ACQUISITION AND MAINTENANCE OF KEYBOARD SKILLS

RACHAEL MAGUIRE

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ABSTRACT

The objective of this research was to examine factors that promote the acquisition and retention of a simple skill. Specifically, the issues addressed included whether manipulating the ‘type’ (massed versus distributed), ‘style’ (blocked versus random) and ‘amount’ of practice affected the acquisition and retention of a keyboard skill. Furthermore the effects of reinstating specific perceptual and motor cues learned at acquisition during the subsequent retention phase was examined. This was performed in order to assess whether specific attributes of the stimuli were learned or whether more general underlying properties of the stimuli were acquired.

A digit entry paradigm was used in all experiments and followed a repeated measures design. At acquisition subjects entered a series of repeating four digit sequences using a computer keyboard. To assess the effects of practice, response times for each repetition of the sequence were measured. Following a retention interval of between one hour and up to two weeks, subjects entered a combination of ‘old’ and ‘new’ sequences at test. Indirect and direct tests were performed at retention; response times and recognition decisions were measured in order to assess whether a performance advantage was found for previously seen stimuli.

Manipulating the ‘type’ or the ‘style’ of practice did not affect acquisition of the task. Regardless of whether practice was ‘massed’ or ‘distributed’, the rate at which the task was learned did not differ. Furthermore, retention performance did not differ as a function of the ‘type’ of practice; old and new sequences were entered at the same speed, but old sequences were discriminated from new. Manipulating the ‘amount’ of practice resulted in comparably different retention effects; ‘old’ sequences were entered faster than ‘new’ and were recognised as such. Recognition was influenced by the speed with which the sequences were entered, which in turn was dependent upon the reinstatement of perceptual and motor cues.

That different retention effects were found across the studies led to the conclusion that both stimulus specific knowledge as well as that of the general regularities underlying sequence formation was acquired and retained. The main benefit of such knowledge development is the ability to adapt performance to novel but similar stimuli whilst maintaining the ability to distinguish previously seen stimuli from new.
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1 SKILL AND SKILLED BEHAVIOUR

1.1 INTRODUCTION
The aim of this chapter is to present a review of the literature, clarifying the processes that occur as an individual embarks upon learning a novel skill. The topics addressed will include a review of the changes in behaviour that occur during ‘acquisition’ of the skill; the principle mechanisms that enhance learning, such as practice and instruction and finally, retention of skilled performance will also be assessed in the context of the events that occur during acquisition. Consequently, a major area of interest is how well the learning strategy adopted during acquisition promotes subsequent performance on the same as well as facilitating transfer of performance to similar skills.

1.2 DEFINING SKILL
The term ‘skill’ is a relative term that describes a series of learned actions that are embedded in the context of other ongoing events (Adams, 1987). As ‘skill’ is primarily regarded as a psychological construct, its attainment has been traditionally inferred from a change in the behaviour of the individual (Annett, 1991). This, however, has been considered a rather vague and unsatisfactory index (Willingham, 1998). More recent evidence from within the neuropsychological domain has augmented these findings showing that changes in brain activity occur as a skill develops; specific areas of the brain are associated with skilled performance and others with non-skilled performance (Posner, DiGirolamo and Fernandez-Duque, 1997). Findings such as these demonstrate concrete physical evidence of a skilled versus non-skilled state of being.

Although various definitions of skill appear within the literature, most suffer from some sort of shortcoming due to the nature of the skill that they are aiming to define, i.e. whether the skill is classified as cognitive, motor or perceptual (Schmidt 1988). Early definitions of skill have either been too specific consequently eliminating a
whole domain of behaviour from analysis, or alternatively, have been too general to contribute to further understanding of skill and skilled performance (Patrick, 1991).

One of the more useful ways of conceptualising 'skill', is as a learned repertoire of behaviours representing solutions to a particular set of problems (Annett, 1991). Although this appears to be a rather vague statement, it has two important functions: Such a view encompasses all skill domains but more importantly however, highlights the definitive characteristics of skilled performance. It is generally agreed that skilled behaviour is characterised as being goal directed, economical of effort and most importantly, learned (Annett, 1991). Thus, if a skill is equated to a 'solution to a problem' then skill acquisition arguably contains two components: the analysis of the problem and the subsequent development of the means by which the problem can be solved; that is, the processes by which the individual learns. In the following section these bases of skill acquisition will be discussed.

1.3 SKILL ACQUISITION
Skill acquisition occurs as follows: An individual is presented with or creates a goal that they want to achieve. A mixture of practice and instruction about how to perform the new task is received and as a consequence new behaviours are learned and existing ones tuned to the requirements of the task (Mumford, Costanza and Baugham, 1994). Over time, performance becomes more fluid and efficient as the individual progresses from 'novice' to 'expert' (Anderson, 1995). Thus, inherent to the attainment of a skill is the fact that an individual is able to perform the task well (Groeger, 1997). It is important to emphasise at this point that being 'skilled' is not the same as having the capacity or the ability to do something. The latter terms imply innate attributes of the individual, i.e. those inherent characteristics which may facilitate skill acquisition but are not developed through proactive learning (Schmidt, 1991).

1.3.1 BEHAVIOURAL CHANGES
If a skill is regarded as the solution to a particular problem then one of the defining
features of acquisition is the process by which solutions are learned and appropriately used. One way to assess whether the relevant aspects of the task are being learned is to monitor the changes in behaviour that occur within the individual. Both ‘quantitative’ and ‘qualitative’ changes in behaviour are characteristic of skill acquisition, with developments in one domain influencing the expansion of the other (Long, 1976).

With respect to quantitative changes, dramatic alterations in numerically measurable aspects of performance occur. For example, decreases in both the time taken to execute a particular movement as well as the number of errors committed whilst doing so are likely to be apparent, alongside increases in the amount of work completed within a given period (Annett, 1991). The rate at which these changes occur is initially rapid as the learner acquires the basic (relatively easy) concepts involved in performing the task, but slowly diminishes with time as the learner becomes more accomplished and there are simply less behaviours to change (Welford, 1987). One of the most effective ways of expressing such changes is by plotting the different performance measures (e.g. response time or error rate) against the number of trials completed; a negatively accelerating learning curve is typically produced (Adams, 1985; Groeger, 1997).

With regard to qualitative changes, the performance strategies used by the individual are modified (Annett, 1991). During the initial stages of learning one way in which the individual can facilitate performance in a novel task is to restructure and reorganise existing behaviours (Ackerman, 1992). At the outset of learning, attention is directed to the less demanding aspects of the task but due to its novelty, performance is still slow and requires effort. As learning progresses and the individual becomes more experienced, clear improvements are evident; strategic shifts are hypothesised to occur, for example the basic components of the task are ‘chunked’ together into larger units of manageable information. The effort necessary to perform these larger chunks decreases resulting in faster, more fluid performance (Anderson, 1993).
These behavioural changes are promoted in one of two ways: through practice and instruction. The two paradigms are qualitatively dissimilar and as a result effect the course of learning differently. Furthermore, differences between the type of practice received and also the amount of instruction given not only alters the temporal duration of skill acquisition but also affect the success with which the skill is retained (Groeger, 1997). Indeed it has been suggested that a more precise indication of learning is that which is retained, not how well an individual does during the training situation (Groeger, 2000). In order to qualify this claim, the aim of the next section is to highlight issues pertinent in assessing retention. This will then be followed by a discussion of mechanisms such as ‘practice’ and abilities such as ‘transfer’ and ‘contextual interference’. All of these factors demonstrate that the events occurring during acquisition cannot be divorced from those at retention.

1.4 RETENTION OF SKILL
Retention refers to the persistence of the ability to perform following a break from a learning period (Richardson-Klavehn and Bjork, 1988). Testing an individual after some interval reveals the true effectiveness of manipulations performed during acquisition (Schmidt, 1988). There is no doubt that it is easier to process something that has already been seen. However, it is not always necessary to realise that a stimulus has already been seen in order for this advantage to be conferred. Retention of material can be assessed both directly and indirectly, by employing recognition tests and priming paradigms, respectively (Schacter, 1992). As has been mentioned and will become clear, the degree to which an individual can perform successfully on any of these tests depends to a large extent upon the learning experience, or the type of practice and instruction received (Groeger, 2000).
1.5 **THE ROLE OF PRACTICE AND INSTRUCTION IN SKILL ACQUISITION**

The effectiveness with which the learner's behavioural repertoire is developed is largely determined by two factors: practice and instruction (Ackerman, 1992). 'Practice' has been referred to as the *sine qua non* of skill acquisition (Annett, 1991) and is the process by which the individual actively accretes and tunes their knowledge to a specific task (Rumelhart and Norman, 1978; Mumford, Costanza and Baugham, 1994). Practice can be distinguished on the basis of its temporal duration in addition to the way in which the schedule is organised. Instruction is important during the early stages of learning where the learner is directed to the key aspects of the task. Instruction can be clearly differentiated from practice and as will become evident adopting one paradigm rather than the other has profound effects upon acquisition and subsequent performance. Indeed, a thorough assessment of the role of practice will highlight the complex interplay that exists between acquisition and retention.

The main difference between the paradigms of practice and instruction concerns the extent to which the individual is a passive or active recipient of information (Annett, 1991). With practice, the learner is proactive, making repeated attempts to perform the task; performance changes which arise are due to the individual's own persistence (Ackerman, 1992). In contrast under conditions of instruction, the learner is passive, being presented with models, simulation, advice and correction rather than disseminating and engaging in the task themselves. The effects of instruction are assumed to arise through formal changes in cognitive processes that incur changes in the way information is perceived, structured and organised.

At the outset of any novel learning situation, some form of instruction is desirable in order to ensure that the individual is learning relevant aspects of the task (Van Lehn, 1996). One of the reasons for this is that such situations are factually very rich and increase the learners reliance upon declaratively based knowledge systems (Anderson, 1995). Instruction provides action-specific detail that enables fine-tuning of performance in addition to feedback that serves as a useful motivational tool for
inspiring confidence in the individual (Groeger, 2000). However, it is only with practice that an individual becomes fully proficient.

1.5.1 THE EFFECTS OF PRACTICE

1.5.1.1 MASSED AND DISTRIBUTED: ACQUISITION

Active participation in the task promotes learning and the way in which this is achieved also has consequences for skill acquisition. One of the major factors that effects the temporal duration of acquisition is the 'spacing' of the practice schedule. Two types have been identified: 'Massed' and 'distributed' (Baddeley, 1982, 1997).

Massed practice is characterised by repetitive, uninterrupted performance on a task; the same stimuli are presented in close proximity to each other and the interval between massed practice sessions is often less than the actual duration of the practice exercise (Schmidt, 1991). The result of massed practice is rapid acquisition of the task. Distributed practice, however, involves participation in tasks which are temporally disparate (Groeger, 1997). Practice sessions are generally shorter than the intervening 'rest' period, the latter often being filled with other, unrelated tasks. By its very nature a distributed regime involves extended periods of learning and when assessed in terms of elapsed time, results in slower skill acquisition.

Baddeley and Longman (1978) performed an experiment illustrating the differences between massed and distributed practice during learning. Their aim was to train post office workers upon a simple motor task – using a keyboard to type postcodes. The postal workers were familiarised with the task before being divided into three training groups, differentiated by the amount and duration of practice sessions received. The critical comparison was between the group receiving one one-hour session per day (distributed) and the group receiving one two-hour (massed) session per day. More correct keystrokes per minute were consistently entered by the distributed group than the massed. A third group who received two, two-hour sessions performed least accurately which suggests a limit to which individuals can effectively learn before
situational variables such as boredom and fatigue impinge upon performance (Baddeley and Longman, 1978). Thus, in terms of successful acquisition of the task distributed practice was found to be the best strategy to adopt, a finding which has been replicated with tasks such as learning sporting tasks (Ma, Trombly and Robinson-Podolsky, 1999) and driving (Groeger, 1997).

In addition to extrinsic determinants of practice style intrinsic factors also influence choice of practice style (Mumford et al, 1994). Subjects were required to learn how to control an automated system and could adopt either a massed or a distributed practice schedule to do so. An influential factor in the choice of practice style was their perceived level of ability prior to the onset of learning. If the individual did not have any appropriate response strategies and were therefore forced to rely upon a general cognitive strategy, they opted for distributed practice. It was hypothesised that this allowed them to capitalise upon the length of time spent performing the task, forming elaborate representations of the procedures involved. In contrast, individuals who felt they had some prerequisite abilities that enabled them to perform the task chose massed practice. Unsurprisingly a noticeable difference in the speed of performance was found – the latter acquiring the task much more rapidly. However, as a cautionary note, it must be also borne in mind that the effort required to perform under conditions of distributed practice may have had a negative effect upon the rate of performance simply because it was a more tiring procedure due to the additional learning involved.

What these findings suggest is that distributed practice is a more appropriate method of learning in situations where the individuals lack knowledge structures of the ‘to-be-acquired’ skill. Where the individual has the potential to apply behaviours more readily, massed practice seems the relevant style to choose (Mumford et al, 1994). This confirms the view that one of the factors influencing the choice of practice style is the ability and the experience of the sample, a consideration also highlighted through the study of individual differences (Ackerman, 1992). As a caveat to this however, and as will be illustrated presently, one also has to consider performance at
retention. It has become increasingly apparent that massed practice may be a powerful performance variable, rather than a learning variable; i.e. the effects of massing are apparent immediately, i.e. during the learning phase, but do not necessarily indicate successful retention of the task (Schmidt, 1988; Groeger, 1997). This will be investigated in more detail in the next section.

1.5.1.2 Massed and Distributed Practice: Retention

Effects of the type of practice at retention will again be demonstrated using the Baddeley and Longman study. Recall that three groups were used in the study, the first who received one, one-hour session, the second who received one, two hour session and the third who received two, two hour sessions. The first group (distributed) was more successful in acquiring the skill. Following a one-month delay the accuracy of the distributed group was greater than the massed group.

A potential reason for the benefits of distributing practice was examined by Kolers and Duchnicky (1985). Their task was involved reading aloud pages of text that had been transformed in a number of geometric orientations. Different orientations were interleaved with one another, resulting in a distributed practice schedule. They found that the rate at which each orientation of text was read did not speed up within a session. However presentation of the same pieces of text were read more rapidly on subsequent days. The authors concluded in support of distributed practice that 'the effects of practice cumulate and then as a separate event are transferred for application to a previously segmented task unit (Kolers and Duchnicky, 1985, p627).

Segmentation and subsequent application of skill has recently been applied to the driving task, in which multiple movements are practised in a distributed fashion and are later recalled successfully in similar situations (Groeger, 2000).

It has also been demonstrated that for motor skills, practice effects also interact with the type of task, i.e. whether it is continuous or discrete (Schmidt, 1991). A study in which these variables were found to interact was performed by Lee and Genovese (1989). Subjects were required to move an object from one position to another either
in single movements, a discrete version of the task, or in blocks of twenty consecutive movements, i.e. the continuous version of the task. Practice was either massed (500ms between trials) or distributed (25s between trials). Retention tests occurred either ten minutes or seven days after practice and subjects from each practice condition were tested under massed or distributed conditions.

With respect to the continuous task, during acquisition as expected the massed practice group performed the task faster and more accurately than the distributed group and this effect was maintained at retention. However, a different pattern emerged with the discrete task. During acquisition, again the massed group acquired the task more rapidly. At retention, however, performance benefits were dependent upon the match between practice and testing conditions. Where the massed practice group were tested under distributed conditions they were less effective at performing the task than those who received distributed practice, and vice versa (Lee and Genovese, 1989).

It is asserted therefore that successful retention of a motor task is partly dependent upon the way in which it is practised, which in turn interacts with the type of task being learned. The apparent differences between massed and distributed practice are empirically tested in Chapter 4.

1.5.1.3 RANDOM VERSUS BLOCKED PRACTICE: ACQUISITION

Another way in which practice effects the temporal duration of skill acquisition is through the ‘organisation’ of the schedule, that is whether it is ‘random’ or ‘blocked’. Under conditions of blocked practice the learner experiences all of the identical elements of the task before being presented with any alternative variations; under conditions of random practice, the presentation of these different elements is varied and unpredictable (Battig, 1972). Blocking or randomising the trials within a practice list determines whether the task will be acquired rapidly or more slowly (Proctor and Dutta, 1993). Intuitively blocking trials in which the same movement or operation is supposed to be performed will lead to faster acquisition of that movement; the learner
will begin to predict and anticipate which stimuli will be presented and thus the required response throughout the trials. Randomising trials negates any anticipatory responding as a different and unpredictable response is required each time; clearly the effects upon the speed of responding will be deleterious (Lee, 1998).

Recent research suggests that there may be limits upon the extent to which blocked practice facilitates acquisition, however. Where adults have been required to perform ‘difficult’ tasks, blocked and random performance has been indifferent (Pollock and Lee, 1997). This implies that the benefits of blocked practice are only found when the task to be learned is relatively easy to acquire; temporary factors such as randomness which influence performance may be reduced as the difficulty increases (Lee, Wulf and Schmidt, 1992). This may be indicative of the learner ‘balancing’ the trade-off between speed and accuracy; they may not want to forsake either so therefore respond with greater consideration across all aspects of the task.

1.5.1.4 BLOCKED VERSUS RANDOM PRACTICE: RETENTION

The finding that random practice rather than blocked practice leads to more successful retention has been demonstrated across a variety of skills, both ‘cognitive’ (e.g. studies of verbal learning (Battig, 1972)) and ‘motor’ in nature.

A classic study demonstrating the effects of random practice upon motor skills was performed by Shea and Morgan (1979). Subjects were required to complete a task that involved knocking down six pegs with their right hand. The pegs could be knocked in one of three specific sequences. Practice was either blocked so that each sequence group was practised prior to the onset of practice for the others (i.e. all of the practice for the first, the second and then the third), or random. Following a retention interval of either ten minutes or ten days, regardless of whether the test trials were random or blocked, the group who received random practice during acquisition performed the task faster and more accurately than the blocked group. The finding that random practice leads to more successful retention has since been replicated numerous times and is regarded as one of the most robust within the learning literature.
CHAPTER ONE
(Imminck and Wright, 1998). The effect has been termed ‘contextual interference’ and once again demonstrates how acquisition and practice are fundamentally interleaved (Chamberlain and Magill, 1992).

1.6 CONTEXTUAL INTERFERENCE
Contextual interference (CI) has been defined as the “effect on learning of the degree of functional interference found in a practice situation when several tasks must be learned and are practiced together” (Magill and Hall, 1990, p 244), i.e. interference that facilitates learning. CI is experienced during acquisition when either variation within the elements of the task itself is present or when levels of distraction are high. The importance of CI is twofold: it not only leads to better retention of the task and its associated variations, but also demonstrates that reinstating the specific encoding conditions is not a prerequisite for successful retention (Magill and Hall, 1990). This finding that contradicts a whole body of research and one that will be returned to presently. So, how does CI improve performance?

During random practice, on any given trial subjects are required to utilise different movement strategies and are unable to predict which response will be required (Lee and Magill, 1985). The possibility arises therefore that the amount of interference caused is related to the different skill variations that are presented. The relationship relies upon establishing whether the variations of the skill being practised are controlled by the same, or different underlying motor programs (Schmidt, 1991), in other words, establishing an index of task difficulty.

A two part hypothesis has been proposed that states when the variations within the skill require different motor programs, the level of CI which results is stronger and in turn leads to more positive effects at retention (Magill and Hall, 1990). When the variations involve parameter modifications of the same motor program and thus no ‘real’ change in the action required, two possibilities arise depending upon the type of practice received. With random practice only, the CI effect will not be found; with a
mixed schedule of blocked practice immediately followed by random practice the CI effect may be evident (Chamberlain and Magill, 1992).

The above findings suggest that even with random practice, an easy task that only incurs parameter modifications of the action will not induce the CI effect. This is a consequence of the trials not being sufficiently difficult or different from each other. By presenting trials in a blocked style prior to random presentation however, the more subtle changes in the task requirements become more noticeable. Thus a task requiring different motor programs is more difficult to perform than one in which the response requirement is always the same or differs only through an alteration of a within task parameter. Increasing task difficulty through restructuring the response requirement in a more overt way undoubtedly increases the effort required to perform the task and thus the level of CI experienced.

Two explanations of the CI effect have been proposed, the first based upon the principles of elaboration and distinctiveness (Battig, 1972; Shea and Morgan, 1979), the second upon reconstruction of the action plan required to perform the task (Magill and Hall, 1990). The ‘elaboration benefit’ explanation is based upon the operation of ‘inter-task’ and ‘intra-task’ mechanisms and the subsequent differential use of multiple and variable encoding processes that lead to conditions of high CI. ‘Multiple’ processing concerns the number of different strategies that must be employed in order to perform the task, while ‘variability’ refers to the fact that the learner does not know when one rather than another response strategy is required (Shea and Morgan, 1979).

The alternative ‘action plan reconstruction’ hypothesis (Lee and Magill, 1985) relies on the premise that successful responding is initially based upon the formation of an action plan, a motor program of the response and details of the parameters required for successful execution of the task (Newell, 1979). It is the extensive retrieval practice that ensues when a particular trial is re-experienced during acquisition that is the key to understanding successful retention. Under conditions of high CI (i.e. random
practice), details of the action plan constantly change due to the variation of the interpolated trials. The learner actively tries to reconstruct what they have performed previously so that at retention each different presentation or aspect of the skill does not distract them. These theoretical assertions are addressed in greater detail in Chapter 6.

However, one of the most important implications of the CI effect is that retention performance is less reliant upon the contextual overlap between study and test (Anderson, Wright and Immink, 1996). This point is at odds with a whole body of literature that argues procedural overlap is the mechanism by which the retention of knowledge is enhanced (Morris, Bransford and Franks, 1979; Kolers and Roediger, 1984). The difference between these perspectives is evident when consideration is given to the issue of transfer and how learning facilitates transfer. As will become clear, depending upon whether the representations formed during study are contextually specific or are more general in nature, different transfer effects will be expected (MacKay, 1982). A brief summary of the issues raised so far will be presented before discussion of transfer.

