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Some factors in movement schema development

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Summary

The thesis examines certain sources of influence on motor schema development. An extensive review of the background theorising and empirical grounds for current concepts of schema memory identifies a number of factors purported to be involved in schema development. These factors are conveniently divided into two groups:

(i) practice-related factors more readily open to short-term manipulations (including the amount of variability and the size of a block; the context of the practice organisation; the distinction between recall and recognition schemas; and performance versus learning considerations) and

(ii) inter-related factors which are less prone to short-term manipulations in that they relate to problems of subject or task constraint (including task complexity; the level of learning of the performer; age and differing strategies; and experience).

Three empirical studies are reported including both a field study (a modified golf-putting task), and two laboratory studies (using an adapted version of Lee and Magill's (1985) knock-down barrier task).

The results provide some support for the primary hypothesis of a *Complexity by Variability* interaction. There is strong evidence that the complexity manipulations generated main effects which mirrored the successful manipulations of variability of practice.

The data represents an important step towards the inclusion of a whole set of factors within the overall construct of transfer arising from variability. Three potential areas of investigation are highlighted. These are: i) the proximal/distal arguments for transfer; ii) the examination of other factors as independent but possibly confounding sources of effects and iii) the possible extension of Schema Theory from the orientation and development of the motor schema to include the issue of learning and how to learn.

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Introduction

An Overview

The thesis examines certain sources of influence on motor schema development. An extensive review of the background theorising and empirical grounds for current concepts of schema memory identifies a number of factors purported to be involved in schema development. These factors can be grouped conveniently together into two groups. The first links more directly practice-related factors such as: the amount of variability and the size of a block; the context of the practice organisation; the distinction between recall and recognition schemas; and performance versus learning considerations. All are factors readily open to short-term manipulations in the examination of schema development. The second group comprises of inter-related factors which are less prone to short-term manipulations in that they relate to problems of subject or task constraint. These include: task complexity; the level of learning of the performer; age and differing strategies; and experience.

All these potential influences are discussed in depth and gradually drawn together in the opening chapters of this thesis. A model is presented which incorporates the factors hypothesised as involved in schema development (Figure 5.2).

In the particular context of the variability of practice hypothesis, one factor that has been hitherto ignored, either as an independent factor or as one that might interact with other factors, is task complexity. This gives rise to three investigations to examine the ways in which complexity interacts with the more obvious and well-documented variability of practice effects during the learning process to aid schema development and facilitate learning.

The opening chapter of this thesis examines in very general terms where the origins of interest in such a topic might lie and highlights some of the potential difficulties that confront researchers in behavioural science. Chapters Two to Five provide a background against which a critical examination of the concept of schema is presented, and its central role within various areas of psychology. The literature on variability of practice is examined in considerable detail. Its relevance to both Schema Theory and the Contextual Interference Effect paves the way for what becomes the main thrust of the thesis. That is, the consideration of the ways in which practice conditions and levels of task complexity might interact independently of, or as an integral part of, a complex array of hypothesised sources of influence in the learning process.

The empirical studies are reported in Chapters Six to Nine, with a field study, incorporating a real-world golf-putting task, being presented initially. The following chapter (Chapter Seven) moves back into the experimental laboratory and discusses the selection of an appropriate task that might be utilised to manipulate levels of complexity. Lee and Magill's (1985) knock-down barrier task is introduced, and Chapters Eight and Nine present two laboratory-based investigations.

Chapter Ten argues that the data presented represent an important step towards the inclusion of complexity as a significant factor within the overall construct of transfer. Suggestions are put forward to indicate the direction in which future research might profitably proceed.

Finally, the work is viewed within a broad educational perspective and brief consideration is given to the transition from theory to practice. Whilst caution is recommended in considering the potential practical implications of theoretical reasoning, the view is clearly implied that (to use the apt and succinctly expressed phrasing of Bertrand Russell): *Nothing is as practical as a good theory*!

CHAPTER ONE

The General Area Of Interest

Our ability to adapt and respond to the demands of our environment seems to be as limitless as the very boundaries of our imagination. While other species have evolved to meet the requirements of their immediate surroundings, we has developed the means to control our movements and actions across a whole spectrum of environmental conditions. Our versitality renders us almost immune to the restrictions that nature might impose, enabling us to out-perform our most adept of rivals, be it on land, in air, or in water. While the structural limitations of the human body prevent us from seriously challenging the *high performers* of the animal kingdom in the environment for which they are specifically adapted, we are endowed with a creative power that enables us to transcend those apparent boundaries of physical performance. We thus have a potential for action far in excess of that suggested by our physical make-up, reflected in our ability to control the environment, be it from behind the wheel of a car, from within the cockpit of an aircraft, or at the helm of a ship.

How do we acquire the control of movement that enables us to perform these actions? Do we all posses the potential for achieving the dexterity of finger control displayed with such apparent ease by the concert pianist, or the style and grace of movements produced so effortlessly by highly skilled performers in sport and dance? The frustration generated through the clumsy, inept attempts of the beginner in struggling to produce a desired movement is probably a feeling with which we are all familiar, for hours of practice can still leave movements that are awkward and inefficient. How are some skills acquired with such little effort while others continue to remain elusive? What factors contribute to our success or failure in trying to become skillful?

In general terms then, we are concerned with the nature of those processes by which individuals make adaptations in their behaviour. The extent to which our ability to procure new movement skill is dependant upon our previous experience and existing levels of expertise is a crucial issue. It must be addressed if we are to find more appropriate methods to facilitate this often slow and arduous process of skill acquisition that is referred to as *learning*. It is these fundamental questions that underlie the more precise and detailed field of enquiry that is the focus of attention for this thesis.

Some Potential Difficulties Facing the Researcher

The most cursory glance at any selection of motor-behaviour or psychology text books will reveal an inherent difficulty in the search for a succinct and definitive interpretation of the term *learning*. (Some kind of definition would seem desirable if only as a means of delineating an area of study). Variations on *a relatively permanent change in behaviour as a result of practice or experience* are the generally accepted definitions. Precise, and sometimes not so precise, distinctions are drawn between *learning* and *performance*. More recently, the term *transfer* has been adopted with reference to experimental designs in which treatment groups are transferred to a common level of the independent variable, in studies investigating learning effects. It is used both as a synonym of the term learning, and as a distinct and separate category of its own in what is obviously a complex and elusive process.

Whilst there is a recognised need for a clarification of terms, it is, important to be aware of the limitations that attaching semantic labels to processes which may not be directly observed can impose on our overall understanding of the learning process. The somewhat arbitrary distinctions that researchers often feel compelled to make in the search for explanations of behaviour (such as, the distinction between *motor* and *cognitive* skills, or between *novel* and *familiar* tasks), may have a restricted use outside the context within which they are made. Such distinctions, when accepted at face value, often conceal underlying, preconceived notions about the elaborate, subconscious operations that enable us to function. The difficulty in describing such operations within the confines and boundaries of language is reflected by the lack of consistency with which such terms are used. Whilst there is perhaps no alternative means whereby we can hope to arrive at any scientific understanding of learning and behaviour, we must concede that no matter how carefully our experimental designs are controlled, or how persuasive appears our empirical data, the emergence of theories of motor control are ultimately extensions of the basic assumptions and conjecture which first fueled the inquiry. It is, therefore, imperative that the basic assumptions and initial conjecture are firmly grounded and based on reasonable interpretations of already existing data. However, any explanation of the organisation of memory and the structure of an underlying base of knowledge has to rely on subjective interpretation of observable behaviour in relation to hypothetical constructs. Our understanding of the form and nature of cognitive structures can, at best, only be derived from inferences and speculation.

This is not to suggest that cognitive research into motor control is not worthwhile, or of less value than other areas of study where hypotheses may be more easily rejected or verified. It is, however, important to remain aware of the limitations under which investigators of human behaviour are required to operate, and proceed with appropriate caution.

The Area of Interest More Closely Defined

The focal point of interest of this thesis centres around the relationship between task complexity and variability: more specifically, task complexity is investigated as a potential influence on the variability of practice effects that have been reported from research studies into aspects of schema theory (e.g., see Shapiro and Schmidt, 1982) and from studies examining *contextual interference* effects (e.g., see Shea and Zimny, 1983). The structure of practice is seen as a major factor in determining the level of transferability that might be predicted.

On the periphery of this main issue there lies a range of inter-related issues which have a direct bearing on the topic of interest. These include questions directly related to schema theory (e.g., the possible nature and form of the schema, the existence of the recall and recognition schemas proposed by Schmidt (1975), the amount of variability necessary for generating transfer effects, etc.), questions more directly related to contextual interference issues (e.g., blocked versus random variable practice), and more fundamental issues that arise irrespective of the framework selected for analysis (e.g., the relationship between learning and performance, transfer as a measure of learning, the effect of age and the development of learning strategies, etc.).

This thesis begins with a brief look at the origins of interest in motor learning and considers some of the fundamental problems confronting research in this area. The historical perspective is aimed at outlining the direction of thinking that has resulted in the emergence of those contemporary issues now at the forefront of empirical debate. Recognition of the inherent flexibility within the controlling system (see Fazey, 1986), is seen as a logical conclusion to accommodate what initially appears to be contrasting and conflicting accounts of the ways in which the human system operates at the motor level. The concept of transfer is introduced as a focal point of much recent research, and some questions are posed about transfer that are subsequently addressed within the context of a schema framework.

The role of practice and the notion of automaticity are considered with respect to transfer and its influence on motor learning. Finally, the interaction between practice, task complexity and the level of learning of the subject is discussed in relation to the dynamic view of memory and the controlling system that is proposed throughout.

The crucial issue of how to measure transfer and learning effects is addressed in detail immediately prior to the presentation of experimental evidence in support of the dynamic view of motor control. It is, after all, the theoretical and practical implications of the model of motor control deemed most appropriate for explaining behaviour, that must be responsible for determining the suitability of the experimental methodology that is finally adopted.

In Summary

This chapter has briefly outlined the general area of interest and advocated a cautious approach to research that by its very nature has to rely on hypothetical constructs to help explain those processes that underlie learning.

The following chapter begins with the origins of interest in motor control and learning, and traces its development from both motor and verbal areas of psychology to the research in the late 70's in cognitive psychology, from which a resurgence of interest subsequently sprung.

CHAPTER TWO

The Origins Of Interest In Motor Control & Learning

There has long been interest in how we learn and control movement. The study of motor behaviour in its present holistic form, however, has emerged only in the last few years, with its origins to be found in two quite distinct bodies of knowledge: neurophysiology and psychology. (For a more detailed review of the history of the field see Schmidt, 1982a). Neurophysiologists have concerned themselves with the study of those neurological structures associated with movement behaviour. More recent studies with animals have also utilised the development of electrophysiological and biomechanical techniques to assist the investigation of the workings of the central nervous system during movement (e.g. Evarts, 1972, 1973; Granit, 1970; and Grillner, 1972, 1975). Cognitive psychologists at a quite different level of analysis have viewed humans primarily as processors of information, and have focused on hypothetically defined brain processes that might explain not only how such information is utilised, but the elementary operations by which such information might be stored, accessed and represented in memory (e.g., Adams, 1971; Adams and Dijkstra, 1966; Posner and Konick, 1966; Pew, 1970, 1974; Schmidt, 1975: – see also Marteniuk, 1976).

A Lack Of Progress In The Field

The area of motor control and learning whilst obviously influenced by other long-established related fields of study in terms of its current research methodology, is still in a state of relative infancy. Although there has certainly been no shortage of empirical research, the most perfunctory survey of the literature, reveals an as yet discernible lack of progress in the formulation of theories that can adequately account for the numerous ways in which individuals seem able to perform and control their actions. Theoretical models of motor control seem inevitably to gain only limited, or somewhat equivocal support, whereby they are discarded in favour of more tenable offers, or relegated to the confines of a particular movement or class of movements. Researchers of late have thus tended to restrict their theorizing to carefully defined classes of movements, invoking criticisms regarding the appropriateness of such methodology:

> *" ... such theories and research findings would only find application where cognitive control is not critical."*
>
> (Whiting, 1980. p. 538)

The Complexity Of The Issues Under Investigation

Whilst there are doubtless several reasons for this lack of progress, it must ultimately be a reflection of the complexity of the issues under investigation. Any theory of motor control must be able to account for the tremendous versatility and flexibility of the controlling system: a system that is capable of achieving a functional, desired outcome via a whole host of movement patterns, yet can at the same time reproduce stereotype movements constrained within narrow limits. Even this distinction, however, is something of an oversimplification of the problem as a closer examination of such movements reveals both a uniqueness of action and variability around very similar limb trajectories in highly practiced situations that may go unnoticed to all but the most acute observer (e.g. Bootsma, 1988). There is thus a degree of stability and consistency in terms of the spatial and temporal properties of movement that coexists with an ability to adapt and amend outgoing responses as a direct consequence of information available to the performer. This may simply involve changing actions to suit conditions or changing the orientation to those conditions to use *favoured* actions (Jagacinsky et al, 1977).

Central Versus Peripheral Views Of Control

Early attempts by motor control theorists to cater for this apparent dichotomy led to the emergence of two seemingly opposing theoretical positions: the central and peripheral views of motor control. The *centralists*, presenting evidence indicating that movements can be produced quite successfully in the absence of feedback (E.g. Lashley, 1917; Lashley & McCarthy, 1926; Lashley & Ball, 1929; Taub & Berman, 1963/1968), held the view that movements must be controlled by some kind of centrally generated motor programme (Keele, 1968). The *peripheralists* on the other hand argued that feed-back mechanisms were essential for controlling movement if deterioration in performance was to be avoided (E.g. Adams, 1971). Empirical evidence supporting both suppositions eventually led to a decline in this polarisation of views as it became evident that acceptance of either the role of sensory feedback in eliciting motor output (the peripheral approach) or the ability of the C.N.S. to generate stored movement patterns (the central approach) in isolation of each other, left too many questions unanswered. Attention thus appropriately became focused on the manner in which central and peripheral processes might interact in coordinating movement.

Recognition For Flexibility Within The Controlling System

The reconciliation of central and peripheral processes again points to the flexibility inherent within the movement controlling system. The system seems capable of performing actions and tasks in quite different ways dependant upon such factors as the level of learning of the individual and the attentional requirements of the situation. In evolutionary terms the availability of some *back-up* system to prevent any reduction in behavioural capability in the event of a temporary or permanent malfunction (E.g. fatigue or injury), is obviously significant. The human controlling system, when viewed as a complex system composed of many separate mechanisms, thus seems quite capable of accommodating much of what has appeared in the past to be contradictory and conflicting theories of motor control. Ultimately the value of such theories lies not in their potential to explain *all*, but rather in their ability to account for what might prove to be relatively limited types of control available to the system in any given instance.

Fazey (1986) has suggested an obvious conclusion to be drawn from the integration of open and closed loop processes to achieve control of skilled movements:

> *"Such a view points to the possibility of a dynamic model of a controlling system capable of accommodating all that we know about the ability of the human system to operate in very different modes of control."*
>
> (Fazey, 1986. p. 13)

The Distinction Between Control & Learning

There is, however, the fundamental problem of trying to describe such a system. Most researchers who have been interested in motor learning have initially focused attention on aspects of motor control before attempting a theoretical explanation of how such control might be affected by practice or experience. Kay (1970) is probably quite representative of the field when he suggests that before speculating on the kind of system that controls human skills it is first necessary to:

> *" ... say exactly what we are trying to understand ... the beginning lies in a precise description of the essential features of skilled performance."*
>
> (Kay, 1970.)

Interestingly there is a parallel in what some authors have said about the necessary steps towards understanding the processes of control and learning with what others have said about the processes themselves. Whiting (1981), for instance, suggests that the structure of the learning environment should be manipulated such that an adequate *image of the act* can be acquired before trying to deal with problems of *control*:

> *" ... the introduction of variations in environmental and movement parameter conditions should be postponed in the process of learning until an adequate 'image of the act' has been developed under one of the many conditions under which the act has eventually to be executed, i.e. 'the image of the act' has first to be developed as a holistic unit, a gestalt, before it can be manipulated to serve acts under changed conditions."*
>
> (Whiting, 1981. p. 226)

Van Rossum (1980) adopts Bruner, Goodnow and Austin's (1956) distinction between ***Formation*** (*the process of abstracting rules* *from specific environmental events*) and ***Attainment*** (*the process of applying those rules in a given situation*), in an article examining the concept of schema in motor learning theory. Formation is to do with the problem of *learning*, whilst attainment is seen as being more akin to the problem of *control*.

Quite clearly, many writers have found it useful to make the distinction between *control* and *learning*. The complexity of the issue is reason enough for such an approach to be favoured. However, perpetuating the idea of a division may, on occasions, detract from the overall picture and actually inhibit the study of both issues.

This is not to imply that making the distinction *per se* is inappropriate, but rather, the mistake is to infer from such a distinction that the two concepts can be viewed in isolation. To return for a moment to Bruner, Goodnow and Austin's (1956) distinction between concept formation and concept attainment, whilst this may clearly be useful as a means of investigating and explaining aspects of the learning process, such a differentiation clearly has its limitations:

> " ... *as Pikas (1966) has pointed out, it* (the distinction) *may be somewhat difficult to determine in practice, since concepts must be formed through the subject encountering instances or they may begin a task by grouping elements according to a well-defined category but find in the course of this activity that the category itself changes or becomes clearer.*"
>
> (Bolton, 1977. p. 15)

Fazey (1986) comes to a similar conclusion and proposes a view of memory that to a large extent is implicit in Bolton's (1977) view of learning as it relates to concept formation:

" ... accepting that the memory system which initiates and controls movement is dynamic, makes it clear that performance and the refinement of performance are inextricably interwoven. There seems to be no identifiable reason why the study of control should be divorced from that of learning."

(Fazey, 1986. p. 14)

Learning – In Search Of A Definition

It is naive to think that any absolute definition of the term *learning* exists, and although a variety of terminology (i.e. *control, performance, transfer, learning*) might on occasions be employed interchangeably to represent a particular point of view, the adoption of one (all to often ill-defined) term over another may blind the user to some important considerations. Magill (1988) alludes to this danger when, in his discussion of what he calls *The Measurement of Learning Question*, he states that:

" ... limiting assessment of learning effects to only one measure is not a very productive approach."

(Magill, 1988. p. 301)

He goes on to add that:

"What must be done ... is to make certain that the assessment procedure followed is appropriate for answering the question under investigation."

(Magill, 1988. p. 306)

This, at the end of the day, would seem to be the only criteria on which to judge whether or not a researcher is justified in both the selection of terminology used to describe what is being measured, and the subsequent conclusions that are drawn from the empirical data.

Ammons (1988) is representative of many authors when he expresses a sense of frustration at the futility of trying to define a notion as seemingly elusive as *learning*:

> *"Perhaps we should ban the concept of learning and confine ourselves to finding what variables at what levels lead to how much resistance to change after what prior experiences."*
>
> (Ammons, 1988. p. 288)

Ammons' advice, whilst no doubt offered with tongue in cheek, is perhaps not as radical as he would have us believe. A more appropriate strategy for researchers might be to confine their speculations to more explicitly defined concepts, and view *learning* as a general notion that refers to the processes by which the physical and mental systems organise themselves. This organisation is memory, and memory is simply organisation.

Memory – The Keystone Of An Information Processing Perspective

An underlying assumption of much recent motor research is the notion that humans may be represented in some way as processors of information. The early stimulus response (S-R) orientation that had dominated experimental psychology in the first half of the century became overshadowed by this cognitive information-processing approach. The primary concern of the approach is the study of those mental or neural processes that support and control movement. Whilst not directly observable, much has been inferred about how information might be coded and stored, and the kinds of mechanisms that might exist to make that information available for future use.

The storage system that retains this information and presumably the location of this processing, is collectively termed memory. The functioning of human memory has been studied and conceptualized in many ways, and researchers have been led to speculate on the existence of hypothetically constructed memory mechanisms segregated according to the quality of information they can retain, the nature in which that information is stored, and the rate at which such information might be lost. Whilst this viewpoint is not universal amongst researchers of motor behaviour (e.g. the levels-of-processing framework initially proposed by Craik & Lockhart, 1972), it is ultimately from the study of memory that investigators hope to find an explanation of how individuals are able to bring about those changes in their internal state that can be inferred from relatively permanent improvements in their performance.

Support For A Flexible View Of The System From The Verbal Domain

The ideas and findings of researchers engaged in the study of verbal memory have exerted considerable influence on the more recent efforts of investigators of memory for movement, not only in terms of paradigms and methodologies, but more directly from theoretical interpretations and empirical data. Within the verbal memory domain, researchers have been conscious of the need for a more dynamic view of the system:

> *"In place of the traditional analysis, I suggest a contextualist approach. This means not only that the analysis of memory must deal with contextual variables but also that what memory is depends on context."*
>
> (Jenkins, 1974. p. 415)

He goes on to add that:

> *"We should shun any notion that memory consists of a specific system that operates with one set of rules on one kind of unit."*
>
> (Jenkins, 1974. p. 426)

Battig (1979) expresses a similar view when he suggests that the flexibility of the human memory system is such that nearly any cognitive information-processing theory can be viewed as either correct or incorrect depending upon both the individual and the occasion of its presentation:

> *"Such inconsistencies clearly call for more complex and flexible theories incorporating multiple processing mechanisms that can be and typically are employed variably within as well as across individual tasks."*
>
> (Battig, 1979. p. 25)

Battig proposes that rather than deciding whether to accept or reject apparently conflicting and overly simplistic theoretical alternatives, it is more profitable to consider how often and under what conditions individuals behave in accordance with any particular view.

The impact of verbal memory research on motor behaviour studies has thus been quite significant. The *contextual interference effects* discussed by Shea & Morgan (1979) for example, were originally identified by Battig (1966) from studies with verbal tasks (e.g. Brown, 1964; Johnson, 1964; Brown & Battig, 1966; Battig, Brown & Schild, 1964), while the *levels of processing theory* (Craik and Lockhart, 1972; Cermak & Craik, 1979) was initially developed as a model of verbal memory. (Both contextual interference and levels of processing are discussed in greater detail in subsequent chapters).

An Integration Of Verbal And Motor Domains

The spread of scientific knowledge amongst these two areas, while having obvious mutual benefit has, nevertheless, prompted criticism from those who feel that the tendency to rely heavily on the more experienced and successful field of verbal memory, is not the most fruitful strategy for developing the scientific structure of the motor domain:

> *"Memory domains are not integrated a priori with the assumption that memory is a unity, obeying the same general laws. Integration is an empirical matter, where laws are discovered in each domain, and only when lawful similarities across domains are seen do we suspect integration."*
>
> (Adams, 1983. p. 12)

It could be argued that the classification of separate domains within human memory is something of an oversimplification, which, in the search for a more dynamic and flexible view of the controlling system, is not the most appropriate way to consider the organisation of memory. Lee and Genovese (1988), for example, on separating motor and verbal learning studies, make reference to Underwood's (1949) distinction whereby motor and verbal skills are classified on a continuum, with high verbal and low motor component tasks at one end, and high motor, low verbal tasks at the other. They are clearly aware of the problem associated with the somewhat artificial separation of these facets of memory:

> *"This distinction becomes even further clouded if one considers the arguments that learning motor skills involves a progression from a highly verbal, or cognitive stage to a more motor and autonomous stage with practice (e.g., Adams, 1971; Fitts, 1964)."*
>
> (Lee and Genovese, 1988. p. 280)

The selection of material for their review of distribution of practice effects in motor skill acquisition consists of "motor" tasks that range from:

> " ... **semi-verbal tasks** *(Underwood, 1949) such as stylus mazes, inverted alphabet printing, and mirror tracing"*

> to:

> " ... **pure motor tasks** *(Underwood, 1949) such as pursuit tracking, balancing, and climbing tasks."*
>
> (Lee and Genovese, 1988. p. 280)

They excluded *non-motor* tasks which were defined as:

> " ... *those* (tasks) *where the motor component was deemed to serve only a perfunctory role, such as speaking or writing a word in a paired-associate learning experiment."*
>
> (Lee and Genovese, 1988. p. 280)

Regardless of how motor or verbal domains be identified, an overlap between the areas is probably inevitable considering both the use of shared terminology, and, more importantly, their early and more recent developments. Many initial motor-skill studies either stemmed directly from, or were directly influenced by the work of general psychologists at the end of the second world war (e.g. Craik, 1948; Wiener, 1948; Shannon & Weaver, 1949; Welford, 1952; Poulton, 1950). Much of this was applied research focusing on the *man-machine interaction* in military as well as industrial settings. The scope of such investigations necessitated the use of concepts and methodologies from a variety of fields.

In addition, the development of both the verbal and motor domains took a somewhat parallel course in terms of the tendency for research to be initially generated via an empirical rather than theoretical base. Regarding the verbal domain Underwood (1966) observed that:

> *" ... the independent variables chosen for manipulation in work on verbal learning were not chosen because of their theoretical relevance...the sustenance of research in verbal learning was provided by the discovery of empirical regulations, not by decisions about theories."*
>
> (Underwood, 1966. p. 490–491)

Similarly, research in motor behaviour has been very much focused on experimental variables and their effect on the performance of motor responses. Recognising the trend away from what Pew (1974) has described as a *task-oriented approach* towards a *process-oriented approach*, a number of functional models of the processes involved in skill acquisition have been more recently presented (e.g. Schmidt 1975, 1976; Pew, 1974). As indicated by Fazey (1986), the heuristic implications of such an approach has no doubt been a major attraction for many researchers.

Research In The New Cognitive Tradition

It is then, within this new cognitive tradition that we proceed. The human organism is thus viewed in some way as a processor of information, and the search for mechanisms that influence and control that processing relies on what can be inferred, rather than directly observed.

This move away from the earlier S-R orientation that had previously dominated psychology provided a much less rigid framework within which theorists could operate. Following the publication of Neisser's (1967) *Cognitive Psychology* which undoubtedly had a significant impact on these developments in experimental psychology and motor behaviour in particular, the next decade saw the emergence of a renewed interest in theory, when Adams presented a feedback-based theory of verbal learning (Adams and Bray, 1970). One year later an adapted theory was presented for motor learning (Adams, 1971). This publication plus the theoretical ideas of Pew (1974) and Schmidt (1975, 1976) in relation to the concept of schema, stimulated considerable research, and further consolidated the trends that had been taking place in the area of motor control and learning.

In Summary

This chapter has traced the origins of contemporary interest in motor control issues up to the publication of Schmidt's (1975) Schema Theory of Discrete Motor Skill Learning. The **Theory** *generated substantial empirical investigation and provided a further boost to research in much the same way that Adams' (1971) publication had done four years earlier.*

Much of the research centred on ***transfer*** *as the measure of learning. Whilst the concept has in fact appeared regularly in the literature since the beginning of the century (e.g., Thorndike and Woodworth, 1901), it seems to have become more important in this* ***new*** *cognitive tradition. This reemergence of interest in transfer* ***per se*** *can be largely attributed to its role within current theories of motor control and learning, and as such, it would seem appropriate to afford it particular attention.*

The following chapter introduces the concept of transfer and its prevalence in experimental motor control research paradigms. The *focus on transfer conveniently sets the stage for Chapter Four, when the concept of schema is introduced, and Schmidt's (1975) Schema Theory is examined in detail.*

CHAPTER THREE

Transfer – The Process Of Learning

> *" ... almost all learned behaviour is interrelated in various complex ways."*
>
> (McGeoch and Irion, 1952)

Transfer, whether it be discussed in terms of *transfer of learning* or *transfer of training*, is concerned with the influence that our existing knowledge, abilities and skills have in the learning and/or performance of a *new* task. Whilst the term is by no means exclusive as a means of describing these effects, it has become increasingly prominent to the point where Battig (1966) observed that:

" ... the magnitude and generality of the effects produced by previous learning upon performance in new learning tasks require that transfer phenomena be placed at or near the head of the list insofar as overall importance to psychology is concerned."

(Battig, 1966. p. 238)

An Increasing Awareness Of The Importance Of Transfer

As the study of motor behaviour has developed, the theoretical implications of both basic and applied research has, on occasions, been preceded by the search for principles on which to base the design of various training systems. The structuring of recreational, educational and industrial training regimes has elicited a growing demand for knowledge regarding the extent to which the learning experiences in any one particular environmental configuration can be adapted to meet the demands of a new, but related, situation.

In purely practical terms, it is not difficult to see why the degree of *physical fidelity* (that is, the difference between the original task and the transfer task: – total physical fidelity consisting of an exact replication) that is required to generate transfer, is of such fundamental importance. The extent to which a flight simulator must resemble an actual cockpit in order to be of any value as a training mechanism, for example, is crucial in terms of the economic restraints under which it is to be constructed, and its eventual efficacy; the specificity or generality of an industrial training programme may well determine the degree of adaptability that a work force possesses – a factor that may ultimately be of greater significance than any initial post-training level of competence and ability. In an increasingly complex and competitive world, there is a growing pressure to create more predictable and efficient learning and training environments.

The Experimental Transfer Paradigm

The concept of transfer has become widely used as a means of exploring the effects of previous experiences on the learning of a new task and much empirical evidence has been generated from studies based on the typical transfer paradigm. The two main features of such a design include the transfer of all groups to a common level of an independent variable (which is then treated as the dependent variable), and the inclusion of a delay period between the initial practice phase and the transfer phase, to allow any temporary effects of the independent variable (such as fatigue) to dissipate.

With reference to the former, there is, implicit within the notion of transfer, the assumption that the transfer task (task 2) is different to the practice task (task 1). Whether or not performance on this secondary novel task has somehow been affected by the initial practice period is the issue under investigation, and subsequent conclusions about learning are drawn on the basis of these performance measures. In other words, transfer could be described in general terms as a phenomenon concerned with the changes in the performance of one task, as a result of previous performance on a different task. In the light of this definition, then, is there any distinction to be made between *transfer* and *learning*?

The Distinction Between Transfer And Learning

At first glance it would seem that the only distinction that might possibly be drawn between the two concepts is that in the case of transfer, *different* tasks are selected, whereas learning often occurs when the *same* task is repeated. This distinction is somewhat superficial, however, when cognizance is taken of the fact that although the same *task* might be attempted, in some ways all *performances* are different, and no attempted movement is ever merely a repetition of a previously performed action. It could thus be argued that what might initially be construed as a repetition of the *same* task in the learning process is, in fact, no different to the transfer paradigm where different tasks necessitate different performances:

> *"When I make the stroke I do not, as a matter of fact, produce something absolutely new, and I never merely repeat something old. The stroke is literally manufactured out of the living visual, and postural 'schemata' of the movement, and their inter-relations."*
>
> (Bartlett, 1932. p. 202)

Looked at another way, the minor variations in repetitions of the *same* movement response might reasonably be ignored if they are accommodated within the framework of Bronowski's (1973) Principle of Tolerance, which Fazey (1986) has suggested may be considered to be highly applicable to the error detection and error labelling mechanisms that are hypothesized to exist in a functional model of motor control:

> *" ... acquiring control will involve learning to ignore those differences which make no difference. The need is to recognise what is functionally equivalent and to set the limits of tolerance for the system."*
>
> (Fazey, 1986. p. 87)

From this point of view a case for distinguishing between learning and transfer with respect to the *same* or *different* tasks and performances may well be made. However, whilst the rational behind such semantic distinctions could be debated almost indefinitely, a more appropriate position to adopt towards transfer and learning is probably that taken by Gick and Holyoak:

> *"We take the view that no empirical or theoretical chasm separates transfer from the general topic of learning. Rather, the consequences of prior learning can be measured for a continuum of subsequent tasks that range from those that are mere repetitions ... , to those that are highly similar ... , to those that are very different ..."*
>
> (Gick and Holyoak, 1987. p. 10)

Schmidt and Young (1987) concur with this viewpoint and suggest that if, as a result of practice, the format of the underlying abilities that determine a level of performance is changed (e.g., Fleishman and Hempel, 1955; Schmidt, 1982), then it is not unreasonable to argue that the task in any one trial is *different* from the trial before, and any previous trial that has been attempted in earlier practice. (This point is addressed in more detail in subsequent chapters where it is suggested that the task and its perceived level of complexity is a function of previous practice and experience. In this sense, the changes in the level of learning of the performer might be expressed as changes in the task from one trial to another). It thus follows under this analysis that approaching the notion of transfer as a unique category of learning, with its own special laws and experimental designs, is not defensible:

> *"Rather, our view implies that transfer and learning are indistinguishable and that care should be taken when searching for the principles of transfer as if they were in some way distinct from those of learning."*
>
> (Schmidt and Young, 1987. p. 49)

Interference & Facilitation Or Negative & Positive Transfer

Whenever we are learning a new skill there are often marked differences between the initial attempt of one beginner compared to that of another. On a superficial level, an encouraging first attempt at a novel task might be explained in terms of a *natural aptitude* or *talent* which that beginner possesses, whilst a poor attempt might be excused on the grounds that previous experience in another skill has left ingrained *bad habits* which are adversely affecting performance on the new skill. An obvious example is that of the tennis player trying his hand at badminton for the first time, and discovering that his *natural* style of play is not only inappropriate for this particular racquet sport, but actually seems to hinder his progress in acquiring this new movement skill. Whatever we may hypothesis to be behind these variations in ability, the fact remains that such inequality is clearly evident.

Early attempts to confront this issue centred on a task analysis approach. The theory of transfer presented by Thorndike and Woodworth (1901; Thorndike, 1903) was based on the notion of *identical elements* that could be determined between the learning task and the transfer task. Similarly, *The Osgood Transfer Surface* (Osgood, 1949) was a model for predicting transfer from one task to another, in terms of positive, negative, and zero transfer effects. Later work focussed more on the individual component sources within a task that might be responsible for producing positive or negative transfer effects. This more microscopic level of analysis also saw the introduction of the words *interference* and *facilitation* as a substitute for negative and positive transfer.

Whilst the inclusion of any comprehensive account of the evolution of transfer studies is beyond the scope of this thesis, the briefest examination of early work clearly indicates that the main issues that were being addressed in these earlier days, are still at the forefront of current debate. The problem of defining *similarities* between tasks has yet to be resolved; the issue of general versus specific transfer of learning is still in contention; the principles of transfer are at the heart of our interest in how we learn; and the methodological problems involved in the examination of transfer as a measure of learning are crucial to any empirical investigation.

The Question Of Task Similarities

To compare one task to another, or identify one task as being different from another, requires that, in one sense, the task must be considered in isolation from the performer. The daunting prospect of categorizing tasks from the point of view of the subject, necessitates evaluations about the way in which that task may be perceived at any given moment, the level of familiarity the subject has with the kind of task under consideration, the level of skill that the performer has already acquired in *related* skills, and a host of other considerations. From this perspective, there would seem to be no absolute from which a task could be measured in terms of its complexity, its simplicity, or its *novelty* (The argument is presented subsequently that *novelty* and *complexity* may, to all intents and purposes, be viewed as one and the same thing).

Fleishman (1984) has approached this question of task classification by trying to identify the dimensions along which one task may differ from another. In his *Taxonomies of Human Performance*, he selects four categories for consideration: The first involves characteristics of the task which are independent of the human subject, examples of which include – stimulus complexity, response precision requirements, goal requirements, and environmental conditions; the second category concerns the underlying abilities that are deemed necessary to perform the task, such as verbal comprehension or multi-limb coordination; the third classification is made on the basis of wider performance functions such as scanning, coding, or problem solving; and finally a more narrowly-defined category of tasks which might include such features as manipulating control handles, or reading dials. Fleishman himself, however, recognizes that:

"The issue of defining 'similarity' between tasks is still with us ..."

(Fleishman, 1987. p. XV)

He focuses on the crux of the issue in his continuing statement:

" ... such conceptualizations need to include information about the abilities of the learner required by both the training and transfer tasks. The input side (subject abilities) has not been easily integrated into the transfer-of-learning paradigms."

(Fleishman, 1987. p. XV)

The Effect of Surface Similarities And Underlying Similarities On Transfer

In determining what constitutes *similarity* between tasks, a distinction has to be made between those surface features of the task that might be identical, and the deeper, underlying structural similarities that might be evident. To return for a moment to Thorndike's (1903) *identical elements* between tasks, there was, as Brown and Kane (1980) point out, considerable dispute regarding the nature of these elements. Generally, however, the theory has been interpreted to mean that:

" ... if two situations share an underlying deep structure but differ in their surface manifestations, transfer cannot be expected, whereas if there are surface elements (e.g. physical or perceptual similarity) in common, transfer will be a "necessary result"."

(Brown and Kane, 1988. p. 494)

An opposing viewpoint held that transfer could be expected if the underlying guiding *principle* at the centre of the learning situation is accessible to the learner. Perhaps the best known experimental evidence offered in its support was that conducted by Scholchow and Judd just before the turn of the century (reported in Judd, 1908), in which twelve-year-old boys who had been instructed in the principles of refraction, performed better on transfer in a dart-throwing task at underwater targets, than did those who had received no such tuition. Transfer was thus seen, not as an automatic process that occurred only on those occasions when surface features were sufficiently similar, but rather dependent upon insight into general principles, whether this be acquired by means of discovery, or via direct instruction.

Other earlier evidence supported Judd's position (e.g., Ruediger, 1919; Ruger, 1910), and even Thorndike (1926) revised his initial ideas. The original theory of identical elements, however, maintained a firm foothold, and Brown and Kane (1988) report that:

> *"Recent laboratory studies of ... learning in children reinforce the view that transfer is a hard-won commodity."*
>
> (Brown and Kane, 1988. p. 495)

Brown and Kane (1988) pose the question whether it is reasonable to think of children as *extreme Thorndikians* whose potential for transfer is dependent on their perception of the surface features of the task. They acknowledge that evidence clearly indicates that:

> *" ... children can make inductive projections on the basis of deep underlying structure such as a natural kind membership, even when it conflicts with surface similarity (Gelman and Markman, 1986, 1988)."*
>
> (Brown and Kane, 1988. p. 496)

At the same time they are also able to:

> *" ... respond on the basis of perceptual similarity on a variety of tasks such as classification, free association, free recall, and word definitions (Mansfield, 1977) as well as analogy, metaphor, and transfer tasks (Brown and Campione, 1978, 1984; Gentner and Toupin, 1986; Vosniadou, 1987)."*
>
> (Brown and Kane, 1988. p. 496)

There would seem to be general agreement on the fact that physical similarities or perceptual attributes are utilised by both children and adults in the process of transfer. The issue is whether or not young children have any other means whereby transfer can be induced.

Possible Maturational Barriers Inhibiting Transfer

If we accept that transfer will not be initiated without the perceptual support that Thorndike's (1903) theory would suggest, there seems to be a strong case for accepting the idea of developmental stages of the kind proposed by Piaget (1970). The existence of a maturational barrier that only time can transcend, would mean that children are required to reach the appropriate stage of development (age), before transfer would be possible without the aid of clearly perceived identical surface features.

Intuitively, the adoption of such a position seems contrary to any dynamic view of an overall controlling system (The question of maturational barriers is discussed in further detail in relation to schema – Chapter 5). The alternative explanation offered by Brown and Kane (1988) seems more favourable:

> *" ... young children have a 'developmental preference' for relying on perceptually salient features if given a choice."*
>
> (Brown and Kane, 1988. p. 496)

Empirical evidence is offered by Brown and Kane (1988) in support of this view and they come to the conclusion that:

> *"Preschool children ... can transfer on the basis of underlying structural similarity; they are not totally dependent on surface features to mediate transfer ... .For young children, and novices who have not yet differentiated the deeper structure, appearance matches serve as a fallback option when theory fails."*
>
> (Brown and Kane, 1988. p. 518, 519)

The explanations that are generally put forward to account for the persistence of a developmental trend include: (1) A lack of *knowledge*, pertinent to the domain in question; (2) Differences in basic *mental capacity*; (3) A lack of *learning strategies*; and (4) *Metacognitive* limitations – the inability to reflect on mental processes.

General Versus Specific Transfer Of Learning

Another way of looking at this question of surface similarities and underlying structures, is to consider it from the perspective of general and specific transfer of learning.

Specific transfer implies that transfer effects from previous learning experiences are relatively insignificant in comparison to the efficiency of the practice schedule immediately preceding the introduction of the new task. If a perceived similarity does not exist, then transfer is not predicted. Much of the research conducted within the early S-R framework is consistent with this view, and (in Fleishman's (1987) opinion) seems to almost ignore the existence of transfer phenomena, with many variables affecting transfer not being taken into account (See Underwood and Postman, (1960)).

The generalist view of transfer holds that previous learning experiences can capitalize on underlying similarities to the extent that emphasis should be directed at *training the mind* so that skills can be acquired that will generalize widely and be applied to the solution of novel problems. The rational behind the structure and organisation of much of our formal education policy has its origins in this basic premise – the emphasis on teaching Latin as a means of enhancing the study of English is a prime example. Similarly, at the root of the educational debate over discovery learning versus more formal and traditional modes of instruction, lies this issue of transfer generalizability. The view that problem solving and creative learning is more efficiently acquired by *insight* as opposed to rote learning, is a reflection of the belief that previous knowledge can be brought to bear on superficially unrelated novel tasks. The student who has learned via a method of trial-and-error, is presumably better equipped with a more general level of expertise with which to apply to the solving of new problems.

Thorndike and Woodworth's (1901) proposal of identical elements existing within the surface features of the learning and transfer tasks, is thus representative of a specific view of learning. Judd's (1908) contention that transfer is dependent upon insight into general principles, on the other hand, is indicative of a more generalist view of the learning process.

