and 'goal-direction' frequently appear in cybernetic literature.

However when these terms are used in cybernetics, they are mathematically specified, in contrast to their vague mentalistic connotations. This added conceptual rigor can be beneficial to psychology in that it encourages psychologists to clarify their own view of these useful concepts.

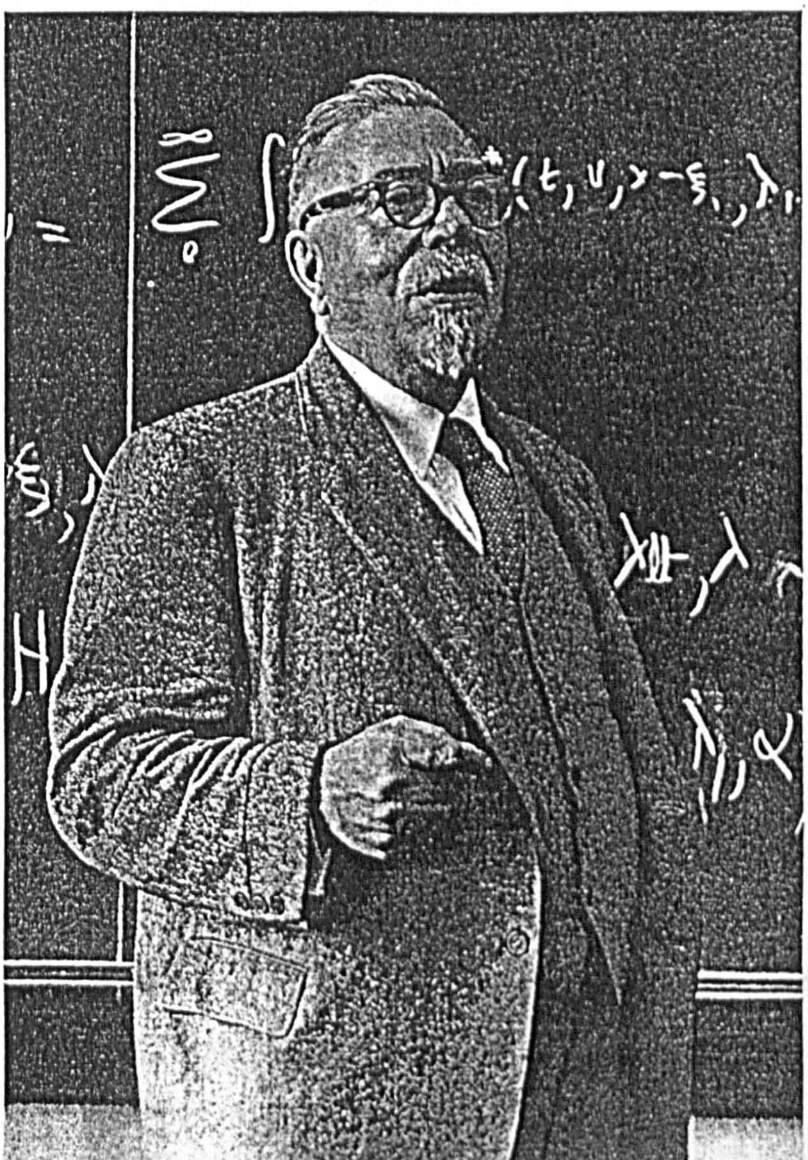
With non-biological systems that have to be controlled, engineers have found it advantageous to ascertain fundamentally distinct ways that a system's parts can function in concert. These various modes of control have been identified and embodied in two types of control systems: closed loop and open loop. The distinction between these two, concerns whether or not the system is sensitive to feedback. Closed loop systems have several elementary functions in common. First the system must have a command function or 'set point', 'reference mechanism', 'goal' or 'purpose'. This sets the standard for the performance of the system. The system must also contain a comparator function which is capable of receiving two inputs, one from the command function and another from its own output or from the environment which is affected by the output. This latter input is called feedback. The comparator function 'matches' the feedback signal with the 'command'. Usually there are two possible outcomes: (i) the signals are equal in which case the system has reached equilibrium and ceases to function, (ii) the signals are not equal. If the error signal is large, in this case an 'enable' signal is sent to the next link in the chain; the effector function. This function generates the output of the system. The output is then compared with the command function to test for equivalence. If equivalence is not achieved the process is repeated and continues to be repeated until equilibrium is reached.

When feedback is used in this way it is called negative feedback and is concerned with error reduction. This is to be distinguished from positive feedback which operates to increase the error signal. The latter is usually unstable and possibly pathological in biological systems; therefore, in studying motor behaviour, the former has been of greater utility. The closed loop systems are usually more complicated than open loop systems. Furthermore, whereas closed loop systems are sensitive to feedback, open loop systems utilise feedforward control and can be 'programmed' to carry out a certain set of instructions regardless of the outcome. That feedforward is a larger scale of organisation of feedback mechanisms has also been suggested.

In contrast to feedback, in which the system is informed of its performance, feedforward has the connotation of anticipation or preparation, either by presenting an effector for future 'commands' for action or to ready sensory systems to 'expect a certain signal'. This mode of control can also be useful in efforts to comprehend CNS control of movement.

Finally, there is the concept of motor programs or motor commands. The concept denotes the idea that the CNS is capable of prestructuring a set of muscle commands which (as with the open loop system) is not sensitive to feedback. A motor program is expressed as an ensemble of movements, it is executive as a whole.

With these concepts in mind, we may proceed to a discussion of some models of behaviour which have made use of them. The references cited by no means exhaust the literature but, taken as a group, they represent a spectrum of opinion extant today. These models are categorised into three groups; those using 'images', those using 'mind' and those using 'goal-direction' in the production and control of movement.



Norbert Wiener (1894–1964)

FIG. 43 from Wiener, N. and Schadé, J.P., 1965, facing p.399.

The Use of Images: William James

James devoted one hundred and six pages of the second volume of his Principles of Psychology (1890) to a discussion of the 'will'. He began his presentation by telling his audience that the prerequisite of voluntary life was involuntary performance.

His 'first thesis' was:

> "... that there need be nothing else, and that in perfectly simple voluntary acts there is nothing else, in the mind but the kinaesthetic idea, thus defined, of what the act is to be."
>
> (James, W., 1890, Vol. 2, p.492-293)

The kinaesthetic idea was "a mental conception made up of memory-images of ... sensations." (James, 1890, Vol. 2, p.492).

These statements are the germ of James' ideo-motor theory of movement. While crediting W.B. Carpetner with the introduction of the term 'ideo-motor' to describe a 'mental curiosity', James thought that:

> "The truth is that it is no curiosity, but simply the normal process stripped of disguise."
>
> (James, 1890, Vol. 2, p.522).

For James, a movement was classified as voluntary if it was preceded by an "idea of movement", the 'idea' being the sensory consequences of the movement. Furthermore, a movement followed an idea of it in a more or less automatic fashion unless it was 'robbed of' its ability to do so by competing ideas.

Fig. 44 is a schematic representation of the processes required for the production of voluntary movement according to James. First, the sensory cell (S) is 'awakened' in response to stimulation and in turn discharges into the motor cell (M) via the connate pathway (solid-line P). The motor cell 'fires', contracting the muscle and thus exciting the kinaesthetic cell (K) which again discharges into M. This process would be self-sustaining were it not for 'inhibition'. However, the important feature is the broken-line P which is an alternate path formed concommitantly with the function of solid-line P. Eventually S, via the dotted path, comes to elicit K before M discharges and thus:

> "... when a sensation has once produced movement in us, the next time we have the sensation it tends to suggest the idea of the movement, even before the movement occurs."
>
> (James, 1890, Vol. 2, p.585).

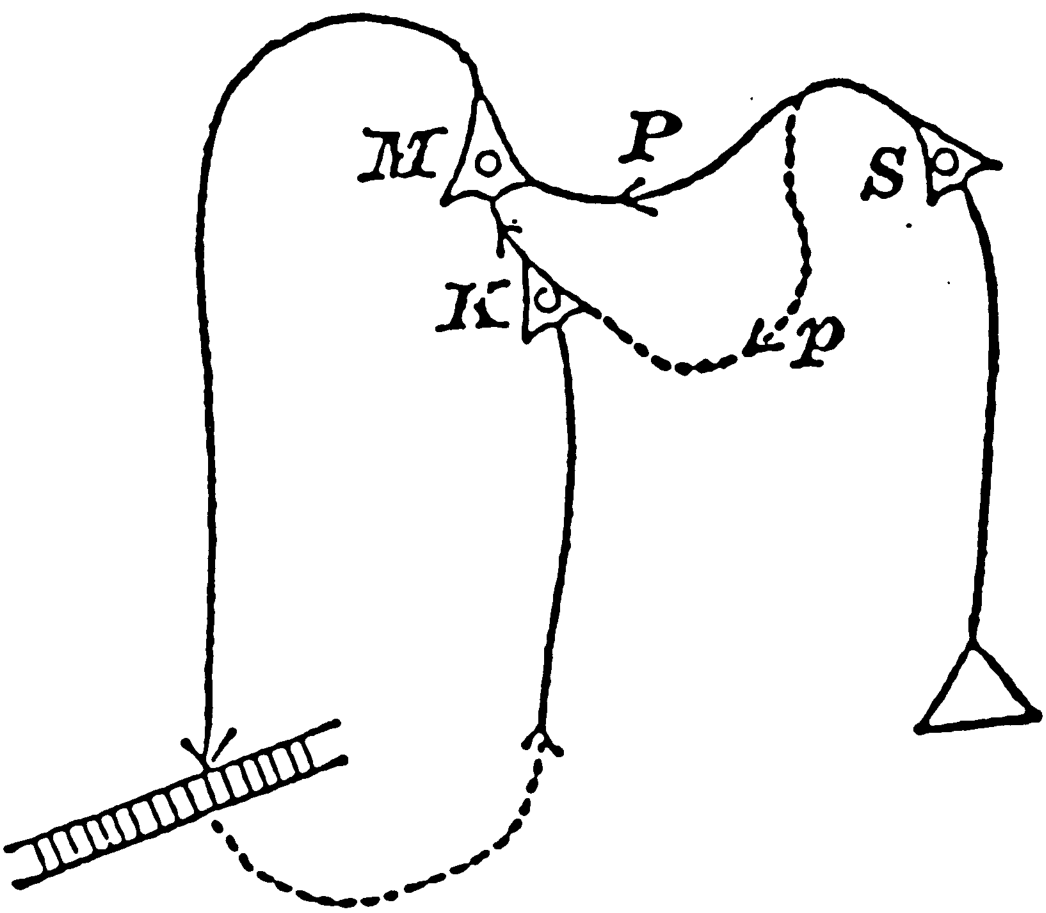


FIG. 88.

FIG. 44 James, W., 1890, p.585.

importantly, James used his ideo-motor theory to account for, not only, what movements occur; but that they occur at all. In James' opinion, 'ideas' which represent various movements could compete for execution, thus:

> "... inhibition of a movement no more involves an express effort or command than its execution does. Either of them may require it".
>
> (James, 1890, Vol. 2, p.527).

Moreover, he considered deliberation of action, without it actually taking place, to be a case of inhibition by antagonistic thoughts.

Finally, James was quick to point out that his ideo-motor theory was entirely conceptual in nature "...and must not be supposed to involve any theory about protoplasmic and axis-cylinder processes." (James, 1890, Vol.2,p.582 (footnote)). He was apparently ignorant of the neurological demonstrations that Cajal had presented to von Kolliker only the year before, 1889. He postulated his theory as a counterpoint to Wundt's 'feeling of innervation', a concept introduced by Von Helmholtz, and embraced not only by Wundt but Bain and Mach as well. This feeling was supposed to be 'a special current of energy' which flowed from the brain to the skeletal musculature during an act of volition. Modern neurophysiology has eclipsed Wundt's 'special current of energy' which, for him, differentiated voluntary and involuntary movement; but James' ideo-motor concept still proves fruitful and viable in current literature, in terms of images as well as ideas.

I.S. Beritoff

I.S. Beritoff gives one of the strongest statements concerning the ability of an 'image' to direct voluntary movements. Indeed, 'voluntary movements' are "behavioural acts which are directed by images of vitally important objects in the environment" (Beritoff, I.S., 1963, p.347). Images of environmental objects are created by the functional integration of all sensory input "by means of internuncial and association pyramidal neurones" (i.e. the so-called cortical analysers) and reproduced by "the action of any component of the object or the environment where it has been perceived" (Beritoff, 1963, p. 341). Further, the biological importance of these images is that they substitute for, and are projected into, the real environment; thus giving the image its behavioural controlling qualities. Therefore, for Beritoff, image directed behaviour is voluntary behaviour. If the same voluntary behaviour is repeated often enough in the same environment then the Pavlovian principle of reflex chaining exerts its effects and the behaviour becomes 'automatized'. However, even though a behaviour may become automatic, the image is still produced but will only manifest its control "when the environment is suddenly changed" (Beritoff, 1963, p.348).

Beritoff also touched briefly on human voluntary behaviour. For this the concept is expanded to include images of planned conscious aims - these being of a verbal nature - which are added to the images of significant environmental objects to direct such voluntary behaviour. Finally, Beritoff claims that most behaviour is voluntary behaviour, especially when concerned with adaptation to the environment (Beritoff, 1963.). Therefore in Beritoff's model of voluntary behaviour, there was an affiliation of the concepts of 'adaptation','voluntary' and 'image'. However, an older contemporary of Beritoff, who also made use of the image concept and has been more influential in the West is Nicholas Bernstein.

Nicholas Bernstein

Nicholas Bernstein used a concept very similar to that underlying James' ideo-motor theory - his 'motor image' or 'program of a movement' - to account for the production of a movement. His writings have only recently begun to be appreciated in the West and the present account is based, in large part, on the excellent review of Bernstein's studies by C.G. Phillips and R. Porter (1977).

Bernstein was a mathematician by training, but he also extensively studied the movements of humans and animals. His mathematical background may have led him to apply "Fourier analysis" to the study of movement of a skilled rhythmic nature in humans, e.g. walking, hammering, filing and piano-playing, among others. His technique was to dress subjects in dark outfits, which had the limbs outlined in white tape or light bulbs; and to take motion pictures of the various actions. The patterns produced were then analysed as planar trajectories. Bernstein used Fourier analysis, a method named after the French mathematician by whom it was developed. It is concerned with sinusoidal oscillations which repeat themselves at regular intervals (cycles) and are a representation of all simple oscillations. The simple 'sine wave' is determined by three parameters: frequency, amplitude and phase. Frequency equals the number of cycles per unit time, usually a second. Amplitude indicates the magnitude of the excursion of the wave above and below a baseline. Phase is more complicated, for the term can be used in three senses: the reference phase orients the wave in time; the momentary phase can be any point in the cycle which captures interest; and the segmental phase is a segment of the cycle which is of interest. All uses of the term, phase, depend on the fact that simple oscillations repeat themselves at regular intervals; the complete cycle being 360 degrees. Thus, for example, if a sinusoidal oscillation had a frequency of one cycle per second, an amplitude of one unit and a phase of 0 degrees; the oscillation would start from baseline (0 degrees), rise to the +1 value (90 degrees), fall back to the baseline (180 degrees), continue its descent to the -1 value (270 degrees) and then rise again to baseline (360 degrees). At this time the 360 degree point would also be the 0 degree point of the next cycle. Fourier analysis makes it possible to describe extremely complex wave forms in terms of added or superimposed sine waves.

Bernstein discovered that he could account for repetitive, learned movements by choosing appropriate sinusoidal oscillations and their harmonies. The chosen oscillation was called the 'fundamental' and there was one fundamental for each plane of movement, therefore three fundamentals in all. A harmonic is an integer multiple of the fundamental's frequency. Thus, a third harmonic, for example, has a frequency that is three times that of the fundamental. Bernstein found that he rarely had to go beyond the sums of the fundamental and its first three harmonics, i.e. the Fourier trigonometric sums, to synthesize and predict the trajectory of the studied movements (Bernstein, N., 1967, pp.23-24). He proposed that the central nervous system possesses

> "... exact formulae of movement ... or their engrams, and these formulae or engrams contain in some form of brain trace the whole process of the movement in its entire course in time."
>
> (Bernstein, 1967, p.37).

Bernstein's interest would now be called motor control, concerned as it was with the role of the CNS in the control of movement. For him this was a hierarchical arrangement with the 'motor image' being at, or near, the top. The 'motor image' was conceived as a comprehensive engram or 'program' that was "simultaneously present in toto in the CNS"; it controlled other 'engrams' further downstream at the 'operational stages' which in turn could affect on-going movement via 'feedback' (Phillips, C.G., & Porter, R., 1977, pp.328-329).

Fig. 45 is a simple diagram of Bernstein's scheme. As one can observe, it has all the ingredients of the model mentioned in the introduction to this chapter. The legend is largely self-explanatory, but it should be pointed out that the function between (4) and (5) was conceived to be an oscillating, rather than a stabilizing one (Phillips, C.G. & Porter, R., 1977, p 330).

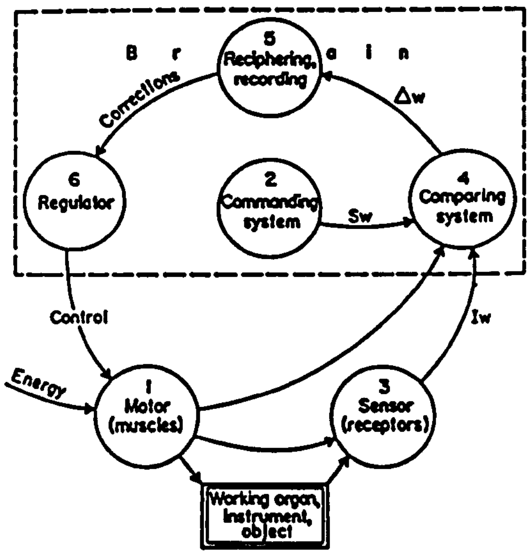


Fig. 8.2. Bernstein's 'simplest possible block diagram of an apparatus for the control of movements' (1957).
1, Motor output; 2, command system or control element specifying required value Sw (Sollwert) for time-course of 1; 3, receptors which detect *factual* time-course Iw (Istwert) of 1; 4, comparator which measures magnitude and sign of mismatch (Δw = Iw—Sw) between 2 and 3 (cf. Oscarsson, 1971: Chapter 4); 5, coding of correction signals for transmission to 6, controller of 1.

FIG. 45 Phillips, C.G. and Porter, R., 1977, p.331.

Bernstein's experiments which cover several decades, have been translated and published under the title The Co-ordination and Regulation of Movement (1967). Concerning this subject matter, Bernstein thought that it entailed '...the co-ordinational reflex is not an arc but a closed circle with functional synapses at both ends of the arcs' (Phillips & Porter, 1977, p. 331). Skilled movements tended to become automatized. That is, control receded from consciousness as the 'connections' involved in its execution were transferred to "lower levels of control" (Phillips, C.G., and Porter, R., 1977, p.33). Phillips and Porter go on to cite Bernstein's recognition that models and 'analogies' are not facts; much as James had perceived. Lastly, they justify their lengthy review of Bernstein, on the grounds that his conception of the 'wholeness' of movement anticipated many similar ideas which are emerging in the area of motor control today. The appreciation of his studies is further indicated by the fact that such a prominent neuroscientist as Karl Pribram has drawn heavily on Bernstein in presenting ideas of his own. For example, in his Languages of the Brain (1971) Pribram evolves a conception of the brain as an information-processing mechanism that monitors bodily action; not as a disconnected, successive series of movements, but as an organized achievement. Pribram hypothesizes that movements, monitored by the brain, are regulated by what he calls an 'image of achievement' which is predictively regulative and virtually identical to Bernstein's view. Another researcher, Eric Von Holst, not knowing of Bernstein's studies, nevertheless utilized the concepts of oscillations, comparators and images in his explanation of behaviour, although he didn't specifically use the latter term.

Erich von Holst

Von Holst worked in a field called behavioural physiology and studied organisms ranging from insects to mammals. He held that reflex chaining was inadequate to explain complex behaviour and criticised behaviouristic psychology for largely ignoring the role of the CNS in the generation of behaviour. His description of the CNS indicated an active organisation of behaviour rather than the passive connection of stimulus and response. This brought his views into close affinity with those of Bernstein.

In describing the central processes responsible for behaviour, Von Holst drew heavily on the concept of oscillators; which are conceived as neural circuits, whose electrical activity is not dependent upon input stimuli. He viewed overt behaviour as the outcome of the competition of two or more central oscillators. He generated most of his ideas from the study of 'medulla operated fish' which essentially gave him a simplified preparation with which to work, much as Sherrington's 'spinal dog'. By the detailed analysis of the fin movements, he was able to present a multitude of graphs, demonstrating what he called the superimposition and magnet effects. The former effect, superimposition, involves the combined output of at least two oscillators, which possess different frequencies. The two oscillators are added to, or superimposed on, one another. The result is a compound (mean) curve representing the combined output. In contrast, the magnet effect involves:

> "... the endeavour of one automatism to impose its tempo and a quite specific reciprocal phase relationship upon another."
>
> (Von Holst, E., 1973, Vol. I, p.25).

While superficially similar, they are importantly different effects because the magnet effect reflects the co-ordinating activity of one central oscillator upon another, while superimposition is related to the summed outputs of two such oscillators.

Further, Von Holst in his description of co-ordinated movement advanced two other concepts of much greater importance: reafference and efference copy. For Von Holst, reafference was a "direct consequence of an efference"; in contrast to exafference which was afference from the 'outside', i.e. environmental events acting on exteroceptors or proprioceptors (Von Holst, 1973, Vol. I, p.151).

He developed his ideas while using an experimental design which produced the optokinetic reaction. This reaction is a visual-motor servomechanism which tends to turn the insect in the direction of a visual stimulus. It can be studied in the laboratory by rotating the entire environment around the organism under examination. The effect of the optokinetic reaction is to reduce the velocity of the moving environment in relation to the organism's visual apparatus. It is a useful method of studying retinal events, central effects and motor responses.

Von Holst placed an insect inside a cylinder that was free to rotate; the inside surface of which was painted with alternating black and white stripes. Thus, if the insect moved, and the cylinder was immobile, an alternating black and white visual image would stimulate its retina; if the cylinder moved, and the insect was immobile, a similar retinal stimulation would occur. In the first case, the retinal stimulation was due to the insect moving; whereas in the second, the same stimulation was due to the environment moving. If the insect was moving, the sensory input was reafference; if the environment was moving, the sensory input was exafference. How can the organism distinguish reafference from exafference? Von Holst's answer was efference copy.

In Von Holst's hierarchically arranged nervous system, efferent (motor) signals descend from higher to lower 'centres'. As the message passes through each 'centre' on its way to the periphery, it leaves a copy of itself. Since Von Holst conceived of the CNS as constantly active, the efference itself is a specific change in descending impulses; and the efference copy is another closely correlated alteration in activity within the neural tissue which is participating in the movement. At each level or centre, the efference also produces a reafference signal which is then compared with the efference copy. If the two signals were equal and opposite in sign they cancelled one another, and the efference signal was terminated.

Von Holst always thought of the various signals as either being added to or subtracted from one another. If there is a mismatch between the efference copy and the reafference signal, the efferent 'command' will be increased or reduced until equilibrium is reached. In order to do justice to these concepts, fig. 45 is presented along with an explanation in Von Holst's own words:

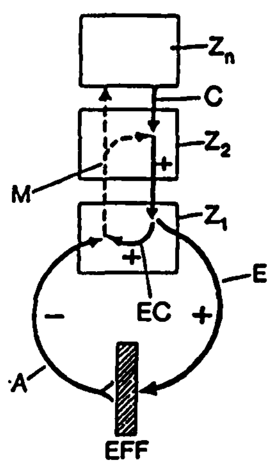


Figure 3.4. General schema for the explanation of the reafference principle.

Let us consider (Fig. 3.4) a given centre Z_1 which has sensory and motor connections with an effector EFF. This effector can be a muscle, a limb or the entire body. One or more further centres (Z_2 to Z_n) are superior to the centre Z_1. Any *command* from Z_n – i.e. a specific *change* in the stream of impulses descending to Z_1, produces an efferent series of impulses (E) from Z_1, which produces a closely correlated alteration in activity – the *efference copy*, EC – which spreads through the neighbouring ganglionic mass with a specific temporal delay. The efferent stream E flowing out to the periphery evokes the corresponding reafference A from the effector, and this reafference interacts with the efference copy. The efference and its copy can be arbitrarily marked with a plus (+), whilst the reafference is marked with a minus (−). The efference copy and the reafference exactly cancel one another out in Z_1, whilst the command descending from Z_n flows outwards without interruption. As soon as the entire afference is too large or too small, as a result of some *external influence* acting upon the *effector*, either a + or a − remains as a residue in Z_1. As we shall see, *this residue is transmitted* upwards, sometimes to the highest centres; it can be referred to as a *message*, M. The ascending message can branch in Z_2 on its way (although it *does not necessarily* do so), where once again it summates with the descending command. In this case, the system from Z_2 downwards will maintain itself in equilibrium, thus producing a *feedback system* of the kind recognized in technology.[1] Let us assume, for example, that an influence affecting the effector EFF produces an *increase* in the − afference in Z_1, in which case the ascending message to Z_2 *reduces* the + command until an equilibrium is reached once again. Conversely, an externally produced *decrease in* the − afference in Z_1 will bring about a + residue which will *amplify* the + command through Z_2. Thus, in both cases, *the efference is modified until no further message is sent out by* Z_1.[2] We have already encountered a feedback system of this kind in the example of postural orientation.

In addition, we can refer to the alteration of the afference which is *not* a direct consequence of an efference but arises through *external* influences (through proprioceptors or exteroceptors) as an *exafference*. The *exafference* in our schema is thus the + or − residue in Z_1 which proceeds upwards as the message.

FIG. 46 Von Holst, E., 1964, p.144

Thus, Von Holst used the term 'efference copy' much as 'corollary discharge' has been used by Roger Sperry (Sperry, R., 1950). Both terms denote a type of internal feedback within the CNS. Indeed, some authors have strongly associated 'corollary discharge' and 'efference copy' with the feedback concept (Miles, M.A., and Evarts, E., 1979). Whether these two former concepts are feedback or feedforward, depends upon where the output of the system projects. If it projects back to effect its own input, it would be feedback; if it projects to some other system's input to 'pre set' such input, it could be viewed as feedforward. These relatively simple concepts are potentially of great conceptual value, as the human-being with its incredibly complex CNS comes to be viewed more and more as a self-regulating mechanism.

Von Holst formulated the reafference principle and efference copy from the study of the optokinetic reaction in insects, and this led him to look at visual perception in humans. Further, it was in this type of experiment that he discussed voluntary commands. Utilizing the well-known phenomena that individuals, with paralysed eye muscles, see the environment move when they attempt to change their gaze; he postulated that this sensory illusion was a direct result of a voluntary command. The 'voluntary impulse' to move the eye sets up an efference copy which is not cancelled by reafference and thus the normally unconscious process intrudes into conscious perception. The same phenomenon is observed in the individual whose eye is mechanically held stationary. However, when normal individuals visually survey their everyday environment, it appears to be immobile. This is because motor processes are set up which anticipate certain sensory consequences and those consequences are met. At the end of the paper, in which he discussed this process, Von Holst laid out his 'actual goal'. After an attack on reflex theory as superstition, he stated:

> "... I regard it as particularly rewarding to demonstrate that active, spontaneous processes are not only present in active behaviour, but even in apparently passive scanning of the environment. Without these processes, the organism would not even be able to 'respond' in an appropriate manner."
>
> (Von Holst, 1973, Vol. I, pp. 218-219)

Von Holst's ideas also lend themselves well to contemporary views of motor porgrams in the generation of behaviour. For the possibility arises that a relatively small number of central oscillators can produce the bewildering number of behavioural variations seen in different species. The principles of reafference and efference copy are very similar to the concept of feedback and perform comparable functions. On the other hand, his view that the central oscillators can perform independently of sensory input approaches the idea of feedforward. Perhaps most important for us, is that, although he speaks of 'voluntary impulses' he does not mean processes independent of natural laws. The central nervous system in all of its awe-inspiring complexity is not an arbitrary system, and it obeys certain principles which are discoverable.

In addition, as stated at the beginning of the discussion of Von Holst's contributions, he never used the term 'image' in his account of the control of behaviour. However, his concept of efference copy lends itself well to such a term. For example, Auschauung, - a visualized picture of a physiological process - has been used to describe Von Holst's models, as contrasted with mathematical formulations of such processes (Jung, R., Kornhuber, H., and Da Fonseca, J., 1963). Indeed, Von Holst avoided detailed mathematical analysis in his studies, in contrast to Bernstein; and relied instead on an Auschauung.

Nonetheless, the notions of Von Holst as well as the other authors, although speculative, are attractive in the light of contemporary cybernetic viewpoints. After all, it is difficult, in a practical sense, to plan movement once and for all. It is widely accepted that, in order to achieve a certain goal, one's movement patterns may necessarily differ from one occasion to another. Nevertheless such ideas may give a conceptual framework within which movements, learned and unlearned, can be accounted for.

In closing this section, we have seen how several major opinion makers have used 'images' to account for the production of movement. For James, images established voluntary movement; but once established, such movement could proceed as automatically as involuntary movement upon which the former was founded. With Beritoff, voluntary movement was based on images, if not by definition, at least almost so; and as with James, such movements were built on involuntary responses and could become automatic. Bernstein made no major distinction between voluntary and involuntary behaviours, except possibly that the learning of skilled movements, - the redundant degrees of freedom of the movement being mastered - may require conscious attention but as they are learned they become, again, automatized. Von Holst was always adamant that all movement followed natural laws; and explicitly rejected any vitalist connotations of the term 'voluntary' or that voluntary movements were in any sense 'special'.

However, there have been other major authors who have applied their formidable intellects to account for voluntary movement and have developed a hypothesis radically different from the views of James, Beritoff and Von Holst. Importantly, this opposition comes from the very highest levels of scientific achievement and intellectual expertise. This is, of course, the dualistic hypothesis, based on the concept of 'mind', of

Sir John Eccles and Sir Karl Popper; a position which is also shared by the distinguished neurosurgeon Wilder Penfield.

The Use of Mind: J.C. Eccles

John Carew Eccles is undoubtedly one of the most distinguished, respected and influential neurophysiologists of the 20th century. Eccles' studies in neurophysiology have been standard-setting, particularly those concerning the microphysiology of neurones in the spinal cord and brain. By using both intra and extra-cellular recordings, Eccles and his colleagues demonstrated the general principles of synaptic action (Eccles, J.C., 1953; 1957; 1964). The subject matter addressed in these books consisted of the experimental research for which Eccles was awarded the Nobel Prize for Medicine and Physiology in 1963.

The first of these publications was entitled The Neurophysiological Basis of Mind, (1953) and in its final chapter, Eccles put forth a neurophysiological model of the 'will'. Thus he does not evade the so-called mind-brain problem, and points out some of the difficulties encountered when addressing this problem; the major dilemma being the existence of mental events themselves. Drawing on the views of Bertrand Russell, Russel Brain and Charles Sherrington; the following position emerges: 1) Mental events are non-inferential (Russell); 2) Mental events are known more directly than physical events (Brain); 3) Mind is a non-sensory concept, in that mental events are experienced, not observed (Sherrington). Given the inferred nature of physical objects and the 'directly known' nature of mental events, these positions are similar to that part of the Cartesian view which held that what we know best are the contents of our own 'minds'.

Further, in contrasting objective and subjective phenomena, Eccles maintained that all observation is primarily 'private and restricted' but achieves objectivity through language. For him this included physical as well as mental phenomena. He concluded:

> "... that mental experiences have the same validity that attaches to our perceptual experiences of 'things'."
>
> (Eccles, J.C., 1953, p.264).

Having stated this, Eccles went on to present a model of 'will' which has a major feature exhibited by 19th century vitalism - that is, the 'will' influences a 'special property' of the cerebral cortex. This special property:

> "... is exhibited by the dynamic patterns of neuronal activity that occur in the cerebral cortex during conscious states, and .... the brain by means of this special property enters into liaison with mind, having the function of a 'detector' that has a sensitivity of a different kind and order from that of any physical instrument."
>
> (Eccles, 1953, pp.267-268)

This may be perceived as a very idiosyncratic statement by an internationally known neurophysiologist. Nevertheless, Eccles asserted that, as all behaviour can be viewed as alterations in the spatio-temporal patterns of activity in the nervous system which, in turn, alters the musculature. Thus the 'will' is organized in some spatio-temporal fashion and for Eccles :

> "... the neuro-physiological hypothesis is that the 'will' modifies the spatio-temporal activity of the neuronal networks by exerting spatio-temporal 'fields of influence' that become effective through this unique detector function of the active cerebral cortex."
>
> (Eccles, 1953, p.277).