1.7 SUMMARY
Skill acquisition is considered the means by which a solution to the problem is achieved, thus acquisition incorporates two components: the analysis of the problem and the consequent development of the means by which the problem can be solved. The success with which a skill has been acquired is measured through assessing performance at retention. Retention refers to the persistence of the ability to perform a skill following a break from a learning period. During learning, practice and instruction are the primary means by which acquisition occurs.

Instruction provides action-specific details that enable fine-tuning of performance in addition to feedback that serves as a useful motivational tool for inspiring confidence in the individual. Practice' has been referred to as the 'sine qua non' of skill acquisition (Annett, 1991) and is the process by which the individual actively accretes
and tunes their knowledge to a specific task. Two types exist: 'Massed' which is characterised by repetitive, uninterrupted performance on a task and 'distributed' whereby the learner participates in tasks which are temporally disparate. Massed practice has been found to be a powerful performance variable but not a learning variable; distributed practice leads to better retention.

The organisation of trials within a practice schedule can also be 'random' or 'blocked'. Random practice rather than blocked practice has been found to lead to more successful retention. This effect is known as Contextual interference (CI); the "effect on learning of the degree of functional interference found in a practice situation when several tasks must be learned and are practised together". One of the more important implications of the CI effect is that the findings have strong implications for issues of transfer, that is whether practicing randomly leads to a greater ability to transfer behaviour to other situations. This will be addressed in the next section.

1.8 TRANSFER

The issue of transfer is concerned with determining when and why skills acquired during the practice of one performance situation apply, or fail to apply to other situations (McDermott and Roediger, 1996). One of the fundamental issues highlighted by the study of transfer is that it is not simply the acquisition of knowledge that is important. Rather it is the acquisition of a particular use of knowledge and the range of contexts in which it is accepted or later used (Singley and Anderson, 1989).

Before discussing the ways in which transfer may occur, basic issues such as the type of transfer that may occur will be initially introduced. 'Transfer' can either be 'positive', 'partial' or 'negative'. Positive transfer is evident in instances where elements of one task (Task A) facilitate performance upon a second (B); 'partial', as its name suggests occurs when only certain aspects of Task A enhance performance upon Task B, while 'negative' transfer refers to situations where Task A interferes
with performance of Task B. In the latter situation, rather than adapting performance to suit the demands of the new task, the learner continues with what they have been trained to do (Schmidt and Young, 1987).

Thus a major question addressed by 'transfer' that has clear implications for the various theories of skill acquisition is whether the knowledge an individual acquires is general or specific in nature (Singley and Anderson, 1989). It is generally true that people will perform a task well when they find themselves in situations requiring similar responses but why this occurs remains unclear (Holding, 1991). Early research postulated that transfer occurred between tasks sharing 'identical elements' (Thorndike and Woodworth, 1901). However, problems with such a theory become immediately apparent when one considers what these common elements are. One must assume that if transfer occurs then common task elements exist, if it does not, they do not (Anderson, 1995). The scope of such a theory is clearly limited; any theory of transfer must specify how and what it is that actually transfers. Different hypothetical accounts of transfer have been proposed, depending upon the theoretical perspective taken regarding how a skill is acquired. The 'process-based' and 'schema-based' accounts of transfer will now be presented.

1.8.1 A 'PROCESS' BASED ACCOUNT OF TRANSFER
Process based theories of skill acquisition are concerned with the transition of knowledge from a declarative into a procedural form. Units of procedural knowledge are characterised as 'productions' which are concerned with generating the hierarchical goal structure hypothesised to control behaviour, rather than the specific actions involved (Anderson, 1995). In conceptualising knowledge as productions, specific claims can be made about the nature of transfer: Positive transfer will occur to the extent that the two skills involve the same productions.

This view of transfer has extended the initial ideas of Thorndike (1908) and his identical elements model - i.e. transfer will occur to the extent that identical elements of the task are shared. The major short-coming of this model has been highlighted in
Studies which focus upon the notion of transfer by analogy (Singley and Anderson, 1989). Here, a learner is given a solution to a problem and is subsequently presented with a similar problem with the same underlying structure; the task aim is simply to adapt the solution. However, transfer of knowledge upon these tasks is poor, unless the individuals are explicitly told about the analogous element of the task (Gick and Holyoak, 1983). A possible reason for this is that individuals focus only upon the surface features of the task instead of the underlying deep functional relationships between the elements (Chi, Glaser and Farr, 1988). Indeed whenever novice and expert performers are compared this is one of the factors upon which their respective performance can be differentiated (Van Lehn, 1996).

1.8.2 A 'SCHEMA' ACCOUNT OF TRANSFER

Transfer between motor skills has been addressed by schema theory (Holding, 1991). As has been stated a basic premise of the theory is the notion that a schema embodies the representation of underlying processes or, the parameters of the action such as timing and sequencing involved in performing the task (Schmidt, 1975). It is these characteristics which are believed to be transferred to a novel skill. However, the success with which this occurs is related to the strength of the schema which in turn is related to the amount and more importantly the variability of practice as mentioned earlier (Chamberlain and Magill, 1992).

In order to test whether transfer performance is a function of schema formation, Wulf and Schmidt (1989) compared groups who performed an experiment in which transfer responses to task variations were either a result of parameter modifications of the practised motor program or, were due to different motor programs. The findings were interpreted as supporting schema-based transfer; variable practice of parameter modifications in response timing led to better transfer to novel parameter modifications than practice of completely different timing responses. However, when the transfer involved performing different timing tasks, variable practice of different tasks was more appropriate (Wulf and Schmidt, 1989). It is interesting to note, that
the results also lend support to a transfer appropriate processing view (Morris, Bransford and Franks, 1977).

1.9 FUNDAMENTALS OF SKILL ACQUISITION

1.9.1 STAGES OF SKILL ACQUISITION

Most theories of skill acquisition whether they are concerned with motor, cognitive or perceptual skills suggest that different knowledge states are reached before an individual is considered skilled. Such hypothetical stages have been described as 'cognitive', 'associative' and 'autonomous' (Fitts, 1964), but more recently have been referred to as the 'declarative', 'knowledge compilation' and 'procedural' stages (Anderson, 1982). Regardless of the descriptive labels used, these stages are qualitatively similar.

During the cognitive phase the development of factual knowledge dominates; instruction and processes of trial and error enable the acquisition of the rules and procedures necessary to perform the task. At this stage although the learner invests time and effort learning the basics of the task, the actual rate of acquisition is rapid, with large gains characterising performance. With practice the learner progresses to the 'associative' stage where the connections between stimuli and responses are strengthened and finally to the autonomous stage where performance is said to occur independently of conscious control and the rate of learning diminishes (Fitts and Posner, 1967).

Although a dated conceptualisation, one of the more important features of the three-stage model is that it highlights the fact that the rate of learning is largely dependent upon the time it takes for the changes to occur within the individual. Changes in can be modelled by relating any observed improvement to the duration of practice (Groeger, 2000).
1.9.2 **MODELLING SKILL ACQUISITION**

Historically, with respect to perceptual-motor skill acquisition, learning characteristics of the individual are typically found to fit one of two mathematical functions, namely either an exponential function or alternatively, recent evidence has suggested that the data are best fitted to a power (log/log linear) function (Mazur & Hastie, 1978; Newell & Rosenbloom, 1981). The theoretical implications of power functions will be discussed in greater detail presently, but with respect to individual differences, two key properties of power functions enable objective assessment to be made of individual performance: The 'intercept' and the 'slope' of the function.

The intercept gives an indication of the individual's initial level of performance prior to training and the gradient of the slope indicates the rate of change in performance (rate of learning) over time. These parameters enable inter-individual comparison of learning as well as allowing the researcher to discern whether the rate of change of performance varies across specific periods during the training schedule, and to ascertain when / if particular target / plateau levels are achieved. Thus, the length of time taken to acquire a particular skill may differ depending upon the initial ability of the learner, but following the necessary training and practice, performance between high and low level learners should be equal.

A key issue is whether training occurs to some criterion level rather than being 'never-ending'. That is, whether or not the learner is expected to master the skill or is simply required to perform at an adequate level - clearly the time taken to reach a criterion level of performance is less than mastery (Groeger, 2000). Arguably, any differences between individual performance are masked due to the fact that full performance potential has not been realised (Ackerman and Kyllonen, 1991). Thus the use of power functions to model performance allows estimations of the relative amount of training different individuals require in order to reach the same level of performance. The importance of power laws in general will be investigated in the next section.
1.9.3 **THE POWER LAW OF LEARNING**

The power law of practice has been referred to as 'ubiquitous' within the literature, quantitatively describing the relationship between the logarithm of the time to perform a given task against the logarithm of the trial number (Mazur and Hastie, 1978). It has been stated that the power law provides a basis from which to investigate the basic mechanisms of turning knowledge into action (Newell, 1981) and indeed that any theory of skill acquisition must be able to account for this relationship (Logan, 1992).

Newell and Rosenbloom's (1981) 'chunking' hypothesis was the first to attempt a comprehensive account of the power law relationship. The data from a series of perceptual-motor (Snoddy, 1926; Crossman, 1959), predominantly perceptual (reading inverted text; Kolers, 1975) and predominantly motor tasks (moving a cursor to a predetermined location, (Card, Moran, and Newell, 1983)) was reviewed. The major commonality between the results of all studies was the existence of a log-log linear relationship between number of trials and time to complete the task. Furthermore, and hence the ubiquity of the law, data from the then emerging cognitive / problem-solving domain were also successfully fitted to power functions (Neves and Anderson, 1981). Such findings indicate the existence of underlying regularities in learning and performance.

The 'mixtures argument', the 'stochastic argument' and the 'exhaustive argument' have all been proposed to account for such regularities (Newell and Rosenbloom (1981). The 'mixtures' argument suggests that learning occurs in a monotonic fashion; an increase in the time taken to complete one aspect of the task increases the overall performance time. However the model also assumes that various aspects of the task are acquired differently and are also dependent upon the rate at which learners learn. The activity of fast learners will initially dominate but as a virtue of such 'fast' learning abilities, their contribution will begin to wane over time. Slow learners will demonstrate learning at a slower rate, but will contribute to performance at a later stage when the fast learners are declining, resulting in a diminished return from practice.
‘Stochastic selection’, is based on the premise that an individual tries out various methods when learning a novel task, retaining those that lead to successful performance and rejecting those that do not (Crossman, 1959). Improvement is based upon the probability with which an individual will select a ‘performance mechanism’ from a fixed population of possibilities, each with their own fixed response times. The change in probability that favours the selection of an appropriate response is a consequence of the difference between the mean time taken to respond over trials and the initial fixed time of the selected method.

It has been argued that practice reduces the signal to noise ratio of the task, facilitating the discrimination of stimuli that lead to successful acquisition (Welford, 1987). Indeed, an important factor distinguishing novice from expert performance appears to be in how well each adapts to the prevailing situation; the ability to know when a specific response is ‘appropriate’ is more important than superiority upon basic performance measures such as co-ordination and timing (Crossman, 1959).

A dual effect of practice results in negative acceleration of learning. Firstly, irrelevant responses are lost through deliberate or chance means (e.g. instruction and intervention) resulting in a reduction in the number of alternative solutions available. Secondly, a concurrent increase in the likelihood of selecting the most optimal response strategy also occurs; specific elements of the task may be ‘fixed’ in memory resulting in an increased chance of the precise method being recalled and repeated (Annett, 1991). It is also likely that that multiple selection processes are operating upon different aspects of the task. Clearly the rate of learning for a sub-task will vary depending upon the learners ability to adapt their existing behavioural repertoire and overall learning of the task will vary as a function of the number of sub-tasks (Crossman, 1959).

‘Accumulator’ and ‘replacement’ models are additional stochastic models. Whilst ‘accumulator’ models are based upon the assertion that the learning occurs due to the build up and domination of correct responses over incorrect responses, proponents of
'replacement' models argue that incorrect responses are completely replaced and are therefore unavailable for use (Restle and Greeno, 1970). Thus practice increases the knowledge base of the individual whilst continuously strengthening the associations between stimuli or between stimuli and responses (MacKay, 1982). An associative mechanism operates and increases the likelihood of automatically choosing an appropriate action and consequently reduces the possibility of alternative, incorrect responses being made. Negative acceleration is accounted for as the learner becomes more adept in performing the skill, there is less to learn which can actually enhance performance (Newell and Rosenbloom, 1981).

The final explanation of the power law of practice is that of 'exhaustion'. It is from this perspective that the 'chunking' model of learning was developed. A fundamental assumption of the model is that learning consists of uncovering and subsequently incorporating improvements to the current strategy used (Newell and Rosenbloom, 1981). 'Chunks' are expressions or structured collections of the knowledge within the environment at the time of learning, containing information about the patterns in the environment as well as that pertaining to the individual's relationship with the environment.

Different explanations of the power law have been provided by Anderson (1982) and Logan (1988). Anderson (1982) argues that the power law of learning can be explained through proceduralisation of the task. Knowledge is converted from a declarative format that is slow and effortful, into procedural knowledge that enables fast responding. It has also been postulated that with complex skills the basic components of the task are also acquired as a power function of practice (Groeger, 1997). The final explanation is given by Logan (1988), who argues that the accumulation of instances via practice which leads to the domination of memory retrieval rather than reliance upon algorithms to solve problems, accounts for the power function speed up. These explanations will be investigated in greater detail presently.
Thus, interpreting the behavioural processes of skill acquisition as a mathematical law, both learner and trainer to make certain predictions about performance. Theoretical accounts of the behavioural and cognitive processing that occurs as a result of performing skilled tasks have been addressed by various theories of skill acquisition. In the next section four different theories will be discussed. Each contrast sharply in their treatment of skill acquisition but nevertheless are based upon these observations that the capabilities and strategies used to respond shift over time. They include ‘strength’, ‘process-based’, and ‘instance’ theories.

1.10 THEORETICAL ACCOUNTS OF SKILL ACQUISITION

1.10.1 ‘STRENGTH’ THEORIES

Strength theorists such as MacKay (1982) argue that the main function of learning trials is to strengthen associations between stimuli and responses. A skilled domain is considered analogous to a network within which the basic components for organising production of the task are represented as nodes. Two systems of nodes exist, the muscle movement and the mental system which control the muscle-specific patterns of movement and the cognitive units for controlling these movements, respectively. Performance improvement is a consequence of strengthening connections between nodes.

The amount of strengthening that occurs is proportional to the difference between the current strength and maximum possible strength of associations. The proportion is constant which implies that performance improvement will be rapid during early learning, slowing down as proficiency increases. Hierarchical representation of nodes accounts for the rapidity of learning observed during early acquisition. Higher level nodes are fewer in number and less likely to reach their maximum strength than lower level nodes; the former are strengthened during early performance which accounts for the rapid speed-up while late performance is characterised by slight changes in strength of lower nodes, hence the negative acceleration of learning.
As MacKay's is a strength theory it assumes an abstract level of representation of hierarchies across which nodes that are associated through practice prime each other. For example, in speech production, it is argued that mental nodes which may relate to phrases, words, syllables or phonemes (depending upon their level in the hierarchy) represent a class of actions within a specific domain. The production of actions is governed by factors such as: 'Serial activation' of the lowest motor movement level nodes; 'priming' at the subthreshold level that increases the strength of the connected nodes. Priming is not self-sustaining and does not result in behaviour. Finally, 'linkage strength' between the nodes is influenced by the amount of practice upon a task. Thus an activated node simultaneously primes and strengthens all of its connected nodes resulting structural changes leading to skill acquisition (MacKay, 1982).

One interesting aspect of this theory is whether and how a hierarchy might be translated to motor learning. For example, with regard to a digit sequence entry task in which individuals are presented with a string of digits and are required to type that string, would a 'type sequence' node be represented in the conceptual system as an abstract entity? The implications from MacKay's theory is that the whole sequence would be perceived and represented at a conceptual level before being broken down into separate elements or subgroups at an intermediate 'transformation' stage; here pairs of keys then individual keys would be represented prior to concrete representation of muscle movement nodes at the implementation stage of the hierarchy. This is merely conjecture, but highlights the importance of the 'applicability' of theoretical propositions across different skilled domains.

1.10.2 PROCESS BASED THEORIES
Anderson (1982) also bases his theory on the idea that a skilled domain can be represented as a hierarchical network. However, a slightly different approach to MacKay is adopted, as it is proposed that different processes underlying behaviour operate to facilitate learning. During acquisition, learning trials result in the 'composition', or generalisation and differentiation of existing procedures. These
procedures are subsequently 'strengthened'. It is the interaction of these two mechanisms which produces the characteristic power function speed up found during skill acquisition.

During composition, adjacent steps of a task are collapsed into one unit of behaviour. Factors influencing the speed with which this will be achieved include the number of adjacent steps to be collapsed and the probability with which they will be combined; the more steps and the lower the probability, the longer composition will take. Composition reduces the number of steps by a constant proportion on each iteration of the procedure resulting in rapid learning early in acquisition.

Strengthening, occurs once the items have been composed and has a dual function. Firstly it increases the probability that a production will be applied, and secondly the speed with which irrelevant productions are eliminated from consideration is increased. Strengthening of a procedure increases by a constant proportion during each correct application and intuitively, is reduced, by a greater proportion, when a production is incorrectly applied. Additional strengthening mechanisms are required to integrate new productions into any system.

The theory still argues for the formation of supergroups, although not in the hierarchical sense advocated by MacKay. Anderson's theory parallels that of Newell and Rosenbloom (1981) and their 'chunking' strategy. Maintaining the idea of multi-layered organisation, chunking results in a shift in control, enabling higher levels to directly trigger responses at the lower level; intermediate levels are superseded. Thus, rather than employing a 'facilitation' mechanism whereby all levels in the hierarchy are activated (cf. MacKay) a 'replacement' process operates as larger chunks are formed. Thus using the example of the digit entry task, the learner would perceive the sequence and rather than breaking it down into pairs of digits and then individual components, for example, they would simply enter the whole sequence.
1.10.3 **ITEM BASED THEORIES**

Item-based theories of skill acquisition are based on the idea that skill acquisition is a consequence of the speed with which *specific* representations of a particular task can be retrieved from memory (Logan, 1988). The main assumptions underlying Instance Theory are: First, encoding into memory is an obligatory, unavoidable consequence of attention; attention to a stimulus is sufficient to commit it to memory, the quality of the representation depending on the prevailing conditions of attention. Secondly, retrieval from memory is an obligatory, unavoidable consequence of attention; encoding and retrieval, therefore are linked through the same act of attention. Finally, each encounter with a stimulus is encoded, stored and retrieved separately (Logan, 1992). The learning mechanism implied by Instance Theory relates to the eventual accumulation of episodic traces in memory and the speed with which memories are retrieved rather than the strengthening of features within a hierarchical network (Logan and Etherton, 1994).

The speed of retrieval and thus performance improvement is influenced by the following factors: When skill is first encountered, behaviour is guided by the use of an algorithm, or a general rule appropriate to the situation. An individual has a general notion or uses inductive reasoning about how to perform in such a situation based upon previous experience. By virtue of performing the task, however, an episodic trace, or ‘instance’ of what was done *in that specific situation* is created. An instance is a separate representation of an event, a constellation of co-occurrences of the features, properties and objects that comprise it; the goal the subject was trying to attain, the stimulus encountered in pursuit of the goal and the interpretation given to the stimuli with respect to the goal and the responses made to it (Logan and Etherton, 1994). Thus again with respect to the digit entry task, for each novel sequence it would be argued that a separate representation containing the different motor and perceptual information would be created. Performance would be facilitated if an identical sequence was presented due to the prior exposure.

Thus performance improves as each encounter with a stimulus increases an
individual’s knowledge base; the accumulation of instances essentially leads to a state where a race between memory (knowledge of the specific state) and algorithm (general strategies) occurs. Adding instances through practice increases the likelihood of rapid retrieval from memory, which is characteristic of skilled behaviour. However, the return gained from direct retrieval of specific solutions to specific problems decreases with time; it is this which results in the power-function change with practice (Logan and Etherton, 1994).

1.10.4 COMMENT ON CHAPTER ONE
Thus regardless of the ‘type’ of skill discussed, practice is the main way in which skills are acquired. This theoretical assertion has interesting implications for the learning and retention of a ‘typing’-based task, i.e., that which forms the basis of the experiments reported in the present thesis. Indeed, in the following chapter, a more detailed discussion of the typing task will be presented and considered in light of the theoretical principles highlighted in the present chapter. The aim of Chapter Two is to specify in greater detail the experimental task chosen for investigation, before presenting the aims and objectives to be achieved in this thesis.
2 PERFORMING A KEYBOARD-BASED TASK

2.1 INTRODUCTION

This chapter is primarily concerned with establishing an appropriate methodological framework within which to test the theoretical assumptions associated with skill development, as introduced in Chapter 1. A general aim of the thesis is to identify factors that facilitate or inhibit skill acquisition and retention. The particular skill that will be used to investigate these issues is that of an individual’s use of a computer keyboard. A pragmatic reason for choosing this skill is that execution of the task can be decomposed into easily measured, discrete units, i.e. the time taken to make each keystroke. Another aspect of this skill, however, lies in the fact that within Western societies, extensive keyboard use pervades both professional and social aspects of life (Trewin and Pain, 1999). Indeed, the most common keyboard skill, that of ‘typing’, has been comprehensively researched; the interplay between perceptual and motor processes has been the main focus of investigation and has resulted in the development of different models accounting for typing performance (e.g. Rumelhart and Norman, 1982; Salthouse, 1984a).

Two main themes will be introduced in the present chapter. The first part will identify the main characteristics associated with skilled typing performance. The second part of the chapter will focus upon establishing what is known about the acquisition and retention of sequence entry tasks. In looking at the two types of keyboard tasks, clarification of the ‘nature’ of the learning that occurs during acquisition will be allowed, i.e. the extent to which the skill is generalisable facilitating performance upon similar tasks, or whether specific features of the stimuli are retained and are reused in specific situations. Finally, the aims and objectives of the experimental work will be established.
2.2 CHARACTERISTICS OF SKILLED TYPING PERFORMANCE
Transcription typing is an example of a complex cognitive task, composed of intertwined perceptual and motor processes. At least two major tasks must be performed during copy typing, encoding of visual text and the subsequent translation of this into a sequence of corresponding manual keypresses (Inhoff and Wang, 1992). These two features must be successfully coordinated in order to ensure the availability of encoded text for continuous manual output (Salthouse, 1986a).