Whilst evidence of both types of transfer may be cited, the fundamental question still remains: Is the ability to gain *insight* the result of a developmental process, the occurrence of which is outside the influence of an externally manipulated learning environment, or is it something that can be acquired through experience? Is there some substance in the notion of *learning how to learn*? Brown and Kane (1988) argue that their data is sufficiently convincing to support this latter view. They conclude that:

> *"Exposing children to a variety of transfer experiences teaches them to 'search for underlying commonalties.'"*
>
> (Brown and Kane, 1988. p. 516)

The appropriate learning environment, it is argued, can thus produce efficient learners whose success can be attributed to readily definable factors:

> *"Efficient learners prepare for transfer by engaging in reasoning processes aimed at elaborating knowledge. With experience, efficient learners develop a mind set to regard new problems, not as isolated examples, but as instances of a general class. Efficient learners come to expect what they learn to be relevant elsewhere ... In short. efficient learners understand some of the principles involved in learning and reasoning; they have a greater metaconceptual grasp of the domain 'learning'."*
>
> (Brown and Kane, 1988. p. 520)

Two Conflicting Views Of Learning

It would seem that it is possible to identify two main, apparently conflicting, views about how we learn and thus increase our potential for transfer.

The first suggests that the subject perceives similarities in the surface features of the task – the greater the number of resemblances, the greater the propensity for transfer. Alternatively, in the total absence of similar stimuli, zero transfer is predicted.

The second view sees the subject, not passively receiving surface information, but rather, actively searching for evidence to support or invalidate a particular hypothesis related to the underlying structure of the task.

Whilst echoes of this debate on the specificity of transfer effects abound throughout the verbal and motor literature (whether it be concerned with the relative importance of general reasoning skills versus domain-specific knowledge, or general knowledge representations versus specific remembered instances), these two opposing theories lie at the centre of the controversy.

A Proposed Reconciliation

In considering the possibility of some kind of developmental restriction that might be responsible for inhibiting transfer, it has already been suggested that these opposing views need not be mutually exclusive. It seem reasonable, for example, that although children may appear to rely heavily on the perceptually salient features of the task, they do so out of preference (e.g., Kane and Brown, 1988), or because the option of deductive reasoning is not readily available (e.g., Piaget, 1970). In other words, a *complete* theory should allow subjects to group elements on the basis of observed similarities, and to perceive connections via the process of testing hypotheses. Vinacke (1952) reasoned along these lines, and argued that either view could be considered appropriate since either, or both might occur depending upon the individual and the situation:

> *"Under some conditions, the individual may be essentially a passive recipient of sensory impressions which gradually summate into the concept. Under other conditions, it may be that an individual proceeds by establishing a hypothesis and then deliberately checking it against instances."*
>
> (Vinacke, 1952. p. 107)

This is consistent with the explanation already presented by Brown and Kane (1988), and would, presumably, find favour with many researchers in the area of motor control. Fleishman (1987), for example, in a similar vein, discusses a study involving, what he refers to as, an analysis of the general abilities required at different stages of acquiring a complex tracking skill:

> *"The most effective training method involved focusing the subjects' attention, through instructions, on the ability requirements of the task at the appropriate stage of learning."*
>
> (Fleishman, 1987. p. XV)

The Underlying Error Inherent In Such Distinctions

What, however, is meant by the *appropriate stage of learning*? Does this imply that there is a necessary developmental procedure to undergo before the subject can competently engage in the active process of hypothesis testing? Have sufficient advances been made in the taxonomies of tasks that allow the experimenter to accurately define the ability requirements of the task?

Bolton (1977) suggests that the fundamental flaw in this kind of thinking, and clearly evident in Vinacke's (1952) reasoning, is that the attempt to reconcile these opposing views perpetuates the notion of a division between sensory experience on one side, and ideas and hypotheses on the other:

> *"Whatever differences exist between inductive and deductive accounts of concept formation, they share the more fundamental error of assuming that reality is already defined for the subject, that is, that the elements which make up a concept-to-be-learned are 'there' for the subject whose only task consists either of attending to them or of interpreting them with the aid of a well-informed hypothesis... It..seems much more likely that the subject elaborates his repertoire of concepts at the same time that he organises his environment and, consequently, we should speak of the construction of reality occurring in parallel with the development of cognitive structures such as hypotheses, concepts and plans."*
>
> (Bolton, 1977. p. 3)

There would seem to be a possible pitfall here in that a loss of valuable insight might result from the failure to recognise the importance of individual differences. Whilst a static view of memory might only require the researcher to establish rules about behaviour on the basis of reactions and responses to stimuli, a dynamic view must:

> *" ... incorporate changes in both the representational structure for a task and its closely associated strategic processing (Shea & Zimny, 1983; Zanone & Hauert, 1987)."*
>
> (Christina and Shea, 1988. p. 292)

In the debate over whether surface similarities might be more important than deeper underlying structures, there is a danger of missing the point. Of course both children and adults will sometimes have a clear idea or hypothesis about what they are looking for, whilst on other occasions they will have no such explicit information to guide them; and of course it is reasonable to suggest that the learning environment can be manipulated in a particular fashion to enhance the process of skill acquisition – that is, teaching how to learn. What is inappropriate, however, is to argue on the basis that one type of behaviour is ***just*** associative, and can be distinguished sharply from another type of behaviour that is defined as cognitive. Perhaps the really key issue concerns the notion that consciousness is always intentional. A more detailed examination of this fundamental premise is, perhaps, best postponed until the concept of the schema is introduced as the basis from which to construct an appropriate framework for analysis (see Chapter 5). The basic idea, however, is expressed quite succinctly in Bolton's (1977) criticism of those theorists who make such distinctions:

> *"Because the development of thinking and the growth of sensitivity to the environment are parallel processes, accommodation to the properties of the environment always presupposes some act of interpretation, however rudimentary, and every interpretation contains some measure of reality-orientation, however slight."*
>
> (Bolton, 1977. p. 47–48)

He goes on to point out the logic of adopting an alternative view:

> *" ... if interpretation were not somehow inherent in sensori-motor behaviour, there would be an unbridgeable discontinuity between the sensori-motor and the conceptual levels of development."*
>
> (Bolton, 1977. p. 48)

Once again then, the argument seems to point quite clearly in the direction of a more dynamic view of memory, and reinforces the notion that transfer phenomena are most appropriately considered within the overall context of learning.

Some Final Comments On Transfer

In the concluding remarks of their chapter entitled *Transfer of Cognitive Skills* (in Cormier and Hagman's (1987) text *Transfer of Learning*), Gray and Orasanu make the following statement:

> *"Writing this chapter has convinced us totally of the symbiotic relationship between theories of learning and transfer. The theoretical and practical goal of understanding the conditions of transfer of cognitive skills cannot go on in a vacuum. Before we can possibly understand what is transferred, we must understand skilled performance and how it is acquired."*
>
> (Gray and Orasanu, 1987. p. 213)

This current chapter on transfer is by no means exhaustive, and many fundamental issues related to this topic have, as yet, been afforded only brief attention. A comprehensive description of transfer must address the fundamental issue of how transfer should be measured, and thus, the question of how to determine the direction and magnitude of transfer. Moreover, in applying the principles of transfer to practical settings, to what extent should training for transfer differ from training for rapid acquisition? Such speculations forced Postman (1976) to conclude that:

> *It is fair to say that the total picture is complex and beset by uncertainties ... with respect to the general conceptualization of the underlying mechanisms of interference. One cannot help but wonder why after so many years of patient experimental effort interference theory today finds itself entangled in so many empirical inconsistences and theoretical complications.*
>
> (Postman, 1976.)

Reiterating the sentiments of Gray and Orasanu (1987) it would thus seem more appropriate to conclude this discussion on transfer *per se*, and focus attention on other related aspects of transfer within the context of a much broader range of pertinent issues directly concerned with motor control and motor learning.

In Summary

This chapter has introduced the concept of transfer and highlighted its importance in terms of the experimental transfer paradigm common in motor control research. The validity of making a distinction between transfer and learning has also been questioned. Motor task similarity, as an issue that naturally emerges from the discussion and is inextricably tied to this notion of transfer, prompts an examination of the existence of possible maturational barriers inhibiting transfer. A compromise is offered with regard to the conflicting views of general versus specific transfer of learning, and the errors underlying such distinctions are addressed.

Many of the issues examined in this chapter preempt related issues that are subsequently discussed at greater depth, and will ultimately form the main thrust of this thesis.

Chapter Four introduces the concept of schema and discusses the use of the concept in providing a framework within which to view the processes responsible for initiating and controlling human movement.

CHAPTER FOUR

The Concept Of Schema

The main issue in this thesis is the relationship between variability of practice and task complexity. Fundamental to this notion of variability of practice as a factor influencing learning (as measured by increased transferability) is the concept of the schema. This chapter introduces this concept and focuses attention initially on the original theory of abstraction as a background to early theorising. The criticisms levelled at the theory of abstraction in terms of its ability to account for the process of concept formation (schema development) sets the stage for the dynamic and flexible view of schema that provides the framework within which the main topics of interest are addressed. The views of Bartlett (1932), Pew (1974) and Schmidt (1975, 1976), in particular, are examined in detail as major influences in the move towards a more appropriate functional model of motor skill, as that proposed by Fazey (1986).

A Familiar Concept In Psychology

A fundamental concept that has been at the forefront of motor skill research for over a decade now is that of the schema. The concept is not new. The term itself has been traced back to Kant (1781, 1787/1963) who developed the idea that experiences are stored in memory and defined by common elements (Fazey, 1986). The neurologist Head (1920) adopted this view, stating that anything that enters consciousness is:

> " ... *charged with its relation to something that has gone before.*"
>
> (Head, 1920. p. 607)

Thorndike (1926) points out the similarity in Woodworth's view on the process of remembering which, he claims, involves the *revival of one's own experiences* (Thorndike & Woodworth, 1901).

The term *schema* seems to have taken on as many different meanings as there are branches of psychology. Head's (1920) ideas of schema were subsequently modified and used in the context of remembering by Bartlett (1932); Piaget (1926) used the concept of schema to describe the formation and development of cognitive structures in children; Gestalt psychologists (e.g. Woodworth, 1938) made use of the term to describe memory for perceptual information; whilst early research into issues of problem solving relied on the concept of schema to explain the operations that guided behaviour. More recently, schema has been a central feature of theorising in the area of motor control and learning (e.g. Pew, 1974; Schmidt, 1975, 1976), and much attention has been focused on the concept from the verbal memory domain, with reference to schematic knowledge about objects, stories, scripts, scenes, frames and events (e.g. Norman and Bobrow , 1975; Mandler, 1984; Minsky, 1975; Rumelhart and Ortony, 1977; Schank and Abelson, 1977; Winograd, 1975).

Whilst the general concept is thus not unfamiliar to the psychology literature the great disparity over the ways in which the term has been employed, led Bartlett (1932) to observe that *schema* was often used by those unable to define exactly what it was they were trying to say.

Mandler (1984) has suggested that although reference to *schema theory* in psychology is now widespread, a more appropriate term might be *schema framework*. He argues that the word *theory* is misleading since it implies a status that is attained only after subjection to the most rigorous, empirical scrutiny:

> *" ... it is not clear that any specific schema theory has yet reached that pinnacle of science. Even the broad principles themselves need to be explored and sharpened, and most vitally, to be made explicit."*
>
> (Mandler, 1984. p. 2)

The Basic Idea

The central theme that is common to all *theories* of schema is the notion that knowledge is stored in human memory in abstract clusters, which are subsequently used to comprehend and store new instances of the concept. This information, it is hypothesized, is encoded in an organised but generalised form. The stored abstract representation may be thought of as a kind of *rule* which, although lacking many of the actual details, may be continually modified and updated by our most immediate experiences. Comprehension of a new instance is guided by the schema which provides both expectations and constraints in terms of the properties associated with a given concept/type of knowledge.

There are clearly strong links between the notion of a schema, and the traditional theory of abstraction. To discuss the concept of schema without any reference to the theory of abstraction is to ignore an important part of the background from which schema theory emerged. Whilst a considerable volume of literature has been devoted to contemporary views on schema, psychologists seem to have taken relatively little notice of, what must surely be considered, a prominent forerunner of much current theorising about the process of learning:

> *" ... whilst there has been a growing readiness among psychologists to accept the thesis that experience and behaviour are guided by cognitive structure, criticisms of the traditional theory of abstraction have come from philosophers more than psychologists."*
>
> (Bolton, 1977. p. 3)

Bolton points out what he regards as a regrettable consequence of this apparent lack of attention:

> *" ... the avoidance of philosophical speculation by psychologists has meant that they have tended to accept without question the notion of the traditional theory of abstraction that concept formation is to do with classification; consequently, they have ignored the many other ways in which subjects organise experience."*
>
> (Bolton, 1977, p. 4)

It would thus seem appropriate to focus briefly on the theory of abstraction as an underlying view of much recent theorising. If any more justification is required from what might be construed as a digression from the main point of interest, it is argued that from an examination of the criticisms levelled at the traditional theory of abstraction, it is possible to identify pertinent theoretical issues that have a direct bearing on contemporary thought on schema from the motor learning domain. Moreover, evidence comes to light that further points to the dynamic view of the motor controlling system that is advocated throughout this thesis.

(The subsequent discussion on the theory of abstraction is relatively brief. For a more in depth account the reader is referred to Bolton

(1977) in which the theoretical and philosophical basis for the study of concept formation is considered in detail.)

The Theory Of Abstraction – The Background To Schema

The Oxford dictionary defines *abstraction* as *"the process of stripping an idea of its accompaniments – a withdrawal"*. The traditional theory of abstraction (which Bolton (1977) points out can be traced back through the works of Locke (1690) and Hume (1739) to Aristotle) holds that through the process of *abstracting* certain resemblances from amongst otherwise dissimilar stimuli, knowledge is acquired and concepts are formed. Central to this view is the belief that behaviour is never merely a reflex reaction to presented stimuli, but rather something intentional, no matter how faintly defined that intent might be for the subject or the observer:

> *"The idea that experience is intentional is implicit in all those psychological theories which deserve to be called 'cognitive'. It is to be found in Miller, Galanter and Pribram's (1960) notion of 'plans' that guide behaviour, in Bartlett's (1932) use of the concept of 'schema' to denote the reconstructive rather than the reproductive nature of remembering, in Kelly's (1955) ideas about the 'constructs' which people employ to predict events and make sense of reality, and in Piaget's theory (Piaget, 1950) that the child develops a system of 'schemes' from the co-ordination of his actions upon objects."*
>
> (Bolton, 1977. p. 3)

This point is important as it seems to be the key factor that distinguishes research in the *cognitive tradition* to other more restrictive frameworks of analysis of the kind that Whiting (1980) has criticised. (The basis of this criticism, as previously mentioned, centres on the failure of much research to have any obvious application to a descriptive account of cognitive control.)

Assumptions Underlying The Theory Of Abstraction

Bolton (1977) has identified three major assumptions implicit in the theory:

The first assumption is that concepts are formed as a result of recognising similarities amongst stimuli. It is noted that these similarities are assumed to be:

> *" ... a property of the subject's environment"*
>
> (Bolton, 1977. p. 10)

and all we are required to do is to attend to them. From this view it follows that the subject's acquired knowledge is thus a copy of reality and:

> *" ... the more advanced he is in conceptual development, the better his copy will be."*
>
> (Bolton, 1977. p. 10)

Second, it is assumed that knowledge acquisition is from the particular to the general. Through the process of observation, similarities in *particular* events are recognised and a subsequent *generalisation* occurs enabling these particular events to be grouped as instances of a general class.

The third assumption is that ***concrete*** knowledge (that is, knowledge about the *physical* world such as *trees* or *animals* or *cars*) is *primary* in the sense that such knowledge lays the foundations for the acquisition of more ***abstract*** concepts which are concerned with the relationships between things (examples of such concepts are, *religion, subtraction, envy*). In other words, through encounters with the physical world *logico-mathematical* knowledge is derived:

> *" ... since logical and mathematical rules are reflections of the workings of this world...it follows that in a different physical environment there would be logical and mathematical rules other than those to which we are accustomed."*
>
> (Bolton, 1977. p. 10)

Some Criticisms Of The Theory Of Abstraction

These three main assumptions have each been challenged.

The first assumption that concepts are formed through the recognition of existing similarities has been criticised on the grounds that what is perceived will, in fact, be determined by the subject's point of view (Cassier, 1953). Whether or not elements are classified as similar will depend on the concepts that are being employed to group elements together. It is thus quite feasible that the same elements might be organised in different ways on separate occasions. The theory itself seems to be unable to account for this:

> *" ... it is because for this theory the subject's only activity consists of attending to and grouping sensations that are 'given' to him. Here we have a one-way causality – the world impresses itself upon a subject who has no point of view of his own – and it becomes quite impossible to do justice to the diversity of points of view which inform our concepts."*
>
> (Bolton, 1977, p. 11)

Others have countered this criticism by suggesting that the similarity amongst elements is not necessarily confined to surface features (e.g. Wittgenstein, 1953). There is no common element, to use his example, to be found in concepts such as *games* or *tools* or *beauty*. Wittgenstein suggests, however, that the components are grouped together to form these concepts on the basis of *family resemblances*. The hammer, the saw and the screwdriver, for example, are thus related in *"a complicated network of similarities overlapping and criss-crossing"*.

Mandelbaun (1965) has pointed out the weakness in Wittgenstein's solution to this problem: in his use of the idea of a *family* to explain similarities, he fails to differentiate between physical resemblances and the genetic ties that link members of a family together. In other words, in the same way that family members are linked, not necessarily through similarities in specific perceptual features, but by virtue of a common descent, so the analogy can be applied to the individual components of the tool-box which, although exhibiting few similarities in terms of their surface structure, they each share a common ancestry in terms of the function and purpose behind their creation. The conclusion that Bolton (1977) logically draws is that:

> *"It is only by recourse to purpose and motives, in short, to intentionality, that we are led not to link solitaire to fortune-telling or wrestling to fighting, in spite of there being many points of resemblance."*
>
> (Bolton, 1977. p. 12)

We thus return once again to this fundamental notion of *intent* which implies an active role on behalf of the subject in interpreting and structuring reality. It is what Husserl (1900, 1901) has referred to as *intentionality of consciousness* and is to be distinguished from the traditional view of consciousness as described by Hume (1739):

> *" ... nothing but a bundle of different perceptions which succeed each other with an inconceivable rapidity."*
>
> (From Bolton, 1977. p. 252)

In terms of the way schema might be developed and used to initiate and control movements, this underlying notion of *intent* has considerable theoretical and subsequent practical implications. If we accept that the subject's *point of view* determines the form and nature of the developing schema, it follows that there is no basis for hypothesizing the existence of any *externally definable* boundary to a schema class. Taking the view that the subject attends, either consciously or unconsciously, to inherent similarities that are *there* waiting to be discovered, seems to deny the fundamentally dynamic nature of the human memory. The question of possible schema boundaries is addressed in more detail in due course.

To move on to the second main assumption, the theory of abstraction (as the very name implies) states that concepts are *abstracted* (drawn away) from specific instances: – abstraction is from the particular to the general. An appropriate example is given by Schmidt (1975) in the introduction of his paper on schema theory:

> *" ... in order to perceive a set of visual stimuli (e.g. a dog) and to classify these stimuli correctly in the category 'dog', we need not have previously received the particular set of stimuli in question. Through our past experiences with seeing dogs, we store these stimuli in recognition memory and also abstract these stimuli into a concept related to dogs for additional storage. This concept forms the basis of a 'schema' or rule for determining whether a new set of visual stimuli should be classified into the category 'dog' or not. Thus to recognise an animal as a dog, and with the use of the schema for dogs, we correctly identify the animals category."*
>
> (Schmidt, 1975. p. 233)

The assumption that such a description is an accurate picture of concept formation has been criticised on the grounds that the traditional theory of abstraction confuses two meanings of the term *abstract* which should be clearly distinguished (e.g., Husserl, 1900, 1901; and, later, Schutz, 1966). Bolton (1977) argues that:

> *" ... it is true that certain particular types can be subsumed under a general category (as when we ignore the differences between spaniels, fox-terriers and poodles and call them 'dogs') ..."*
>
> (Bolton, 1977. P. 14)

On the other hand, however:

> *"We should not be able to group spaniels along with fox-terriers unless the quality of 'doginess' had already been grasped in the one and extended to the other."*
>
> (Bolton, 1977. p. 14)

In other words:

> *" ... whilst 'dog' as an abstract concept may be defined by reference to the resemblances among the particular types, the concept of dog is not formed through a noting of the resemblances among the particular types, since there must be some intuition of the general in the perception of the particular."*
>
> (Bolton, 1977. p. 14)

An obvious parallel exists here between this distinction and that adopted by Van Rossum (1980) from Bruner, Goodnow and Austin (1956), about the difference between *formation* and *attainment* being:

> *" ... to do with the abstraction vs. the application of rules or schemata."*
>
> (Van Rossum, 1980. p. 274)

Van Rossum (1980) suggests that not enough attention has been paid to this distinction and he proposes a:

> *"...slightly more detailed orientation towards the motor schema notion...*
>
> *The suggestion is that the motor schema is not only an abstracted rule in which sources of information are represented, but is more specifically a system in which informational aspects are stored, which are related to the typical solution one has discovered for a class of similar motor problems. This implies that relevant information ... does not have to be regarded as relevant for those, who have not discovered this aspect as informational yet."*
>
> (Van Rossum, 1980. p. 277)

Bruner, Goodnow and Austin (1956) see the process of *attainment* as being involved with applying already existing knowledge; grouping elements into categories which are already clearly defined and understood. The process of *formation* is concerned with the activity of forming and defining the concept. Van Rossum (1980) applies this notion to the motor schema and thus sees the process of *formation* consisting of:

> *" ... the gradual change in distinguishing the relevant informational aspects."*
>
> (Van Rossum, 1980. p. 277)

Bolton (1977) makes the point that since the intention and point of view of the subject is fundamental to this process, it follows that the concept is predictive in nature:

> *" ... to form a concept is to anticipate that certain future experiences will take a certain form."*
>
> (Bolton, 1977. p. 16)

This is implicit in Bartlett's (1932) view of the schema and reflected in his notion of the reconstructive process of remembering:

> *"In remembering, the subject uses the setting, or scheme, or pattern, and builds up its characteristics afresh to aid whatever response the needs of the moment may demand."*
>
> (Bartlett, 1932. p. 208)

The assumption, then, that knowledge acquisition and concept formation is from the particular to the general does not seem an adequate description of the process. Intentional consciousness means that stimuli are perceived from the subject's point of view. Generalization has already occurred since the object of perception is an example of what the subject expects to find.

Bolton (1977) points out another source of influence on the generality of the concept; the fact that the developmental process occurs in a society within which there are agreed names and labels for objects and events:

> *"If language did not posses the power of communicating agreed meaning, then our concepts would remain idiosyncratic and incommunicable."*
>
> (Bolton, 1977. p. 16)

This is not to suggest that language acquisition is a prerequisite for concept formation, only that in looking for the origins of concept formation or schema development, the acquisition of language may, in some instances, be a major source of influence.

The final assumption of the theory of abstraction to be challenged relates to the formation of *logico-mathematic* concepts. Such concepts (examples of which include the logical operations of *not*, *if...then*, etc.) obviously do not exist in the same way that concrete or abstract knowledge exists. The theory, however, holds that all concepts are abstracted from our experiences of the world, and offers no alternative explanation.

Beth and Piaget (1966) make the distinction between this kind of knowledge and physical knowledge, and illustrates the distinction with an example of a child playing with pebbles: The child is able to discover physical knowledge about the pebbles themselves (e.g. their weight and texture), as well as logico-mathematical knowledge (e.g. when the pebbles are laid in a row, the same numerical total is reached whether the count starts at the left and finishes at the right, or vice versa). Whilst the distinction is useful, these two types of knowledge remain necessarily interdependent. In Piaget's developmental analysis these interdependent modes of knowledge are traced from their origins in the sensori-motor experience through to their most advanced stages where they manifest themselves in logical and mathematical reasoning. For Piaget the growth and development of the intellect is seen not as something that occurs independently or externally to the individual, but rather as:

> *" ... a process of self-construction, governed by existing formations of cognitive structures. To be sure, it happens in relation to the world, and it is a process that has evolved in such fashion that its results are biologically and socially adaptive; the world plays its regulative function. But it is not a matter of stimulus and response ... Rather, environmental events are assimilated as well as they can be to existing structures...and, finally, only occasionally do they result in fundamental changes in such structures."*
>
> (Gruber and Voneche, 1977. p. xxviii)

Gruber and Voneche (1977) do point out in a subsequent footnote that:

> *"There is some room for discussion as to whether Piaget believes that change is continuous or sporadic. In our view he makes a distinction on this score between assimilation and accommodation: "assimilation, the fundamental fact of psychic development", he writes in his theoretical introduction to the* ***Origins of Intelligence*** *(p. 42); we believe he treats assimilation more thoroughly than accommodation and regards it as more fundamental. Maybe it is true that in some sense it is more characteristic of an organism to go on functioning as it has done, to preserve its identity, than it is for it to change."*
>
> (Gruber and Voneche, 1977. p. xxviii)

There are obvious parallels to be drawn between Piaget's (1963) *accommodation* and *assimilation*, and Van Rossum's (1980) *formation* and *attainment.*

Bolton (1977) concludes by stating that:

> *" ... although we may talk of the general features of conceptualization, those forces which constrain and channel the development of concepts into particular forms must not be ignored. The subject develops in a particular environment ... ; he is a member of a certain society ... ; he uses a particular language and is guided by certain values. These facts raise the question of the extent to which concept formation is influenced by social and linguistic variations."*
>
> (Bolton, 1977. p. 19)

To summarise: the fact that these main assumptions of the theory of abstraction can be shown to be inaccurate does not imply that the theory itself is completely erroneous. Without doubt it is true that:

i) through existing concepts it is possible to recognise resemblances in stimuli;

ii) encounters with a variety of experiences is an important part of concept formation; and

iii) through the use of physical objects the development of logico-mathematic concepts is facilitated.

In trying to ascertain how concepts are formed or how schemas might develop, however, the proposed view of schema sees the role of experience quite differently to that which is implicit in the theory of abstraction. The best way of outlining this proposed view of the schema is to return initially to what is probably its major source of influence: – Bartlett's (1932) notion of the schema.

Bartlett's View Of The Schema

When Bartlett introduced the concept of the schema in his book *Remembering* in 1932, the existing use of the term was, he felt, much in need of clarification:

> *"It* (the term 'schema') *is at once too definite and too sketchy. The word is already widely used in controversial psychological writing to refer generally to any rather vaguely outlined theory. It suggests some persistent, but fragmentary, 'form of arrangement' and it does not indicate what is very essential to the whole notion, that the organised past results or past changes of position and posture are actively doing something all the time; are, so to speak, carried along as complete, though developing, from moment to moment."*
>
> (Bartlett, 1932. p. 200)

Whilst Bartlett recognised that the current use of the term in psychology was not adequate to explain what he saw as the organisation of the knowledge base responsible for controlling movement, he was at a loss for an alternative word with which to replace *schema*:

" ... it is certainly very difficult to think of any better descriptive word to cover the facts involved."

(Bartlett, 1932. p. 200)

He had to be content to redefine the term *schema*, which he did in the following way:

"'Schema', refers to an active organisation of past reactions or of past experiences, which must always be supposed to be operating in any well adapted organic response. That is, whenever there is any order of regularity of behaviour, a particular response is possible only because it is related to other similar responses which have been serially organised, yet which operate, not simply as individual members coming one after the other, but as a unitory mass. Determination by schemata is the most fundamental of all the ways in which we can be influenced by reactions and experiences incurred sometime in the past. All incoming impulses of a certain kind, or mode go together to build up an active, organised setting: visual, auditory, various cutaneous impulses and the like, at a relatively low level; all the experiences connected by a common interest: in sport, in literature, history, art, science, philosophy and so on, on a higher level. There is not the slightest reason, however, to suppose that each set of incoming impulses, each new group of experiences persists as an isolated member of some passive patchwork. They have to be regarded as constituents of living, momentary settings, belonging to the organism, or to whatever parts of the organism are concerned with making a response of a given kind, and not as a number of individual events, somehow strung together and stored within the organism."

(Bartlett, 1932. p. 201)

Bartlett thus sees the schema as an all-embracing organisation that is not confined or restricted by any limitations, but involves information from long-term memory that is relevant to the performer's immediate situation within a particular environmental configuration. The *momentary setting* is constructed out of *past reactions* and *past experiences* from memory at the same time that *incoming impulses* are influencing the *organised setting* for which the active schema is responsible. The result is a schema that is seen to be both:

" ... at once dynamic and yet permanent."

(Fazey, 1986. p. 26)

This differs from earlier views of schema in the sense that Bartlett recognizes the dynamic nature of memory organisation. Head's (1926) earlier suggestion that the Sensori Cortex is the *store-house* of schema is severely criticised by Bartlett:

" ... the store house is a place where things are put in the hope that they be found again when they are wanted exactly as they were when first stored away. The schemata are, we are told, living, constantly developing, affected by every bit of incoming sensational experience of a given kind. The store house notion is as far removed from this as it well could be."

(Bartlett, 1932. p. 200)

Nevertheless, Head's (1926) contribution to schema should not be underestimated:

"Later writers rightly rejected the 'Storehouse' notion but miss the point that, here, Head is referring to what are stored as 'impressions' and not to specific experiences or instances. As such they are not used in the form in which they are stored but are transformed for use as images or organised models of ourselves."

(Fazey, 1986. p. 21)

Piaget's View Of The Schema

Piaget's Sensori-Motor Schema is not so far removed from the ideas expressed by Bartlett (1932), and has, both directly and indirectly, been a major source of influence in contemporary psychology. An appraisal of Piaget's view of the schema is most appropriately undertaken within the context of the general theory of cognitive development within which he operated.

Like other cognitive developmental psychologists (e.g., Halford, 1970; Flavell, 1971), Piaget recognised developmental changes that could be conveniently classified into stages. He did not, as is often mistakenly assumed, specify the specific ages at which these stages occur, but he did insist on the invariable nature of these changes which were at the very least age-related if not actually age-determined. Whist the question of sequential invariability was not uniformly accepted amongst researchers (e.g., Flavell, 1971), the idea of progressive developmental stages found support amongst numerous researchers.

Four principal stages of development were identified:

The Sensori-Motor Stage

This stage occurs approximately from birth until eighteen months of age. It is during this early period of life that the foundations of the schema are laid down. Through the initial movement experiences of the child, his actions change from those which are primarily reflex in nature to more coordinated actions, as he begins to interact with the physical world.

The Pre-Operational Stage

This stage is from eighteen months of age until about seven years, and is characterised by the development of representational intelligence (particularly mental imagery), and the emergence of language.

The Concrete Operations Stage

During this stage, from about seven years of age until eleven, more complex task-solving abilities are acquired with mental operations involving the use of logico-mathematical knowledge.

The Formal Operations Stage

This is the final stage, estimated to occur from around the age of about eleven years, during which the child becomes capable of completely abstract thought.

It is then at the earliest stage of development that the origins of Piaget's schema are to be found. In their most primitive form they are represented as reflex actions to external stimuli, but are gradually adapted and modified to form the basis from which the individual is able to interact with the world around him. It is these schemas that ultimately determine his behaviour and are responsible for constructing his very concept of reality.

As a new situation confronts the individual, a process of *assimilation* allows the existing schema for action to adapt, resulting in an updated schema capable of ever-expanding applications. When the demands of the new situation exceed the limitations of the existing schema, a process of *accommodation* results in a modification to the schema, thus increasing the individual's potential for action.

Whilst Piaget's schema have their origin in this early Sensori-Motor Stage, and are formed as a result of the interactions between the simplest inherited reflex actions and externally presented stimuli, they are ultimately responsible for guiding and controlling all the intelligent behaviour patterns exhibited by the individual, and are not restricted to any one single domain of knowledge.

Although all schemas, are seen as having their origins in the same early stage of development, Piaget (1963) does distinguish between those schemas responsible for lower order motor functioning, and those involved in higher order cognitive processes:

> *"A sensory motor schema is the functional equivalent of a concept in as much as it results in intelligibility and generalisation, but from a structural point of view, the two are by no means identical. It is characteristic of the sensory motor schema, that its various motor applications cannot be realised simultaneously, so that 'extension' and 'intention' cannot be coordinated by reference to one another."*
>
> (Piaget, 1963. p. 372)

He continues to give a more precise definition of the schema responsible for motor activity:

> *"A sensory motor schema consists of a stable pattern of movements, together with a perceptual component geared to the recognition of appropriate signals. The schema can be applied to a series of new objects, if these are sufficiently similar to one another, or to situations which are analogous with one another: e.g., swinging suspended objects, or obtaining an object on a sheet of paper or a cloth by pulling the support."*
>
> (Piaget, 1963. p. 372)

Fazey (1986) offers the following succinct interpretation of Piaget's view of the schema:

"In Piagetian terms ... A schema is seen as a knowledge structure which governs action. At first schemata are essentially only related to sensory motor functioning and are constructed by the progressive adaptation of inherited reflexes. The consequence of further functioning is the emergence, by adaptation, of the cognitive constructs which guide all forms of human activity, including the highest order of intellectual functioning."

(Fazey, 1986. p. 30)

He goes on to focus attention on this essential link between perception and action, and draws the inevitable conclusion that, for Piaget:

" ... the schema is all inclusive. It contains the necessary information to provide for the organisation of a usable processing strategy and thus governs and informs all the mechanisms involved in perceiving and responding."

(Fazey, 1986. p. 30)

It thus follows that:

"Such schemata, whilst seen to be relatively stable, will be susceptible to practice and are modified by experience."

(Fazey, 1986. p. 30)

There is then a distinct overlap between Bartlett's (1932) and Piaget's (1963) views of the schema in the sense that both see the schema as an overt, rather global organisational structure of memory, that is constantly being reshaped and adapted by experience. Exactly how schemas are constructed and modified, and the nature of the underlying psychological processes that are reflected in differing performance abilities at each stage of development, are questions that Piaget leaves essentially unanswered. Whilst his contribution to educational psychology has been significant, his theories are largely confined to descriptions of surface structures and do little to address the fundamental question of what it is that actually develops from one stage to another. To use for a moment the analogy of the computer, the question remains as to whether these reported developmental changes are occurring in the *hardware* of the system (that is, changes in the neural circuitry resulting in greater storage capacity and enhanced efficiency), or whether they are confined to the *software* (such as changes in the available control processes and processing strategies, or developments in metacognitive skills)?

Whilst Piaget meticulously charts the progress of problem-solving abilities in children, and presents a wealth of information pertaining to these developmental stages, much of his work has been criticised on the grounds that his observational methodology lacks stringent scientific controls, and his conclusions are not supported by solid statistical evidence (e.g., Halford, 1978; Kuhn, Ho and Adams, 1979; Case, 1981). Furthermore, Piaget all but ignores the question of individual differences: a weakness already identified in the original Theory of Abstraction (see page 43). Nevertheless, Piagetian theory was probably the most influential as psychological research moved into the *new* area of cognitive development in the ever-continuing search for explanations of the learning process.

A Restricted Use Of The Term *Schema*

As research in the various branches of psychology progressed, an important distinction began to surface between the earlier uses of the term *schema* and those employed in newly emerging studies, especially from the field of perception (e.g., Attneave, 1957):

> *"The schema was no longer viewed as a global memory structure which relates to all aspects of human functioning ... but it was now compartmentalised and each separate sort of 'schema' was to be considered in isolation."*
>
> (Fazey, 1986. p. 34)

This was a significant change, and one that was of particular relevance to the area of motor control, when in 1975 Schmidt published his *Schema Theory of Discrete Motor Skill Learning.* This was heavily influenced by the work of Pew who had published a technical report the previous year (Pew, 1974) in which he had made some important conceptual statements regarding the nature of a schema for motor learning. Considerable influence was evident from the field of perception and in particular from Posner and Keele's (1968) work in which subjects were successfully trained to identify and classify nonsense dot patterns from prototypes that had never been visually presented. Pew (1974) was led to conclude that:

> *"The concept of schema learning introduced by Bartlett (1958) and defined experimentally by Keele and Posner (1968) seems an appropriate way to think about the generalised nature of what is stored for the production of movement patterns."*
>
> (Pew, 1974. p. 50)

A follow up experiment by Posner and Keele two years later (Posner and Keele, 1970) further convinced Pew of the appropriateness of a schema-based model for motor learning:

> *"I believe it* (Posner and Keele's 1970 study) *captures the essence of the kind of schema that must be stored for the production of motor patterns."*
>
> (Pew, 1974. p. 51)

He was, however, aware of the problem of defining such a schema:

> *"Of course, identification of a motor schema as a critical aspect of acquiring motor skill raises more questions than it answers. What properties of a movement sequence are encoded? What properties are intrinsic to a particular schema, and what properties are only dimensional parameters that are free to vary from one execution to another?"*
>
> (Pew, 1974. p. 51)

When Schmidt (1975) followed Pew's (1974) lead and presented a schema model for motor behaviour, the level at which the schema was hypothesised to operate was limited to the parameter settings of a generalised motor programme that could be run off rather analogously to that of a computer programme. The word *schema* was thus now restricted in use, and no longer referred to the overall organisation of memory responsible for governing the whole of the human action system. Schmidt's choice of the word *schema* could only add confusion to what had already become a poorly defined concept already susceptible to idiosyncratic use and inconsistency:

> *"That Schmidt should have chosen a term which 50 years earlier had been referred to as: –*
>
> > 'Already widely used in controversial psychological writing to refer generally to any rather vaguely outlined theory.' (Bartlett, 1932. p. 201)
>
> *– without apparently taking cognisance of the points which Bartlett made, is unfortunate."*
>
> (Fazey, 1986. p. 38)

Whilst Schmidt's (1975) model thus emerged from something of a resurgence of interest in the notion of schema and in learning theory *per se*, and followed in the general wake of the cognitive revolution that psychology was currently experiencing, there was another major source of influence that gave considerable impetus to its original conception:– the publication four years earlier of Adams' (1971) *Closed Loop Theory of Motor Learning*. In fact it was partly as a response to the limitations of this earlier theory that Schmidt was prompted to present an alternative, that would have application to a wider range of human actions than for which Adams' theory could adequately account.

Although Adams' (1971) theory was not a *schema theory* as such, as a significant forerunner of contemporary research in the area of motor learning it merits particular attention.

Adams' Closed-Loop Theory

Adams' (1971) Closed-Loop Theory in some ways marked a turning point in the field of motor learning. Prior to its publication, a theoretical framework specific to motor skill learning had been conspicuously lacking, with the majority of research being conducted within other, albeit related, branches of psychology. There were some notable exceptions (e.g., Smith's (1966) cybernetic approach to motor learning; and Welford's (1952) proposal of a single channel through which information passes serially, and his work on the role of feedback in the control of a single motor act (Welford, 1968)), but it was not until 1971 that a theory of motor control was presented that could not only account for a portion of earlier research findings, but was, more importantly, testable. Following its publication, the theoretical implications for KR (knowledge of results) were examined (e.g., Adams, Geotz and Marshall, 1972), the role of an error detection mechanism was discussed (Schmidt and White, 1972) and a number of studies investigating the effects of practice on the mechanism assigned by Adams to guide skilled performance – the *perceptual trace* – were conducted (e.g., Williams and Rodney, 1978). The theory thus generated a substantial volume of research taking the field of motor learning into its age of maturity.

The theory postulated two states of memory: a *perceptual trace* and a *memory trace.*

The perceptual trace acted as a reference of correctness against which information feedback could be compared in order to evaluate performance. Necessary error adjustment could be made thus giving the theory its *closed-loop* characteristic. It was hypothesised that this perceptual trace, acquired through practice, was strengthened with each repetition of movement to the point where feedback eventually became redundant, and could be withdrawn without any notably adverse effect on performance. The function of the perceptual trace was, thus, to monitor accuracy.

The function of the second state of memory, the *memory trace,* was to select and initiate movement. Adams (1971) reasoned that movement initiation could not logically be the responsibility of the perceptual trace since, if the same mechanism had both functions (that is, to select the movement and guide it), then the selected movement, from a subjective point of view, would always be correct. The perceptual trace was thus hypothesised to come into play once the movement had actually begun.

Adams' (1971) theory had important implications for the role of KR in the learning process:

Because the perceptual trace becomes more firmly established with each successive trial, the theory predicted that degrading or restricting sensory feedback would retard the development of the perceptual trace, particularly in its early stages of development, and thus inhibit learning. In other words, making errors would not facilitate learning, rather, they would be actually detrimental to the learning process;

Some earlier researchers (e.g., Trowbridge and Carson, 1932) had compared KR with the concept of *reinforcement* (In classical experimental psychological learning studies with animals, food is offered as a reward to *reinforce* a particular behaviour pattern). Adams (1971) rejected this notion and assigned KR the sole role of providing the necessary information to successfully complete a motor task.

Criticisms Of Adams' Closed-Loop Theory

The theory has received criticism (see, for example, Dickinson, 1985) for its failure to accommodate some earlier findings from motor behaviour research that were not considered relevant to a closed-loop model: the effects of distributed practice on performance and learning had already proved quite robust within an S-R theoretical framework (e.g., Archer, 1958); and a number of transfer effects had been established prior to Adams' publication in 1971 (see Holding, 1965). More fundamental, however, were the limitations inherent within the theory that were identified either by Adams himself (1971) or as a direct result of subsequent research.

Perhaps the most obvious limitation was that the theory was restricted to the kind of slow linear-positioning arm movements that typified experimental research tasks of the day. Its inability to account for rapid ballistic tasks was a consequence of the minimum time required to process feedback information. (The time required to process feedback has traditionally been estimated to be within the area of about 200 msec., although more recent studies involving visual information have suggested a much faster processing capability may in fact exist (e.g., Nashner and Berthoz, 1978; Smith and Bowen, 1980; see also Carlton, 1979)).

A second problem for the theory was how to account for the increasing number of studies that supported the contention that movements could be learned and performed in the total absence of sensory feedback information (see Taub and Berman, 1968). The classic example is Lashley's (1917) patient with gunshot wounds to the spine who, without any sensory feedback from his lower leg, was able to produce desired movements and even judge the position of the limb in space with a remarkable degree of accuracy. More recently, Laszlo (e.g., Laszlo and Manning, 1970) has attempted to simulate these effects by the application of a blood-pressure cuff to temporarily induce a loss of afferent feedback. Her results concurred with the earlier findings of Taub and Berman (1968), but Pew (1974), as an experimental subject of Laszlo, warns that:

"Laszlo's evidence should be taken as supportive rather than definitive in light of the uncertainties of interpretation of exactly what musculature and receptors are affected and to what degree."