Moreover, for the 'will' to be operative, the cerebral cortex must be active, excited or desynchronized, i.e. low voltage, high frequency E.E.G. In such a state, the 'will' may influence on-going neuronal activity; not by the massive management of multitudinous neurones, but by 'influencing' a small number of critically effective synaptic contacts on a relatively small number of cortical neurones whose excitability level is at the threshold of discharge. But given the rapid nature of neurophysiological events (Eccles assumed one milli-second for synaptic events) the 'influence' of the 'will' could be quickly amplified and summated to alter the on-going spatio-temporary pattern. Further, for 'mind' to liaise with the cerebral cortex, only part of the latter - Eccles cited 10% - need be in the proper state of activity, that is, with the neurones on the verge of discharge (Eccles, 1953). Hence, at least some part of the cerebral cortex must be able to detect the 'extraneous influence' of the 'will', although Eccles did not commit himself, at this time, to any particular region of the structure.

An additional feature of Eccles' model is that it is 'interactive', or more correctly, it is a variant of interactive dualism. Thus, brain activity can affect 'mind' - this action is perception in Eccles' view - whereas when 'mind' activity affects brain - it is voluntary action. He, possibly wisely, does not elaborate on the nature of mind, except to point out its spatio-temporal nature. Finally, Eccles is quite willing to draw parallels between his 'will' and Gilbert Ryle's 'ghost in a machine'. But Eccles' 'ghost' delicately and subtly operates on those neurones just at threshold to discharge, and so alters the on-going spatio-temporal pattern of neuronal activity.

From this first attempt to account for voluntary activity, Eccles evolved a more elaborate scheme which took into consideration the growing data base concerning the structure and function of the nervous system. Put in the most general terms, the 'nervous system' is composed of numerous interacting sub-systems which are arranged in a hierarchical fashion, with 'higher' elements controlling 'lower' ones. Many times, the jargon of the electrical engineer finds its way into this description. For example, various circuits are diagrammed with 'open' and 'closed' loops, with 'feedback' and feedforward' mechanisms, while the learning of a movement is couched in terms of pre-programming various 'circuits'. For Eccles, this hierarchy has seven levels: from the motor unit of Sherrington (level one) through simple and complex spinal reflexes; the role of the cerebellum; the motor cortex-cerebellar 'loop'; to 'cerebrally initiated movement'; and finally 'freely willed actions' (level seven):

> "The hierarchical structure ... is more than a heuristic exercise. It represents operative characteristics of movements in all degrees of complexity. For example, in the execution of a voluntary movement, there is not only the performance of neuronal machinery in the hierarchical levels 6 and 7, but also subsidiary operations at all levels, with eventually the execution of a movement via motor unit activity at level 1. Furthermore, it is to be recognised that any one movement builds in its train all manner of movements of compensation and adjustment."
>
> (Eccles, J.C., 1975, p.84)

Thus, level 1 - the Sherringtonian motor unit - is the most peripheral structural basis of movement and "... all movements are ensembles or composites of contractions of individual motor units" (Eccles, 1975, p.61). There are about 200,000 motor units in the spinal cord of the human and with the exception of the head, their co-ordinated activity plays an essential role in all movement. Eccles' 2nd level is basically the structures studied by Ragnar Granit - that is, the motor unit plus muscle spindle activity and that of the 'gamma' (γ) motor neuron. Thus it seems that movement is not just a matter of the large alpha motor neuron 'firing' and contracting a muscle; but a complex interaction between the alpha motor neuron, the smaller gamma motor neuron (which innervates the muscle spindle) and the muscle spindle, whose activity is correlated with muscle length (Granit, R., 1970). The details cannot be entered into here, but this entity has been a much-explored and fruitful area of research for those concerned with motor control. Nonetheless, it is a very peripheral element.

Level 3 in Eccles' hierarchy draws again on Sherrington's study of the 'spinal' and 'decerebrate' cat. These experimental preparations involved the removal of the brain and brain stem of the animal in the first case, and the removal of the cerebral cortex in the second. The experimental results of the original Sherrington studies suggested that distant stimulation (e.g. of the ear) could entrain "..... complex alternating movements of the scratch reflex" (Eccles, 1975, p.67). Sherrington held the opinion that, conceptually, these levels are best viewed as being superimposed upon one another, and thus it follows that the first level - that of the motor unit - is the most, as it were, 'superimposed on' element in the hierarchy.

Ascending, Eccles relentlessly pursues the hierarchical notion and places voluntary movement - willed actions - at the very highest level (level 7). His excursion into the role of the cerebellum (levels 4, 5 and 6) is detailed far beyond the theme intended here. But let it be said that any future model proposing to describe cerebellar function must meet the standards set by Eccles and his associates (Eccles, J.C., Ito, M., and Szentagothai, J., 1967). Therefore, a few words are necessary which describe the role of the cerebellum in the production of movement.

Overall, the cerebellum is dominated by inhibition. All neurones, except the so-called granule cells, in the cerebellar cortex, are inhibitory; including the powerful Purkinje cells. The latter inhibit various sub-cortical cerebellar cells - the intracerebellar cells (ICNC) - and via these neurones the Purkinje cells present a 'negative' image of the excitation which converges upon them. Further, the Purkinje cells are organised as 'colonies', with each colony being composed of cells which have a related integrative function:

> "This colonial pattern is preserved in the distribution of Purkynje cell axons, which is evident by the discharge patterns to the nuclear neurones in respect of specific cutaneous and muscle inputs. Only in the light of this concept is it possible to explain how the cerebellum carries out its vital function in the control of movement."
>
> (Eccles, 1975, p.70).

Besides the colonial arrangements, Eccles emphasized the role of the cerebellum in the maintenance of posture, and 'automatic' movement; for these processes form a 'background discharge' upon which other evolving movement is superimposed. Figure 47 schematically represents Eccles' overview of cerebellar function.

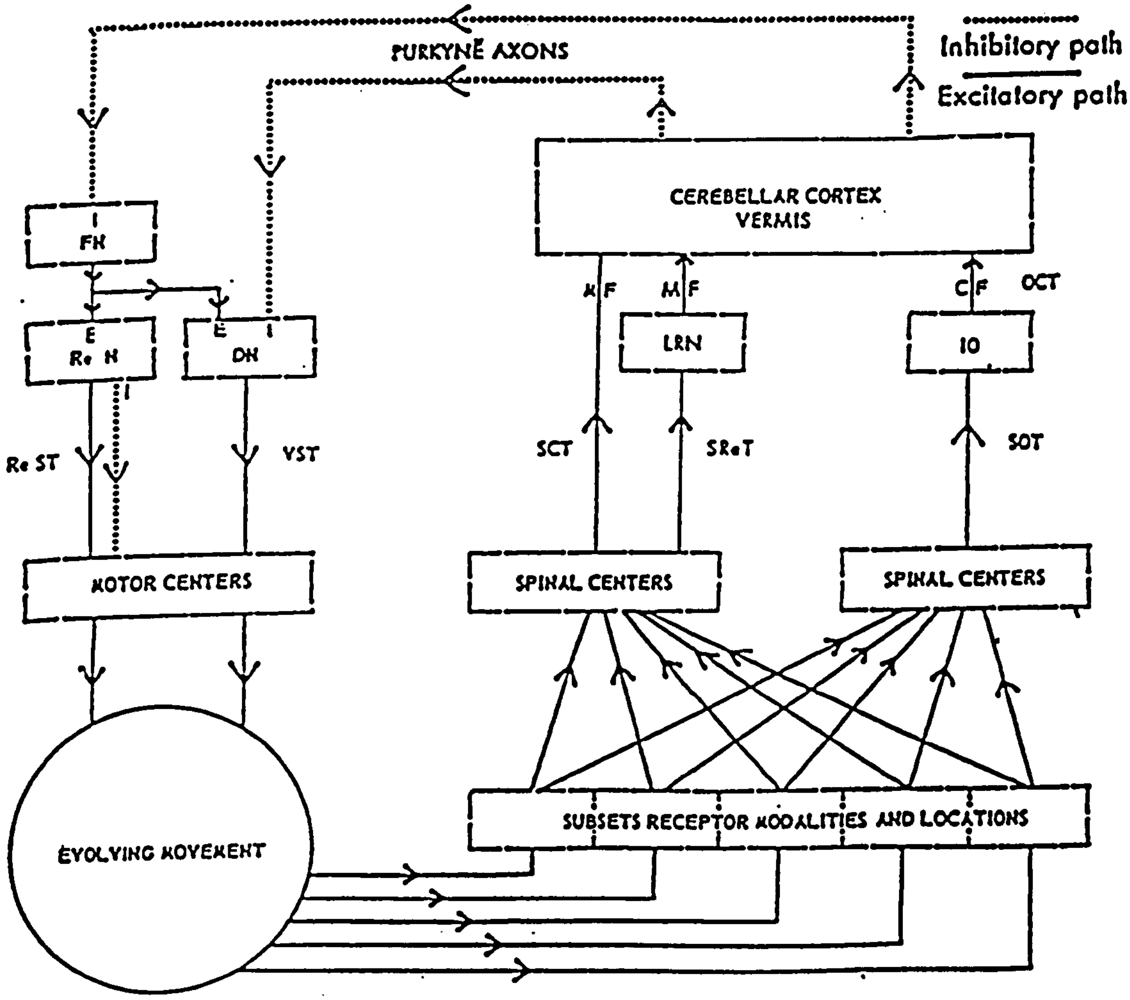


Fig. 12. Diagram showing in detail the pathways involved in the cerebellospinal circuits. The continuous and the dotted lines show respectively the excitatory and inhibitory neural pathways. Spino-olivary tract, SOT, to inferior olive, IO, with climbing fibres, CF, in olivocerebellar tract, OCT; MF, mossy fibres of spinocerebellar tracts, SCT; FN, nucleus fastigeus; ReN, reticular nucleus with reticulospinal tract, ReST; DN, Deiters' nucleus with vestibulospinal tract, VST; LRN, lateral reticular nucleus. (Eccles, 1969)*.

FIG. 47 Eccles, J.C.,1975, p.71.

The cerebellum can be functionally divided into three parts, and may participate in an equal number of hierarchical levels of motor control. Each part is responsible for a separate duty in the control of movement: first, posture and related 'automatic' movements are the responsibility of the vermis and its sub-cortical projection, the fastigial nucleus (FN).

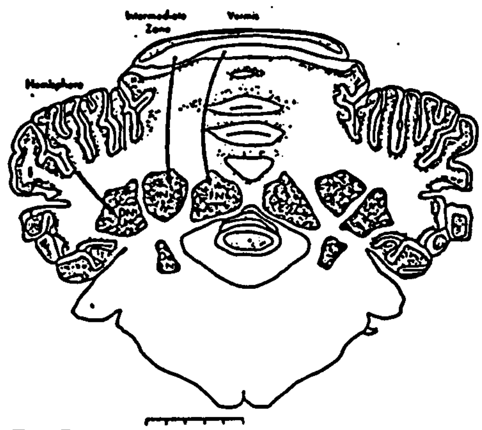


Fig. 7

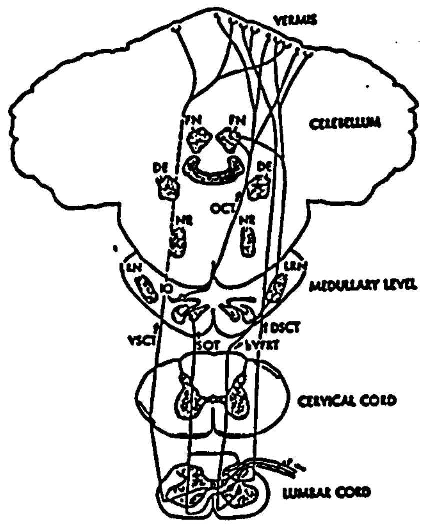


Fig. 8

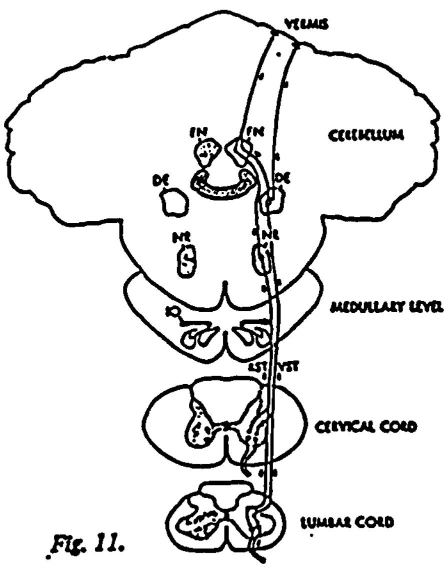


Fig. 11.

Fig. 7. Transverse section of cerebellum and brain stem along the transverse plane indicated in Fig. 6. The large arrows indicate the lines of projection from the cerebellar cortex to the cerebellar nuclei. FN, fastigial nucleus; IN, interpositus nucleus; DN, dentate nucleus; DeN, Deiters' nucleus.

Fig. 8. Diagram showing the pathways from the spinal cord up to the vermis of the cerebellum: FN, fastigial nucleus; DE, Deiters' nucleus; NR, medial reticular nucleus; LRN, lateral reticular nucleus; IO, inferior olive; OCT, olivocerebellar tract; SOT, spino-olivary tract; DSCT, dorsal spinocerebellar tract; VSCT, ventral spinocerebellar tract; bVFRT, bilateral ventral flexor reflex tract.

Fig. 11. Descending pathways from cerebellar vermis to spinal cord, diagrammed similarly to Fig. 8; and with similar symbols. RST, reticulospinal tract; VST, vestibulospinal tract.

FIG. 48 Eccles, 1975, top p.69; right p.69;bottom p.71.

Second, the interpositus nucleus (IN) and pars intermedia of the intermediate zone participate in:

> "... a dynamic loop concerned in the on-going correction of movements carried out via the motor cortex and pyramidal tracts."
>
> (Eccles, 1975, p.68).

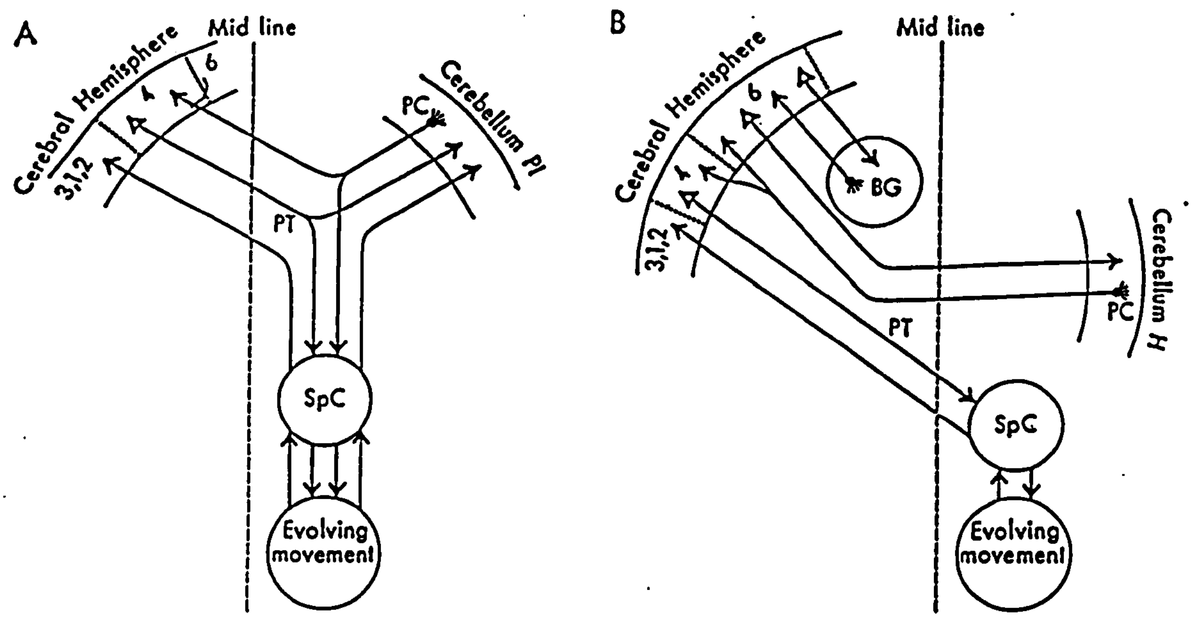


Fig. E3—6. Cerebro-cerebellar circuits in motor control are shown simplified by omission of the synaptic connectivities. A shows the circuits from pyramidal cell in motor cortex *(4)* via pyramidal tract *(PT)* to spinal cord, and so the evolving movement, and with collateral to the pars intermedia *(PI)* of the cerebellum. The Purkyně cell *(PC)* in *PI* communicates (via synaptic relays) back to the motor cortex and also down the spinal cord to the spinal centres *(SpC)*. Also shown is the projection from spinal centres to *PI* and to the somaesthetic area *(3, 1, 2)*. In B the circuits are shown from the cerebrum (principally area *6*) to the hemisphere *(H)* of the cerebellum. The return circuit from the Purkyně cell, *PC*, is back to areas *4* and *6*. From area *4* there is the projection down the spinal cord by the pyramidal tract, *PT*, as in A, and the return circuit from the evolving movement via the spinal centres to areas *3, 1, 2*. Additionally there is shown the circuit from area *6* to the basal ganglia *(BG)* and the return to the cerebrum.

Fig. 49 Popper, K., and Eccles, J.C., 1977, p. 289.

Last, and most important, Eccles conceives of the lateral 'hemispheric' area, and the dentate nucleus (DE) to which it projects, as performing an important role in 'pre-programming' voluntary movement.

Fig. 50 illustrates Eccles' adoption of the diagram of Allen and Tsukahara. The direction of the arrows indicates the sequence involved in the production of movement. The important feature, for us, is the suggestion that the voluntary movement is initiated by an 'idea'; thus harking back to ideo-motor theory. Presumably, the 'idea' would act on the 'pre-programmed' movements of the premotor association cortex.

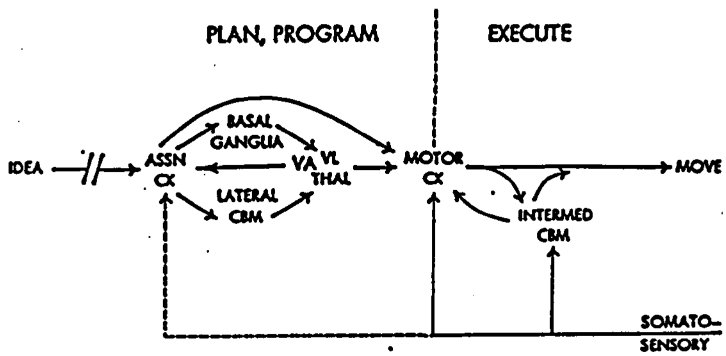


Fig. 1. Diagram showing pathways concerned in the planning, execution and control of voluntary movement. *ASSN CX*, association cortex; *lateral CBM*, cerebellar hemisphere; *Intermed CBM*, pars intermedia of cerebellum. Full description in text. Allen and Tsukahara [4]. *CF*, climbing fiber; *GrC*, granule cell; *IO*, inferior olive; *IP*, interpositus nucleus; *LPrC*, large pyramidal cell; *LRN*, lateral reticular nucleus; *MF*, mossy fiber; *PC*, Purkinje cell; *PF*, parallel fiber; *PN*, pontine nucleus; *PT*, pyramidal tract; *RN*, red nucleus; *RST*, rubrospinal tract; *SPrC*, small pyramidal cell; *VA(thal)*, ventro-anterior thalamic nucleus; *VL(thal)*, ventro-lateral thalamic nucleus

FIG. 50 Eccles, J.C., 1982, p. 609.

Allen and Tsukahara (1974) have made intensive experimental study of the association cerebral cortex and its connection with the cerebellar hemispheres and have concluded that the pre-motor association areas function in concert with the lateral cerebellum to 'pre-program' movement. In addition the basal ganglia are also involved, in a fashion similar to the cerebellar cortex; in the regulation and smoothing of evolving movement (Allen, G.I., & Tsukahara, N., 1974). We may now proceed to Eccles' most controversial level - level 7 - the level of freely willed actions.

Here Eccles draws on two recent sources: the electrophysiological experiments of Hans Kornhuber (1974) and the anatomical studies of Janos Szentagothai (1978). The latter has extended the colony concept of the cerebellum to the cerebral cortex, and has convincingly argued for a similar arrangement there. Thus, anatomically, the 'basic unit' of the cerebral cortex appears to be a column or module of about 110 cells composed of several types:

> "The operation of a module can be imaged as a complex of circuits in parallel with summation of hundreds of convergent lines onto neurones and in addition, a mesh of feed-forward and feedback excitatory and inhibitory lines ..."
>
> (Eccles, 1975, p.83)

Eccles used the neocortical modules, described by Szentagothai, as the 'detector' units postulated previously. These units are able to detect the influence of the 'pure-ego', and by entraining other aspects of the neural apparatus, execute its commands.

The 'pure ego' is manifested electrophysiologically by a slowly rising negative potential known as the Bereitschaftspontential, or readiness potential (RP). The RP apparently preceeds voluntary movement and was first described by Hans Kornhuber and Lüder Deecke. Kornhuber and his associates have conducted a long series of experiments which have attempted to identify the cerebral bioelectrical potentials underlying voluntary movement. Their data indicate that the RP is widespread and is seen in both hemispheres eventually coalescing over the motor cortex just before the onset of movement. This potential is perceived by Eccles as the "... neuronal counterpart of the voluntary command." (Eccles, 1975, pp.80-1). Its long rise time (about 0.8 secs.) suggested to Eccles that neuronal circuits were being pre-programmed prior to the discharge of the pyramidal tract (PT) neurones, and hence muscular contraction. For more details of Kornhuber's experiments, consult the section devoted to him .

It should be said that Eccles has not changed his initial position only his terminology. That is, the 'mind influence', 'pure ego' or 'self-conscious mind' are non-physical concepts, in the sense that they cannot be detected and measured; but nonetheless can influence on-going neuronal activity which is detectable by 'special properties' of the cerebral cortex. He also resists the identification of the mind with its neural effects.

Whereas Eccles was vague about the location of the mind-brain liaison areas in previous versions of his theory, in the mid-seventies he became quite specific: they were located in (i) Broca's and Wernicke's areas - those regions of the dominant hemisphere in the adult human most intimately concerned with language; (ii) The Parietal Lobe - particularly areas 39 and 40; and (iii) The pre-frontal lobes. Moreover the self-conscious mind can influence the minor hemisphere via the corpus collosum which connects the two. Hence the liaison to consciousness is restricted to the dominant hemisphere. In developing this point of view he draws upon the 'split brain' studies of Roger Sperry and his colleagues.

Moreover Eccles drew some explicit conclusions from his assumptions, the most interesting of which are that pre-language children do not possess a self-conscious mind and are therefore incapable of producing a voluntary movement. Furthermore no animal can produce such a movement because none have a language or a self-conscious mind. (Popper, K. and Eccles, J.C., 1977).

Eccles has felt the need to account for the apparent unity of conscious experience throughout a lifetime. A lifetime very often punctuated by unconscious states - mainly, sleep. He felt - rightly - that there wasn't an adequate neurophysiological theory that could account for this. He then extended this inadequacy to voluntary movement and the ability to remember previous events. Eccles perceived that these subjective features could be encompassed by such a concept as the self-conscious mind. He realized that the self-conscious mind and the physical nervous system must be able to influence one another. That is, the active neuronal machinery must reach the self-conscious mind and the self-conscious mind must be able to influence certain aspects of the neuronal machinery for voluntary movement to occur. The 'three-world' scheme of Sir Karl Popper gave him a philosophical framework in which to operate.

Popper divides the universe into three areas: World 1 - the world of physical objects, atoms, molecules, cells, nervous systems; World 2 - the world of mental states - this includes both conscious and unconscious states as well as 'psychological dispositions'; and World 3 - the world of human endeavour - tools, buildings, social institutions, works of art, scientific problems and theories etc. (fig. 51). This scheme was not an original of Popper's but nonetheless has been greatly exploited by him.

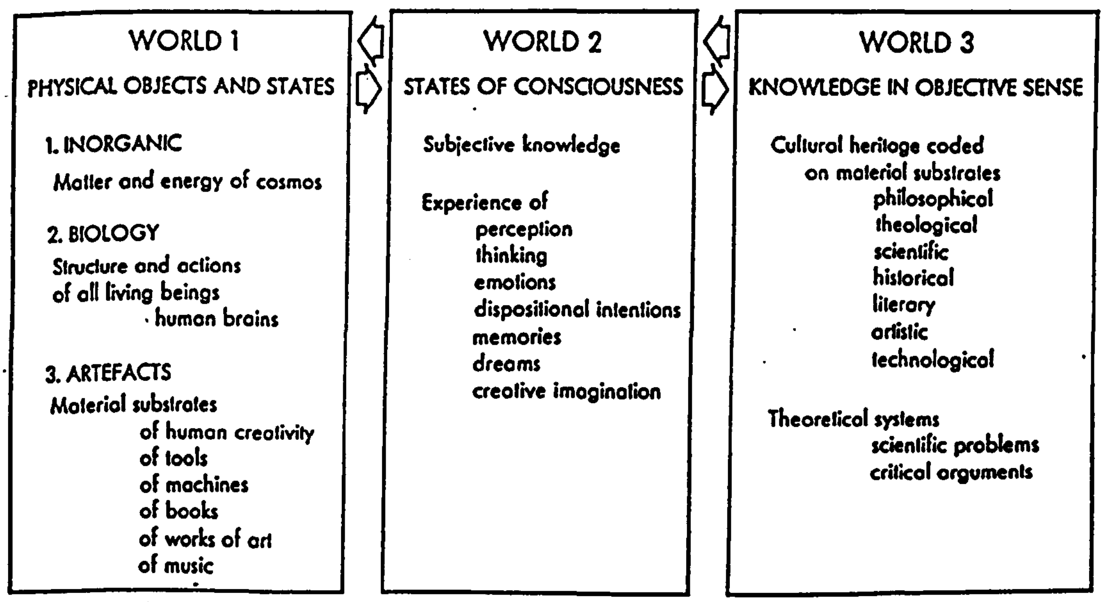


Fig. E7–1. Tabular representation of the three worlds that comprise all existents and all experiences as defined by Popper (Eccles, 1970).

FIG. 51 Popper, K. and Eccles, J.C., 1977, p.359.

The three Worlds can interact with one another as the arrows in FIG. 51 suggest. Some objects, say a work of art to use Popper's example, can be placed in all three Worlds. Importantly, the three Worlds' ability to interact is thought by Popper to be "... a decisive argument for calling a thing real." (Popper and Eccles, 1977, p.39).

Accepting the reality of the three worlds, their interaction has a major intellectual advantage - it presents an open universe. Open, that is, in the sense that one World can influence another and vice versa. This 'openness' was exactly the feature that Eccles needed for his 'mind influence', 'pure ego', or 'self-conscious mind' to influence neuronal activity as well as for neural events to influence the self-conscious mind. Thus he accepted Popper's variety of dualistic interaction in lieu of a materialistic theory that would tend to close 'World 1' from 'World 2'. Eccles accepted a strong dualist-interactionist explanation of mind/body interaction in order to contrast the active feature of the self-conscious mind with the passive aspects of mental experience as implied in materialism. The latter concept usually conceives of mental events as another aspect of neural events or as 'corresponding' to them or epiphenomenal to them in some way. (Popper and Eccles, 1977).

As Eccles developed his concept of the 'self-conscious mind', it accrued the characteristics familiar to vitalistic concepts in general, i.e. not detectable or measurable by scientific instruments as well as have a 'special' relationship with special properties of the cerebral cortex. Indeed, in The Human Psyche (1980) Eccles asserted the single most important feature found in the traditional vitalistic perception of the human being: he suggested that self-consciousness, or at least its 'psychic core', was supernatural in origin. Hence Eccles has suggested the ultimate separation of mind and body, which in turn would virtually preclude direct scientific enquiry (Eccles, J.C., 1980). For purposes of comparison a series of diagrams follows which illustrates the evolution of Eccles' thoughts on these matters.

The active causal effectiveness of the self-conscious mind is illustrated in fig. 52 . Note that it is an 'information flow diagram' as distinguished from an energy flow diagram because Eccles does not feel that the first law of thermodynamics is a significant obstacle to his concept of the mind/brain relationship.

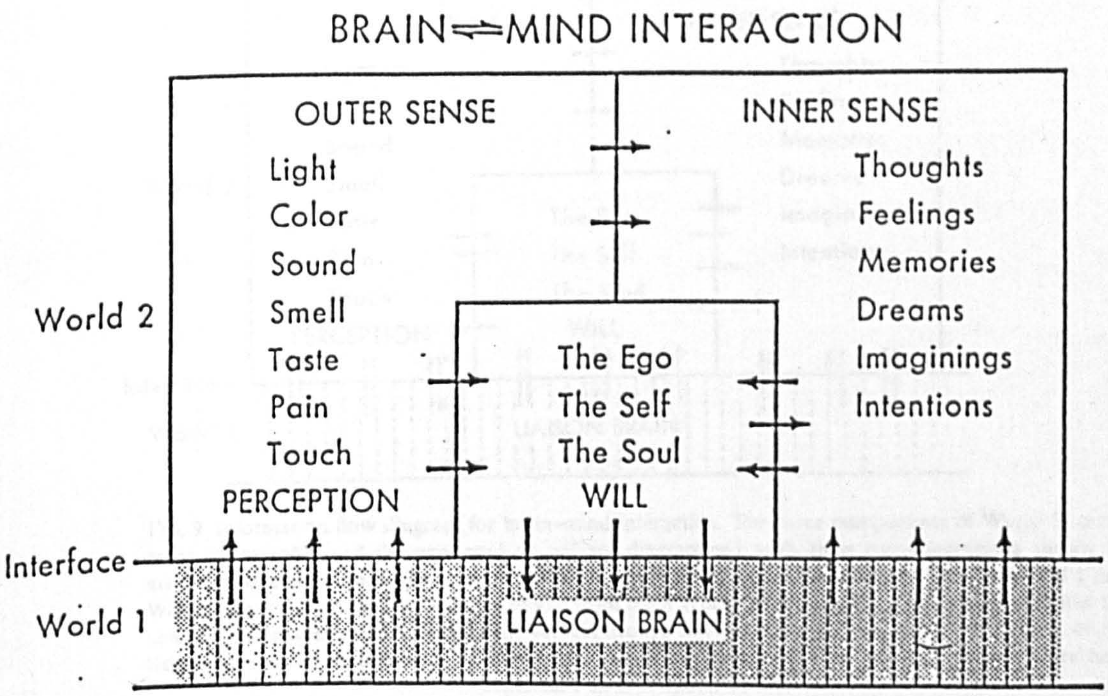


Fig. E7–2. Information flow diagram for brain-mind interaction. The three components of World 2: outer sense, inner sense and the ego or self are diagrammed with their connectivities. Also shown are the lines of communication across the interface between World 1 and World 2, that is from the liaison brain to and from these World 2 components. The liaison brain has the columnar arrangement indicated (cf. Figs. E1–5 and 6; E2–6 and 7). It must be imagined that the area of the liaison brain is enormous, with open modules numbering a hundred thousand or more, not just the two score here depicted.

FIG. 52 Popper and Eccles, 1977, p.360.

Eccles has continued the twin themes that brain-mind interaction occurs via the 'liaison brain' and that mental commands are expressed in the activity of cortical modules. The 'interaction' feature of his model has received further emphasis as indicated by the proliferation of reciprocal arrows between the 'liaison brain' (World I) and the inner and outer sense (World 2) (Figure 51). The self has developed direct as well as indirect reciprocal relationships with the outer senses. (Eccles, J.C., 1981).