2.2.1 QUANTITATIVE ASPECTS OF TYPING
The main way of assessing typing proficiency is to determine how much an individual can type within a given time period. Four basic measures can be derived, these are: ‘Net words per minute’ (wpm), ‘gross wpm’, ‘error rate’ and ‘median inter keystroke interval’ (IKI). ‘Net wpm’ is the most commonly used measure, combining information about both speed and accuracy of performance; ‘gross wpm’ and ‘error rate’ represent the speed and accuracy components of ‘net wpm’, respectively. Median IKI is more sensitive to the motor processes involved in the task, indicating typing speed uncorrected for errors and thus more accurately reflecting the speed of finger movements (Bosman, 1993).

Individuals who have received relatively little practice typically reach typing speeds of about 30 wpm and average error rates of 34% (Bosman, 1994). However, experienced transcription typists, i.e. office typists, who typically receive over 10,000 hours of practice upon this task can reach rates of up to 80 wpm, an average of about seven keystrokes per second (Gentner, Larochelle and Grudin, 1988). Furthermore, there appears to be no speed-accuracy trade off. The mean number of errors committed within each of these groups diminishes as speed increases, rates being 0.3% and 0.1% respectively.

‘Launch times’ of the finger to a target key are closely related to the striking of a key earlier in the sequence; they are not random. The finger starts to move to the target within 20ms of the striking of the preceding key on 40% of occasions, within 40ms on
90% of occasions and never exceeds 60ms (McLeod and Hume, 1994). In terms of the interval between each successive keystroke, the median IKI for learner typists is 177ms, decreasing to 60ms for experienced typists which for comparative purposes, is close to simple response times for single stimuli and is much faster than the time taken to in typical choice reaction time tasks (500ms; Salthouse, 1986). One of the characteristics of skilled performance is a reduction in the variability between IKIs (Salthouse, 1984a). This implies that greater precision of movements and hence fluidity of actions is a consequence of experience and skill development. This also implies that the physical properties of the keyboard interact with the lexical nature of the word to influence the rate at which words are typed.

Eye-movements of transcription typists differ dramatically compared to when the same individuals are reading text. Typists, when reading, average 246 wpm but only 60 net wpm when actually typing (Salthouse, 1986). The average length of time transcription typists spend fixating upon words is longer (380ms) than when reading (120ms). Typists also execute saccades, i.e. the interval between fixation points, which span approximately 3.5 character spaces and often execute regressive saccades to previously viewed text (Salthouse, 1986; Inhoff and Wang, 1992). Thus, numerically quantifiable differences in performance can be identified within typing performance; strategic differences in typing performance will be discussed in the next section.

2.2.2 QUALITATIVE ASPECTS OF TYPING PERFORMANCE

Qualitative differences in performance between novice and expert typists are mainly due to their respective use of feedback and more importantly, the type of feedback relied upon. One of the major characteristics of skilled typing performance is the ability to look only at the copy text and ignore the screen and the keyboard (Salthouse, 1986). This is a gradual progression and relies upon the use of both visual and kinesthetic feedback. Visual feedback is obtained from two sources: the copied text on the VDU and the keyboard. While the former provides information on errors and format and the latter primarily provides guidance information (Cooper, 1983).
Novice performance is characterised by increased reliance upon visual feedback. Rather than focussing on the copy text, novices spend 90% of their time either looking down at the keyboard, due to lack of knowledge about the spatial layout of the keypad, or, looking at the VDU in order to detect errors (Grudin, 1983). Indeed, studies investigating the impact of these sources of visual feedback suggest that 'error detection' receives the highest priority during the initial stages of learning. For instance, in masking both the copied text and the keyboard, the effect upon typing speed _per se_ is negligible, but error rates markedly increase (Long, 1976).

In contrast, for skilled performers the primary source of feedback is proprioceptive (Salthouse, 1986). 'Kinesthetic' feedback in terms of information provided by the joints and muscles on the location of and movement of the hands and fingers is obtained when aiming for and depressing a key and 'tactile' feedback from the application of pressure when touching the key. Reliance upon visual feedback is diminished; it is hypothesised that visual function is freed for 'back up' processes of unfamiliar key location and error correction (Barret and Kreuger, 1994). In terms of error detection, this is a rapid process often detected before the execution of the subsequent keypress and possibly occurring as a consequence of kinesthetic feedback; knowing that the trajectory of the keypress was incorrect (Rabbitt, 1978).

Thus, differences clearly arise in the typing performance of both novice and experts and the speed and accuracy with which they type. However, proficiency in performing the task does appear to asymptote; ultimately there is a limit upon the speed of processing and execution of the task. The reason for this is due to the combination of 'central' and 'peripheral' and 'external' constraints upon performance.

### 2.2.3 CONSTRAINTS ON TYPING PERFORMANCE

Constraints imposed on performance affect the rate at which the ability to type is learned, in addition to the level of proficiency that is reached following practice. The constraints that have been distinguished include: 'Peripheral' factors, which reflect biomechanical constraints during manual movement execution, such as hand and
finger anatomy that place physical limitations upon performance; 'central' constraints imposed by linguistic processes supporting text representation and the planning of responses, such as the lexical properties of the words, and finally, externally manipulated variables that affect factors such as 'eye-hand span'. All three interact to effect the speed and accuracy with which an individual can type (Gentner, 1983).

2.2.3.1 Peripheral constraints on typing performance

The way in which the fingers traverse the keyboard has a profound influence upon performance. The main evidence for this is demonstrated when characters to be typed are done so with either the same or alternate hands (Salthouse, 1986). It has been demonstrated that median IKIs for digraphs (i.e. combinations of two letters) typed by opposite hands are shorter than those recorded for digraphs taken by the same hands. For example, median IKIs for digraphs typed by different hands (163ms) were faster than those typed with two different fingers on the same hand (202ms) which in turn were faster than those typed by the same finger on one hand only (221ms) (Heath and Willcox, 1990). These effects are robust; the motor translation for a right hand keypress can be made simultaneously with the execution of a preceding left-hand keypress resulting in an advantage of up to 30 to 60ms for alternate hand IKIs (Salthouse, 1986). With respect to the typing of digraphs with different hands, initiation of a keystroke for an alternate hand sequences occurred 32ms before the termination of the preceding keypress, in comparison to 36ms after the prior keystroke for the same hand (Larochelle, 1984).

As a caveat, it is interesting to note that the difference in typing with the same and alternate hands is developmental; novice typists are constrained more by between hand transitions early in practice; familiarity with the spatial layout leads to an improvement in performance with practice (Heath and Willcox, 1994).
2.2.3.2 CENTRAL CONSTRAINTS ON TYPING PERFORMANCE

Central constraints arise primarily as a consequence of the linguistic nature of the text and the operation of higher level processes upon the stimuli, rather than the motor capabilities of the performer. The finding that not all levels of language processing are necessary to maintain peak performance in transcription typing has increased investigation within this area. Thus the focus of research has been upon the semantic, lexical and sublexical features of the text.

Semantic constraints upon typing times have been investigated in terms of the relative time taken to copy-type passages of prose, random words, non-words and passages of foreign text; several studies have failed to reveal any syntactic and semantic effects on typing performance (Gentner, Larochelle and Grudin, 1988). For example, it has been demonstrated that significant decreases in speed or accuracy do not arise when typists change from transcribing normal prose to transcribing a random combination of the same words. A difference of only 2.8% for meaningful words was reported by West and Sabban (1982), a statistic approximating the difference in copy typing text in a foreign rather than the native language (Salthouse, 1986). When typists were asked to transcribe non-words (i.e. words in which the syllables have been spliced and then recombined), it was found that IKI times increased. These findings suggest that some form of language processing is involved in typing but it may not extend to units larger than the word; comprehension of the text is not necessary (Salthouse, 1986).

2.2.3.3 EXTERNAL CONSTRAINTS ON TYPING PERFORMANCE

The intertwining of perceptual and motor constraints is prominent when consideration is given to the role of external factors on typing or, those that the subject has no real control over. One of the biggest constraints upon typing performance per se is the amount of text available for viewing, the 'preview' effect (Pashler, 1991). It has been demonstrated that typing performance is detrimentally affected if too little information is presented on the screen. In order to promote optimum typing levels (indexed by asymptotic levels of saccades and IKIs) between five and seven characters to the right
of fixation, a feature known as the 'perceptual span', should be available for viewing; this is less than that required whilst reading (Salthouse, 1986).

The amount of text that is viewed and executed is referred to as the 'keystroke' span. IKIs increase when the window of usable text reveals fewer than three character spaces; this therefore is the least amount of text that can be shown when once the typist has begun execution of the sequence. Once the action is underway, an increase in the amount of effortful processing required is again evident. The perceptual span appears to reflect the way in which identified letters are used for the specification of a to-be-executed manual movement sequence (Inhoff and Wang, 1992).

In terms of ongoing typing processes, it is evident that during typing the eyes are generally several characters ahead of the executed keypress. Indeed, the 'eye-hand span', defined as the amount of material between the character receiving the attention of the eyes and the character that is currently being pressed, measures about three characters for average typists and up to seven characters for expert typists. Clearly, this one aspect of the typing task that differentiates between skilled and non-skilled typists, the span increasing with practice (Salthouse, 1986).

Manual movements therefore appear to constrain text perception and the planning of eye movements during typing. Although one could argue that this is truly a peripheral constraint, the effects are further compounded by the influence of external factors such as the amount of information available for viewing. The oculomotor system appears to adapt to the disruption of visual encoding by executing more and smaller saccades per manual movement planning cycle but this compensatory mechanism can only be of benefit if the text can be seen from the outset (Inhoff and Gordon, 1998).

In summary, words constitute the basic psychological units during typing and as such, influence oculomotor and manual movement coordination during copy typing. Central processes appear to represent the selection and the ordering of keyboard locations and peripheral processes to represent the specification of movement
trajectories across successive keyboard locations. Eyes can be moved to a new word when representations controlling the specification of central and peripheral movement parameters have been formed but only if the words are available for encoding.

2.3 THE EFFECTS OF PRACTICE ON TYPING

One of the main themes of the preceding chapter was the role of practice in promoting skilled performance. With respect to the rate of learning, a distinction was drawn between types of practice, i.e. 'massed' and 'distributed' and it was demonstrated, using a keyboard based task, that although massed practice generally leads to faster learning, the effects of distributed practice are more durable (Baddeley and Longman, 1978). However, such studies do not examine what 'aspects' of the task improve with practice. The aim of this section is to address these issues.

As has been mentioned previously, one of the features of skill development and a correlate of practice is an improvement in the speed of making keystroke sequences involving alternating hands but not in the speed of typing sequences involving repetition of the same keystroke and thus the same hand (Gentner, 1983; Salthouse, 1984b). This pattern suggests that a contributory factor influencing acquisition is learning to overlap successive finger movements efficiently; clearly no overlap can occur when the same finger is involved in typing the sequences. The advantage for alternative finger therefore may be due to improved efficiency in preparing for, or anticipating future finger movements while simultaneously executing current movements. The latter assertion is supported by the fact that skilled typists have a larger eye-hand span and need more visible characters in order to maintain their normal rate of typing than less skilled typists (Salthouse, 1986).

These propositions were empirically tested by Salthouse (1988). A sample of non-typing subjects were given twenty hours’ practice upon a typing task, each session lasting one hour and consisting of 32 blocks of 100 characters. A standard display contained seven characters but this varied from 1 to 6 characters throughout the blocks. The subjects were required to type the characters as quickly and accurately as
possible. Following twenty hours of practice, the median IKI decreased from 708ms to 252ms. Familiarisation with the keypad did not contribute to the findings - factors such as these effect performance at initial stages of the task and in a minor way only.

Furthermore, anticipatory effects, which have been suggested to improve with practice did not contribute greatly to performance in this instance; highly probable stimuli were responded to more efficiently within the first session of 3200 responses only. It seems unlikely that keying proficiency develops by increased sensitivity to varying event probabilities. An interesting finding was that the IKIs found for digraphs for the same hand were faster than those found for alternate hands. The fact that the typists in this experiment were not skilled coupled with the finding that between hand digraphs improved more rapidly with practice suggests that a characteristic of skill is an increased readiness to make responses to different stimuli. Indeed this is supported by the fact that skilled typists demonstrate the reverse pattern of responding (Bosman, 1994).

One unambiguous shift with practice was the number of displayed characters needed to maintain a normal rate of keying. During the first session, regardless of how many characters were on the screen, only the to-be-typed key needed to be visible. However, by the twentieth session at least two visible characters were necessary for subjects to perform at their much faster, normal rate suggesting that this would increase further with practice. Again, such changes in eye-hand span and efficiency of certain keystroke sequences is indicative of alterations in preparatory effects. Improvements in the former indicate that the subjects are beginning to process impending stimuli before the completion of the prior keystroke and the greater improvement for keystroke sequences involving the possibility of current and future finger movements implies that subjects are learning to respond to stimuli in a less discrete and more sequential manner, i.e. are processing in parallel (Salthouse, 1985). It is interesting to note however, the differential rate at which these processes improve, i.e. the perceptually based processes developing faster than the motor based processes.
2.4 THE EFFECTS OF TRANSFER UPON TYPING

Another interesting theoretical issue raised in the first chapter concerns the degree to which performance of one skill, in this instance the characteristics of the typing task can be transferred to other, similar tasks. Two studies that have examined different aspects of transfer will be reported. The first study investigated whether kinesthetic and proprioceptive feedback provided from a conventional keyboard facilitates transfer to other keyboard tasks. The typing performance of a group of skilled and non-skilled typists using a ‘piezo-electric’ keypad, essentially a flat pad from which the usual ‘travel’ and ‘tactile cues’ discriminating key contact areas is unavailable, was used (Barrett and Kreuger, 1994).

It was hypothesised that performance would suffer in the absence of feedback. Previous research, however, has suggested that there may be an interaction between skill level and performance decrement (Anderson, 1987). Performance of skilled touch typists was expected to suffer following initial transfer, however, due to their level of skill, it was hypothesised that rapid perceptual and motor adaptation to the new task would occur. For non-touch typists, a difference in performance between keypads was not expected; due to a lack of experience using the conventional layout performance would be equally as good using the novel format.

Results showed that the difference in IKI for the conventional keyboard between the experienced (330ms) and the non-skilled users (500ms) during the first session of practice was 170ms, increasing to about 200ms by the last session of practice. Using the flat piezo keyboard, however, during the first session of practice the difference was only 30ms, the experienced group (600ms) performing marginally faster than the non-skilled (630ms). Thus, at the outset of performance the detrimental effect of the change in keypad was much stronger for the skilled group. Although a rapid practice effect was found for the skilled group, by the end of practice, there was still a 200ms difference performance on the slower, piezo-keyboard than the conventional type. Interestingly, the size of the practice effect did not differ to that found for the non-skilled users, which suggests that the non-skilled users were effected by their
inexperienced at typing *per se*.

This suggests therefore that the performance of the experienced typists does not reflect a process of learning in which adaptation or transfer is central. Error detection data lend further support to this view: non-skilled typists corrected more errors than they left uncorrected, with both keyboards. The same pattern of responding was found for the touch typists with respect to the conventional keyboard, but with the flat keyboard, more uncorrected errors were made. Thus perceptual-motor skills necessary for touch typing appear to involve kinesthetic feedback or key discrimination information (Barrett and Kreuger, 1994).

Motor transfer was also investigated by Bosman (1994), who assumed that extensive experience upon a typing task would generalise to another motor task. The task used was a choice reaction time task assessing the latencies required to type two consecutive keystrokes, but only in certain instances. Two indices of performance were measured: The 'initial latency', sensitive to the duration of translation or encoding and other pre-execution factors, and the 'IKI', which is more sensitive to execution processes. The fact that these different indices exist is shown by the low correlations that exist between the two measures; the initial latency is significantly longer than the interkey latency.

For the typing task, subjects entered 60 digraphs, 30 using both hands and 30 using two fingers of the same hand. For the choice reaction time task subjects were presented with the letters 'L' and 'R' on the computer screen which were paired with the actual keys 'Z' and '/ ', respectively. Subjects had to type the corresponding key. It was hypothesised that the typing related experience would facilitate performance on the choice reaction time task.

Two opposing predictions were made with respect to transfer between the tasks, based on the two timing latencies. More specifically, in terms of the IKIs, it was hypothesised that transfer between the two tasks would be found. In contrast, with
respect to the initial latency measure, no transfer (or difference) was predicted. The main reason for this divergence is that executing successive keys is more similar between the tasks than the encoding and production of the initial response, i.e. having to learn novel stimulus response mappings in the choice reaction time rather than being able to press the ‘known’ key. Indeed, this is what was found. Regression analysis indicated a difference in the initial latency time for the two tasks, which suggests that the actual motor processes that are involved in the execution of typing transfer while the encoding processes do not. This could be due to the similarity and the highly practiced nature of the action (Salthouse, 1986).

Thus the results suggest that certain motor aspects of the typing task do transfer to other related keyboard tasks. However there appears to be a caveat to this, namely that they transfer as long as the appropriate feedback is available. This may be due to the increased similarity and the fluency which is involved in performance. Certainly, the results would suggest that the more identical elements integral to the tasks, the greater evidence of transfer (Bosman, 1994).

2.5 **MODELS OF TYPING PERFORMANCE**

The basic aim of all models of keying tasks, including typing, is to account for highly consistent trends within timing and accuracy as a function of a particular motor pattern (Kornbrot, 1989). It is generally assumed that people load a high level representation of the sequence of units to be executed into a special motor output store of some kind and then decode that high level representation for execution at a lower level. A theoretical question concerns how processing of information differs at each of the levels within the different models. Three different models of typing performance will be presented. Although the focus will be on the models’ of Salthouse (1986) and Rumelhart and Norman (1982), the model proposed by Shaffer will be briefly introduced as it is that which has formed the basis of the later models.
2.5.1 Shaffer’s Model of Typing

Shaffer (1973) proposed that any word intended for typing was represented in one of two hierarchically organised ‘buffer memories’, one associated with an ‘input stage’ and the other with an ‘output stage’. The input stage of the process was concerned with storage of characters or words to-be-typed in the input buffer; a ‘perceptual memory’ component hypothesised to scan and retain visual information about the original copy text facilitated this process. Decomposition of words into letters and ultimately motor features occurred in the output buffer.

Shaffer (1973) argued that each letter in the output buffer was indexed; a special (but rather vaguely defined) pointer was responsible for tracking the indices so that each letter was executed in the correct sequence. The organisation of the sequences was one factor controlling the timing of performance; it was argued that the letters were arranged in a hierarchical structure through which the pointer had to move. Another was reflected by the constraints imposed by the physical features of the typist and keyboard. It was specified that certain actions were more difficult to execute than others, based upon the location of the keys and the finger movements required. However, Shaffer (1973) did not specify what these were to the extent of subsequent models of performance. Thus it was this model upon which subsequent ones were based. Salthouse (1986) focusses more upon the ‘representational’ nature of the task while Rumelhart and Norman (1982) concentrate more upon the physical aspects.

2.5.2 Salthouse’s Model of Typing

Salthouse (1986) produced a composite information processing model of transcription typing in order to localise the effects associated with skill development. The basic premise of the model is that specific top down ‘preparatory processes’ decompose large elements of the task into convenient units, simplifying the task from the outset. It would appear that although focussing on different types of task, such a model would align itself alongside an account of skill acquisition proposed by Anderson (1993).

Four components responsible for processing particular types of information are
specified. The initial ‘input’ stage is where the material to be typed is perceived by the visual system, encoded and broken down into smaller units of easily remembered information. These units are then rendered, or ‘parsed’ into smaller, discrete characters. It is this parsing mechanism that isolates the single character to be typed. The ‘translation’ stage follows the parsing stage; here the properties of the characters are translated into specifications for movement. The final stage of the process is ‘execution’ and is expressed as an overt movement of the finger and hands. The movement is ballistically implemented and once under way is no longer subject to control; any errors which occur are detected and corrected after the event (Salthouse, 1986).

Qualitatively different spans which reflect the type of processing occurring at each stage are used to support this model. These include: The ‘copy span’ or, the unit of text reflecting what has been input into the system and that can be accurately typed; the ‘eye-hand span’ or the material intervening between that being typed and that being fixated upon and is thought to be governed by processes arising in the parsing stage; the ‘replacement span’ is the point at which the typist commits themselves to typing a particular character (this measure is an index of how quickly the information is translated as it leaves the parsing stage where commitment to a movement has been made) and finally, the ‘stopping’ span, which measures only one or two keystrokes, is defined as the amount of material to which the typists is irrevocably committed to type (Logan, 1982).

Thus Salthouse proposes an information processing account of typing performance and provides empirical support for each of the hypothesised stages. However, a body of research grounded more in the motor aspects of typing offers a different account of the typing process. The most prolific model of typing processes is that proposed by Rumelhart and Norman (1982), in which the ‘action’ specifications of the stimuli are extensively discussed.
2.5.3 RUMELHART AND NORMAN’S MODEL OF TYPING

The activation model of Rumelhart and Norman (1982) extends below the level of the keystroke to the specification of muscle groups controlling gross hand and individual finger movement. The model relies heavily on schema theory proposed by Schmidt (1982), arguing a hierarchical structure of schemata controls the selection of letters to be typed, then via algorithmic processes, the movements of fingers and hands. They developed a computer simulation in which timing patterns are determined by the physics of the keyboard and the peripheral physiology of the human, rather than any internal organisation of the model.