(Pew, 1974. p. 54)

In any event, if Adams' theory was correct, and the mechanism for guiding movement relied on feedback information to generate a perceptual trace, then the subjects involved in these studies would have been unable to produce the actions of which they proved capable.

A further problem with Adams' (1971) theory involved the inseparable problems of novel task production and motor programme storage. To postulate the existence of some kind of motor programme (open-loop theories) or a reference of correctness against which feedback is compared (closed-loop theories) for *each movement* poses the problem of where that programme or reference of correctness originates if the movement has never been previously performed. Furthermore, if each movement requires such a programme or reference of correctness (perceptual trace), this presupposes an almost infinite storage capacity in memory. Whilst there seems to be no neurological evidence to the contrary, such an inconsistency with current thought on memory makes an alternative approach more appealing.

Finally, Schmidt (1975) has pointed out a number of logical inconsistences inherent in the theory. Adams (1971) assigns the perceptual trace the function of placing a limb at a correct location and also of providing information about the size of any error (i.e., how far the movement was from the target) after completion of the movement. Schmidt argues that if the former function is indeed correct, then no additional information can be available for detecting errors. He presents empirical evidence to support his reasoning that no error-detection mechanism exists after the completion of a slow positioning task, contrary to the predictions of the theory (Schmidt and Russell, 1974), although this does not hold for fast, ballistic-type movements in which a perceptual trace is presumably incapable of functioning (Schmidt and White, 1972).

Adams' (1971) Closed-Loop Theory of Motor Learning whilst unable to provide many answers to the question of how the process of motor skill acquisition occurs, was invaluable for accelerating research in the area, and providing the impetus for an alternative explanation which came four years later in the form of Schmidt's (1975) Schema Theory of Discreet Motor Skill Learning. It is to this view of the schema that attention is now turned.

Schmidt's Schema Theory

Schmidt (1975) proposes that when a movement is performed that is orientated towards some goal, four aspects of the movement are stored in memory:

The initial conditions

(Both internal and external) including, for example, the shape and weight of an object being propelled, or the state and location of the body in space, etc.;

The response specifications

The configuration of parameter settings that were utilised in the motor programme that has just been activated – including such factors as speed and force;

The sensory consequences of the produced response

What the movement *felt* like according to the sensory feedback information; and

The outcome of the movement

Was the response appropriate? Did the ball successfully reach the target? How far was the object propelled?

As a number of movements are performed, the subject is hypothesised to abstract information about the relationship amongst these four factors, in the development and formation of a motor schema. The specific instances of a movement may thus be forgotten, but the general rule is retained, enabling the movement, or a variation of it, to be repeated. Kerr (1978) provides an apt example of the schema idea as it relates to a baseball overhand throw:

> *"There is a relationship among a particular distance to be thrown and the required muscular force, arm speed and angle of release to reach that goal. The more 'particular' instances generated by the performer, the more abstract the schema becomes. Once established, the motor schema enables the individual to select the appropriate level of each dimension for a throw of a novel distance quite accurately. Thus an outfielder can throw accurately to second base from new or novel positions on the field ..."*
>
> (Kerr, 1978, p. 16)

The Variability Of Practice Hypothesis

Thus, one of the important predictions to emerge from Schema Theory (and directly implicit in Kerr's (1978) example above) is that increased variation in practice will facilitate schema development and manifest itself in an increase in transfer. Immediately following Schmidt's (1975) publication, a substantial volume of research focussed on this prediction as a test of the schema notion, and was centred around what Moxley (1979) later termed *The Variability of Practice Hypothesis* (e.g., Hogan, 1977; Moxley, Fazey, Hawkins, and McCabe, 1977; Moxley, 1979; Newell and Shapiro, 1976; Zelaznik, 1977). This is a distinct contrast to Closed-Loop Theory which predicts no such advantage for a *variable* practice group over a *constant* practice group since a transfer movement or novel movement will have had no opportunity to develop the appropriate perceptual trace, irrespective of the practice condition, having never been previously performed.

Regarding the theory itself, Schmidt postulates the existence of three fundamental elements:

- The generalised motor programme;
- The recall schema; and
- The recognition schema.

These two states of memory and the notion of a programme of commands that can be run off to produce a desired action, thus lie at the core of the theory.

The Generalised Motor Programme

The generalised motor programme is an hypothesised, abstract memory structure responsible for producing a desired movement once it has been activated.

The notion of a motor programme is particularly appealing in the light of the evidence depicting the production of movement responses in the absence of feedback (refer to page 69), a phenomenon for which Closed-Loop Theory has no readily available explanation.

Although the concept of a motor programme as the central tenet of a schema-based theory of motor behaviour emerged from Pew's (1974) technical report entitled *Human Perceptual-Motor Performance*, to be developed one year later in Schmidt's (1975) Schema Theory publication, the seeds of this notion had, in fact, already taken root, with supporting evidence coming indirectly from Armstrong (1970). He had observed that similar movements had variant and invariant features. Using a spatial temporal sequence of four movements of the forearm, Armstrong found that subjects who inadvertently moved too quickly or too slowly on the initial part of the movement sequence, maintained that relative timing across the entire movement. In other words, while the overall timing either increased or decreased, the relative timing across the individual component parts (*phasing*) appeared to remain constant. This observation was subsequently interpreted by Pew (1974) and Schmidt (1975) to imply that this phasing was an *invariant feature* of a generalised motor programme.

Another factor which, it was speculated, might belong in this category of invariant features included *relative force*. Shapiro and Schmidt (1982) offer the example of an overarm throw in which force would be an easily identifiable common factor within any number of such movements all fitting the same description. The idea of invariant features thus enables a *class* of movements to be recognised, and offers a possible explanation that accounts for the ability to produce similar actions, even involving quite different muscle groups, that retain a common pattern. The classic example (put forward by, amongst others, Pew, 1974) is the ability to write one's signature with a pen on a piece of paper, and then reproduce a similar output on a large scale using chalk on a blackboard. Whilst the difference in size requires the use of quite different groups of muscles, the signature retains its unique characteristics making it immediately identifiable as that of the writer.

A movement class can thus be thought of as:

> " ... *a group of responses that posses the same pattern.*"
>
> (Shapiro and Schmidt, 1982. p. 133)

In terms of the structure of the motor programme then, its invariant properties define its essential characteristics, whilst the potential for a whole variety of different movement parameters (such as speed and force) provides it with a variant quality which gives rise to a considerable range of possible movement outcomes. Pew (1974) gives an example of a golf swing which, he suggests, may be represented in memory as an *instance*:

> *"The instance may be thought of as a stored representation of a path in space through which the members of the body will move. The schema instance exists in complete form at a single point in time.* ***It is like a computer programme waiting to be read.***" (My emphasis)
>
> (Pew, 1974. p. 57)

Schmidt (1975) suggests that this programme might be executed in a number of ways with the selection of different parameter settings (*response specifications*) dependant on the intended action. Thus not every different movement would require a separate motor programme; rather the same programme would be responsible for a particular class of movement. Such a proposition immediately raises questions concerning the possible delineations of a movement class, and what features of the programme might be adjustable before the response requirements demand the activation of a new and separate programme.

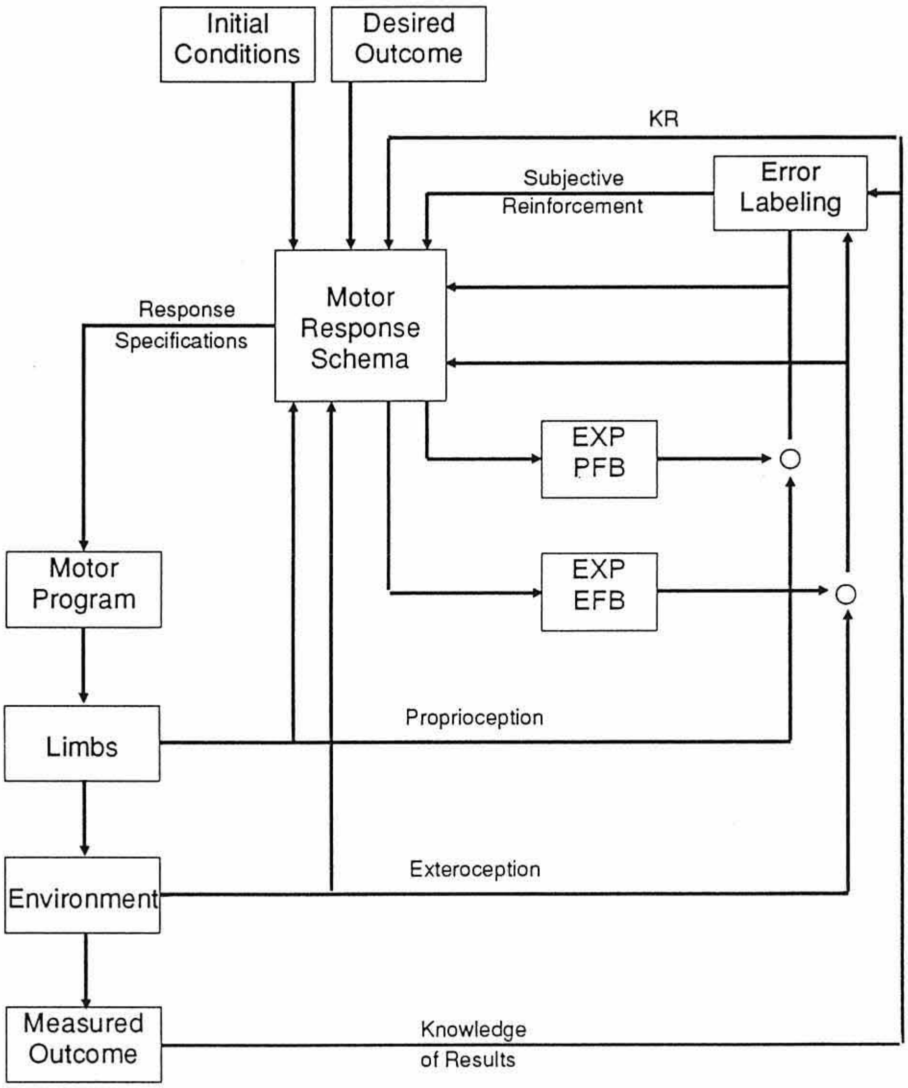
Looked at another way, the question is concerned with the possible *boundaries* of a schema class and, accepting that such boundaries exist, the factors that might determine the extremities of that class. In fact, viewed in this light, there would seem to be no real distinction to be made between the schema itself (as conceptualised by Schmidt (1975)) and the actual motor programme. Shapiro and Schmidt (1982) point out that contrary to what is often assumed, the schema (as presented in Schmidt's (1975) theory) does **not** have the function of selecting the appropriate generalised motor programme:

> *"The theory does not concern itself with the selection of a kicking or a throwing programme, but instead focuses on the processes that occur after the generalised motor programme has been selected (namely, parameter selection) to effectively execute the programme."*
>
> (Shapiro and Schmidt, 1982. p. 115)

The following diagram (Figure 4.1), taken from Schmidt (1975), shows the elements that are, according to the theory, essential in performing a movement. Although the *Motor Response Schema* and the *Motor Programme* are labelled separately, looking for a means of classifying movements into appropriate classes that are under the control of a particular motor programme, and searching for the limits of a schema boundary (i.e., the point where a new schema emerges in preference to the adaptation of an already existing schema) would seem to be fundamentally one and the same thing. That is to say, trying to determine the size of a Response Class and estimating where one schema finishes and another takes over, are simply different perspectives on exactly the same issue. (This question of scheme boundaries is addressed in greater detail later in this chapter.)

Other evidence supporting the notion of the motor programme has come from Summers (1977) who trained subjects to respond

Flow Diagram of the Elements Essential in the Performance of a Movement – from Schmidt's Schema Theory of Discrete Motor Skill Learning (1975)



EXP PFB:– Expected Proprioception Feedback
EXP EFB:– Expected Exteroceptive feedback
KR:– Knowledge of Results

Figure 4.1 : From Schmidt (1975)

to a particular configuration of lights by pressing keys. When subjects attempted to perform the task from memory as rapidly as possible, their performance was heavily influenced by the overall temporal structure that had been present during practice, suggesting that this *phasing* was an integral part of the motor programme.

Shapiro *et al.* (1981) conducted a study involving walking and running on a treadmill, to ascertain whether the two activities were governed by the same motor programme. Kinematic data indicated that an increase in treadmill speed induced no changes in the relative timing of the *Philippson* (1905) *step cycle* during either action, but did result in a new pattern on the point of changeover from walking to running. The interpretation of these findings was that the two activities are under control of different generalised motor programmes.

Whilst experimental evidence related to the concept of motor programmes seems quite supportive, and from a theoretical perspective, the idea is obviously appealing as an alternative to the limitations of Closed-Loop Theory, the structure of the programme, if it exists at all in the form hypothesised, has yet to be determined. Moreover, subsequent research has raised more questions than it has answered in this respect, to the point where Schmidt himself has had to conclude that:

> *" ... the underlying motor-programme representations may not be as the theory has assumed."*
>
> (Shapiro and Schmidt, 1982. p. 144)

The Recall Schema

The recall schema, one of two states of memory proposed by Schmidt (1975), is primarily concerned with the selection of the motor programme parameters (and **not** the selection of the motor programme itself) that are required in the production of an appropriate response to achieve a desired outcome. Each generalised motor programme has a recall schema associated with it, the formation of which occurs through prior attempts to execute the programme. In the development of the schema (or *rule*), three types of information are deemed important:

- The initial conditions;
- The response specifications / parameter settings; and
- Information pertaining to the movement outcome.

(See page 71)

The individual begins to abstract information about the relationship between these three sources of information over the course of several executions of the movement. Each time a response is made, the parameter settings (response specifications) are adjusted according to the initial conditions as perceived via incoming sensory information to the individual. Once the movement has been generated, the response outcome is noted, and further adjustments can be incorporated into subsequent movement responses. This generalised rule (or *schema*) is stored in memory ready to be accessed when any desired movement pattern is attempted to which that schema applies. The idea of schema learning can thus be thought of as:

> *" ... rule learning, and the strength of the relationship is hypothesised to be a positive function of the number of KR trials and the variability of practice."*
>
> (Shapiro and Schmidt, 1982. p. 116)

In other words, the greater the number of movements experienced by the subject, the more firmly established the rule will become, resulting in an enhanced degree of accuracy regarding response specification selection, and consequently increased chances of success in novel movement response production.

The Recognition Schema

The second independent state of memory hypothesised by Schema Theory is the recognition schema which has the responsibility of evaluating the completed movement response. Its formulation occurs in a manner analogous to that of the recall schema, and three sources of information are considered important in its development:

- The initial conditions;
- Past actual outcomes; and
- Past sensory consequences.

Once again this rule (schema) is strengthened as a result of increasing the amount of variability, and the number of trials in which KR is available to the performer. In the case of a novel movement being attempted, a well-developed recall schema allows a more accurate prediction of the expected sensory consequences of the novel response. In the case of rapid movements (during which feedback information has no time to be processed (e.g., Keele, 1968)), this evaluation occurs once the response is completed. For slower positioning tasks, this recognition process may take place at different times during the response.

The diagram on the following page (Figure 4.2) shows the relationship between these two states of memory – recall schema and recognition schema – and the various sources of information important in their development (from Schmidt, 1975).

Recall Schema and Recognition Schema related to the various sources of information – from Schmidt's Theory of Discrete Motor Skill Learning (1975)

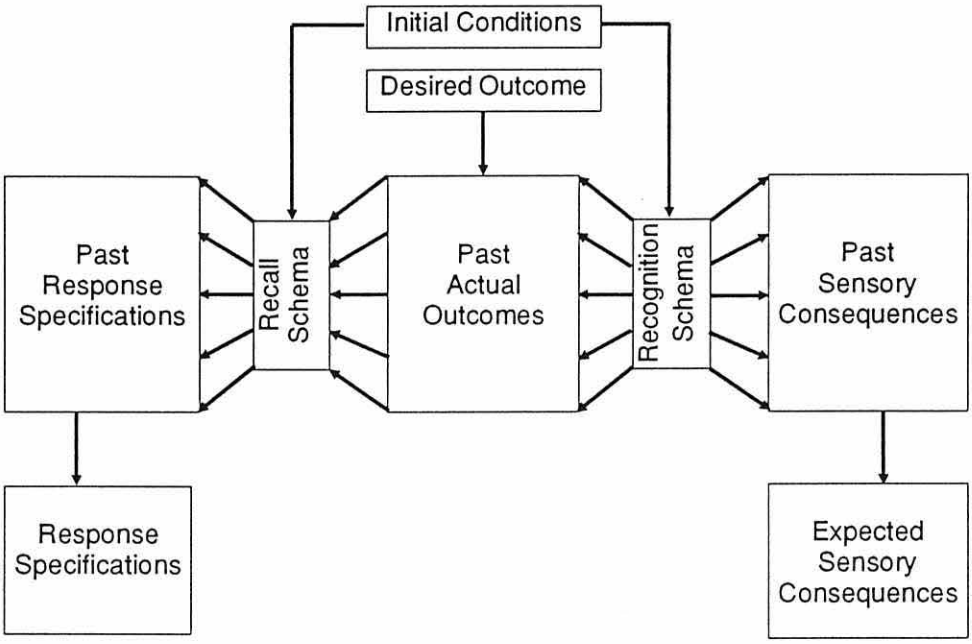


Figure 4.2 : From Schmidt 1975

Schmidt's Schema Theory – A Reasonable Proposition?

In general terms, the theory is appealing in that it offers a possible explanation regarding the earlier problem of novel task production whilst simultaneously solving the question of motor programme storage. Moreover, its application extends to rapid, ballistic-type movements the control of which is not immediate influenced by feedback information.

An additional strength of the theory lies in the fact that its theoretical implications leave themselves open to empirical investigation, and supporting evidence, although not unequivocal, soon began to lend credence to its suppositions. The theory is not, however, without its problems.

Much of the initial research on Schema Theory centred around the prediction related to variability in practice. It soon became apparent that support for Schmidt's (1975) view of the schema seemed to be largely dependent on the ways in which variability was manipulated (See Shapiro and Schmidt, 1982; and Lee, Magill and Weeks, 1985 for comprehensive reviews). (This issue of variability manipulation is addressed in greater detail in Chapter Five.)

Other studies attempted to focus on the development of the recall schema or the recognition schema as separate, independent states of memory. Whilst recall schema development has been relatively straightforward to operationalise experimentally by manipulating variability in terms of, for example, the ***weight*** of an object to be propelled (e.g., Carson and Wiegand, 1979; Pigott, 1979); the ***distance*** of the target to be reached – whether by moving the target itself (e.g., Drummer, 1978; Hunter, 1977; Kelso and Norman, 1978; Kerr, 1978; Kerr and Booth, 1977), or by moving the subjects in ***relation to the target*** (e.g., Beatty, 1977; Moxley, 1979; Moxley and Fazey, 1977a); or the ***time*** to move a fixed distance (e.g., Newell and Shapiro, 1976, Experiment 1), recognition schema examination has proved to be more of a problem.

Some investigators (e.g., Hogan, 1977; Newell and Shapiro, 1976; McCracken and Stelmack, 1977) asked subjects to make verbal estimates of their errors following a trial, where the accuracy of the estimation was argued to be a reflection of recognition-schema strength, but this begs the question of the need for a translatory mechanism to act between *knowing* about a movement and/or its outcome, and being able to say something about it.

Another technique has been to provide subjects with indirect 'KR' in the form of auditory information (a tape recording) about the required movement that has been produced by a third party. The theoretical reasoning is that since the subjects aren't actively producing any response themselves, any subsequent reduction in errors can be attributed to an increase in recognition-schema strength (e.g., Zelaznick, Shapiro, and Newell, 1978).

These, and additional studies, were well documented by Shapiro and Schmidt (1982). The inconsistences in their findings, however, brings into contention the assumption that these two states of memory can be hypothesised to be operating independently. As Fazey (1986) points out:

> *"The two memory states may well remain logically separable but to date there is no convincing evidence that either can function or develop independently of the other."*
>
> (Fazey, 1986. p. 43)

Another problem for Schema Theory arises from a body of evidence suggesting that the initial conditions, as an essential source of information for both recall and recognition schema, is not always a prerequisite for the correct selection of movement parameters to produce the appropriate response (e.g., Bizzi, Dev, Morasso, and Polit, 1978; Bizzi, Polit, and Morasso, 1976; Polit and Bizzi, 1978, 1979; Kelso, 1977: – See Shapiro and Schmidt, 1982 for a review). In the light of such evidence, at the very least, significant modifications to the schema model would seem to be in order.

Other weaknesses of the theory include its failure to account for the origins or the structure of the hypothesised motor programmes which, it assumes, are readily available for selection when required. Moreover, on other factors which undoubtedly exert an influence on the learning process, such as mental rehearsal, motivation and observational learning, Schema Theory is notably silent. Evidence suggesting that mental rehearsal can be as effective as physical practice (e.g., Rawlings, Rawlings, Chen, and Yilk, 1972) or even superior (Corbin, 1972), or that motivation, at least within the context of incidental motor learning research, has a significant bearing on the acquisition of motor skill (Dickinson, 1977, 1978; Crocker and Dickinson, 1984), is not easily accommodated within Schmidt's (1975) model. In terms of observational or imitative learning (i.e., the ability, having been shown a skill, to *learn* it in so far as an appropriate response can be produced), although evidence is limited (e.g., Carroll and Bandura, 1982), Dickinson's (1985) intuition would probably find favour with those interested in such issues:

> " ... *the experience of learning motor skills and of teaching suggests that in fact this* (observational learning) *is one of the most common means by which motor learning occurs.*"
>
> (Dickinson, 1985. p. 221)

Such reflections, along with what little empirical evidence does exist, however, are not obviously accounted for or explained by Schmidt's (1975) Schema Theory.

Of course, it might well be that:

> " ... *the fundamental framework of schema theory may have to be abandoned for some different set of assumptions about human performance and learning.*
>
> (Shapiro and Schmidt, 1982. p. 144)

In any event, the theory must be considered of value if only by virtue of the quantity of important research it has generated through the provision of a functional model, receptive to empirical scrutiny and investigation. In assessing its worth, its strongest asset, in terms of support, is undoubtedly the prediction regarding variability in practice. Even this, however, may not be sufficient:

"It can be argued that any conceptual view of memory as something to do with 'generalised abstractions about relationships' will accommodate much of the empirical data which has been collected in tests of the prediction that positive transfer occurs as a function of the variability of practice."

(Fazey, 1986. p. 44)

Fazey goes on to imply that a return to a more general (*global*) view of the schema, as that originally proposed by Bartlett (1932) may be a more fruitful path for future theorising:

"This seems especially true if such a view is not tied to the idea that the schema is the rule which determines only the parameter settings of a single generalised motor programme serving distinct and tightly bounded response classes."

(Fazey, 1986. p. 44)

Schema – Have We Reached A Verdict?

Almost sixty years on from Bartlett's (1932) condemnation of the term *schema* as both:

" ... too definitive and too sketchy"

(Bartlett, 1932. p. 200)

are we any closer to an accurate description or definition? Perhaps the question itself is inappropriate. Schemas are not *objects* that the cognitive pathologist can scrutinize in some neurological postmortem. Nor are they *things* stored in some recess of memory, collecting dust until they are summoned to assist in the production of a particular movement response.

From the earliest references to *schema* (e.g., Kant, 1787/1963) the concept has been at best, something of an enigma, at worst, an obscurity enveloped in mystery. With the welter of information about schema now in existence, how might this knot of confusion be untangled?

Perhaps an appropriate starting point is to decide what characteristics should be identifiable within a schema.

Rumelhart, Smolensky, McClelland and Hinton (1986) suggest that of the schemas presented in the literature to date, none so far posses all the properties that are necessary for a complete description of cognitive processing; a high degree of flexibility, with generative capability, yet at the same time be able to operate within highly structured situational contexts. They pose the question:

> *"How can we get a highly structured schema which is sufficiently rich to capture the regularities of a situation and to support the kinds of inferences that schemata are supposed to support and at the same time is sufficiently pliable to adapt to new situations and new configurations of events?"*
>
> (Rumelhart, Smolensky, McClelland and Hinton, 1986. p. 20)

The answer, they suggest, lies in the fact that:

> *"Schemata are not explicit entities, but rather are implicit in our knowledge and are created by the very environment that they are trying to interpret – as it is interpreting them."*
>
> (Rumelhart, Smolensky, McClelland and Hinton, 1986. p. 20)

This is, of course, very much in keeping with the views expressed by Bolton (1977) in his criticisms of the early theory of abstraction (page 49).

The interpretation of the schema that Rumelhart and his associates at the PDP Research Group offer has much in common with some of the more conventional notions of the schema, although their interpretation, they argue:

> " ... *captures almost all of the important aspects of the schema with a view that is at once more flexible than the previous interpretations and yet highly structured.*"
>
> (Rumelhart, Smolensky, McClelland and Hinton, 1986. p. 21)

Whilst it is beyond the scope of this current work to discuss the relationship between their view of the schema and the sequential thought processes in *Parallel Distributed Processing* models, it is worth including the briefest outline of their approach as both an indication of future trends in schema conceptualization within psychology, and as an alternative interpretation more akin to the view of a flexible schema that is advocated throughout this thesis.

The idea is basically this: Incoming information is hypothesised to activate a set of interconnected units which together constitute a state, described as:

> " ... *a sort of constraint satisfaction network ...*
>
> *The inputs determine the starting state of the system and the exact shape of the goodness-of-fit landscape. The system then moves towards one of the goodness maxima. When the system reaches one of theses relatively stable states, there is little tendency for the system to migrate towards another state.*"
>
> (Rumelhart, Smolensky, McClelland and Hinton, 1986. p. 20)

In the more conventional language of schema theory:

"It is these coalitions of tightly interconnected units that correspond most closely to what have been called schemata. (And)

... the maxima in the goodness-of-fit space corresponds to interpretations of the inputs or, in the language of schemata, configurations of instantiated schemata."

(Rumelhart, Smolensky, McClelland and Hinton, 1986. p. 20)

Whilst there is, thus, some overlap in the notion of schema, there is an important migration from the more traditional descriptions presented by schema theorists:

"One important difference between our interpretation of schemata and the more conventional ones is that in the conventional story, schemata are stored in memory. Indeed, they are the major ***content of memory****. In our case,* ***nothing stored corresponds very closely to*** *a schema. What is stored is a set of connection strengths which, when activated, have implicitly in them the ability to generate states that correspond to instantiated schema. This difference is important – especially with regard to learning. There is no point at which it must be decided to create this or that schema. Learning simply proceeds by connection strength adjustment, according to some simple scheme ... As the network is reorganised as a function of the structure of its inputs, it may come to respond in a more or less schema-like way."*

(Rumelhart, Smolensky, McClelland and Hinton, 1986. p. 21)

The conclusion thus reached is that although there are some commonalities with conventional notions of schema this current interpretation has the advantage that:

" ... the schema becomes much more fluid and flexible and able to accommodate itself to inputs."

(Rumelhart, Smolensky, McClelland and Hinton, 1986. p. 56)

Whilst no attempt has been made to examine any of the theoretical propositions of Parallel Distributed Processing and reference to a view of schema within this context may appear as something of a digression, its inclusion serves to illustrate the move away from more specific or microscopic descriptions about possible schema operations, to a more general and open use of the term to help explain the various cognitive processes that ultimately control our actions. The concluding remarks from Rumelhart, Smolensky, McClelland and Hinton (1986) are highly relevant in that they focus on what must surely be the crux of the issue:

> *"We see the relationship between our models and schema theory as discussed by other researchers as largely a matter of levels of analysis."*
>
> (Rumelhart, Smolensky, McClelland and Hinton, 1986. p. 56)

An issue which must be resolved before progressing further.

Differing Levels Of Analysis

It is apparent from the literature that much of the confusion about the schema stems from two, quite distinct ways in which the term is employed: either as an organisation of memory operating at a *macro* level, responsible for *classes* of movements and actions (cf. Piaget); or operating at a *micro* level, with responsibility for the configuration of the parameter settings of the motor programmes which issue commands to the musculature (cf. Schmidt). Fazey (1986) is probably correct when he says that:

> *"Most would agree with Shendon (1984) and McLoed (1983) that it seems necessary for the schema to provide more than just information about the microstructure if a schema theory is to help explain skill."*
>
> (Fazey, 1986. p. 47)

This is not to suggest that Schmidt's (1975) theory should be dismissed, rather it seems more profitable to try and establish the methods by which the individual comes to successfully integrate the schemas available to him, within a framework of changing cognitive strategies and differing dimensions of control. Fazey (1986) presents a convincing argument for regarding Schmidt's (1975) view of the schema, in which the motor programme takes the predominant role in the production of motor responses, as something of a special case. Such a move, he argues, accommodates the existing body of evidence depicting a high degree of invariability in movement production (e.g., Shapiro, 1977; Viviani and Terzulo, 1980; Shapiro, Zernicke, Gregor and Diestel, 1981; Denier van der Gon and Thuring, 1965; Vredenbregt and Koster, 1971) without automatically excluding alternative propositions for which empirical support is available. The impulse-timing view of motor programming on which Schmidt's Schema Theory so heavily relies has, for example, been brought into serious contention by, amongst others, the work of Bizzi *et al* (see page 83). Retaining the motor programme as the central feature of a schema theory makes it exceedingly difficult to accommodate such potentially damaging findings, which lend themselves readily to the notion of some kind of mass-spring model of control (Crossman and Goodeve, 1963; Astryan and Fel'dman, 1965; Fel'dman, 1966a,b).

Fazey (1986) presents a revised version of the schema model for motor control which attempts to reconcile much of the apparently contradictory evidence from the literature, and which is better able to account for the myriad ways in which the human control system can be observed to operate. The fact that it presupposes a high degree of dynamism and flexibility within the system is seen as one of its major strengths over previous theoretical proposals. Whilst Fazey (1986) himself admits that the model may not represent the full picture, it would seem to be a stride in the right direction. A full evaluation of its potential for explaining the cognitive process governing action will have to be postponed until some later date following its publication!

A Revised Model Of Motor Control

The model presented by Fazey (1986) is seen as an extension of the ideas of Pew (1974) and Schmidt (1975), with noticeable influences from much of the earlier theorising about schema in general, and with a return to a less restricted use of the term, more analogous to Bartlett's (1932) *organised settings*. In some ways, an outline of the model is rather premature in that much of the background theorising that prompted its development originated from issues, as yet, only superficially broached: the question of *schema boundaries* and the implications of variability within the practice structure on the learning process. (Both these topics are addressed in greater detail in the following chapter.) Briefly, however, the model was designed out of a growing dissatisfaction with existing models of control. In particular:

i) The inappropriateness of restricting the idea of schema to one particular process or group of processes –

Fazey (1986) argues that the work of Jagacinsky *et al* (1977) and Frohlick and Elliot (1984) on recall and recognition schema development as influenced by variability in practice, is supportive evidence for a much wider perspective of the schema idea. Additional support is provided from much of the Variability of Practice data following the presentation of Moxley and Fazey (1977) at the annual NASPSA conference, two years after Schmidt's (1975) original publication.

ii) The problem of defining a *class* of movements and consequently the difficulty in predicting subsequent transfer effects following practice –

The concept of *similarity* is redefined with the result that:

> *" ... where movements are practiced as if they are similar then they will be governed by the same schema."*
>
> (Fazey, 1986. p. 113)

iii) The inadequacy of the current modelling of the error detection and correction function –

A schema-based system able to operate within different levels of control logically implies, it is argued, a separation of the mechanisms required for error detection and error correction. Whilst low-level, automated modes of control may *subconsciously* rely on sensory feedback information and a well-developed recognition schema to detect and correct errors without any cognitive intervention from the subject (e.g., Carlton, 1983; Wing, 1977), higher level modes of control utilising sensory, perceptual or KR feedback information, may involve quite different processing strategies invoking alternative control functions.

"At the lowest levels of response organisation, the logically independent functions of detection and labelling errors...may function as if they are permanently harnessed together.

...at higher levels in the system it may be the case that error detection and error labelling do not always function in concert. Given the individual's cognitive control over the processing strategies which are employed to initiate, guide and reorganise any movement or sequence of movements,...detected errors may not lead to the unification of a correction based upon a thorough evaluation of an error."

(Fazey, 1986. p. 100)

And, closely related;

iv) The inability to cope with the variability in response output that detailed analysis reveals underlies superficially similar actions –

The notion of a *Bandwidth of Tolerance* is incorporated enabling the error detection system to:

" ... identify errors that are meaningful and not merely respond to every mismatch.

(Thus)

... acquiring control will involve learning to ignore those differences which make no difference.

(Fazey, 1986. p. 87)

Fazey's (1986) Model of Motor Control

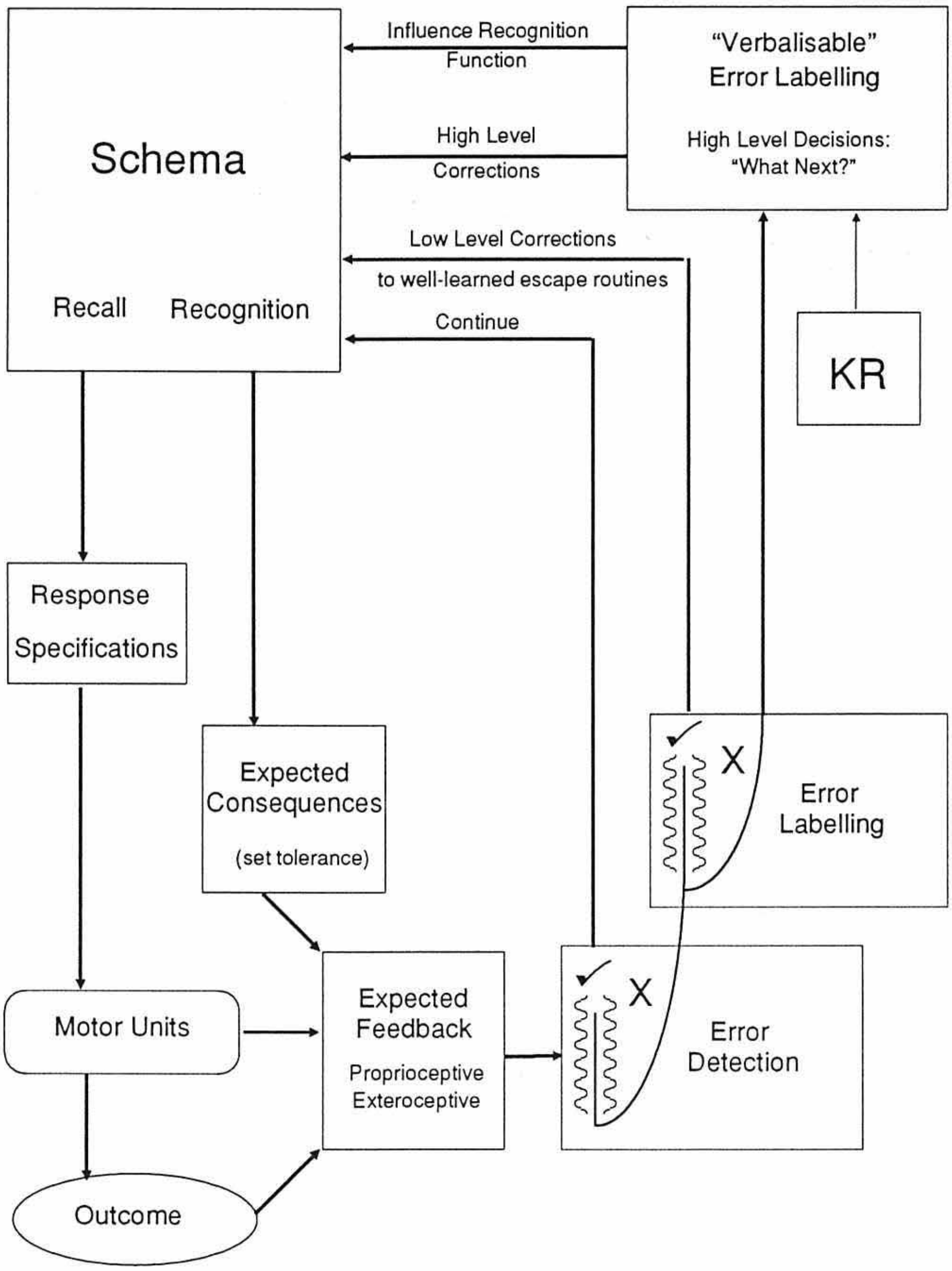


Figure 4.3 : From Fazey 1986

Whilst this is far from a complete description of the model, the diagram on the previous page (Figure 4.3) gives a summary of the proposed revisions that Fazey (1986) adopts.

Schema – More An *Idea* Than A *Theory*

A dynamic view of the schema is not in itself new; evidence of a recognition of the need for an expanded view over existing theories can be found scattered about the literature. Neisser (1976), for example, implies such a notion when he says that:

> *"The schema is not only the plan but also the executor of the plan. It is the pattern of actions as well as a pattern for action."*
>
> (Neisser, 1976. p. 56)

This view is indorsed by Newell and Barclay (1982) who, in a similar vein, suggest that:

> *" ... a schema is not only the product of the organism-environment interaction but also the cognitive 'set' or processing rule for understanding and acting in subsequent interactions. The exercise of a schema is the process through which future knowledge is acquired."*
>
> (Newell and Barclay, 1982. p. 186)

Fazey (1986), however, has taken the initiative and offered a functional model to facilitate an explanation of the control of voluntary movement. As the culmination of a number of developing ideas based on existing theoretical constructs, Fazey's (1986) model of control provides a basis for an alternative interpretation of empirical observations and, not surprisingly, accounts for much of the supportive data on which previous models have relied.

Whether this schema-based model can justifiably be awarded the status of a *theory* or simply be considered as a *frame-work* within which memory organisation is considered to be operating in a schema-like way, is probably not a crucial issue at this stage. What is clear is that the schema idea as a basis for understanding the workings of the human operating system, is proving to be very useful. Of course, there is no reason to suppose that such processes, in reality, conform very closely to any of the verbal descriptions which, with the limitations of our language, they are given (see page 3), and, as tempting as it may be to equate such functional models with actual neurological structures, such an assumption does not automatically follow. Nevertheless, if progress is to continue in our understanding of the processes underlying skill acquisition, this seems to be an appropriate path to tread.

In Summary

This chapter has presented an overview of the historical antecedents of the concept which generated more research in the field of motor control and learning in the late 70's and early 80's than any other single proposal – the motor schema. Schmidt's (1975) Schema Theory was examined in detail and variability of practice was identified as a well-documented source of influence on schema development. The view was reached that differing interpretations of the schema notion can be largely attributed to differing levels of analysis. Although it may be premature to award the schema-based model the status of ***theory****, it was argued that as a framework within which to examine the processes that contribute to learning, the concept proves very useful.*

The following chapter examines the question of schema boundaries and looks more closely at the implications of variability in practice for learning. The empirical findings from schema theory research are also considered in the light of **Contextual Interference** *and* **Depth of Processing** *studies from the verbal learning domain, and it is proposed that much of this data is readily open to reinterpretation. Other factors influencing schema development are discussed including developmental issues (the relevance of age as a delineating factor in learning), levels of learning (the highly skilled expert versus the beginner), and task complexity (as a potential influence on variability effects). The interaction between these factors becomes the focal point of the chapter and sets the scene for an empirical investigation examining the extent to which task complexity exerts an influence on the predictability of transfer effects.*

Chapter Five opens with an examination of the traditional view of memory in which a more dynamic and flexible view is presented and the prevailing theories of motor control can be examined.

CHAPTER FIVE

The Traditional View Of Memory

The traditional form of presentation of an information processing view of memory has been one of a linear multi-stage system that can be conveniently segregated into diagrammatic boxes typically labelled *Sensory Memory*, *Short-term Memory* and *Long-term Memory*.

The first of these boxes, the sensory store, is considered to have a large capacity (Sperling, 1960), but information is lost very rapidly (something in the order of less than five seconds) depending on the mode of the input – iconic (visual), echoic (auditory), or proprioceptive (Craik and Lockhart, 1972; Kinsch, 1977). Sensory memory is believed to require little or no effort on the part of the individual, and retrieval necessitates immediate output of the stored information (Neisser, 1967).

Short-term Memory, regarded by Broadbent (1958) as a kind of holding mechanism, is often referred to in the literature as *working* *memory*, since an effort on the part of the individual is required if information is to be retained. A loss of information, whether resulting from interference (Waugh and Norman, 1965) or decay (Broadbent, 1958; Peterson and Peterson, 1959) is only prevented by continuous attention and subsequent rehearsal (Anderson, 1980). The capacity of short-term memory is considered to be quite restricted (Miller, 1956; Broadbent, 1958) with the duration of a memory trace believed to be limited to less than thirty seconds (Craik and Levy, 1976).

The final of the three boxes, the long-term memory store, differs from both the sensory store and the short-term store in that information is thought to be processed in some kind of semantic form (at least as far as verbal items are concerned); that is, processed for meaning (Baddeley, 1966). The capacity of this memory store is hypothesised to be virtually unlimited (Broadbent, 1958; Shiffrin and Atkinson, 1967). Once information has become established in long-term memory through repetition and rehearsal, it is thought to remain almost indefinitely (Shiffrin and Atkinson, 1967).

Whilst the exact form in which information is stored remains largely a matter of conjecture, it is generally accepted that information is encoded in some way and stored, not as specific instances or experiences, but in a generalised form that can be modified and updated (see Chapter Four, page 45). The ultimate reductionist resolution of these issues lies in the biochemistry and neurophysiological realm. Whilst such knowledge may well help in discounting some of the conjecture we have about how memory functions to guide behaviour, our functional models will remain important heuristic tools to investigating more observable phenomena.