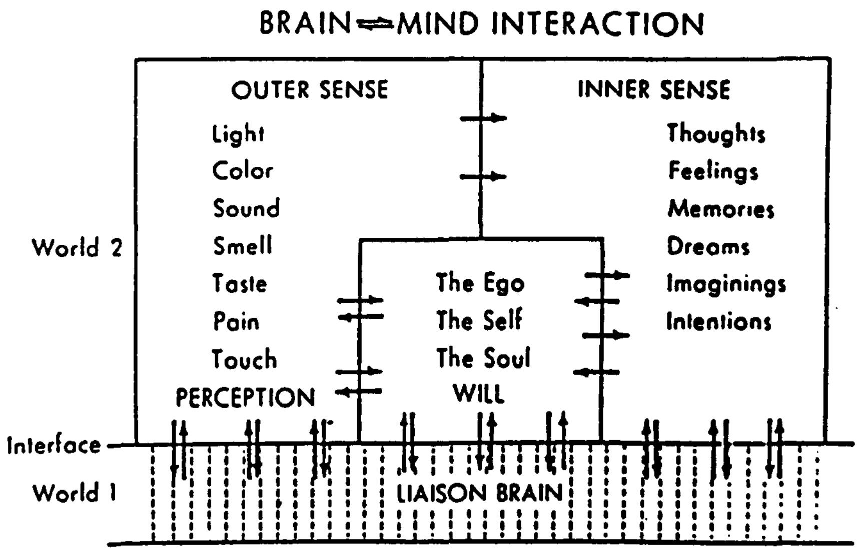


FIG. 9. Information flow diagram for brain–mind interaction. The three components of World 2: outer sense, inner sense and the ego, soul or self are diagrammed with their communications shown by arrows. Also shown are the lines of reciprocal communication across the interface between World 1 and World 2, that is from the liaison brain to and from these World 2 components. The liaison brain has the columnar arrangement indicated by the vertical broken lines. It must be imagined that the area of the liaison brain is enormous, with open modules numbering over a million, not just the two score here depicted. Full description in text.

FIG. 53 Eccles, J.C., 1982, p.1852.

For Eccles:

> "... mental events in World 2 and neural events in World I are independent entities that interact across the interface in the manner indicated by the reciprocal arrows which signify transmission of information, not energy. The neural correlates of the conscious experiences are in the neocortex - the liaison brain, with its modular columns."

(Eccles, 1981, p.1850).

More recently Eccles has drawn upon

> "three independent lines of experimentation that, since 1979, have wrought a transformation of the scientific evidence relating to voluntary movement. All three indicate that in voluntary movement the initial brain actions are exhibited in the supplementary motor area (SMA)."
>
> (Eccles, J.C., 1982, p.271)

The SMA was described in humans by Wilder Penfield in his extensive electrical stimulation studies of the cerebral cortex. Penfield located the SMA almost entirely within the interhemispheral fissure and considered it to be the medial part of the 'premotor area' (PM) - area 6). His electrical stimulation of the SMA most often produced co-ordinated changes in posture and movements of the upper limbs. Vocalizations were also frequently evoked, but ongoing speech was arrested by electrical stimulation. Furthermore unilateral ablation of this area was followed by post-operative slowness of movement in the contralateral extremities. (Penfield, W. and Jasper, H., 1954). In primates ablation of area 6, which included the SMA, has produced spasticity as contrasted with the flaccid paralysis which follows area 4 (primary motor cortex) lesions. (Brinkman, C., 1982).

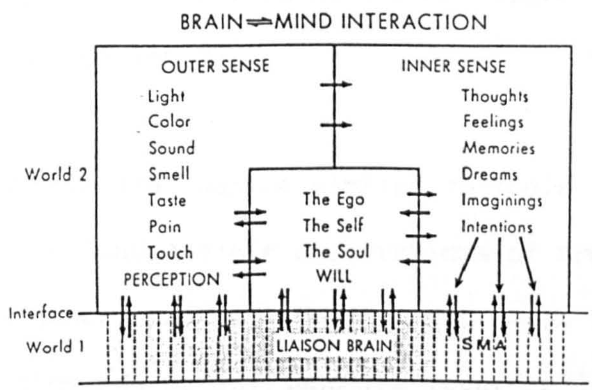


FIG. 7. Information flow diagram for brain – mind interaction in human brain. The three components of World 2, outer sense, inner sense and psyche or self, are diagrammed with their communications shown by arrows. Also shown are the lines of communication across the interface between World 1 and World 2; that is, from the liaison brain to and from these World 2 components. The liaison brain is the columnar arrangement indicated by the vertical broken lines.

FIG. 54 Eccles ,1982, p. 280.

Concerning the SMA, the first line of evidence cited by Eccles focused on the studies of Brinkman and Porter (1979, 1982). These experiments used Java monkeys (Macaca fascicularis) as subjects. Bilateral single cell activity in the SMA was recorded by chronically implanted electrodes when the animals performed a simple learned task, which could be executive with either hand. The monkeys were trained for 3-6 weeks to pull a horizontal spring-loaded lever from an initial position to a 'target zone'. The lever was to be held in the 'target zone' and released upon the presentation of an auditory signal. If the task was completed successfully the subject was immediately rewarded with food. The task was always performed with either one hand or the other, never with both at the same time. The experimenters reported the most common finding to be bilateral activity in the SMA about 250 milliseconds before the onset of a unilateral movement as measued by Electromyogram (EMG) (Brinkman, C. and Porter, R., 1979).

Evarts (1982) has established through well confirmed experimental data that the earliest pyramidal cell activity of the primary motor cortex (MI) occurs 140-120 milliseconds (MS) before the onset of movement; with most activity occurring 40-60 ms prior to the muscular response. Therefore the neurons of the SMA appear to 'fire' at least 100 ms before those of the MI.

Using an experimental design similar to their 1979 study, Brinkman and Porter (1982) extended their observations of area 6 to include not only the SMA but other parts of the pre-motor area (PM) as well. In addition, after they had established the lever-pulling response in the monkeys, they then surgically severed the corpus collosum of their subjects and repeated the experiment.

Brinkman and Porter (1982) reported part of the PM exhibited neuronal activity very similar to the activity of the SMA; that is, bilateral PM discharges preceding assumed MI activity during a unilateral task. Brinkman and Porter did not directly measure MI activity in either experiment. After commissurotomy, PM activity resembled the traditional profile of MI neurones immediately preceding movement, i.e. two-thirds of the PM neurones discharged were associated with only contralateral movements. The previous bilateral activity of the PM was apparently suppressed. However, the SMA responses continued to be bilateral, with no significant decrease in the number of active cells (Brinkman and Porter, 1982).

The second line of evidence was drawn from a regional cerebral blood flow (rCBF) study of P.E. Roland and his associates. Roland et al, 1980 used a multidetector scintillation camera (gamma camera) with 254 channels to detect the clearance of ^{133}Xe radioisotope injected into the internal carotid artery. The clearance of this radioisotope is an index of rCBF; based on the hypothesis that neuronal activity, cerebral oxygen consumption and cerebral blood flow are related.

Normal, conscious human subjects were <u>instructed</u> and trained to complete a complex unilateral finger-thumb touching sequence within a set time limit, about one minute, beginning the sequence 10 seconds before injection of ^{133}Xe. The eyes and ears of the subjects were covered with cotton wool to eliminate visual and auditory feedbacks although cutaneous and proprioceptive feedbacks were prominent.

Among the results reported were statistically significant increases in rCBF bilaterally in the SMA and unilateral increase in the MI during the execution of the motor-sequence test. More intriguing, however, was the reported bilateral increase in rCBF in only the SMA (60% of execution values) during 'internal programming' (mental rehearsal) of the motor-sequence test. Increases in rCBF in other parts of the cortex were not observed during the rehearsal segment. MI was reported to be completely inactive during this period as well as there being no detectable EMG or movement of body parts. Thus the SMA and only the SMA was active when the subjects mentally practiced executing the motor-sequence test without actually doing so (Roland, P.E., Larsen, B., Lassen, N.A. and Skinhøj, E., 1980).

Eccles' third line of evidence defining the SMA as the cortical area involved in the initiation of voluntary movements was, again, certain electrophysiological experiments of Hans Kornhuber and his colleagues. For example, Deecke and Kornhuber (1978) examined the profile of the readiness potential (RP in patients with bilateral parkinsonism. Subjects which exhibited pronounced akinesia but very little tremor were selected and age-matched with healthy control subjects. The required response was pulling the trigger of a pistol with the onset of movement measured by EMG.

These researchers reported that when the RP parkinsoniam patients were compared with that of normal controls there was no statistically significant difference between amplitude of the RP of the vertex (SMA) lead or parietal leads. Furthermore, the SMA lead exhibited a greater amplitude of the RP than the parietal leads. However, the RP of the lateral pre-central leads, which were over the hand area of MI, in the parkinsonian subjects, was either absent or showed slight positivity whereas the controls demonstrated the usual clear negative precentral RP. The difference between the groups was statistically significant. Since the MI of the parkinsonian subjects the MI was intact and functioning it was conjectured that lesions of basal ganglia, which are a prominent feature of parkinsonism, contributed to the abolishment of the pre-central RP.

These data have led Eccles to maintain that the SMA carries an inventory of all 'motor programs' which he operationally defines as:

> "an organized assemblage of muscle contractions and relaxations for bringing about a particular learnt movement."
>
> (Eccles, 1982, p.270).

The variety of such programs is 'incalculable' and are stored, not in the SMA, but in the association cortex, basal ganglia and cerebellum. Eccles conjectured that a specific mental code carries each intention. The mental code 'selects' a motor program from the SMA's inventory which in turn activates the program using the address system outlined by Allen and Tsukahara (1974). Figure 55 is the most recent modification of their scheme by Eccles. Note that the SMA is interspaced between 'idea' and the rest of the system. He considers this a vast improvement over his previous speculations.

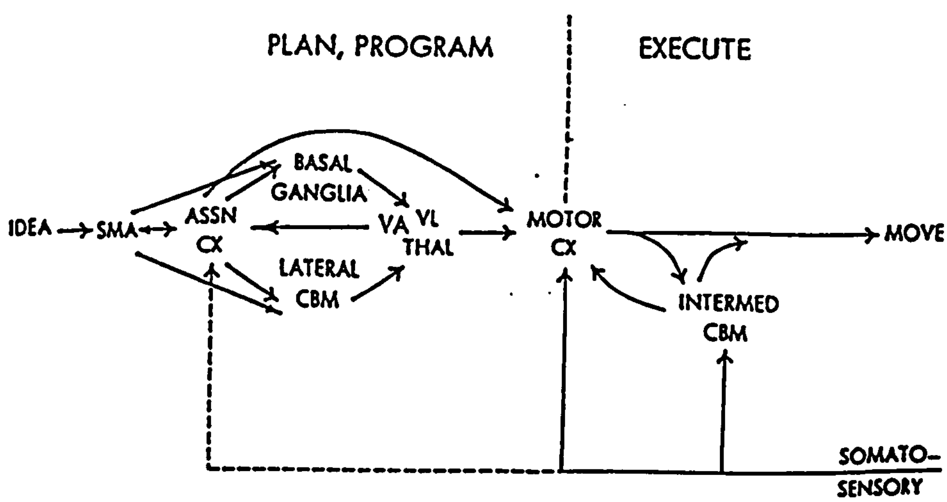


FIG. 6. Diagrammatic representation of pathways concerned with the execution and control of voluntary movement ASSN CX, association cortex; lateral CBM, cerebellar hemisphere; intermed. CBM, pars intermedia of cerebellum. The arrows represent neuronal pathways composed of hundreds of thousands of nerve fibres (modified from Allen & Tsukahara 1974).

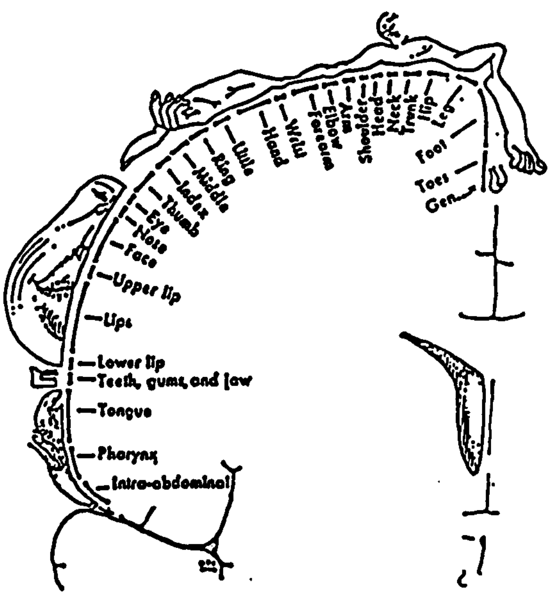
FIG. 55 Eccles, 1982, p.279.

Indeed, Eccles has repeatedly demonstrated the ability to adduce the most recent neurophysiological data to confirm his dualistic hypothesis. This is partly due to his comprehensive knowledge of the field - both its content and techniques. However, it is also arguable that a strong vitalistic concept such as a self-conscious mind - of possible supernatural origins - can foster a theoretical framework the robustness of which would be almost without limit. No matter what new developments emerge concerning the role of the central nervous system in 'voluntary' behaviour, a self-conscious mind - or its conceptual analogue - can always be postulated to fill in any gaps in such knowledge. Even if no gaps existed, it could be viewed as the 'real', but not directly observable, source of voluntary behaviour. A source which would be immune to scientific study as it is presently known. Nonetheless, John Eccles has been a potent force in bringing to the fore such traditionally intractable and important problems as that of the relationship between mental and physical events. Whereas Eccles, in pursuing his speculations, never has been overly disturbed by the problem of 'energy transfer' between mind and brain, another researcher, while eventually postulating 'mind' in his account of voluntary behaviour, was deeply concerned with this issue; he was the internationally acclaimed neurosurgeon, Wilder Penfield.

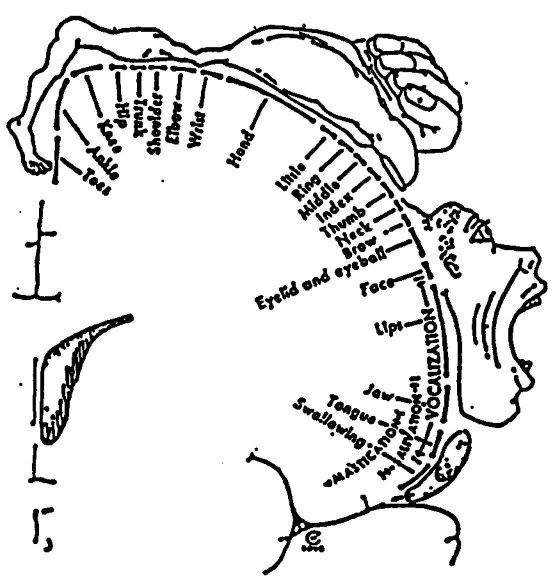
Wilder Penfield

Penfield and his co-workers at the Montreal Neurological Institute have made very important contributions to the literature concerned with cerebral function by utilizing the method of mild, direct electrical stimulation of the cortex in fully alert, fully conscious humans (Penfield, W. and Rasmussen, T., 1950; Penfield, W. and Jasper, H.H., 1954; Penfield, W. and Roberts, L., 1959).

A major result of these clinical studies has been, of course, the universally recognised sensory-motor homunculus; which at the time, was a major conceptual advance. It revealed that there is not an equal distribution of muscle 'representation', but that greater areas were given to the hand and vocal apparatus. Eccles has noted that 'finesse' of control seems to receive the largest representation in this case instead of size of muscles.



4.5. Sensory homunculus. The right side of the figure is on a cross-section of the hemisphere, drawn somewhat in proportion to the extent of sensory cortex devoted to it. The length of the underlying block lines indicates more accurately the comparative extent of each representation. Compare with 4.6. From Wilder Penfield and Theodore Rasmussen, *The Cerebral Cortex of Man* (New York: Macmillan, 1950).



4.6. Motor homunculus. The right side of the figure is on a cross-section of the hemisphere. Compare with 4.5. From Wilder Penfield and Theodore Rasmussen, *The Cerebral Cortex of Man* (New York: Macmillan, 1950).

FIG. 56 Granit, 1979, pp.64/65.

Penfield's work involved hundreds of operations and stimulation procedures. His data led him to note that the human cerebral cortex was marked by vast increases of areas that are hereditarily undetermined (uncommitted) with respect to their specific functions, allowing its 'programming' or conditioning by experience; in contrast to 'committed' areas which were given to sensory and motor functions of various types (Penfield, W., 1975).

Although all the cerebral cortext of humans exhibits large increases compared with other species, it is the uncommitted areas which show the greatest enlargement: the latter areas are made up of two major regions - the prefrontal and temporal cortices. Fig. 57 illustrates these enlargements.

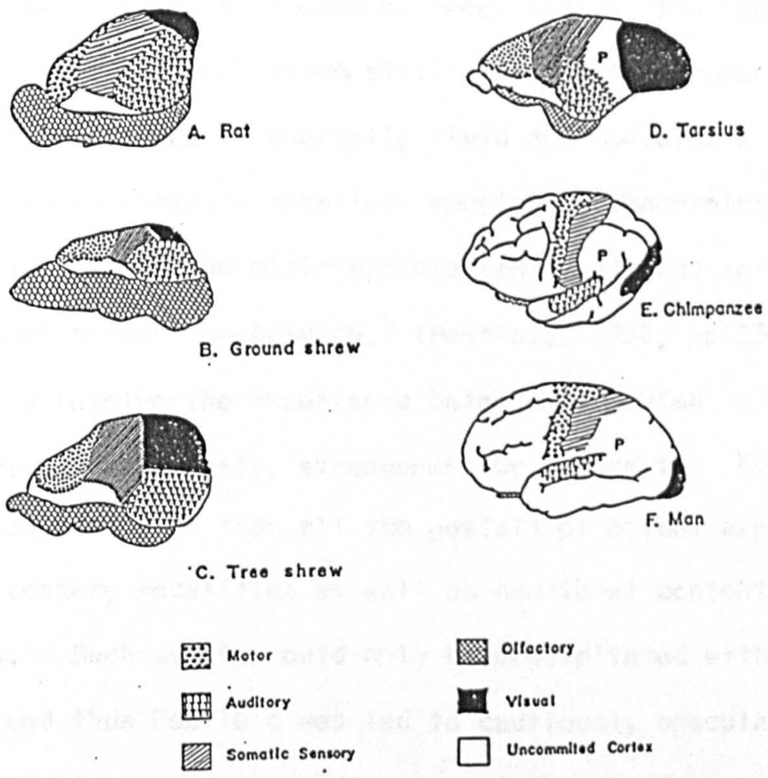


FIGURE 2. *Uncommitted Cortex.*

Functional diagrams of the cerebral cortex of some mammals. The blank areas suggest the approximate extent of gray matter that is not committed to motor or sensory function at birth. In man, for example, the auditory sensory-cortex has really been crowded off the external surface of the brain into the fissure of Sylvius. For this figure, I am indebted to the late Stanley Cobb.

FIG. 57 Penfield, W., 1975, p.20.

Functionally, Penfield assigned the 'capacity for planned initiative' to the prefrontal cortex; whereas in the temporal region the capacity for speech develops, as well as the ability to interpret "present experience in the light of past experience" (Penfield, 1975, p.19). Hence he has labelled this region the interpretive cortex. Out of all Penfield's studies those concerning the interpretive cortex have yielded the most controversial results. It was from this area that:

> "... positive psychical responses which have been produced by electrical stimulation ... are clearly of a different physiological order from those produced by stimulation elsewhere in the brain."
>
> (Penfield, W., 1958, p.20)

Put very briefly, these "psychical responses" are divided into two categories: (1) experiential hallucinations; (2) interpretive illusions.

In hallucinations of experience or recollection the subject relived a period of the past although he was still aware of the present. This recollection of experience is unusually vivid and contains a richness of detail unknown in voluntarily recalled memories. Concerning interpretive illusions, "This is a sudden misinterpretation or altered interpretation of the meaning of present experience." (Penfield, 1958, pp.23-4). Many times this would involve the experience being interpreted in such fundamental precepts as familiarity, strangeness or absurdity. Further, these evoked events carried with them all the gestalt of actual experience including all sensory modalities as well as emotional content and interpretation. Such events could only be precipitated within the temporal lobe, and thus Penfield was led to cautiously speculate that this portion of the brain was necessary for the storage and/or retrieval of memory (Penfield, W., 1952).

It should be pointed out that Penfield was well aware that the neural tissue directly beneath his electrode may not be the actual site of memory storage; but that it could activate other areas, distant from the stimulated site (Penfield, W., 1959). Indeed his surgical experience has led him to believe that the hippocampus is a key structure in converting experience into memory (Penfield, W. & Mathieson, G., 1974). This feature is part of the limbic lobe of Broca and has been implicated in the expression of emotion by Papaz (Papaz, J.W., 1937). It is also prominent in the "limbic system" of MacLean (MacLean, P.D., 1952). The group of structures which make up this system have numerous connections with the diencephalon which encompasses the thalamus, epithalamus and the hypothalamus (Ransom, S.W. and Clark, S.L., 1959).

In Penfield's view, the diencephalon is the single most important structure in the human brain; for it is the seat of his so-called centrencephalic integrating system. This functional system is composed of two parts: a) the highest brain-mechanism which is essential for consciousness and voluntary movement; b) the automatic sensory-motor control mechanism which is responsible for the more-or-less automatic discharge of behaviour. By working in concert the two subsystems:

"... make sensory input available and motor output purposeful." (Penfield, 1975, p.44). Moreover while the centrencephalic system is normally a functionally integrated unit, the sub-units can be separated.

Penfield explains that when the automatic sensory-motor mechanism is functioning without participation of the highest-brain mechanism (e.g. due to pathological conditions such as epilepsy); a mindless automaton results. This automaton can perform highly complex acts without any learning or memory being established. Further, one of the most important aspects of the 'automatism' is that it cannot make decisions. For example, if events in the environment require a change in on-going behaviour, the automatic sensory-motor mechanism fails to respond appropriately. If the environment demands a rapid change of behaviour or a 'choice' to be made; the highest brain-mechanism must be functioning for the demand to be appropriately met (Penfield, 1975).

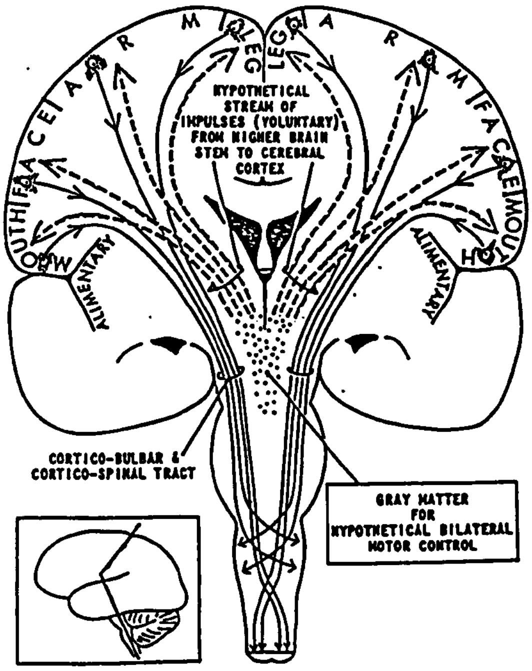


FIGURE 10. *The Automatic Sensory-Motor Mechanism.*
This much-simplified diagram outlines only the direction of the executive, or motor, messages of the mechanism that takes bilateral control of the body either under direction of the mind or automatically. It makes use of the motor cell-stations in the precentral gyrus of both sides, as shown here from leg down to face and mouth. The entire mechanism is a portion of the centrencephalic integration and coordination that makes effective mind-action possible. One may call it "man's computer." It makes available the many skills (including that of speech) that have been learned and recorded in the individual's past. It controls the behavior of the "human automaton" while the mind is otherwise occupied, or when the highest brain-mechanism is selectively inactivated, as in epileptic automatism. On the other hand, epileptic discharge within its central gray matter produces interference with its function, and calls forth active responses from the motor centers in the cortex of both hemispheres, thus producing a generalized convulsion (*grand mal*). (Drawing by Eleanor Sweezey.)

FIG. 58 Penfield, 1975, p.41.

Fig. 58 diagrams Penfield's suggestion that the centrencephalic system is the source of voluntary movement. Thus, for Penfield, voluntary movement is a sub-cortical function; and the motor cortex is a final 'relay station', rather than the area of initiation of such movements. On this latter point, he is in agreement with Eccles except that Penfield assigns the initiation of voluntary movements to the diencephalon instead of the self-conscious mind.

However, late in his career Penfield did make a place for 'mind' in his scheme of things. Interestingly, his doing so grew out of his studies of those very areas that Eccles had delineated for his 'liaison brain'; that is, the areas of Broca and Wernicke - the areas of speech. Space restrictions preclude the recording of details and nuances of Pinfield's clinical studies, interesting as they may be; (see Penfield, 1975, 1968). Nonetheless, let it be said that stimulation of speech areas inhibits on-going or attempted speech. The patient's efforts to speak and their later verbal reports convinced Penfield that he was on the 'psychico-physical frontier', where mind meets brain (Penfield, 1975, p.53).

Penfield tells us that for most of his professional career he was an advocate of the 'one-element hypothesis'. By this he meant a variant of psycho-physical parallelism in that the

> "... activities of the highest centres and mental
> states are one and the same thing, or are
> different sides of the same thing."

- apparently a position also held by John Hughlings Jackson and Edgar Adrian (Penfield, 1975, p.114). However the 'later' Penfield found this position inadequate and as he perceived that the only other alternative was a dualistic one he chose the latter of these two 'improbabilities'; thus joining his contemporary, John Eccles. It is of interest to note in passing that both Eccles and Penfield were students of Charles Sherrington, who also thought dualism was the most reasonable hypothesis.

Penfield's dualism was less extreme than that of Eccles in that his 'mind' was much more dependent on the brain than Eccles' 'self-conscious mind'. His 'mind' assumed the responsbility of directing voluntary action, focussing attention, reasoning, understanding, as well as deciding what was learned and what went into memory stores. Although, again unlike Eccles' conception, it did not have a memory of its own. Further, and this is of great importance, Penfield's 'mind' depended on energy to discharge its duties. Indeed, for him, mind-brain interaction can:

> "... only be brought about by expenditure of energy."
>
> (Penfield, 1975, p.76).

He felt so strongly on this point that he postulated an unknown 'second' form of energy involved in the mind-brain interaction and called upon physicists for help in finding it. In addition, he speculated that if the mind survived death it would have to do so by finding some form of energy to sustain it. He concluded his thoughts on this topic by stating:

> "... I believe that one should not pretend to draw a final conclusion, in man's study of man, until the nature of the energy responsible for mind-action is discovered as, in my own opinion, it will be."
>
> (Penfield, 1975, p.144)

Thus Penfield, as had Eccles, conceived of voluntary movement as a 'special' form of movement. But in doing so, both authors felt the need to evoke a separate entity - a mind - capable of an existence independent of the brain. Such views are held here to be vitalistic and as such they do not lend themselves to the possibility of empirical verification or falsification. Therefore their scientific fruitfulness will prove meagre.

Interestingly, when the 'early' Penfield conjectured his centrencephalic system - to which the 'highest brain mechanism' as assigned - to be sub-cortical; it was a penetrating insight, which contemporary neuroanatomy and neurophysiology has confirmed. Neuroanatomically, a major advance has been the elegant studies of Walle H. Nauta, which have convincingly shown that the connection between the limbic system and the frontal lobe are so massive that the latter is now considered a direct outgrowth of the former (Nauta, W.J.H. and Feirtag, M., 1979). Neurophysiologically, the concept of 'goal-directed' and/or 'purposive' behaviour has been very useful to a number of researchers who have been interested in the role of the central nervous system in the production of movement. Sub-cortical structures are most often thought to be the neural substrate of goal-directed behaviour. We will now turn to the role of 'goals' in the explanation of behaviour. This discussion includes studies directed not only at central nervous structures, but peripheral ones as well.

The Use of Goal Direction or Purpose: Ragnar Granit

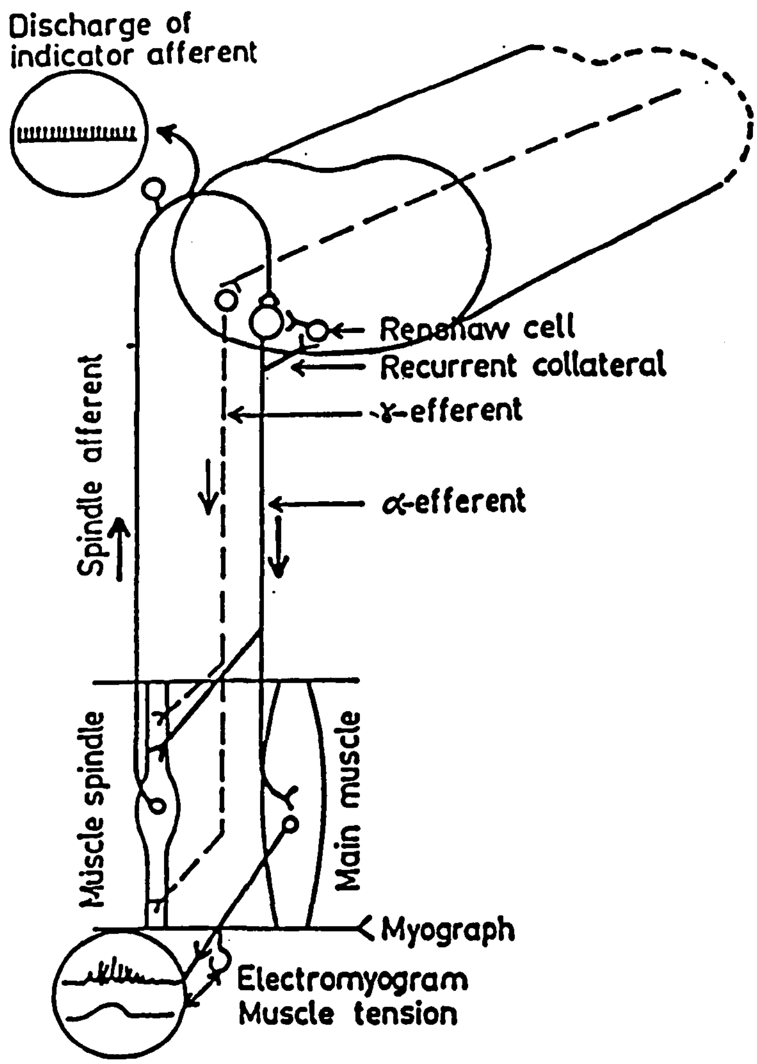
The Nobel Laureate, Ragnar Granit, has spent much of his professional career studying the interaction between the motor unit of Sherrington - the alpha motor neuron and the muscle fibre it innervates (the extra-fusal fibre) - and smaller gamma motor-fiber which innervates the muscle spindle (the intrafusal fibre). The alpha and gamma motor neurons represent the most peripheral neural structures involved in the production of movement, and it is recognized that all movement must be expressed through them. This being the case it is obvious that when studying such structures one is presented with the 'degrees of freedom' problem discussed earlier. It was recognition of this fact that led Granit to realize that some organised constraint must be placed on alpha-gamma activity in order for movement to occur in a co-ordinated fashion (Granit, R., 1973). This constraint for him is embodied in the concept of 'purpose'.

> "An essential point to remember is that this movement itself is the integrater, either of a sensory input or of something stored that emerges as a voluntary or an automatic analysable act. This means that the element of purposiveness and thus of production is very much in the foreground in the motor field, so much so that non-purposive movements tend to be regarded as outright pathological."
>
> (Granit, R., 1979, pp.134-135)

and more explicitly

> "What is volitional in voluntary movement is purposive."
>
> (Granit, R., 1979, 176)

The structures studied by Granit and his associates are illustrated in figure ( ). The exact nature of the inter-relationships between the alpha motor neuron, the gamma motor neuron, the muscle spindle and their inter-connections within the spinal cord is considered an internal debate in neurophysiology, for the purposes of this thesis. Suffice it to say that this area has been a major field of research in the attempt to explain the production of movement. For an expansion of these topics consult Granit's The Basis of Motor Control, 1970, as well as M.T. Turvey's review (1977).



7.1. Diagram of extrafusal and intrafusal innervation of muscle and the circuits involved. The muscle spindle with its large primary afferent placed in parallel with the main muscle, sends its message monosynaptically to the motoneurons in the spinal cord. The ventral horn cell is provided with a recurrent collateral through the Renshaw cell. The gamma motor nerves (broken line) lead to the muscular poles of the spindle which they contract, thereby exerting a pull on the sense organ. The supraspinal control of the gamma motoneurons is indicated (within the spinal cord). For analysis, this circuit can be intercepted at several points but the diagram shows only a recording from a branch of the dorsal root as well as a myogram and electromyogram. All results are displayed on cathode ray oscillographs.