Schemata are proposed to act as motor programs, or “flexible, interactive control structures...that govern the actions that are to be performed....the rules that are followed in the action, not the actual motion” (Rumelhart and Norman, 1982, p7-8). The simulation model is based upon elucidating the control mechanisms responsible for the activation and selection of particular hand and finger movements. The input of the model is the text to be typed and the output, a sequence of finger movements.

Three phases are specified before the final ‘typed’ product: ‘Perceptual processing and parsing’, the ‘activation’ process and finally, ‘movement’. Perceptual processes are attended to within the simulation in so far as they interpret the input. The operations of the typing model truly begin once the word strings have been stored in the buffer of the parser. Thus in both Salthouse’s and the present model the word is broken down or parsed into easily managed units.

The ‘activation process’ is concerned with the excitation of keypress schemata. Each schema specifies the target position of the key. This information is sent to the ‘response system’, which is responsible for configuring the appropriate hand and finger movements and also for feeding back information about the current location of the fingers to the keypress system. This latter source of information is crucial for the triggering conditions of the schemata. The conditions are satisfied when the current finger positions are within some criterion distance of the target and the appropriate
schema is activated. The keystroke is then launched with a force proportional to its activation level. After each schema is launched its activation is decreased resulting in the release of inhibition and thus the activation for subsequent schemata.

The model of Rumelhart and Norman (1982) is successful in simulating the performance of skilled typists. However, Rumelhart and Norman (1978) clearly acknowledge that their model is deficient in certain respects, such as capturing the true anatomy and abilities of the hand and how the environment is represented. However, they do offer a view of the nature of skilled motor co-ordination as a locally occurring parallel process.

Thus, the components that are involved in the ability to type have been clarified. Clearly the thrust of the propositions concerns the facility to break down the information presented into easily managed pieces or chunks of information and the subsequent speed up with which they are processed. However, in conjunction with this the individual must know how to organise the consequential series of actions. It is here where the importance of being able to sequence ones behaviours is evident.

2.5.4 SUMMARY
The aim of the preceding sections was to demonstrate how a simple but widely experienced perceptual-motor task is acquired. An individual’s typing performance is constrained by a number of factors, central, peripheral and external. Different theoretical models of typing performance show that at a very basic level typing consists of an ‘input’, an ‘intermediate’ and an ‘output’ stage. The models of Salthouse (1986) and Rumelhart and Norman (1982) differ in the way in which they describe the processes that occur, but suggest that the information is encoded, decomposed and transformed into a representation based on motor units. Practice increases the speed and accuracy with which an individual is able to do this. However, what is less certain is whether practice increases the ability of the individual to transfer their performance to similar typing related tasks, or whether word-specific effects are strengthened, resulting in little adaptation and generalisation.
The aim of the second part of the chapter therefore is to specify a different type of keyboard task and to examine whether the processes that facilitate acquisition and retention in this instance are similar to those that are found for typing. Thus a brief introduction of the importance of sequencing behaviour shall be given before establishing the main findings regarding sequence entry tasks.

2.6 THE ABILITY TO SEQUENCE ACTIONS

The ability to organise sequences of actions underlies practically all of the everyday skills that a human can perform (Clegg, 1998). From predominantly motor skills such as typing (Kornbrot, 1989) to higher level skills such as speaking or writing (Lindemann and Wright, 1996), the learner must learn to execute the series of actions in a coherent and logical order (Cohen, Ivry and Keele, 1990). Two strands central to the study of any type of sequence learning concern the nature of the sequential representation formed and the level of awareness 'experienced' during a particular episode, i.e. whether the individual is aware that they are acquiring an organised series of behaviours. These aspects are the focus of the present section.

One way in which 'sequencing' has been studied is through incidental learning paradigms, the relevance being that many of the skills that a human acquires in the 'real world' such as learning grammatical rules are done so unintentionally (e.g. Reber, 1969). In laboratory based tasks, such paradigms enable the examination of fundamental processes involved in performance without involving the influence of higher level cognitive operations; for example, thinking about how to type a specific letter on a keyboard affects the way in which the stimulus is perceived and as a result, alters the fluency and the efficiency with which the appropriate action is executed (Clegg, 1998). One of the factors under present investigation is how the representation of an essentially meaningless piece of information is encoded and represented differently to comprehensible text that is to be typed. In order to answer this it is necessary to examine what is acquired during sequencing tasks.
CHAPTER TWO

2.6.1 WHAT IS ACQUIRED DURING SEQUENCE LEARNING?
The emphasis of study in sequence learning paradigms is placed either upon the learning of general underlying regularities of the task or properties specific to different sequences (Ivry, 1996). Learning general regularities between stimuli is facilitated in situations where multiple repetitions of component parts of sequences are processed. Evidence for this effect is demonstrated through performance advantages upon tasks in which the action per se has been practiced; specific sequence learning is evident when the only advantage observed when subsequent performance is measured is for a specific previously practiced sequence (Marsolek and Field, 1999).

The fact that the two types of perceptual-motor sequence can seemingly be learned independently raises questions concerning the nature of the underlying system supporting learning. Are there two independent subsystems, one for 'general' and the other for 'specific' properties, or can one single learning system serve both types? Support for the latter idea comes from neural network modelling in which sequence patterns are represented as patterns of activation across a network (Rumelhart and McClelland, 1986). It is the distribution of the representations across a network that is the key factor here. Not only do the links store distinctive information about specific sequences but also due to the spread within a network information about shared structural properties of the sequences is contained. If this were the case then typing sequences would be no different from typing per se. Arguably, any task that involved keypressing would rely on the same fundamental processes in so far as the individual performing the task had to encode a series of information and subsequently execute it. This has not been shown to be the case, recall the differential typing times recorded for words, non-words and nonsense syllables reported above (Grudin, 1983).

The basis of research advocating the existence of two independent subsytems comes from the simple observation of differences arising between the types of information each system is specified to learn. Learning both the general and the specific components of any sequences places contradictory demands upon one of the
subsystems (Marsolek and Field, 1999). For example, within a ‘general features’ system, it is clearly advantageous that suppression of distinctive information should occur. This would reduce the possibility of being able to differentiate between whole sequences in favour of the ability to process details of the invariant components, for example high frequency digraphs, co-occurring within sets of sequences. Where specific sequences are to be learned then naturally the reverse would be true. The idea underlying specific learning is that sequences are represented holistically; that is the entire perceptual representation of the sequence is represented along with the motor representation of action. The parallel between this view and that according to instance representation advocated by Logan (1988) is clear; a distinctive episodic trace of the experience would be recorded.

A test of whether general feature learning and specific-sequence learning is supported by independent systems was performed by Marsolek and Field (1999). The critical manipulation used to assess this was whether the keypad used to enter sequences during training changed at test. At training subjects were presented with a series of digit sequences all of which conformed to a sequence rule; a subset of these sequences was ‘repeated’, while the remaining ones were presented only once (‘unique’). At the test session sequences were divided into: ‘New-rule unique’ which adhered to a sequence rule opposite to the one used during training; ‘old-rule unique’ followed the same rule as at training but had not been presented and ‘old-rule repeated’ were those which had been repeated during training. Based upon the premise that dissociable subsystems exist, the following predictions were made. Where the ‘same’ keypad was used between study and test, a general-regularity effect in addition to a positive specific-sequence effect would be found. In the ‘different’ key configuration, a general regularity effect but no specific-sequence effect was predicted.

Indeed the results supported these predictions. Subjects who entered the sequences at test using the same keypad demonstrated both general-regularity and sequence-specific learning. ‘New-rule unique’ sequences were entered more slowly than ‘old rule unique’, which were in turn entered more slowly than ‘old-rule repeating’
sequences. Furthermore, those subjects who used a different keypad formation exhibited general regularity learning but not sequence-specific; the subjects were able to freely transfer their abilities between the two types of 'old-rule' sequences. An additional finding with respect to the sequence-specific group however, was the fact that they could distinguish between the two types of old sequences. This finding was interpreted as evidence for declarative memory of the sequences which counteracted the negative effects of not being able to rely on procedural memory.

Marsolek and Field (1999) interpret these findings on the basis of knowledge of different neural substrates. They argue that general-regularity learning relies on the formation of links between representations of visual sequences and representations of sequence components stored in a motor system, which is mediated via the basal ganglia (Knowlton, Mangels and Squire, 1996). However, declarative learning of the sequences is said to rely upon links formed via the medial-temporal structures between visual representations and motoric conceptual representations that are more flexible than those involved in procedural learning. The fact that neurological evidence has been found to supports the existence of different learning systems strengthens this argument.

Thus if there are indeed two different learning systems, the question arises concerning what actually is learned?

2.6.2 WHAT IS REPRESENTED DURING A LEARNING EPISODE?
One of the main aims of sequencing paradigms is to elucidate what is represented and hence learned, during the learning episode (Cohen, Ivry and Keele, 1990). Potential sequential dependencies that might be learned include stimulus based responses, motor responses or more central processes involved in response selection. The idea that the these processes could offer separable contributions to performance was investigated by Willingham, Nissen and Bullemer (1989).

In their experiment the colour and the location of a sequential stimulus were
independently manipulated between learning and test. The following three groups were trained to respond to the colour of the stimulus: A ‘random’ group for whom the colour and the location in which the stimuli appeared was completely random; the ‘perceptual sequence’ group, in which the location of the sequence followed a pattern but the colour and hence the response order was random, and finally the ‘response sequence’ group, whereby the colour, and thus the responses, followed a sequence but the locations were random. Following the training session, all groups were transferred to a task in which ‘location’ was responded to rather than colour.

During the training phase, the perceptual sequence group (in which location followed a sequence) showed no evidence of learning compared to the random group and furthermore, displayed no evidence at transfer. This suggested that location and thus the response based component was not a factor which was learned in the task. The response sequence group showed learning of the sequence during practice (i.e. with the colour) but this same sequence did not transfer to location at test. The fact that the motor pattern did not transfer suggests that the basis of learning was not ‘response’ but rather, ‘perceptually’ or stimulus based. However, these results have to be treated with caution due to the lack of learning within the perceptual group; Willingham et al finally concluded that associations between different aspects of the task, in the present case, colour and location were important for learning.

The separation of response components was further investigated by Cohen, Ivry and Keele (1990) who employed a transfer task to discern the representation of information. Subjects were presented with 1000 trials of sequential stimuli. Each stimulus was associated with one of three buttons and each button was in turn, compatibly mapped to one of the middle three fingers of the right hand. The task requirement during this stage was to make the appropriate motor response when presented with the stimulus. Following these trials, subjects were required to complete the same sequences using only one finger of their right hand. There was no decrement in performance following the transfer manipulation which suggests that learning was effector independent, i.e. not specific to certain muscle groups.
However, the fact that the subjects in the present experiment transferred to a relatively easier task undermines these findings; for instance, it would be harder to learn how to respond using three fingers than one.

Using the same paradigm, a more extreme test of stimulus-based learning investigated the effect of transferring from a manual to a verbal response (Keele, Jennings, Jones, Caulton and Cohen, 1995). In this instance transfer was incomplete; despite the stimulus information remaining constant some of the learning was lost which challenges the notion that learning is stimulus based per se, and suggests that response-based representation does have a separable influence upon performance (Clegg, 1998), a finding also supported by other studies of digit entry tasks (Fendrich, Gesi, Healy and Bourne, 1995).

Evidence for pure stimulus based representation of learning has been demonstrated by Mayr (1996). Subjects in his experiment learned a sequence, in which each component corresponded to one of four locations upon a computer screen. Subjects were not required to make a response in these experiments yet still managed to learn the sequence. One of the important features highlighted by this study, however, is the nature of the response based component - to what extent did eye movements constitute a response in this study? It seems appropriate at this stage to conclude that both types of representation are learned which are differentially used depending upon the requirements of the task. Definitive evidence supporting one representational mechanism over the other has not been established (Clegg, 1998). (Although it seems again pertinent to mention the specificity of learning in perceptual skills, as reported in the previous chapter. While performance on motor tasks were reported to transfer, this was not the case for perceptual tasks (Goldstone, 1998).

The complexity involved in establishing the nature of learning is demonstrated further through findings that indicate individuals can learn the sequential structure of trials even though learning is not part of the stated objectives. The second strand of 'sequencing' therefore concerns the extent to which the individual is aware that they
are learning a highly structured series of events.

2.6.3 LEARNING WITH OR WITHOUT AWARENESS
The possibility of 'learning without awareness' has arisen due to the ways in retention performance of sequence entry tasks has been assessed (Blaxton, 1995). A division has arisen between proponents of independent 'forms' of memory on the one hand and the 'process-based' theorists on the other (Richardson-Klavehn and Bjork, 1988). 'Implicit' (without awareness) and 'explicit' (with awareness) forms of memory have been proposed on evidence from tests such as word fragment- or stem-completion and recall or recognition tasks, respectively (Schacter, 1992).

'Forms' of memory are essentially a description of the behavioural expression, or the phenomenal experience of the individual performing the task (Groeger, 1997). Explicit memory is characterised as intentional or conscious recollection of past episodes, whereas "implicit" refers to unintentional, nonconscious use of previously acquired information' (Schacter and Tulving, 1994, p501). The two forms are said to operate independently (Graf and Schacter, 1985; Gabrieli, 1995).

Nissen and Bullemer (1987) presented participants with a sequence of visual stimuli, each stimulus (an asterisk) appearing in one of four horizontal positions upon a computer screen. Presentation of the stimuli was manipulated such that the sequences were random or repeating; one block contained ten successive repetitions of the sequences, the repeating sequence following the pattern: 4 2 3 1 3 2 4 3 2 1. Subjects were told to press the response key corresponding to the stimulus as quickly as possible. Subjects in the repeating sequence condition showed substantial improvement in performance across trials; median response times (RTs) reduced from 330ms to 160ms, while in the random condition little improvement occurred (360ms to 350ms). This was taken as convincing evidence for learning without awareness. Furthermore, Nissen and Bullemer demonstrated that Korsakoff syndrome patients who suffer from amnesia were able to show RT savings to the repeated sequence yet quite clearly had no explicit knowledge of what was presented.
However, equally convincing evidence has demonstrated that this interpretation may be premature. It has been argued that faster responding within the repeating rather than random group could be due to the development of response biases (Shanks and St.John, 1994). Within the Nissen and Buller sequence, the event probabilities of the sequence were not equal, 2 and 3 occurring three times, 1 and 4 twice. Thus the subjects could have been learning frequency information of the stimuli rather than the entire sequence. Clearly this factor could have accounted for the improvement in RTs in terms of anticipatory responding. In their review of the findings Shanks and St.John argue that the evidence indicates that subjects “are aware of the relevant knowledge and that knowledge consists of fragments of the training sequence” (pp 388-389) which clearly opposes the notion that separable systems exist. An alternative view will now be presented.

### 2.6.4 THE ‘PROCESS-BASED’ VIEW OF MEMORY

Research which has primarily been based upon the ideas promoted by the ‘transfer appropriate processing’ (TAP) framework has resulted in a different concept of memory within which the notion of ‘independence’ is challenged. Here, learning is viewed as the ability to re-perform a specific act as a consequence of the transfer that occurs from one situation to another (Morris, Bransford and Franks, 1977). Process-based theorists argue that the degree to which an individual is successful at retrieval and is therefore said to have a ‘memory’ for an event, is governed by the type of processing that occurs during acquisition of the task and the way in which it is later tested (Roediger, Weldon and Challis, 1989).

Two types of task have been discerned, ‘perceptual’ and ‘conceptual’ tasks. While the former relies upon ‘data-driven’ processing characterised by low level, perceptual operations (Jacoby, 1983), the latter involves processing of the semantic features ‘conceptually-driven’ processing involving higher level semantic operations (Blaxton, 1995). At retention, the match in processing requirements is the fundamental factor effecting what is remembered (Kolers and Roediger, 1984).
Inherent to the process viewpoint is the notion that all information is potentially recallable; performance may be implicitly influenced, but that does not mean the information is permanently out of awareness (Healy and Bourne, 1995). This has been demonstrated in a body of work known as ‘procedural reinstatement’ which is grounded in the theory that the match between procedures governs the success of subsequent performance upon a task (Kolers and Roediger, 1984).

2.6.5 PROCEDURAL REINSTATEMENT
The framework of ‘procedural reinstatement’ is based on the premise that retention of a skill, assessed both directly and indirectly, depends upon the degree of similarity between cognitive and motor processes used during study and then again at test (Fendrich et al, 1995). The argument rests directly upon the assumption that specific processing of the procedures used and the context in which they were experienced are incorporated into a memory for an event (Kolers and Roediger, 1984). Performance is most appropriately tested in terms of the type of processing employed at acquisition (Blaxton, 1995).

In their test of ‘procedural reinstatement’, Fendrich et al required subjects to perform a digit entry task at two temporally distinct phases, ‘acquisition’ and ‘retention’. The subjects experienced two acquisition sessions separated by one week. Subjects were required to reproduce a series of sixty, four-digit sequences by pressing the corresponding keys on a computer keypad, modified such that the arrangement mimicked either that of a ‘telephone’ or ‘calculator’. Of the sixty sequences, twenty were unique.

Retention was tested one week later; perceptual and motor contributions to memory were examined through the incorporation of a transfer paradigm. The same digit entry task was used, but half of the subjects from each group used either the same keypad (‘same’ transfer group) or the alternative format (‘switch’ transfer group). Three sets of sequences were presented to the switch transfer group in a random order: ‘old
motor' (same motor pattern, different perceptual representation), 'old digit' (same percept, different motor pattern) and 'new'.

It was hypothesised that retention of the material, measured both indirectly and directly would be enhanced where previously practiced procedures had been performed. Indeed this is what was found. With respect to indirect tests, RTs for old sequences were found to be reliably faster than new within both groups. Furthermore, where the same keypad was used at test, sequences were entered faster than when it was switched. These results indicate that perceptual and motor representations of the task were formed during acquisition, both of which implicitly influenced performance. Furthermore, where recapitulation between study and test occurred, performance was enhanced, a finding also obtained when direct tests of memory were performed.

Specific features of the keyboard task appear to be encoded; i.e. those which would not be found for other tasks such as typing. This is supported by results from the direct tests.

With respect to recognition of the sequences, it was found that the ability to discriminate old sequences from new was significantly greater than chance for both transfer groups. More importantly however, was that the same keypad condition was more accurate than the switch – reinstating procedures benefited responding. However, recognition decisions were influenced by the subjective perception of response times, sequences entered faster were judged ‘old’, those entered more slowly were judged ‘new’, regardless of their actual status. Judgements appeared to be based upon the fluency with which the sequences were perceived; implicit effects of memory facilitating explicit judgements (Jacoby and Dallas, 1981). This suggests that in addition to benefiting from perceptual fluency, a motor memory (or schema) for the action is formed which, at retention, contributes to the feelings of ‘motor fluency’. Motor fluency operates upon the same principles as perceptual fluency, augmenting feelings of familiarity and thus recognition (Jacoby and Dallas, 1981).

The results reported above indicate that highly specific stimulus based knowledge is
learned during acquisition phases of sequence entry paradigms. A caveat to this however, is that such specificity will only be evident depending upon whether the test of retention appropriately encompasses what has been learned. This issue will be addressed in detail throughout this thesis. Indeed, the rationale for using the experimental paradigm and the aims and the objectives of the experiments reported in this thesis will now be presented.

2.7 AIMS AND OBJECTIVES
The overall aim of the thesis is to examine the processes that facilitate the acquisition and maintenance of a keyboard based skill. In order to achieve this aim, the experiments conducted will test some of the issues raised in this and the preceding chapter. Before focussing upon these objectives, the experimental paradigm that will be used will be reviewed.

The experiments conducted will incorporate the procedural reinstatement paradigm and a series of sequence entry tasks. However, in order to address the objectives set, the paradigm will be used more extensively than previously (cf. Fendrich et al, 1991, 1995). One of the most important but so far overlooked attributes of the procedural reinstatement paradigm is the incorporation of the acquisition phase. Clearly the acquisition phase allows an investigation into the characteristics of learning; when examined in conjunction with the retention phase a more in-depth analysis of the processes that occurs during learning can be conducted. The effects of any manipulations made can thus be examined on both occasions to affording a more cohesive and coherent account of learning. Thus, the experiments aim to provide a more extensive view of the processes underlying and factors effecting acquisition and maintenance of keyboard based tasks, and skills in general.

In the preceding and present chapter, the characteristics of skill learning and factors effecting such learning were reviewed. The factors that will be addressed in greater detail in the experiments reported will included: the 'effects of practice', 'global versus stimulus specific learning', 'transfer', 'the effect upon retention of reinstating
conditions between study and test’ and whether ‘forms’ or a ‘unitary’ memory exist. Each of these issues will be addressed in turn.

2.7.1 THE EFFECTS OF PRACTICE
Due to the fact that learning *per se* has not been addressed in studies using the procedural reinstatement paradigm, an initial objective to establish is whether practice results in those features that typically characterise learning. That is whether learning is negatively accelerated and is best described using a power function of practice. Clearly it is fundamental to establish that learning is actually occurring when making predictions about and manipulating factors that are known to effect it. In establishing these characteristics from the outset, the results of further predictions can be discussed with greater confidence.

With respect to the wider issues of practice, the objectives include clarifying how performance differs as a function of the type of practice received, the amount of practice received and the ‘difficulty’ of the practice received. Each of these elements will be addressed at different points throughout the thesis. With respect to the ‘type’ of practice, it has been shown that the literature is divided regarding the effects of ‘massed’ and ‘distributed’ practice, i.e. ‘massed’ practice has been hypothesised to lead to faster learning, while ‘distributed’ leads to more durable learning. The converse has also been suggested. The intention therefore is to clarify this issue using the procedural reinstatement paradigm. Regarding the durability of the effects, a broader measure of performance will be attained through the incorporation of both indirect and direct tests.

The effects of manipulating task difficulty as a function of practice, i.e. ‘blocking’ or ‘spacing’ stimuli, will also be examined in a more in-depth manner. Again, the differential effects predicted to arise at acquisition and retention will be tested using a digit entry task. Clearly the aim is to establish the practice regime that promotes optimum learning and retention of the task an issue of great importance when consideration is given to the effects upon wider typing performance.
One other aspect of practice that will be manipulated in the present set of experiments is the amount of practice received. Conventionally the amount of practice has not been regarded as a factor that affects learning and retention to the extent of manipulating the 'style' for example. However, given the nature of the original paradigm and the emphasis placed upon contextual reinstatement it is worth examining whether reducing the amount of practice increases the dependency upon contextual / retrieval cues.