Although there is not universal agreement regarding the actual details of this model of memory, the overall idea seems to have gained general acceptance, and evidence of this underlying view of memory organisation abounds throughout the literature. The model itself has not escaped criticism (Melton, 1963; Murdock, 1972), and the appropriateness of several of its features have been brought into contention (e.g., Tulving and Patterson, 1968; Shallice and Warrington, 1970). However, it is only in comparatively recently years (especially in the field of motor behaviour) that the effect of cognitive processing on learning has led researchers to view the subject more as an active participant in the learning process rather than simply a passive recipient of information, and thus employ learning paradigms not based solely on the underlying premiss of memory as a linear multi-stage system (e.g., Battig and Shea, 1978; Diewert and Stelmach, 1978; Ho and Shea, 1978, 1979).

A More Dynamic And Flexible View Of Memory

Jenkins (1974), in a paper aptly titled *Remember That Old Theory of Memory? Well, Forget It!* refers to a number of empirical investigations that he and his colleagues had performed over a number of years, that have led them to observe that:

> *" ... the subject's orientation towards comprehension changed the nature of what was remembered in such a way as to produce radical changes in recall and recognition."*
>
> (Jenkins, 1974. p. 417)

These studies, they concluded, implied that:

> *" ... we cannot deal with memory without dealing with instructions, perception, comprehension, inference, problem solving and all the other processes that contribute to the construction of events."*
>
> (Jenkins, 1974. p. 427)

It thus became clear to Jenkins and his colleagues that:

> *" ... we should shun any notion that memory consists of a specific system that operates with one set of rules on one kind of unit."*
>
> (Jenkins, 1974. p. 426)

In place of the traditional view of memory Jenkins suggests the more appropriate approach taken by the contextualists:

> *"This means not only that the analysis of memory must deal with contextual variables but also that what memory is depends on context."*
>
> (Jenkins, 1974. p. 415)

Two *theories* of learning to have emerged from the verbal domain to influence research in the motor sphere, that have clearly adopted such a position are, the *Levels of Processing* framework (Craik and Lockhart, 1972) and *Contextual Interference Theory* (Battig, 1966). It is to these two views of memory that attention is now turned.

Levels Of Processing

Craik and Lockhart's (1972) *Levels of Processing* framework for memory research was based on the notion of a series or hierarchy of processing stages involved with the encoding of stimulus events. Accepting that perception entails a rapid analysis of stimuli at several different levels or stages (Selfridge and Neisser, 1960; Treisman, 1964; Sutherland, 1968), Craik and Lockhart (1972) proposed that memory was a function of the *depth* of processing carried out on the incoming stimuli. A word, for example, might be processed in terms of its visual features (e.g., upper case or lower case), its phonemic characteristics, its semantic connotations, or perhaps its verbal associations. At the lowest levels of processing involving purely a physical or sensory analysis of the stimuli, processing is defined as shallow. At the other end of the spectrum where analysis entails a far greater degree of semantic and cognitive analysis, a deeper level of processing is considered to have occurred. The traditional dichotomous view of short and long-term memory stores is thus avoided, and although it might be perfectly feasible to classify the different levels of processing in terms of labelled boxes analogous to short and long-term memory stores, such an approach:

> *" ... both oversimplifies matters and evades the more significant issues."*
>
> (Craik and Lockhart, 1972. p. 675)

It is interesting to note that although the Levels of Processing framework was presented in the early nineteen-seventies as an alternative view from which to conduct memory research, the basic tenets of this approach seem to have been stated seventy years earlier at the very beginning of the century:

> *"Attention to the meaning of words does not imply equal attention to their spelling, nor attention to their spelling equal attention to their length, nor attention to certain letters in them equal attention to other letters."*
>
> (Thorndike and Woodworth, 1901. p. 249)

It is, thus, with Thorndike and Woodworth's (1901) observation clearly in mind, that Craik and Lockhart (1972) move on to propose that the degree of processing that a presented stimulus undergoes is determined by the context of its presentation and the previous experiences that the subject brings with him to the situation. Should this incoming stimulus take, for example, the form of a word, its recognition may trigger a whole variety of associations, visual images, or recollections, the origins of which might be traced to some former direct or indirect encounter with the word somewhere in the realms of previous experience. A stimulus may thus be subjected to further processing by:

> *" ... enrichment or elaboration."*
>
> (Craik and Lockhart, 1972. p. 675)

Craik and Lockhart further suggest that this *elaboration coding* (Tulving & Madigan, 1970) applies not only to verbal material but extends to the processing of any perceived stimuli be it visual, auditory, or whatever. As stimuli are presented:

> *"Analysis proceeds through a series of sensory stages to levels associated with matching or pattern recognition and finally to semantic-associative stages of stimulus enrichment."*
>
> (Craik and Lockhart, 1972. p. 675)

With regard to the memory trace, its strength is hypothesised to be proportional to the extent of processing that has ensued such that:

> *" ... trace persistence is a function of depth of analysis with deeper levels of analysis associated with more elaborate, longer lasting, and stronger traces."*
>
> (Craik and Lockhart, 1972. p. 675)

Memory is thus viewed as a function of the depth of processing in contrast to the more traditional notions related to storage capacity and rehearsal. The byproducts of this perceptual processing (the factors involved in the encoding process, such as contextual factors, environmental factors or individualistic strategies and operations) are, it is hypothesised, simultaneously encoded as part of the total encoding procedure, with the result that highly familiar, meaningful stimuli (that is, stimuli that are:

> *" ... compatible, by definition, with existing cognitive structures")*
>
> (Craik and Lockhart, 1972. p. 676))

are processed more rapidly and at greater depth, and thus much better retained.

Memory is thus envisaged as:

> *" ... a continuum from the transient products of sensory analyses to the highly durable products of semantic-associative operations."*
>
> (Craik and Lockhart, 1972. p. 676)

A second method by which stimuli may be retained is also proposed:

> *" ... by recirculating information at one level of processing."*
>
> (Craik and Lockhart, 1972. p. 676)

Craik and Lockhart (1972) adopt the term *Primary Memory* (PM) to refer to this operation of maintaining information at one level of processing, which, they argue, is analogous to such notions as:

- *"continued attention to certain aspects of the stimulus"*
- *"keeping the items in consciousness"*
- *"holding the items in the rehearsal buffer"* (or)
- *"retention of the items in primary memory."*

(Craik and Lockhart, 1972. p. 676)

In other words, the items are considered to be still in consciousness, and information will be lost only once attention is diverted from the item, and then at a rate relative to the level of processing that has occurred.

In summary then, the proposed framework for viewing memory suggests that:

> *" ... the memory trace is better described in terms of depth of processing or degree of stimulus elaboration. Deeper analysis leads to a more persistent trace. While information may be held in PM, such maintenance will not in itself improve subsequent retention; when attention is diverted, information is lost at a rate which depends essentially on the level of analysis."*
>
> (Craik and Lockhart, 1972. p. 677)

The Levels Of Processing Framework – Some Support & Criticisms

The majority of research examining the levels of processing view of memory has focused on the prediction that the sensory processing of stimuli will result in a greater tendency for forgetting than less shallow processing at an intermediate or phonemic level. Similarly, processing at this level will, in turn, produce less durable memory traces than for items subjected to processing at the deeper, semantic level.

Anderson (1974), for example, utilising an immediate versus delayed retention interval experimental paradigm, concluded that the physical characteristics of a presented stimulus were better recalled under the immediate retention condition, whereas subjects in the delayed retention condition had time to process stimuli at a semantic level of greater depth.

Craik and Tulving (1975) in a series of experiments attempted to induce different levels of processing through the use of carefully constructed questions. The presentation of a word would be accompanied by a question related to either its physical characteristics (e.g., Is it printed in upper or lower case?), its phonemic qualities (e.g., Does it rhyme with *boy*?), or the semantics of the word (e.g., Is it a type of animal?). The three levels of question were thus designed to influence the degree of processing allocated to each presented stimulus, and subjects were subsequently tested on a variety of retention tasks taking the form of free recall, cued recall or recognition.

Craik and Tulving (1975) concluded that greater depth of processing, as operationalised in their investigations, facilitated memory. They further concluded that even when more difficult tasks took longer to process at a shallow level, a more rapid, deeper level of processing still resulted in better recall, indicating that *depth* of processing, and not *time* to process, determined the degree of subsequent retention. Moreover, their research suggested that the degree of elaboration or the spread of encoding (that is, for example, analysing words in terms of several descriptive features) was an important determinant of memory trace durability.

Bellezza *et al* (1976, 1977), following on from Craik and Tulving's (1975) studies, provided additional support for this view, and Postman and Kruesi (1977) also arrived at the opinion that *depth* on its own was an insufficient description for explaining enhanced recall performance.

In contrast to the prediction of Craik and Lockhart's (1972) framework of memory, Nelson (1977) presented evidence suggesting that multiple repetitions enhanced recall performance for items processed at the phonemic level. These findings were further corroborated by Glenberg *et al* (1977) who found maintenance rehearsal to facilitate the recall of words. Rundus (1977), however, reported no such facilitatory effects for the maintenance of shallowly-processed items (even when the rehearsal time was extended), thus supporting Craik and Lockhart's contention that once a level is reached continued rehearsal will have no beneficial effect on subsequent recall.

Research into Craik and Lockhart's (1972) original propositions has thus resulted in some equivocality, and a number of modifications would seem to be warranted. Craik (1979, 1979a) himself more recently redefined levels of processing as:

> " ... *memory from the point of view of depth, elaborateness, extensiveness of the encoding induced at input*"
>
> (Craik, 1979. p. 77)

and he further conceded that a continuum of analysis (that is, from purely structural to semantic) is not an adequate description of the processing procedure (Craik, 1979). Rather, the possibility of some kind of random switching from one processing level to another would seem to be a more reasonable proposition (see Neisser, 1976). This would accommodate Nelson's (1979) proposal that extensive sensory encoding can indeed result in enhanced levels of retention, comparable with a minimal semantic (deep) analysis, implying that the degree of analysis at any one level is both a function of selected strategies and task demands.

Direct criticism of the levels of processing proposition has come from Eysenck (1978) with regard to the framework's failure to adequately account for the procedures involved in information retrieval. Whilst he admits that encoding is obviously a major element in the organisation of memory, a certain degree of congruity between encoding and retrieval would seem to be an essential requirement for memory to function effectively (e.g., Tulving, 1979).

Further criticisms of the depth of processing view have centred on the lack of an appropriate index of measurement for determining the depth or breadth of processing. Baddeley (1978) argues that since the processing of familiar items apparently occurs immediately at deeper levels without following the continuum originally suggested by Craik and Lockhart (1972), *response latency* (Craik and Tulving, 1975), as a measure of processing depth, is inappropriate.

In total contrast, Battig (1979) suggests that those facets of the Levels of Processing framework that might be regarded as inadequacies may, in actual fact, conceal a major asset of this view of memory, over other, more perspicuous, theoretical propositions:

> *" ... my preference for levels-of-processing and contextualism over other simpler or more explicit theoretical approaches is precisely due to the flexibility and other theoretical insufficiencies that have been so strongly criticised by others (e.g., T.O. Nelson, 1977)."*
>
> (Battig, 1979. p. 25)

Levels Of Processing And Motor Control

Comparatively few studies have attempted to apply Craik and Lockhart's (1972) depth of processing view to the area of motor-memory. The notable exception comes from Ho and Shea (1978) who, whilst employing a methodology consistent with studies from the verbal domain, induced subjects to process information at particular levels by either: i) having the subjects create a verbalised label to attach to a required motor response; ii) attach a ready-supplied label to the response; or iii) attach no label at all. The movement task required subjects to position a handle at a predetermined point on a linear positioning apparatus, give the produced movement the required verbal label (if appropriate) and then return to the starting position. At a given signal the subject attempted to reproduce the response.

The results of this investigation revealed a significantly better recall performance for the verbal label groups compared to those not required to attach any label to their response. These findings were subsequently interpreted to indicate a more extensive and deeper level of encoding as a consequence of attaching verbal labels (and hence some *meaning*) to the motor response.

In a further experiment, Ho and Shea (1979), using an incidental learning paradigm, investigated the effects of verbal estimates, verbal discrimination and an absence of verbal labels, on the recall of a linear movement response. Although no significant differences were reported between the verbal estimate group and the verbal discrimination group, both were significantly better on recall performance than the group with no verbal labels. These results once again were taken as indicative of the more extensive encoding induced by attaching verbal responses to the movement, and thus providing some measure of support for Craik and Lockhart's (1972) framework. Ho and Shea's (1979) observation that:

> *" ... it is not the intention to learn that determines retention"*
>
> (Ho and Shea, 1979. p. 140)

is thus very much in keeping with Craik and Lockhart's hypothesis that:

> *" ... with an appropriate orienting task and an inappropriate intentional strategy, learning under incidental conditions could be superior to that under intentional conditions."*
>
> (Craik and Lockhart, 1972. p. 677)

In summary, it would appear that the original levels of processing framework has required some modification, in particular, with regard to the notion of a continuum of analysis proceeding from sensory processing to semantic. As an alternative to the traditional view of memory relying so heavily on storage capacity and repetition as indicators of retention, its strengths lie in its underlying assumption of memory as a function of cognitive analysis, and its move towards a far more dynamic and flexible view of the controlling system and its organisation.

In a somewhat similar vein to the Levels of Processing framework, Contextual Interference theory has also emerged from research in the verbal domain to offer explanations pertaining to the interaction between cognition and motor control, in the processes involved in movement skill acquisition. In its presupposition of a flexible memory structure, Contextual Interference closely parallels the Level of Processing framework.

Contextual Interference Theory

The origins of Contextual Interference Theory can be traced to a number of empirical investigations into aspects of verbal memory, performed around the early nineteen-sixties. Incorporating a variety of paired associate (PA) learning paradigms, evidence was accumulated suggesting that interference during learning seemed to have beneficial effects on retention (e.g., Brown, 1964) and an increase in the number of errors committed during training was more often that not, counterbalanced by a reduction of errors on later recognition tests (Johnson, 1964). Merikle (1964), for example, utilising a basic experimental transfer design in a study examining stimulus and response meaningfulness, reported that an increase in meaningfulness resulted in detrimental effects during the learning/acquisition stage, but enhanced transfer performance. Similarly, Schild and Battig (1966), in an examination of the effects of interference induced by directional changes in a PA learning paradigm, presented evidence indicating that increased difficulty during learning facilitated later recall.

With regard to the field of motor memory, Battig (1956), in a study undertaken more than thirty years ago, investigated the effects of verbal pretraining on the learning of a motor task. Employing a finger positioning task of varying degrees of complexity, he reported that verbal pretraining, as an additional source of information incorporated into the learning situation, facilitated the learning of a one and two finger motor task, although on the more complex three and four finger variations, no such facilitatory effects were evident.

It was, thus, amidst a climate of:

> *"... accelerated increase in human-learning research in general, and particularly in those paired-associate verbal-learning studies which have traditionally represented the major domain of transfer research (Battig, 1965)"*
>
> (Battig, 1966. p. 215)

that William Battig (1966) presented an important paper titled *Facilitation and Interference* in which he addressed the issues of intratask interference and its implications for motor-skills research. Fox (1966), invited to comment on this paper, suggested that the two main implications to have been drawn out by Professor Battig (1966) were:

> *"First, interference in the performance of a second task may be obscured or lessoned by sources of interference within the first task. This possibility is explicitly stated by Battig and follows directly from his hypothesis that intratask interference leads to intertask facilitation. The second implication...concerns the observation that in verbal research introduction of a second task has been an effective means of analysing learning processes going on in the first. The suggestion is made that similar procedures may be usefully applied to motor-skills research."*
>
> (Fox, 1966. p. 245)

Twenty-Five Years On ...

As the search progresses for explanations of how intentions for action are transformed into appropriate motor output, Contextual Interference effects have recently become something of a *hot* issue, as an example of the interaction between cognition and motor control: – an example which provides a clear demonstration of the intervention by conscious mechanisms in the translation process that, particularly in the case of tasks not well-learned, would seem a prerequisite in the acquisition of skill (Schneider and Shiffrrin, 1977; Shiffrin and Schneider, 1977).

The effects of contextual interference, originally identified by Battig (1966, 1972, 1979) as a curious paradox in the verbal literature, are thus observed when either the similarity amongst the items to be learned is increased, or when the variety of processing requirements on successive trials is increased (interference).

In his 1979 paper, Battig extended his intratask interference hypothesis and presented eight key features which he saw as:

> *" ... closely interrelated encoding, processing, and/or retrieval characteristics associated with effective long-term memory in general and in particular with within-individual processing differences or with memory facilitation produced by contextual interference during learning."*
>
> (Battig, 1979. p. 26)

These were:

- *Multiple Processing*
- *Variable Processing*
- *Elaboration and Organisation*
- *Distinctiveness*
- *Contextual Factors*
- *Contextual Interference*
- *Contextual Variety* (and)
- *Encoding-Retrieval Congruence*

With the publication of this paper, Battig (1979) made a number of significant statements about the role of interference, the context in which learning occurs and, of particular importance, the influence of the learning context on the nature and extent of processing. The term *intratask interference* was subsequently abandoned in favour of *contextual interference*; a more appropriate term given the dependence on context which features so strongly in Battig's (1979) conceptualisation of memory.

Contextual Interference and Motor Control

Shea and Morgan (1979) examined the effects of contextual interference on motor learning, retention and transfer. The motor task required subjects to grasp a tennis ball, knock down a series of barriers in rapid succession, and then place the ball in a predetermined position. The location and the number of barriers could be varied to elicit different movement responses. The aim was to complete the task in as short a time as possible. The interference effects were created by introducing three variations during practice. A *blocked* practice group performed all practice trials of one variation (eighteen trials) before proceeding to the next (thus completing a grand total of fifty-four trials from three variations). A *random* group performed the same number of trials of each variation, but with the variations presented in a totally random fashion.

The results of this study demonstrated a superiority of performance for the random group on transfer, although the blocked group recorded faster response times during acquisition. Shea and Morgan's (1979) evidence suggested that the condition in which contextual variety was prominent (random) was sufficient to produce considerable retention effects, and subsequent research studies from their lab supported this contention (see Shea and Zimny, 1983). Support was also forthcoming from other laboratory-type investigations (e.g., Hagman, 1983; Wulf, 1985) as well as studies in more applied settings (Goode and Magill, 1987).

Distribution Of Practice – The Same Phenomenon?

Shea attributed these findings to the increased cognitive processing requirements brought about by the contextual variety effects of the random condition (Battig and Shea, 1980; Shea and Morgan, 1979; Shea and Zimny, 1983). Schmidt (1988) draws attention to the similarity between these results and a much earlier phenomenon from the field of verbal memory research – *the spaced-repetition effect* (Melton, 1967), and Lee and Magill (1983), making the same observation, argue that in the light of this earlier research, Shea and Morgan's (1979) interpretations would seem quite tenable:

> *"Beyond the obvious procedural similarities with respect to the repetition of events during the practice or presentation phase (random/distributed vs. blocked/massed conditions), these phenomena show parallel effects on performance as well: Whereas nonrepetition of events during practice/presentation is much more demanding of processing requirements, there is an ultimate facilitation on retention (Cuddy and Jacoby, 19823; Johnston and Uhl, 1976; Shea and Zimny, 1983)."*
>
> (Lee and Magill, 1983. p. 731)

In a recent review of the effects of the distribution of practice, and based on the results of a meta-analysis, Lee and Genovese (1988) came to the conclusion that:

> *" ... distributed practice is beneficial to both the performance and learning of motor skills, although the effect on performance is greater than the effect on learning."*
>
> (Lee and Genovese, 1988. p. 282)

They then proceed to highlight evidence from other areas of motor learning research where commonalities are evident:

> *"The most closely related practice schedule effects is the so-called 'contextual interference' effect (Shea and Morgan, 1979)."*
>
> (Lee and Genovese, 1988. p. 284)

They do, however, point out that a major difference would seem to be the effects observed during acquisition. Where distributed practice conditions facilitate performance, random practice conditions have the opposite effect. This, they suggest, might be accounted for by the interaction between the *spacing* effect and type of task, in motor skill learning. Whilst most contextual interference studies have involved the use of discrete tasks, the earlier distribution of practice studies relied almost entirely on continuous tasks such as the pursuit rotor. The exceptions, in the case of distribution of practice research, produced quite different results from those employing continuous tasks (cf. Carron, 1969; Lee and Genovese, 1988), as too did the contextual interference studies using the pursuit rotor (Lee and Magill, 1981; Whitehurst and Del Ray, 1983). In these instances, the typical blocked and random effects predicted from other contextual interference research failed to materialise. The conclusion was thus drawn that:

> *" ... the similarity in retention effects between distribution of practice and contextual interference studies may only be a superficial similarity."*
>
> (Lee and Genovese, 1988. p. 285)

Magill (1988), however, casts doubt on the validity of this interpretation:

> *" ... there has not been clear evidence that the spacing effect as reported for verbal information is the same phenomenon as the distribution of practice for motor skills (Meeuwsen and Magill, 1987)"*
>
> (Magill, 1988. p. 304)

and goes on to question the usefulness of resurrecting the practice of distribution problem. A more profitable avenue of inquiry, he argues, might be to focus on a wider range of issues related to the intertrial interval:

> *"What seems to have more promise for helping us understand learning processes are comparisons of various conditions within the same or different lengths of intertrial intervals."*
>
> (Magill, 1988. p. 304)

Forgetting As An Aid To *Remembering*!

An alternative view to Shea's explanation (e.g., Shea and Morgan, 1979; Shea and Zimny, 1983) of greater retention and transfer performance exhibited under random (compared with blocked) practice conditions being due to better elaborative and distinctive cognitive analyses during acquisition, has been proposed (e.g., Cuddy and Jacoby, 1982; Lee and Magill, 1983; Lee (in press)), suggesting that *forgetting* can actually facilitate learning. Separating practice trials (either with or without the introduction of some interpolated, similar or dissimilar activity) as in the random condition, prevents subjects, it is argued, from remembering the previous response, and thus forces the action plan to be recreated on each successive trial. The blocked practice condition, on the other hand, allows the subject to simply remember the preceding trial and thus generate the same *solution* without having to repeat those mental processes that originally produced that response. Accepting that this process of generating solutions is actually the process of *learning*, blocked practice, whilst resulting in better acquisition performance, will, not surprisingly, yield inferior results on transfer tests that measure retention and learning, compared to a random practice condition.

Cuddy and Jacoby (1982) thus reached the same conclusion as Magill (1988) and imply that further research related to the conditions surrounding the intertrial interval may help to shed some light on what factors are *remembered* in the learning process – some products of the presented item and the processing activities of the learner (e.g., Craik and Lockhart, 1972; Jenkins, 1974) or perhaps the operations which are performed on the presented stimulus (Kolers, 1976):

> *"To specify the effect of repetitions, it must be determined which, if any, processing is repeated across presentations of an item, and then plot performance against that which is truly repeated. One factor that likely influences the probability of processing being repeated is the accessibility of the memory for a prior presentation of an item when that item is repeated."*
>
> (Cuddy and Jacoby, 1982. p. 466)

The Relationship To Schema Theory

The most intuitively appealing aspect of Schmidt's (1975) schema theory is the hypothesis which states that increasing variability in practice, whilst resulting in a detrimental performance during the practice structure, will facilitate schema development (which in Schmidt's case involves a strengthening of the *rule* between the movement parameters of the motor programme and the movement outcomes, based on previous experiences of that and *similar* movements), and consequently be reflected in enhanced performance on transfer (see Chapter Four, page 73). If variable practice is viewed from a contextual interference perspective, the random practice condition not only requires the subject to assign a new set of movement parameters to the motor programme as schema theory would hold, but forces the learner to generate a *different movement* on each successive trial – a process that can be regarded as indicative of learning (Lee and Magill, 1983). Would it then not be inappropriate to conceive of schema theory's *random-varied practice* label (Schmidt, 1975, 1976) and the *contextual interference effect* (Shea and Morgan, 1979) as being essentially the same (that is, separated primarily by nothing more than terminology), both of which might more effectively be explained by the depth of processing framework (Craik and Lockhart, 1972) and/or the *forgetting hypothesis* as outlined above? Such speculation, at least as far as schema theory and contextual interference theory afford similar predictions, has not gone unnoticed in the literature:

> *"Although this interpretation does not refute the potential benefits of 'motor' practice variability, it does suggest that in conjunction with random practice schedules, the development of movement schemas underscores the dynamics between cognition and motor control."*
>
> (Lee and Magill, 1983. p. 744)

Lee and Magill continue in their conclusion by suggesting that:

> *"Future research regarding the interaction of the various factors that underlie practice variability effects would seem a fruitful endeavour towards a better understanding of the processes involved in skill acquisition"*
>
> (Lee and Magill, 1983. p. 744)

Following their advice, it would seem appropriate to commence with a brief examination of the literature on variability in practice to see if some of the equivocality of this research might not be reconciled within a broader, overall perspective. Although Schmidt's (1975) schema theory had nothing to say in terms of predictions regarding the *order* in which practice trials should be undertaken, a model incorporating a less restricted use of the term *schema* may well be able to accommodate much of the existing evidence from research into transfer predictions of schema theory, whilst at the same time, capitalise on the similarities between these *alternative* explanations, and assist in the move towards a less antagonistic, more cohesive account of the memory organisation underlying skilled movement (e.g., Fazey's 1986 model).

Variability And Tests Of Schema Theory

Of the numerous studies involved with variability of practice predictions as tests of schema theory, enough have presented sufficiently convincing evidence to guarantee the variability of practice hypothesis some kind of role in any up and coming theoretical account of the processes underlying skill acquisition (see Shapiro and Schmidt, 1982 for a detailed review of these studies). The fact that these studies have resulted in a certain amount of equivocality has generally been explained as either a reflection of some kind of developmental influence (e.g., Schmidt, 1976; Shapiro and Schmidt, 1982) or related to the nature of the variability and the structure of the practice session (e.g., Magill and Weeks, 1983).

Age: A Possible Delineating Factor In Schema Development

Unlike Piaget (1936, 1977), Schmidt (1975) did not specifically refer to any *developmental* aspects of schema although he did suggest that studies attempting to find evidence of schema development would be well advised to:

> *" ... use limbs and movements that have not been used extensively."*
>
> (Schmidt, 1975. p. 246)

The implication of this comment thus being that children might be more suitable as subjects than adults. In his following publication this suggestion was stated more explicitly:

> *"... experiments should be attempted using more novel tasks, perhaps with younger children in whom such schemas would have more opportunity to be strengthened."*
>
> (Schmidt, 1976. p. 53)

Following this advice many experimenters have opted to use children in their studies (e.g., Beatty, 1977; Carson and Wiegand, 1979; Dummer, 1978; Hunter, 1977; Kelso and Norman, 1978; Kerr and Booth, 1977, 1978; Moxley, 1979; Moxley and Fazey, 1977; Pigott, 1979) with the result that Shapiro and Schmidt (1982) are drawn to the obvious conclusion that:

> *" ... children's motor skills are apparently more easily affected by variability in practice than are those of adults."*
>
> (Shapiro and Schmidt, 1982. p. 121)

Such results, from the point of view of Schmidt's (1975) schema theory are thus straightforwardly interpreted to mean that:

> *" ... schemata are easily developed in children; adults, on the other hand, may have already developed schemata for the relatively simple tasks employed in the experiments reported here."*
>
> (Shapiro and Schmidt, 1982. p. 121)

For those studies using adult subjects (e.g., Hogan, 1977; Johnson and McCabe, 1977; McCracken and Stelmach, 1977; Melville, 1976; Newell and Shapiro, 1976; Wrisberg and Ragsdale, 1979; Zelaznik, 1977), results varied from partial support for schema theory to, in the case of Melville (1977) and Zelaznik (1977), no support at all. Shapiro and Schmidt (1982) thus concede that:

"Taken together, the results of these studies provide, at best, minimal support for the variability prediction ... for adult subjects."

(Shapiro and Schmidt, 1982. p. 120)

They are quick to point out, however, that:

"Except for the Zelaznik (1977) experiment ... the means are ordered in a way predicted by the theory, although the effects were generally not large enough to reach conventional levels of statistical significance."

(Shapiro and Schmidt, 1982. p. 120)

The differences between those investigations using adult subjects compared with children, is not, of course, as clear cut as it may first appear; indeed the basic design of the experiments performed by Moxley, Fazey, Hawkins and McCabe (1977) and Moxley (1979) with children, were largely based on earlier observations of studies with young adults in which variable practice groups had transferred with greater success to novel variations of a task (see Moxley and Fazey, 1977; Fazey, 1986, page 51). Where, then, might the answer to this equivocality lie?

Moxley and Fazey's (1977) suggestion that demonstrating the validity of the schema notion by testing the variability of practice hypothesis is simply a matter of:

" ... looking in the right way, at the right time, in the right place."

(Fazey, 1986. p. 51)

is probably as close to the truth as any of the seemingly more academically-worded, theoretically inspired or empirically based speculations that have so far been offered. However, whilst the *right place* may well not prove to be a great stumbling block, what exactly is the *right way* and the *right time*?

The answers might possibly be found in two closely related issues – the question of *novelty* in relation to task complexity and level of learning, and the relevance of *age* when viewed in relation to previous experience, respectively.

Task Complexity And Level Of Learning

Fundamental to Schmidt's (1975) schema theory is the prediction that variability will lead to greater transfer on *novel* variations of a task. It has already been suggested that *novelty* is, to some extent, a relative term since few motor tasks are ever exact replicas of previously presented tasks (e.g., Bartlett, 1932; see page 27), and even in the most *closed* of skills, the conditions surrounding the initiation of a well-rehearsed motor response may, on closer examination, reveal quite marked variations. Nevertheless, as far as Schmidt's (1975) prediction is concerned, the meaning is quite clear – tasks that lie outside the range of practice and yet are still hypothesised to be governed by the same schema (motor programme) should be more easily accomplished as a result of varied practice.

With children, selecting a task that is sufficiently novel to generate variability effects seems not to present any great difficulty. With adults, however, it might well be that only relatively complex tasks (or at least, tasks sufficiently complex to be perceived as *novel*) will enable variability effects to be demonstrated (cf. Moxley and Fazey, 1977). In this sense, *complexity* becomes the other face of *novelty*.

In terms of error production, the less complex a task becomes, the lower will be the number of errors generated. Conversely, the number of errors will rise in direct proportion to any increase in complexity. Thus the notion of complexity, when viewed from this subjective perspective, is a consequence of the level of learning already acquired by the performer. The highly complex task, from the point of view of the novice, may be a relatively simple task for the expert, with a whole continuum of possible classifications in between.

The *"right way"* to demonstrate the validity of the schema idea might thus be merely a question of selecting either the right task (that is, one of sufficient complexity in the case of adult subjects), or the right subjects (that is, younger children who are less likely to have already well-developed schemas for the task being used).

Age And Experience

Extending the line of thought presented above, it seems reasonable to suggest that the discriminating factor in those studies resulting in either success or failure to produce variability effects in favour of the schema notion, is not so much developmental (that is, related to age), but simply a question of previous experience. In other words, whilst a given task may be appropriate to generate variability effects with young children, those same children, with sufficient training, may equal the performance of older subjects to the point where variability effects may only be demonstrated by increasing the complexity of the task. Evidence supporting such a supposition comes from Lipps Birch (1978) who effectively removed the differences in performance between older and younger subjects on a time sharing task, by allowing the younger subjects as much practice as was necessary. Fazey (1986) interpreted these findings as:

> *" ... very convincing evidence that not least amongst the factors which covary with age is experience."*
>
> (Fazey, 1986. p. 49)

and suggests that:

"The introduction of age as a delineating factor with which to best describe the structure of a schema for the control of motor skills ... unnecessarily complicates the issue."

(Fazey, 1986. p. 48)

Thus, it could well be that *"looking ... at the right time"* in order to obtain support for the schema notion, might entail nothing more than selecting subjects who have had an appropriate amount (or rather, lack) of previous experience relative to the task that has been selected by the experimenter.

There is, of course, something of a circularity in the line of reasoning that asks whether task complexity is the same as level of learning, or whether the question of age differences would not be more appropriately replaced with questions about previous experience. Indeed, the two subheadings *Task Complexity And Level Of Learning* and *Age And Experience*, could just have easily been substituted for an alternative combination such as *Task Complexity And Experience* and *Level Of Learning And Age*. The factors are inextricably interwoven and when examined from a perspective not restricted by developmental barriers or definitive classifications of complexity and expertise, become almost synonymous in their description of events, albeit from opposite sides of the spectrum.

Whilst such a view may help to make sense of what might first appear to be a whole jumble of closely intertwined, related, yet often contradictory influences on the learning environment, is it a tenable proposition, implying, as it no doubt first appears to do, that the plethora of literature from the field of child psychology that stresses maturational stages of development, should be all but ignored?

The Existence Of Maturational Barriers

Van Rossum (1980), in a critical review of some earlier studies testing the validity of Schmidt's (1975) schema notion, argues that insufficient attention has been paid to the differences between *formation* and *attainment* (see Chapter Two, page 13), and suggests that a possible explanation for the inferior performance of the younger children in his own study undertaken the previous year (Van Rossum, 1979), was due to the fact that they:

> " ... *do not envisage both versions of the throwing task as 'similar'.*"
>
> (Van Rossum, 1979. p. 147)

or, as he suggests later:

> "*'similar' means different things to people of different ages.*"
>
> (Van Rossum, 1980. p. 276)

He implies that the problem is a perceptual one very much related to age, and this age restriction is reflected, perhaps, in an inability to apply higher order dimensions of control.

Whiting (1980) follows a similar line of argument referring to the problems associated with the establishment of hierarchical control:

> " ... *since the schema refers to a complex set of relations, it would seem for example that in devising any training programme for schema development, it would make sense to know which of these relationships is weak, i.e.* ***what are the dimensions of control which the subject currently cannot handle*** *(Van Rossum, 1978)?*" (My emphasis)
>
> (Whiting, 1980. p. 548)

It thus appears, at least as far as Van Rossum and Whiting are concerned, that children's level of ontogenetic development is reflected in an inappropriate establishment of a higher order (perceptual/cognitive) dimension of control; or, at best, that the current level of development leads to the invocation of a controlling strategy very different from that of an adult or skilled performer.

In an explicit example, Van Rossum (1980) suggests that the choice of proprioceptive information as the independent variable in a test of the variability of practice hypothesis (e.g., Carson, 1978; Moxley, 1979) can only be justified:

> *" ... when it is known that subjects of, say, 7 years of age can effectively handle proprioceptive information as an initial condition, and, say, 4-year-olds cannot...Clues for such dimensions of information are given in the developmental literature: changes in dominance of sensory system, increase in intersensory coordination, and improvement in intrasensory discrimination are some examples (e.g.Birch and Lefford, 1967; Connolly and Jones, 1970; Fellows, 1968; Whiting and Cockerill, 1972, 1974)."*
>
> (Van Rossum, 1980. p. 276)

Schema Boundaries

Fazey (1986) interprets Van Rossum's dilemma in trying to resolve two differing views of schema development, one of which stresses the importance of maturation (Piaget, 1970), while the other regards the amount of varied practice as the dominant factor (Schmidt, 1975), as fundamentally a question of schema boundaries. The existence of boundaries is, of course, an inherent implication or assumption of Schmidt's (1975) schema theory, but no real attempt has been made to define what exactly constitutes a *movement class*, and consequently, the boundaries remain unspecified.

Van Rossum (1979) clearly recognises that the problem centres around a basic difference in the level at which the schema is conceived to be operating (see Chapter Four, page 89), and he suggests that Piaget's (1970) view of the schema as something that:

> *" ... represents what can be repeated and generalised in an action (e.g. the schema is what is common in the action of 'pushing' an object with a stick or any other instrument)."*
>
> (Van Rossum, 1979. p. 146)

implies a view of the schema as:

> *" ... an organisation on a rather global, 'macro' or 'action' level."*
>
> (Van Rossum, 1979. p. 146)

In contrast, Schmidt's (1975) suggestion that movements of a particular limb are controlled by specific schemas is interpreted as:

> *" ... a more specific, 'micro', or 'movement' level of control."*
>
> (Van Rossum, 1979. p. 146)

Examining this question in an earlier unpublished study, Hooper (1981) focuses on what is surely the central issue:

> *"The crux of the matter ... seems to centre around the question of whether any 'barriers' persist beyond the time when a 'new' schema emerges (as Piaget would suggest), or whether the boundaries of schema are merely a function of variability and amount of practice (the Schmidt view). If the latter is the case, then manipulating variability and practice shortly after the emergence of a 'new' schema should theoretically show enhanced performance in a novel variation of the skill in advance of that predicted by the 'developmental' or maturational breakdown of a schema's boundary."*
>
> (Hooper, 1981. p. 11)

A subsequent empirical investigation of schema development in a series of two-handed co-operation tasks led the conclusion that:

> *" ... although development may differentially effect the applicability of schema across body laterality, then should a boundary exist, practice can transcend that boundary."*
>
> (Hooper, 1981. p. 37)

In whatever way the notion of schema might be presented, the idea of some kind of existing boundary is appealing as either a reference point from which a hierarchical model can describe a particular level of schema operation, or as a guide from which future transfer can be predicted. Any attempt to define such boundaries, however, logically conceals an underlying view of memory that is both rigid and static. The attraction of Fazey's (1986) view of the schema stems precisely from the fact that it presupposes a memory system and organisation that is fundamentally dynamic in nature. As such, it naturally follows that:

> *"Rather than looking for static, or structurally determined movement or action classes, it is not only easier, but more logical, to propose that if schema boundaries exist, then they do so as a result of the practice which created them."*
>
> (Fazey, 1986. p. 57)

He goes on to point out two logical predictions that arise from a view of schema boundaries that are created by practice:

> *"On the one hand high variability should lead to a broad schema which can generate highly varied, novel movements. On the other hand extensive repetition and overlearning should lead to a highly specific schema in which only a limited set of parameters, within a limited range of values, can be easily changed."*
>
> (Fazey, 1986. p. 58)

Seen in this perspective, much of the data from tests of the variability of practice hypothesis is easily accommodated.

This line of reasoning is not intended to decry the importance of developmental factors in the learning situation. Rather, the view is taken that although developmental stages might be easily identified with, or related to, a particular age, such an observation does not necessarily imply that those stages are determined by that age. That is to say, whist it might be true that in the *normal* course of events children of a particular age group typically display certain behavioural characteristics reflective of an identifiable level of cognitive ability, an alternatively structured learning environment may result in behaviours more usually associated with an older, or at least different, age group. Such a view should not be considered in any way a radical departure from the most conventional approach to viewing the learning process, but, as Belmont (1978) implies, and as much of the literature seems to suggest, it might be:

> *"The dependence on age as an evaluative criterion is so pervasive in our dealings with children that laymen and professionals alike speak and write as though age* **causes** *growth; they are less inclined to search for age-related processes that can account for age-related differences in cognition and which unlike age might be alterable to the benefit of the child."*
>
> (Belmont, 1978. p. 156)

Constraints On Knowledge Acquisition

Whilst this view of a flexible and dynamic operating system can be seen as *the* alternative to what might be described as a strictly developmental perspective, in so far as the study of cognitive development does not focus exclusively on changes related to an increase in age, there is another approach which examines what factors remain constant throughout conceptual change:

> *"What constraints are there on natural cognitive structures and processes, and how do they limit the kinds of developmental changes that occur?"*
>
> (Keil, 1981. p. 197)

This question would seem to be important for a number of reasons: first it seems to suggest that children arrive at the learning situation armed with a set of *a priori* constraints that are going to determine to some degree the nature of the learning that might take place; secondly, such a supposition at first sight appears to question the view that memory is simply the product of previous experience rather than restricted by some kind of predetermined, developmental progression (or at least, implies that the situation may be more complex than the flexible, dynamic approach seems to suggest); and third, account has to be taken of theorising and research from quite different academic disciplines such as linguistics and philosophy – a process which should enhance both the standing and credibility of motor behaviour research, and yet one to which researchers in the field have seemed reluctantly inclined.

Keil (1981) points out that:

> *"The necessity of a priori constraints has been acknowledged by many others in linguistics and philosophy, but few cognitive psychologists have directly investigated the issue."*
>
> (Keil, 1981. p. 198)

As far as motor-skills research is concerned, the issue seems to have been altogether ignored, although such constraints would seem to be a relevant issue to any theoretical account concerning the acquisition of knowledge.

Chomsky (1965) is well known for his work on first language acquisition, much of which focuses on the relationship between constraints and cognitive development. Citing Peirce (1931–1935) as a major influence on his current theorising, Chomsky (1968) illustrates the relevance of this notion:

> *" ... with the well established proposition that all knowledge is based on experience, and that science is only advanced by the experimental verifications of theories, we have to place this other equally important truth, that all human knowledge, up to the highest flights of science, is but the development of our inborn animal instincts."*
>
> (Peirce, 1931–1935. Vol. 2. p. 752–754)

A point of fact that, for Peirce, clearly implies that:

> *" ... if men had not come to it* (nature) *with special aptitudes for guessing right, it may well be doubted whether in the ten or twenty thousand years that they may have existed their greatest mind would have attained the amount of knowledge which is actually possessed by the lowest idiot."*
>
> (Peirce, 1931–1935. Vol. 2. p. 752–754)

Chomsky (1975, 1980) argues that this issue of constraints warrants investigation by not only linguistics and psycholinguistics, but by cognitive psychologists in general, which, presumably, includes those within the field of motor control and learning.