FIG. 59 Granit, R., 1979, p.148.

However it should be stated that many of the earlier experiments, that led to the conception of the muscle spindle as a servo-mechanism, were carried out on decerebrate animals (Eldred, E., Granit, R. and Merton, P.P. 1953) among others. Therefore of much more importance to us are the pioneering studies of Hagbarth and Vallbo (1968) who studied muscle spindle activity during 'voluntary' movement in intact, conscious human subjects; themselves. They inserted tungsten semi-microelectrodes percutaneously into the peripheral nerves of their arms and legs, and their results were unequivocal, unlike the opinions of Eldred, Granit and Merton - alpha motor neuron activity always preceded gamma motor neuron activity during voluntary contraction of muscles in conscious man. Their finding has been called alpha-gamma linkage or alpha-gamma co-activation. (Hagbarth, K.-E., and Vallbo, A.B., 1968, 1969; Vallbo, A.B. and Hagbarth, K.-E., 1970; Vallbo, A.B., 1970). Their experiments are now considered a watershed in this area of research, as two recent reviews suggest (Prochazka, A., 1981; Burke, D., 1981).
This leads up to the interesting point of this area of research for us. Hagbarth and Vallbo used themselves as subjects and thus their 'voluntary' movements were performed at their own discretion. As research developed, other experimenters either signaled or instructed their subjects to 'voluntarily' contract various muscles (Honk, J.C., 1972; Marsden, C.D., Merton, P.A. and Morton, H.B., 1976; Roland, P.E. 1978 among others).

It is apparent that most researchers in this area would use the concept of voluntary response much as would Granit in that

> "Most voluntary acts are merely 'triggered' by willing, triggered in the sense that the act is voluntarily demanded but then accomplished automatically."
>
> (Granit, R., 1979, p.134).

Thus a voluntary response is viewed as a 'demand' placed on the peripheral apparatus. Therefore, neurophysiological researchers use an approach similar to that adopted by psychological experimenters. That is, if a subject can produce a certain muscular contraction on demand or instruction, that response may be classed as 'voluntary'.

It is important to point out here that 'voluntary' is a psychological concept, not a neurophysiological one. In the hands of neurophysiologists, who are interested in elucidating the role of the nervous system in the production of movement, it is used as an experimental convenience and does not signify a class of well-understood behaviours. Indeed it appears that experimental expediency is of greater importance to these researchers than the conceptual difficulties that the use of the term gives rise to for the experimental psychologist. However the problem has not gone completely unrecognised. For example, Elwood Henneman in discussing the organization of motor systems has pointed out:

> "The motor system of the brain exists to translate thought, sensation and emotion into movement. At present the initial steps in this process lie beyond analysis. We do not know how voluntary movements are engendered, nor where the "orders" come from. Most of the information that is available concerns the circuits that execute these shadowy commands."
>
> (Henneman, E., 1974, p.60).

Nonetheless, Henneman's 'shadowy commands' are quite extensively used by experimenters studying the peripheral apparatus of the nervous system. Hence Granit, who used instructions to obtain voluntary muscle contraction, proposed that a key element in a voluntary movement is its purposefulness, but for him, however, all movement is purposeful, otherwise it tends to be pathological. Therefore under Granit's scheme there is no clear, distinct objective criteria that can be applied to distinguish voluntary from involuntary movements. Another researcher who used the concept of 'goals' in the explanation of behaviour and recognized that there were no definite criteria for distinguishing what he called 'psychomotor' behaviour from other types in the general behavioural gestalt, was W.R. Hess.

Walter Hess

Walter R. Hess' experimental studies revolved around electrical stimulation of the diencephalon; a major, extremely complex sub-cortical structure made up mainly of the thalamus and its surrounding sub-divisions, the epithalamus, subthalamus and perhaps most importantly the hypothalamus (House, E.L., and Pansky, B., 1967). His researches are now looked upon as 'classic', and the importance of his endeavours has been recognized by his being awarded the Nobel Prize in 1949 for discovering that this area of the central nervous system was the prime co-ordinator of the activity of sympathetic and parasympathetic nervous systems. He presented a synopsis of his experiments in The Functional Organization of the Diencephalon (1957) in which he made the general statement:

> "Actually, there is a constant play of forces acting in the central nervous system, stimulating inactivity when there is a state of equilibrium, appearing as function where there are shifts of equilibrium and manifesting itself as a pathologic symptom when only a disequilibrium exists. We stress the fact that the road to basic knowledge must entail an understanding of this point."
>
> (Hess, W.R., 1957, pp.X-XI)

Such a statement is reminiscent of von Holst, in that the CNS is conceived of as being constantly active, and the final expression of this activity, behaviour, is the result of the interplay of dynamic processes within the CNS.

Hess utilised animal subjects, mainly cats, in his experimental studies and pioneered the use of chronically implanted electrodes in unanaesthetized, unrestrained animals. By this technique he was able to precipitate a variety of behaviours in his animals. These included locomotion, feeding, drinking, attack, and flight as well as alterations in cardiovascular, thermo-regulatory and sexual behaviours (Hess, W., 1957). In other words, by electrical stimulation of these sub-cortical areas, especially the lateral hypothalamus, Hess was able to produce well co-ordinated autonomic and somatic responses. Thus his experiments were a major step towards a unified perception of what was usually perceived as two separate areas, (i) the study of homeostatic regulation or autonomic response; (ii) the study of overt movement - skeletal responses, each taking place in internal and external environments respectively (Mountcastle, V., 1974, p.227).

Within Hess' 'unified view', goal-directed processes were a central feature and were termed Gestalten (Hess, W., 1968, p.35). These goal-directed processes came about through 'drives' - a term which even today has no universally accepted definition (Wise, R.A., 1980; Deutsch, J.A., 1979; Morgan, M.J., 1979) - but was used by Hess as analogous to 'motivation'. Both concerned "... the preservation of the self or the species" and "... in the last resort go back to somatic needs" (Hess, 1968, p.34). In addition, Hess did not share with the behaviouristic psychologists the reluctance to anthropomorphise - for him a food-deprived animal was a hungry animal; and a hungry animal sought food. In this sense there is a 'drive-reduction' flavour to Hess' view, but this is only true within limits.

Hess' goal-directed behaviour was not a blind, random process but an active, selective one which was guided by experience. Indeed experience was a decisive element in determining which 'drive' would be expressed at any given time. And experience itself was not capricious, but actively organised.

> "Out of the different signals that come to the organism, the central nervous system develops images or Gestalten that activate the latent powers of the various muscles to goal-directed co-ordinate acts. In this way the proper parts of the surroundings are made useful and disturbing influences are suppressed."
>
> (Hess, 1968, p.31).

Here Hess seems to use Gestalten much as Beritoff has used 'images'; but he also saw them as an integrated part of a goal-directed process as well. The latter connotation developed in his discussion of consciousness.

Just as he perceived a food-deprived animal as a hungry animal, Hess thought that the hungry animal was aware of the fact that it was hungry - it was conscious of feeling hungry. Thus he did not hesitate to endow animals with consciousness, although it may not be the same quality as that of humans. Moreover the content of consciousness developed from experiences in a way that is causally inexplicable - at least at the present time. In spite of this limitation, the actual relations of experiences and consciousness can be dealt with, and for him:

> "Information does not come to consciousness as the sum of experience, but ... is worked over as Gestalten, or goal-directed processes."
>
> (Hess, 1968, p.35).

Of interest to us is the fact that Hess used the 'conscious goal' as the basis of voluntary behaviour.

Goal-directed voluntary movement, while being conscious, was not associated with any well-defined structural 'centre' but was the product of the functional integration and co-ordination of diverse parts of the CNS including the cerebral cortex and the brain stem.

Again as with all movements, Hess stressed the dynamic interplay of CNS processes in voluntary movement and pointed out:

> "... how many combinations of impulses can be given out without conscious effort."
>
> (Hess, 1968, p.76).

He repeatedly asked his audience to remember:

> "... that the final results of any motor activity is a composition of forces that are co-ordinated simultaneously and successively."
>
> (Hess, 1968, p.74).

Thus, for Hess, voluntary movement in the human is not the result of a detached self-conscious mind, as Eccles would have us believe, but firmly rooted in the physical activities of the CNS. Further, he attributed conscious, voluntary movement to a wide spectrum of the animal kingdom; possibly including the level of fishes. However:

> "Since we have no definite criteria, we leave the problems of psychomotor behavioural consciousness in lower vertebrates open."
>
> (Hess, 1968, p.78).

In the hands of Walter Hess, voluntary movement lost its vitalistic connotations and became a common feature of the organic world, even though its origins are beyond the pale of causal determination at the present time, as Hess freely admitted. Nevertheless the scheme is more open to experimental attack than those of Eccles or Penfield; for the responses produced by electrical stimulation are remarkably similar:

> "... to the adaptative, goal-directed behaviors investigated by Charles Darwin and other biologists."
>
> (Morgenson, G.J., Jones, D.L., and Yim, C.Y., 1980, p.71).

In addition to the studies of Walter Hess (directed to levels 4 and 5 of Eccles' system) and those of Granit (directed to Eccles' level one); other experiments concerned with voluntary movements have been carried out at the upper level of Eccles' hierarchical concept (level six); the cerebral cortex. We have in mind here the electrophysiological contributions of H.H. Kornhuber and his associates. It will be remembered from the discussion of the views of John Eccles, that the results of Kornhuber's experiments were cited by Eccles as being strong evidence of his 'self-conscious mind' in action. Given such an interpretation, it is felt that a brief discussion of Kornhuber's experiments is warranted.

H.H. Kornhuber

The problem in the study of voluntary movement is how to get the subject to carry out a movement, even a simple one, entirely at his own discretion. If one wishes to study cerebral cortical activity in intact humans one must record from the surface of the skull, a point at which the electrical potentials are very small. The amplitude of these potentials vary with the irregular thickness of the skull. To overcome this difficulty, the potentials of the lead site must be averaged and this requires accurate timing. Hans Kornhuber and his associates, by a simple and ingenious method that he calls 'opisthochronic analysis' - time reversed analysis - solved these problems.

The general experimental design was as follows. The subject was instructed to make a very simple movement for example the rapid flexion of the right index finger. There was no external signalling, the subject moved the finger at will. The onset of the EMG potentials, involved in the movement, triggered a computer which initiated an analysis of the previous 2 seconds of EEG records. Moreover the subject had to actually move his finger before the computer would analyse the previous 2 seconds of the EEG. Thus if a subject 'intended' to move his finger, but did not, the EEG analysis would not take place. The important feature of this design is that the subject made the decision to move the finger: Eccles claimed that Kornhuber's subjects were not under the control of the experimenter in any way. However, in order to statistically extract the potentials at the lead site from the background noise, the signal must be presented many times. Kornhuber (1974) recorded 1000 movements/experiments. Therefore the subject has to move his finger during a set time period but can do so at any point he chooses. This feature prevents the experiment from being prohibitively long.

As the legend of the fig. 60 shows, three distinct potentials emerge in the moving of the finger. The generation of these potentials involves large areas of the cerebral cortex, particularly in the pre-central and parietal lobe, and take a long time, by neurophysiological standards, to be produced; somewhat less than a second. It was these features that intrigued John Eccles. The motor potential (MP), derived from the motor cortext finger area was straightforward enough, but another potential, the pre-motor positivity (PMP) was recorded, about 90 ms before the onset of movement (EMG). Thus the PMP precedes MP by 40 ms. Of more interest was the appearance of yet another potential .08 sec. before movement. This potential is bilateral and covers large areas of the parietal and precentral cortices. It is called the Bereitschaftspotential or readiness potential (RP). It is conjectured to represent the integrated activation of the cerebral cortex in the preparation of a movement. The total length of the MP and PMP would therefore be within the 'range' of activity of pyramid cells (i.e. about 150 - 50 ms.) It was in this potential that Eccles saw physical evidence of the influence of his 'self-conscious mind'. Kornhuber himself, however, has not made such a conceptual leap and prefers to speak of movements in the 'goal-directed' sense. Thus he states:

> "Movements are parts of actions, and actions have to satisfy the needs of the organism and secure the survival of the species. Therefore they must be guided by messages from the internal milieu as well as from the environment."
>
> (Kornhuber, H.H., 1974, p.267).

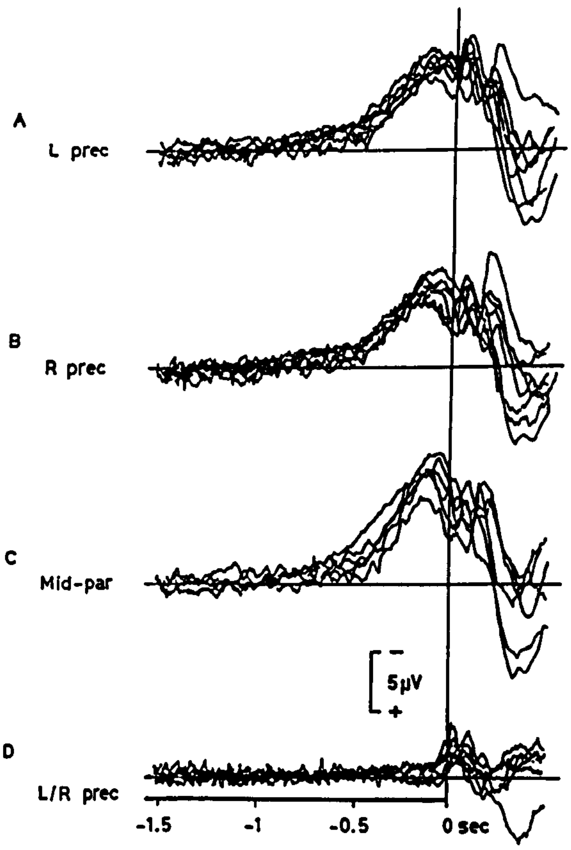


Fig. 1. Cerebral potentials preceding voluntary finger movement. Superposition of the traces from 8 different experiments performed on different days of the same subject. Each trace represents the average of about 1,000 trials involving a rapid voluntary volar flexion of the *right* index finger. Negativity of the active electrode records upwards. The upper three groups of records represent recordings from left precentral (A), right precentral (B) or mid parietal (C) against linked ears reference. *D* Bipolar recording between the left (negative upwards) and the right precentral leads. The time is indicated in seconds along the abscissa, zero time representing the onset of the earliest EMG activity in flexor indicis muscle. The records disclose a high consistency and allow the identification of three components: (1) The negative BP or RP starting about 0.8 sec (onset time prior to first EMG activity) bilaterally over parietal and precentral regions. (2) The PMP, onset time 90–80 msec, also bilateral over parietal and precentral regions. (3) The negative MP, onset time 60–50 msec, unilateral, restricted to contralateral motor cortex, best seen in bipolar left versus right precentral recording.

FIG. 60 Deecke L. and Kornhuber, H.H., 1977a, p.134.

Kornhuber is a clinical neurologist by training and, in the formulation of his opinion, he draws not only on experimental evidence, but on the observed effects of neural pathologies such as Parkinsonism and Huntington's chorea as well. Indeed it was the results of his studies with Parkinsonism subjects that justified Eccles' relocation of the self-conscious mind in the SMA. Kornhuber and his colleagues have measured large amplitude RP potential over the SMA, but the RP was abolished in bilateral Parkinsonism. Hemiparkinsonism patients showed a significant reduction in the amplitude of the RP, contralateral to the basal lesion site but a large potential over the SMA.

He has developed a model of voluntary behaviour, based on these studies. For him the CNS uses not only stimulus dependent feedback functions in the regulation of movement but also 'function generators', which actively produce spatiotemporal patterns which are 'something more' than reflexes (Kornhuber, H.H., 1974). These latter functions are associated with voluntary movement and are located in the brain stem, basal ganglia and cerebellum. However, the function generators work in close collaboration with the entire cerebral cortex and the vestibular system to produce orderly, goal-directed movement. Thus Kornhuber has conceived of the CNS as possessing motor sub-systems, which act in concert to produce all movement. These subsystems are classified into two general categories; strategic and tactical as seen in figure 61.

The former category receives input from the internal milieu and determines the 'goals' of behaviour; the latter receives input from the external environment and determines how the strategy will be carried out on any given occasion. The important feature of the scheme is that both strategy and tactics have access to the sub-cortical function generators.

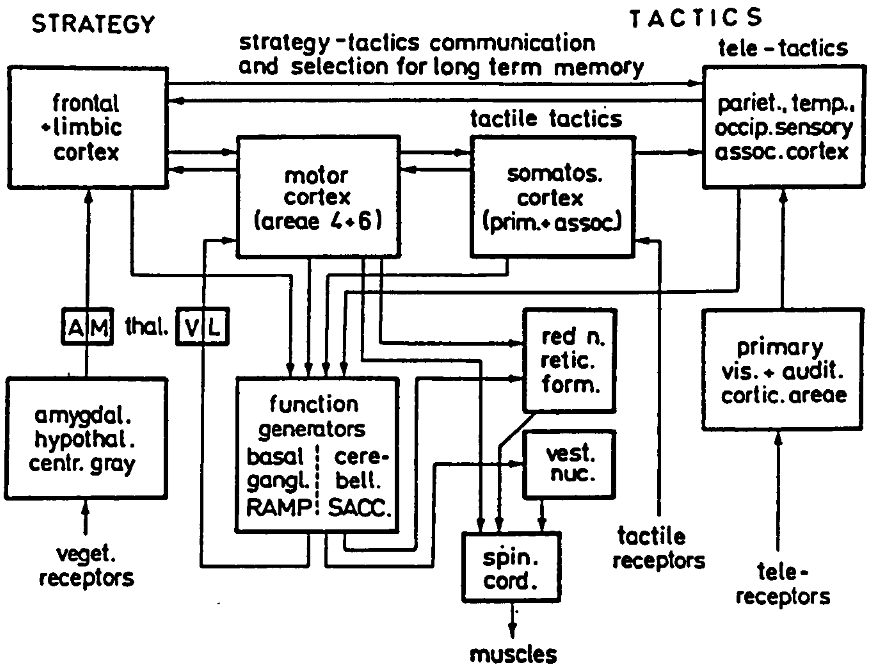


FIGURE 11 Information flow diagram of strategic and tactical mechanisms in voluntary actions. The mechanisms of strategy (represented at cortical level in the frontal lobe and cingulate gyrus) as well as the mechanisms of tactics (in the posterior association cortex) have their own access to the motor function generators in cerebellum and basal ganglia. A anterior, M medial, VL ventrolateral thalamus. The communication lines between frontal and sensory association cortex are also important for data selection from short- to long-term memory (see Kornhuber, in Zippel, ed.: *Memory and Transfer of Information*. Plenum Publ. Comp. New York 1973.) The neural mechanisms underlying the strategy of actions (e.g. hypothalamus, amygdala, and orbitofrontal cortex) receive, of course, exteroceptive in addition to vegetative information; the former, however, in a preprocessed format from the sensory association areas; the hypothalamus gets this information indirectly via the cingulate gyrus-hippocampus loop.

FIG. 61 Kornhuber, H.H., 1974, p.278.

Kornhuber rejects the idea that there is a single, all-encompassing system such as Penfield's centrencephalic system. There is no. single superhomunculus, nor is there:

"... a single superdrive like Freud's libido."

(Kornhuber, 1974, 278).

Instead there is an interplay of dynamic forces along the lines conceived by Hess. Hs is also similar to Hess in that behaviour is expressed as a gestalt, e.g. movements are part of actions, and actions are guided by both internal and external 'messages'. Kornhuber is firmly committed to a mechanistic explanation of behaviour although he does not advocate any 'model'. He asserts that all models of behaviour must conform to the law of the conservation of energy (Kornhuber, 1978).

Kornhuber uses 'goal-directed behaviour' as a unifying concept under which the many diverse movements exhibited by organisms can be described. This would bring him again close to the views of Walter Hess and Von Holst. The outcome of this interplay is voluntary behaviourism to contrast to Eccles, who has always conceived the cerebral cortex the area of expression of the self-conscious mind thus voluntary behaviour.

Kornhuber has also proposed that voluntary movements can be divided into two major categories: ballistic and ramp movements.

According to Kornhuber a ballistic movement, for example an eyesaccade, takes place too rapidly to be regulated by sensory feedbacks; it is pre-programmed. This is accomplished by the cerebellum which then transmits the program as a 'gestalt' to the spinal cord and in turn the behaviour is completely expressed, independent of sensory feedbacks. Therefore a ballistic movement is a feedforward movement.

In contrast the slower, 'ramp' movements are under sensory feedback control and programmed in the basal ganglia. Hence Parkinsonism patients find slow movements more difficult.

Kornhuber's hypothesis is, in large measure, a cybernetic model of the broad views of Hess and Von Holst. For him movement takes place through the interplay of strategy (subserved by the frontal limbic system) and tactics (subserved by the sensory association cortex,parietal, temporal and occipital lobes). The neural underpinning of Kornhuber's concepts of 'strategy' and 'tactics' have much in common with those of a model of behaviour which has been developed by Mogenson et al (1980).

Mogenson, Jones, and Yim

Mogenson, Jones and Yim (1980) have put forth a 'tentative model' which is intended to explain behaviour in terms of the interaction of 'emotive' and 'cognitive' brains. The 'emotive' brain initiates both homeostatic (hunger) and non-homeostatic (fear) behaviours and carries the connotations of goal-direction. The 'cognitive' brain produces movement based on cognitive events such as images. Hence this model uses conceptual analogues of both images and goal-direction in the explanation of behaviour.

The tentative model of Mogenson et al (1980) is eclectic and draws on the ideas of Kornhuber, Hess and Konorski. It is illustrated in figure 62. Two features are immediately obvious; (i) the authors accept the tripartite division of a motor response, following Allen and Tsukahara (1974) much as Eccles has done, and (ii) they accept the function generator concepts of Kornhuber. The major addition to their model is the recent neuroanatomical evidence that asserts the nucleus accumbeus is an important structural link between the limbic system and the motor system (Graybel, A.M., 1976). It is also the functional interface between the limbic system and the motor system, or as the authors state; the interface between the 'emotive brain' and the 'cognitive brain' of Konorski (1967). Mogenson attaches great importance to the nucleus accumbeus (NA) and suggests it may be only the first of several links between the 'emotive brain' and the 'cognitive brain'. He and his associates are presently experimentally exploring the biochemistry of the NA.

Mogenson et al maintain that both the limbic system and the a association cortex can initiate a movement. Furthermore they account for

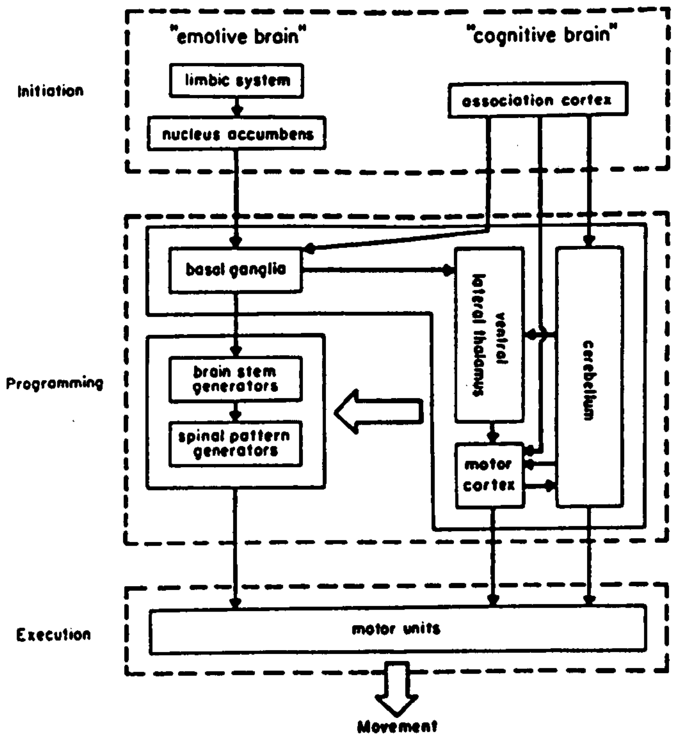


FIG. 3. A schematic representation of the organization of the neural mechanisms that translate emotive and cognitive processes into behavioral motor responses. Motor control of behavior is complex, involving feedforward and feedback information processing between the motor cortex, cerebellum, basal ganglia as well as the brain stem and spinal cord. The motor system can be viewed as being organized in a hierarchical manner generally corresponding to an increase in the complexity of sensory-motor integration up the neuraxis. For simplicity, sensory feedback pathways are omitted from this figure, but it must be emphasized that control of a motor response depends on the integration of extensive proprioceptive and exteroceptive information together with CNS feedforward commands (Evarts, 1979). It is also useful in the discussion of the motor system to conceptualize the processes involved in the generation of a motor response as being divided into three phases: initiation phase, programming phase, and execution phase (Allen and Tsukahara, 1974). The neural components involved primarily in each of the three phases are enclosed by the dotted rectangles. Motor units are the common terminus of all CNS motor commands. Integration of the activities of individual motor units form the basis of all movements. The temporal and differential activation of the motor units constitute a motor program that elicits a specific motor response. Both emotive processes including homeostatic (such as hunger, thirst) and non-homeostatic (such as sex, fear, rage) drives, as well as cognitive processes, which are more prominent in the higher mammals, initiate behavioral motor responses. At the top of the figure, the neural processes for the initiation of responses are depicted. The terms "emotive" brain and "cognitive" brain are from Konorski (1967).

FIG. 62 Mogenson, G.J., JOnes, D.L. and Yim, C.Y., 1980, p.76.

the interaction of the two brains in cybernetic terms. Thus in the programming phase:

> "... particularly in volitional movements, the cerebral cortext, cerebellum, and basal ganglia are involved in first selecting motor programs or strategies for an act, then preparing the brain stem and spinal cord for the appropriate responses and finally initiating muscular contractions."
>
> (Mogenson et al, 1980, p.76).

In the 'motivation to action' model, the sub-cortical structures are given crucial roles, as in Kornhuber's hypothesis. This tendency reflects contemporary neurophysiology's increasing appreciation of such structures in the production and control of movement, including 'voluntary movement'. The discussion of Mogenson's model is shorter than previous presentations because its author has not elaborated beyond the notions put forth in this single publication.

The Zeitgeist that has developed is that the processes of the CNS and its control of behaviour can be accounted for by mechanical model. This analogical force has grown with the advent of cybernetic technology, which involves the construction of mechanical devices with seemingly purposive and self-adaptive features. The blend of computer and robotic technologies has led to machines exhibiting modes of behaviour long held to be peculiar to living systems. With the appropriate information (programs) these machines are able to play chess, compose music, prove mathematical theorems and calculate, with a speed and efficiency unapproachable by the human 'mind'.

The design and construction of such machines has suggested various useful hypotheses in psychology and neurophysiology, especially concerning reflex mechanisms and analogous operations occurring in the brain. Indeed the prototypes of the most advanced machines meet the criteria used by Descartes to show that man was not an automaton - he will speak when spoken to. The corresponding model of man, that is emerging, is a composite of the earlier physicochemical machine under the guidance of a computer-like system.

How will these contemporary prospects influence the distinction of voluntary and involuntary behaviour? In this chapter we discussed traditional as well as recent neurophysiological models of behaviour under three broad headings; i) images, ii) mind and iii) goal-directed. Although many of these models are asserted to be mechanist, they do nonetheless harbour conceptual analogues of the voluntary-involuntary distinctions. The terms 'image' and 'mind' are mentalistic and 'goal-direction' has been traditionally linked with teleology. The latter idea has been eschewed by science. However, the concept of 'mind' is noted for its invulnerability to experimental attack, but, if accepted, has great explanatory power.

Conceptually, 'images' may have considerable explanatory power in accounting for behaviour. In this, the formulations of James and Von Holst have a particularly wide contemporary following and have been applied to a wide variety of animal species - from insects to men. However attractive 'images' are, in an account of behaviour, such a concept suffers from at least one serious drawback - the mechanism which establishes the image is not known with any certainty. Nonetheless, once established, it has considerable versatility in accounting for the initiation and termination of movement. Recently, 'images' have been assigned a role in the navigation of insects (Collett and Cartwright (1983)).

We have seen in the theories of Granit, Hess, Kornhuber and Mogenson, et al, the great utility of the concept of 'goal-directed behaviour'. Such theories usually stress the interaction of the organism with its environment, and in broad outline fit in well with cybernetic concepts of self-regulation. Within the cybernetic framework, the organism is conceived of as a self-regulating machine which is in a constant state of adjusting to both its internal and external environments through behaviour.

However, when using the concept of 'goal-directed behaviour', authors assume an organism has certain biological needs, such as food and water, which must be met in order that it may survive. Thus animal species may exhibit numerous and diverse behaviours in acquiring food or water but nonetheless all such behaviours would be goal-directed.

Implied in all formulations of goal-directed behaviour is Cannon's concept of homeostasis. The internal environment must remain stable and if fluctuations appear as a consequence of biological deprivation, overt behaviour is energized to meet such a need. Furthermore when the goal is met by the organism the behavioural sequence is terminated. Implicit in such a scheme is that since animals have more than one biological need then overt behaviour, or most of it, reflects the interaction of the various 'goals' as they vie for access to the 'behavioural apparatus'. Although the process by which one goal comes to dominate the others is unknown, but presumably it is based on physical processes within the body which can detect and compare the existing environment with a previously established 'optimum'. Therefore if there is a discrepancy between the actual state and the 'optimum' state an 'error signal' is sent and a behavioural sequence is instituted which attempts to reduce such a discrepancy. Conceptually the 'optimum' state of a biological organism is equivalent to the 'set-point' of a mechanical system. In mechanical systems the 'set-point' represents the desired operating characteristics and is fundamental in determining its behaviour. In biological systems how the value of the 'set-point' is established is, again, unknown. Be this as it may, Mogenson, et al, synthesises such important experimental studies as Hess and Kornhuber and offers an approach to the explanation of behaviour that is compatible with the evidence from the experimental psychology of learning.

CHAPTER 5

CONCLUDING DISCUSSION

The debates which have surrounded the distinction between voluntary and involuntary behaviour have been sensitive indicators of a family of basic issues not only in psychology but contemporary philosophy and biology as well. These include : whether mental events are actually physical events, the immateriality of the human mind, the immortality of the soul, the existence of other minds, and the contention that movement has two sources : thought and desire. Many times the voluntary -involuntary dichotomy has been conflated with these issues.

These debates have taken several forms and, together, reveal chronic symptoms of dissatisfaction with the mechanistic interpretation of psychological and biological phenomena developed in the 17th century. However, the 'clockwork' analogy of such phenomena has been conceptually reshaped under the impact of evolutionary theory and the methods of modern psychology and biology. These concepts, together with the dramatic development of electronic computers and cybernetics, have compelled another look at the foundations of modern science and a re-evaluation of their adequacy for explaining the behaviour of adaptive systems; be they animals, men or machines.

As we have seen, the classification of behaviours into voluntary-involuntary categories is at least as old as the early Greek philosophers and possibly much older. Therefore this distinction may well have been a contemporary development of the separation of animate from inanimate movement. At this early date the voluntary-involuntary distinction was based on intuition, introspection and speculation. Indeed, when the concept of voluntary action was addressed in Greek philosophy, it usually took the form of speculative thought concerning 'ethics' and the moral responsibility of the individual. In this context, those who would deny the intervention of 'the gods' in human affairs turned to a materialistic doctrine as an alternative explanation. However, at this early stage such a doctrine was incapable of sustaining itself as a convincing alternative to the supernatural explanations of the 'theologi'.

With the rise of the Christian era and its emphasis on the detachment and immortality of the soul, the voluntary-involuntary distinction was perceived with great ease. It was widely accepted that God had created man with an immortal soul and endowed him with 'free will'. Man was 'free' to choose his own behaviour. Indeed behaviour became classified under the more broad, and judgemental, categories of 'good' and 'evil', between which one was free to choose. The denial of free will was equivalent to the denial of God, who had endowed it. Such a denial was, of course, heresy.

However, by the 16th century the ecclesiastical dominance of educated thought began to lessen. (i) Copernicus published his heliocentric theory of astronomy which not only revolutionised man's perception of the universe but also completely reorganised his place therein; (ii) Vesalius' description of the structure of the human body eclipsed all others in its clarity and accuracy. These events, together with Harvey's description of blood circulation, radically altered man's image of himself. Copernicus' view implied that man was not at the centre of the universe and was perhaps not the supreme achievement of a divine creator. Vesalius' anatomy lent itself to the conception of the body as a mechanical contrivance. But ecclesiastical power was still very strong and did not take these matters lightly, as the burning of Bruno exemplifies.