2.7.2 GLOBAL VERSUS SEQUENCE SPECIFIC LEARNING AND TRANSFER
One of the main objectives of the studies is to examine whether what is learned are the global features of the task or, whether 'stimulus-specific' knowledge of the task is developed throughout the learning phase. With respect to 'global' sequence learning it would be predicted that responding to the stimuli per se would facilitate learning and performance upon the task as a whole. Transfer to other similar types of stimuli would be expected. However, if stimulus specific learning were occurring, one would expect facilitation on specific exemplars of the sequences; learning stimulus-specific attributes would not enhance transfer performance. Furthermore the use of digit sequences as stimuli enables a closer examination of whether component parts of the sequences are responded to differently; for example, whether encoding differs from execution and whether knowledge of one component is more likely to transfer than another, for example. Investigation of whether global or specific sequence learning occurs will be addressed both at acquisition and retention.

2.7.3 THE EFFECTS OF PROCEDURAL REINSTATEMENT
The main premise of the procedural reinstatement argument is that retention performance is dependent upon the extent to which the processing conditions at study and test overlap. The greater the overlap, the better retention performance will be. The experiments in this thesis will allow the procedural reinstatement argument to be tested under a variety of learning conditions. Clearly the aim is to establish whether
such dependencies upon previous processing conditions applies to all learning situations.

2.7.4 'SYSTEMS' VERSUS 'PROCESSES' VIEWS OF MEMORY
Related to the procedural reinstatement argument is the debate surrounding views of memory as dissociable systems or rather as a unitary phenomenon. By including both indirect and direct tests of retention, the studies will allow an examination of whether individual's can operate without awareness, i.e. demonstrate implicit effects without recognising that the stimuli have been previously seen, or whether retention is more dependent upon the processing used during study and test. Clearly the latter is related to the procedural reinstatement perspective.

These objectives will be explored in the series of studies which follow in order to achieve the aim of identifying the factors that facilitate the acquisition and maintenance of keyboard skills.
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3 METHOD

This chapter provides an outline of the participants, the materials, and the design and the procedure used throughout the forthcoming experiments. Modifications particular to appropriate studies will be described in the relevant experimental chapter.

3.1 PARTICIPANTS

Participants were recruited through advertisements placed around the University of Surrey campus and within the Department of Psychology. For all of the experiments therefore, the majority of participants were post- or undergraduate students studying at the university. The criterion for selection was that all participants were right-handed. Native English speakers were used in the experiments. Although no differences were expected in the typing ability of participants, it was felt that differences in the vocalisation of numbers and letters for foreign languages may interfere with responses.

3.2 MATERIALS AND APPARATUS

3.2.1 KEYBOARD MODIFICATIONS

The entire task was computer based. All stimuli were presented on a standard ten inch P.C. monitor. Participants were required to respond to the stimuli using a modified keyboard. Throughout the entire series of experiments four different keyboards were used, two for studies 1 to 5 and two for studies 6 and 7. Apart from the numeric keypad to the right of the keyboard, function keys ‘F1’ to ‘F6’ located at the top of the keyboard and the ‘return’ key, all of the remaining keys were covered, indicating that these keys were not to be used.

For Studies 1 to 5, the keys on the numeric keypad to the right of the keyboard were covered with nine ‘number’ stickers, the digits ‘1’ to ‘9’. Following this modification
the format reflected either a ‘telephone’ or a ‘calculator’. A schematic representation of each keypad is shown on Figure 3.1; the difference between the two formats arises because of the transposition of the top row and the bottom row of the keypad.

![Figure 3.1 Telephone and calculator keypad formation used in studies 1-5.](image)

The six ‘function keys’ located horizontally at the top of the keyboard at the top of the keyboard were covered with blue coloured stickers in order to reflect a six-point response scale. The intensity of colour of each key decreased from ‘F1’ (i.e. darkest) to ‘F6’ (lightest). The ‘return’ key was also highlighted; pressing this key initiated the experiment.

In Studies 6 and 7 ‘letters’ were placed over the keys on the keypad to the right of the keyboard, as shown in Figure 3.2.

![Figure 3.2 Keypad formations used in Studies 6 and 7](image)

### 3.2.2 Stimulus Lists
Participants responded to two stimulus lists within each experiment, one at acquisition and another at retention. All stimulus lists contained a series of four-digit sequences. ‘Number-sequences’ were presented in studies 1 to 5, ‘letter-sequences’ were presented in studies 6 and 7. One of the aims of the study was to establish the effects
upon performance of manipulating practice schedules. For this reason, the stimulus lists were designed to enable cross comparison of results between studies. The stimulus lists used are shown in the Appendices (Appendix 1).

3.2.2.1 Acquisition Lists

The lists presented at acquisition were designed in the same way for each of the experiments, differing in the amount of sequences presented and depending upon whether the digit sequences were comprised of letters or numbers. Five practice sequences were always shown at the beginning of the list. The experimental sequences were then displayed. Presentation of the test sequences was not random. Lists were divided into four ‘blocks’. Each block contained five novel sequences, repeated either three or six times (the exact number of repetitions will be clarified in the Method section of the specific experiment). The set of five unique sequences was presented followed by the second repetition of that set and then the third repetition of the set, e.g. 1,2,3,4,5,1,2,3,4,5,1,2,3,4,5, before the next block of sequences was presented. There was no gaps between successive blocks and the same order of presentation was maintained within all four blocks.

3.2.2.2 Retention Lists

Two lists were used at retention, one presented to participants in the ‘same’ condition and one to those in the ‘switch’ condition. Each list contained forty sequences, twenty ‘old’ sequences presented during acquisition and twenty ‘new’ sequences. Within the ‘same’ transfer group, ‘old’ sequences were identical to those shown at acquisition. For the ‘switch’ transfer group, however, ten ‘old digit’ sequences (repetition of visual stimuli but different motor pattern) and ten ‘old motor’ sequences (different visual stimuli, repetition of motor pattern) were displayed. Figure 3.3, over the page, gives an example of a sequence change for number sequences following this manipulation.
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2791 2791 8137

| Acquisition sequence | 'Old digit' sequence | 'Old motor' sequence |

Figure 3.3 An example of an 'old' sequence at acquisition and the effect of manipulating the keypad formation to produce 'old digit' and 'old motor' sequences.

Old and new sequences were randomly presented, with the constraint that within a group of eight, four 'old' and four 'new' sequences appeared.

3.2.2.3 CONSTRAINTS USED IN THE DESIGN OF SEQUENCE LISTS

Sequences were randomly generated, but were subject to the following constraints: the digit '0' was excluded; a sequence had to contain at least one number from each row of the keypad and, adjacent numbers on the row of the keypad could not follow each other (e.g. 4 followed by 5 was not allowed). The latter modifications were performed in order to ensure a truly different motor pattern for the switch group during the retention test. The combination of digits 1 and 9 at the start of any sequence was also disallowed, as this could artificially inflate the familiarity of the sequence.

The letter sequences were subject to the following constraints. Vowels were excluded. A q-sort was then performed on the remaining consonants. All English-speaking participants (not used in any of the experiments) were asked to sort the consonants based on the similarity of their sound and subsequently their distinctiveness. The consonants depicted in Figure 3.2 were chosen as the least similar sounding (to each other) and the least distinctive of all the consonants.

3.3 DESIGN

The experiment used a mixed design, incorporating both between- and within-subject factors. At acquisition, within subjects factors were due to manipulations within the sequence list. Independent variables included:

'Repetition', which referred to the number of times a sequence had been presented
across the session, up to six times in total.

'Sequence', which referred to the twenty novel sequences presented within the list. Response time (RT), measured to the nearest millisecond was the dependent variable. Three RTs were measured: 'total time', referred to the length of time taken to enter the entire sequence, from the onset on the screen up until the final keypress. 'Encoding time' was recorded from the onset of the sequence upon the screen until the first keypress was made. Execution time reflected the time taken to enter the final three digits of the sequence, thus comprised three component keystroke times.

At retention, a 2 x 2 ('transfer group' by 'sequence type') mixed design was used. The formation of the keypad was manipulated between study and test, creating the between subjects factor of 'transfer group'. The keypad formation was either changed ('switch' transfer group) or remained the same ('same' transfer group). 'Sequence type' was manipulated within subjects. Each transfer group was presented with 'old' and 'new' sequences. In addition, for the switch transfer group, three types of sequence were used: 'new', 'old digit' (same perceptual representation different motor response) and 'old motor' (same motor response, different perceptual representation). Both RTs to sequences and RTs of subjects were used as the unit of analysis. Where one or the other is used is described in the Results section of each experimental chapter.

At retention in addition to RTs, recognition decisions were also measured\(^1\). Subjects were required to indicate whether the sequence had been presented during acquisition.

\(^1\) Recognition decisions were measured using \(A'\). \(A'\) is a measure of sensitivity based upon the area underneath the 'receiver:relative operating characteristic' or ROC space. The area increases from \(.5\) for chance performance to \(1\) for perfect responding and gives an indication of the proportion of responses correct by an unbiased observer in a two-interval forced choice experiment. With \(A'\) the area under the ROC is calculated using the average between minimum and maximum performance. \(A'\) can be calculated without any adjustment to the data (unlike \(d'\)) and thus approximates a non-parametric measure of sensitivity (Macmillan and Creeleman, 1991). The formulae used to calculate \(A'\) can be seen in Appendix 3.
3.4 PROCEDURE
Participants completed both the acquisition and the retention sessions individually. Each session took approximately ten minutes to complete.

Acquisition Instructions of the experimental procedure were presented on the computer screen. Participants were informed that a series of four digit sequences would be presented horizontally in the centre of the computer screen. The task was to type the sequences shown using the keypad to the right of the keyboard. A highlight was used to indicate to the participants the digit to be pressed. The entire sequence remained on the screen until the last digit had been typed. A prompt resembling the six coloured function keys located at the top of the keyboard subsequently appeared in the centre of the screen. Participants were required to 'Press any blue key'. Following this response, the next sequence appeared. This procedure was repeated until the task completed. Five practice trials were provided prior to the experimental trials.

Retention Participants returned to the same laboratory for the retention test. Instructions were presented on the computer screen. Participants were informed that they would be performing the same digit entry task, typing forty four-digit sequences. In addition participants were informed that a recognition response would be required after each sequence had been entered. The prompt shown at acquisition again appeared but was accompanied by the instruction 'Make your recognition response now'. Participants were then required to decide whether the sequence was 'Definitely old' or 'definitely new'. Following this response the next sequence appeared. The procedure was repeated until all forty sequences had been entered.

At the end of the experiment, subjects were thanked for their participation.

3.5 INSTRUCTIONS TO PARTICIPANTS
During both sessions, participants were explicitly informed that they were to enter the digit sequences as quickly and accurately as possible with their right hand, using the
numeric keypad to the right of the keyboard. Responses upon the blue rating scale were to be made with the left hand only.

A full script of the instructions presented at both acquisition and at test can be seen in the Appendices (Appendix 2).
4 THE EFFECT OF PRACTICE UPON A DIGIT ENTRY TASK

4.1 SUMMARY
The main aim of Study 1 was to examine the learning characteristics of a digit entry task during and following practice. Performance improvement during acquisition was initially measured in terms of a RT speed up with practice; the rate of learning observed was then examined by fitting power functions to the data and finally, the pattern of learning demonstrated was investigated, i.e. whether global improvements in task performance were evident or whether responding improved based on the specific feature of the stimuli. Furthermore, using both indirect and direct tests of memory, the durability of learning was examined at retention. Study 2 extended the exploration of the effects of practice. The same paradigm was used and the same questions were addressed. However, in comparison to Study 1, a massed practice schedule was used. It was hypothesised that massed practice would lead to less effective learning during acquisition but not necessarily at retention. Within both studies RTs improved across the practice session and furthermore specific learning patterns appeared to be formed. These findings were supported at retention when old sequences were entered faster than new. Comparison of the practice groups however, revealed that the distributed practice group performed the task more quickly at acquisition but learned the task at the same rate as, and were no different to the massed group with respect to performance at retention.
4.2 STUDY 1 ESTABLISHING THE LEARNING CHARACTERISTICS OF A DIGIT ENTRY TASK

4.2.1 INTRODUCTION
The definitive characteristic of skilled behaviour is that it is 'learned' (Annett, 1991). Regardless of whether the principal component of the skill is cognitive, motor or perceptually based, the main way in which the learning process is facilitated is through practice (Adams, 1987). Practice is the process by which the individual actively accretes and tunes their knowledge to a specific task, leading to qualitative and quantitative changes in behaviour (Rumelhart and Norman, 1978; Mumford, Costanza and Baugham, 1994).

Qualitative changes refer to strategic shifts in performance while quantitative changes focus upon alterations in numerically measurable aspects of performance (Annett, 1991). Taken together these allow predictions to be made about the temporal duration of the practice schedule to be employed (Groeger, 2000). During practice, the rate of change in performance is initially rapid as the learner acquires the basic concepts involved in executing the task, but as they become more accomplished there are fewer behavioural components to change and hence the rate slowly diminishes with time (Welford, 1987). One of the most effective ways of expressing such changes is by plotting performance measures (e.g. response time or error rate) against the number of trials completed. The typical outcome is a negatively accelerating learning curve (Adams, 1985; Groeger, 1997), generally fitting a power function better than any other.

The power law of practice describes the relationship between the logarithm of the time to perform a given task against the logarithm of the trial number (Groeger, 1997). First demonstrated by Snoddy (1926) the power law was increasingly recognised as the most appropriate measure of learning. To illustrate, Crossman (1959) assessed the cigar-rolling abilities of female operators using 'special-purpose cigar making
machines' (p156). Following one-million practice trials, over a period of one-year the mean time taken to perform the task was ten minutes. Following another one-million trials during the second year of practice, a twenty percent improvement in cycle time was observed; mean cycle time reduced to eight minutes. The findings indicated that performance had not reached an asymptote following extensive periods of frequent practice; operators experienced a diminished return from practice which a defining feature of the power law.

The theoretical basis for Crossman's experiment lay in findings that suggested an individual's performance is adapted to and hence specific to the skill being performed, i.e. the speed up in performance arises as a consequence of individual's opting for specific responses; inappropriate responses are discarded as a consequence of practice. 'Specificity of learning' has since been redressed in more recent theoretical accounts of skill acquisition. For example, Logan (1985) proposes that skill acquisition is a consequence of the speed with which specific episodic representations of a particular task can be retrieved from memory, arguing that each encounter with a stimulus is encoded, stored and retrieved separately (Logan, 1992). The implied learning mechanism relates to the eventual accumulation of episodic traces in memory and the speed with which memories are retrieved rather than the strengthening of general features within a hierarchical network (Logan and Etherton, 1994).

The above view contrasts to theories that propose improvements in general features of performance, such as the central organisation of action and the formation of temporal relationships between responses lead to skill acquisition. MacKay (1982), for example suggests that practice increases the knowledge base of the individual whilst continuously strengthening the associations between stimuli or between stimuli and responses. More recently, Anderson (1982) has argued that the power law of learning can be explained through proceduralisation of the task. It is proposed that different processes underlying behaviour co-operate to facilitate learning. During acquisition, learning trials result in the 'composition', or generalisation of existing procedures that are subsequently 'strengthened' with practice, i.e. knowledge shifts from a declarative
to a fast, procedural format that enables generic responding upon tasks requiring similar responses (Anderson, 1995).

A task in which such 'similar responses' are required is typing (Rumelhart and Norman, 1982). The mechanisms underlying improvements in typing performance were examined by Salthouse (1986a). Practice was hypothesised to improve the ability to prepare for future keystrokes while simultaneously executing current movements. This was tested in an experiment in which subjects were required to enter a series of digits, displayed in one of two sizes; 'small' digits were entered using a keypad to the right of a keyboard and 'large' digits on a keypad to the left. Each session consisted of 32 blocks of 100 digits with seven digits in a display, in addition, seven blocks of 100 digits in which the number displayed was varied (i.e. from seven to one visible) were subsequently presented.

Results revealed that the median interkey interval reduced from 708ms to 252ms, between the first and the final session of practice. Furthermore, the size of the display needed to maintain a normal rate of typing increased with practice, from one character at the outset to two characters by the final session. Thus an inverse relationship between the time taken to execute the movement and the number of digits required to ensure efficient responding was found. Savings in the time taken to make a specific keystroke were attributed to improved efficiency in preparatory processing, or the planning of the response. However, whether improved planning was related to specific sequences or was a more global benefit of practice was not investigated by Salthouse.

The 'nature' of the representation underlying skilled performance has been investigated in studies incorporating transfer paradigms (Singley and Anderson, 1989). In this study, subjects learned to use different text editors, two of which were line editors (ED and EDT), the third a text-editor (EMACS). A two (number of line editors learned) by two (initial line editor learned) design was used with two additional control conditions, the first learned to use EMACS only, the other spent the
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learning period simply typing before transferring to EMACS. Text editing was performed on six consecutive days; subjects received three hours of practice per day with a ten minute break separating the first and the second, and the second and the third hours. The first line editor was practiced on the first and second day. Subjects learning two line editors were switched to the second on day three. On the fifth day all conditions transferred to EMACS, which was subsequently practiced during the final two sessions.

Results showed that overall, the improvement that occurred decreased as a power function of the number of days practice and did so for different components of the task. Edits took 48 seconds in total on day one, decreasing to 16s per edit by the end of the ‘learning’ phase (i.e. day 4). However, with respect to ‘execution time’ only, i.e. the physical production of the edit, on day 1 this took 13s compared to 8s on day 4. The magnitude of improvement for the execution component was minimal compared to the overall improvement. This demonstrates that the effort involved in the planning component was greater and improved more as a function of practice than execution. Subjects spent about 75% of their time ‘planning’ during day 1, compared to 54% during day 4. Thus ‘learning’ of the task appears to be in the strategic, planning component, supporting the results reported by Salthouse (1985). The absence of change in the execution component implies that previous keystroke experience may contribute, or transfer to a new task more readily, i.e. it is a generalisable aspect of performance.

The results from the transfer test confirm this. Generalisability of the task was examined in greater detail by looking at performance during days 5 and 6. Near total transfer was found between the line editors, ED and EDT when switched after two days (transfer scores of 91% and 87%, and 99% and 105% for locating lines and modifying text, from ED and EDT, respectively). However, only a moderate amount of transfer was found between line editors and EMACS on the fifth day (61% and 62%; transfer scores represented savings on a transfer task relative to a theoretical upper limit derived from the learning data, p242). These results were interpreted as
evidence for the formation of general response strategies that would facilitate performance upon related 'editing-type' tasks. However, it is evident that performance suffered when the actual response requirement differed (i.e. from line to text editors), calling into question whether what is learned does generalise effectively. Adopting more thorough performance measures to see what is retained following acquisition enables a more conclusive picture of what is learned.

A framework that has been used to assess performance at retention is that of 'procedural reinstatement' (Healy and Gesi, 1991). The basic premise of the framework is that retention of a skill, assessed both directly and indirectly, depends upon the degree of similarity between cognitive and motor processes used during study and then again at test (Fendrich, Healy, Gesi and Bourne, 1995). The argument rests upon the assumption that processing of the procedures used and the context in which they were experienced are incorporated into a specific memory for that event (Kolers and Roediger, 1984).

Fendrich et al required subjects to perform a computer based digit entry task. During the learning phase, each subject participated in all of the following conditions: 'Keypad', digits were entered using the keypad to the right of the keyboard; 'row', digits were entered using the row of number keys along the top of the keyboard, and 'read', digits were read only and the spacebar pressed for each digit. Within each condition 40 different items were entered, but twenty of those items were repeated three times. The testing session was one week later. Subjects served in two conditions, 'keypad' and 'row' and entered 120 'old' sequences and 120 'new' sequences. An equal number of the items presented in each condition at study was presented at test. In addition to entering the sequences, subjects were required to judge whether they had seen the sequence before.

The effects of procedural reinstatement were established through implicit and explicit tests of memory. The first indication was provided through analysis of response times; 'old' sequences were entered faster than 'new', a classic implicit finding
(Nissen and Bullemer, 1988) indicative of facilitation form prior experience. The main evidence for procedural reinstatement was found by assessing RTs for the old sequences only. Where the same motor response was made between study and test, RTs were reliably faster than when the response differed (due to the different keypad formation being used i.e. form keypad to row, or vice versa). The largest decrement in performance was found where sequences had been 'read' only at study (no prior motor response had been made); these sequences did not differ from new sequences at test. Procedural reinstatement had a stronger effect on recognition memory. Subjects were able to differentiate between 'old' and 'new' sequences when the same motor response was performed at test. When the motor response differed, it was found that recognition memory was no better than when sequences had been read at study only.

These results suggest that specific features of the stimuli are learned leading to specific representations of what is involved in performing the task. It is as if episodic memories of the acquisition phase are formed. However, Fendrich et al did not analyse the acquisition phase. The present series of experiments seeks to redress this deficiency.

The present study uses the procedural reinstatement paradigm to assess performance at acquisition and at retention. The main aim is to assess the learning that occurs during acquisition; to examine whether learning is specific to the stimuli presented or whether practice results in a general improvement in the underlying ability to type and perform typing based tasks. During the acquisition phase this will be established by presenting multiple repetitions of the stimuli and examining whether there is a cumulative effect of practice in that a uniform speed up in responding emerges, or whether specific sequences are responded to differently. The locus of improvement in performance will also be established; more specifically whether 'planning' rather than 'execution' of the response is enhanced. Finally, the rate of change with practice will also be examined at acquisition to see whether the power law of learning can account for any speed up evident.
The incorporation of a retention test that includes a manipulation of the response requirement of the task allows stronger conclusions to be drawn about the nature of learning. That is, whether specific features of the stimuli are learned, or rather general or global improvements are evident. The stimuli at retention will be manipulated such that 'old' and 'new' sequences are presented. In addition, the response format used to make the response will be transposed for half of the sample.