In trying to ascertain the difference between children and adults in terms of their processing abilities, Keil (1981) identifies three distinct views of cognitive development which he represents schematically (see Figure 5.1 on the following page: from Keil, 1981). The first sequence (A) reflects those theories of cognitive development that suggest a fundamental reorganisation and reconstruction of conceptual frameworks underlying the process of cognitive development (e.g., Bruner, Olver, Greenfield, *et al*, 1966; Vygotsky, 1962). Such a viewpoint, Foder (1972, 1975) argues, fails to explain how, given that the knowledge structures of children and adults are radically different, adults and children are able to understand each other. Keil (1981) extends this very same argument when he suggests that, for children, in the case of learning a first language:

> *"Unless they share with adults certain ways of construing the world, they will not be at all likely to acquire the same concepts and meanings."*
>
> (Keil, 1981. p. 201)

The second approach to cognitive development (B) represents an increase in access to an unchanging cognitive structure. Foder (1972) and Rozin (1976) are cited by Gelman and Gallistel (1978) as examples from two quite different fields of study, whose work is seen as reflective of a recent trend in cognitive developmental research – a theoretical orientation that regards the developmental process as an increased ability to apply cognitive structures and subroutines to an increasingly broadening scope of tasks. The interpretation thus being that:

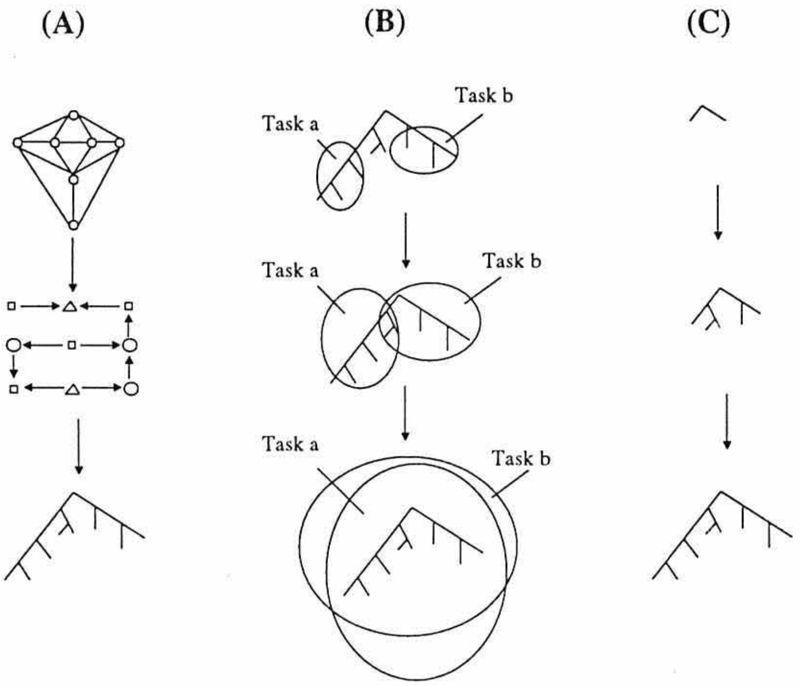


Figure 5.1: From Keil, 1981. p. 202: Three views of cognitive development: (A) structural reorganisation, (B) increasing access to an unchanging structure, and (C) structural change governed by constraints.

> *" ... children may fail on certain tasks because they cannot access a skill that they can use in another task."*
>
> (Keil, 1981. p. 201)

Thus, tasks a and b in this second sequence can only access a subset of the overall structure and it is not until a later stage of cognitive development that, to use Van Rossum's (1979) term, they may be envisaged as 'similar'.

Sequence C, which Keil (1981) regards as possibly a more accurate representation of much of cognitive development, shows a structural change, but one that is clearly constrained to a degree that at different stages of development, commonalities between the formal properties of the partial structure and the completed structure, can be easily identified.

Sequences B and C are not, of course, mutually exclusive. Keil (1981) correctly points out that:

> *"If increasing access were the only developmental process, there would be one and only one final adult structure, or fragments thereof."*
>
> (Keil, 1981. p. 202)

Some combination of B and C would seem to be the most likely explanation, reflected in situations where children are not able to demonstrate a particular piece of knowledge, not because of a failure to appropriately access, but simply because the knowledge has not yet been acquired. The important point is that:

> *"What knowledge children do have conforms to the same formal constraints as adult knowledge, but it is less elaborated."*
>
> (Keil, 1981. p. 202)

(cf. Craik and Lockhart's, 1972; Tulving and Madigan, 1970; see page 112)

It thus follows that:

> *"An adequate account of cognitive development must include increasing access and structural change, but both of these phenomena must be viewed in the context of constraints."*
>
> (Keil, 1981. p. 202)

Keil (1981) makes a distinction between views that are *constraints-oriented* and those that are simply *increased competency* views; the former of which are generally subsumed within the latter, but the reverse not necessarily being true. As an example of a view attributing greater competency to children, Keil (1981) cites the work of Chi (1978) who has demonstrated an ability in very young children, who are experts in, for example, chess or dinosaur classification, to exhibit very *adultlike* behaviour in tasks of memory. Conversely, adult novices have been shown to exhibit very childlike behaviour. The suggestion is usually made that such differences are a reflection, not so much of different cognitive abilities between children and adults, but a difference in knowledge base – an argument, Keil (1981) suggests, is only successful if:

> *" ... one has principles for distinguishing what is merely a change in a knowledge base from what is a change in computational and representational machinery."*
>
> (Keil, 1981. p. 204)

Keil does concede that Chi (1978) seems to present an operational method by which these two can be distinguished in that children in special circumstances can be made to perform like adults, and vice versa. The argument is thus presented that children and adults are therefore distinguishable in the same way as one might differentiate between novices and experts (cf. the previously presented arguments regarding the relationship between task complexity, level of learning, age and experience, pages 122–124).

Keil (1981) warns, however, that:

"Without some independent set of constraints, such a method can only be a rough heuristic. What makes a developmental change knowledge based or competence based cannot be decided merely by the degree to which a cognitive skill is alterable by experience."

(Keil, 1981. p. 204)

This may well be true, but to some extent, at least as far as motor control and its pedagogical implications are concerned, the issue is not perhaps a crucial one. That is to say, if structuring the learning environment in such a way that children can be made to acquire levels of skilled performance usually reserved for later stages of development, whether this is explained in terms of a change in knowledge base or an increase in competence, has little bearing on the practical implications. From a theoretical point of view, however, the point is important and it is certainly not the intention to imply that progress towards a *complete* theory of motor control and learning should proceed from the empirical to the theoretical. On the contrary, it is advocated that empirical investigation should have its base firmly in hypothesis emanating from theoretical constructs.

In terms of applicability to issues of motor control, the apparent total absence of any investigation examining possible constraints affecting motor skill acquisition means that any propositions must be purely speculative. The view of memory that is presented throughout this thesis, emphasising as it does an expert-novice distinction not so far removed from that of Chi (1978), may well be interpreted as supportive of a view of constraints, but such an interpretation does not necessarily follow. Nevertheless, the existence of constraints, at least to some degree, is not considered a matter of contention. The question that has to be addressed by motor control theorists concerns their nature, and what the possible implications might be for a theoretical model of motor control and learning

In terms of the B and C sequences reflecting different views of cognitive development, both are quite easily accommodated. The fact that children's propensity for learning is constrained in some way need not imply that any age-dependent restriction is in force – rather that the learning of movement skills, particularly those that appear to be acquired *naturally*, may proceed almost spontaneously with little assistance in the form of formal instruction.

Regarding what aspects of knowledge are likely to be tightly constrained, Keil (1981) states that what evidence there is suggests that:

> " ... *the more complex and abstract the knowledge, the more constraints are needed at the cognitive level ... strongly constrained knowledge is knowledge that is acquired relatively effortlessly and rapidly ... Moreover it is knowledge that is universally acquired.*"
>
> (Keil, 1981. p. 224)

Furthermore, this tightly constrained knowledge appears to be:

> " ... *less open to conscious introspection* (and) *less susceptible to manipulation by means of learning strategies and other sorts of conscious manipulations.*"
>
> (Keil, 1981. p. 224)

To some extent it could, of course, be argued that the kind of laboratory-type tasks typically employed in studies of motor control are no more *natural* or *ecologically valid* than the nonsense words frequently used in verbal memory investigations and, as such, cannot be justifiably regarded as representative of *naturally* acquired movement skills. Whether a button-pushing task or knocking over barriers is any less *realistic* in comparison to a similarly constructed, more spontaneous action performed outside the experimental environment, is something of a moot point. Suffice to say that Keil (1981) is probably correct when he suggests that:

"The expert-novice distinction may ... be more useful in characterizing some types of knowledge acquisition than others. In particular, it may be very valuable in describing knowledge that is acquired through formal, explicit instruction ... and not so helpful in describing knowledge that is acquired more spontaneously."

(Keil, 1981. p. 204)

The Structure Of Variability

To return to the notion of schema and the variability of practice hypothesis, from which the preceding discussion of schema boundaries and, subsequently, developmental influences and constraints on knowledge, originated, a second possible source of inquiry that might shed some light on the equivocality apparent in tests of the validity of the schema notion (the first having been related to possible developmental issues) concerns the nature of the variability and the structure of the practice session.

Varied practice in the form of randomly presented trials has, as has already been noted (Chapter Five, page 120), resulted in enhanced performance on transfer in the case of children, but not consistently so in the case of adults. Lee and Magill (1983) direct attention to the structure of the variability practice session as a potential resolution of this equivocality, and distinguish between *random-variable* practice, where the variability is introduced in a totally random fashion (i.e., with each consecutive trial being different from the preceding one), and *blocked-variable* practice, where several trials of the same type are presented before another variation is introduced (i.e., a subject might perform four or five trials of one variation at a time before beginning the next block of trials of another variation, and so on). Indeed, they point out that of six published articles reviewed by Shapiro and Schmidt (1982) testing the variability of hypothesis in adults, those that failed to provide support for the predictions of the theory, or indicated only partial support, all presented variable practice in a *blocked* fashion (Husak and Reeve, 1979; Newell and Shapiro, 1976; Zelaznik, 1977). In contrast, the studies that supported Schema theory's predictions quite well, constructed variable practice conditions in the form of *random* trials (McCracken and Stelmach, 1977; Wrisberg and Ragsdale, 1979; Zelaznik, Shapiro and Newell, 1978).

As it stands, Schmidt's (1975) schema theory can do little to shed any light on these findings, although cognisance has been taken of its author's suggestions of a possible experience-related, developmental influence underlying them, and which has already been discussed at some considerable length. Examined in the light of contextual interference and/or depth of processing theoretical perspectives, however, it comes as no great surprise that the *blocked* studies failed to generate the effects predicted by schema theory.

Some Reinterpretation Of Existing Data

The above results are quite consonant with the contextual interference effect (Del Rey *et al*, 1982; Lee and Magill, 1983; Shea and Morgan, 1979; Shea and Zimny, 1983) and Shea's (e.g., Shea and Morgan, 1979; Shea and Zimny, 1983) contention that *random* conditions (as compared to *blocked* conditions of practice) result in greater retention and thus propensity to transfer due to more elaborative and distinctive cognitive analyses during the acquisition phase. The *random-variable* structure requires subjects to actively regenerate a completely new movement plan for each trial of the acquisition phase, unlike the *blocked-variable* condition where, except for the initial trial of each new block of a different variation, subjects can *remember* the previous response and simply repeat it, thus undermining the reconstruction process (learning process) that is vital for later transfer. The *random* condition thus forces subjects to engage in what Lee and Magill (1983) have described as more "*cognitively effortful*" activities to solve the motor task at hand – an explanation which , they suggest, is quite compatible with other relevant contemporary research findings:

> *"Indeed, this effort-related explanation ... is consonant with recent perspectives on the acquisition of purely cognitive tasks (Eysenck and Eysenck, 1979; Kunen, Green and Waterman, 1979; Tyler, Hertel, McCallum and Ellis, 1979) as well as for short-term retention of preselected movements (e.g., Kelso, 1981; Lee and Gallagher, 1981).*
>
> (Lee and Magill, 1983. p. 744)

Those studies which have used children as subjects and have had more success in providing evidence in support of schema theory (with the exception of Pease and Rupnow, 1983; Wrisberg and Mead, 1983), have incorporated both *random-variable* practice (e.g., Carson and Wiegand, 1979; Kelso and Norman, 1978; Wrisberg and Mead, 1981), *blocked-variable* practice (e.g., Moxley, 1979), *alternating blocks* (e.g., Pease and Rupnow, 1983), or variable practice in the form of *random blocks* (e.g., Pigott and Shapiro, 1983; Poretta, 1982; Wrisberg and Mead, 1983). The failure of such studies to produce the marked difference between *random* and *blocked* practice conditions that are evident in adult studies, may be attributed to the fact that:

> *" ... perhaps blocked variable practice conditions create enough breadth of information to facilitate transfer in children"*
>
> (Lee, Magill and Weeks, 1985. p. 295)

In other words, because children have less well developed schemas (e.g., Schmidt, 1976; see Chapter Five, page 120) the degree of *randomness* that is required to generate variability effects and so enhance transfer, is not so great; *blocked* variable practice will probably suffice. With older subjects, however, the *blocked* variable practice may not be sufficient and a completely *random* practice structure will be necessary.

An alternative approach

Rather than simply manipulating variability, an alternative approach would be to increase the complexity of the task (as argued earlier in this chapter – see page 122). An increase in task complexity, it has been suggested, increases the number of errors committed during the acquisition trials and creates in older subjects a level of performance more reminiscent of the novice (or *childlike*). In such circumstances, taking the argument to its logical conclusion, *blocked* variable practice may be sufficient to produce predicted variability effects although the subjects are not children. The combination of *high task complexity/adult* subjects may sufficiently counterbalance the low level of *randomness* (i.e., *blocked practice*) in the practice structure to give the same results that would be expected with a *low task complexity/children* configuration.

Of course an increase in randomness can, in itself, be seen as tantamount to an increase in task complexity in the sense that forcing the subject to adopt different strategies in an attempt to improve performance, requires more cognitive effort (Lee and Magill, 1983) than in the less difficult condition in which each successive trial involves only a repetition of the response produced on the preceding trial.

A further influence in this equation of factors must also be the size of the block and the number of trials. Presumably, in experiments with children, only a few trials might be sufficient to enhance transfer (cf. Pigott and Shapiro, 1984 who demonstrated an effect with only twenty-four trials using a *blocked* structure of practice condition. The *random* structure produced no such effects possibly indicating a cut-off point where the task becomes too difficult and requires a much greater number of trials). If the task is more complex or alternatively a completely *random* structure of variable practice is in force, a greater number of trials may be required (cf. Carson and Weigand, 1979, who reported effects from a totally *random* condition incorporating one hundred trials).

Pigott and Shapiro (1984) conclude that:

" ... there appears to be an optimal way to structure the variable practice session...Perhaps there is an optimal number of repetitions which depends on the task, the extent of practice, and the age of the subject."

(Pigott and Shapiro, 1984. p. 44)

An optimal way to structure the variable practice session there undoubtedly is. Taking into account the question of individual differences, the problem confronting the researcher remains one of arriving at an appropriate theoretical description on which to base subsequent applications.

A Variety Of Factors Influencing Schema Development

The factors influencing schema development are thus both intricate and varied. No single factor can be considered in isolation. Figure 5.2 (overleaf) is a schematic representation of those factors which have been identified as sources of influence on schema development. The following empirical investigation highlights one section of that complex interaction and examines the effects of *manipulating task complexity* under *random* and *constant* practice conditions on the propensity for learning, as measured by transfer. Such a move is seen as the next logical step in terms of research, and a response to Lee and Magill's (1983) reflection that:

Future research regarding the interaction of various factors that underlie practice variability effects would seem a fruitful endeavour towards a better understanding of the processes involved in skill acquisition."

(Lee and Magill, 1983. p. 744)

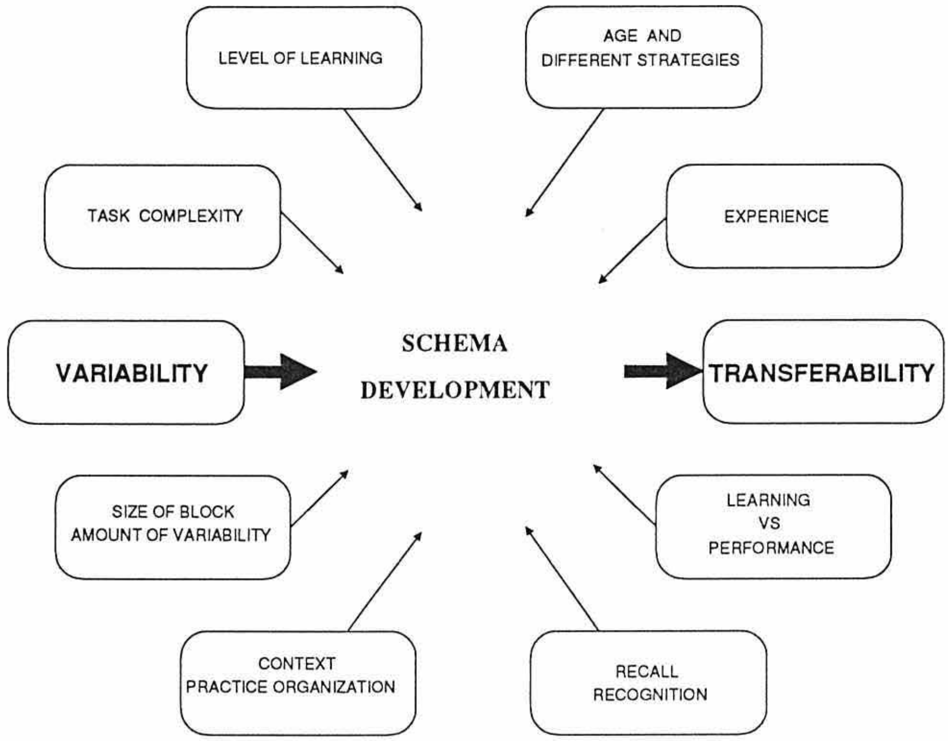


Figure 5.2:
Factors hypothesised as involved in schema development.

A Move Forward

To summarise then, the contextual interference issues that originated from the verbal learning literature (Battig, 1966) emerged at a time of considerable interest in the notion of schema, to influence theorising in the motor sphere (e.g., Shea and Morgan, 1979). These issues aroused particular interest over the prediction from Schmidt's (1975) schema theory that variability in practice will lead to enhanced retention and learning and thus manifest itself in subsequent transfer. As experimenters became acquainted with the idea of orienting around a target, changing the initial conditions, balancing out the proximity effects and introducing levels of variation, a *blocked* structure of practice was more often than not selected, not on the basis of any prior theorising, but because, given the nature of the types of tasks commonly devised, it was generally more practical to have one subject complete a number of trials from one location, than to change after each and ever trial.

The structure of practice was thus a fairly arbitrary one that naturally emerged as researchers sought convenient, controlled forms of variability in practice.

The question concerning the possible effects of presenting variability in an alternative way is thus a logical progression, and involves the more fundamental issue about the learning environment relative to the performer and the task.

In Summary

After introducing the traditional view of memory the argument was presented for a more dynamic and flexible view of the controlling system, and attention turned to the verbal domain where the Levels of Processing framework (Craik and Lockhart, 1972) and The Contextual Interference Effect (Battig, 1966) were introduced. Consideration was given to their relevance to motor control and their relationship to schema theory. Much of the existing data from schema theory research was reexamined in a fresh light. From these discussions, there emerged a number of factors that were identified as possible sources of influence on schema development, including age, level of learning and task complexity. As a logical progression of the preceding arguments and a possible move forward, the concept of task complexity was examined in greater detail as a factor which may generate similar effects to variability of practice, and may also account for differences in learning and transfer between adult and child subjects.

In the following chapters empirical evidence is presented to demonstrate that task complexity, level of learning and practice structure are indeed inter-related. As such, they have important implications for the structuring of an environment which is conducive to learning. Much of the confusion that has built up from seemingly conflicting and contradictory theoretical accounts begins to dissipate when this complex interaction is examined from a perspective that reflects a view of memory as a flexible and dynamic process. Within this the schema must have an almost infinite capacity for adaptation (albeit within a complex set of constraints).

The need for a model of control that can reconcile these viewpoints and capitalise on their commonalities is sought after and, so far, the schema notion still seems the most useful candidate for occupation of the central position.

CHAPTER SIX

Experiment One

The task selected initially for investigation was a variation on golf putting; a move away from the laboratory-type, button-pushing tasks more typically favoured by experimental researchers.

The investigation of the logic that complexity and variability of practice are likely to be inter-related and will interact in a systematic way, demands constructs which are operationally valid. The behavioural differences predicted in the preceding chapters have to be clearly seen in the performance of tasks which satisfy the observer that they reflect the underlying changes that we claim as *learning*.

The selection of a golf putting task through which differing conditions of practice and the effects of complexity might be observed was made on two grounds:

i) A variation of golf putting has been shown to be susceptible to variability manipulations (Moxley & Fazey, 1977b; Sanderson, 1986); and

ii) Operationalising the concept of complexity by increasing the *motoric* demands of this particular task (in this case by increasing the degrees of freedom), could be relatively easily achieved.

Whilst tasks might be classified according to a variety of criteria, the dimension of *complexity* is open to a number of different interpretations. With the type of task under consideration, however, Fitts' (1964) suggested criteria for classification proves particularly useful. Identifying the performer/operator as one element in the task and the object to be propelled as a second element, three permutations are possible with regard to whether the elements are moving or stationary – that is:

- Both elements stationary
- First element moving, second element stationary
- Both elements moving.

(Should the target be identified as a third element then six permutations become possible.)

Applying this classification to the task in question, levels of complexity might be reasonably categorised as follows:

- *Simple task* – Propel a stationary object from a stationary position
- *More complex task* – Propel a moving object from a stationary position
- *Most complex task* – Propel a moving object from a moving position.

In practical terms, these levels of complexity could thus be categorized as follows:

Putting to a target

- *Level 1* – Subject stationary, Ball stationary
- *Level 2* – Subject stationary, Ball moving
- *Level 3* – Subject moving, Ball moving

The theorising behind this study led to the conclusion that although the experimental subjects were not children but young adults (from sixteen to eighteen years of age), and the nature of the task was not perhaps entirely *novel* (although care was taken to ensure that no *golfers* of any level were included), the task could be made sufficiently different to generate the level of *novelty* required to produce a significantly enhanced performance on transfer to a novel variation of the task, for those subjects who had received practice in a *Random* organisation, as distinct from a *Constant* practice schedule (Moxley & Fazey, 1977b).

It was intended that the *Level One* complexity condition might be insufficient to produce any differences on transfer on account of:

i) in Schmidt's (1976) terms, the task being insufficiently novel, given the age of the subjects, and there would thus be little or no opportunity for any schema strengthening to occur (Moxley & Fazey, 1977b); or

ii) in terms of Contextual Interference Theory / Depth of Processing, the task would be too easy for the subjects, resulting in a mere repetition of each trial, and eliminating the level of cognitive effort required during the construction of an appropriate action plan each time, to facilitate memory, and enhance performance (Shea & Morgan, 1979).

It was recognised that even at *Level One*, random practice might be sufficient to induce a variability effect. If this were the case then considerable restructuring of the theoretical position would be necessary, as it would indicate that with young adults, random practice of variations of even familiar tasks will enhance transfer, and this has not generally been shown to be the case. Should the *Random* groups perform significantly better than the *Constant* groups on transfer, it would be reasonable to conclude that the action of putting on the opposite side to what is *natural* (i.e., a left-handed putt in the case of right-handed subjects), was, in itself, sufficiently *novel* to generate the kind of results that might only have been expected using young children as subjects (i.e., subjects whose schema(s) for producing the required action had had insufficient opportunity to develop).

At Complexity *Level Two*, however, it was predicted that the increase in the complexity of the task would be sufficient to produce the differences between the *Constant* and *Random* groups' performances on transfer, that might have failed to materialise at Complexity *Level One*.

By Complexity *Level Three*, this effect would be either more pronounced (i.e., an even greater difference at transfer between the *Constant* and *Random* practice conditions), or the complexity level would be too high, and result in what might be interpreted as:

i) the absence of any schema for performing the task, or an insufficient amount of practice to adequately adapt an existing schema to the point where it could accommodate the new variation; or

ii) a level of complexity too great to allow an appropriate action plan to be formulated, and thus preventing any processing from taking place from one trial to another.

In either event, the outcome would be the same: a return to the situation where there was no difference between *Constant* and *Random* groups on transfer, although this time, for possiblly quite different reasons.

The following hypothesis was thus formulated:

Hypothesis:

The level of complexity of the task being practiced and the structure of the practice will interact to generate different levels of performance on transfer to a novel variation of the task.

Method

Subjects

Thirty-six, right-handed, male high-school students (aged from sixteen to eighteen years).

Apparatus

A floor area was marked out so that a semi-circular grid was displayed with markings A, B, C, D, E and F, and then further subdivided into twenty units, as shown in Figure 6.1 on the following page. A circular marker indicated the spot from which the stationary ball was to be struck (Complexity *Levels One* and *Two*). A second marker indicated the point from which moving subjects (Complexity *Level Three*) would initiate their actions. Finally, a ball delivery apparatus was set up, consisting of an elevated tube inclined at an angle of 20° through which the ball was released, providing a delivery with consistent direction and velocity (Complexity *Levels Two* and *Three*).

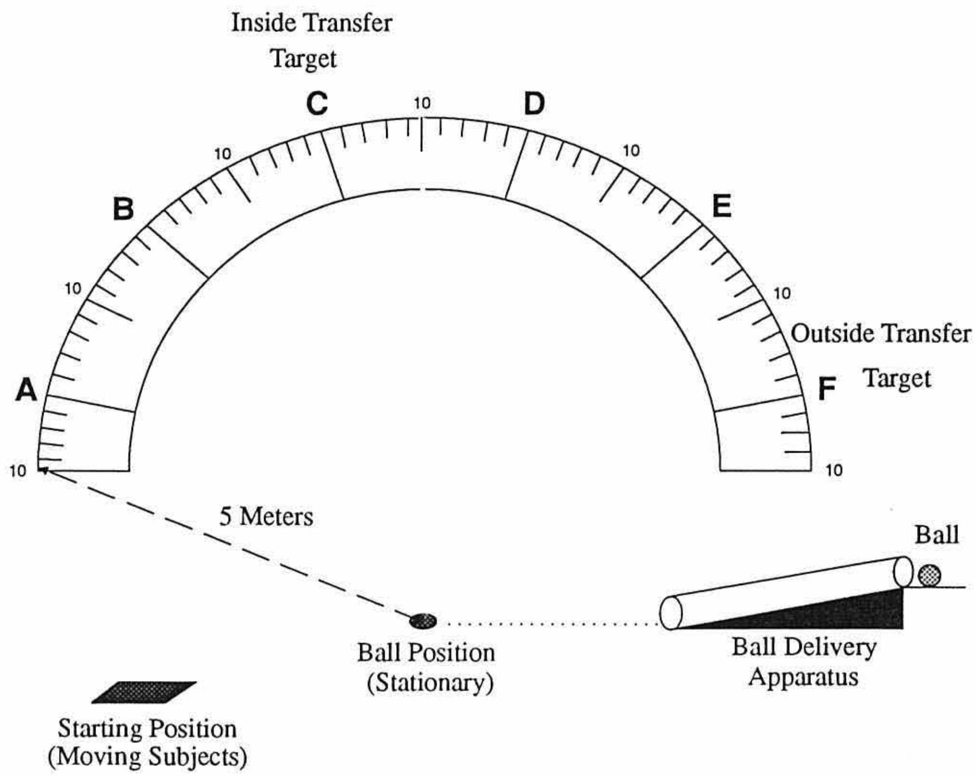


Figure 6.1 :
The experimental layout for the Golf Experiment

The three complexity levels were operationalised as follows:

- Complexity *Level One*: From a stationary position, subjects attempted to propel the ball from its fixed position on the circular marker, to a given target.

- Complexity *Level Two*: Subjects were positioned at the starting position as indicated in Figure 6.1, and instructed to move forward, simultaneously propelling the ball from its fixed position to the given target.

- Complexity *Level Three*: The ball was placed at the far end of the inclined tube, and subjects were instructed to leave their starting position as the ball was released. By the time the ball crossed the circular marker (the stationary ball position for Complexity *Levels One* and *Two*), subjects attempted to propel it towards the specified target, while still in motion themselves.

Acquisition Phase:

Subjects were randomly assigned to one of six groups of equal size. Half were given *Constant* practice and half were given *Random* practice. All subjects were required to putt with their left hand as the dominant hand (i.e., using a left-handed putter), thus providing an additional *novelty* aspect to the task for the exclusively right-handed participants. The object was to propel the ball as accurately as possible along a given trajectory towards a target. The amount of force applied was of no consequence, although over-enthusiastic subjects were requested to exert some restraint and propel the ball at a force appropriate to the indoor surroundings in which the experiment was being conducted.

The *Constant* practice groups practiced sixty trials to one of four different targets (A, B, D or E) and given KR after each successive trial. KR took the form of size of error from the specified target, as marked out on the floor in arbitrary units of equal size (e.g., *ten too far to the left*, or *sixteen too far to the right*).

The *Random* practice groups performed sixty trials with the same targets (A, B, D and E) presented totally randomly, with the proviso that no one target could be selected more than twice in succession, and that every twelve trials, each of the four targets had been selected three times.

The inter-trial interval was kept relatively constant for all groups (approximately ten seconds).

Transfer Phase

On completion of the acquisition phase, a five minute break was allowed for each subject. Subjects then performed twenty-four transfer trials: twelve to Target C (*Inside* transfer) and twelve to Target F (*Outside* transfer). Subjects alternated between these two modes of transfer in order to eliminate any possible retention effects that might have obscured the results. KR was withheld on transfer by the erection of a screen which prevented the subjects from viewing the target as they actually performed each trial. They were, however, permitted to see the target immediately prior to each attempt.

Data Analysis

Statistical analyses were performed on the transfer scores for Modulus of Constant Error (MCE) and Variable Error (VE).

Experimental Design

A three-way analysis of variance (ANOVA) with repeated measures on one factor was performed. For a schematic representation of the statistical design refer to Figure 6.2 below.

PRACTICE CONDITION	COMPLEXITY	n	TRANSFER Inside	TRANSFER Outside
CONSTANT	level 1	S1 - S6		
	level 2	S7 - S12		
	level 3	S13 - S18		
RANDOM	level 1	S19 - S24		
	level 2	S25 - S32		
	level 3	S33 - S36		

Figure 6.2 : Statistical Design for the Golf Experiment

Results and Discussion

The mean error scores were subjected to a 2 (Practice Conditions) by 3 (Complexity Levels) by 2 (Transfer Conditions) ANOVA with repeated measures on the last factor.

For Modulus of Constant Error (MCE), no significant main effects or interactions were revealed, although the *Complexity by Transfer* interaction approached significance ($F(2,30) = 3.13$; $p < .06$). The *Practice Condition by Complexity* interaction which was predicted to occur did not materialise (See Appendix 1.i. for a complete table of MCE results).

For Variable Error (VE), one significant main effect and one interaction were reported.

VARIABLE ERROR (VE)	
Main Effects	
Complexity:	F(2,30) = 9.17; p < .01
Interactions	
Complexity by Transfer:	F(2,30) = 3.61; p < .05

Table 6.1 :
Statistically significant main effects and interaction revealed in the ANOVA for Variable Error

The *Complexity* main effect was as expected, with Complexity *Level One* (the simplest of the three configurations) being significantly better than *Levels Two* and *Three*. Tukey's Multiple Comparison Procedure (Appendix 3.iii.) revealed that the more complex of the three tasks (*Level Two*) and the most complex (*Level Three*) were not significantly different from each other, although *Level Two* was very marginally better than *Level Three* (See Figure 6.3 on the following page), and both were significantly worse than *Level One*. The effect is generated to a large extent by the two-way interaction of *Complexity by Transfer*.

Critical Difference (Tukey HSD) > 3.52 units
F(2,30) = 9.17; p < .01

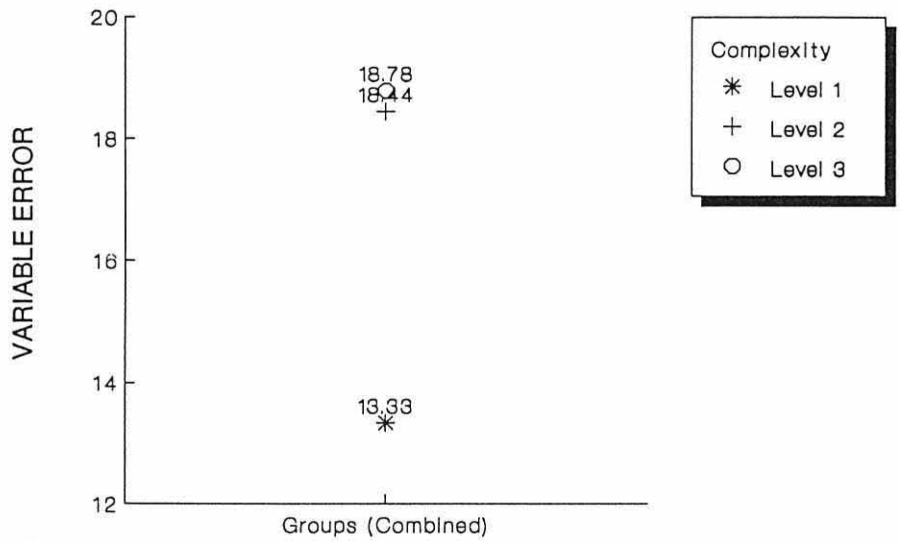


Figure 6.3 : (VE) Complexity Main Effect

In the *Complexity by Transfer* interaction (Table 6.1), Tukey's Multiple Comparison Procedure (Appendix 3.iv.) revealed only one significant difference; between Complexity *Level One* and Complexity *Level Two* on the Outside transfer condition. (It can be seen from Figure 6.4 that *Level Two* and *Level Three*'s, error scores on *Outside* transfer were almost identical, and, consequently, the difference between *Level One* and *Level Three* on *Outside* transfer, closely approaches significance).

Critical Difference (Tukey HSD) > 7.63 units
$F(2,30) = 3.61; p < .05$

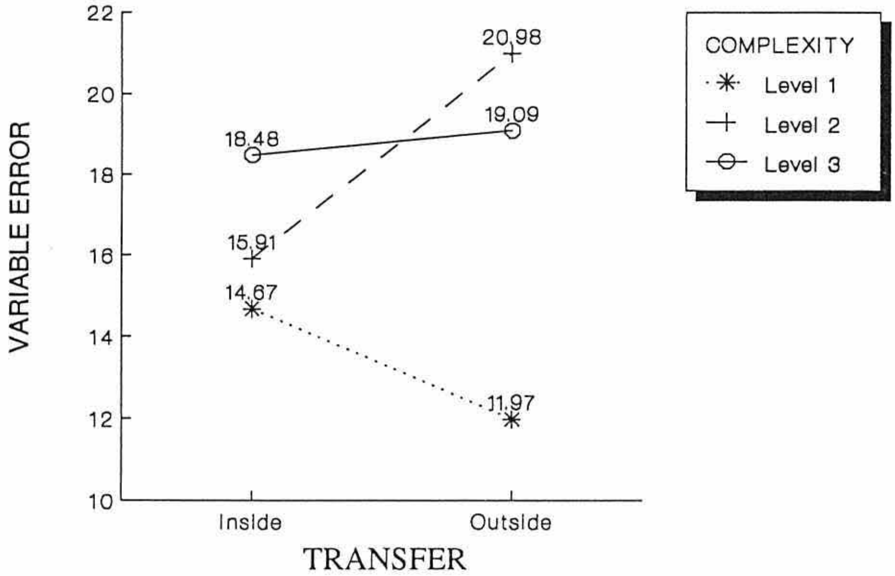


Figure 6.4 : (VE) Complexity by Transfer interaction

Henry's Root Mean Square Error (E) was calculated as an overall measure of variability, but failed to reveal any significant results (Refer to Appendix 1.v. for a complete table of results).

Clearly, the results of the study provide little support for the hypothesis. The order of the complexity levels suggests that to some extent the attempt to operationalise this concept by introducing additional components to the task, was not altogether inappropriate. It resulted in a greater number of errors being recorded on transfer, for the more *difficult* task configurations, irrespective of practice condition (*Constant / Random*) or type of transfer (*Inside / Outside*). The fact that no *Practice Condition* main effect occurred, nor any *Practice Condition by Complexity* interaction, suggests that perhaps the task itself was inappropriate in relation to the level of learning (age and/or experience) of the subjects. It could be that the modified putting task was not suitable for generating the kinds of variability effects that similar *field* studies have produced with children (e.g., Moxley's (1979) velcro-covered shuttlecocks task with elementary school children aged between six and eight years).

Whilst it is interesting to note that Complexity *Level One* subjects performed significantly better than their counterparts on the *Outside* transfer task, their increase in performance on *Outside* transfer from *Inside* transfer contrasts with the decrease in performance for *Level Two* subjects, although only marginal in both instances and not statistically significant. This rather confuses the issue.

It might be, of course, that we should accept the null hypothesis and reluctantly concede that complexity does not interact with different types of practice condition in the way envisaged, to act as a major source of influence on learning. Such a dismissal of the formally presented arguments, however, would be rather premature. In any empirical investigation conducted in the *field*, failure to maintain adequate control over extraneous variables all too easily results in subsequent misinterpretations of experimental findings.

The point should be noted that the decision to pursue a task in the *real* world in no way derived from any sense of inappropriateness with the type of tasks commonly employed in the laboratory. Whilst it may be true that button-pushing, for example, bears little relation to the kind of motor skills that are necessary in order to engage in regular sporting and physical activities, such tasks do not require justification in these terms. The laboratory provides a setting where the researcher possesses a high degree of control over the environment in which any observations and measurements are to be made. The *artificiality* of such an environment is inconsequential provided any subsequent claims emanating from the research are presented within the confines of the experimental methodology that has been employed. As long as caution is exerted in generalising empirical findings, valuable contributions to our understanding of motor behaviour can ensue.

Experiment One might thus be more appropriately regarded as a valuable pilot study at one end of the spectrum, and the subsequent investigations turn to the button-pushing, knock-down barrier world more commonly associated with the experimenter's laboratory.

CHAPTER SEVEN

Selecting An Appropriate Task.

To investigate the extent to which task complexity might exert an influence on predicting possible transfer affects, it was obviously necessary to select a task that had demonstrated its susceptibility to such effects, prior to introducing an element of complexity. An obvious choice was Lee, Magill and Weeks' (1985) knock-down barrier task.

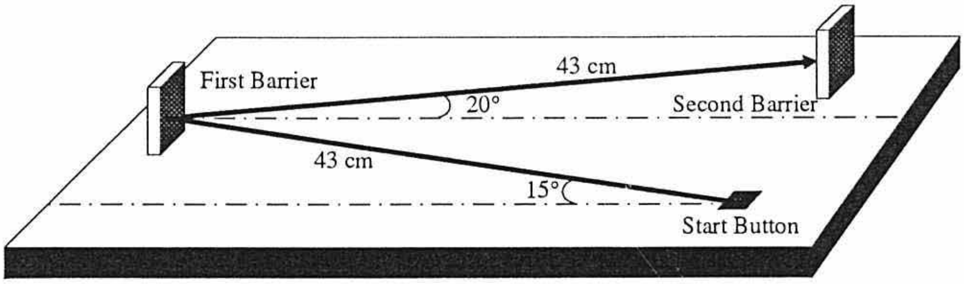


Figure 7.1 : Lee, Magill and Weeks' (1985) task

This task, illustrated on the previous page (Figure 7.1), required subjects to move from a depressed microswitch (start button) to knock over a hinged barrier measuring eight centimeters by eleven centimeters, and then reverse their movement and knock over a second barrier of equal proportions. A microswitch was attached to each barrier controlling the onset and offset of two ms timers. (For the exact experimental procedure, refer to Experiment Two, Chapter Eight.)

An initial pilot study tentatively suggested that this two-movement motor task might indeed have potential. Whilst the *Constant* practice groups out-performed the *Random* practice groups in the predicted way, there were, however, no statistically significant results. Although the apparatus and experimental procedure replicated that of Lee, Magill and Weeks' (1985) study, it failed to replicate their results.

A possible contributory factor might have been that unlike Lee, Magill and Weeks (1985), subjects in this current study were not Physical Education students, nor were they participating in the experiment for course credit. During this initial study it was noted that a lack of interest or motivation was quite discernible in the attitude of some of the participants. This observation was reinforced by the post-experimental comments that the subjects were invited to make.

Whilst it is recognised that Lee, Magill and Weeks' (1985) subjects were naive as to the purpose of the experiment, it is nevertheless, not unreasonable to suppose that Physical Education students participating in an experiment for course credit might be more suitable as subjects: extrinsic motivation in the form of course credit may well just be an additional factor to both a general interest in motor control issues, and a greater familiarity with laboratory-type experimental procedure. Whilst randomization should be sufficient to control any within-subject motivational differences that might exist, members of the *Constant* practice groups are inevitably more susceptible to lapses of concentration by virtue of the fact they are required to practise the same simple motor task sixty consecutive times. A second pilot study was thus conducted with slight modifications intended to enhance motivation.

The procedure for this second study was identical to that of the first but with the additional feature that subsequent to each practice trial, subjects were awarded a number of points depending on the accuracy of their performance. These points were displayed as an accumulative score after each trial.

The results of this second pilot study suggested that this two-movement rapid timing task was indeed susceptible to the kind of transfer effects predicted by Schmidt (1975, 1976) and the Variability of Practice Hypothesis (Moxley, 1979).

Whilst the literature indicates that:

> *"(Predicted) ... differences appear to be largely easier to demonstrate with children than with adults"*
>
> (Shapiro and Schmidt, 1982. p. 143)

the selected task appeared to be sufficiently *novel* to generate variability effects with adults. The next step was thus to run the experiment with a larger sample, and introduce an element of complexity in order to empirically evaluate the influence that this additional factor might exert on the degree of transferability that could be predicted.

Defining Levels of Complexity

It has already been argued that *complexity* is a relative term. Whilst the independent characteristics of a motor task may well have some identifiable elements that could be classified according to the demands they place on the performer (E.g., *Fleishman's 1984 Taxonomies of Human Performance*), a perceived level of complexity must be directly proportional and inextricably related to the subject's previous experience and level of learning. In other words, the task can only be regarded as *complex* until a sufficient amount of practice and experience can render it *simple*, and capable of being performed with ease. What was initially a highly attention-demanding task now requires relatively little attention in order to be successfully accomplished.