The next century witnessed the emergence of the scientific method. Henceforth, hypotheses about natural phenomena were subjected to experimentation and careful observation. Galileo applied this method with with great success in physics; and in biology, Harvey used it to discover the circulation of the blood. Harvey's discovery added support to the view that a mechanical interpretation of bodily functions was feasible, and encouraged the interpretation that the 'contrivance' was hydraulically powered. One of the most influential advocates of such a view was Rene Descartes.

Descartes perceived animals as automata - they behaved in a mechanical fashion. He put forth an early reflex theory of nervous system function to account for the observed behaviours. In this theory, the nervous system functioned to 'reflect' a stimulus input as motor output. The process was totally automatic and animal movement was conceived of as wholly involuntary. The implication of Descartes' argument was that man, being an animal, was also an automaton. After all, if God had created animal machines, could He, being omnipotent, not create man-machines ? To counter anticipated ecclesiastical persecution, he offered a dualistic view of man. Under this scheme, men were held to possess minds as well as bodies, whereas animals only possessed bodies. Therefore biological phenomena could be subsumed under the domain of physics; thus abolishing the distinction between animate and inanimate movement. All of the natural world could be included in physics, except the mind of man. By correlating 'voluntary' with mind and 'involuntary' with body, Descartes was able to separate mind from body and maintain the voluntary-involuntary distinction as well.

Nonetheless, Descartes contended that most human movement was independent of the mind/will and gave the examples of digestion, blinking, and 'passions'. Most of the 'motor control' of man depended upon the response of the 'animal spirits' to environmental stimuli. However, in man, the mind could also direct the movement of the 'animal spirits' and, hence, control motion.

Mechanistic explanation as applied to the human body and animals had considerable utility as an alternative to vitalistic explanation in physiology. Moreover, the mechanistic approach received significant support from such technical innovations as the telescope and microscope.

Moreover the microscopic examination of biological material soon revealed common features among species which suggested a continuity. A concept denied by both metaphysics and theology. Continuity was opposed, throughout the debate, by implicit or explicit appeal to some special feature, mental faculty or power which separated men from animals. Thus ascertaining which faculties only belonged to man became the issue..

For Descartes, thought was uniquely human. Locke held 'ideas of reflection', general laws and powers of abstraction, were possessed only by men. La Mettrie boldly proclaimed that man was a machine. At least man was a machine insofar as animals were machines. La Mattrie thought that if an animal can be conceived of as a mechanical contrivance, then man could be so conceived as well. He did not consider his position as one that dethroned man, indeed he thought it an honour that man could be viewed as one of the animal species.

The mechanistic trend was greatly expanded in the 19th century, not only in physics but in physiology as well. As Chapter One suggests, the rise of mechanistic physiology brought with it an enormous amount of experimental deta concerning the structure and function of biological organisms. However, the most important single factor in the debate on mind since Descartes was the formulation and acceptance of the theory of evolution, for it asserted the continuity of species. Mechanistic modes of thought were being appreciated for their explanatory power. Nonetheless the fundamental issues did not change. Descartes' opponents insisted that animals have 'mind'; only a decision as to where on the scale it first appeared was at stake. The context remained dualistic and attempts were made to infer mental states from behaviour. Psychology itself became 'mechanistic' with the establishment of behaviourism.

Behaviouristic psychology, accommodated the terms 'voluntary-involuntary' into its behavioural taxonomy. Most of the attempts to test this classifying scheme involved the experimental conditioning of such simple responses as salivation, the knee jerk, the galvanic skin response and the eyelid reflex. These 'conditioned responses' were based on automatic , unconditional responses, which could be modified by 'voluntary acts' or 'instructions'. The classification of responses as to conditioning procedures was dealt with in Chapter Three. The instructed response, as voluntary response, is both the methodological and conceptual legatee of the conditioning procedures.

Therefore the 'instructed response' warrants close examination. Several studies indicate that this would require an exacting methodology, for the precise nature of the instructions is crucial. For example Gelfan and Carter (1967) have concluded that there is no muscle sense in man . This conclusion was based on experimental results derived from conscious, intact human subjects. The subjects had various tendons (usually of the hand), surgically exposed for repair of injury or removal of growths. Gelfan and Carter pulled on the exposed tendons with fine-toothed forceps and asked the subjects to report any sensation referable to the muscles. The reports of the subjects were unanimously negative. The subjects reported no such sensation.

In a similar experiment, Matthews and Simmons, (1974) pulled on some of the same surgically exposed tendons of conscious human subjects.. In this case, however, it was noted that muscle receptors contribute to 'conscious proprioception', a result diametrically opposed to the findings of Gelfan and Carter. The contrary results were accounted for by the different instructions given to the subjects in the experiments. In the case of Gelfan and Carter, the subjects were asked to report any sensation of muscle stretching, whereas Matthews and Simmons' subjects were to report if their finger was moving or not. Therefore it seems that small shifts of emphasis in instructions can greatly influence the experimental results. This theme has been taken up by P.E. Roland.

Roland (1978), in a paper entitled "Sensory feedback to the cerebral cortex during voluntary movement in man", agreed with Matthews and Simmons that there is a 'muscle sense'. His study and the commentary which followed have highlighted the use of the 'instructed response' as an experimental method to investigate the role of sensory feedback in voluntary control. Hence the question might be asked, "Is instructed movement, as voluntary movement, different from other movement in the organism's behavioural repertoire ?" In answer to such a question, Roland states :

> "Gradually increasing insight into the functions of alpha and gamma motorneurones and muscle spindles has led to the conviction that voluntary movements are to a large extent automatic in character."
>
> (Roland, P.E., 1978, p.131)

This is much in the character of Ragnar Granit. But for Granit the chief feature of the voluntary response was its purpose. Roland himself asserts that voluntary responses are influenced by feedback mechanisms and that there exist within the central nervous system, memories for motor orders which code for the parameters of a particular movement. The motor image or memory is written in 'kinaesthetic language' , i.e. is based on sensory feedback of movements. Moreover, once established, the motor image can assume the role of a command function against which future kinaesthetic feedback is compared (Roland, 1978).

However, we shall avoid internal debates in this area and focus on the effects of instructions on one group of subjects.

In Roland's experimental design were subjects that had their left hand partially paralyzed with gallamine (a curare-like drug). The subjects were asked to press a strain gauge and then match the press with the unparalyzed right hand. When subjects were instructed to match 'efforts' there were consistent errors of overestimation, whereas when instructed to match 'forces' no such errors emerged. Roland has suggested that the sense upon which performance is based, i.e. sense of force or effort, could depend on the instructions given. Clearly the subjects could discriminate between the two terms in maintaining an isometric contraction. Therefore one might well ask, how do bodily movements acquire their verbal labels?

Behaviourism offers a plausible view on how specific words became identified with specific environmental events objects as well as specific movements. This involves the simple principle of associationism. For example, when a child raises his arm, his mother says "You have raised your arm", given suffucient repetitions the child eventually will say "I have raised my arm" when he raises his arm as well as raising his arm upon request. Thus arm-raising has been programmed and the program integrated into the behavioural repertoire. The process of integration is complished by the CNS. In this context it is of interest to note that Sussman and MacNeilage (1971) used a pursuit auditory tracking task to investigate hemispheric dominance for sensorimotor control of speech-related movements. Their subjects were asked to match a continuously varying reference tone with a tone controlled by the movements of the tongue, mandible or lips. They were better able to match the reference tone if it was presented to the right rather than the left ear. Sussman and MacNeilage speculated that there is, in the left hemisphere, an auditory sensorimotor integration mechanism which is specialized to integrate kinaesthetic and tactile feedbacks resulting from articulatory movements with auditory concomitants of those same movements (Sussman, H.M. and MacNeilage, P.F., 1971).

Another integrating mechanism has been suggested by Ojemann and Mateer (1979). By conducting electrical stimulation mapping studies of the perisylvian cortext in the frontal, temporal and parietal lobes these researchers have identified a cortical region in the left hemisphere where mechanisms for both verbal and non-verbal oral movement production and phonemic identification overlap. They conjectured that such an area may reflect the presence of an evolutionary process in which the human brain evolved unique mechanisms structured in terms of the matched requirements for the development and maintenance of speech production and perception.

Other neuro-physiological evidence in support of overlapping functional cortical areas for oral movement or speech production and perception emerges from studies which measure regional cerebral blood flow (rCBF), a variable closely associated with tissue metabolism. Although this non-invasive procedure lacks the fine grain resolution required of some anatomical structures, it can be used to study entities of a cm^2 and larger. It has been found that large areas of the cerebral cortex are activated during speech including the somatosensory motor and premotor face area and the supplementary motor area. Further, Broca's area, long thought to be involved in expressive language functions, is activated together with the primary auditory areas when a normal subject listens to speech. Thus an area thought to be primarily part of a motor response pathway is active during assumed auditory analysis (Roland, P.E., Shinhøj, E., Lassen, N.A. and Larsen, B., 1980, b).

Moreover, Roland et al (1980b) found contrast in the rCBF based on whether or not the bodily movements took place in'intrapersonal' or 'extrapersonal' space. In the first case - interpersonal space - detailed instructions were given concerning movement strategy. In the second case, the instructions were general and the subject chose the movement strategy. Both movements were 'voluntary'. The task demand "extra-personal' group drawing a spiral in the air. Both groups exhibited bilaterally rCBF increases in the SMA and the 'pre-motor convexity'. However the 'intrapersonal' group had increases in rCBF in the auditory area, frontal fields and inferior frontal regions whereas in the 'extrapersonal' group the increases in rCBF developed in the parietal lobes. Roland et al concluded that (i) the SMA elaborated programs for motor sub conscious upon which skilled voluntary movement is based; (ii) the convexity of the PM is involved in the 'filing' of new programs and the updating of old ones; (iii) the parietal lobes supply information about extrapersonal space demands to proprioceptive reference systems.

These researchers concluded that the reference system in which movements are performed decided the cerebral organization of a voluntary movement. This particular experiment was the twin of another publication (1980 (a)), which was one of the 'lines of evidence' used by Eccles to confirm the action of his 'self-conscious' mind (Eccles, 1982). Thus Eccles gives us a convenient touchstone as well as a final point of departure. He also brings us full circle.

Accepting the 'instructed response' as 'voluntary response' and making the mechanistic assumption that the processes by which instructions are transformed into voluntary behaviour occur through the offices of the CNS; neurophysiological data was presented which suggested potential integrating areas within the CNS analogous to the simple associationistic account of how verbal labels become attached to events and movements. In doing so we find ourselves citing evidence similar to that cited by Eccles in postulating the primacy of the self-conscious mind. This should give us pause for thought, and reflection suggests that wider issues may be involved.

It will be recalled, that Eccles, in presenting his views, has consistently asserted that voluntary behaviour is the product of mental activity upon physical events. Thus the 'voluntary-involuntary distinction' of behaviours is again, conflated with the mind-brain 'problem'. Therefore a brief comment shall be made, on each of the three 'lines of evidence' cited by Eccles in support of his views.

(i) Roland et al, 1980 a. What impressed Eccles most about this experiment was the dramatic increase in bilateral activity (rCBf) in the SMA when the subjects were performing 'internal programming' of the motor test sequence. That is, the subjects were instructed to rehearse the motor test but not perform it (produce no EMG); during this period only the SMA showed increased rCBf. However, Roland et al state that whereas all their subjects were visually examined for movements, EMG was measured on only one-third of them. Eccles fails to mention this aspect of the experiment. Moreover, Roland states that there was lack of control of mental activity in the reference state -rest condition - and after the experiment most subjects admitted that they could only perform the task by internal counting. Counting is assumed to take place during rehearsal as well and therefore 'internal language' may help organize movement. Technically, it takes 45 seconds to measure rCBF. Hence any cerebral activation of less duration could be excluded from the data and the crucial time relations between different cortical events would be lost.

(ii) Deecke and Kornhuber, 1978. The type of experiments conducted by Kornhuber and his colleagues are beset by numerous technical problems, mostly concerned with 'artifacts'. However, these difficulties have not precluded the existence of the readiness potential as an established phenomenon. The important point, however, is that Kornhuber interprets the large vector potential, presumably over the SMA, in terms of 'generator' mechanisms - ramp or ballistic - and not in terms of 'mind' as does Eccles.

(iii) Brinkman and Porter (1979). From a technical point of view, the recording of single cell activity by chronically implanted electrodes is by far the most functionally concise approach. It also invites a precise study of the temporal relationships between different cortical events. Addressing this experiment, Eccles stated that:

> "The movements were trained motor programs of brief pulling movements on a lever that were voluntarily initiated by the monkey. The animal was not restrained in arm usage, pulling with the right or left hand in random sequence."
>
> (Eccles, 1982, p.271).

A careful reading of the study by Brinkman and Porter reveals, however, that on those occasions that the monkeys consistently pulled with one hand, "a mere signal from the experimenter was sufficient" to get the monkeys to change hands. Again, Eccles fails to mention this feature of the experiment. Thus the 'randomness' of the data is suspect. Furthermore the design of this experiment is standard in the neurophysiological study of 'motor control'. That is, the neurophysiologist uses the operant conditioning procedure to establish a reliable overt response in order to study its neural correlates. In other words, a discriminative operant is established. It is then called a 'voluntary response', a proclivity which was questioned in Chapter Three. Thus in neurophysiology experimental expediency is asserted at the expense of conceptual considerations in psychology.

The above commentary was presented not only to point out the fact that experimental data is open to a variety of interpretations but to demonstrate a central feature of vitalistic arguments. A review of the discussion of Eccles indicates that the 'self-conscious mind' can accommodate any evidence by the addition of more structures (arrows) between itself and the rest of the physical world. A historical approach points to this fact.

For example Eccles began his recent article:

> "The title of this article presupposes that there is a conscious self. This selfhood is a central fact of our experience, not requiring a demonstration or a proof. To deny it is absurd. Likewise, we have the experience that a mental act of intention can lead to the desired movement, a voluntary movement, which is known scientifically to result from some brain performance. To deny that also is absurd, because the denial requires some signalling action, and that involves a contradiction of the denial."
>
> (Eccles, 1982, p.271).

This is a restatement of the 'Cogito' proof of Descartes; to deny the 'Cogito', I think, is to assert it. The assumption being that there must be a thinking 'thing' which can either assert of deny.

John Eccles has been extremely important in the latter half of the 20th century in proclaiming a strong interactive, dualistic position or the mind-brain problem, and by extension the voluntary-involuntary dichotomy. In doing so, he has helped force attention on many of the problems which underlie a seemingly scientific and objective psychology. In response, other influential authors have advanced their opinions on this issue. As a result, an array of alternatives have been offered which compete with any of the past. Indeed, the intellectual issues of the contemporary world reflect those of the past. In this context, D.M. Mackay, for example, has been a peacemaker - a middle-of-the-roader. Hence in an article entitled 'Ourselves and Our Brains: Duality without Dualism", he opened a recent response to Eccles:

> "The problem of relating mental activity to brain events (and vice-versa) presents difficulties of two kinds. One difficulty is to discover and evaluate relevant empirical evidence. The other and logically prior difficulty is to discover an operationally satisfactory way of framing the questions to which we would like empirical answers. The argument of this paper is that the present confused and inconclusive debate over the 'mind/brain' problem arises largely from failures in the second category."
>
> (Mackay, D.M., 1982, p.285).

Mackay, a communications engineer, draws heavily on the programme/computer analogy of the mind/body problem. Mackay contends that the 'programme' is embodied in the computer much as the 'mind' is in the body. By such a device he hopes to avoid both dualism and 'identity-theory'.

The Nobel Laureate, R.W. Sperry, has offered an 'emergent' solution to these issues which also denies both dualism and 'identity theory'.

He has stated his position as follows:

> "I hold that every time the elements of creation, whether atoms or concepts, are put together in the same way under the same conditions, that the same new properties would emerge and that the emergent process is, therefore causal and deterministic."
>
> (Sperry, R.W., 1980, p.200).

Finally, in contrast to the opinions of Eccles, Mackay and Sperry, Steven Rose has invited us to:

> ".... seek an understanding of the unity of the multiple levels of description of the entity of the behaving and experiencing organism as a relationship of identity. Specific biochemical states correspond to specific behavioural states not because the biochemistry causes the behaviour but because it is the behaviour, at a different level of analysis, expressed in a different language. Altered synaptic connections do not cause but are memory; the firing of particular cells in the hypothalamus and elsewhere does not cause anger, it is anger. What is to be studied is the ontological unity of the organism, not a collapsed unidimensional array of nucleotides, a wiring diagram or an EEG pattern."
>
> (Rose, S.P.R., 1980, III-IV).

Thus Rose represents modern 'identity theory' and must seek a psycho-physical isomorphism which could confirm his hypothesis.

Therefore we have at our disposal a wide range of authoritative opinion from which to choose. Must we choose? If so, which opinion? Can using a historical approach to analyse concepts be of use? Have we proven our case? Only the reader can give an answer to the first two questions. Concerning the latter question a weak, but honest, yes can be given. If this contention is accepted, can a prescription be given for the future? To highlight these issues, in simple fashion, the reader's attention is directed to figures 63 - 66 which are arranged in contrasting pairs. Thus figure 63 can be contrasted with figure 64 ; figure 65 with figure 66.

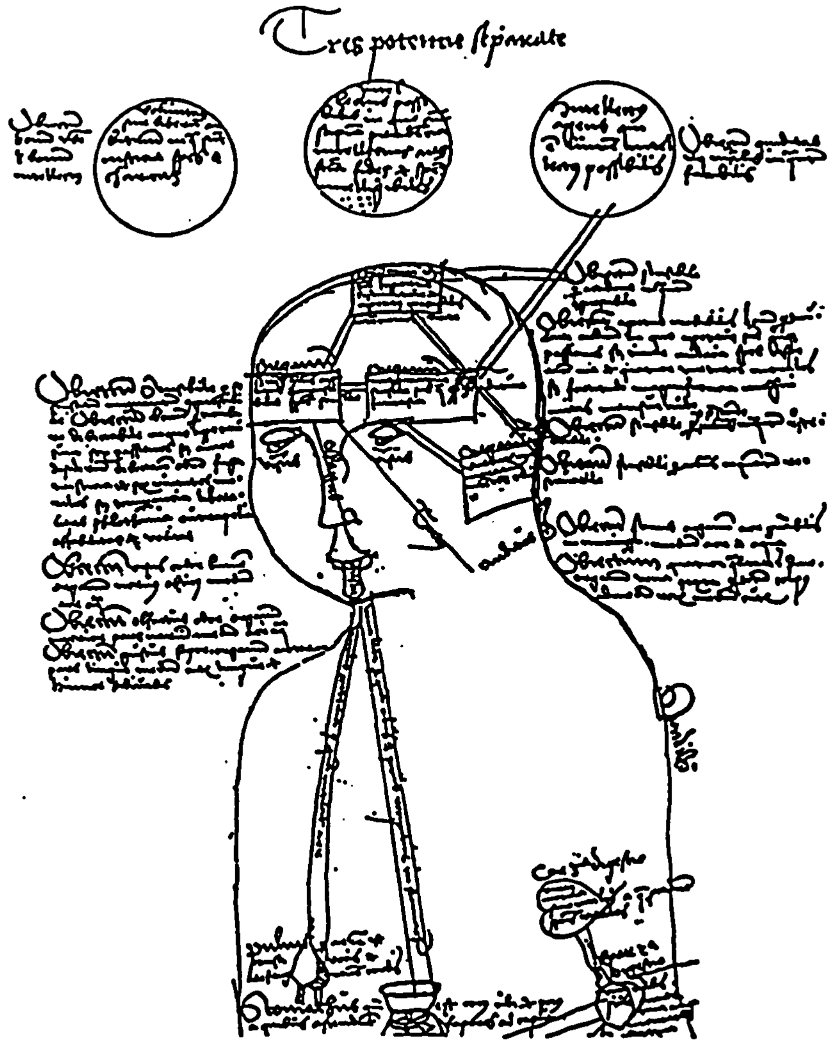


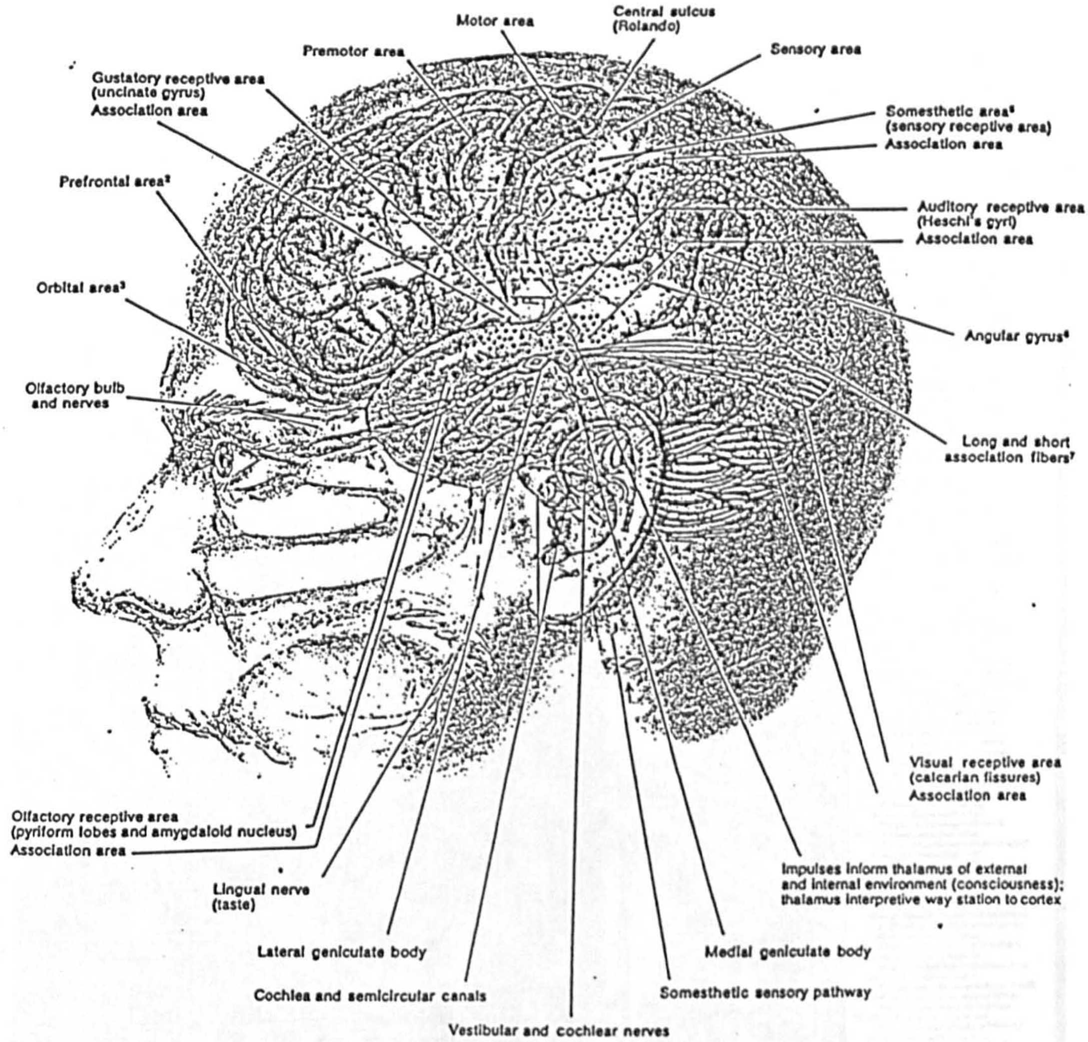
Figure 47

From a manuscript of about 1500, *Tractatus de potentiis animae et corporis organis et modo intelligendi* (p.135), bound with tracts on Aristotle and Thomas Aquinas. It was advertized in a book catalogue of J. Halle of Munich in 1928 but its present whereabouts has not been traced.[75] The writer may have been Petrus Tozler.

It is headed by "The three powers are separate" and the three circles below this from left to right contain comments regarding will or free-will, potential intelligence, and active intelligence. The squares on the head represent four cells and are connected to each other. Although it is very difficult to decipher the writing in them, they seem to represent the usual mental faculties (cf. Figure 30). The lower of the two squares forming the second cell is linked to the circle labelled "active intelligence ...". The writing around the head describes the senses.

FIG. 63 Clarke and Dewhurst, 1972, p.34.

Plate 14.
The Five Senses of Consciousness

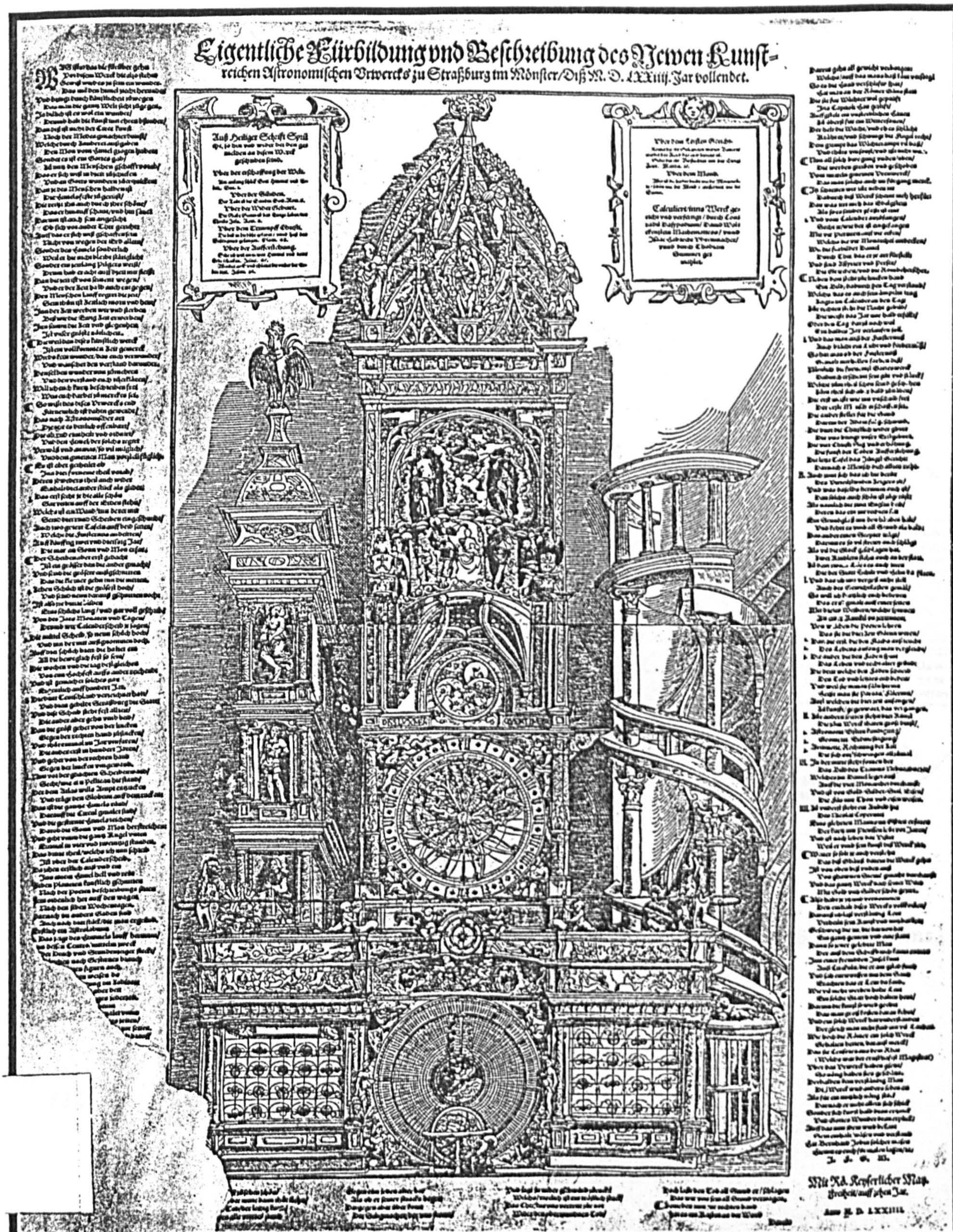


[1] Frontal lobe
Controls personality stability, ambitions, responsibilities, and properties of behavior
[2] Prefrontal area
Relatively high association evaluation and control of emotion, judgment, and conduct, and center for complex motor capabilities

[3] Orbital regions
General areas of autonomic control presiding over hypothalamus to control basic rhythms of life
[4] Temporal lobe
Basic intellectual, emotional and sexual activities
[5] Somesthetic area
Evaluation of muscular activity and interpretation of touch and other physical properties

[6] Angular gyrus
Visual speech center (symbolic communication); ability to recognize the written word
[7] Long and short association fibers link together various primary association (memory) sensation areas into more complex memories.

FIG. 64 Epstein, M.H. and Long, D.M., 1977, p.31.



The Great Strasbourg Clock.

FIG. 65 The Open University, 1974, cover.

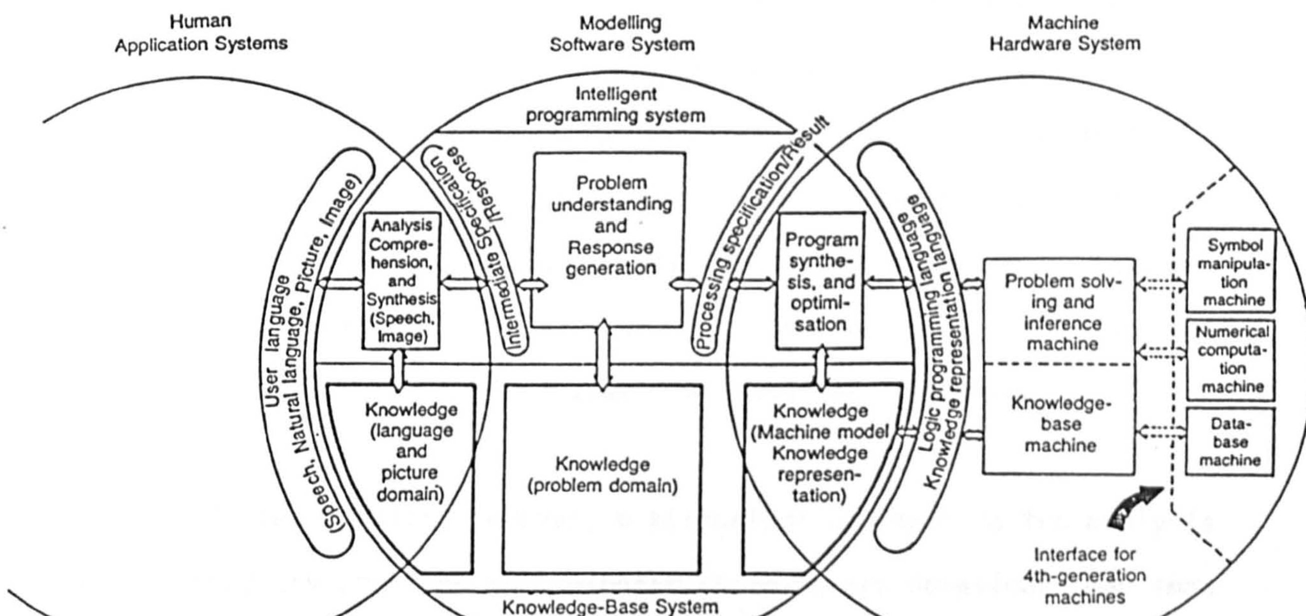


Figure 2.2 Conceptual View of Fifth-Generation Computers
(Source: *Proceedings of International Conference on Fifth-Generation Computer Systems*, 19-22 October, 1981, JIPDEC)

FIG. 66 Simons, G.L., 1983, p.46.

The first pair of figures 63,64 are separated by about five hundred years. The point to be made by their presentation is that the pursuit of 'localization of function' is likely to continue regardless of the intellectual climate. The scond pair of figures 65-66, sharpen our focus. Figure 65 is a facsimile of the Great Clock of Strasbourg. This contrivance was cited by early members of the Royal Society, particularly Robert Boyle, as an artifact whose complexity of movement most approached that of human beings. Figure 66 is a 'conceptual view of fifth-generation computers'. Again it is a mechanical device which, when fully developed, will purportedly mimic much of what is taken for intelligent human behaviour. These figures suggest that Mankind has consistently attempted to interpret his own behaviour through a mechanical model and will probably continue to do so. Hence, today, we are beset by the same problems that puzzled our forebears and the great accumulation of scientific data has not altered the basic issues that have been broached.