If global response strategies are adopted then these manipulations should not effect performance; the underlying regularities that are learned will transfer to other sequences, resulting in a facilitation of performance upon the task as a whole. If specific representations of the sequences are formed upon an episodic basis during acquisition, however, then a distinction between those sequences repeated at retention and novel sequences will be expected. Specificity in responding by definition does not support transfer of performance unless those elements that are learned are repeated. Completely novel sequences will require additional processing. Furthermore, taking into consideration the procedural reinstatement account of performance, where stimuli are repeated at test, discrimination of these stimuli should be evident as measured upon direct and indirect tests of memory.

4.2.2 METHOD

4.2.2.1 PARTICIPANTS
Forty right-handed individuals participated in the experiment, 16 males and 24 females with a mean age of 22.18 years (SD = 3.42yrs). All subjects were undergraduate or postgraduate students at The University of Surrey.

4.2.2.2 MATERIALS AND APPARATUS
Two modified keyboards upon which the numeric keypad resembled either a 'calculator' or a 'telephone' format were used.

Three stimulus lists were presented, one during the acquisition session and two during the retention test. Lists consisted of either sixty (acquisition) or forty (retention),
four-digit sequences (both lists can be seen in Appendix 1).

**Acquisition** The list presented during acquisition comprised sixty-five sequences in total, five practice sequences and twenty test sequences, repeated three times. The list was divided into four ‘blocks’. Each block contained five novel sequences repeated three times, i.e. a,b,c,d,e,a,b,c,d,e,a,b,c,d,e. The next block of sequences was then immediately presented.

**Retention** Two lists were used at retention. The list presented to participants in the ‘same’ condition contained twenty ‘old’ and twenty ‘new’ sequences. The list for the ‘switch’ condition comprised 10 ‘old digit’ (repetition of visual stimuli but different motor pattern), 10 ‘old motor’ (different visual stimuli, repetition of motor pattern) and 20 ‘new’.

### 4.2.2.3 Design

The experiment used a mixed design, incorporating both between- and within-subject factors.

At acquisition, within subjects factors were due to manipulations within the sequence list. Independent variables included:

- **Repetition**, which referred to the number of times a sequence had been presented across the sessions, up to six times in total.
- **Sequence**, which referred to the twenty novel sequences presented within the list.

Three response time measures were recorded (to the nearest ms): ‘total time’, or that taken to enter the entire sequence; ‘encoding time’ the time taken to make the first keypress from the onset of the sequence on the screen, and ‘execution time’ the time taken to enter the final three digits of the sequence.

At retention, a 2 x 2 (‘transfer group’ by ‘sequence type’) mixed design was used. A between subjects factor of transfer group had two levels: ‘switch’ and ‘same’ reflecting the manipulation in keypad formation between study and test. The within subject factor of ‘sequence type’ also had two levels ‘old’ and ‘new’. In addition, for the ‘switch’ transfer group three types of sequence were used: ‘new’, ‘old digit’ and ‘old motor’. Independent variables of interest in this experiment, therefore, were ‘transfer group’ and ‘sequence type’. Dependent variables were response time and
recognition decision.

4.2.2.4 PROCEDURE

Instructions were presented to participants on the computer screen and were verbally repeated in order to ensure complete understanding of the task. Subjects completed the five practice trials before typing the sixty four-digit number sequences. Following a one-week interval participants returned for the second acquisition session. Exactly the same procedure was performed.

The retention test was completed following another one-week interval. Participants typed forty four-digit number sequences. Following the entry of each sequence a recognition response regarding the 'old' / 'new' status of the sequence was made. The procedure was repeated until all sequences had been entered.

At the end of the experiment, subjects were thanked for their participation.

4.2.3 RESULTS

The main aims of the study were to assess: Whether task performance improved during acquisition; and whether performance transferred to a similar but different task following a retention interval. Results will be reported in two subsections, the first based upon those for the acquisition session, the second based upon retention. With respect to the acquisition phase the aim was to establish that an improvement with practice occurred, in addition to identifying where the improvement lay, i.e. the planning or the execution component.

4.2.3.1 ACQUISITION PERFORMANCE

To recap, within each of the two acquisition sessions, twenty four-digit sequences were repeated three times. Sequences were presented in four blocks, each block containing five novel sequences repeated three times. An interval of one week separated each acquisition session.

Mean median RTs were used in the analyses; three RT measures were taken, 'total'
time reflecting the time taken to enter the entire sequence, ‘encoding’ time or that taken from the time the sequence appeared upon the screen until the first keypress, and ‘execution’ time, the time taken to enter the final three digits of the sequence. The median across sequences or across subjects was taken in order to reduce the effect of outliers inflating response times.

4.2.3.2 EVIDENCE OF LEARNING DURING THE ACQUISITION PHASE

To assess whether performance improved across the acquisition phase, the difference in time taken to enter the first repetition of the sequences was compared to the sixth repetition. Figure 4.2.1 shows the mean total time for each of the sequences (plus SDs).

Figure 4.2.1 Total time (in ms with SD) taken to enter the first and sixth repetition of each sequence.
Using a paired t-test upon the RTs of each of the sequences, it was found that overall, the sixth repetition (2456ms) was entered reliably faster than the first (2786ms; \( t(19) = 4.502, p < 0.001 \)). Furthermore, the variability in responding reduced between the first \( (SD = 241ms) \) and the sixth \( (SD = 192ms) \) repetition.

Proportional relationships between the repetitions were calculated as a preliminary indication of the change that was occurring across the acquisition phase. The time taken to enter the sixth repetition of the twenty sequences as a proportion of the first, the third as a proportion of the first, and the sixth as a proportion of the fourth were examined. A 12% improvement in time was found between the sixth repetition and the first (mean \( \approx 0.88; SD = 0.04 \)).

Within the first session, a 6% improvement was found between the third and the first repetition, (mean \( \approx 0.94, SD = 0.02 \)); within the second session an improvement of 3% was found between the sixth and fourth repetition (mean \( \approx 0.97, SD = 0.037 \)), suggesting an inverse relationship between amount of practice and improvement. The difference in the proportional improvement between the two sessions (i.e. 3rd and 1st compared to 6th and 4th) was found to be reliably different \( t(19) = 3.382, p < 0.01 \) illustrating improvement occurs to a greater extent during the earlier stages, rather than the later stages of practice.

The 'nature' of the learning was subsequently examined using RTs for each of the specific sequence pairs (sequences 1 - 20, repetitions 1 and 6), included in Table 4.2.1.
Table 4.2.1 Mean median total times (in ms), t-values and correlation coefficients for each sequence pair.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>1st rep. (in ms)</th>
<th>6th rep (in ms)</th>
<th>t-value</th>
<th>Pearson’s r</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (4726)</td>
<td>2776</td>
<td>2597</td>
<td>1.863</td>
<td>0.386</td>
</tr>
<tr>
<td>2 (8267)</td>
<td>3017</td>
<td>2370</td>
<td>6.472*</td>
<td>0.289</td>
</tr>
<tr>
<td>3 (6284)</td>
<td>2340</td>
<td>2342</td>
<td>0.865</td>
<td>0.155</td>
</tr>
<tr>
<td>4 (8167)</td>
<td>3254</td>
<td>2402</td>
<td>2.074*</td>
<td>0.552*</td>
</tr>
<tr>
<td>5 (6726)</td>
<td>3038</td>
<td>2163</td>
<td>5.066*</td>
<td>0.411</td>
</tr>
<tr>
<td>6 (4186)</td>
<td>2593</td>
<td>2232</td>
<td>2.953*</td>
<td>0.315</td>
</tr>
<tr>
<td>7 (6826)</td>
<td>2854</td>
<td>2460</td>
<td>0.722</td>
<td>0.018</td>
</tr>
<tr>
<td>8 (8417)</td>
<td>2668</td>
<td>2328</td>
<td>4.178*</td>
<td>0.667*</td>
</tr>
<tr>
<td>9 (9438)</td>
<td>2641</td>
<td>2681</td>
<td>0.519</td>
<td>0.484*</td>
</tr>
<tr>
<td>10 (5816)</td>
<td>2772</td>
<td>2925</td>
<td>0.646</td>
<td>0.506*</td>
</tr>
<tr>
<td>11 (3753)</td>
<td>2408</td>
<td>2316</td>
<td>1.483</td>
<td>0.604*</td>
</tr>
<tr>
<td>12 (8269)</td>
<td>2549</td>
<td>2474</td>
<td>0.118</td>
<td>0.404</td>
</tr>
<tr>
<td>13 (7168)</td>
<td>3021</td>
<td>2366</td>
<td>3.645*</td>
<td>0.398</td>
</tr>
<tr>
<td>14 (7627)</td>
<td>2655</td>
<td>2744</td>
<td>0.979</td>
<td>0.030</td>
</tr>
<tr>
<td>15 (1761)</td>
<td>2607</td>
<td>2472</td>
<td>0.615</td>
<td>0.494*</td>
</tr>
<tr>
<td>16 (5824)</td>
<td>2718</td>
<td>2205</td>
<td>3.966*</td>
<td>0.464*</td>
</tr>
<tr>
<td>17 (1863)</td>
<td>2846</td>
<td>2462</td>
<td>1.583</td>
<td>0.248</td>
</tr>
<tr>
<td>18 (9157)</td>
<td>2543</td>
<td>2488</td>
<td>1.533</td>
<td>0.404</td>
</tr>
<tr>
<td>19 (8673)</td>
<td>3318</td>
<td>2475</td>
<td>4.938*</td>
<td>0.562*</td>
</tr>
<tr>
<td>20 (4375)</td>
<td>2605</td>
<td>2563</td>
<td>0.545</td>
<td>0.351</td>
</tr>
</tbody>
</table>

(* significant where p < 0.05)

To recap, the key question was whether the ability to respond to individual sequences improved with practice. RT data were analysed using Pearson’s product moment correlation to examine the amount of shared variance between the first and the sixth repetition of the sequences¹.

¹ The rationale for using Pearson’s Product Moment correlation centered on the fact that variables which are highly correlated share most of the variance in performance. The amount of available
As is evident from Table 4.2.1, eight of the sequence pairs were reliably correlated ($p < 0.05$). Of these sequences, the maximum amount of shared variance between the repetitions was 44%, which suggests that some information from the first sequence was being used to facilitate performance upon the sixth presentation. However, for the remainder of the sequences the shared variance was small (averaging about 25%), which suggests that new information was being used and responding between repetitions was not related.

For clarification, a paired t-test was used to test for differences between the sequence pairs. Again Table 4.2.1 shows that for eight of the pairs, RTs for the first repetition were reliably slower than the sixth ($p < 0.05$), suggesting that these particular sequences benefited more from practice. For the remaining twelve sequences, responding was not different from the outset of practice again supporting the fact that little information was shared between repetitions. For sequences 4 (8167), 8 (8417), 16 (5824) and 19 (8673), both the t-test and the correlation were reliable suggesting that performance was improving for the same amount for each subject.

In summary, the results do suggest a performance speed-up across the acquisition session, suggesting that learning of the task does occur. As expected, the proportional change between the repetitions suggests that there is greater evidence of learning within the first acquisition session than the second. In addition, the results suggest that particular sequences were learned differently from each other. While changes in learning occur for certain sequences, there are no changes in performance for others. Furthermore, this did not appear to be a consequence of the order of presentation, but was seemingly due to the properties of the individual sequences. The nature of this learning will be examined in more detail in the subsequent section.

Information is inversely related to the amount of variance. Thus if the individual is using information obtained from a previous encounter with the stimulus (i.e. the first repetition of the sequence), the variability in performance would be low (i.e. the shared variance would be high). If the individual was using novel information then the amount of shared variance would be low. However it is worth noting that in analysing RTs, central and peripheral factors also influence performance and may dampen the correlation.
4.2.3.3 Changes in the rate of learning

The learning characteristics exhibited across the acquisition session were additionally assessed by fitting power functions to the RTs for each sequence\(^2\). Two methods of were used to demonstrate learning. Power functions were fit to the data based upon either the ‘presentation’ of the sequence (the number of times (1 - 6) the sequence appeared) or, the ‘position’ (the numerical order of a specific sequence within the list)\(^3\) (Appendix 4 shows the \(r^2\), slope and intercept values found for each of the sequences).

The fit of the line, or the \(r^2\) value was calculated for both methods. The mean \(r^2\) for ‘presentation’ was 0.324, for ‘position’, \(r^2\) was 0.320. There was no difference between the two methods used when the functions were compared between sequences (\(t(19) = 0.486, p > 0.05\)). This is a major finding with respect to the learning strategies that are being developed. The lack of difference indicates that additional practice did not facilitate learning; when intervening sequences were taken into consideration the fit did not give a better account of the data compared to the typing of particular repetitions \textit{per se} \(^4\).

The ‘slope’ and the ‘intercept’ of the curve were subsequently examined. The slope of the curve indicates the rate of change in learning over the sequences. A mean value of -0.071 (range = 0.002 and -0.223) was found. A one-sample t-test found the value of the slope to be reliably different from zero (i.e. the state where no learning is occurring), indicating that learning of the task was possible (i.e. there was no floor

\(^2\) Linear fits were also performed on the data. The mean \(r^2\) was 0.322, which did not differ from the power function fit (\(p > 0.05\)). As the use of power functions is widely accepted to be the most appropriate way to describe learning (e.g. Newell and Rosenbloom, 1982), it was decided to proceed with this method.

\(^3\) Two methods were used to assess learning as a function of the power law. The first method was based upon the ‘presentation’ of the sequences within the list, i.e. whether the sequence was shown for the 1\(^{st}\), 2\(^{nd}\), 3\(^{rd}\), 4\(^{th}\), 5\(^{th}\) or 6\(^{th}\) time. This method examined learning of the specific sequences only. The second method used was based on the ‘position’ of the sequences within the list, e.g. sequence 1 was shown at position 1, 6, 11, 61, 66, 71; such analysis took into account the practice received from the intervening sequences.
effect) and that learning was occurring ($t(19) = 4.492, p < 0.001$). As Figure 4.2.2 shows, the gradient of the curve increased when a new ‘set’ of sequences was presented; this indicates that the amount of change was greater when novel sequences were presented.

![Slope values for each of the sequences.](image)

**Figure 4.2.2** Slope values for each of the sequences.

The intercept values obtained gave an indication of the initial level of difficulty of the task requirements. The mean intercept value was 2.758 (range between highest and lowest intercepts was 3.142 (sequence 9: 9438) and 2.372 (sequence 16: 5824), respectively). The most important finding here is that again the intercept values suggest that particular sequences were responded to differently; as sequence order ascended, the intercepts did not reduce, suggesting that general attributes of the task were not being learned.

In summary, again the results show evidence of learning across the acquisition session. However, the results suggest that learning of specific sequences is occurring, rather than general typing abilities being developed. The most convincing evidence of this was the demonstration that when the extra practice received from typing interleaving sequences was taken into account, the curve did not fit the data any better than when learning of specific sequences was analysed. This assertion can be examined in greater detail through the analysis of the perceptual and planning versus...
the execution components of the task.

4.2.3.4 LEARNING OF SEQUENCE COMPONENTS

RTs for the sequences were decomposed into ‘encoding’ time and ‘execution’ time in order to measure the changes in the ‘perception and planning’ component and the ‘motor response’ or ‘execution’ component, respectively. Encoding times will be examined initially.

4.2.3.4.1 RESPONSE PERCEPTION AND PLANNING

The difference in time between the first and the last sequence repetitions was initially examined.

![Figure 4.2.3 Encoding times (in ms) for the first and sixth sequence repetition.](image-url)

Figure 4.2.3 Encoding times (in ms) for the first and sixth sequence repetition.
Figure 4.2.3 shows that the sixth repetition was encoded faster than the first, mean RTs being 1200ms ($SD = 136ms$) and 1425ms ($SD = 124ms$), respectively (for means and $SD$s for all sequences see Appendix 5). Although variability in responding increased within the sixth repetition, using a paired t-test, still encoding was faster than the first repetition ($t(19) = 5.840, p < 0.001$), suggesting that practice improves the ability to plan the required response.

Encoding of individual sequence pairs was more closely examined. (Median encoding times, t-values and correlation coefficients are shown in Appendix 5 for each sequence pair). Correlation coefficients were initially calculated in order to examine the shared variance between the repetitions; all sequence pairs were reliably correlated (Pearson’s $r$ was significant where $p < 0.001$); coefficient’s ranged from .161 (sequence 19: 8637) to .716 (sequence 18: 9157); the mean coefficient was .235 ($SD = .10$). Again, some of the information used to encode the initial representation was used at the final presentation. Using paired t-tests it was found that thirteen pairs were encoded reliably faster upon the sixth repetition compared to the first ($p < 0.05$) supporting the idea that the information that is initially learned is facilitating subsequent performance.

The results support the suggestion that planning is facilitated with practice. Furthermore, the results suggest that particular sequences were being responded to differently to others, indicating specific response strategies were being learned. It would appear that rather than being able to more readily relate multiple sequences to a specific motor plan, the experience of typing is facilitating access to previously typed patterns. Analysis of the execution time component will allow a more thorough analysis of this claim.

4.2.3.4.2 MOTOR RESPONDING

Execution time was used as an index in the amount of time taken to perform the majority of the motor response and comprised three separate RTs for Keystrokes 2, 3
and 4. The time taken to execute the first and sixth repetition of each of the sequences is shown on Figure 4.2.4, containing three figures, covering the following three pages.

The mean RT for Keystroke 2 was 335ms (st.dev. 66ms) and 319 (st.dev. 83ms) for the first and the sixth repetitions, respectively. RTs were not reliably different ($t(19) = 0.749$, $p > 0.05$), which appears to be due to the increased variability within the sixth repetition. The pattern reversed for Keystroke 3, the sixth repetition (575ms) was executed slower than the first (434ms) and moreover, the difference was reliable ($t(19) = 3.804$, $p < 0.001$). For the fourth and final keystroke, mean RTs were 290ms and 250ms for the first and sixth repetition respectively, a reliable difference ($t(19) = 3.384$, $p < 0.01$).
These results suggest that the execution of the sequences does not benefit from practice to the same extent as the planning phase, the most convincing piece of supporting evidence being the increased time taken to enter the third keystroke at the sixth repetition. Conclusive evidence to suggest that either global or specific learning strategies were being adopted is not provided. However, the absence of overall improvements in execution suggests that the formation and implementation of global motor plans does not occur; if global response strategies were used, then a speed up across the entire phase would have been expected. By default, the lack of findings lend further support to the notion of improvements in perception and planning for specific sequences during encoding. When the total time taken to enter the sequences...
is considered, again, the interpretation that specific properties of the sequences are being learned, gains support.

During acquisition therefore, there is a definite improvement in the speed with which sequences are typed over time. However, practice appears to facilitate the planning component involved in typing to a greater extent than the actual execution of the sequence. Furthermore, the learning that does occur is not uniform across the trials. Rather, the results suggest that specific properties of the sequences are learned and responding based on these features is enhanced with practice.

Consideration will now be given to the durability of learning that is occurring. Retention of the sequences will now be analysed.

4.2.3.5 RETENTION

The durability and specificity of learning was examined at retention. The learning strategy adopted at test was examined by comparing RTs for 'old' and 'new' sequences both at acquisition and at retention. In addition the performance of individuals who changed keypad formation at retention only was assessed. It was hypothesised that increasing the mismatch between conditions at study and then at test would lead to decrements in performance and would lend support to the notion that specific response strategies are developed with practice. Finally, direct tests of memory were performed, in order to examine whether subjects recognised that the sequences presented to them were indeed 'old' or 'new'.

4.2.3.5.1 DURABILITY OF LEARNING

The durability of learning between acquisition and test was assessed by comparing RTs for the 'sixth repetition' from acquisition and RTs for the same twenty sequences presented at retention ('same-test' sequence set). The RT measure used in the analysis was the total time taken to enter the sequence.
Figure 4.2.5 Mean median total times (in ms) taken to enter the sixth repetition during the acquisition session, the ‘same-test’ sequences and ‘new-test’ sequences.

Figure 4.2.5 illustrates the time taken to enter each sequence for the ‘sixth repetition’ (at acquisition), the ‘same-test’ and the ‘new-test’ set (the latter at retention). The mean time taken to enter the ‘sixth repetition’ was 2456ms ($SD = 192$ms) faster than that taken to enter the ‘same-test’ sequences (2749ms, $SD = 222$ms). The difference between the two sets was reliable ($t(19) = 4.073, p < 0.001$), suggesting forgetting of the response requirement between study and test$^5$.

This relationship was examined further by correlating the RTs of each sequence within the ‘sixth repetition’ set and the corresponding sequence within the ‘same-test’ set. Responses for each of the sequence pairs were positively correlated, but not reliably ($p > 0.05$) so. The fact that low correlations were found between the sequences at the two presentations indicates that the amount of shared variance between the pairs is low and that the specific features of the stimuli were not retained between the two phases. The correlation coefficients and accompanying significance

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$^5$ The proportional difference in time between the presentation of the third repetition and the fourth repetition of the sequences during acquisition was examined, as a one week interval separated the two. This was compared to the proportional difference for the sixth repetition and the ‘same-test’ sequences, shown on Appendix 6. The graph shows that while improvements in time occur between the third and fourth repetition of the sequences (mean 3% decrease in RT), increases in RT occur between the sixth repetition and test (mean 12% increase in RT). This again suggests that interference is occurring between study and test. However, the possibility of interference from the new sequences cannot be ignored.
values can be seen in Appendix 7).

RTs taken to enter 'new-test' sequences (i.e. those that have not been seen previously) are also shown on Figure 4.2.5. The mean time taken to enter the 'new-test' set was 2846ms ($SD = 426ms$), which was reliably slower than the time taken to enter the 'sixth repetition' set ($t(19) = 3.983, p < 0.001$) but not different from the 'same-test' sequences ($t(19) = 0.935, p > 0.05$). Again the results suggest that specific knowledge of the sequence is not retained and more global response strategies are used at retention.