Whilst it may not be possible to delineate a level of complexity *per se*, it is, however, quite feasible to operationalise the concept by increasing the demands of a task. This may be accomplished by increasing the number of degrees of freedom (an approach adopted in the *Golf* pilot study reported at the end of this chapter), or by introducing additional components, including changes of direction, to a task. Whilst the number of demands within a task can be increased, it is important to ensure that such increases are *motoric* in nature, and not simply adding to the perceptual or attentional loads that are placed upon the performer.

Using Lee, Magill and Weeks' (1985) task, complexity levels were operationalised by requiring subjects to make additional reverse movements in order to complete a trial. The apparatus was modified to include five additional knock-down, hinged barriers, and a second starting button. Depending on the level of complexity, the procedure was as follows:

Complexity Level 1

Subjects were required to move from the depressed switch (Button A) to knock over Barrier Three and then reverse their movement to knock over Barrier Seven. (See Figure 7.2 below.)

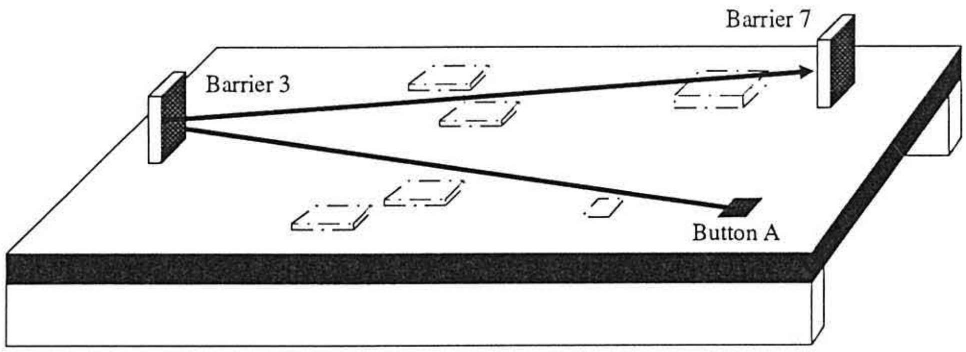


Figure 7.2 : Complexity Level One task

Complexity Level 2

(i) Subjects moved from the depressed switch (Button A) to knock over Barrier Three. They then reversed their movement to knock over Barriers Four and Five in the direction indicated, before completing a third movement reversal to knock over Barrier Six. (See Figure 7.3 on the following page.)

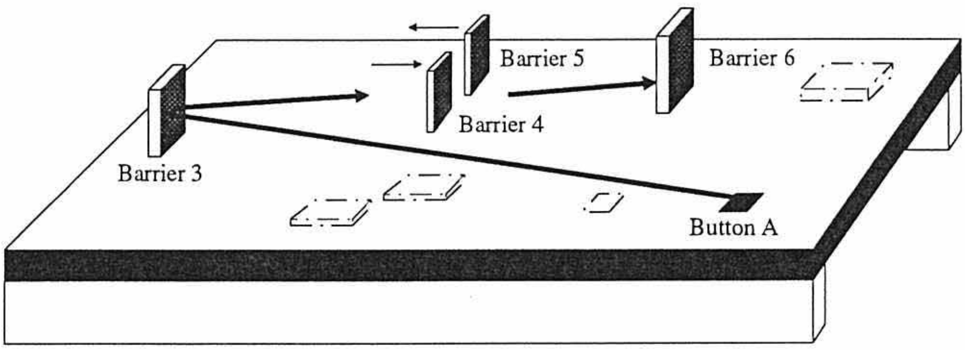


Figure 7.3 : Complexity Level Two task

alternatively

(ii) Subjects moved from the depressed switch (Button B) to knock over Barriers One and Two in the direction indicated, and Barrier Three. They then reversed their movement again to knock over Barrier Seven. (See Figure 7.4 below.)

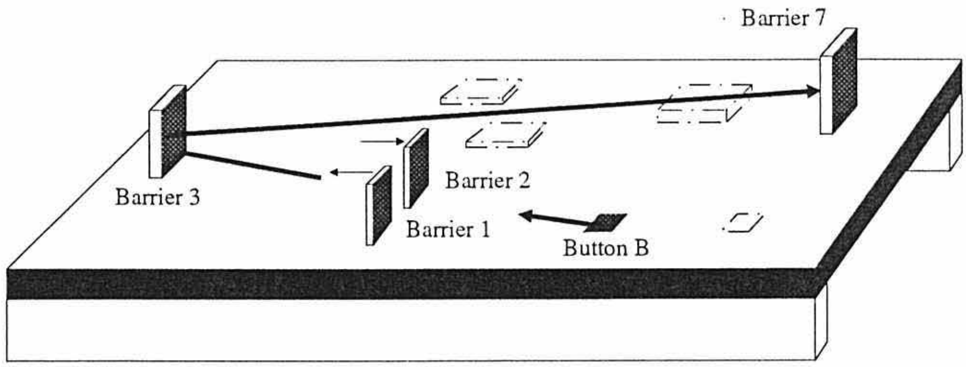


Figure 7.4 : Complexity Level Two task

Complexity Level 3

Subjects were required to move from the depressed switch (Button B) to knock over Barriers One and Two and then knock down Barrier Three. This whole movement was then reversed with Barriers Four and Five being knocked down prior to Barrier Six. (See Figure 7.5 below.)

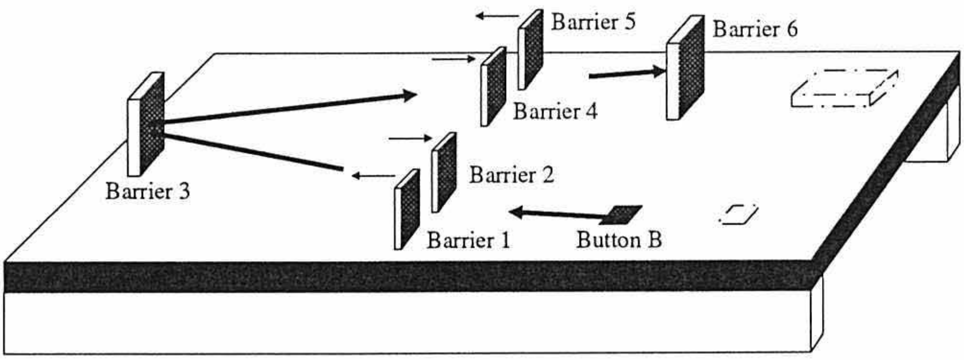


Figure 7.5 : Complexity Level Three task

The initial pilot studies have already suggested that this kind of task (at least as far as Complexity *Level One* is concerned) is susceptible to transfer effects. Were the task any less complex, then such transfer effects may only be possible to demonstrate with children as subjects. As things are, at Complexity *Level One*, the task has already proved sufficiently complex (or *novel*) to produce differences in *Constant* and *Random* practice groups using adult subjects.

Extending the arguments presented in Chapter Six, it follows that, by implication, as the task becomes more complex, less randomness is necessary to induce variability effects. As complexity increases, the relative level of learning of the subject decreases to the point where the task takes on the characteristics of being totally *novel*. (Viewed another way, the adult subject's level of learning relative to the complex task is equivalent to the child's level of learning relative to the simple task. Both tasks are thus sufficiently *novel* to produce the predicted transfer effects.) Conversely, as the task becomes more simple and the relative level of learning of the performer increases, the amount of randomness required to generate variability effects is also increased.

There will of course be a cut-off point where the complexity level becomes too high for the task to be performed. As this stage approaches, the difference between *Constant* and *Random* groups will decline along with the general decline in performance score for both groups.

Experiment Two (Chapter Eight) was conducted to investigate these possible effects using two practice conditions (*Constant* and *Random*), and the three levels of complexity (Complexity *Level One – Simple*; Complexity *Level Two – Intermediate*; and Complexity *Level Three – Complex*).

CHAPTER EIGHT

Experiment Two

There are really three predictions to be considered in the following experiment, each of which relates to a separate level of complexity. Whilst overall, it is intended to demonstrate a *Practice Condition by Complexity* interaction, indicating that complexity is an identifiable source of influence on schema development and learning, in what form and direction might this interaction reasonably be expected to manifest itself? The answer ultimately must be determined by how accurately this concept of complexity has been operationalised in the modified version of Lee, Magill and Weeks' (1985) apparatus. Complexity labels *One*, *Two* and *Three* have been attached to the various task configurations. In the absence of any absolute complexity scale of reference these designations have been primarily based on the idea that complexity is in some way determined by the number of degrees of freedom to be controlled in executing the task (Schmidt, 1991). It would seem reasonable to speculate that a single reversal movement is the *least* complex of the three task variations, an additional reversal is *more* complex, and two additional movement reversals constitute the *most* complex.

We have ascertained, through previous pilot studies, that configuration One (Complexity *Level One*) is susceptible to variability effects, so an initial hypothesis predicting enhanced performance on transfer at Complexity *Level One*, would seem in order. Given that the levels of complexity have been appropriately gauged, it may be hypothesised that the following results will be forthcoming:

At Complexity *Level One*, the *Random* group would out-perform the *Constant* group on transfer.

At Complexity *Level Two*, the difference between these two practice conditions on transfer would be more pronounced; an effect similar to that which might be expected on *Level One* using children as experimental subjects rather than adults. (If, of course, the level of *randomness* is sufficient to produce strong variability effects at Complexity *Level One*, then it does not necessarily follow that more pronounced differenced will be observed at Complexity *Level Two*.)

By Complexity *Level Three*, there are two obvious possibilities. Either there will be a continuation of the effects predicted at *Level Two* (i.e., the differences on transfer between *Constant* and *Random* practice conditions would be even more significant, and consequently, greater confidence that such findings could be easily replicated), or the task will be *too* complex, and the differences between *Constant* and *Random* practice conditions on transfer will either revert back to those observed at *Level One*, or fail to materialise at all.

Hypotheses

The above hypotheses can be summarised as:

The level of complexity of the task being practiced and the structure of the practice will interact to generate different levels of performance on transfer to a novel variation of the task.

Method

Subjects:

Twenty-four, right-handed Physical Education students served as subjects: Four per group (two male / two female).

Apparatus:

Subjects were required to move from a depressed switch to knock over a sequence of 8 x 11 cm. hinged barriers using an arm reversal swing. The course and direction of the movement for each level of complexity is described above (See Figures 7.2, 7.3, 7.4 and 7.5.) Although the apparatus was modified to introduce levels of complexity, the specifications adopted by Lee, Magill and Weeks (1985) were adhered to. Thus the movement distance from Button A to Barrier Three of 43 cm (see Figure 7.1) was equal to the calculated distance moved from Button B to Barrier Three, via the extra two barriers – Barrier One and Two (see Figure 7.4). Similarly, the same was true moving from Barrier Three to Barrier Six via Barrier Four and Five (see Figure 7.3).

A series of micro switches interfaced with a 380Z Research Machine enabled the movement times to be recorded. Each movement time was divided into two parts: The initial half of the movement being from the depressed switch (Button A or B) to Barrier Three, and the latter half of the movement, from Barrier Three to the final barrier (Barrier Six or Seven).

Procedure:

Each subject practiced an arm movement as accurately as possible to a given criterion time. An acquisition phase consisting of sixty trials was followed by a transfer phase of twenty-four trials.

Acquisition Phase

Subjects were randomly assigned to one of six groups of equal size. Half were given *Constant* practice, and half were given *Random* practice.

The *Constant* practice groups practised sixty trials at one of four different movement criterion times: (1) 500–900 ; (2) 600–800 ; (3) 800–500 ; (4) 900–600. (For example, the target time of 500–900 required the subject to move from the depressed switch (Button A or B) to Barrier Three in a movement time of 500 msecs., and from Barrier Three to the final barrier (Barrier Six or Seven) in 900 msecs., as accurately as possible.)

The *Random* practice groups performed sixty trials with the same target times presented totally randomly with the proviso that no one target time could be performed more than twice in succession, and that every twelve trials, each of the four target times had been presented three times.

A T.V. monitor displayed the *Target Time* for each trial, and subjects were instructed to *Begin When Ready* . KR was provided after each trial and displayed as *Actual Time.* The inter-trial interval was kept relatively constant for all groups (approx. 10 secs.).

The point scoring system introduced to enhance motivation enabled subjects to score from one to seven points depending on the accuracy of their trial times. Their accumulative score was displayed on the monitor after each trial.

Practice trial scores that failed to achieve at least 60% of the criterion target time were not accepted and subjects were informed that the trial was *Not Accurate Enough ... Please Repeat.*

Transfer Phase

On completion of the acquisition phase a brief five minute break was provided for each subject. During transfer, all subjects performed either twelve trials with a target time of 700–700 (*inside transfer*), followed immediately by a further twelve trials of target time 1000–1000 (*outside transfer*), or alternatively twelve *outside* trials followed by a further 12 *inside* transfer trials. Having subjects alternate between these two modes of transfer was intended to eliminate the possibility of any simple retention effects that might influence the interpretation of the experimental results. No KR was available during the transfer phase.

Data Analysis

Transfer scores were transformed into signed error scores. Statistical analyses were performed for Modulus of Constant Error (MCE), Variable Error (VE) and Henry's Root Mean Square Error (E) (See Figure 8.6 for the experimental design).

Lee, Magill and Weeks (1985) included *segments* as a separate factor in their design, where segment one was the initial movement from the depressed switch to the first hinged barrier, and segment two was the reverse movement to the second barrier. Their reasoning was that:

> *"Some researchers (e.g., see Quinn & Sherwood, 1983) have argued that a movement reversal requires 2 separate motor programmes, while altering the velocity of a continuous arm swing involves reparameterisation of the same motor programme. This modification was made, in part, with the intent that experience from each movement segment would lead towards the development of only one generalised motor programme."*
>
> (Lee, Magill & Weeks, 1985, p. 297)

Movement segments were not included as a separate factor in this study for the following two reasons:

1. Although Lee, Magill & Weeks found a significant Groups x Segments interaction on the transfer phase of their initial experiment, they failed to replicate these findings in a subsequent re-run. In the pilot studies performed earlier, no significant effects for segments were recorded, and including segments as a factor seemed to unnecessarily complicate the analysis.

2. This study is not concerned about motor programmes *per se*. The issue is about the organisation of *output* by a schema which may well consist of more than one motor programme. Moving away from Schmidt's (1975, 1976) idea of the schema as a *generalised motor programme*, the schema is seen as containing all the information that is necessary to generate one or more motor programmes. This is in contrast to the idea of a schema containing a generalised motor programme that has to have its parameters adjusted to meet the requirements of a given situation. (For a detailed view of the Schema refer to Chapter 4.)

Experimental Design

A three-way analysis of variance with repeated measures on one factor was performed. For a schematic representation of the statistical design, refer to Figure 8.1 on the following page.

PRACTICE CONDITION	COMPLEXITY	n	TRANSFER inside	TRANSFER outside
CONSTANT	level 1	S1 - S4		
	level 2	S5 - S8		
	level 3	S9 - S12		
RANDOM	level 1	S13 - S16		
	level 2	S17 - S20		
	level 3	S21 - S24		

Figure 8.1 : Statistical Design for Experiment Two

Results and Discussion

The mean error scores were subjected to a 2 (Practice Conditions) by 3 (Complexity Levels) by 2 (Transfer Conditions) ANOVA with repeated measures on the last factor.

For Modulus of Constant Error two significant main effects and two significant interactions were revealed. (Refer to Appendix 1.i. for a complete table of results.)

MODULUS OF CONSTANT ERROR (MCE)	
Main Effects	
Practice Condition:	$F(1,18) = 26.38; p < .001$
Complexity:	$F(2,18) = 8.6; p < .001$
Interactions	
Prac. Cond. by Comp. :	$F(2,18) = 3.68; p < .05$
Prac. Cond. by Transfer:	$F(1,18) = 6.57; p < .05$

Table 8.1 :
Statistically significant main effects and interactions revealed in the ANOVA for Modulus of CE

The significant *Practice Condition* by *Complexity* interaction ($F(2,18) = 3.68$; $p < .05$) is of most immediate relevance to the experimental hypothesis (See Fig. 8.2 below).

Critical Difference (Tukey HSD) > 79.79

$F(2,18) = 3.68$; $p < .05$

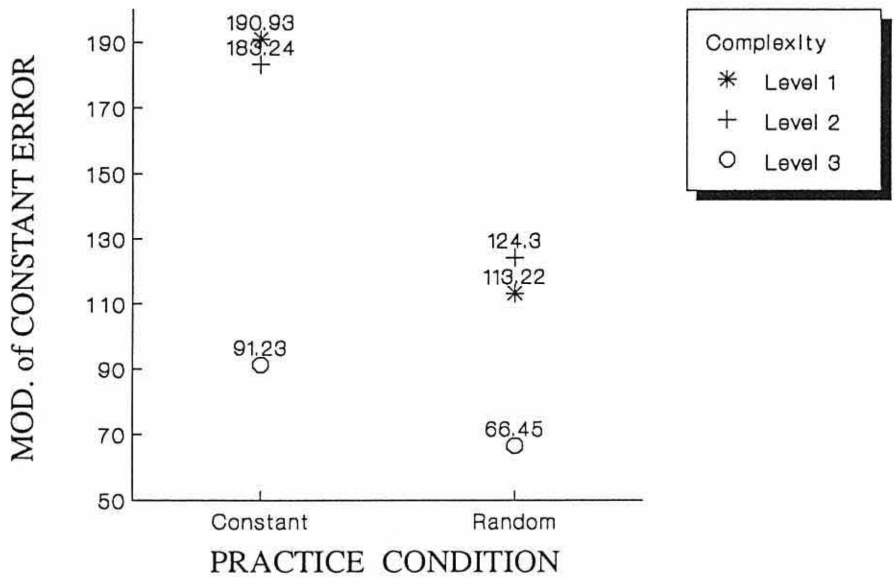


Figure 8.2 : (MCE) Practice Condition by Complexity

Tukey's Multiple Comparison Procedure (Appendix 1.iii.) revealed that the *Random* groups at Complexity *Level One* and Complexity *Level Two* were significantly better than both *Level One* and *Level Two Constant* groups.

At each level of complexity the *Random* groups are out-performing the *Constant* groups (although the difference in performance is not statistically significant in each case). Whilst at *Level One* this difference in performance is significant, and at *Level Two* it is approaching significance, the trend at *Level Three* is not supported statistically. This appears contrary to the hypothesis which predicted the largest increase in performance on transfer to be observed at *Level Three* (the most difficult). It is also interesting to note that the *Constant Level Three* group is significantly better than either *Level One* or *Level Two Constant* groups: a position accounted for by the influence of complexity, and readily interpreted as evidence of a Contextual Interference effect. Any explanation of these Modulus of Constant Error results, however, is somewhat premature until a more complete perspective of the overall performance of the practice groups can be ascertained by consideration of the Variable Error results.

The *Practice Condition by Transfer* interaction ($F(1,18) = 6.57$; $p < .05$), after undergoing Tukey's Multiple Comparison procedure (Appendix 2.iv.), revealed that for the *Constant* practice group, their performance was significantly worse on the *Outside Transfer* condition com-

Critical Difference (Tukey HSD) >

$F(1,18) = 6.57$; $p < .05$

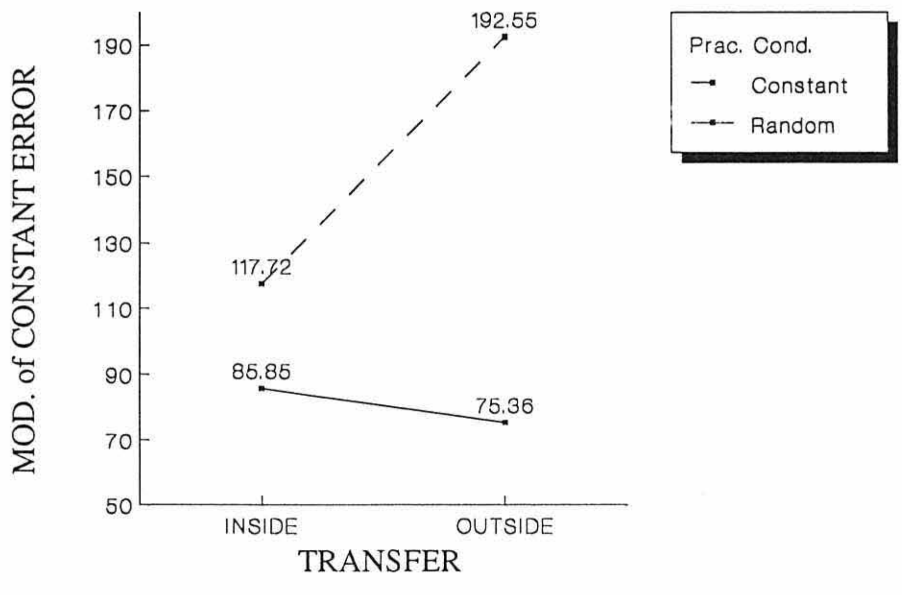


Figure 8.3 : (MCE) Practice Condition by Transfer

pared to the *Inside Transfer* condition, while the *Random* group maintained a similar performance level throughout transfer. There was also a significant difference between the *Constant* and *Random* groups on *Outside Transfer*. The graph above (Figure 8.3) shows the *Practice Condition* by *Transfer* interaction, with Complexity Levels collapsed.

The main effect for *Practice Condition* (F(1,18) = 26.38; p < .001) is a reflection of the overall difference between the *Constant* and

Critical Difference (Tukey HSD) > 66.6

F(1,18) = 6.57; p < .05

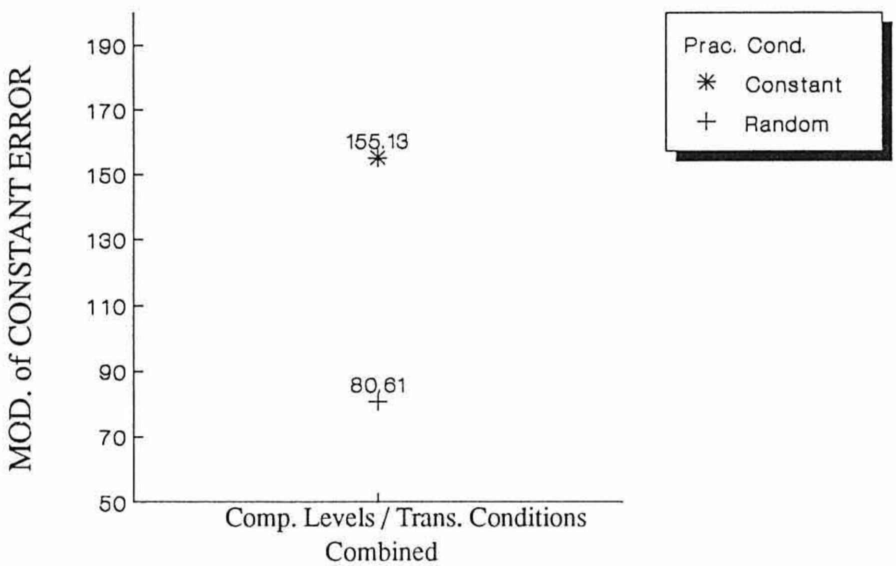


Figure 8.4 : (MCE) Practice Condition Main Effect

Random practice condition, irrespective of the level of complexity, across all transfer trials (See Fig. 8.4 above). This result was predicted as the previous pilot studies had already demonstrated the task's susceptibility to Variability effects.

A main effect for *Complexity* (F(2,18) = 8.6; p < .005), whilst not surprising in itself, was unusual in so far as the order in which the error scores increased across the three levels (See Figure 8.5 below).

Critical Difference (Tukey HSD) > 45.34

F(2,18) = 8.6; p < .005

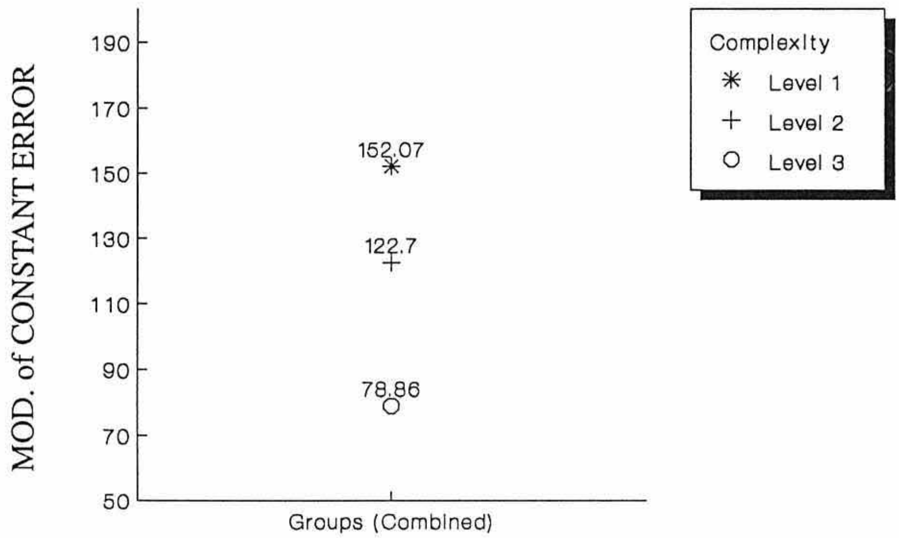


Figure 8.5 : (MCE) Complexity Main Effect

Tukey's Multiple Comparison procedure (Appendix 2.11.) revealed the only significant difference to be between *Level One* and *Level Three*, although the difference between *Levels Two* and *Three* approached significance. Intuitively one would have expected the increase in complexity to have been accompanied by an increase in error. The opposite was the case, however. A possible explanation for this result might be that for subjects in the *Level One* condition, and to a lesser extent in the *Level Two* condition, there was more scope for completing the movement too quickly (and thus generating a high Modulus of Constant Error score) than for subjects in the *Level Three* condition. The reason being that in the Complexity *Level Three* condition, subjects were required to make five separate movement reversals in order to complete one trial. In other words, had a subject attempted to complete a trial at Complexity *Level Three* in as short a time as possible, his Modulus of Constant Error score would be lower than that of a similar subject at Complexity *Level One* simply because the complexity of the movement necessitates a greater length of time to complete (although the distance moved remains approximately constant at 43 msec.). This result for Modulus of Constant Error considered in isolation to any Variable Error information would thus be of limited interest. The alternative view is that the complexity manipulation generated an effect equivalent to that obtained by varying practice. That is that increasing the complexity of a movement is in itself sufficient to support transfer. This could possiblly be explained in a contextual interference way or by considering the amount of variability between trials (the number of mistakes made in practice).

For Variable Error two main effects were reported and no interactions. For a complete table of results refer to Appendix 2.v.

VARIABLE ERROR (VE)	
Main Effects	
Complexity:	$F(2,18) = 7.37; p < .01$
Transfer:	$F(1,18) = 41.52; p < .001$

Table 8.2 :

Statistically significant main effects revealed in ANOVA for VE (No significant interactions were reported).

The main effect for *Transfer* ($F(1,18) = 41.52$; $p < .000$) reflected the deterioration in performance (in so far as how consistent subjects were around their own mean scores) during the *outside* transfer condition compared to the *inside* transfer condition, irrespective of practice condition or complexity level (See Figure 8.6 below).

$F(1,18) = 41.52$; $p < .000$

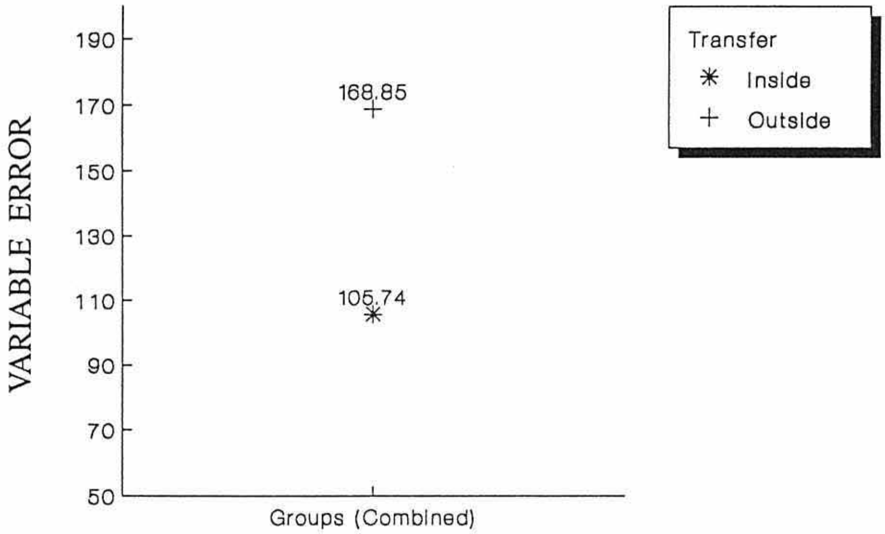


Figure 8.6 : (VE) Transfer Main Effect

For the *Complexity* main effect ($F(2,18) = 7.37$; $p < .005$), Tukey's follow-up test revealed a significant difference between *Level Two* and the other levels of complexity (Appendix 2.vi.). At Complexity Level *One* and *Level Three* subjects were equally consistent in their performance, but at the *Level Two* condition, Variable Error scores were significantly higher (see Figure 8.7 below.)

Critical Difference (Tukey HSD) > 39.49 msecs.
$F(2,18) = 7.37$; $p < .005$

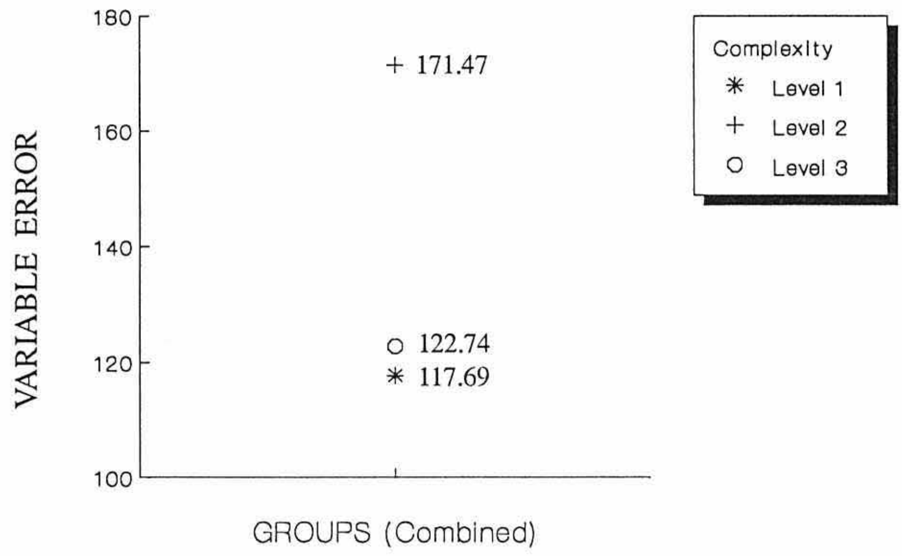


Figure 8.7 : (VE) Complexity Main Effect

Looking at the Modulus of Constant Error (MCE) and Variable Error (VE) scores for *Complexity*, subjects in the *Level Two* condition, whilst performing no worse than those in *Level One*, were far less consistent. In what was presumed to be the most complex condition (*Level Three*) subjects appeared to not only perform at least as well as in the other two conditions, but were as consistent around their own mean scores as subjects in *Level One*. No *Practice Condition by Complexity* interaction was reported for Variable Error.

As a measure of total variability, Henry's Root Mean Square Error was calculated, giving an indication of the overall accuracy achieved. (Henry's Root Mean Square Error (E) was calculated in preference to Absolute Error (AE) in the light of the reservations expressed by Schutz and Roy (1973), regarding the uncertain contribution of CE and VE in calculating the final error score. The more simple combination of CE and VE used by Henry makes interpretation of E far easier than that of AE.)

Three main effects were reported:

HENRY'S ROOT MEAN SQUARE ERROR (E)	
Main Effects	
Practice Condition:	$F(1,18) = 27.35$; $p < .000$
Complexity:	$F(2,18) = 17.08$; $p < .000$
Transfer:	$F(1,18) = 24.53$; $p < .000$

Table 8.3 :
Statistically significant main effects revealed in the ANOVA for Henry's Error Score (No significant interactions were reported).

There were no significant interactions. For a full table of results refer to Appendix 2.vii

The main effect for *Practice Condition* again reflected the superior performance of the *Random* practice condition over the *Constant* practice condition. Similarly, the *Transfer* main effect showed once more a deterioration in overall accuracy on the *outside* transfer condition compared to the *inside* transfer condition. The *Complexity* main effect was the least expected (see Figure 8.8) in that subjects in the most complex of the three conditions (*Level Three*) performed significantly more accurately than those in either *Level One* or *Level Two* (For details of Tukey's follow-up procedure see Appendix 2.viii.)

Critical Difference (Tukey HSD) > 31.54

F(2,18) = 17.08; p < .000

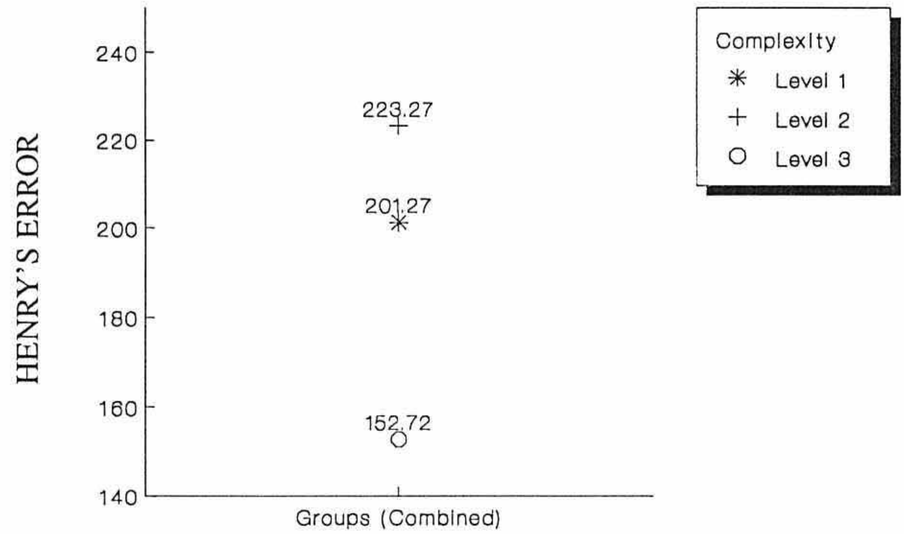


Figure 8.8 : (Henry's E) Complexity Main Effect

A table summarizing the results of Experiment Two is presented below (Table 8.4).

Main Effects	Probability of F–ratios in ANOVAs		
	MCE	VE	E
Practice Condition	.001	N/S	.001
Complexity	.001	.01	.001
Transfer	N/S	.001	.001
Interactions	**Probability of F–ratios in ANOVAs**		
	MCE	**VE**	**E**
Prac. Cond. by Complexity	.05	N/S	N/S
Prac. Cond. by Transfer	.05	N/S	N/S
Complexity by Transfer	N/S	N/S	N/S
Prac. Cond. by Complexity by Transfer	N/S	N/S	N/S

Table 8.4 :
A summary of the results for EXPERIMENT TWO showing the probability of the F–ratios in the relevant ANOVAs (Appendices 1.i., 1.v., & 1.vii.) and indicating (N/S) where these are greater than 5%.

The hypotheses seem to have been partially supported, with the predicted *Practice Condition by Complexity* interaction revealed in Modulus of Constant Error. Whilst this interaction did not reveal the largest increase in performance on transfer to be observed at the *Level Three* condition of complexity (as predicted by the hypothesis), nevertheless, the order of the complexity levels on transfer with *Level Three* out-performing *Levels One* and *Two* in both *Constant* and *Random* practice conditions (see Fig. 8.2), strongly suggests that in some way complexity is a determining factor in achieving enhanced performance on transfer. Whilst the task then is obviously susceptible to the *Variability of Practice Hypothesis* transfer effects, at this stage, manipulating the level of complexity has not produced interactions in any easily identifiable pattern. The results have, however, strongly indicated that task complexity is an additionally potentially important factor. The *Practice Condition by Transfer* interaction (Fig.8.2), which showed a reduction in performance (MCE) for the *Constant* practice group on the *outside* transfer, clearly supports earlier findings (Lee, Magill and Weeks, 1983), and pilot studies show that in some way the task is susceptible to varied practice effects.

If the logic is correct, the fact that subjects in Complexity Level *Three* consistently performed at least as well as, if not better than, those in *Levels One* and *Two*, suggests that perhaps *Level Three* is not actually the most complex of the three task configurations. It could be that repeating the movement from *Button B* to *Barrier Three* (in reverse) to complete a trial (i.e., from *Barrier Three* to *Barrier Seven*) in *Level Three* is, in fact, easier than the configuration in *Level Two* where only half the trial requires the extra movement reversals. That is to say, the uniformity of the *Level Three* condition, where the latter half of the movement becomes merely a repetition (albeit a mirror image) of the former portion of the movement, necessitates no alteration in the fundamental *rhythm* of the movement, just a variation in the speed of execution. It could be argued that in producing the second half of the movement, only one global timing parameter in the controlling programme has to be changed.

It was recognised that a limitation in Experiment Two was the small number of subjects per group (n = 4). Such a small sample size obviously reduces the probability of obtaining statistically significant differences in order to maintain an appropriately powerful experimental design. However, the basic approach now common in psychophysics and neuro-behavioural research of replicating findings obtained in small sample experiments was favoured, and a third experiment (Experiment Three) is reported which sheds more light on the nature of the transfer effects that might be predicted under different levels of complexity.

CHAPTER NINE

Experiment Three

The methodology and procedure for Experiment Three replicated that of the previous experiment but the number of subjects per group was doubled (n=8)*. Similarly, the hypotheses formulated for Experiment Two remained unchanged, except in respect of examining performance levels at the end of practice.

Experimental Design

As in the previous experiment, a three-way analysis of variance with repeated measures on one factor was performed, the factors being:

* See Note 1 at the end of this chapter (Page 206).

- Practice Condition (2) – *Constant* and *Random*;
- Complexity (3) – *Level One*, *Level Two*, and *Level Three*;
- Blocks (3) – The last 12 *Practice* trials, *Inside* Transfer and *Outside* Transfer.

A schematic representation of the statistical design is given in Fig. 9.1.

PRACTICE CONDITION	**COMPLEXITY**	**n**	**BLOCKS** last 12 practice trials	inside transfer	outside transfer
CONSTANT	level 1	S1 - S8			
	level 2	S9 - S16			
	level 3	S17 - S24			
RANDOM	level 1	S25 - S32			
	level 2	S33 - S40			
	level 3	S41 - S48			

Figure 9.1 : Statistical Design for Experiment Three

Results and Discussion

Mean error scores were subjected to a 2 (Practice Conditions) by 3 (Complexity Levels) by 3 (Blocks) ANOVA with repeated measures on the last factor.

For Modulus of Constant Error (MCE) three significant main effects and one significant interaction were reported statistically significant: See Table 9.1 below.

MODULUS OF CONSTANT ERROR (MCE)	
Main Effects	
Practice Condition:	$F(1,42) = 6.96; p < .05$
Complexity:	$F(2,42) = 3.92; p < .05$
Blocks:	$F(2,84) = 36.05; p < .001$
Interactions	
Prac. Cond. by Blocks:	$F(2,84) = 8.69; p < .001$

Table 9.1 :

Statistically significant main effects and interactions revealed in the ANOVA for Modulus of CE.

Refer to Appendix 3.i. for a complete table of results.

The *Complexity* main effect (see Appendix 3.ii for details of Tukey's follow-up test) revealed a significant difference between complexity *Levels One* and *Three* ($F(2,42) = 3.92$; $p < .05$). This result replicated that of Experiment Two as can be seen from the graphs below (Fig. 9.2), with the three levels of complexity again arranged in an order contrary to that which would intuitively be predicted. Once again the only significant difference lay between Complexity *Level One* (inferior performance) and *Level Three* (superior performance), although in both cases, the differences between both *Level One* and *Level Three*, and *Level Two* and *Level Three* also approached significance.

EXPERIMENT TWO
MCE : Complexity

Critical Difference (Tukey HSD) > 45.34

$F(2,18) = 8.60$; $p < .005$

EXPERIMENT THREE
MCE : Complexity

Critical Difference (Tukey HSD) > 31.01

$F(2,42) = 3.92$; $p < .05$

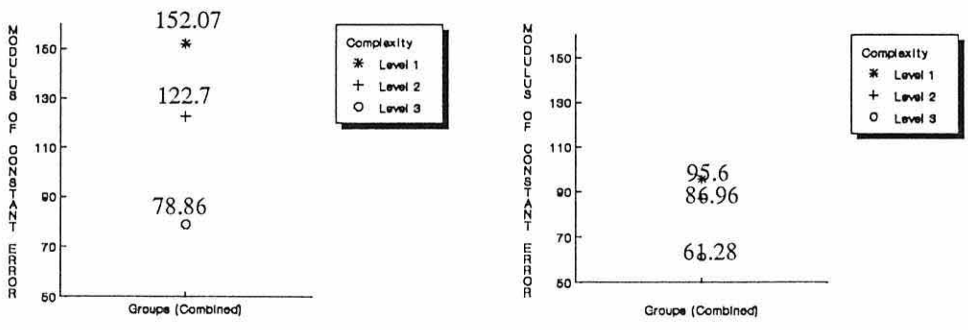


Figure 9.2 : (MCE) Complexity Main Effects (Exp. 2 & 3)

Regarding the *Blocks* main effect reported for Modulus of CE, follow-up tests revealed differences between each condition: – i.e., differences between performance at the end of the *Practice* condition and both transfer conditions, and between the *Inside* and *Outside* transfer conditions (See Figure 9.3 below). Not surprisingly, the performance at the end of *Practice* was significantly better than performance on *Inside* transfer, across all groups, which in turn was significantly better than performance on *Outside* transfer.