As intimated earlier, however, a historical approach to the analysis of such refractory problems as 'voluntary-involuntary behaviour' may lead to the identification of issues which have consistently recurred. These appear to be related to three debates: (i) the problem of other minds; (ii) the problem of the 'reduction' of mental events to physical events; (iii) thought and desire as sources of motion. The first case can be dealt with by regarding the solipsist position - the position which maintains that only the mind of the speaker exists - as being incapable of coherent formulation. Thus ascribing 'mind' to oneself would presuppose its ascription to other and vice- versa. Such a presupposition does not completely solve the problem but, if accepted, a major barrier is overcome.

The second problem, usually generates more heat than light, as contemporary 'neuroscience' opinion indicates, for it has yet to be shown that mental events are physical events or that psychology can be reduced, without remainder, to chemistry and physics. Hence the 'weak but honest yes' stated previously. Ever since the formulation of mechanistic doctrine in the 17th century it has been thought that material objects and the forces acting on them are fundamental to scientific explanation. But attempts to account for the self-adapting behaviour of man, animals and some machines has created an inconsistency in the mechanist's conceptual scheme This involves the ultimate appeal to variables which have traditionally been restricted to the mental realm: intentions, purposes, goals; which could not be 'reduced'.

Today the field of cybernetics and allied areas of research offer a possible clarification of this problem. Computers and robots are, without doubt, mechanical systems, and yet they can exhibit apparently purposive behaviour, performing many traditional tasks associated with the 'mind'. It is becoming apparent that the traditional mind-body/ voluntary-involuntary issues are analogous to the problems encountered in describing the behaviour of machines. Indeed, the contemporary debate inverts the traditional one. In lieu of asking such questions as 'Are men and animals machines or do they possess minds?" it must be asked if the mindlike behaviour of some machines can be accounted for in mechanistic terms. The answer is yes. The programmes or algorithms which are the goals, intentions and purposes of computers can be given a precise, indeed, a mathematical description. This feature separates such machines from their predecessors. Therefore, the mathematically describably mind-like behaviour of machines could serve as an analogue of the mind-like behaviour of men. It is important, however, to keep in mind that analogues are not facts and avoiding the fallacy of leaping from 'analogy' to 'fact' would seem to be a responsible scientific enterprise. None the less, in principle, the mechanisms underlying the behaviour of machines may be precisely specified and therefore form a useful platform for future research.

The third debate concerns the notion that the under concepts of thought and desire, or their analogues, are subsumed the sources of movement. This idea appeared in Aristotle, later it was reiterated by Locke and Hume, and Descartes recognised that at times 'the passions' were beyond the control of the will. Recently a similar theme has emerged in the studies of Kornhuber - strategy and tactics - and Mogenson - motivation - action interface.

Conceptually this theme draws its importance from the fact it invites a recognition that behaviour is an outcome of the interaction the neural substrates subserving 'thought and desire'. Broadly speaking activity in the frontal-limbic system underlies 'desire', 'strategy' and 'emotion', whereas the parietal, temporal, occipital and sensory association cortices subserve 'thought', 'tactics' and 'cognition'.

Therefore by emphasizing the interaction of these levels of discourse a worthy enterprise is served. Addressing the area between the domains of physiological and psychological explanation will help bring to the fore problems implicit in the both types of explanation; which emerge periodically in some form of 'mind-body problem'.

At this stage perhaps, it would be useful to set aside the traditional strict separation of the nervous system into motor and sensory systems, and the serial (S-R) interpretation of causality that such a view implies. There is a growing realization that central nervous mechanisms which govern movement not only involve the selection of inputs and the generation of appropriate output responses but also an 'analysis' of the significance of the inputs and their comparison with 'internally represented' information. The output responses may also contribute to sensory input. Hence a circular causality, involving organism and environment, is encouraged. Above all,the major challenge to experimental studies addressing the role of the CNS in the production and control of movement is to discover and analyse the mechanisms by which control is accomplished and not merely a description of associations.

In closing, a statement about much broader issues is in order ; for these form the intellectual backdrop upon which is projected the outline of specific concepts.

Eccles recently expressed surprise (or lament) of the fact that his presentation of the dualistic position was received with 'incredulity' by an assembly of brain researchers. This was the same meeting at which Hans Kornhuber had earlier reminded the audience of the Law of the Conservation of Energy (Buser, P.A. and Rougeul-Buser, A., 1978). Hence a wide range of opinion was available. Most of those present were mechanist/materialist and, for them, mental events will ultimately be explained by physical events but the way this is done is not yet known.

The fact that the mechanists do not know how this is done makes it impossible for them to prove their case. Therefore Eccles can, with some justification, maintain that his position cannot be refuted. However his own argument is not enlightening or scientifically fruitful. Both arguments devolve into metaphysics. This is the broader issue ; there are no final answers. If historical trends continue, the development of concepts to deal with refractory problems, particularly those concerning image of Man, will depend on prejudice as much as scientific evidence. For example, Eccles has called for the mind-body/mechanism-vitalism debates to be fought on the grounds of 'the evidence' and not on prejudice. He seems to have failed to realize that his rejection of the reductionistic strategy precludes his acceptance of the mechanistic position.

The mechanists are committed to the reductionist strategy and, in turn, are precluded from accepting vitalism. They assume that whatever can interact causally with a physical system must itself be physical. This amounts to a denial of the notion that an immaterial substance, a substance whose properties are non-physical, is a coherent one.

In the conceptual framework of the dualist however, the notion denied by the mechanists is taken as an assumption. At this level both views are metaphysical. On the one hand such an impasse indicates that we do not have a very clear idea of what we are denying when we deny that dualism is true. On the other hand, what with the state of modern physics and its unknown and possibly unknowable qualities, it is difficult to ascertain exactly what is being affirmed when it is asserted that materialism is true.

Andrew Huxley (1984), in a recent Presidential speech before the Royal Society, pointed out that neither psychology nor physiology, nor any other descipline, have adequate concepts for dealing with such problems. Eccles, Sperry, MacKay and Rose agree. Thus there is a growing recognition that a problem exists; a necessary step for any solution to be formulated. This manuscript is meant to enhance such a recognition.

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APPENDIX A

PSYCHOPHYSIOLOGY
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Oxygen Consumption and Ambulation During Operant Conditioning of Heart Rate Increases and Decreases in Rats

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ABSTRACT

Using a shock-avoidance procedure, large discriminated increases and decreases in mean heart rate (HR) were conditioned respectively in two groups of free-moving rats. Accompanying the conditioned HR responses were equally significant variations in Oxygen Consumption and Ambulation indicating a nonspecific effect of the experimental contingencies. Ambulation and Oxygen Consumption were found to be correlated in some but not all experimental conditions. Thus, partial indices of somatomotor activity may not provide an adequate reflection of variations in general activity (energy consumption) and therefore may not be employed to draw meaningful conclusions regarding the integration of cardiac and somatomotor processes. Discriminated HR responses were acquired more rapidly by subjects in the Increase condition than by subjects in the Decrease condition. However, the latencies of the discriminated HR changes were considerably longer for the Increase than for the Decrease subjects. An unexpected result was that 5 of the 6 Decrease subjects developed profound bradycardic arrhythmias. These arrhythmias were under strong stimulus control and were exhibited only during a stimulus (S^D) signalling that the reinforcement contingencies were in effect.

DESCRIPTORS: Operant conditioning, Heart rate, Somatomotor activity, Ambulation, Oxygen consumption.

In a free-movement situation variations in heart rate (HR) are normally highly correlated with variations in somatomotor activity. HR changes, however, may occur independently of observable changes in striate muscle activity. In the intact organism such dissociations of the cardio-somatic Gestalt tend to be associated with stressful environmental demand situations (Obrist, 1976).

Conditioned HR variations have also been reported in animals which have had their striate musculature temporarily immobilized by administration of d-tubocurarine chloride (DiCara, 1970; Hothersall & Brener, 1969; Miller, 1969; Slaughter, Hahn, & Rinaldi, 1970). Though failing to obtain effects of the magnitude reported by Miller and DiCara (1967) recent studies of HR conditioning in curarized rats have found it to be a replicable if somewhat fragile phenomenon (Cabanac & Serres, 1976; Gliner, Horvath, & Wolfe, 1975; Middaugh, Eissenberg, & Brener, 1975; Thornton & Van Toller, 1973a, 1973b). These studies suggest that afference from the striate musculature is not an essential element of the conditioning process. They do not, however, justify the proposition that HR may be conditioned independently of somatomotor processes since curare acts upon only the most peripheral manifestation of those processes. Curare does not necessarily interfere with cardio-somatic interaction at any level proximal to the myoneural junction. Indeed, a number of transfer studies strongly suggest that HR conditioning in the curarized animal leads to nonspecific adjustments in the neurohumoral mechanisms responsible for regulating general increases and decreases in activity (Black, Note 1; DiCara & Miller, 1969; Germana, 1969; Goesling & Brener, 1972).

Operant reinforcement contingencies have also been shown to condition HR changes in noncurarized members of a number of species: Man (Obrist, Howard, Lawler, Galosy, Meyers, & Gaebelein, 1974), Monkey (Engel & Gottlieb, 1972), Baboon (Harris, Gilliam, & Brady, 1976), Rat (Black, Osborne, & Ristow, 1976). These studies, however, employed only discrete and partial indices of somatomotor activity, such as eye-blinks

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and other visually detectable movements, electromyographic recordings from selected sites, respiratory rate or amplitude, allowing few conclusions concerning the nature of somatomotor variation to be drawn. They provide scant evidence, therefore, for a cardiospecific effect of the contingencies. Elliott (1974) found the covariation between cardiac and somatic activities to be more stable and predictable when a gross measure of somatomotor activity, namely stabilimeter recordings, is employed. Even here, however, isometric muscle contractions which are known to be associated with profound disturbances of cardiovascular activity (Goodwin, McCloskey, & Mitchell, 1972) will escape detection resulting in underestimation of any correlation between cardiac and somatic activities.

In the present study operant reinforcement contingencies were applied to obtain bidirectional changes of HR in free-moving rats. Ambulation was recorded and additionally the gross level of somatomotor activity was assessed by continuous monitoring of oxygen consumption. In the final analysis all somatomotor processes involve energy expenditure, variations in which are reflected by precisely correlated variations in oxygen consumption. If operantly conditioned variations in HR are embedded within general behavioral adjustments involving the striate musculature, they should be positively correlated with variations in oxygen consumption.

Method

Subjects

Twelve male brown-hooded rats, weighing between 365g and 550g at the start of the experiment, from the colony maintained in the Department of Psychology at the University of Hull were arbitrarily divided into two equal experimental groups.

Apparatus

The experimental environment was a running wheel 36.8 cm in diameter and 13 cm wide. The wheel floor was constructed of 0.3 cm aluminum rods spaced 1.54 cm apart and connected to a shock generator scrambler (BRS model SGS-003) through a five-pole commutator.

The wheel was enclosed within a clear Perspex box measuring 40.4 cm high × 31.9 cm deep × 43.9 cm wide. The box door, which also formed the door to the running wheel, possessed a rubber seal to ensure an airtight fit. Inside the door was affixed a semicircular Perspex hood which fitted within the upper half of the wheel, when the door was closed.

The entire apparatus was enclosed within an electrically shielded, sound attenuating, lightproof box housed in a cubicle adjacent to a room containing recording and analyzing equipment. An audible tone generator (Sonalert Model SC 628H) was mounted on the back wall of the sound attenuating box. One light was positioned on each side of the Perspex box in a plane parallel to the floor of the running wheel.

Measurement

The electrocardiogram (EKG) was recorded from subcutaneous stainless steel electrodes implanted dorsolaterally in a standard limb-lead configuration under Nembutal anesthesia. The electrode leads were brought out through a scalp incision to a four-pole plug which was cemented to the subject's skull. A flexible lead connected the subjects via a four-pole mercury commutator mounted inside the door hood to a Grass Model 7P3A preamplifier which controlled one channel of a Grass Model 7 polygraph. The output of the corresponding driver amplifier was fed to a Grass Model 7P4D tachograph and also shaped to give on each R-wave a square pulse suitable for driving solid state BRS programming circuitry and one channel of an electromechanical print-out counter (Practical Automation Company Model MMP-6).

Ambulation was measured by counting the number of floor rods that interrupted a photobeam as the wheel rotated. The output of the photosensor was fed to the electromechanical print-out counter and also integrated using a Grass Model 7P3A preamplifier to drive a channel of the polygraph providing a graphic record of ambulation calibrated in metres per min (mpm).

Oxygen Consumption was measured by calculating the volume of oxygen (O_2) extracted and utilized by the subjects from air which was circulated through the Perspex box at a controlled rate of 4 litres per min. Air flow was controlled by a vacuum pump that delivered a negative pressure of approximately 5 cm of water (Secomak Air Products Model 37/18). Room air entered through a tube at the rear of the Perspex box and was extracted via an airline at the apex of the door hood above the subject. Using a two-way manual air valve (Enots) it was possible to pass the air either entering or leaving the subject compartment, via drying tubes filled with silica gel, through a Taylor-Servomex Model OA 272 Oxygen Analyzer. The Analyzer provided an output of 2mv/ml O_2 which was further amplified by a Grass Model 7P1A DC preamplifier to drive a channel of the polygraph. The output of the corresponding driver amplifier was fed to a voltage-to-frequency converter which drove a channel of the print-out counter at a rate directly proportional to the O_2 content of the air irrigating the Analyzer. The O_2 content of room air was sampled prior to and immediately following each experimental session to assess the stability of the measurement system. Throughout each session the system was used to continuously monitor the O_2 content of the air leaving the subject compartment. Oxygen Consumption which was expressed in terms of cubic centimetres per min (ccs/min) was calculated by subtracting the average O_2 content of air leaving the compartment each min from the average O_2 content of air entering the compartment. An estimated time lag of 1 min in detecting variations in O_2 Consumption existed using this system and was taken into account in scoring the data.

Every min throughout each session the print-out counter gave a numerical record of O_2 Consumption, HR, Ambulation, and number of electric shocks presented.

Conditioning Procedure

Subjects were arbitrarily divided into two equal groups, one to be conditioned to increase HR the other to decrease HR.

All subjects were tested on each weekday but not weekends, for 20 sessions each of 48 min duration. During the first 5 sessions the subjects were adapted to the apparatus; the houselights were off and no experimental stimuli were presented (S^{Δ} condition). Following adaptation they received 15 conditioning sessions each comprising 6 successive 8-min periods. The first, third and fifth periods were designated S^{Δ} and the conditions prevailing were identical to those during adaptation. The remaining periods were designated S^{D}. The onset of every S^{D} period was signalled by illumination of the houselights which remained on until the start of the next S^{Δ} period.

During S^{D} periods the subjects in the two groups could avoid electric footshock by respectively increasing or decreasing their HRs. Successive samples of 5 inter-heartbeat-intervals (IBIs) were compared to an adjustable experimenter-controlled criterion. If a sample was of shorter duration than the criterion it qualified as a high HR, if longer it qualified as a low HR. High HR was designated the avoidance response for subjects of the Increase group and low HR that for subjects of the Decrease group. Whenever, during S^{D}, the subject emitted a 5 IBI sample that did not meet the avoidance criterion, a tone (4.4 KHz at 80 dB) was presented and remained on if the subject continued to emit noncriterion responses. Following the 7th successive noncriterion sample, an inescapable electric footshock (1 mA scrambled for 1 sec) was delivered to the floor of the wheel. Electric shock was followed by a 10 sec Time-out during which the houselights were extinguished and the avoidance contingency suspended. After a Time-out the lights were re-illuminated and the contingency re-applied. If the subject emitted a criterion HR response following onset of the tone but prior to the electric shock the tone terminated and the noncriterion response counter reset to zero. Thus, provided the subjects emitted at least one sample of five IBIs that met criterion in every sequence of 7 samples electric shock could be avoided continuously.

The adjustable HR criterion was set at the beginning of each S^{D} period on the basis of the subject's HR during the preceding S^{Δ}. During S^{D} the criterion was made more stringent whenever the subject either avoided electric shock for more than 2 consecutive min or received no tones for a continuous period of 30 sec excluding Time-outs. The criterion was relaxed if the subject received 3 or more electric shocks in a single min. Each unit adjustment of the criterion altered its value by .01 sec.

Results

Means for O_2 Consumption, HR, and Ambulation were computed for each subject for each of the 6 successive 8-min periods that constituted each session. The means for each of these variables were submitted to separate analyses of variance for the 5 Adaptation and 15 Conditioning Sessions respectively.

Adaptation

Analyses of variance indicated that the groups did not differ significantly[1] in any aspect of their Adaptation performance. Furthermore, the Adaptation analyses revealed that none of the three measures of performance changed significantly over sessions. However it was found that both O_2 Consumption ($F(5/50)=4.99$) and HR ($F(5/50)=20.13$) declined significantly within sessions. It will be seen from Fig. 1 that apart from the first 8 min period of Adaptation, HR and O_2 Consumption show parallel decreases. Although Ambulation tended to decline over the first 32 min of Adaptation sessions and then increase again during the final 16 min, this effect was not statistically significant. Nevertheless it should be noted that 10 of the 12 subjects displayed lower rates of Ambulation during the final 8 min of Adaptation sessions than during the first 8 min.

Conditioning

The group means for each of the three measures of performance are plotted as a function of Sessions in Fig. 2 with the S^{D} and S^{Δ} values separated for the Conditioning sessions. These data provide clear evidence of discriminated HR conditioning. By the final conditioning session Increase subjects display a mean S^{D} HR that is 68 bpm higher than in S^{Δ} whilst the mean HR of Decrease subjects is 78 bpm lower in S^{D} than S^{Δ}. During the final S^{D} period Increase subjects displayed a mean HR 127 bpm higher than the Decrease subjects, whereas during the S^{Δ} period they were 20 bpm lower than the Decrease subjects.

Although the discriminated HR changes are symmetrical for the Increase and Decrease subjects by the 15th session, it will be observed that the acquisition curves for the two groups differ substantially. In particular the discriminative effect appears to emerge immediately in the case of Increase subjects and only gradually as a function of Sessions for the Decrease group. The reliabilities of these effects were confirmed by analysis of variance which provided a significant Groups effect ($F(1/10)=10.63$), a significant Groups by S^{D}/S^{Δ} interaction ($F(1/10)=21.88$), and a significant Groups by S^{D}/S^{Δ} by Sessions interaction ($F(14/140)=3.69$).

It will be observed from Fig. 2 that the HR changes were closely paralleled by variations in both O_2 Consumption and Ambulation. The intercorrelations between these variables during condi-

[1]The .05 rejection region was adopted for all statistical tests.

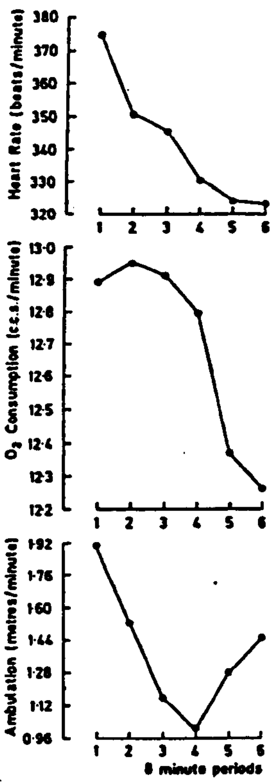

Fig. 1. Within session means (12 subjects) of HR, O_2 Consumption, and Ambulation collapsed over 5 Adaptation Sessions.

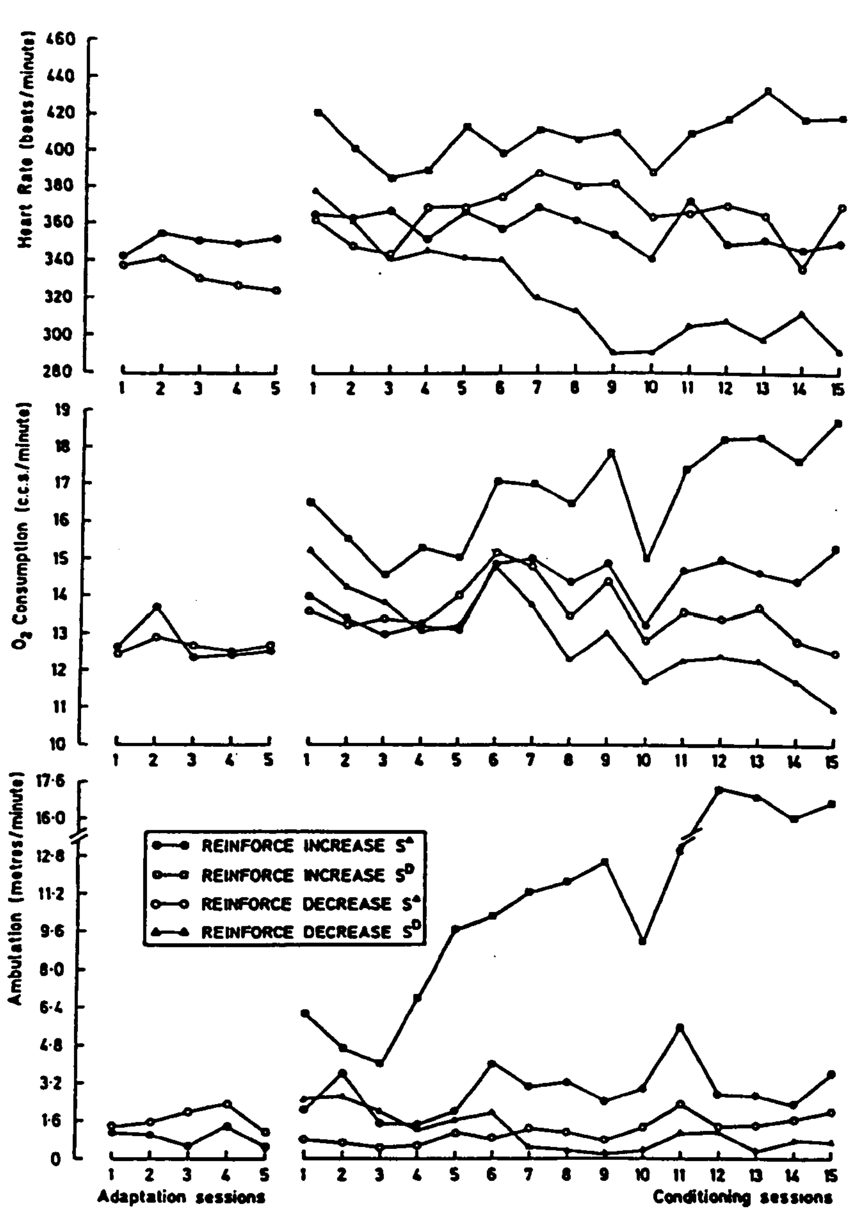

Fig. 2. Group means for HR, O_2 Consumption, and Ambulation as a function of Sessions during Adaptation and Conditioning. Note that the same conditions prevailed during Adaptation as during the S^{Δ} periods of Conditioning.

tioning were examined by computing the product-moment correlation coefficients between the 15 Session means for each activity. These coefficients are presented separately for the S^D and S^{Δ} periods for each group in Table 1. It will be seen here that all the measures are highly intercorrelated during S^D periods but not during S^{Δ} periods.

Both O_2 Consumption and Ambulation were found to respond to the experimental treatments in much the same way as HR. Increase subjects displayed significantly greater O_2 Consumption ($F(1/10) = 10.25$) and Ambulation ($F(1/10) = 12.36$) than Decrease subjects. Significant Groups × S^D/S^{Δ} interactions for both Ambulation ($F(1/10) = 16.44$) and O_2 Consumption ($F(1/10) = 32.30$) reflected the tendency of Increase subjects to display higher levels and Decrease subjects to display lower levels of activity during S^D than S^{Δ} periods. These group

TABLE 1

Product-moment correlations between three measures of activity during S^D and S^Δ segments of successive conditioning sessions (N=15) for increase and decrease subjects

Activity Measures	Correlations			
	S^D		S^Δ	
	Increase	Decrease	Increase	Decrease
Heart Rate/Ambulation	.678*	.899*	.217	.050
Heart Rate/O_2 Consumption	.743*	.816*	−.017	.583*
Ambulation/O_2 Consumption	.870*	.734*	.556*	−.293

*$p<.05$.

differences in discrimination also became more pronounced as a function of training as indicated by significant Groups × S^D/S^Δ × Sessions interactions for both Ambulation ($F(14/140)=3.68$) and O_2 Consumption ($F(14/140)=4.83$).

Examination of the shock densities indicated that Increase subjects received approximately twice as many shocks as did Decrease subjects (16.2 vs 9.92 shocks per session). Although this observation could imply that the higher levels of activity displayed by the Increase group were elicited by the higher shock density, two aspects of the data discredit this possibility.

Subjects within each group were ranked in terms of the magnitude of their terminal (Session 15) discriminative performance. In the Increase group the subject displaying the greatest positive S^D-S^Δ HR difference (+136 bpm) received a rank of 1 and the subject showing the smallest positive difference (−8 bpm) received a rank of 6. Conversely in the Decrease group the subject with the greatest negative difference (−117 bpm) received a rank of 1 and the subject with the smallest negative difference (−24.2 bpm) received a rank of 6. These ranks were correlated (Spearman's rho) separately for each group with subject rankings based on the total number of shocks received throughout conditioning (the subject within each group receiving the highest number of shocks received a rank of 1). In both groups a perfect negative correlation (−1.0) was found. If tonic HR levels had been a positive function of shock density, a positive correlation would have been expected for subjects in the Increase Group. It is possible that the performance of Decrease subjects was affected to some extent by shock density since the subjects that received fewest shocks displayed the largest discriminated HR decreases.

Correlations (Pearson's product-moment) between the mean number of shocks and the mean S^D HR for each day of conditioning (N=15) were also computed separately for each group. The correlations between shocks and HRs were −.313 for the Increase subjects and .691 for the Decrease subjects. Thus for the Increase subjects, the higher the HR, the lower the shock density and for the Decrease subjects, the lower the HR the lower the shock density.

Discussion

The results of this experiment clearly show that shock-avoidance reinforcement contingencies effectively condition discriminated tonic increases and decreases in HR of considerable magnitude. Though not without certain difficulties (Black, 1971) the bidirectional design provides strong evidence that the results are attributable to the contingency between shock presentation and mean HR, rather than a classical conditioning process. Furthermore, despite the inequality of shocks received by the two groups, it has been shown that the difference in mean HR between groups cannot be accounted for in terms of the positive chronotropic effects of increased shock stimulation.

Accompanying the very substantial conditioned HR responses found in this study were equally significant changes in somatomotor activity measured by both Ambulation and O_2 Consumption. Thus, although the procedure had profound effects upon cardiac activity, the present data do not suggest a cardiospecific effect of the contingency applied. It seems that, as others have indicated (Obrist, Webb, Sutterer, & Howard, 1970), there is an integrated responsiveness of cardiovascular and somatomotor activities. Such integration of cardiac and somatic activities is further indicated by the high positive correlations between the measures of performance particularly during S^D periods. During S^Δ periods, however, the correlations between the three indices of activity are considerably lower and for Increase subjects at least, suggest some measure of cardiac-somatic differentiation. It will be observed from

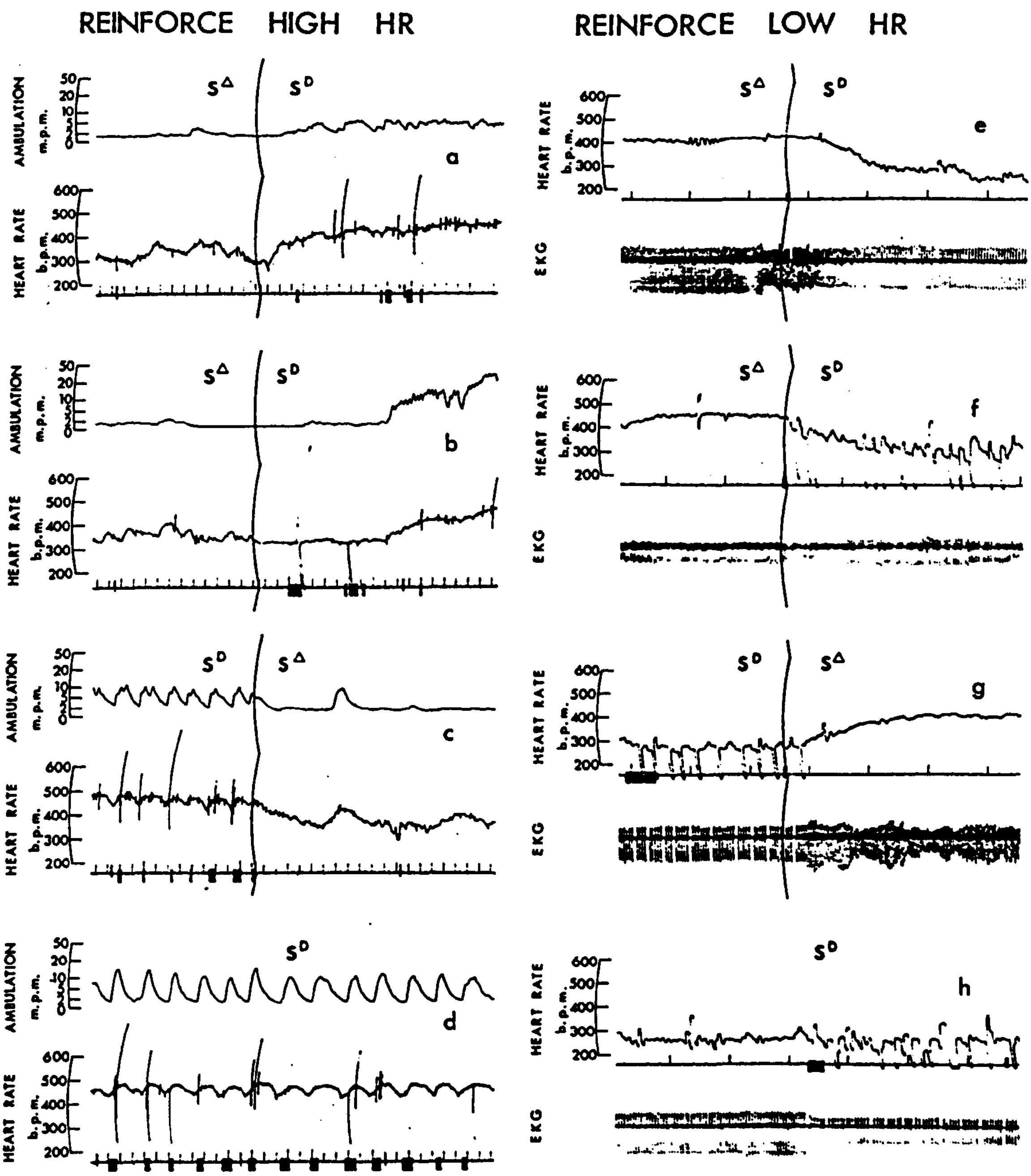

Fig. 3. Polygraph records illustrating significant features of performance. The paper speed for records of the Decrease subjects (e, f, g, & h) is five times faster than for records of the Increase subjects (a, b, c, & d). (5-sec periods are marked on the event line by the larger vertical blips.) Tone presentations are identified by dark bands below the event lines. Records for Increase subjects display HR in bpm and Ambulation in metres per min (mpm). For the Decrease subjects HR is displayed on one channel and the EKG on the second channel; since these subjects displayed very little ambulation, records of this activity are not included for this group.

Record a. Subject 7, Conditioning Session 13, S^{Δ}/S^{D} transition: Both HR and Ambulation increased on entry to S^{D} but more than a minute was required to attain stable tonic adjustments.

Record b. Subject 10, Conditioning Session 8, S^{Δ}/S^{D} transition: Again HR and Ambulation increased simultaneously some time after entry into S^{D}. Moreover, although an electric shock was delivered after the first tone (indicated by the large biphasic HR artifact), there was not an immediate increase in HR.