To confirm this, the final piece of analysis performed on the total time data examined whether the first typing of a sequence at acquisition (2779ms, $SD = 259ms$) was different to the typing of the 'same-test' (2749ms, $SD = 222ms$) and to the 'new-test' sequences (2846, $SD = 426ms$). There was no difference between either the 'same-test' ($t(19) = .571, p > 0.05$) or the 'new-test' sequences ($t(19) = .421, p > 0.05$) compared to those at acquisition, nor was the correlation between the sequence sets reliable ($p > 0.05$); there was no difference in the magnitude of the correlation for acquisition and 'old-test', than for acquisition and 'new-test' ($p > 0.05$). The results imply forgetting of the specific sequence pattern.

4.2.3.5.2 RETENTION OF PERCEPTUAL COMPONENTS

The RT measure analysed was 'encoding' time, or that taken to enter the first digit of the sequence. A manipulation in the keypad between study and test was incorporated to enable a more accurate examination of the retention of perceptual factors. To recap, in changing the keypad formation at test, half of the subjects (the 'switch' transfer group) used a transposed layout compared to study (i.e. calculator to telephone and vice versa) and entered a combination of 'old digit' and 'old motor' sequences.

Encoding times for each sequence type and transfer group was analysed using a 2 x 2 ('sequence type' by 'transfer group') repeated measures ANOVA; mean RTs can be
seen in Table 4.2.2. Although RTs within the switch transfer group were faster than the same group, the effect of ‘transfer group’ was not significant, (F(1,34) = 0.09, p > 0.05). Changing the keypad formation between study and test did not lead to a decrement in performance.

**Table 4.2.2** Mean encoding times (in ms and SDs) as a function of sequence type and transfer group.

<table>
<thead>
<tr>
<th>Transfer Group</th>
<th>New</th>
<th>All Old</th>
<th>Old motor</th>
<th>Old digit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>1679 (309)</td>
<td>1614 (339)</td>
<td>1606 (339)</td>
<td>1622 (334)</td>
</tr>
<tr>
<td>Switch</td>
<td>1520 (300)</td>
<td>1468 (271)</td>
<td>1526 (272)</td>
<td>1427 (268)</td>
</tr>
</tbody>
</table>

With respect to sequence type, within the ‘same’ transfer group, old sequences (1614ms) were encoded faster than new (1679ms) a pattern also found within the ‘switch’ transfer group (‘old’ sequences, 1468ms; ‘new’, 1520ms). A main effect of sequence type was found (F(1,34) = 5.71, p < 0.05) indicating a benefit for having perceived and planned the same response at an earlier stage. There was no interaction between ‘sequence type’ and ‘transfer group’ (F(1,34) = 0.08, p > 0.05), indicating comparable response strategies between the groups.

RTs within the switch group only were subsequently analysed in order to assess the differences between the two types of old sequence. A main effect of sequence type was found (F(1,18) = 9.36, p < 0.05), which reflected reliably faster encoding of the ‘old digit’ sequences compared to the remaining types. Indeed, the difference between ‘old motor’ and ‘new’ sequences was not reliable (t(18) = 0.02, p > 0.05).

The results suggest that with respect to planning, responding is facilitated only when the perceptual representation of the stimuli is reinstated. Two lines of support emerge: ‘Old’ sequences in the ‘same’ transfer group and ‘old digit’ sequences within the ‘switch’ group were encoded faster than ‘new’ and, ‘old motor’ (i.e. change in digits) and ‘new’ within the switch group are no different. Where the perceptual representation changed, planning suffered.
4.2.3.5.3 RETENTION OF MOTOR COMPONENTS

Analysis of execution time data was performed in order to assess the influence of motor processing at retention. Table 4.2.3 shows the execution times of each transfer group for each sequence type.

Table 4.2.3 Mean median execution times (in ms and SDs) as a function of transfer group and sequence type.

<table>
<thead>
<tr>
<th></th>
<th>Same</th>
<th></th>
<th>Switch</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New</td>
<td>Old</td>
<td>New</td>
<td>Old</td>
</tr>
<tr>
<td>Key 2</td>
<td>275 (53)</td>
<td>266 (58)</td>
<td>326 (89)</td>
<td>300 (64)</td>
</tr>
<tr>
<td>Key 3</td>
<td>478 (365)</td>
<td>450 (333)</td>
<td>410 (198)</td>
<td>417 (175)</td>
</tr>
<tr>
<td>Key 4</td>
<td>262 (66)</td>
<td>255 (56)</td>
<td>260 (61)</td>
<td>270 (72)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Old motor</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>321 (94)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>408 (192)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>289 (81)</td>
<td></td>
</tr>
</tbody>
</table>

A 2 x 2 (sequence type x transfer group) repeated measures ANOVA with the additional three level factor of keystroke was used to analyse the data. A main effect of sequence type was found (F(1,34) = 5.65, p < 0.05), old sequences were executed faster than new, but the difference between the transfer groups was not reliable (F(1,34) = 0.66, p > 0.05). A main effect of keystroke was also found, (F(2,68) = 23.46, p < 0.001) reflecting the increased time taken to execute the 3rd keystroke compared to the 2nd and 4th. There was no interaction between transfer group and sequence (F(1,34) = 1.37, p > 0.05). There was no difference in the speed with which sequences were typed within the switch group.

Thus, ‘old’ sequences were executed faster than ‘new’ suggesting a benefit for having previously used the motor pattern required to type the sequence. The fact that there was no difference in execution times between the transfer groups suggests that the planning involved in making the response is minimal at this stage. That differences between sequences were found for encoding time supports this assertion; most of the perceptual processing is accounted for by encoding time.
4.2.3.5.4 RECOGNITION OF PREVIOUSLY SEEN STIMULI

Recognition judgements about the 'old' / 'new' status of the sequences were made. Hit and false alarm rates were calculated. These rates were subsequently used to obtain an $A'$ score which provided a measure of accuracy regarding recognition judgements of the sequences. This $A'$ score was further analysed to find out whether recognition was significantly greater than the chance detection level of 0.5. Analysis was performed for both the same and the switch transfer groups.

For the same transfer group, the proportion of false alarms was 0.37, the proportion of hits 0.58. $A'$ was subsequently calculated and equalled 0.70, a score which was significantly greater than chance ($t(15) = 6.10$, $p < 0.001$), implying that the subjects recognise having previously typed old sequences.

For the switch transfer group, the proportion of hits and false alarms was 0.56 and 0.37, respectively. $A' = 0.67$, which was found to be reliably greater than chance performance, ($t(14) = 5.95$, $p < 0.001$).

Although the results indicate that accuracy of recognition decisions is greater when the conditions between acquisition and retention match, there was no difference between the groups and the level of recognition accuracy found; the present findings suggest both groups of subjects remember having previously typed certain sequences.

4.2.3.6 SUMMARY OF RESULTS

4.2.3.6.1 ACQUISITION

The findings at acquisition demonstrate clearly that learning occurs with practice. The rate of learning was negatively accelerated, there being more learning within the first acquisition session than the second. The principal component that appeared to be facilitated by practice was 'perception and planning' for which a speed up in RTs
across repetitions was found. In contrast, a speed up in the time taken to execute the sequences was not obtained.

Results, principally from the power function fits support to the claim that specific learning strategies are being developed; \( r^2 \) values indicated that the learning was best accounted for when functions were fit to RTs for individual sequences only, rather than when intervening practice was included in the analysis. Furthermore, the slope and the intercepts obtained did not rank in ascending sequence order, as would be expected if general improvements in the ability to type were occurring.

### 4.2.3.6.2 RETENTION

At retention, it was demonstrated that the learning that had occurred during the acquisition phase was absent. RTs for the sequences presented at acquisition were faster than the same sequences presented at retention. Furthermore, 'old' and 'new' sequences presented at retention did not differ in overall entry time. However, analysis of the component processes found a difference in 'encoding' and 'execution' between 'old' and 'new' sequences at retention, supporting the claim that certain specific, i.e properties particular to a certain sequence, rather than global features i.e. those properties that would facilitate performance upon similar tasks, of the stimuli had been learned and successfully retained. Retention of the perceptual features of the sequences appeared to be stronger than the motor aspects, however. The fact that there was no difference due to the keypad manipulation supports this assertion.

### 4.2.4 DISCUSSION

The present experiment was designed to investigate the ways in which practice facilitates skill acquisition and retention. The experiment examined whether the learning that occurred during practice was specific to the stimuli presented or whether more global responding emerged. Performance during the acquisition phase and the retention phase of the experiment was assessed. The locus of change in performance
was examined both during and following practice. It was predicted that if global response strategies were formed, a uniform speed up would be found across the acquisition session and furthermore, should enhance performance on a modified typing task at test; the assumption was made that it was the task *per se* rather than the specific stimuli that was being learned.

The 'basic' characteristics of responding were initially established. The obvious finding that emerged was that RTs were significantly faster following practice. More importantly, however was the fact that learning was negatively accelerated. The amount of improvement was greater during the first half of the acquisition session than the second half. Clearly this is congruent with previous research and suggests that with the digit entry task, the amount *available* to learn is greater during the initial stages of practice, but diminishes with time (Welford, 1987; Groeger, 1997).

The locus of this improvement was examined more closely by assessing the component 'processes' involved in typing the sequence. The effort required to 'perceive and plan' the sequence, decreased significantly throughout the acquisition session whereas there was no change in the speed with which the sequences were executed. These results are in accordance with the findings of Singley and Anderson (1989) who demonstrated that the time spent planning a response decreased by almost 50% during their six-day practice session but no comparative change in execution. Such results suggest that one of the benefits of practice is to increase ones' ability to co-ordinate a perceptual and spatial representation into a motor output, i.e. to immediately know where and now to respond upon perception of the stimulus; with respect to typing, the ultimate refinement of the 'search and peck' strategy (Rumelhart and Norman, 1978). Indeed, the results support the occurrence of simultaneous planning and execution of responses (Salthouse, 1986b).

Although differential learning of particular sequence components was established the question of whether general typing-based, or specific sequence-based representations
were formed is perhaps of greater theoretical interest. On the basis of a lack of change in execution of the sequences Singley and Anderson (1989) concluded that general properties or 'productions' underlying performance were being learned that would facilitate performance on a host of typing related tasks. This interpretation appears to be somewhat over-inclusive. The fact that there was no change in execution cannot be divorced from the change in the planning and perceptual component of the task. In the present experiment the planning time for each sequence differed, but did so unsystematically, i.e. not in ascending sequence order as would be predicted if general improvements in performance were occurring. This implies that rather than being more readily able to relate multiple sequences to a general motor plan as suggested by Anderson (1995), the experience of typing is facilitating access to previously typed patterns a prediction made by an instance theory of learning (Logan, 1992).

The results of fitting power functions to the data supports such an interpretation. Two methods of analysis were used, both based on the typing of specific sequences (i.e. one to twenty). The first method took into account the intervening practice obtained through typing all of the sequences, the alternative focussed only on the typing of each repetition of a particular sequence. Learning was better accounted for when curves were fitted to data points for individual repetitions only. Secondly, the intercept and the slope values used to give an indication of the degree of difficulty incurred when typing each sequence did not rank in ascending sequence order. Clearly if a general response strategy was being used in which typing performance per se was being strengthened with every experience, then each consecutive sequence would be expected to benefit from some improvement (Anderson, 1995). The fact that this is not happening suggests that particular instances of the sequences, or maybe some 'clusters' of sequences or sequence components are being responded to at acquisition, resulting in what can be described as 'part-global' rather than 'total-global' learning (and equally, 'part-specific' rather than 'total-specific').

One of the main features of the study that allowed further investigation to the nature of the representation however, was the incorporation of a retention test. More
specifically through the inclusion of manipulations in ‘sequence type’ and ‘transfer group’ a more in depth examination of the representation formed during the learning phase was enabled. To recap, subjects typed twenty ‘old’ sequences, (i.e. those presented at acquisition) and twenty ‘new’ sequences using either the ‘same’ or the ‘switched’ keypad formation at test. Different results would be predicted by the two learning theories based upon this mismatch between study and test. If a global response strategy was learned than responding the manipulations would not be expected to have any effect. However, if specific response strategies were being learned then an advantage would be expected for old sequences and where the keypad formation remained the same.

The results do not offer a clear interpretation of the learning that occurred. Following a one week retention interval it appeared that that representations of specific stimuli had been forgotten; the durability of learning was minimal. Responding to the stimuli at test appeared to be equivalent to performing the task for the first time. Three lines of evidence supported this: There was no difference between RTs for the first repetition of the sequences at acquisition and when those same sequences were presented at test and, there was no difference between old and new sequences at test. Performance at the end of the acquisition session was faster than at the retention test, however.

That there was no advantage for having previously practiced the sequences, i.e. no difference between ‘old’ and ‘new’ sequences lends support to the idea of generalisability of task performance. However, closer analysis of the component processes involved in typing the sequence found that there was an advantage at the perception and planning stage of performance when the perceptual representation used at study was maintained at test (i.e. when the same sequence was shown). Even when the execution component of the task was manipulated, such that a different motor response was required, the time taken to perceive the stimulus and plan the response was faster when the sequence had been previously. The fact that only old sequences were executed faster than new suggests a benefit for previous practice and indeed
offers tentative support for an instance view of learning (Logan, 1992).

The fact that the manipulation of the execution requirement of the task did not effect performance is perhaps unsurprising given the findings at acquisition, i.e. that there was no change with practice. The effects of disrupting the motor component at test appears to manifest at the planning stage; the change in motor requirement results in increased time spent planning the response rather than involving a reassessment once the execution of the sequence is underway. Again, such an argument would appear to support the idea that certain sequences are being responded to differently to others.

One aspect of the present experiment demonstrating that learning was definitely occurring was the finding that discrimination between old and new sequences was found to be above the level of chance for all subjects. This result in combination with the findings from the indirect tests of retention, suggests that in the present study subjects may rely upon perceptual fluency mechanisms to influence their judgment. Rather the sequences appear to have been learned almost on an episodic basis. Such an argument detracts from the idea that performance is based purely on the formation of general response strategies (Anderson, 1995).

Thus it would appear that specific features of the stimuli presented are learned during acquisition. However, at retention, limited effects of practice are found as measured by indirect tests. Somewhat surprisingly, in terms of direct tests, however, recognition of the stimuli appears to occur. Such a dissociation may be a reflection of the practice given. Subject's received extended practice over two sessions. In this respect one can argue that it approximated a 'distributed' regime and therefore the finding that enhanced 'durability' of the learning was found (i.e. the recognition of the material) is not as surprising as first thought. Such an assertion has direct theoretical relevance to the 'type' of practice argument. One way in which the effects can be examined more closely therefore involves testing performance using a 'massed' practice schedule. This will be the focus of the following experiment: What are the learning characteristics following a massed practice schedule.


4.3 STUDY 2 THE EFFECTS OF MASSED PRACTICE UPON THE ACQUISITION AND RETENTION OF A TYPING TASK.

4.3.1 INTRODUCTION

In the previous study, evidence of learning and retention was found upon a simple digit-sequence entry task. Subjects participated in two temporally disparate phases of practice, each phase being separated by a one-week interval. During each phase, identical stimulus lists were presented to the subjects; within the lists multiple repetitions of sequences were presented. A retention interval of one week separated the final practice session from test; learning of the task was evident through a RT speed-up across the practice phases and retention was demonstrated using direct tests of memory. The regime used in the previous experiment approximated a distributed practice schedule – the practice phases were of shorter duration than the temporal delay between phases. One of the major factors that effects the temporal duration of the acquisition process is the spacing of the practice schedule employed. Along with distributed, ‘massed’ practice has also been found to affect learning and retention of a task; however, it does so in different ways (Baddeley, 1982, 1997).

While massed practice is characterised by repetitive, uninterrupted performance on a task, under conditions of distributed practice, the learner participates in episodes which are temporally disparate, being separated by different intervening tasks or by time *per se* (Groeger, 1997). When assessed purely in terms of elapsed time, massed practice is hypothesised to lead to rapid acquisition of a task while distributed practice, due to the fact that it involves extended periods of shorter learning episodes, is characterised by slower skill acquisition (Adams, 1987). However, when assessed in terms of performance accuracy, a more complex picture emerges; concentrated sessions of practice do not necessarily equate to superior learning (Baddeley, 1997).

A seminal study investigating the effect of massing and distributing practice used a transfer design to evaluate learning (Adams and Reynolds, 1954). Performance on a
pursuit rotor task was assessed. Practice in the distributed condition comprised thirty seconds performance and thirty seconds rest while massed practice was characterised by 30 seconds performance and five seconds rest. Five groups of subjects were tested: The first group (D) participated in forty trials under distributed conditions, four remaining groups were tested under massed practice conditions for either five (M5), ten (M10), fifteen (M15) or twenty (M20) trials. The massed groups then received a ten minute rest period before performing the remainder of the trials (i.e. up to forty) under distributed conditions. Thus the amount of learning in the earlier trials was assessed by comparing performance on the later trials.

Time-on-target was used as an index of performance; marked decrements were found when practice was massed. For the fully distributed practice group, 90ms was spent on target at the end of the first five trials. This was a significantly longer amount of time-on-target than the massed groups. Prior to transfer, the time spent on target was 50ms, 59ms, 60ms and 70ms for groups M5, M10, M15 and M20, respectively. When the massed groups transferred to distributed conditions, however, the difference between the groups diminished after three trials on average. Adams and Reynolds concluded that massing practice is a variable that affects performance only while massing is present. The effects are diminished when learning is assessed by performance on a transfer task in which the participant responds to mixed / distributed trials.

Similar findings were reported by Baddeley and Longman (1978). The study was concerned with identifying the most effective practice regime for subjects required to learn to touch type within a relatively short period of time. Four practice conditions were compared. Group one received one one-hour session of practice per day, Group two received two one-hour sessions per day, Group three received one two-hour session and Group 4 received two, two-hour sessions per day.

The main findings indicated that after completing thirty hours of practice, Group one, or the 'distributed' group, executed on average fifty-eight correct keystrokes per
minute. In contrast, Group four, the 'massed' group, took forty-six hours' of practice to execute fifty-three correct keystrokes per minute. In addition, Group 4 performed more slowly and less accurately than the second and third groups. Thus the findings suggest that the distributed group learned the layout of the keyboard and performed the task more accurately following the least number of hours' practice, opposing the idea that massing practice leads to rapid acquisition. Retention of the task was also tested. After a one-month interval, the group who received distributed practice performed more accurately than the massed, a superiority that was maintained even after nine months practice.

In addition to extrinsic determinants of practice style, an interesting set of findings reported by Mumford et al (1994) illustrates the influence of intrinsic factors. Subjects were required to learn how to control an automated system, adopting either a massed or a distributed practice schedule. An influential factor in choice of practice style was perceived level of ability prior to the onset of learning. If an individual did not have any appropriate response strategies and was forced to rely upon general cognitive strategies, distributed practice was opted for. It was hypothesised that this allowed individuals to capitalise upon the length of time spent performing the task, forming elaborate representations of the procedures involved. In contrast, individuals who felt they had some prerequisite abilities that enabled them to perform the task chose massed practice. Unsurprisingly a noticeable difference in the speed of performance was found – the latter acquiring the task much more rapidly.

Taken together, the results of the studies reported above conflict over the efficacy of adopting a distributed practice schedule over a massed. While massing practice seems to have a detrimental effect on performance during the initial stages of learning, the effect is reported to be either transitory and diminishes when performance is retested (Adams and Reynolds, 1954; Shea and Morgan, 1979) or is persistent and still results in inferior responding at retention (Baddeley and Longman, 1978). However, such findings also appear to be dependent upon intrinsic factors such as the belief in one’s ability to acquire the task. This has interesting implications for the nature of learning.
that occurs.

The effects of massing practice will be more closely examined in the present experiment. The paradigm as in the previous study will again be used, but a massed practice regime will be incorporated into the design. All of the stimuli will be practiced in one week before the test. The same assessment of learning will be made as for Study 1: The rate of learning will be examined; the change in how different components of the stimuli are responded to and the specificity of learning based upon the two learning theories (i.e. global versus instance-based task representation) will be examined at acquisition. The durability of learning will be tested through the use of the indirect and direct measures of retention; old sequences should be entered faster than new and furthermore should be recognised as old. With respect to the specificity of learning the manipulation in keypad condition will give an indication of whether global or specific learning underlies performance.

4.3.2 METHOD

4.3.2.1 PARTICIPANTS

Thirty-eight right-handed volunteers, 14 male and 24 female, with a mean age of 23.2 years \((SD = 5.2\text{years})\), participated in this experiment. Each subject was a student at the University of Surrey and was randomly assigned to one of four conditions upon arrival at the acquisition session.

4.3.2.2 MATERIALS AND APPARATUS

Three stimulus lists were used in this experiment, one during the acquisition session and two during the retention test. Lists consisted of either 120 (acquisition) or 40 (retention), four-digit sequences, the list at retention being the same as that used in Study 1.

Acquisition The first list presented during acquisition comprised five practice sequences and twenty test sequences, the latter repeated six times.
Presentation of the test sequences was not random. The list was divided into four 'blocks'. Each block contained thirty sequences; five unique sequences repeated six times, sequences would be presented as follows: \(a, b, c, d, e, a, b, c, d, e, a, b, c, d, e, a, b, c, d, e, a, b, c, d, e\). The next block of sequences was then presented. The same order of presentation was used for all four blocks.

Retention Two lists were used at retention, one for subjects in the 'same' condition and one for those in the 'switch' condition. Both lists contained the twenty sequences presented during acquisition (old sequences) as well as twenty new sequences. (See Appendix 1 for the sequence lists).

Stimuli were presented in exactly the same way as Study 1 (see section 4.2.2.2).

4.3.2.3 DESIGN AND PROCEDURE
The design and procedure used in the present experiment was the same as Study 1 (see Sections 4.2.2.3 and 4.2.2.4) apart from there being only one acquisition session. During this session, 120 sequences were typed. A one-week interval separated acquisition and the retention test.