Critical Difference (Tukey HSD) > 26.67
F(2,84) = 36.05; p < .001

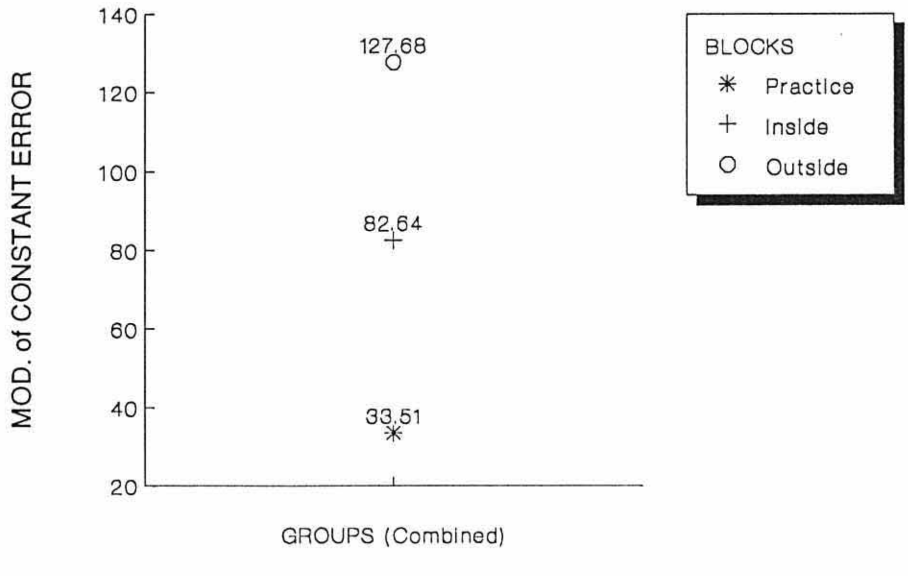


Figure 9.3 : (MCE) Blocks Main Effect

Of greater interest was the *Practice Condition by Blocks* interaction (Shown in Figure 9.4 below). This shows quite clearly that at the end of practice, although there were no statistically significant differences between the *Constant* and *Random* groups' levels of performance as far as the MCE scores are concerned, the *Constant* group is performing marginally better. (Subsequent analysis of the Variable Error revealed that, not surprisingly, the *Random* group had a VE score considerably higher than that of the *Constant* group at this stage, prior to transfer.) On transfer, however, this trend is reversed in the classic style and on the *Outside* transfer condition, the *Random* group are performing significantly better than the *Constant* group. Furthermore, the members of the *Random* groups maintain their level of performance throughout the two transfer conditions, and although there is a significant difference between performance at the end

Critical Difference (Tukey HSD) > 46.15

F(2,84) = 8.69; p < .001

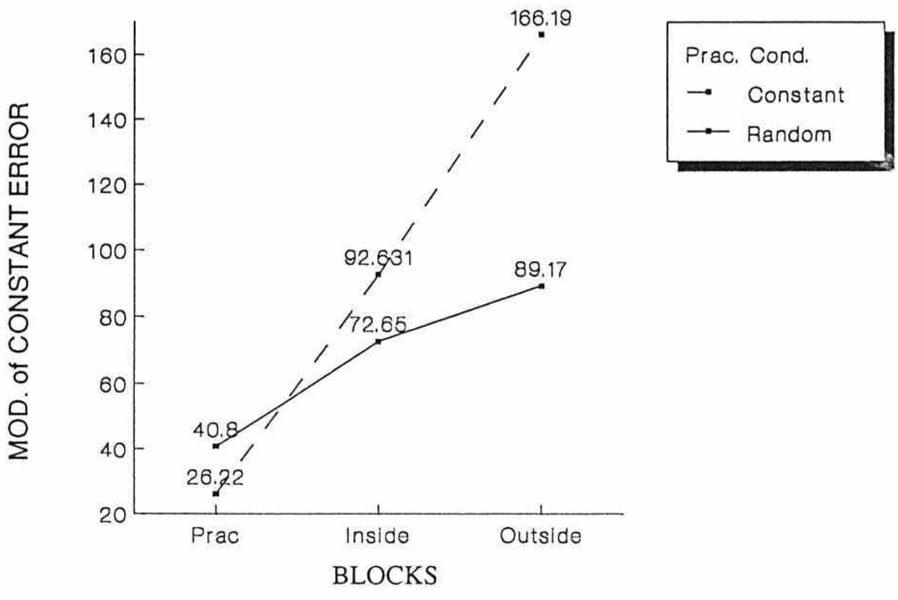


Figure 9.4 : (MCE) Prac. Condition by Blocks Interaction

of *Practice* and *Outside* transfer, there is no difference in performance between *Inside* and *Outside* transfer. The *Constant* group's performance, on the other hand, deteriorates drastically on *Outside* transfer, as is clearly visible from the above graph.

For Variable Error (VE), three main effects and two interactions were reported. The table below (Table 9.2) provides a summary of the results.

Refer to Appendix 3.v. for a complete table of results.

VARIABLE ERROR (VE)	
Main Effects	
Practice Condition:	$F(1,42) = 7.61; p < .01$
Complexity:	$F(2,42) = 8.91; p < .005$
Blocks:	$F(2,84) = 25.43; p < .001$
Interactions	
Prac. Cond. by Blocks:	$F(2,84) = 17.34; p < .001$
Complexity by Blocks:	$F(4,84) = 13.34; p < .001$

Table 9.2 :

Statistically significant main effects and interactions revealed in the ANOVA for VE

Follow-up tests once again reveal that for the *Complexity* main effect, complexity *Level Two* is significantly worse than either *Level One* or *Level Three. Level Two* and *Level Three* are not significantly different from each other (See Figure 9.5 below). Once again this corroborates the findings in Experiment Two which also revealed Complexity *Level Two* scoring significantly worse than either *Levels One* or *Three*, in terms of consistency of performance as measured by VE.

EXPERIMENT TWO
VE : Complexity

Critical Difference (Tukey HSD) > 39.49
$F(2,18) = 7.37$; $p < .005$

EXPERIMENT THREE
VE : Complexity

Critical Difference (Tukey HSD) > 25.40
$F(2,42) = 8.91$; $p < .005$

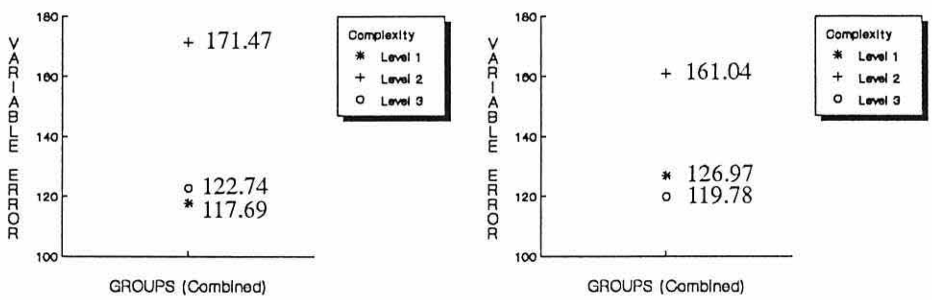


Figure 9.5 : (VE) Complexity Main Effects (Exp. 2 & 3)

For the *Blocks* main effect, Fig. 9.6 below shows quite clearly that the *Outside* transfer condition is significantly worse than either the end of *Practice* or the *Inside* transfer condition.

Critical Difference (Tukey HSD) > 18.07
F(2,84) = 25.43; p < .001

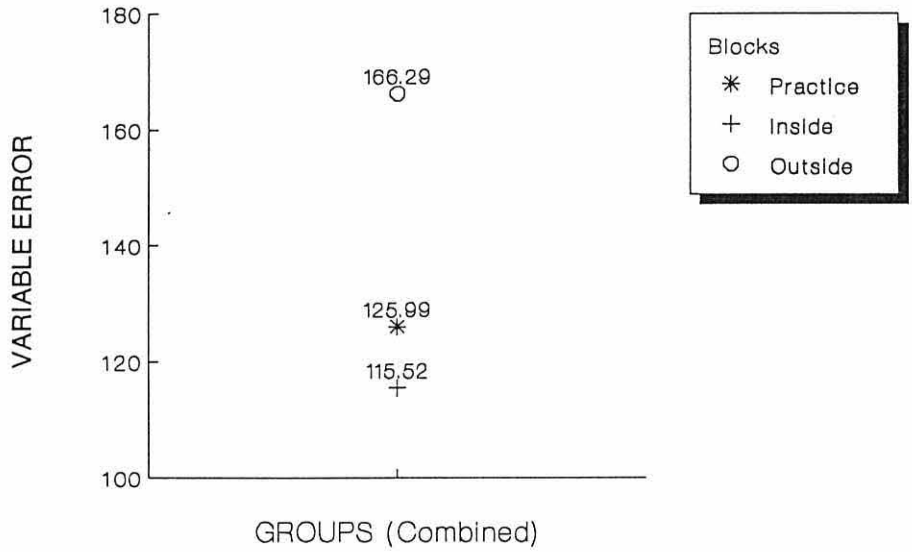


Figure 9.6 : (VE) Blocks Main Effect

The *Practice Condition by Blocks* interaction for VE (Figure 9.7 overleaf) shows a marked difference between the *Constant* and *Random* groups at the end of *Practice*. Whilst the MCE scores revealed no significant difference between the groups at the end of *Practice* (although the *Constant* group was marginally better), the *Constant* group are far out-performing the *Random* group in terms of consistency, as measured by VE scores. On transfer, however, this situation is dramatically reversed. On the *Inside* transfer condition, *Random* subjects improve their VE performance significantly, and are marginally, although not significantly, more consistent than the *Constant* group. On *Outside* transfer, their level of consistency drops back to that recorded at the end of *Practice*, and the *Constant* group's VE scores deteriorate further to match those of the *Random* group.

Critical Difference (Tukey HSD) > 31.27
F(2,84) = 17.34; p < .001

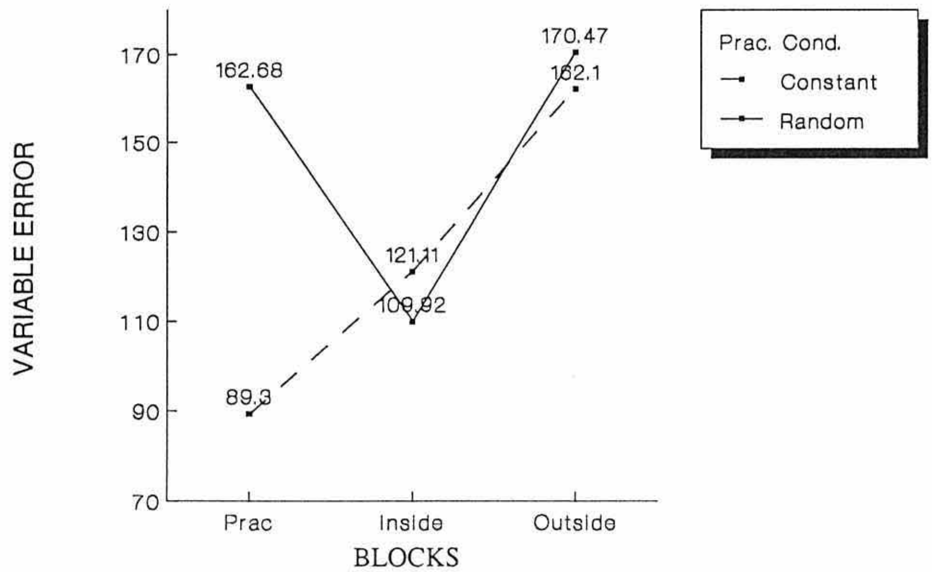


Figure 9.7 : (VE) Prac. Condition by Blocks Interaction

The *Complexity by Blocks* interaction (Figure 9.8) is of particular interest with regard to *Level Two*, especially in the light of earlier speculations made regarding Experiment Two, that perhaps the sequences of directional change in one segment of the movement, but not the other, might, in fact, make *Level Two* the most complex of the movement configurations, or at least, in some respects, a different sort of task.

Critical Difference (Tukey HSD) > 41.89
F(2,84) = 13.34; p < .001

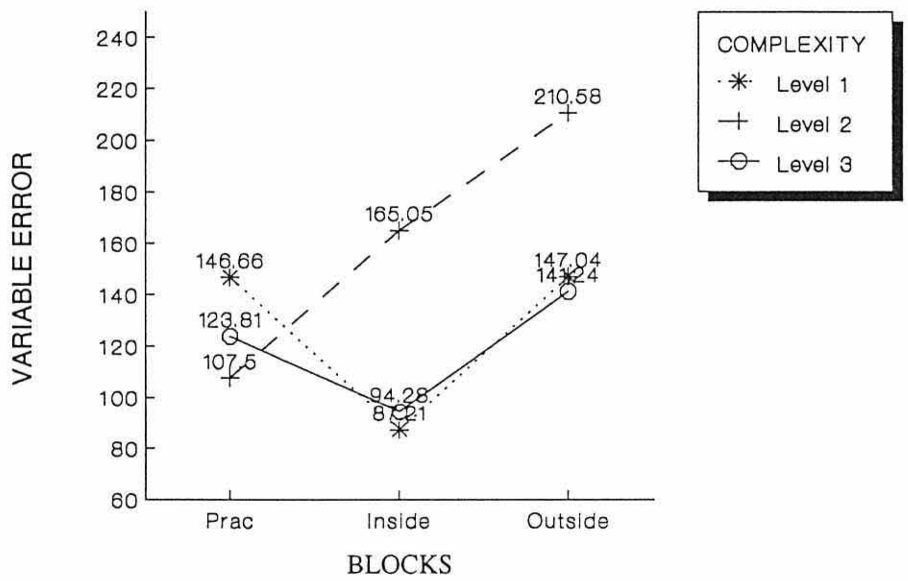


Figure 9.8 : (VE) Complexity by Blocks Interaction

The results of analysis of the practice data show no significant difference between any of the three levels of complexity. Given that each group enjoyed similar opportunity to practice, it seems fair to acknowledge that, in terms of achieving a reasonable level of performance following a limited number of trials, there is no real difference between the three levels of complexity after sufficient practice has occurred (that is, ignoring the practice conditions). On the transfer phase of the experiment, however, complexity *Level One* improves significantly on *Inside* transfer, and maintains the same performance level achieved at the end of practice on *Outside* transfer. Complexity *Level Three* follows a similar pattern, but the differences between its VE scores at each block are not significant. Complexity *Level Two*, however, is significantly worse on *Inside* transfer, with performance deteriorating still further on *Outside* transfer.

Examining Henry's Root Mean Square Error as a measure of overall variability, two main effects and two interactions were reported.

HENRY'S ROOT MEAN SQUARE ERROR (E)	
Main Effects	
Complexity:	$F(2,42) = 7.54; p < .002$
Blocks:	$F(2,84) = 61.75; p < .000$
Interactions	
Prac. Cond. by Blocks:	$F(2,84) = 29.52; p < .000$
Complexity by Blocks:	$F(4,84) = 7.58; p < .000$

Table 9.3 :

Statistically significant main effects & interactions revealed in the ANOVA for E

The *Complexity* main effect again shows *Level Three* out-performing *Levels One* and *Two*, although only the difference between *Level Two* (the worst condition) and *Level Three* is significant; a similar pattern to that recorded for VE (Fig. 9.9 below).

Critical Difference (Tukey HSD) > 29.6
$F(2,42) = 7.54$; $p < .002$

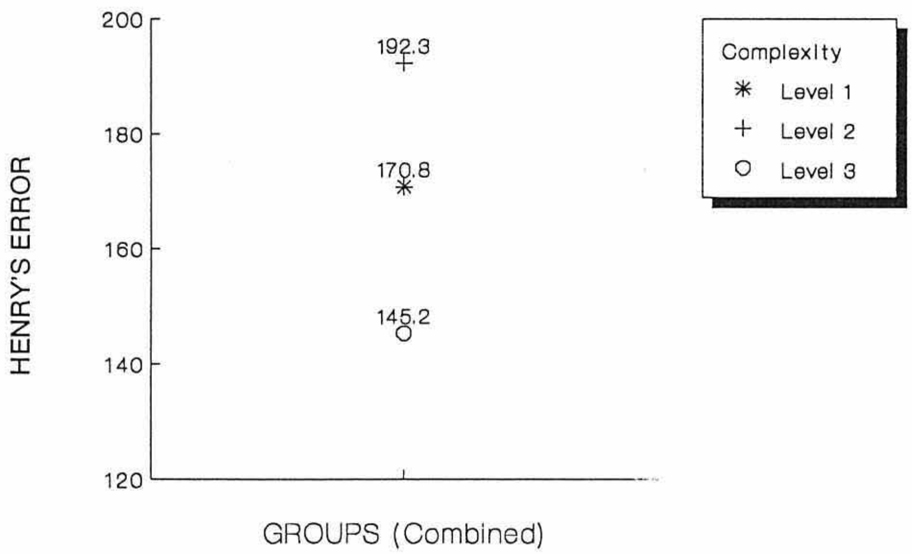


Figure 9.9 : (E) Complexity Main Effect

The *Blocks* main effect, not surprisingly, shows the highest error score on the *Outside* transfer condition (significantly worse than both *Inside* and *Practice* conditions), with performance at the end of *Practice* being significantly better than either of the two transfer conditions (See Fig. 9.10 below).

Critical Difference (Tukey HSD) > 20.4
F(2,84) = 61.75; p < .000

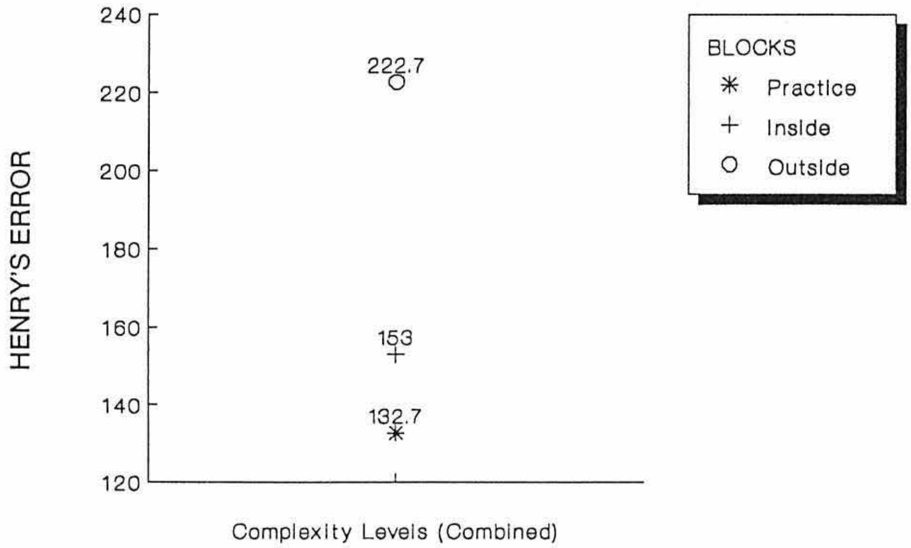


Figure 9.10 : Blocks Main Effect

The *Practice Condition by Blocks* (Fig. 9.11 overleaf) interaction again follows a predictable pattern with the *Constant* groups performing significantly better than the *Random* groups at the end of *Practice*, but showing a marked significant deterioration in performance on *Inside* transfer, and a further decline in performance on *Outside* transfer. The

Random groups, however, deteriorate only marginally on *Inside* transfer (at which stage the two practice conditions have actually reversed their relative positions and the *Random* practice groups are now marginally, but not significantly, better than the *Constant* practice groups), but show a significant increase in error on *Outside* transfer. Overall, however, the *Random* groups' performance at the end of *Practice*, compared to that at the end of transfer, is not significantly different. That is to say, the *Random* groups maintained their performance level on *Outside* transfer, although they deteriorated slightly on *Inside* transfer. The *Constant* groups' performance, in contrast, continues to deteriorate rapidly on transfer.

Critical Difference (Tukey HSD) > 35.4
F(2,84) = 29.52; p < .000

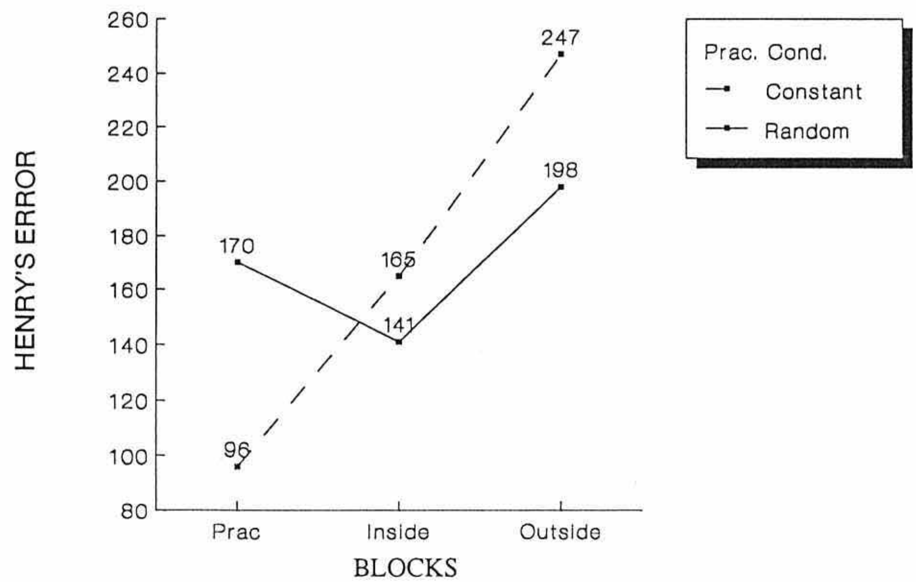


Figure 9.11 : Practice Condition by Blocks Interaction

The *Complexity by Blocks* interaction (Fig. 9.12 below) shows no significant difference between any of the mean error scores for the three complexity levels at the end of *Practice*, although *Level Two* is marginally better than the other two levels. On *Inside* transfer, however, *Level Two*'s performance deteriorates significantly, whilst *Levels One* and *Three* maintain a similar performance to that achieved at the end of *Practice* (On *Inside* transfer, *Level Two* is no only significantly worse compared to its own *Practice* performance, but is also significantly worse than *Level Three*, and marginally worse than *Level One*). This trend continues for *Level Two* on *Outside* transfer, by which time the error score is significantly different from both *Level One* and *Level Three*, and also from its own *Inside* transfer performance score. *Level One* and *Level Two* deteriorate on *Outside* transfer, with both performance levels being significantly worse than those recorded on *Inside* transfer, but not significantly different from each other.

Critical Difference (Tukey HSD) > 47.4
F(4,84) = 7.58; p < .000

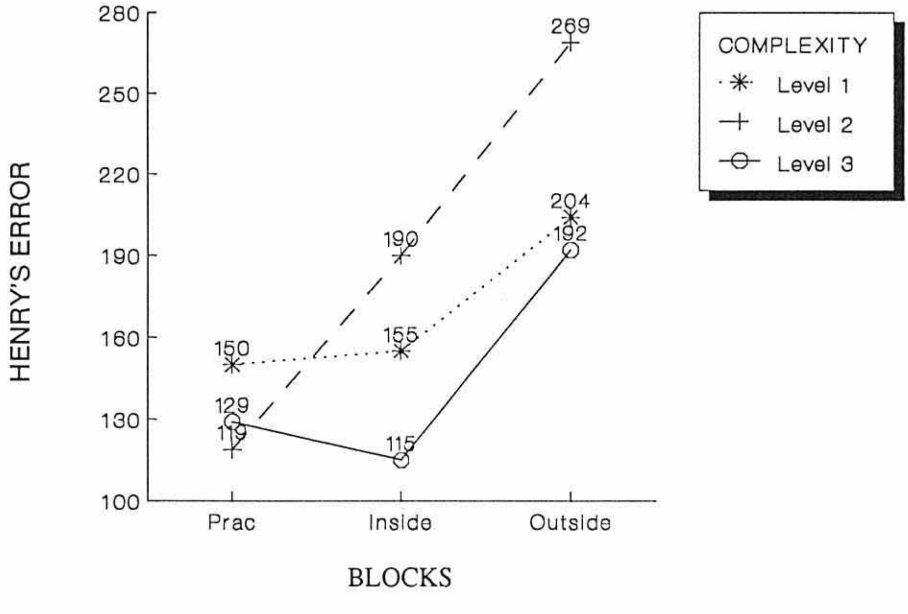


Figure 9.12 : Complexity by Blocks Interaction

A table summarizing the results of Experiment Three is presented below (Table 9.4).

Main Effects	**Probability of F–ratios in ANOVAs**		
	MCE	**VE**	**E**
Practice Condition	.05	.01	N/S
Complexity	.05	.005	.002
Blocks	.001	.001	.000
Interactions	**Probability of F–ratios in ANOVAs**		
	MCE	**VE**	**E**
Practice Condition by Complexity	N/S	N/S	N/S
Practice Condition by Blocks	.001	.001	.000
Complexity by Blocks	N/S	.001	.000
Practice Condition by Complexity by Blocks	N/S	N/S	N/S

Table 9.4 :

A summary of the results for EXPERIMENT THREE showing the probability of the F-ratios in the relevant ANOVAs (Appendices 2.i., 2.v., 2.x.) and indicating (N/S) where these are greater than 5%.

Table 9.5 on the following page provides a summary of the results of both experiments (Experiment Two & Experiment Three), for comparison.

Main Effects	Probability of F–ratios in ANOVAs					
	MCE		VE		E	
	Exp. 2	Exp. 3	Exp. 2	Exp. 3	Exp. 2	Exp. 3
Practice Condition	.001	.05	N/S	.01	.001	N/S
Complexity	.001	.05	.01	.005	.001	.002
Transfer *	N/S	.001	.001	.001	.001	.000

Interactions	Probability of F–ratios in ANOVAs					
	MCE		VE		E	
	Exp. 2	Exp. 3	Exp. 2	Exp. 3	Exp. 2	Exp. 3
Prac. Condition by Complexity	.05	N/S	N/S	N/S	N/S	N/S
Prac. Condition by Transfer *	.05	.001	N/S	.001	N/S	.000
Complexity by Transfer *	N/S	N/S	N/S	.001	N/S	.000
Practice Condition by Complexity by Transfer *	N/S	N/S	N/S	N/S	N/S	N/S

* Whilst ***Transfer*** (2) was used in EXPERIMENT TWO to donate *Inside* and *Outside* Transfer conditions, ***Blocks*** (3) was used in EXPERIMENT THREE to represent the Last 12 *Practice* Trials, *Inside* Transfer and *Outside* Transfer.

Table 9.5 :

A summary of results from EXPERIMENT TWO & THREE showing the probability of the f-ratios in the relevant ANOVAs (Appendices 1.i., 1.v., 1.vii & 2.i., 2.v., 2.x.) and indicating (N/S) where these are greater than 5%

The *Practice Condition by Complexity* interaction, which would provide a basis for an explanation how the factors of complexity and variability might interact in the learning process, did not materialise as it did in Experiment Two, and needs to be replicated to support the main hypothesis. This apparently negative finding, nevertheless, has important theoretical and practical implications.

Notes

- 1. Given the fact that naivity on the part of the subjects was a requirement for participation, the available pool of subjects was severly limited due to the number of pilot studies that had been carried out prior to te reported investigation. The pragmatics of the situation thus dictated that a somewhat reisky strategy had to be adopted within which it was recognised that the chances of making a Type II error was increased.

- 2. To obtain an acceptable level of power (.80) given the effect sizes (ES) elicited in Experiments Two and Three (and an α of .05), it was calculated that should the sample size be increased in subsequent experiments of this design to at least twenty subjects per cell, similar differences would be significant at the traditionally acceptable level.

Effect sizes were calculated using Cohen's (1992) calculation:

$$d = \frac{M_A - M_B}{\sigma}$$

Estimated sample sizes were obtained from Winer (1971).

CHAPTER TEN

Discussion And Conclusions

On a theoretical level, the hypothesis was proposed that the control of movement timing skills is influenced by a complex relationship between the conditions of practice (*variability*), and the nature of the task itself (*complexity*).

The transfer effects due to complexity manipulation shown by the *Practice Condition by Complexity* interaction for MCE in *Experiment Two*, and the *Complexity* main effects across all error measurements in both *Experiments Two* and *Three*, are similar to those expected of, and produced by, manipulating variability. It is assumed that the results come from increasing the complexity of the task to the point where it becomes sufficiently *novel*. This can be explained in two theoretical ways. The rationale is either that:

(i) In Contextual Interference terms, the increase in complexity induces an increase in cognitive effort on the part of the subjects as they attempt to construct an appropriate action plan on each trial: – too low a level of complexity and the task becomes sufficiently simple for subjects to merely repeat each previous attempt with little or no cognitive effort; or

(ii) In Schema terms, the increase in complexity creates a task for which a well-developed schema does not already exist, and variability is generated in performances which are marked by large errors. In other words, subjects experience a wider range of performance.

On the other hand, attempts to manipulate *variability* were equally successful. This is shown by the *Practice Condition by Transfer* interaction across all error measurements in Experiment Three. Similarly in the comparisons of two transfer conditions using VE and E in *Experiment Two* and across all error measurements in *Experiment Three*, random practice structure, or increasing the unpredictability of the sequence of events, seems to have generated the main effects predicted by the Variability of Practice Hypothesis. This leads to the theoretical reasoning that:

(i) In Contextual Interference terms, varied practice requires a more cognitively-effortful state of alertness and readiness on the part of the subject. It is this additional processing that facilitates learning as manifested by enhanced performance on transfer; or

(ii) In Schema terms, the more random the practice structure, and consequently the greater the number of variations of the task practiced, the more robust will be the emerging schema, and thus more better equipped to deal with new variations of the task when presented.

The preceding arguments, however, conveniently ignore some of the confusing effects associated with what was labelled Complexity *Level Two*, and failure to provide easily identifiable evidence in support of the above hypotheses may well infer that the notion of complexity is itself misleading. Indeed it may be that the concept is only meaningful in relation to a particular stage or level of learning. Whilst the above speculations appear sound in relation to the results of *Level One* and *Level Three* data, and post hoc arguments can be put forward for there being different levels of complexity of a similar task, *Level Two* subjects appeared to progress differently across the practice and transfer phases of Experiment Three.

Experiment Three confirmed that performance after practice was similar for all tasks, but the *Complexity by Blocks* interaction for VE (Fig. 9.8) in Experiment Three shows the *Level Two* group performing progressively worse on transfer in a pattern contrasting sharply with *Levels One* and *Three.* A question thus arises about the robustness of schema predictions in relation to movements which are made up of portions that go together in a *natural* way, and movements which any attempt to combine results in *interference* with individual segments. The possibility that the *Level Two* task was, in fact, more difficult than the supposedly most complex configuration (*Level Three*), has not escaped attention; a likely explanation being that the *Level Three* task required a second movement segment that was merely a mirror image of the first, and thus, although temporally similar in structure, possibly different in overall timing. Indirect support for such a notion comes from recent studies in the laboratory on bimanual task performance and related issues of time-sharing.

Swinnen and Walter (1991) in an investigation of the effect of practice on the parallel organisation and control of discrete, asymmetrical bimanual movements, distinguished between what they termed *metrical* and *structural dissociation*; that is, a distinction between those variables that are held to be critical in the organisation of motor responses, and those that are not:

> ***Essential*** *variables are concerned with the preservation of a movement's qualitative structure or topological organization (e.g., its spatiotemporal pattern);* ***nonessential*** *or metrical variables relate to the scaling of movement, or the generation of quantitative changes without affecting the movement's basic structure (Kelso and Tuller, 1984; Kugler, Kelso, and Turvey, 1980; Newell, 1985).* (My emphasis.)
>
> (Swinnen and Walter, 1991. p. 368.)

The comparison is drawn with related concepts from Schmidt's (1985, 88) motor programming perspective, and the distinction between *invariant features* and *control parameters* – for example:

> *I can use the same underlying structure (represented in the generalized motor program) to throw a ball from a distance of 3, 5, or 9m through a specification of the appropriate intensity level. It is generally argued that control parameters allow movements to be adjusted or scaled to varying environmental circumstances while leaving the underlying movement structure essentially untouched.*
>
> (Swinnen and Walter, 1991. p. 368.)

Although their concern was with dual-task operations, their findings would seem to be applicable to this identified issue of movement segment interference. They conclude that:

> *The most difficult dual-task conditions are hypothesized to be those requiring different structural and metrical prescriptions – in other words, when both movements have a different intensity specification as well as a fundamentally different organizational structure.*
>
> (Swinnen and Walter, 1991. p. 380.)

and thus offer the suggestion that:

> *This framework may be useful to assess difficulty level in dual-task performance.*
>
> (Swinnen and Walter, 1991. p. 380.)

Extending Swinnen and Walter's (1991) arguments still further, it does not seem unreasonable to speculate that this framework may be useful to assess difficulty level in single, unimanual tasks, especially those that lend themselves to division into segments such as the knock-down barrier task selected in the current investigation.

Further relevant research findings that have emerged from the motor-control laboratory, centre around what Langley and Zelaznik (1984) have identified as the *higher-order variable hypothesis*: – an alternative explanation to that offered by Contextual Interference Theory, as to why segmental practice training (*phasing*) produced better results on transfer than nonsegmental practice training (*duration*). Langley and Zelaznik (1984) suggested that phasing (i.e., training on two separate timing segments) is a skill that is *subservient to* or *a subcomponent of* duration (i.e., training on the overall timing of the complete task). Consequently, whether the practice session involves phasing or duration-type practice is immaterial, provided transfer is to a duration-criterion task. Conversely, when transfer is to a segmental/phased-criterion task, prior duration training is insufficient to generate an appropriate level of a timing skill that:

> *"...appears to behave as an essential, higher-order variable"*
>
> (Langley and Zelaznik 1984, p. 298 - 299)

that is related to the skill developed by duration training.

Seen as a contextual interference effect, the phase training subjects (who were required to practice three times the number of frames per trial as the duration subjects), were exposed to much greater between-task interference which led to the kind of

> *"...processing strategies appropriate for the transfer to new materials."*
>
> (Langley and Zelaznik 1984, p. 299)

as presented by Battig (e.g., 1979); Shea and Morgan (1979); and Lee and Magill (1983).

Carnahan and Lee (1989) attempted to compare and evaluate these two hypotheses in a knock-down barrier task, identical to that used in the current investigation. They concluded that there was no evidence that the effects observed in their study or the previous study could be accounted for in terms of contextual interference effects, and that segment training alone was responsible for the improved performance on transfer. They did concede, however, that the inferior performance in practice (in terms of high CE and VE scores) for the variable-phase group reflected the increase in between-task interference, but these *performance* effects were insufficient to predict possible transfer outcomes. They concluded that although more research is needed to study these phenomena, the higher order hypothesis proposed by Langley and Zelaznik (1984) can be regarded as:

> *"...a specific hypothesis that is subsumed under the more general constraint of* transfer-appropriate processing *(Bransford, Morris, Franks, and Stein, 1979; Lee, 1988)"*

and thus:

> *"...motor learning (and learning in general) is viewed as an interaction between the processing requirements promoted by conditions of practice and the processing requirements promoted by the conditions of the transfer test(s)."*
>
> (Carnahan and Lee, 1989. p. 58)

Looking for an interaction between these factors of complexity and variability by experimentally generating the potential for a *Practice Condition by Complexity* interaction, has been only partially successful as an approach, and looking for possible *solutions* in an attempt to verify the formulated hypotheses, may not be the most appropriate course to pursue. Rather, it may well transpire that determining how the manipulation of one factor might be preferable to another in any given instance, is a far more profitable direction in which future research should proceed, and more cognizance should be taken of Carnahan and Lee's (1989) contention that:

> *"...the efficacy of conditions of training cannot be divorced from the requirements of transfer"*
>
> (Carnahan and Lee, 1989. p. 58)

Notwithstanding the doubts expressed about the relative levels of complexity used in the experiments, two findings stand out from the data. The first is that in a task which is susceptible to variability of practice manipulations in facilitating transfer, increasing the complexity of the practice task may be, of itself, sufficient to aid transfer. The second is that there appears to be no straightforward interaction effect to be discerned between the two factors as they were operationalised.

It cannot be claimed that this thesis clearly demonstrates that complexity is simply another species of those factors which demand variability of output generation (by either changing task demands or by interference). Neither can it be claimed that the outcomes show complexity and variability to be orthogonal factors which may be considered independent of each other. There is a strong case to be made for pursuing other means of investigating the covariance structures which might underlie the combinations which are implied by concepts such as levels of learning, task complexity, variability and the parameters of motor schema development as were discussed in Chapter Five (See Fig. 5.2., page 137).

Some Suggestions For Future Research

The main focus of study then has centred around the relationship between complexity and variability, but this was only one aspect of an expanded model of potential effects. Although this issue has yet to be finally resolved, the study has raised some additional questions that might be profitably addressed in respect of other, hitherto ignored, factors.

The classical *Practice Condition by Transfer* interaction for MCE in *Experiment Two*, and the *Practice Condition by Blocks* interaction across all error measures in *Experiment Three*, shows that transfer to variations within the boundaries of practice is greater than transfer to a variant which lies outside of the range of practiced variations. This leaves the outstanding question of whether such effects are really categorical or, in fact, continuous. That is, whether they should be discussed in terms of *inside* and *outside* transfer, or *proximal* and *distal* transfer. It may well prove to be that as the practice task and criterion task become more distant, so the expected degree of transfer will progressively decrease as a continuous effect. The notion of *inside* versus *outside* transfer with its clear categorical connotations may be rendered obsolete.

An experimental design in which the transfer variation immediately outside the boundaries of practice is compared to other more distant variations is an obvious next step. Smith and Rudisill (in press) have, it seems, already taken the initiative here and have evidence to support the view that proximal/distal transfer may be a better perspective. A further *inside / near-outside / far-outside* (*proximal / near-distal / far-distal*) design would be a natural progression to resolve this issue.

A second, and perhaps more important question, asks to what extent other identifiable factors might act as confounds on any single source of influence. The model has conveniently grouped the potential factors into two distinct categories: The top half of the model includes

- Task Complexity
- Level of Learning
- Age and Different Strategies
- Experience.

The bottom half includes

- Size of Block / Amount of Variability
- Content / Practice Organisation
- Recall / Recognition
- Learning versus Performance.

An obvious question now emerges relating to the functional similarities in these classifications. Whilst complexity was the factor selected for examination, do other factors from that same group generate similar main effects? If the model is correct then manipulating other factors within that top category should produce similar results. Such speculations can now be tested.

The factors in the bottom group are related to the organisation of practice in terms of optimal ways of supporting or accelerating representations in memory (schemas). The challenge here will be to understand how the short term experiences of different practice organisations or emphases in the information given (recall / recognition) work with the active process of memory, not only in orienting a schema in current performance terms, but also in transforming the retained aspects of memory. Short-term *experience* effects might be predicted to lead to not only different levels of retention and transfer performance on similar motor tasks but can be predicted to be a major influence on the way in which learners behave when faced with new things to learn. This is an extension to the schema prediction that varied practice will not only lead to an accelerated improvement gradient on a performance curve for a new variation of a task (Schmidt, 1975), but that a variety of such varied practice will lead to more rapid acquisition of motor tasks *per se*. A sort of learning schema for learning. Such a prediction is clearly testable but will require a more complex time-consuming approach than that usually possible in motor learning experiments. If this is the case, then research into motor learning may have very wide ranging but direct implications for learning in other domains.

The three theoretical questions which are obvious next steps are, therefore, to do with the issues of:

- 1) *Inside / Outside* transfer or *Proximal / Distal* transfer
- 2) The likelihood of main effects similar to those generated by variability and complexity manipulation arising from examination of level of learning, age and different strategies, and experience;

- 3) The extension of the learning aspect of Schema Theory to an overarching principle which leads to a much broader and general view of the overall influence of variability (and anything that functions like variability) predictions. That is, perhaps, the development of a schema for learning.

CHAPTER ELEVEN

Some Additional Comments

In general terms, the current study set out to examine what is, no doubt, a complex relationship between a number of factors that have been identified as potential sources of influence on schema development; in particular, the way in which variability in practice might lead to greater transferability. More specifically, interest focused on the ways in which different arrangements of practice trials in conjunction with tasks of differing levels of complexity, might enable us to predict with greater certainty the potential for improved performance on transfer.

The theoretical base from which this investigation originated regarded the idea of *schema* as still a most useful concept for explaining how movement patterns are initiated and controlled, and further impetus was given to the inquiry by the emergence of what at first appeared to be the potentially conflicting theoretical frameworks of *Contextual Interference* and *Depth of Processing*. Much of the equivocality in the evidence offered in support of these theoretical speculations dissipates when the description of the schema is no longer confined to a narrow, hypothetical construct deemed responsible for determining the specifications and parameters of a movement action. When a dynamic model of control is substituted, which presupposes an inherent flexibility within the system to operate in numerous ways, the search for those knowledge structures, that determine what information is selected and abstracted and its subsequent interpretation and integration, broadens, and previously conflicting accounts become accommodated under the umbrella of a single framework.

In the process of conducting the above research, and trying to determine how the factors selected for investigation interacted during the learning process, a distinction became evident between two separate problems that required attention: the first related to how complexity and variability interacted in the learning process, within the learning environment specifically created by the experimenter to observe the phenomenon; the second asked how one or both factors might be manipulated to the learner's advantage in any particular set of environmental conditions. This distinction is important, not only because of its implications for future research, but because it reflects an underlying, fundamental issue that is frequently responsible for divisions in the various fields of psychology; an issue which Mandler (1984) summarizes as being concerned with:

> *"...too much emphasis on the virtues of conceptually-driven processing under the control of a structured mind versus data-driven processing under control of a structured environment."*
>
> (Mandler, 1984, p. 113.)

He makes a suggestion as to how this dilemma of the way in which the mind organizes itself, might appropriately be resolved:

> *"One of the best ways at arriving at that organisation is to examine the regularities in the world upon which it is based."*
>
> (Mandler, 1984, p. 113.)