Record c. Subject 12, Conditioning Session 12, S^{D}/S^{Δ} transition: A close phasic relationship existed between Ambulation and

Fig. 2 that during successive S^{Δ} periods, the HRs of Increase subjects do not exhibit any clear trend whereas their O_2 Consumption and Ambulation scores show a somewhat erratic but nevertheless clearly increasing trend. These tendencies are reflected in the correlational data: HR shows low and insignificant correlations with O_2 Consumption and Ambulation whereas there is a significant positive correlation between Ambulation and O_2 Consumption. Several factors may contribute to this effect: a) Compensatory vagal processes may come more and more to dominate HR during successive S^{Δ} periods as the conditioned sympathetic activation during associated S^D periods achieves a higher and higher magnitude; b) the significant increase in O_2 Consumption and Ambulation observed during successive S^D periods may have induced progressively larger O_2 debts that were repaid via increased O_2 Consumption during the associated S^{Δ} periods. This possibility is consistent with the observation that over sessions variations in O_2 Consumption during S^D periods were highly correlated with variations during corresponding S^{Δ} periods ($r(13)=.903$) in the Increase Group.

In the Decrease Group, O_2 Consumption during the S^D and S^{Δ} periods was also significantly but not as highly correlated ($r(13)=.622$). Since this group showed sub-Adaptation levels of O_2 Consumption during S^D periods from Session 8, a simple O_2 debt explanation cannot be advanced in accounting for this correlation. Reference to Fig. 2 indicates that over successive S^{Δ} periods, Decrease subjects tended to show a slight but systematic increase in Ambulation with a corresponding decrease in HR and O_2 Consumption. The correlational data here do not indicate cardiac-somatic differentiation since variations in HR and O_2 Consumption over sessions are significantly correlated ($r(13)=.583$). Since during S^{Δ} periods, variations in Ambulation are not significantly correlated with O_2 Consumption or HR for this group it is suggested that this is a case in which Ambulation is not the primary means of expressing somatomotor activity. This possibility is also consistent with the uncorrelated variations in Ambulation and O_2 Consumption observed during Adaptation sessions (Fig. 1).

The present interpretation that conditioned tonic HR and somatomotor activity covary conflicts with that of Engel, Gottlieb, and Hayhurst, (1976) who reported that "tonic levels of HR are largely independent of tonic levels of somato-motor activity [p. 293]." The apparent dissociation found by Engel could well be a result of the use of a partial index of somatomotor activity. A valid gross measure of somatomotor activity, such as O_2 Consumption, must be employed for meaningful arguments to be constructed concerning cardio-somatic interaction.

Although the avoidance contingency acted to produce both conditioned HR increases and decreases, notable differences were evident in the performances of the two groups. Acquisition of the discriminative response was much faster for the Increase group being apparent in Conditioning Session 1, than for the Decrease group which did not reveal the S^{Δ}/S^D discrimination until Conditioning Session 5. This difference in acquisition may be accounted for by the unconditional eliciting effects of electric shock which facilitated heart and ambulation rate increases thereby interfering with the acquisition of the decrease HR response.

Further differences between Increase and Decrease HR performances are shown in Fig. 3 which provides examples of polygraph records illustrating different aspects of performance. It should be noted that the paper speed of the records for Decrease subjects is five times that of the records for Increase subjects, as shown by the event line. It can be seen that for S^{Δ}/S^D transitions changes in tonic HR were more rapid for Decrease subjects (Records e and f), being completed after a few seconds, than for Increase subjects (Records a and b) which re-

HR during S^D. On entry to S^{Δ} both Ambulation and HR declined. As for S^{Δ}/S^D transition, readjustment of the tonic HR was relatively slow.

Record d. Subject 12, Conditioning Session 19, S^D period: Conditioning was continued beyond 15 sessions for this subject. It can be seen that performance in S^D became extremely stereotyped. A high tonic HR was maintained and superimposed upon it were phasic variations that were highly correlated with tone-controlled variations in Ambulation.

Record e. Subject 29, Conditioning Session 9, S^{Δ}/S^D transition: On entry to S^D HR decreased and reached a lower stable level within only a few seconds.

Record f. Subject 30, Conditioning Session 9, S^{Δ}/S^D transition: On entry to S^D an immediate tonic adjustment of HR was made accompanied by an abnormal cardiac rhythm.

Record g. Subject 29, Conditioning Session 6, S^D/S^{Δ} transition: S^D performance was characterized by a low arrhythmic HR. On exit from S^D the EKG abnormality was immediately abolished and HR readjusted to a higher tonic level in only a few seconds.

Record h. Subject 29, Conditioning Session 9, S^D period: HR was maintained at a low tonic level. However, when the tone signalled the threat of shock, an even lower HR characterized by the abnormal rhythm occurred. Thus, the profound bradycardia appears to be under strong stimulus control.

quired 1–2 min to attain stable tonic adjustments. A similar difference between the two groups can be seen for the S^D/S^Δ transition (Records c and g).

The subjects of the Increase group exhibited conspicuous variations in Ambulation during S^D which were accompanied by phasic HR changes (Record d). For Increase subjects, therefore, it seems that not only tonic but also phasic HR changes are closely correlated with somatomotor variations. Since subjects of the Decrease group rarely ambulated (see Fig. 2) their Ambulation records are not shown.

By Conditioning Session 15, 5 of 6 Decrease subjects exhibited severe bradycardic arrhythmias during S^D (Records, f, g, and h). Inspection of the EKG during such arrhythmic episodes revealed a high incidence of non-conducted P-waves suggesting functional second degree heart block. During the early conditioning sessions such abnormal cardiac rhythms were not seen even though bradycardias were induced (Record e). When abnormal cardiac rhythms were present they appeared to be under strong stimulus control occurring within 1 to 2 sec of the onset of S^D (Record f) or in response to a warning signal despite the HR having attained a low tonic level (Record h).

The differences between the two groups indicate that although similar procedures were applied to both Increase and Decrease groups the processes involved in meeting the avoidance criterion may differ. The short latency required by Decrease subjects and the much longer latencies required by Increase subjects to achieve adjustments in mean HR following transitions between S^D and S^Δ are probably related to the dual neurohumoral system of HR control. Warner and Cox (1962) have demonstrated that there is a difference in speed of action of the two aspects of autonomic control of HR. Vagal responses are fast with time constant of less than a second, whilst sympathetic responses are slower with time constant of the order of several seconds. Both vagal and sympathetic influences probably act in harmony to alter tonic HR but we suggest the Decrease response is of predominantly parasympathetic origin. Consistent with this view is the knowledge that cardiac abnormalities of the type seen in the EKGs of Decrease subjects may be elicited by vagal stimulation (Hurst, Logue, Schlant, & Wenger, 1974).

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Energy Expenditure, Heart Rate, and Ambulation During Shock-Avoidance Conditioning of Heart Rate Increases and Ambulation in Freely-Moving Rats

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ABSTRACT

Using shock-avoidance procedures with equivalent reinforcement criteria and in a running wheel situation, one group of rats was reinforced for heart rate increases (HR group) and another group for running (Amb group). Throughout 5 Habituation sessions and 5 Conditioning sessions, each 2 hrs in duration, continuous recordings were made of heart rate (HR), ambulation (Amb), and oxygen consumption (OC). The groups did not differ in their mean levels of HR, Amb or OC during Habituation or during Conditioning, although the introduction of the contingencies did elicit significant increases in the mean levels of all three variables. Amb group subjects distributed their activity more effectively in relation to the experimental contingencies, resulting in 5/6 subjects acquiring successful avoidance behavior against only 2/5 subjects in the HR group. Examination of individual subjects in both groups indicated that learners all exhibited very similar behavior profiles regardless of the contingencies applied during conditioning, and the same was true of nonlearners. Accordingly the data were regrouped for learners and nonlearners and reanalyzed. These analyses revealed that nonlearners differed from learners in the nature of the relationships they displayed between variations in HR, OC and Amb during both the preconditioning (habituation) and conditioning phases of the experiment. These differences are discussed together with data derived from additional conditioning sessions in which autonomic blocking agents (Propranolol and Methyl Atropine) were administered to a subgroup of learners.

DESCRIPTORS: Heart rate, Energy expenditure, Ambulation, Shock-avoidance, Autonomic blockade.

A large body of evidence indicates that operant procedures may be used to condition cardiac changes in several species including man (Black, Osborne, & Ristow, 1977; Brener, Phillips, & Connally, 1977; Engel & Gottlieb, 1972; Harris, Goldstein, & Brady, 1977; Obrist, Galosy, Lawler, Gaebelein, Howard, & Shanks, 1975). However, the nature of the conditioning process, and in particular its specificity or otherwise, remains the subject of much enquiry and debate.

The reliable covariation of respiratory and somatomotor activity with cardiac activity is based upon the intermediate role of the heart in delivering oxygen (O_2) from the lungs to the striate musculature. The activities of the somatomotor system account for the greatest proportion of the O_2 consumed by an active organism. Much evidence indicates that the coordination of somatic and cardiovascular activities is achieved by central neural integration (Gellhorn, 1967; Germana, 1969; Smith, 1974). However, peripheral integration is also of importance as indicated, for example, by the observation of Donald and Shepherd (1963) that in dogs the normal relationship between cardiac output and oxygen consumption (OC) is maintained following surgical denervation of the heart. It is therefore unsurprising that conditioned changes in cardiac activity are frequently accompanied by concomitant

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changes in somatomotor activity and vice versa (Black, Note 1; Freyschuss, 1970; Goesling & Brener, 1972; Obrist, 1976; Obrist, Webb, & Sutterer, 1969; Roberts & Young, 1971). The findings (Obrist et al., 1975) that in man the magnitude of conditioned heart rate change is inversely related to the degree of somatomotor restraint applied during conditioning suggests that conditioned heart rate changes do not merely accompany somatomotor changes but are an integral component of a generalized cardiosomatic response state.

A recent study (Brener et al., 1977) showed that large heart rate (HR) increases and decreases operantly conditioned in freely-moving rats were accompanied by equally significant and directionally equivalent variations in both ambulation and in general activity levels as indexed by OC, a precise measure of overall energy expenditure. This finding indicates that the operant reinforcement of HR did not have a cardiospecific effect but instead produced an integrated behavioral adjustment of which the conditioned cardiac changes were but one component. An implication of this interpretation is that the reinforcement contingencies failed to distinguish or discriminate between components of the gross behavioral adjustment induced by the conditioning procedure. If so, one might expect similar behavioral adjustments to result irrespective of which response component of an integrated behavioral 'Gestalt' is identified as the operant by the reinforcement contingencies. This hypothesis was tested in the present experiment where two groups of rats were conditioned in a running wheel, one to increase tonic HR and the other to ambulate, using matched signalled shock-avoidance procedures.

Method

Subjects

Twelve male brown-hooded rats from the colony maintained in the Department of Psychology, University of Hull, and weighing between 390g and 530g (mean 460g) at the start of the experiment, were arbitrarily divided into two equal groups.

Apparatus

Subjects were tested in a running wheel 36.8 cm in diameter and 13 cm wide enclosed within a clear Perspex box measuring 40.4 cm high × 31.9 cm deep × 43.9 cm wide, which was airtight when closed. A shock generator scrambler (BRS model SGS-003) was connected via a five-pole commutator to the aluminum rods, spaced 1.54 cm apart, which formed the wheel floor. An adjustable friction brake was set to apply a force to the circumference of the wheel of 125g torque.

The entire apparatus was enclosed within an electrically-shielded sound-attenuating, lightproof box housed in a cubicle adjacent to the recording room. An audible tone generator (Sonalert Model SC 628H) was mounted on the back wall of the outer box. A light was positioned on each side of the Perspex box in a plane parallel to the floor of the running wheel.

Measurement

Subjects' electrocardiograms (EKGs) were recorded from stainless steel electrodes implanted subcutaneously in a standard limb-lead configuration under Nembutal anaesthesia. The electrode leads were brought out through a scalp incision to a four-pole Amphenol socket cemented to the subject's skull. A flexible lead connected the animal to a Grass Model 7P3A preamplifier which controlled one channel of a Grass Model 7 polygraph via a servo-assisted electro-cannular swivel which permitted the animal to move in all directions with minimal extra work being required to rotate the swivel. The output of the corresponding driver amplifier was fed to a Grass Model 7P4D tachograph and also shaped to give, on each R-wave, a square-wave pulse suitable for driving solid state BRS programming circuitry and a channel of an electromechanical printout counter (Practical Automation Company Model MMP-6).

Ambulation (Amb) was measured by counting and timing the number of floor rods which interrupted a photobeam as the wheel was rotated. The output of the photosensor was fed to one channel of the printout counter and also integrated using a Grass Model 7P3A preamplifier to drive a channel of the polygraph, thus giving a graphic record of ambulation calibrated in meters per minute (mpm).

Oxygen consumption was measured by calculating the volume of oxygen (O_2) extracted by the subject from air circulated under negative pressure through the Perspex box at a controlled rate of 10 liters per minute. Samples of air entering and leaving the subject compartment were passed via silica gel drying tubes, through separate channels of a Taylor Servomex OA 184 Oxygen Analyzer under positive pressure. The Analyzer calculates the volume of O_2 extracted by the animal by continuous comparison of the O_2 content of the two samples, and gives a voltage output which is directly proportional to the volume of O_2 extracted by the subject.

Every minute throughout each session the printout counter gave a numerical record of OC, HR, Amb, and number of shocks presented.

Conditioning Procedure

Subjects were divided into two equal groups (6 rats/group), one to be conditioned to increase HR and the other to Ambulate.

All animals were tested on each weekday but not weekends for 10 sessions each of 2 hrs duration. During the first 5 sessions, the subjects were habituated to the apparatus; the houselights were off and no experimental stimuli were presented (S^{Δ} condition). Following Habituation, the subjects received 5 Conditioning sessions, each comprising 6 successive 20-min periods. The first, third and fifth periods were designated S^{Δ} and the conditions then prevailing were identical to those during Habituation. The remaining 3 20-min periods were designated SD. Onset of every SD period was signalled by illumination of the houselights, which remained on until the start of the next S^{Δ} period.

During SD periods the subjects in the two groups could avoid electric footshock by respectively increasing HR (HR Group) or ambulating (Amb Group). For the HR Group successive samples of 5 inter-heartbeat-intervals (IBIs) were compared to an adjustable experimenter-controlled criterion. If a sample was of shorter duration than the criterion, it qualified as a high HR and thus an avoidance response. Whenever a subject emitted a 5 IBI sample which did not reach criterion, a tone (4.4 KHz at 80dB) was presented and remained on while the subject continued to emit non-criterion IBI samples, until following the seventh non-criterion response an inescapable footshock (1.5 mA scrambled for 1 sec) was delivered. For the Amb Group the experimenter-controlled criterion assessed the subject's rate of ambulation. The subjects were required to rotate the wheel 16 cm in a given time interval which was designated by the criterion. Failure to ambulate at the required rate resulted in the onset of the tone and following 7 successive sec of non-criterion ambulation an inescapable footshock was delivered. Following electric shock a 10-sec Time-out was initiated during which no experimental stimuli were presented.

The adjustable criterion was set at the beginning of each SD period on the basis of the individual's performance. During SD the criterion was made more stringent whenever the subject either received no tones for 1 min or avoided electric shock for 2 min. The criterion was relaxed if the subject received two or more shocks in any single minute. In this way the subjects of both groups had equal opportunity to avoid electric shocks throughout conditioning.

Drug Probes

After completion of the Conditioning phase, 4 subjects (all learners) from the Amb Group were submitted to 6 additional Conditioning sessions following intraperitoneal injections of autonomic blocking agents. The subjects received intraperitoneal injections of Propranolol (5 mg/kg), Methyl Atropine (10 mg/kg), or a mixture of Propranolol (5 mg/kg) and Methyl Atropine (10 mg/kg). Each subject received one conditioning session under the influence of each of these agents and each drug session was preceded by a control conditioning session when the subject received an intraperitoneal injection of isotonic saline.

Results[1]

HR vs Amb Contingencies

Habituation. Analyses of variance indicated that the two groups did not differ in any aspect of their habituation performance. Accordingly the data for all subjects (n = 12) were combined for further analyses and are presented for the 6 20-min periods of each Habituation session in Fig. 1. It will be seen that HR, OC and Amb all display systematic decreases within each session with the greatest decreases occurring between the first and second

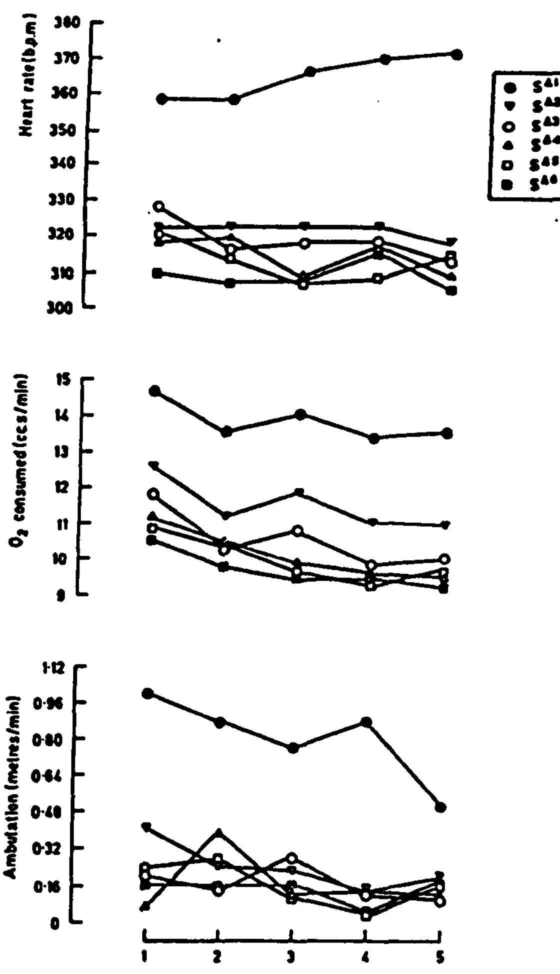

Fig. 1. Within session period means (12 subjects) of heart rate, oxygen consumption, and ambulation over 5 Habituation sessions.

20-min periods. These within session variations were found to be significant for HR ($F(5/55) = 36.00, MS_e = 718.05$), OC ($F(5/55) = 55.65, MS_e = 2.60$), and Amb ($F(5/55) = 14.72$, $MS_e = 10.56$). In addition the mean level of OC was found to decline significantly over sessions, $F(4/44) = 4.76$, $MS_e = 5.37$. Although HR and Amb did not show significant changes over sessions, Pearson product-moment correlations computed from the 6 20-min means in each of the 5 sessions (N = 30) indicated that the three variables were significantly intercorrelated ($p < .01$) over the course of habituation ($r_{HR/OC} = .912$; $r_{HR/Amb} = .880$; $r_{OC/Amb} = .884$).

Conditioning. One subject in the HR group (#87) did not survive throughout conditioning and his data were excluded from all conditioning analyses.

The HR and Amb contingencies appeared to be

[1] The .05 rejection region was accepted for all statistical tests except where otherwise indicated.

differentially effective in conditioning discriminated avoidance behavior. Five of the 6 Amb subjects acquired reliable avoidance performance as indicated by the high percentage of warning stimuli terminated (greater than 90%), whereas only 2 of 5 HR subjects acquired comparable performance. However, group comparisons employing analyses of variance indicated that the groups did not differ in their overall (SD + S^{Δ}) mean levels of HR, OC or Amb. Nevertheless, the mean levels of all three variables were found to be significantly higher during SD than S^{Δ} periods (HR:$F(1/9)$ = 13.1, MS_e = 1506.97; OC:$F(1/9)$ = 13.82, MS_e = 12.09; Amb:$F(1/9)$ = 19.267, MS_e = 1426.99). Both HR, $F(4/36)$ = 3.56, MS_e = 183.95, and OC, $F(4/36)$ = 5.749, MS_e = 2.95, displayed significant decreases over the course of conditioning. The between-sessions decrease in HR was due mainly to the HR subjects which displayed significantly greater decreases than the Amb subjects, as reflected by the significant Groups × Sessions interaction, $F(4/36)$ = 4.23, MS_e = 183.95.

Learners vs Nonlearners

The interpretation of statistical comparisons between the Amb and HR groups was rendered difficult because each group comprised both learners and nonlearners, resulting in substantial within-group variability. However, examination of the individual performances of the subjects indicated that regardless of the contingencies applied during conditioning (Amb or HR), learners all displayed very similar behavioral profiles characterized by significantly higher levels of HR, OC and Amb during SD than S^{Δ}, whereas nonlearners displayed little evidence of discrimination in their activity.

The mean HR, OC, Amb and shock rates recorded over the 5 conditioning sessions for each subject are presented in Table 1. It will be noted that although the reinforcement criterion rules were rigorously applied, considerable differences in mean shock rate between subjects emerged. This is particularly pronounced for subject #80 in the Amb group. Since this subject only ambulated during SD periods following shock delivery, even very lenient criteria resulted in a high shock density. On the other hand, the most successful adaptations in terms of reduction of shock density were achieved by the 2 learners in the HR group.

Despite the variations in shock density within groups, it will be observed that the SD/S^{Δ} differences for all three measures of activity were consistently greater for learners than for nonlearners. In an effort to describe the behavioral profiles associated with these two relatively homogenous groups of subjects, the data were repartitioned and differences between the mean performances of learners and nonlearners, both prior to and during conditioning, were statistically evaluated.

Habituation. The overall changes within and between habituation sessions have already been reported in conjunction with the comparisons between the Amb and HR contingency groups. Further analyses of the habituation data revealed that the learners and nonlearners did not differ significantly in their mean levels of HR, OC and Amb over the course of habituation. However, analyses of variance performed separately on the habituation data of the two groups revealed that learners alone exhibited significant decreases in OC ($F(4/24)$ = 2.95, MS_e = 1.91) and Amb ($F(4/24)$ = 4.75, MS_e = .83) over successive habituation sessions. These

TABLE 1

SD and S^{Δ} means for learners and nonlearners during conditioning

Contingency	Rat No.	HR		OC		Amb		Shocks
		S^{Δ}	SD	S^{Δ}	SD	S^{Δ}	SD	
Learners								
Amb	77	316.0	355.5	13.87	18.46	5.91	43.25	36.0
Amb	78	334.7	382.3	14.92	19.81	9.91	48.33	25.6
Amb	79	333.7	390.7	13.31	17.52	1.22	41.65	35.0
Amb	82	356.1	404.1	11.02	15.64	2.25	58.94	21.4
Amb	83	311.7	359.1	11.69	15.88	5.68	56.13	30.2
HR	88	307.5	353.5	11.85	15.35	4.65	53.06	8.6
HR	90	356.6	405.0	16.16	20.29	5.06	69.41	11.6
Nonlearners								
Amb	80	317.2	326.2	12.58	12.09	4.42	4.18	172.4
HR	86	348.9	340.7	11.73	11.35	2.29	3.25	28.0
HR	91	347.1	333.1	11.41	10.93	2.94	11.64	35.0
HR	92	397.2	386.6	12.61	12.02	2.19	11.59	36.2

effects are illustrated in Fig. 2, which displays the mean habituation and conditioning performances of the learners and nonlearners.

Conditioning. Performance during the conditioning period was also assessed using analyses of variance. These confirmed the results illustrated in Fig. 2. Although the two groups did not differ in their overall mean HR levels, the significant Groups × Sessions interaction, $F(4/36) = 4.23$, $MS_e = 183.95$, may be attributed to the systematic decrease in HR over sessions displayed by the nonlearners alone.

Learners displayed significantly higher levels of OC ($F(1/9) = 12.42$, $MS_e = 26.15$) and Amb ($F(1/9) = 77.99$, $MS_e = 182.42$) over the course of conditioning than did nonlearners. It will be seen from Fig. 2 that these group differences in means are mainly attributable to the learners exhibiting significantly higher levels of activity on all three variables during SD periods than the nonlearners. These effects were reflected by significant Groups × SD/S$^{\Delta}$ interactions for HR ($F(1/9) = 141.96$, $MS_e = 127.52$), OC ($F(1/9) = 425.25$, $MS_e = .34$), and Amb ($F(1/9) = 62.59$, $MS_e = 190.54$). It will also be seen from Fig. 2 that there are systematic decreases in the SD/S$^{\Delta}$ differences for the nonlearners over the course of conditioning which are not displayed by the learners. The statistical reliability of this result is indicated by the significant Groups × Sessions × SD/S$^{\Delta}$ effects for HR ($F(4/36) = 2.63$, $MS_e = 89.47$, $p = .05$), OC ($F(4/36) = 4.11$, $MS_e = .51$), and Amb ($F(4/36) = 3.80$, $MS_e = 45.02$).

Correlations and Regression Analyses

Pearson product-moment correlation coefficients were computed separately for learners and nonlearners to measure the degree of association between variations in the three measures taken two at a time over the course of habituation and conditioning. Linear regression lines were also fitted to each data set which comprised the 6 20-min group means for

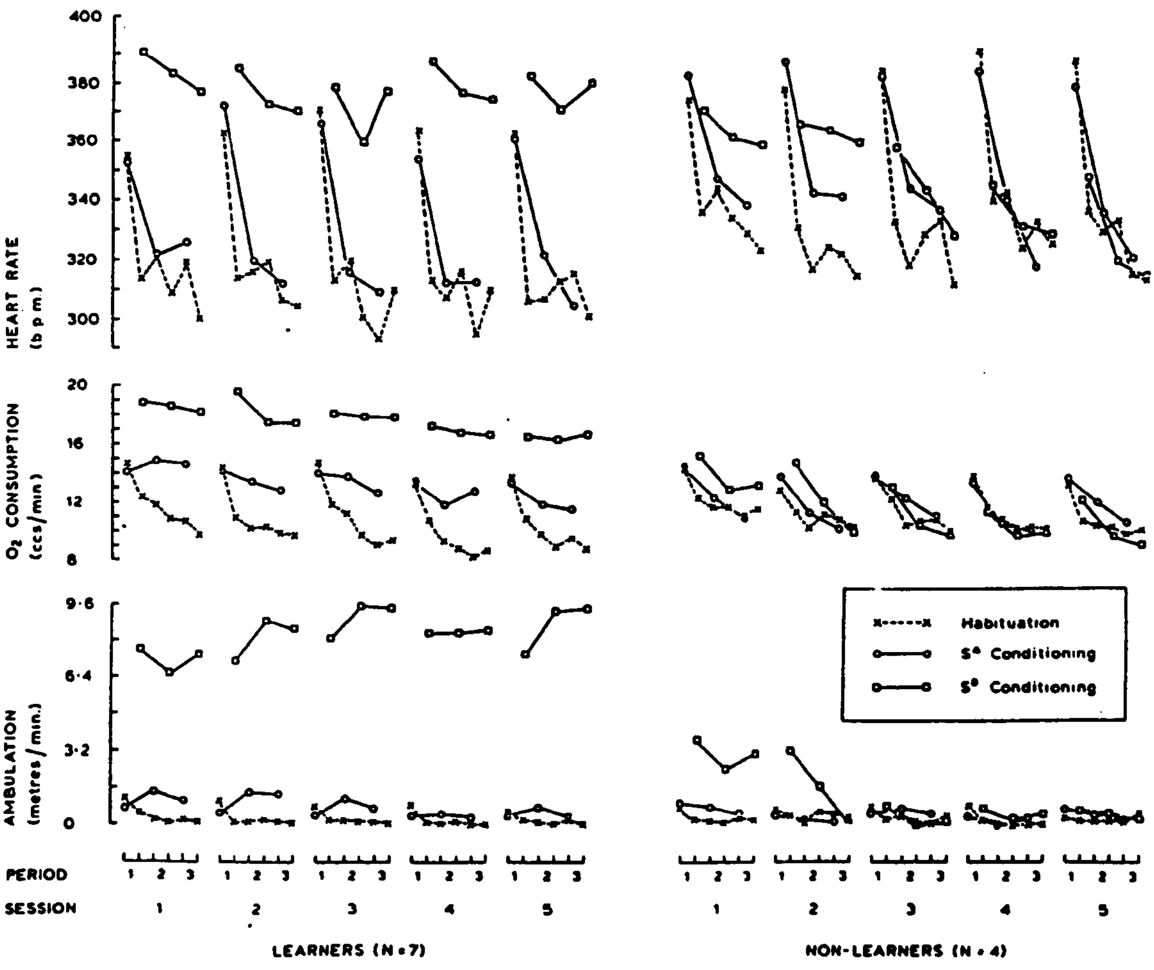

Fig. 2. Twenty-min group means of heart rate, oxygen consumption, and ambulation during each of 5 Habituation and 5 Conditioning sessions for learners (N = 7) and nonlearners (N = 4).

each variable recorded during each of the 5 habituation sessions (N = 30) and each of the 5 conditioning sessions (N = 30). The correlation coefficients together with the slopes and Y-intercepts of the regression lines describing the relationships between HR, OC and Amb are presented in Table 2. The relationship between each pair of variables is described separately. All statistical comparisons reported in this section employed methods described by Kleinbaum and Kupper (1978).

Heart Rate and Oxygen Consumption. HR was highly correlated with OC for both groups during both habituation and conditioning. The Y-intercepts and the slopes of the regression lines fitted to the habituation HR/OC data differed significantly between the two groups. The regression analysis indicated that during habituation nonlearners showed a significantly greater ($z = 3.24$) increase in HR (16.70 bpm) for each additional ml/O_2 consumed than did the learners (10.67 bpm). However, during conditioning the slopes of the HR/OC regression lines did not differ between the two groups.

Although the Y-intercept of the regression line fitted to the nonlearners' habituation data was significantly lower ($z = 2.64$) than that fitted to the learners' data, the comparison is rather artificial since OC seldom falls below the Basal Metabolic Rate (BMR). The BMR for rats of the size run in this experiment is estimated by Kleiber's (1947) formula to be approximately 5.6 ml/O_2/min. Heavy exercise may lead to increases in metabolic rate of up to sixteen times the BMR. Even small changes in behavioral state such as standing at rest rather than lying down are associated with increases in metabolic rate of up to two times the BMR. We have reliably found that following prolonged habituation (10 hrs), rats at rest in the experimental apparatus used in this experiment display metabolic rates equal to approximately 1.4 times the BMR estimated by Kleiber's formula. We term this the Resting Metabolic Rate (RMR) and for rats of the size used in this experiment the calculated RMR is equivalent to an OC rate of 8 ml/O_2/min. This value conforms well to that reported by Le Magnen (1976).

The mean HRs at this level of OC were predicted on the basis of the regression lines fitted to the learners' and nonlearners' habituation and conditioning data. In order to determine whether the predicted resting (RMR) HRs of the two groups differed during either habituation or conditioning, the 95% confidence bands of these estimates were also calculated. These calculations indicated that during habituation the mean resting HR estimated for the learners (288.92 bpm) was not significantly different from that estimated for the nonlearners (281.99 bpm). However, during conditioning the estimated resting HRs were 277.33 bpm for the learners and 308.43 for the nonlearners. Since the 95% confidence bands associated with these esti-

TABLE 2

Linear relationships ($y = Mx + C$) between HR, OC, and Amb during habituation and conditioning for learners and nonlearners

Variables	Periods	Groups	Y-intercept (C)	slope (M)	r
HR(y) / OC(x)	Habituation	Learners	203.54 } ***	10.67 } ***	.89
		Nonlearners	148.43	16.70	.90
	Conditioning	Learners	194.07	10.41	.85
		Nonlearners	222.64	10.72	.86
HR(y) / Amb(x)	Habituation	Learners	302.28 } ***	9.64	.89 } ***
		Nonlearners	322.20	7.96	.56
	Conditioning	Learners	328.08 } *	.93	.77 } *
		Nonlearners	342.15	1.43	.42
OC(y) / Amb(x)	Habituation	Learners	9.39 } ***	.82 } **	.91 } ***
		Nonlearners	10.34	.51	.65
	Conditioning	Learners	12.95 } ***	.09 } **	.88 } **
		Nonlearners	10.90	.18	.65

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

mates were 257.64–297.02 bpm for the learners and 298.01–318.86 bpm for the nonlearners, it may be concluded that during conditioning, nonlearners displayed significantly higher resting HRs than learners. In fact, over the full range of OC values recorded, HRs displayed by nonlearners were significantly higher than those of learners.

Heart Rate and Ambulation. HR variations tended to accompany variations in Amb more reliably in the learners than the nonlearners. During habituation, approximately 79% of the HR variation may be accounted for by variations in Amb for the learners (r = .89), as opposed to only about 31% for the nonlearners (r = .56). This difference in the HR/Amb correlations during habituation was statistically significant (z = 2.90). Although HR tended to vary more independently of Amb during conditioning for both groups, the correlation between these two variables remained higher for learners than for nonlearners (z = 1.69).

The regression analysis also revealed that nonlearners displayed higher HRs at zero Amb rates (Y-intercepts) than learners during both habituation (z = 3.23) and conditioning (z = 1.95).