Such a sentiment is reminiscent of Fazey's (1986) earlier suggestion that demonstrating the validity of the schema notion necessitates:

> *"...looking in the right way, at the right time, in the right place."*
>
> Fazey (1986, p. 51)

and future research may well be more profitably accomplished by looking, not for a rule to govern how our identified sources of influence affect the process of learning, but for *when* and *under what conditions* can we confidently predict that a given set of circumstances will yield a particular set of results. The schema notion thus translates into a set of expectations, the formation of which are constructed from many different mental structures, which might not all necessarily be schematic in nature, but combine to produce an overall *schema* that is responsible for initiating and guiding our actions.

Those that are hoping for *the all-encompassing theory* explaining human behaviour, that they might utilize as a kind of reference source from which to structure the ultimate learning environment for any given set of specifications (i.e., the learners, their current level of knowledge, the task to be learnt, the structure of the practice session etc.), are going to be disappointed. Its very existence is precluded by the almost infinite number of variables to be taken into account, the vast potential for human adaptation and unpredictable change, to say nothing of the inevitable range of individual differences that are observable in any given population. What is not unreasonable, however, is to strive towards a greater understanding of how behaviour and performance might be more accurately predicted within specified boundaries, on the basis of theoretical suppositions that have their basis firmly rooted in sound empirical investigation. The move away from a single theory to explain *all*, in terms of how our identified factors influence learning, towards an explanation of when those factors might be expected to interact in a particular fashion, seems a more profitable avenue of inquiry. Moreover, research in this direction has potentially valuable contributions to make in the progression from theory into practice.

From Theory to Practice

It seems appropriate at the end of a thesis such as this, to say a word about the relevance of theoretical research to the kind of practical settings confronting the teacher or learner in the *real* world. In fact, it doesn't seem unreasonable to suggest that the value of a piece of research should be judged, not only on its contribution to the advancement of theory *per se*, but on a broader level that considers that theory's relevance for the formulation of pedagogic principles, and ultimately their effective actualization in practice. This is not to suggest that the criterion for evaluating theoretical, academic inquiry should necessarily relate directly to its propensity for application, rather the opinion is offered that if theory is left exclusively to an elite band of academic researchers, with little interest in any effective operational relevance it might possess, the whole object of the exercise is lost.

Many *teachers*[1] involved in aspects of physical education, sport and movement would confess to knowing next to nothing about *theory*, but, nevertheless, construct a learning environment around a firmly held set of principles that have been acquired through experience, experimentation, a highly-developed sense of intuitiveness, and the occasional flash of inspirational insight. In fact, the very use of the word *teacher* here presupposes a philosophy or set of theoretical principles (held consciously or subconsciously) on which teaching is based.

1 The word teacher is not used in the sense that it implies a recipient of qualifications or credentials that officially confer the title upon an individual; rather it is used as a description of any mediator in the learning situation attempting to organise and enhance this process of knowledge acquisition

In many ways, the teacher's dilemma in constructing an appropriate setting for learning to take place, mirrors that of the researcher. In the same way that the researcher designs experiments to test hypotheses, so the teacher attempts to test established principles by the implementation of various techniques. The methodological decisions facing the researcher in validating experimental designs, are akin to the decisions required of the teacher in matching up his/her *theoretical* principles to practical reality. Teaching might thus be viewed on occasions as a research activity, although the additional commitments that teachers have to their students (compared with those of the researcher to the experimental subjects), require a teacher to *induce* learning wherever possible, and prevent the clinical, detached observation of various experimental conditions, simply to satisfy an intellectual curiosity, or confirm a previously held suspicion.

The effective teacher would thus seem to be involved in two major activities: one aimed primarily at the learner, is concerned with what we might term *instruction*, and involves the employment of tried and tested techniques for promoting this process of knowledge acquisition; and the second is *experimentation*, aimed at the teacher, where these techniques are manipulated and evaluated on the basis of observation. The two activities are self-enhancing, and serve the dual purpose of education for both teachers and students alike.

What, then, is the role of theoretical research in the everyday, practical world of teaching and learning? Chomsky (1965), as a researcher into the structure of language and the nature of cognitive processes, was asked much the same question in relation to the relevance of linguistic research and psychology to the actual practicalities of teaching language. He replied that:

> *"...the teacher of language would do well to keep informed of progress and discussion in these fields, and the efforts of linguists and psychologists to approach the problems of language teaching from a principled point of view are extremely worthwhile, from an intellectual as well as social point of view. Still, it is difficult to believe that either linguistics or psychology has achieved a level of theoretical understanding that might enable it to support a* **'technology'** *of language teaching."*
>
> (Chomsky, 1965. Quoted in Allen van Boren, 1971)

He goes on to warn teachers that:

> *"...suggestions from the* **'fundamental disciplines'** *must be viewed with caution and skepticism."*
>
> (Chomsky, 1965. Quoted in Allen van Boren, 1971)

Chomsky's remarks have often been used in support of a view that theory has little direct relevance to practice, but Widdowson (1990) correctly points out the error in such an interpretation:

> *"...if one troubles to read what Chomsky says here, it is apparent that he recognizes that linguistics and psychology are associated with ways of approaching 'the problems of language teaching from a principled point of view'. What he questions is whether these descriptions can...directly inform pedagogic technique."*
>
> (Widdowson, 1990. p. 10)

Widdowson's (1990) own opinion is that although theoretical research may not be directly transposed to a *classroom* context, it does, nevertheless, play a crucial role both theoretically and methodologically:

> *"Theoretically, it can serve as a source of ideas and insights which are of potential relevance for the formulation of principles...Methodologically, it can provide precept and example of what is involved in critical enquiry, of how intuition can be subjected to conceptual and empirical evaluation."*
>
> (Widdowson, 1990. p. 3 - 4.)

The field of motor control, like linguistics and psychology, has yet to achieve 'a level of theoretical understanding that might enable it to support a technology of teaching'. Nevertheless, it is hoped that those involved in the learning process, whether formulating hypotheses, collecting data, devising lesson plans or evaluating teaching methods, will be active participants in the field, so that theory might be realised through practice, and practice, in turn, be kept informed by theory.

Whether or not the field of motor control and learning will ever be judged by the likes of Chomsky as having reached a sufficient level of theoretical understanding to support a technology of (motor) teaching, is something of a moot point. Those, however, who feel that progress comes too slowly, might take heart from the astute observation of Emerson Pugh (1977) who noted that:

> *"If the human brain were so simple that we could understand it, we would be so simple that we couldn't."*
>
> (Emerson Pugh, Quoted by George Edgin Pugh, 1977)

The Concluding Remark

At the outset of any empirical investigation, researchers no doubt hope that by the time all the data has been collected and analysed, the hypotheses have been weighed against the evidence, the appropriate conclusions have been drawn, and the final chapter is eventually underway, they can at last relax, safe in the knowledge that yet another valuable contribution to our understanding in the field has been made. At best, the researcher will be armed with an arsenal of evidence to protect his hypothesis and leave it in position unscathed; at worst, the hypothesis can be confidently reappraised or rejected, and an explanation found that adequately accounts for the results of the investigation. In either event, the concluding remarks will close the book on a previously unanswered question, and indicate quite clearly the direction that future research would be wise to follow!

In some branches of science researchers may indeed be fortunate enough to embark on such a course, fully anticipating that its conclusion will yield a categorical, definitive answer to whatever question is under consideration. In the field of human behaviour, however, such research all too often poses more questions than it appears to answer. The very nature of our discipline dictates that we operate on a platform of hypothetical constructs that are supported only fragilely by sets of underlying assumptions. Progress in the field is inevitably an arduous process often entailing little more than the gradual accumulation of sufficient evidence to support or refute a given prevailing theory. Every so often an individual piece of research will emerge as a stepping-stone above the continual flow of academic inquiry, allowing a stride forward towards our goal of understanding human behaviour. In the main, however, it is through the process of tackling the outstanding questions that such research leaves in its wake, that we are able to verify the direction in which we are proceeding, and inch our way further forward – or at least allow someone else to make progress!

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APPENDICES

Appendix 1.i.

Experiment One

Modulus of Constant Error

THREE-WAY ANOVA with REPEATED MEASURES

(Using MANOVA - SPSS)

Dependent Variable: Units away from Target

Source	df	SS	MS	F	Sig. of F
BETWEEN SUBJECTS	35				
PRAC. CONDITION	1	47.13	47.13	.43	.516
COMPLEXITY	2	102.30	51.15	.47	.630
P.C. by COMP	2	54.97	27.49	.25	.779
ERROR-BETWEEN	30	3269.79	108.99		
WITHIN SUBJECTS	36				
TRANSFER	1	266.10	266.10	2.33	.138
P.C.. by TRANS	1	38.16	38.16	.33	.568
COMP by TRANS	2	716.13	358.07	3.13	.058
P.C. by COMP by TRANS	2	12.90	6.45	.06	.945
ERROR-WITHIN	30	3429.42	114.31		
TOTAL	71	7936.9			

* Denotes significant difference at the 0.05 level of significance.

Appendix 1.ii.

Experiment One

Variable Error

THREE-WAY ANOVA with REPEATED MEASURES

(Using MANOVA - SPSS)

Dependent Variable: Units away from Target

Source	df	SS	MS	F	Sig. of F
BETWEEN SUBJECTS	35				
PRAC. CONDITION	1	9.11	9.11	.37	.546
COMPLEXITY	2	448.58	224.29	9.17	.001*
P.C. by COMP	2	62.46	31.23	1.28	.294
ERROR-BETWEEN	30	733.99	24.47		
WITHIN SUBJECTS	36				
TRANSFER	1	17.89	17.89	.71	.406
P.C.. by TRANS	1	55.55	55.55	2.20	.148
COMP by TRANS	2	182.09	91.05	3.61	.039*
P.C. by COMP by TRANS	2	88.88	44.44	1.76	.189
ERROR-WITHIN	30	756.72	25.22		
TOTAL	71	2355.27			

* Denotes significant difference at the 0.05 level of significance.

Appendix 1.iii.

Experiment One

Variable Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Complexity

- Degrees of Freedom (ANOVA): 2,30
- Error Mean Square (ANOVA): 24.47
- *q* 0.05 (*k*=3, *v*=30): 3.49
- n (Number of Observations): 24

The Critical Difference for Comparison of Means = 3.52

	18.78	**18.44**	**13.33**
18.78	-	0.34	5.45*
18.44		-	5.11*
13.33			-

* Denotes significant difference at the 0.05 level of significance

Appendix 1.iv.

Experiment One

Variable Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Complexity by Transfer

- Degrees of Freedom (ANOVA): 2,30
- Error Mean Square (ANOVA): 25.22
- *q* 0.05 (*k*=6, *v*=30): 4.30
- n (Number of Observations): 8

The Critical Difference for Comparison of Means = 7.63

	11.97	**14.67**	**15.91**	**18.48**	**19.09**	**20.98**
11.97	-	2.7	3.94	6.51	7.12	9.01*
14.67		-	1.24	3.81	4.42	6.31
15.91			-	2.57	3.18	5.07
18.48				-	0.61	2.5
19.09					-	1.89
20.98						-

* Denotes significant difference at the 0.05 level of significance

Appendix 1.v.

Experiment One

Henry's Root Mean Square Error

THREE-WAY ANOVA with REPEATED MEASURES

(Using MANOVA - SPSS)

Dependent Variable: Units away from Target

Source	df	SS	MS	F	Sig. of F
BETWEEN SUBJECTS	35				
PRAC. CONDITION	1	.31	.31	.00	.950
COMPLEXITY	2	326.98	163.49	2.07	.144
P.C. by COMP	2	67.90	33.95	.43	.654
ERROR-BETWEEN	30	2368.91	78.96		
WITHIN SUBJECTS	36				
TRANSFER	1	61.88	61.88	.90	.351
P.C.. by TRANS	1	81.81	81.81	1.19	.284
COMP by TRANS	2	421.24	210.62	3.06	.062
P.C. by COMP by TRANS	2	66.53	33.27	.48	.622
ERROR-WITHIN	30	2066.55	68.89		
TOTAL	71	5462.11			

* Denotes significant difference at the 0.05 level of significance.

Appendix 2.i.

Experiment Two

Modulus of Constant Error

THREE-WAY ANOVA with REPEATED MEASURES

(Using MANOVA - SPSS)

Dependent Variable: Actual time minus Criterion time (msec.)

Source	df	SS	MS	F	Sig. of F
BETWEEN SUBJECTS	23				
PRAC. CONDITION	1	66649.57	66649.57	26.38	.000*
COMPLEXITY	2	43458.74	21729.37	8.60	.002*
P.C. by COMP	2	18610.95	9305.48	3.68	.046*
ERROR-BETWEEN	18	45470.13	2526.12		
WITHIN SUBJECTS	24				
TRANSFER	1	12420.35	12420.35	3.73	.069
P.C.. by TRANS	1	21836.45	21836.45	6.57	.020*
COMP by TRANS	2	12686.86	6343.43	1.91	.177
P.C. by COMP by TRANS	2	1376.64	688.32	.21	.815
ERROR-WITHIN	18	59870.96	3326.16		
TOTAL	47	282380.65			

* Denotes significant difference at the 0.05 level of significance.

Appendix 2.ii.

Experiment Two

Modulus of Constant Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Complexity

- Degrees of Freedom (ANOVA): 2,18
- Error Mean Square (ANOVA): 2526.12
- q 0.05 (k=3, v=18): 3.61
- n (Number of Observations): 16

The Critical Difference for Comparison of Means = 45.34

	152.073	**122.695**	**78.843**
152.073	-	29.378	73.23*
122.695		-	43.852
78.843			-

* Denotes significant difference at the 0.05 level of significance

Appendix 2.iii.

Experiment Two

Modulus of Constant Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Practice Condition by Complexity

- Degrees of Freedom (ANOVA): 2,18
- Error Mean Square (ANOVA): 2526.12
- *q* 0.05 (*k*=6, *v*=18): 4.49
- n (Number of Observations): 8

The Critical Difference for Comparison of Means = 79.79

	66.45	**91.23**	**113.22**	**124.30**	**183.24**	**190.93**
66.45	-	24.73	46.77	57.85	116.79*	124.48*
91.23		-	21.99	33.07	92.01*	99.70*
113.22			-	11.08	70.02	77.71
124.30				-	58.94	66.63
183.24					-	7.69
190.93						-

* Denotes significant difference at the 0.05 level of significance

Appendix 2.iv.

Experiment Two

Modulus of Constant Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Practice Condition by Transfer

- Degrees of Freedom (ANOVA): 1,18
- Error Mean Square (ANOVA): 3326.16
- q 0.05 (k=4, v=18): 4.00
- n (Number of Observations): 12

The Critical Difference for Comparison of Means = 66.60

	75.365	**85.851**	**117.719**	**192.549**
75.365	-	10.486	42.354	117.184*
85.851		-	31.868	106.698*
117.719			-	74.83*
192.549				-

* Denotes significant difference at the 0.05 level of significance

Appendix 2.v.

Experiment Two

Variable Error

THREE-WAY ANOVA with REPEATED MEASURES

(Using MANOVA - SPSS)

Dependent Variable: Actual time minus Criterion time (msec.)

Source	df	SS	MS	F	Sig. of F
BETWEEN SUBJECTS	23				
PRAC. CONDITION	1	.97	.97	.00	.982
COMPLEXITY	2	28224.28	14112.14	7.37	.005*
P.C. by COMP	2	8573.78	4286.89	2.24	.135
ERROR-BETWEEN	18	34446.90	1913.72		
WITHIN SUBJECTS	24				
TRANSFER	1	47799.09	47799.09	41.52	.000*
P.C.. by TRANS	1	102.15	102.15	.09	.769
COMP by TRANS	2	1318.31	659.16	.57	.574
P.C. by COMP by TRANS	2	6243.80	3121.90	2.71	.093
ERROR-WITHIN	18	20722.21	1151.23		
TOTAL	47	147431.49			

* Denotes significant difference at the 0.05 level of significance.

Appendix 2.vi.

Experiment Two

Variable Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Complexity

- Degrees of Freedom (ANOVA): 2,18
- Error Mean Square (ANOVA): 1913.72
- q 0.05 (k=3, v=18): 3.61
- n (Number of Observations): 16

The Critical Difference for Comparison of Means = 39.49

	171.467	**122.742**	**117.687**
171.467	-	48.725*	53.78*
122.742		-	5.055
117.687			-

* Denotes significant difference at the 0.05 level of significance

Appendix 2.vii.

Experiment Two

Henry's Root Mean Square Error

THREE-WAY ANOVA with REPEATED MEASURES

(Using MANOVA - SPSS)

Dependent Variable: Actual time minus Criterion time (msec.)

Source	df	SS	MS	F	Sig. of F
BETWEEN SUBJECTS	23				
PRAC. CONDITION	1	33395.70	33395.70	27.35	.000*
COMPLEXITY	2	41699.33	20849.67	17.08	.000*
P.C. by COMP	2	3610.36	1805.18	1.48	.254
ERROR-BETWEEN	18	21976.56	1220.92		
WITHIN SUBJECTS	24				
TRANSFER	1	58544.90	58544.90	24.53	.000*
P.C. by TRANS	1	9219.47	9219.47	3.86	.065
COMP by TRANS	2	4103.16	2051.58	.86	.440
P.C. by COMP by TRANS	2	3008.49	1504.24	.63	.544
ERROR-WITHIN	18	42960.34	2386.69		
TOTAL	47	218518.31			

* Denotes significant difference at the 0.05 level of significance.

Appendix 2.viii.

Experiment Two

Henry's Root Mean Square Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Complexity

- Degrees of Freedom (ANOVA): 2,18
- Error Mean Square (ANOVA): 1220.92
- q 0.05 (k=3, v=18): 3.61
- n (Number of Observations): 16

The Critical Difference for Comparison of Means = 31.54

	223.273	**201.273**	**152.722**
223.273	-	22.000	70.551*
201.273		-	48.551*
152.752			-

* Denotes significant difference at the 0.05 level of significance

Appendix 3.i.

Experiment Three

Modulus of Constant Error

THREE-WAY ANOVA with REPEATED MEASURES (Using MANOVA - SPSS)

Blocks (3) = The Last 12 Practice Trials / Inside Transfer / Outside Transfer

Dependent Variable: Actual time minus Criterion time (msec.)

Source	df	SS	MS	F	Sig. of F
BETWEEN SUBJECTS	47				
PRAC. CONDITION	1	27173.46	27173.46	6.96	.012*
COMPLEXITY	2	30588.02	15294.01	3.92	.027*
P.C. by COMP	2	7931.15	3965.58	1.02	.371
ERROR-BETWEEN	42	163869.44	3901.65		
WITHIN SUBJECTS	96				
BLOCKS	2	212954.60	106477.30	36.05	.000*
P.C. by BLOCKS	2	51364.76	25682.38	8.69	.000*
COMP by BLOCKS	4	26893.86	6723.47	2.28	.068
P.C. by COMP by BLOCK	4	7185.06	1796.27	.61	.658
ERROR-WITHIN	84	248114.35	2953.74		
TOTAL	143	776074.70			

* Denotes significant difference at the 0.05 level of significance.

Appendix 3.ii.

Experiment Three

Modulus of Constant Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Complexity

- Degrees of Freedom (ANOVA): 2,42
- Error Mean Square (ANOVA): 3901.65
- q 0.05 (k=3, v=42): 3.44
- n (Number of Observations): 48

The Critical Difference for Comparison of Means = 31.01

	61.28	**86.96**	**95.60**
61.28	-	25.68	34.32*
86.96		-	8.64
95.60			-

* Denotes significant difference at the 0.05 level of significance

Appendix 3.iii.

Experiment Three

Modulus of Constant Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Blocks

- Degrees of Freedom (ANOVA): 2,84
- Error Mean Square (ANOVA): 2953.74
- q 0.05 (k=3, v=84): 3.4
- n (Number of Observations): 48

The Critical Difference for Comparison of Means = 26.67

	33.51	**82.64**	**127.68**
33.51	-	49.13*	94.17*
82.64		-	45.04*
127.68			-

* Denotes significant difference at the 0.05 level of significance

Appendix 3.iv.

Experiment Three

Modulus of Constant Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Practice Condition by Blocks

- Degrees of Freedom (ANOVA): 2,84
- Error Mean Square (ANOVA): 2953.74
- *q* 0.05 (*k*=6, *v*=84): 4.16
- n (Number of Observations): 24

The Critical Difference for Comparison of Means = 46.15

	26.22	**40.80**	**72.65**	**89.17**	**92.63**	**166.19**
26.22	-	14.58	46.43*	62.95*	866.41*	139.97*
40.80		-	31.85	48.36*	51.83*	125.39*
72.65			-	16.51	19.98	93.54*
89.17				-	3.47	77.03*
92.63					-	73.56*
166.19						-

* Denotes significant difference at the 0.05 level of significance

Appendix 3.v.

Experiment Three

Variable Error

THREE-WAY ANOVA with REPEATED MEASURES (Using MANOVA - SPSS)

Blocks (3) = The Last 12 Practice Trials / Inside Transfer / Outside Transfer

Dependent Variable: Actual time minus Criterion time (msec.)

Source	df	SS	MS	F	Sig. of F
BETWEEN SUBJECTS	47				
PRAC. CONDITION	1	19915.83	19915.83	7.61	.009*
COMPLEXITY	2	46647.37	23323.68	8.91	.001*
P.C. by COMP	2	7921.17	3960.59	1.51	.232
ERROR-BETWEEN	42	109923.81	2617.23		
WITHIN SUBJECTS	96				
BLOCKS	2	68974.33	34487.17	25.43	.000*
P.C. by BLOCKS	2	47052.81	23526.40	17.34	.000*
COMP by BLOCKS	4	72379.49	18094.87	13.34	.000*
P.C. by COMP by BLOCK	4	3655.16	913.79	.67	.612
ERROR-WITHIN	84	113939.13	1356.42		
TOTAL	143	490409.10			

* Denotes significant difference at the 0.05 level of significance.

Appendix 3.vi.

Experiment Three

Variable Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Complexity

- Degrees of Freedom (ANOVA): 2,42
- Error Mean Square (ANOVA): 2617.23
- q 0.05 (k=3, v=42): 3.44
- n (Number of Observations): 48

The Critical Difference for Comparison of Means = 25.40

	119.78	**126.97**	**161.04**
119.78	-	7.19	41.27*
126.97		-	34.07*
161.04			-

* Denotes significant difference at the 0.05 level of significance

Appendix 3.vii.

Experiment Three

Variable Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Blocks

- Degrees of Freedom (ANOVA): 2,84
- Error Mean Square (ANOVA): 1356.42
- q 0.05 (k=3, ν=84): 3.4
- n (Number of Observations): 48

The Critical Difference for Comparison of Means = 18.07

	115.52	**125.99**	**166.29**
115.52	-	10.47	50.77*
125.99		-	40.296*
166.29			-

* Denotes significant difference at the 0.05 level of significance

Appendix 3.viii.

Experiment Three

Variable Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Practice Condition by Blocks

- Degrees of Freedom (ANOVA): 2,84
- Error Mean Square (ANOVA): 1356.42
- q 0.05 (k=6, v=84): 4.16
- n (Number of Observations): 24

The Critical Difference for Comparison of Means = 31.27

	89.30	**109.92**	**121.11**	**162.10**	**162.68**	**170.47**
89.30	-	20.62	31.82*	72.81*	73.39*	81.17*
109.92		-	11.19	52.18*	52.76*	60.55*
121.11			-	40.99*	41.57*	49.36*
162.10				-	0.58	8.37
162.68					-	7.79
170.47						-

* Denotes significant difference at the 0.05 level of significance

Appendix 3.ix.

Experiment Three

Variable Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Complexity by Blocks

- Degrees of Freedom (ANOVA): 4,84
- Error Mean Square (ANOVA): 1356.42
- q 0.05 (k=9, ν=84): 4.55
- n (Number of Observations): 16

The Critical Difference for Comparison of Means = 41.89

	87.21	94.28	107.50	123.81	141.24	146.66	147.04	165.05	210.58
87.21	-	7.07	20.29	36.60	54.03*	59.45*	59.83*	77.84*	123.36*
94.28		-	12.72	29.53	46.96*	52.38*	52.76*	70.77*	116.29*
107.50			-	16.31	33.74	39.16	39.54	57.55*	103.08*
123.81				-	17.43	22.85	23.23	41.24	86.77*
141.24					-	5.42	5.80	23.81	69.34*
146.66						-	0.38	18.39	63.92*
147.04							-	18.01	63.54*
165.05								-	45.52*
210.58									-

* Denotes significant difference at the 0.05 level of significance

Appendix 3.x.

Experiment Three

Henry's Root Mean Square Error

THREE-WAY ANOVA with REPEATED MEASURES (Using MANOVA - SPSS)

Blocks (3) = The Last 12 Practice Trials / Inside Transfer / Outside Transfer

Dependent Variable: Actual time minus Criterion time (msec.)

Source	df	SS	MS	F	Sig. of F
BETWEEN SUBJECTS	47				
PRAC. CONDITION	1	.02	.02	.00	.998
COMPLEXITY	2	53674.28	26837.14	7.54	.002*
P.C. by COMP	2	12722.69	6361.35	1.79	.180
ERROR-BETWEEN	42	149518.48	3559.96		
WITHIN SUBJECTS	96				
BLOCKS	2	214114.94	107057.47	61.75	.000*
P.C.. by BLOCKS	2	102367.02	51183.51	29.52	.000*
COMP by BLOCKS	4	52540.78	13135.19	7.58	.068
P.C. by COMP by BLOCK	4	8339.24	2084.81	1.20	.316
ERROR-WITHIN	84	145626.49	1733.65		
TOTAL	143	738903.94			

* Denotes significant difference at the 0.05 level of significance.

Appendix 3.xi.

Experiment Three

Henry's Root Mean Square Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Complexity

- Degrees of Freedom (ANOVA): 2,42
- Error Mean Square (ANOVA): 3559.96
- *q* 0.05 (k=3, v=18): 3.44
- n (Number of Observations): 48

The Critical Difference for Comparison of Means = 29.6

	145.2	**170.8**	**192.3**
145.2	-	25.6	47.1*
170.8		-	21.2
192.3			-

* Denotes significant difference at the 0.05 level of significance

Appendix 3.xii.

Experiment Three

Henry's Root Mean Square Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Practice Condition by Blocks

- Degrees of Freedom (ANOVA): 2,84
- Error Mean Square (ANOVA): 1733.65
- *q* 0.05 (*k*=6, *v*=84): 4.16
- n (Number of Observations): 24

The Critical Difference for Comparison of Means = 35.40

	96	**141**	**165**	**170**	**198**	**247**
96	-	45*	69*	74*	102*	151*
141		-	24	29	57*	106*
165			-	5	33	82*
170				-	28	77*
198					-	49*
247						-

* Denotes significant difference at the 0.05 level of significance

Appendix 3.xiii

Experiment Three

Henry's Root Mean Square Error

Tukey's Multiple Comparison Test

Dependent Variable: Actual time minus Criterion time (msec.)

Effect: Complexity by Blocks

- Degrees of Freedom (ANOVA): 4,84
- Error Mean Square (ANOVA): 1733.65
- q 0.05 (k=9, ν=84): 4.55
- n (Number of Observations): 16

The Critical Difference for Comparison of Means = 41.89

	115	119	129	150	155	190	192	204	269
115	-	4	14	35	40	75*	77*	89*	154*
119		-	10	31	36	71*	73*	85*	150*
129			-	21	26	61*	63*	75*	140*
150				-	5	40	42*	54*	119*
155					-	35	37	49*	114*
190						-	2	14	79*
192							-	12	77*
204								-	65*
269									-

* Denotes significant difference at the 0.05 level of significance

Appendix 4

COMPUTER PROGRAMME

For the 380Z Research Machine to record the Movement Times for Experiments One and Two.

```
10  REM JAN.25
20  PRINT "DATA DISK IN?"
30  PRINT "PRESS ANY KEY WHEN READY"
40  LET ZZ=GET()
50  RESET
60  CLEAR
70  CLEAR 2000
80  PRINTER 4,1
90  REM ******** HOOPER 1 ********
100 RANDOMIZE
110 REM ***** REPLICATION OF LEE MAGILL AND WEEKS
120 DIM TT(2),TT$(2), MT(2,15,4),CT(6,2),R(2),T(12,2,2)
130 DIM KT(4),CK(4),VT(60)
150 DATA 500,900,600,800,800,500,900,600,700,700,1000,1000
160 DATA 16,32,64
170 FOR K=1 TO 4: LET KT(K)=0: CK(K)=0: NEXT K
180 LET K=0: KO=0: NT=0: TR=0: AV=0: QB=0
190 FOR I=1 TO 6: FOR J=1 TO 2: READ CT(I,J): NEXT J: NEXT I
200 DIM B(3)
210 FOR I=1 TO 3: READ B(I): NEXT I
220 INPUT" Test Pad ?";A$
230 IF A$="Y" OR A$="y" THEN GOSUB 1330
240 REM ******** INITIALISE CLOPAD ********
250 CALL "RESOLUTION",0,2
260 CALL "CLOPAD",7
270 INPUT "GROUP NUMBER 1,2,3...";GN
280 IF GN= 1 THEN GN$="CO"
290 IF GN= 2 THEN GN$ ="BL"
300 IF GN= 3 THEN GN$="RA"
```

```
310 INPUT "COMPLEXITY LEVEL..(1,2,3 OR 4)";PB
320 IF PB<1 OR PB>4 THEN PRINT "BETWEEN 1 AND 4 PLEASE...": GOTO
    310
330 INPUT "SUBJECT NUMBER (within group)";SB$
340 CD$="0"
350 IF GN=2 OR GN=3 THEN GOTO 380
360 INPUT "CONDITION 1, 2, 3 OR 4";CD$
370 LET CD=VAL(CD$)
380 K=1
390 IF GN=3 THEN GOSUB 1950
400 FOR K=1 TO 4: LET CK(K)=0: NEXT K
410 K=1
420 REM ********SELECT TRIAL ********
430 LET ZZ=GET(300): GRAPH 0: GRAPH 1
440 IF TR=60 THEN GOSUB 1050
450 TR=TR+1
460 PLOT 15,30,"
470 PLOT 15,40,"
480 GOSUB 1280
490 LET S$=STR$(S)
500 LET BU$=STR$(BU)
510 REM ***** PRE-TRIAL CHECK *****
520 IF PB=1 THEN PLOT 10,45,"BARRIER 7, BARRIER 7 AND BUTTON A
    SHOULD BE USED."
530 IF PB=2 THEN PLOT 10,45,"BARRIER 7, BARRIER 7 AND BUTTON B
    SHOULD BE USED."
540 IF PB=3 THEN PLOT 10,45,"BARRIER 7, BARRIER 6 AND BUTTON A
    SHOULD BE USED."
550 IF PB=4 THEN PLOT 10,45,"BARRIER1, BARRIER 6 AND BUTTON B
    SHOULD BE USED."
560 GOSUB 2260
570 IF AV<>A THEN PRINT "WRONG BARRIERS";: GOTO 560
580 LET TR$=STR$(TR)
590 IF PB=1 THEN PLOT 10,45,"BARRIER 7, BARRIER 7 AND BUTTON A
    SHOULD BE USED."
600 IF PB=2 THEN PLOT 10,45,"BARRIER 7, BARRIER 7 AND BUTTON B
    SHOULD BE USED."
```

```
610 IF PB=3 THEN PLOT 10,45,"BARRIER 7, BARRIER 6 AND BUTTON A
      SHOULD BE USED."
620 IF PB=4 THEN PLOT 10,45,"BARRIER 6 AND BUTTON B SHOULD BE
      USED."
630 PLOT 10,55, TR$
640 REM ***** MAIN PROGRAMME FOR A TRIAL *****
650 GOTO 670
660 LET R(1)=TR: R(2)=K: GOTO 920
670 CALL "CLOPAD",8,VARADR(A): IF A=AV THEN PRINT "PRESS
      START";S: GOTO 670
680 CALL "CLOPAD",8,VARADR(A): IF A=AC TEN PRINT "WRONG START
      BUTTON...PRESS THE OTHER ONE": GOTO 680
690 PLOT 10,20,"
700 IF A=AV GOTO 670
710 IF A<>QB THEN PLOT 10,20,"CHECK BARRIERS AND PRESS START":
      GOTO 670
720 PLOT 50,50, "BEGIN WHEN READY"
730 PUT 12
740 CALL "CLOPAD",8,VARADR(C): IF CAV GOTO 740
750 CALL "CLPOAD",0
760 PLOT 50,50,"                    "
770 CALL "CLOPAD",8,VARADR(A): IF A = AV THEN GOTO 770
780 CALL "CLOPAD",1,VARADR(R(1))
790 CALL "CLPOAD",8,VARADR(C): IF C=A OR C=AV THEN GOTO 790
800 CALL "CLOPAD",1,VARADR(R(2))
810 LET R(2)=R(2)-R(1)
825 CALL "CLOPAD",9,VARADR(F6): IF F6=110 OR F6=78 THEN GOTO 670
827 IF TR>60 THEN GOTO 1010
830 IF ABS(R(2)-TT(2))((3*TT(2))/5) AND ABS(R(1)-TT(1))((3*TT(1)/5) THEN
      PZ=PZ+1: GOTO 910
840 PUT 12
850 IF TR>60 THEN GOTO 890
860 PLOT 10,20,"NOT ACCURATE ENOUGH.....PLEASE RE-
      PEAT"+STR$(R(1))+STR$(R(2))
870 PZ=PZ-1: EZ=EZ+1
880 LET ZZ=GET(200): PLOT 10,20,"                    "
890 GOSUB 2260
```

```
900  GOTO 670
910  PLOT 45,40,"ACTUAL TIMES"
920  LET R$=STR$(R(1)): PLOT 80,40,R$
930  LET R$STR$(R(2)): PLOT 90,40,R$
940  IF ABS(R(1)-TT(1))<(TT(1)/10) THEN PZ=PZ+3
950  IF ABS(R(2)-TT(2))<(TT(2)/10) THEN PZ=PZ+3
960  PLOT 10,20,"TOTAL POINTS SCORED="+STR$(PZ)
970  FOR I=1 TO 2
980  LET MT(I,NT,K)=R(I)-TT(I)
990  NEXT I
1000 GOTO 420
1010 REM DATA STORES FOR TRANSFER DATA
1020 T(NN,DT,1)=R(1)-TT(1): T(NN,DT,2)=R(2)-TT(2)
1030 IF NN=12 AND DT=2 THEN GOTO 1190
1040 GOTO 420
1050 REM ***** CLOSE DOWN BY STORING AND PRINTING DATA. *****
1060 TEXT: PUT 12: PLOT 10,10, "PLEASE WAIT...A 5 MINUTE BREAK"
1070 LET F$="B: PR"+CD$+GN$+SB$+".DTA"
1080 CREATE $10, F$
1090 FOR J=1 TO 15
1100 PRINT $10, F$
1110 FOR K=1 TO 4
1120 PRINT $10,MT(1,J,K);MT(2,J,K),
1130 NEXT K: PRINT $10,"     ": NEXT J
1140 CLOSE $10
1150 FOR M=2700 TO 1 STEP-3000: LET T$=STR$(M/6000)
1160 PLOT 10,20,T$: PLOT 20,20, "MINIUTES TO WAIT": LET ZZ=GET(3000)
1170 PLOT 10,20,"                         ": NEXT M
1180 RETURN
1190 GOSUB 1850
1200 INPUT "PRINT OUT TRANSFER DATA?"; R$
1210 IF R$<> "Y" AND R$<> "y" THEN GOTO 1260
1220 FOR I=1 TO 2
1230 J=1 TO 12
1240 LPRINT T(J,1,I), T(J,2,I)
1250 NEXT J: LPRINT: NEXT I
1260 TEXT
```

```
1270 END
1280 REM ******** SUB TO SELECT TRIAL ********
1290 GOSUB 1430
1300 S=1: BU=3
1310 RETURN
1320 IF A=B(1)+B(2) THEN PRINT "BARRIERS 1 + 2 ARE UP"
1330 REM ******** TEST PAD ********
1340 PUT 12
1350 PRINT "TESTING PAD"
1360 CALL "CLOPAD",7
1370 CALL "CLOPAD",8,VARADR(A)
1380 PRINT A
1390 IF A<113 GOTO 1370
1400 IF A=119 THEN PRINT "RELEASE BUTTON AND PRESS ANY KEY"
1410 LET ZZ=GET()
1420 RETURN
1430 REM ******** SUB FOR SELECTING TIME INTERVALS
1440 IF TR>60 THEN GOTO 1600
1450 IF GN=1 THEN GOTO 1700
1460 IF GN=3 THEN GOTO 1530
1470 KO=KO+1
1480 IF KO=16 GOSUB 2160
1490 IF KO=16 THEN KO=1: K=K+1
1500 NT=KO
1510 TT(1)=CT(K,1): TT(2)=CT(VT(TR),2)
1520 GOTO 1770
1530 TT(1)=CT(VT(TR),1): TT(2)=CT(VT(TR),2)
1540 LET K=VT(TR)
1550 LET CK(K)=CK(K)+1
1560 LET NT=CK(K)
1570 GOTO 1770
1580 NT=CK(K)
1590 GOTO 1770
1600 IF TR=73 THEN GOSUB 2160
1610 IF TR>72 THEN GOTO 1660
1620 NN=TR-60: DT=1
1630 NT=NN
```

```
1640 TT(1)=CT(5,1): TT(2)=CT(5,2)
1650 GOTO 1770
1660 TT(1)=CT(6,1): TT(2)=CT(6,2)
1670 NN=TR-72: DT=2
1680 NT=NN
1690 GOTO 1770
1770 REM ******** CONSTANT GROUPS ********
1710 IF CD=1 THEN TT(1)=CT(1,1): TT(2)=CT(1,2): GOTO 1750
1720 IF CD=2 THEN TT(1)=CT(2,1): TT(2)=CT(2,2): GOTO 1750
1730 IF CD=3 THEN TT(1)=CT(3,1): TT(2)=CT(3,2): GOTO 1750
1740 TT(1)=CT(4,1): TT(2)=CT(4,2)
1750 LET NT=NT+1
1760 IF NT=16 THEN K=K+1: NT=1
1770 PUT 12: REM ******** DISPLAY TARGET TIMES ******
1780 GRAPH 1
1790 PLOT 45,30,"TARGET TIMES"
1800 LET TT$=STR$(TT(1))
1810 PLOT 80,30,TT$
1820 LET TT$=STR$(TT(2))
1830 PLOT 90,30,TT$
1840 RETURN
1850 LET F$="B: "+CD$+GN$+SB$+".DTA"
1860 CREATE $10,F$
1870 PRINT $10,F$
1880 FOR J=1 TO 12
1890 FOR K=1 TO 2
1900 PRINT $10, T(J,K,1); T(J,K,2)
1910 NEXT K
1920 NEXT J
1930 CLOSE $10
1940 RETURN
1950 REM ***** SUB FOR SETTING VARIED TRIALS *****
1960 PRINT "SETTING TARGETS...PLEASE WAIT"
1970 LET MN=0
1980 FOR G=1 TO 5
1990 FOR L=1 TO 4: LET KT(L)=0: NEXT L
2000 FOR BK=1 TO 12
```

```
2010 LET RN=INT((5-1)*RND(1)+1)
2020 LET GZ=GZ+1
2030 IF GZ=10 THEN GZ=0: GOTO 1950
2040 IF RN=PN AND RN=KK THEN GOTO 2010
2050 IF KT(RN)=3 THEN GOTO 2010
2060 LET KK=PN: PN=RN
2070 LET KT(RN)=KT(RN)+1
2080 LET MN=MN+1
2090 PRINT MN
2100 LET VT(MN)=RN
2110 LET CK(RN)=CK(RN)+1
2120 GZ=0
2130 NEXT BK
2140 NEXT G
2150 RETURN
2160 REM ******** BEEP SUBROUTINE ********
2170 PUT 12
2180 FOR J=50 TO 150 STEP 4
2190 PUT 27,64,J,5,65,7
2200 NEXT J
2210 PUT 27,64,40,10,65,7
2220 PLOT 55,20,"NEW TARGET TIMES"
2230 LET ZZ=GET(250): PUT 12
2240 PUT 27,64,20,10,65,7
2250 RETURN
2260 REM ******** SUB FOR COMPLEXITY LEVELS *******
2270 IF PB=4 THEN GOTO 2380
2280 IF PB=3 THEN GOTO 2350
2290 IF PB=2 THEN GOTO 2320
2300 AV=80: QB=85
2310 GOTO 2400
2320 REM ******** COMPLEXITY LEVEL 2 ********
2330 AV=80: QB=82
2340 GOTO 2400
2350 REM ******** COMPLEXITY LEVEL 2 ********
2360 AV=48: QB=51
2370 GOTO 2400
```

```
2380 REM ******** COMPLEXITY LEVEL 3 ********
2390 AV=48: QB=51
2400 CALL "CLOPAD",8,VARADR(A): IF A=0 THEN PRINT "ALL BARRIERS
     DOWN": GOTO 2400
2410 IF A=B(1) THEN PRINT "BARRIER 3 IS UP": GOTO 2400
2420 IF A=B(2) THEN PRINT "BARRIER 6 IS UP": GOTO 2400
2430 IF A=B(3) THEN PRINT "BARRIER 7 IS UP": GOTO 2400
2440 IF A=B(1)+B(2) THEN PRINT "BARRIERS 3 AND 6 ARE UP"
2450 IF A=B(1)+B(3) THEN PRINT "BARRIERS 3 AND 7 ARE UP"
2460 IF A=B(2)+B(3) THEN PRINT "BARRIERS 6 AND 7 ARE UP": GOTO 2400
2470 IF A=B(1)+B(2)+B(3) THEN PRINT "ALL UP": GOTO 2400
2480 IF A <32 THEN GOTO 2400
2490 IF AV<>A THEN PRINT"...RELEASE BUTTON AND RAISE BARRIERS"
2500 RETURN
```