Oxygen Consumption and Ambulation. Learners exhibited significantly higher correlations between OC and Amb than nonlearners during habituation (z = 2.76) and conditioning (z = 2.21). Over both phases of the experiment approximately 80% of variations in OC could be accounted for by Amb variations in the learners, as opposed to only about 42% in the nonlearners.

The Y-intercept of the OC/Amb regression line is an estimate of the organism's level of energy expenditure when it is not ambulating. In these terms the regression analyses indicate that during habituation at zero ambulation rates, nonlearners were more active than learners (z = 2.847). This suggests a metabolic basis for the significant difference observed in the Y-intercepts of the regression lines fitted to the habituation HR/Amb data of the learners and nonlearners, as referred to above. However, during conditioning learners displayed a significantly higher level of energy expenditure when not ambulating than nonlearners (z = 4.494) but a lower level of HR (see Table 2). We think it likely that the high rates of OC associated with the S^{Δ} performances of learners during conditioning were attributable to short-term oxygen debts incurred by high rates of Amb in the preceding SD periods (see Fig. 2). Nevertheless the analysis provides good evidence that during conditioning the higher HRs estimated for nonlearners at zero Amb rates cannot be attributed to elevated metabolic demands in that group.

The slope of the regression lines fitted to the OC/Amb data may be viewed as an index of the energy efficiency of ambulation: the shallower the slope, the less energy is consumed per ambulation work done (distance × force). It will be noted that both groups consumed substantially less O_2 per Amb unit during conditioning than they did during habituation. This effect was most marked for the learners whose ambulation was significantly more energy efficient than that of the nonlearners during conditioning (z = 2.303). Although the analysis indicated that nonlearners displayed more energy efficient ambulation than learners during habituation, the interpretation of this observation is unclear. During habituation energy efficient ambulation confers no obvious adaptive advantage on the organism.

Drug Probes

The drug probes were carried out to examine the effects of sympathetic and parasympathetic blockade on the relationship between HR and OC. However, because the small group of subjects (n = 4) was tested for only one session under each of the drug conditions, the relevant data are sparse and must be interpreted with caution.

Linear regression lines were fitted to the 6 20-min group means of OC and HR recorded during the conditioning session under each of the drug conditions. No differences in performance were observed during the 3 Saline control sessions and hence Saline data were averaged across the 3 days to provide a fourth set of 6 data points. Summary statistics associated with the drug probes are presented in Table 3.

It will be observed that Beta-adrenergic and Vagal blockade produced their anticipated effects on mean HR (Adolph, 1967). The HR range displayed under Propranolol was consistently below that associated with the Saline condition, whereas the range of HRs displayed under Methyl Atropine was consistently above the Saline range. Nevertheless, under all conditions the correlations between HR and OC were high and positive.

Propranolol appeared to achieve its effect on mean HR by drastically reducing the ceiling of HR variation and thereby reducing its range. Since the HR estimated under resting (RMR) conditions during the Propranolol session did not differ significantly from that estimated for the Saline sessions, the data suggest that sympathetic influences on the heart are not prominent at rest. It will however be observed that the slope of the HR/OC regression line fitted to the Propranolol data is substantially lower than those associated with the other drug treatments, particularly the Saline and Methyl Atropine data. This suggests that under the conditions

TABLE 3

Effects of autonomic blockade on HR, OC, and Amb and on the relationship between HR and OC

Drug Probes	HR (bpm)*		OC (ml/O_2/min)		Amb (m/min)		Shocks per Session	r HR/OC	Slope (M) HR/OC	Y-intercept (C) HR/OC	RMR HR Estimate	95% Confidence Bands
	Mean	Range	Mean	Range	Mean	Range						
Saline	351.42	309.50–385.00	13.21	10.77–15.75	28.60	1.44–57.03	9.67	.86	11.95	193.57	289.19	234.90–343.47
Propranolol	288.16	271.00–303.83	13.54	10.01–17.05	29.74	1.28–62.74	7.67	.84	3.45	241.50	269.07	249.66–288.48
Methyl Atropine	422.02	385.20–444.50	11.40	9.31–14.05	22.55	.33–54.19	21.33	.79	9.71	311.37	389.03	349.21–428.85
Mixture	337.95	318.50–352.60	11.91	9.90–13.78	22.67	.35–49.91	19.00	.92	7.98	242.96	306.78	286.35–327.20

*HR = $M \times OC + C$.

of this experiment, as energy expenditure increased sympathetic influences on the heart became more prominent.

The administration of Methyl Atropine led to a very sizable increase in mean HR but did not greatly reduce the range of HR variation or the slope of the HR/OC regression line from those observed under Saline conditions. Methyl Atropine tended to reduce the level of OC. This is probably attributable to the vagolytic impairment of respiratory function which reduced the efficiency of aerobic metabolism.

Finally it will be noted that the restricted HR range associated with Beta-adrenergic blockade and the lowered OC levels associated with Vagal blockade are both represented in the performance observed under conditions of combined blockade. The mean HR under conditions of combined blockade closely approximated that observed under Saline conditions and was substantially lower than the mean HR recorded during the Methyl Atropine session. This suggests that under the conditions of this experiment, vagal activity functioned to offset the positive chronotropic effects of a high tonic level of sympathetic activity.

Discussion

The primary question addressed by this experiment, whether avoidance conditioning of HR increases produces a similar behavioral adjustment to avoidance conditioning of ambulation, was not fully answered. Despite the attempt to equate the HR and Amb conditioning procedures for probability of reinforcement, failure to ambulate was punished more severely than failure to maintain criterion HR levels. This inequality in the procedures may account for why 5/6 subjects in the Amb group acquired efficient avoidance behavior as opposed to only 2/5 subjects in the HR group.

However, it should be noted that the 2 subjects in the HR group which did learn, displayed behavioral profiles that were indistinguishable from those of the Amb group learners. In terms of the reinforcement contingency rules, subjects in the HR group could terminate the warning stimulus and avoid electric shock independently of ambulating, but in fact their avoidance behavior was characterized by high Amb rates. This observation conforms with the results of experiments cited in the introduction indicating that operantly-conditioned HR variations are learned as one component of nonspecific variations in activity.

The running wheel situation appears to release ambulatory responses in rats (Bolles, 1970), and therefore in this situation ambulation was a prominent means of expressing variations in energy expenditure. Furthermore, HR variations, by virtue of their functions in energy metabolism, are reliably associated with variations in energy expenditure (Astrand, Cuddy, Saltin, & Sternberg, 1964). In the present experiment the high correlation between HR and OC was not disrupted by failure to learn or by the administration of autonomic blocking agents. On these bases it may be anticipated that under the conditions of this experiment, HR variations will be reliably associated with variations in ambulation.

The data reported here indicate that HR, OC and Amb were significantly intercorrelated for both learners and nonlearners. Nevertheless, whereas 79% of the variation in HR during habituation could be accounted for by Amb variation among the learners, Amb was associated with only 31% of the HR variation among the nonlearners. The very high correlation observed between Amb and OC in the learners indicates that in this group variations in energy expenditure were reliably accompanied by variations in ambulation. Likewise the observation that OC/Amb correlations were significantly lower for nonlearners indicates that among these subjects, activities other than ambulation contributed significantly more to variations in energy expenditure. This preconditioning difference in Amb between the groups may well have contributed to the different behavioral adaptations they displayed to the avoidance task.

The performance profiles illustrated in Fig. 2 do not fit easily with traditional views of the learning process, although it should be noted that the performance of the nonlearners does clearly illustrate a generalized habituation process. By the final session on which nonlearners were receiving approximately twice as many shocks as learners (medians: 32 vs 15), the former group displayed HR, OC and Amb levels which overlapped precisely with their habituation performances. The performance of this group during conditioning strongly suggests a process of learned helplessness similar to that described by Seligman, Maier, and Solomon (1971). On the contrary, the terminal (Session 5) performance profile of the learners is not easily distinguishable from the one they exhibited on the first conditioning session. In this group, a high rate of ambulation accompanied by parallel increments in HR and OC emerged with the introduction of the reinforcement contingencies. Over the course of conditioning this initial response did not habituate. Nevertheless the data do indicate that among learners, Amb, the adaptive response, increased in efficiency over the course of conditioning. This seems to be a reasonable interpretation of the observation that Amb rates displayed a slight increase over successive SD periods whereas OC displayed a significant decrement. In other words, the data suggest that as a function of training, a greater proportion of the learners' total energy output was committed to the execution of work which functioned to control the aversive stimuli. Alternatively it might be said that the data reflect the waning or habituation of functionally redundant (non-ambulatory) activities. Thus in both the learners and the nonlearners, changes in performance over the course of conditioning were exhibited by a waning of activity. This habituation process excluded the ambulation response in the learners but included it in the nonlearners. In this context it should be noted that introduction to the avoidance contingencies elicited a substantially higher ambulation rate in learners than in nonlearners (see Fig. 2). It may be that the shock avoidance contingencies functioned to prevent the habituation of the adaptive (Amb) response, and that this effect was only achieved provided that the Amb rate was high enough. This suggestion is compatible with the hypothesis that in this experiment preconditioning differences between subjects, rather than the reinforcement contingencies to which they were submitted (HR vs Amb), may have differentiated learners from nonlearners.

It has been noted that subjects which failed to acquire shock-avoidance behavior exhibited differences in performance from learners prior to conditioning. Apart from displaying a less reliable covariation of Amb and OC, nonlearners also differed from the learners in the nature of the relationship they displayed between variation in HR and OC. In particular, during habituation the HR/OC regression line was significantly steeper for nonlearners than for learners. The drug data imply that this difference may be attributed to greater sympathetic involvement in cardiac control among nonlearners than among learners. During conditioning, although the slopes of the HR/OC function did not differ between the groups, nonlearners displayed significantly higher HR levels at all recorded rates of OC than did learners. Further analyses also revealed that during habituation, at all levels of OC above the mean for both groups, nonlearners displayed significantly higher HRs than learners. These observations are compatible with the recent findings of Blix, Stromme, and Ursin (1974) and Langer, Obrist, and McCubbin (1979) that under stressful environmental conditions HR exceeds levels which are warranted by the metabolic demands of the organism's current activity state (suprametabolic HRs). The present results offer evidence that suprametabolic elevations in HR characterize the performance of rats which fail to acquire effective shock-avoidance behavior. This observation, which primarily reflects the performance of subjects submitted to the HR avoidance contingencies, implies a paradox for researchers who seek evidence of "unmediated" HR conditioning.

The drug data suggest that the relative contributions of the sympathetic and parasympathetic systems to the regulation of HR may be reflected by the relationship between HR and OC. In particular it would appear that the slope of linear regression line relating HR to OC is influenced by beta-adrenergic blockade but not by cholinergic blockade. The administration of Methyl Atropine produced tonic elevations in HR (Y-intercept) apparently by unmasking the effects of sympathetic tone. Thus the effect of vagal blockade was abolished by combined vagal and beta-adrenergic blockade. The reliability and generality of these observations seem worthy of investigation.

Finally, attention is drawn to certain general features of the results.

1. The range of HR variations observed in this experiment is comparable to those reported previously (Brener et al., 1977). Oxygen consumption, however, displayed a greater range than we have previously reported. This reflects a substantial improvement in our method of measuring OC. The oxygen analyzer employed in the present experiment is a two-channel device which simultaneously

monitors the O_2 content of the air entering and the air leaving the animal compartment and calculates a difference score. The Taylor Servomex OA 184 also has excellent thermal and pressure compensation systems which minimize errors due to fluctuating environmental conditions. Consequently it was possible to monitor OC at an air flow rate of 10 liters per minute rather than 4 liters per minute as previously. The previous measurement system had a very long time constant which acted to average out relatively short-term extreme values of OC. Despite these improvements, the system still displays a recording latency which renders it unsuitable for measuring phasic variations in OC which occur over periods of seconds rather than minutes. Because increasing the rate of airflow would dilute the concentration of expired gases to a level that would be too low to measure reliably, future improvements in the recording latency of the system will require decreasing its dead-air space.

2. The total level of energy expenditure reflected by OC provides a global measure of the organism's level of activity. It was observed that OC declined significantly over successive habituation sessions. In other experiments involving similar conditions and the same measurement techniques, but where habituation comprised either 5 or 10 48-min sessions rather than the present 5 2-hr sessions, significant decreases in OC over sessions were not found (Phillips, Brener, & Connally, Note 2). We interpret this decline in OC as an indication of a decrease in responsiveness and suggest that between-sessions habituation is dependent upon the duration of exposure for each session. A similar finding has been reported by Howarth (1962).

3. Ambulation, which is a popular index of general activity, was found to have a significantly lower correlation with both HR and OC among nonlearners than among learners. These observations support our previous assertion (Brener et al., 1977) that the assessment of cardiac-somatic relationships requires the use of a valid measure of general activity level rather than a partial index. For example, among nonlearners, only 31% of the HR variation during habituation and 18% of the HR variation during conditioning could be accounted for by variations in ambulation. However, this does not indicate cardiac-somatic dissociation because in this group only 42% of the variation in energy expenditure (OC) was accounted for by variations in ambulation. Furthermore the correlations between HR and OC were very high for both groups of subjects.

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APPENDIX B

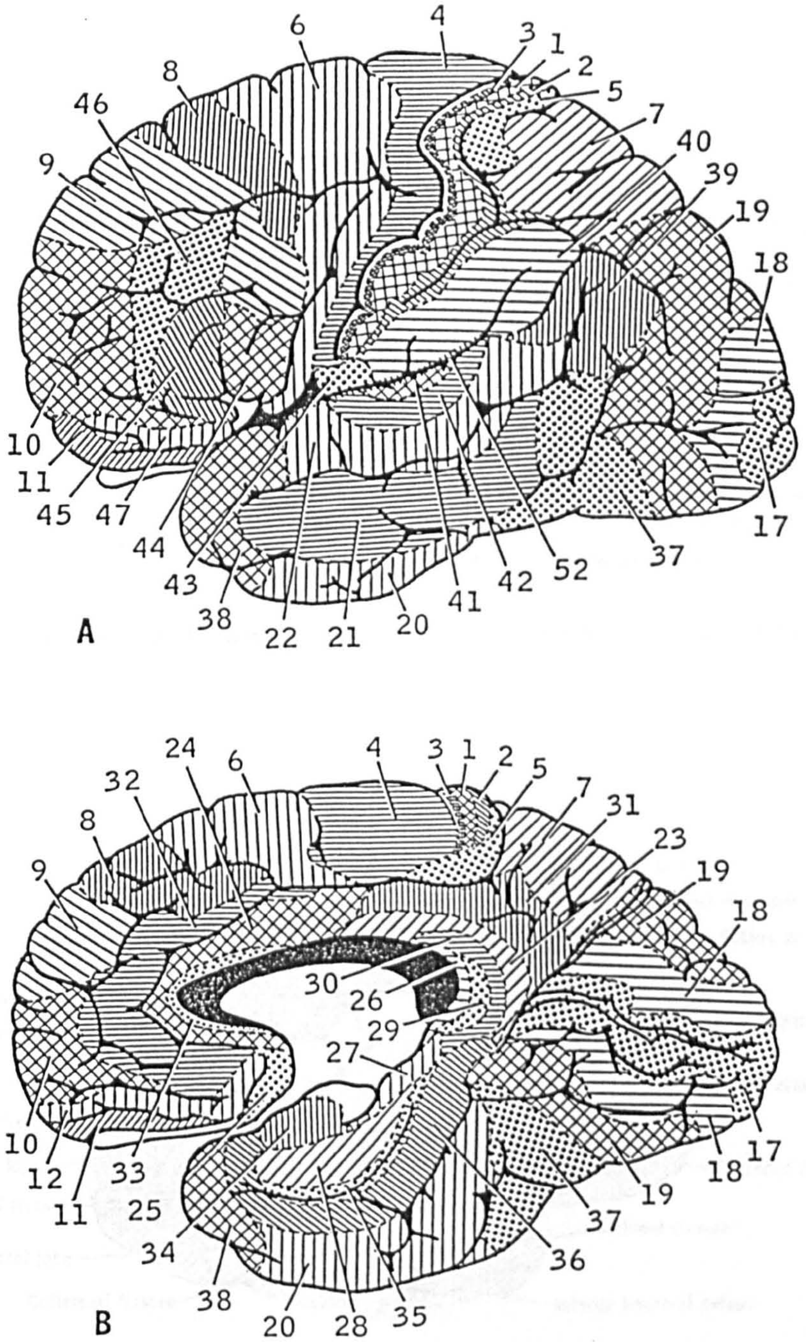

Fig. 23-8. Cytoarchitectural maps of the human cerebral cortex. (*Adapted from Brodmann, in Peele, The Neuroanatomical Basis for Clinical Neurology, McGraw-Hill Book Company, Inc., Blakiston Division, New York,* 1954.) *A.* Lateral surface. *B.* Medial surface.

FIG. 67 from House, E.L., and Pansky, B., p.457.

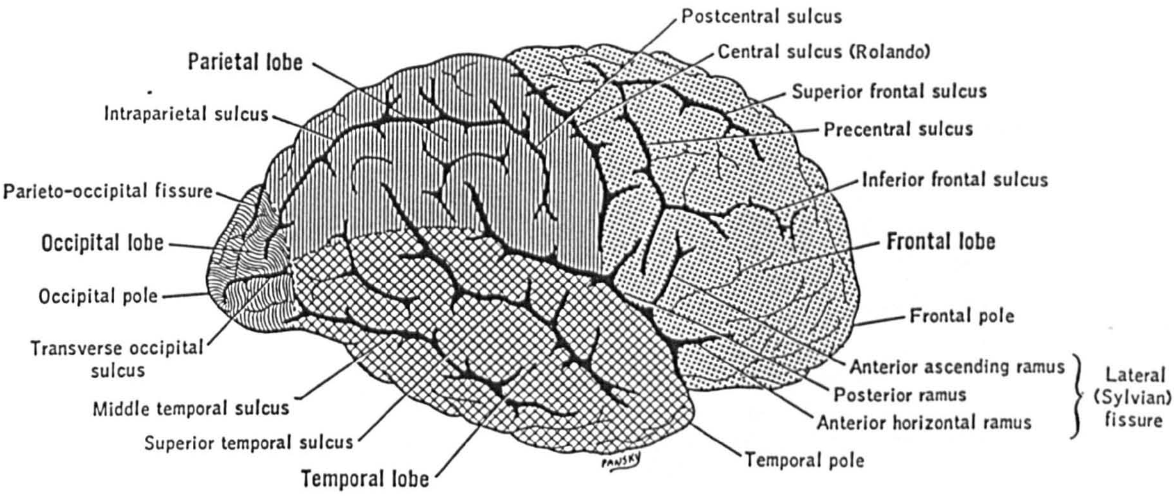

Fig. 2-2. Lateral view of the human cerebral hemispheres illustrating the principal sulci and lobes.

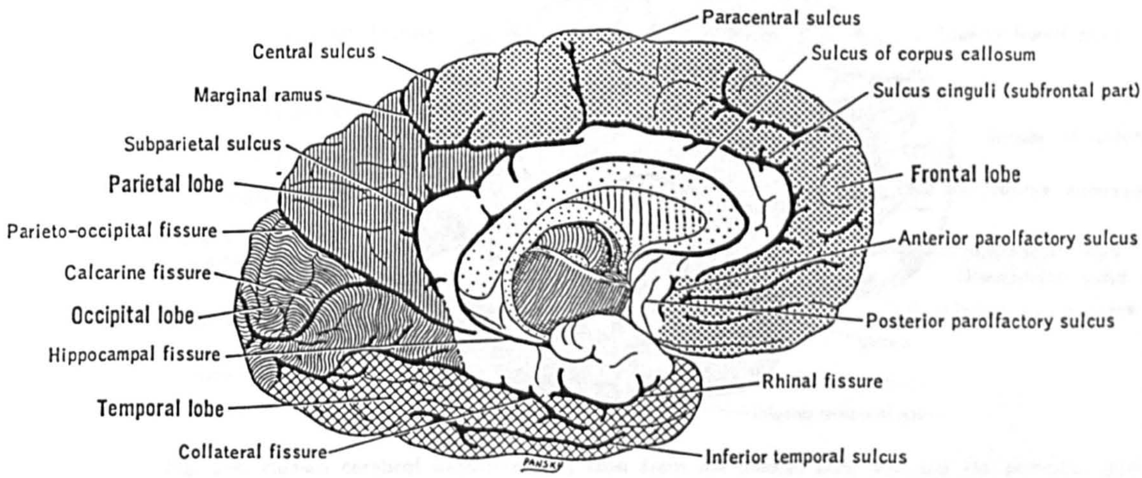

Fig. 2-5. Human cerebral hemisphere as viewed from the medial side, showing the lobes together with the principal sulci.

FIG. 68 from House, E.L., and Pansky, B., 1967, top. p.10; bottom, p.12.

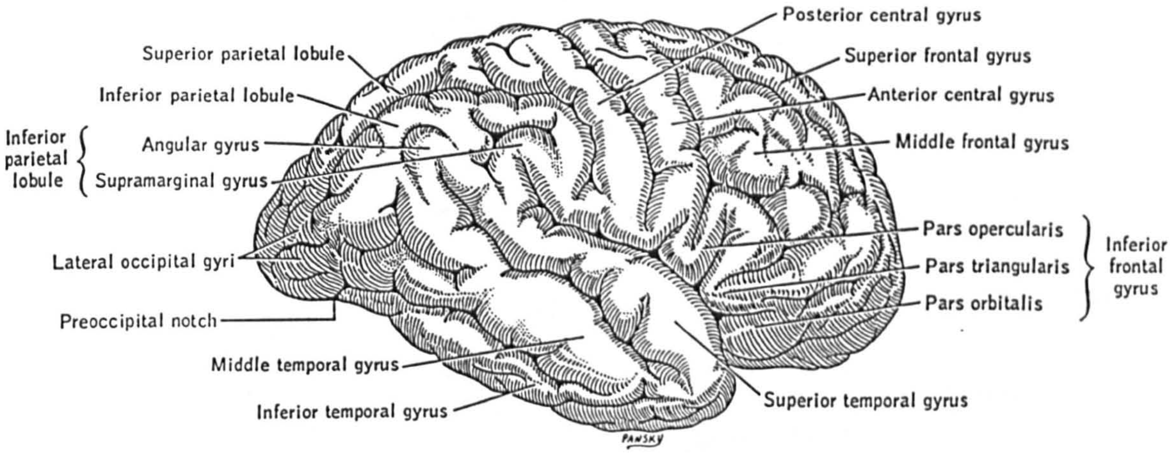

Fig. 2-1. Lateral view of the human cerebral hemispheres illustrating the principal gyri.

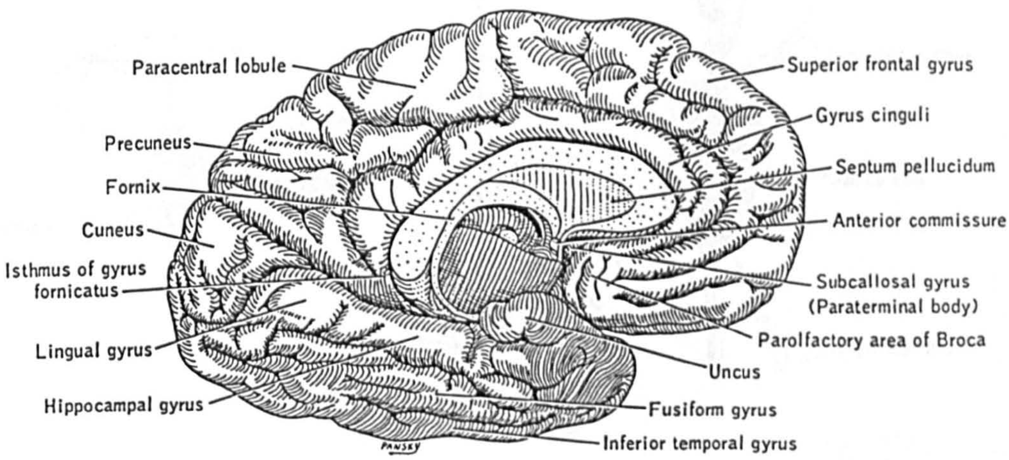

Fig. 2-4. Human cerebral hemisphere as seen from the medial side, showing the principal gyri.

FIG. 69 from House and Pansky, 1967, top p.10;
bottom p.12.

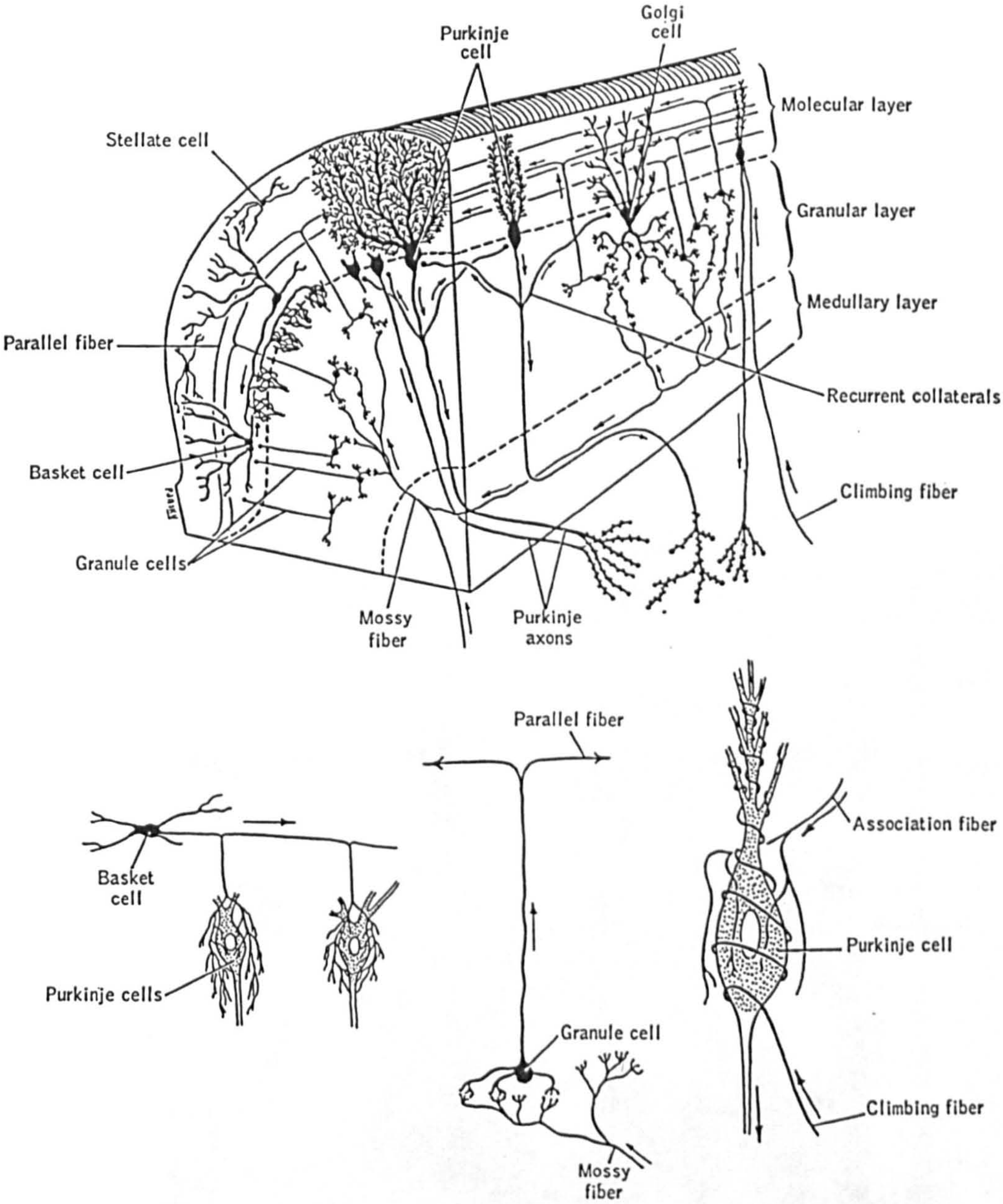

Fig. 18-3. A diagrammatic representation of a folium of the cerebellar cortex showing the arrangement of cells and fibers as seen both in longitudinal and transverse sections. The relationship between fiber types and cells is also illustrated.

FIG. 70 from House and Pansky, 1967, p.34

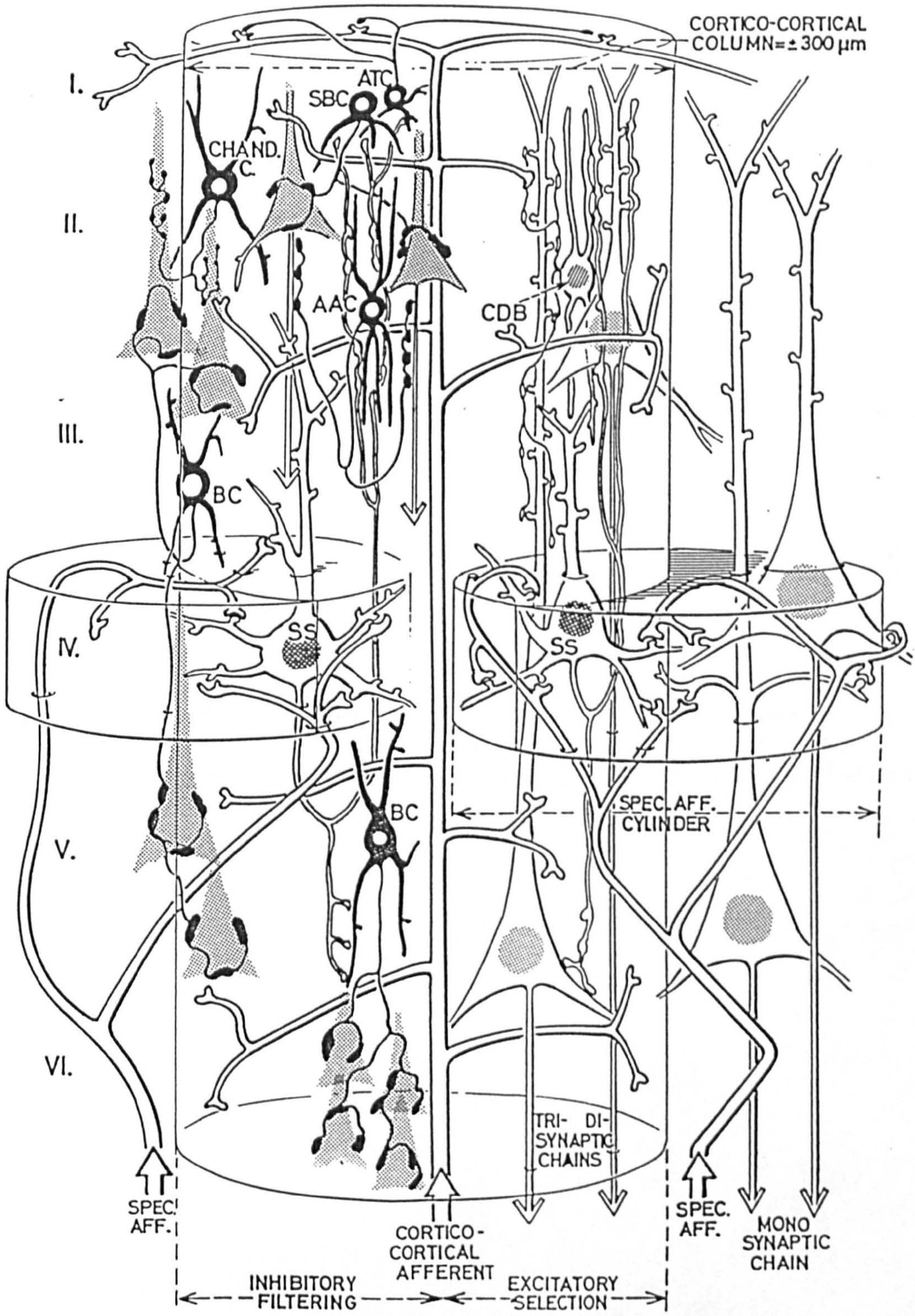

Fig. 1. Diagram illustrating a single cortico-cortical column and two specific subcortical afferent arborization cylinders. Lamination is indicated on the left margin. The right half of the diagram indicates impulse processing over excitatory neuron chains, while the left half shows various types of inhibitory interneurons (in full black).

FIG. 71 from Szentagothai, J., 1978, p.132.

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