4.3.3 RESULTS
Results will be reported in two subsections, the first based upon analysis of data from the acquisition session, the second based upon retention. With respect to the acquisition phase, the following questions were asked: Is there evidence of learning during the acquisition phase? Do changes in the rate of learning occur, and are some aspects of the sequences, i.e. the perceptual or motor components learned differently?

4.3.3.1 ACQUISITION PERFORMANCE

4.3.3.1.1 EVIDENCE OF LEARNING
In order to obtain an index of whether learning occurred across the entire acquisition session, an initial comparison was made between the mean 'total' time (i.e. that taken to enter the entire sequence) of the first and the final (i.e. sixth) repetition of each of the sequences, as shown on Figure 4.3.1.
Using a paired t-test on the RTs across sequences, it was found that the time taken to enter the first repetition of the sequences was reliably slower than that taken to enter the sixth repetition ($t(19) = 9.378, p < 0.001$), mean RTs being 2950ms ($SD = 247ms$) and (2602ms, $SD = 165ms$), respectively. The range between RTs within the first and sixth sequence set was 795ms and 503ms, respectively, indicating increased variability in responding to the first repetition (fastest and slowest RTs here being 2589ms and 3368ms, respectively). The full range of mean median RTs and $SDs$ for each sequence can be seen in Appendix 8).
The proportional relationship between the time taken to enter specific repetitions was calculated in order to examine the percentage improvement occurring between the repetitions. Figure 4.3.2 shows the time taken to enter the sixth repetition as a proportion of the first; the third as a proportion of the first and the sixth as a proportion of the fourth.

![Figure 4.3.2](image)

**Figure 4.3.2** Time taken to enter the sixth repetition of each sequence as a proportion of the first (tot61); the third as a proportion of the first (tot31) and the sixth as a proportion of the fourth (tot64).

The mean time taken to enter the sixth repetition as a proportion of the first was .88 (SD = .042) overall, a 12% decrease in RT occurring with in practice. Learning during the first and the second half of the practice session was examined by calculating the time taken to enter the third repetition as a proportion of the first (3\(\times\)1) and the sixth as a proportion of the fourth (6\(\times\)4), respectively. As expected less improvement was found and variability reduced during the second half, proportions being .92 (SD = .39) and .96 (SD = .27) for 3\(\times\)1 and 6\(\times\)4, respectively. These proportional values were reliably different (t(19) = 3.567, p < 0.01), suggesting the rate of learning and the change across sequences was negatively accelerated across the session.

RTs of specific sequence pairs were subsequently examined to identify whether any shared information was being used in responses to the first and the sixth repetition.
Pearson’s product moment correlations were calculated between the first and sixth repetition of each of the sequences. Table 4.3.1 shows that responses to all of the sequences apart from four and ten were reliably positively correlated (p < 0.05).

Table 4.3.1 Mean RTs (in ms), t-values and correlation coefficients for each sequence

<table>
<thead>
<tr>
<th>Sequence</th>
<th>1st rep. (in ms)</th>
<th>6th rep (in ms)</th>
<th>t-value</th>
<th>Pearson’s r</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (4726)</td>
<td>3155</td>
<td>2673</td>
<td>4.374**</td>
<td>.655*</td>
</tr>
<tr>
<td>2 (8267)</td>
<td>3276</td>
<td>2790</td>
<td>3.324*</td>
<td>.636*</td>
</tr>
<tr>
<td>3 (6284)</td>
<td>3059</td>
<td>2866</td>
<td>2.330*</td>
<td>.745**</td>
</tr>
<tr>
<td>4 (8167)</td>
<td>3069</td>
<td>2615</td>
<td>1.960</td>
<td>.418</td>
</tr>
<tr>
<td>5 (6726)</td>
<td>3288</td>
<td>2703</td>
<td>3.605*</td>
<td>.636*</td>
</tr>
<tr>
<td>6 (4186)</td>
<td>2589</td>
<td>2370</td>
<td>1.377</td>
<td>.507*</td>
</tr>
<tr>
<td>7 (6826)</td>
<td>2734</td>
<td>2661</td>
<td>1.092</td>
<td>.787**</td>
</tr>
<tr>
<td>8 (8417)</td>
<td>2993</td>
<td>2458</td>
<td>2.529*</td>
<td>.822**</td>
</tr>
<tr>
<td>9 (9438)</td>
<td>3368</td>
<td>2804</td>
<td>3.321*</td>
<td>.771**</td>
</tr>
<tr>
<td>10 (5816)</td>
<td>2997</td>
<td>2426</td>
<td>2.349*</td>
<td>.450</td>
</tr>
<tr>
<td>11 (3753)</td>
<td>3043</td>
<td>2796</td>
<td>3.142*</td>
<td>.909**</td>
</tr>
<tr>
<td>12 (8269)</td>
<td>3013</td>
<td>2828</td>
<td>2.333*</td>
<td>.750**</td>
</tr>
<tr>
<td>13 (7168)</td>
<td>2633</td>
<td>2426</td>
<td>1.386</td>
<td>.664*</td>
</tr>
<tr>
<td>14 (7627)</td>
<td>3185</td>
<td>2651</td>
<td>1.399</td>
<td>.748**</td>
</tr>
<tr>
<td>15 (1761)</td>
<td>2589</td>
<td>2466</td>
<td>0.058</td>
<td>.828**</td>
</tr>
<tr>
<td>16 (5824)</td>
<td>2573</td>
<td>2325</td>
<td>1.966</td>
<td>.838**</td>
</tr>
<tr>
<td>17 (1863)</td>
<td>2812</td>
<td>2539</td>
<td>2.155*</td>
<td>.579*</td>
</tr>
<tr>
<td>18 (9157)</td>
<td>2719</td>
<td>2464</td>
<td>0.850</td>
<td>.748**</td>
</tr>
<tr>
<td>19 (8637)</td>
<td>2971</td>
<td>2651</td>
<td>0.825</td>
<td>.729**</td>
</tr>
<tr>
<td>20 (4375)</td>
<td>2938</td>
<td>2531</td>
<td>2.095*</td>
<td>.695**</td>
</tr>
</tbody>
</table>

(*significant where p < 0.05; ** where p < 0.001).

The amount of shared variance between these repetitions ranging from 25% to 82% (sequences 6 (4186) and 11 (3753), respectively. For 12 of the sequence pairs, over
50% of the variance was shared, which suggests that knowledge of the first repetition is being used to enter the sixth repetition. Furthermore, it is interesting to note that compared to the previous study, using massed practice appears to result in higher correlations or, that more of the same specific information is used to respond.

Table 4.3.1 shows that for eleven of the sequence pairs, the sixth repetition was entered reliably faster than the first. Of these, repetitions for sequence 10 (5816) were not reliably correlated. For the remainder, this suggests that sequence information was being formed, shared and used to facilitate performance. For those sequences where neither the correlation nor the t-test is significant, it may be that these sequences were not learned as quickly as the others, or individual differences in responding appears likely.

In summary, the results support the fact that learning occurs across the acquisition phase, RTs improving with practice. More specifically, the results suggest that rather than global improvement on the task, i.e. typing performance improving as a whole, performance is changing and becoming more efficient for responses to specific sequences.

4.3.3.2 CHANGES IN THE RATE OF LEARNING

Changes in the rate of learning were assessed by fitting power functions to the data for each subject, across sequences\(^6\). Two methods of fitting power functions to the data were initially used, the first based upon the 'presentation' of the sequences the second upon the 'position' of the sequences within the list\(^7\). The mean r² values were 0.3019 and 0.299 for 'presentation' and 'position' fits respectively. There was no difference between the fit of the curve based upon whether intervening practice was taken into account or whether particular sequences were typed per se (t(19) = 0.786, p > 0.05).

---

\(^6\) Linear functions were also fit to the data, but the r² value found (0.293) did not provide a better fit than the power function, which was therefore used.

\(^7\) The methods used were based on the 'presentation' of the specific sequence, i.e. 1st, 2nd, 3rd, 4th, 5th, 6th appearance of a particular sequence or the ascending position of the sequence within the list, as for Study 1.
This finding suggests that functions taking into account the typing of specific sequences provide a better account of the data than those which take into account the practice received from interleaving sequences. Appendix 9 shows the results of the fit based upon the ‘presentation’ of the sequences.

The slope and the intercept values of the fit using the ‘presentation’ method were subsequently examined. The slope of the line gives an indication of the rate of improvement over time; mean slope values for each sequence are shown on Figure 4.3.3.

![Figure 4.3.3 Mean slope values for each sequence collapsed across subjects.](image)

The mean slope was -0.0685, ranging from -0.1117 (sequence 9 - 9438) to -0.0149 (sequence 18 - 9157). The value of the slope was tested against zero (i.e. where no learning is occurring) using a one-sample t-test in order to ensure that learning was occurring. The slope was reliably different from zero (t(19) = 8.787, p < 0.001) demonstrating that overall performance was able to improve with practice.

Figure 4.3.3 that the curve follows an upward trend suggesting an improvement in responding to the sequences. However, Figure 4.3.3 also suggests that the rate of improvement differs for different sequences. When sequences were ranked based

---

8 Due to the lack of differences between the two methods used and the implications for the formation of specific response strategies rather than a general improvement in the ability to perform the task, the results of the curve fitting will be presented for the ‘presentation’ method of analysis only.
upon the slope values, the order that emerged did not suggest a general improvement was occurring, i.e. the slopes were not ranked in ascending sequence order. (Appendix 10 shows the ranked order of the sequences based upon both slope and intercept values.) The intercept values obtained also suggest specific response strategies were being developed for particular sequences.

The initial level of typing difficulty was found by comparing the intercept for each sequence. The largest intercept was 3.062 found for sequence 15 (1761), the lowest was 2.651 found for sequence 17 (1863), the mean was 3.062. The fact that intercepts for these specific sequences were extremes suggests that ease of typing was not necessarily due to lack of previous experience in performing the task. The intercept for the first sequence (4726) was 3.310, although higher than many others it was, nevertheless, less than sequence 15; the twentieth sequence (4375) had an intercept of 3.085, again higher than the average value.

In summary, the results from the curve estimation analysis suggest that specific properties of the sequence were being learned and were subsequently influencing the ease with which it was typed, rather than there being a global improvement in learning. The fact that the $r^2$ values reveal the fit of the function does not provide a better account of the data when intervening practice trials are included in the analysis, the slope and the intercept are different for different sequences, all support this assertion.

4.3.3.3 LEARNING OF SEQUENCE COMPONENTS

In order to answer this question, RT measures were decomposed into ‘encoding’, or the time taken to make the first keypress and ‘execution’ time, (i.e. that taken to enter the final three digits of the sequence). These RTs are assumed to reflect the amount of ‘perceptual processing/planning’ and ‘motor response execution’ involved in performing the task, respectively. Improvements occurring as a consequence of global and specific learning were assumed to be exhibited differently within each component.
4.3.3.1 Sequence Perception and Planning

As for the total time a preliminary measure of the speed up was obtained by comparing the time taken to enter the first and the final repetition of the sequences for both RT measures as shown on Figure 4.3.4. Using a paired t-test, it was found that the time taken to encode the sixth repetition of the sequences (1434ms, $SD = 150ms$) was reliably faster than the time taken to encode the first (1601ms, $SD = 187ms$; $t(19) = 4.288, p < 0.001$). The range between the fastest and slowest entered sequences within the first and the sixth repetition was 431ms and 238ms, respectively, suggesting that the variability in responding decreases, but also that amount of change in encoding reduces with practice.

Figure 4.3.4 Encoding time (in ms) of the first and sixth repetition for each sequence.
Clarification of the speed-up between repetitions was obtained by comparing the encoding times of the twenty sequence pairs. The main findings will be reported; median RTs for each of the sequences, the corresponding t-test values in addition to Pearson’s product moment correlation coefficients can be seen in Appendix 11. Of the twenty pairs, 18 were entered faster at sixth repetition compared to the first.

Using Pearson’s product moment, positive correlations were found for all sequence pairs ($r$ was significant where $p < 0.001$) indicating that the time taken to encode each sequence at the sixth repetition was related to encoding time for the first repetition. Furthermore, the coefficient’s ranged from .372 (sequence 17) to .766 (sequence 8); the mean $r = 5.80$ ($SD = .10$). Thus the maximum amount of variance accounted for was 58% which suggests that information from the first repetition is being used to facilitate performance at the sixth repetition.

Indeed, this is supported by the results of the paired t-test. Results showed that the difference in encoding times for twelve of the sequence pairs was reliable ($p < 0.01$), suggesting that for certain sequences, encoding does reliably improve over time. For five sequences, (16 to 20), it is interesting to note that the t-test did not find a reliable difference between encoding times. This suggests an interaction between sequence and presentation i.e. perception/planning of the sequences improves more during the first fifteen sequences of the first repetition but then begins to stabilise.

4.3.3.4 MOTOR RESPONDING

The time taken to enter the final three digits of the sequence was used as an index of execution. Execution of the first and sixth repetition of the sequences was examined. Figure 4.3.5 shows the difference in execution times for all three keystrokes.
CHAPTER FOUR

Keystroke 2

(20) 4-3-7-5
(19) 8-6-3-7
(18) 9-1-5-7
(17) 1-8-6-3
(16) 5-8-2-4
(15) 1-7-6-1
(14) 7-6-2-7
(13) 7-1-6-8
(12) 8-2-6-9
(11) 3-7-5-3
(10) 5-8-1-6
(9) 9-4-3-8
(8) 8-4-1-7
(7) 6-8-2-6
(6) 4-1-8-6
(5) 6-7-2-6
(4) 8-1-6-7
(3) 6-2-8-4
(2) 8-2-6-7
(1) 4-7-2-6

response time (in ms)
CHAPTER FOUR

Keystroke 3

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Response time (in ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(20) 4-3-7-5</td>
<td></td>
</tr>
<tr>
<td>(19) 8-6-3-7</td>
<td></td>
</tr>
<tr>
<td>(18) 9-1-5-7</td>
<td></td>
</tr>
<tr>
<td>(17) 1-8-6-3</td>
<td></td>
</tr>
<tr>
<td>(16) 5-8-2-4</td>
<td></td>
</tr>
<tr>
<td>(15) 1-7-6-1</td>
<td></td>
</tr>
<tr>
<td>(14) 7-6-2-7</td>
<td></td>
</tr>
<tr>
<td>(13) 7-1-6-8</td>
<td></td>
</tr>
<tr>
<td>(12) 8-2-6-9</td>
<td></td>
</tr>
<tr>
<td>(11) 3-7-5-3</td>
<td></td>
</tr>
<tr>
<td>(10) 8-1-3-6</td>
<td></td>
</tr>
<tr>
<td>(9) 9-4-3-8</td>
<td></td>
</tr>
<tr>
<td>(8) 8-4-1-7</td>
<td></td>
</tr>
<tr>
<td>(7) 6-8-2-6</td>
<td></td>
</tr>
<tr>
<td>(6) 4-1-8-6</td>
<td></td>
</tr>
<tr>
<td>(5) 6-7-2-6</td>
<td></td>
</tr>
<tr>
<td>(4) 8-1-6-7</td>
<td></td>
</tr>
<tr>
<td>(3) 6-2-8-4</td>
<td></td>
</tr>
<tr>
<td>(2) 8-2-6-7</td>
<td></td>
</tr>
<tr>
<td>(1) 4-7-2-6</td>
<td></td>
</tr>
</tbody>
</table>

The bar chart above shows the response times for Keystroke 3. The first and 6th repetitions are indicated separately. The average difference between the first and 6th repetition is shown for each sequence. The analysis indicates a significant difference between the first and 6th repetition for sequences 1, 2, and 3. Further analysis reveals that the difference is statistically significant for sequences 1 and 3. The results suggest that practice and familiarity with the keystroke sequence improve response times.
The mean RT for the first and the sixth repetition for the second keystroke was 358ms ($SD = 103ms$) and 292ms ($SD = 62ms$), respectively, a reliable difference ($t(19) = 4.527, p < 0.001$). Figure 4.3.5 suggests that the difference in RTs is due to the inflated time of sequence 9 (9438: first repetition), but this is not the case, a reliable difference between repetitions was found when the sequence was excluded from the analysis ($t(19) = 3.854, p < 0.001$). Faster responding was found for the sixth repetition (412ms $SD = 6ms$) compared to the first (499ms, $SD = 10ms$) for both the third keystroke and the fourth keystroke (280ms, $SD = 04ms$ and 308ms, $SD = 05ms$, respectively). These differences were reliable (third: ($t(19) = 3.590, p < 0.05$); fourth: ($t(19) = 2.781, p < 0.05$), indicating that the motor response required to produce the
sequence benefits from practice.

In summary the results suggest that practice facilitates both the planning and the response components of the task. The execution time data clearly shows that motor performance speeds up across the acquisition phase. Perception of the sequences and planning of responses benefits from practice, indexed by a speed up in the time taken to encode the sequences. Again the fact that certain sequences are encoded and executed faster than others suggests that the learning that occurs reflects an improvement for the typing of specific sequences more so than an improvement in task performance in general. The latter assertion was tested further with respect to performance at retention.

4.3.3.5 RETENTION

As for Study 1, the first question concerned ‘durability’ of learning, that is whether what was learned during acquisition was successfully retained. It was hypothesised that ‘same-test’ sequences would be typed faster than ‘new-test’, but would show comparable response ‘characteristics’ to those presented at acquisition if specific sequence representations were formed for sequences during acquisition. If a global response strategy was learned then no differences would be expected between ‘same-test’ and new-test’ sequences.

The second question concerned the contribution of perceptual and motor factors to performance and whether these components affected the response strategy adopted. The main way in which this was assessed was through a manipulation in the keypad formation coupled with the old and new sequence types. It was hypothesised that for subjects who experienced a manipulation in the keypad design between study and test, RTs would increase if specific response strategies are learned during acquisition; if global strategies were learned then the manipulation would be overcome.
4.3.3.5.1 DURABILITY OF LEARNING

The time taken to type the sixth repetition of the sequences at acquisition and those same sequences again at retention was compared and with respect to retention, typing times for ‘same-test’ sequences and ‘new-test’ sequences were analysed.

A paired t-test was used to compare the difference in RTs between the mean total time taken to enter the ‘sixth repetition’ (2606ms, $SD = 169ms$) during the acquisition stage and the time taken to enter the ‘same-test’ sequence set (2842ms, $SD = 305ms$). The difference in RTs across sequences was reliable ($t(19) = 3.252$, $p < 0.01$), the ‘sixth repetition’ was entered faster than the ‘same-test’ sequence set. RTs for the ‘sixth repetition’, the ‘same-test’ sequences and the ‘new-test’ sequences are shown on Figure 4.3.6.

The slope of the curve on Figure 4.3.6, suggests a post-rest decrement in performance for the ‘same-test’ sequences, the time taken to enter the first sequence being 3632ms compared to 2673ms for the sixth repetition. However, when the sequence was
omitted from analysis, the difference between the sets was still reliable ($p > 0.05$).

The mean time taken to enter 'new-test' sequences was 3008ms ($SD = 511ms$), slower than the two other sequence sets. As expected, the difference between the mean RTs for the 'new-test' and the 'sixth repetition' sequences was reliable, ($t(19) = 3.770, p < 0.001$). However, the difference between the 'same-test' and the 'new-test' sequences was not reliable ($t(19) = 1.809, p > 0.05$). This result suggests that at retention, performance does not appear to benefit from having previously seen or typed the sequence set.

Typing times between study and test were examined more closely, RTs for the first time each of the sequences was entered at acquisition ($M = 2950ms, SD = 247ms$) was compared to the time taken to enter both 'same-test' ($M = 2837ms, SD = 302ms$) and 'new-test' ($M = 3008ms, SD = 497ms$) sequences. There was no difference in typing speed between the first time a sequence was typed at acquisition and whether at retention the sequence had been typed previously ($t(19) = 0.524, p > 0.05$) or was new ($t(19) = 1.305, p > 0.05$). These findings again suggest that forgetting of specific sequence attributes occurs between the retention interval.

In summary, in comparing the sequences at acquisition and then again at test, it would appear that there is some forgetting of what has previously been typed. The finding that there is no difference between the sequences when first typed at acquisition and then again at test indicates that practice is facilitating the formation and learning of representations at acquisition, However, the fact that differences in RTs between the 'same-test' and 'new-test' sequences were not found, suggests that if specific representations of the sequences are formed at acquisition, they were not being relied upon at test.

4.3.3.5.2 RETENTION OF PERCEPTUAL AND MOTOR COMPONENTS

RTs analysed included 'encoding' time, or that taken to enter the first digit of the sequence, and execution time, or the time taken to enter the final three digits of the
sequence. These measures reflected the planning and the execution of the response, respectively. The keypad formation was manipulated for half of the subjects between study and test. The layout was transposed (i.e. from calculator to telephone and vice versa), creating a ‘switch’ transfer group of subjects who were required to enter ‘old digit’ and ‘old motor’ sequences, the sequence types were assumed to reflect perceptual processing and motor processing, respectively. For the ‘same’ transfer group old sequences were exactly the same as at acquisition).

4.3.3.5.3 RETENTION OF PERCEPTUAL COMPONENTS

Table 4.3.2 shows encoding times for each of the sequence types, for both the ‘same’ and the ‘switch’ transfer groups.

<table>
<thead>
<tr>
<th>Transfer Group</th>
<th>New</th>
<th>All Old</th>
<th>Old motor</th>
<th>Old digit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>1688 (348)</td>
<td>1753 (485)</td>
<td>1773 (500)</td>
<td>1733 (507)</td>
</tr>
<tr>
<td>Switch</td>
<td>1907 (567)</td>
<td>1899 (611)</td>
<td>1874 (573)</td>
<td>1976 (656)</td>
</tr>
</tbody>
</table>

A 2 x 2 (‘transfer group’ by ‘sequence type’) repeated measures ANOVA was performed on these data. Table 4.3.2 shows that a consistent pattern of encoding did not emerge. Within the ‘same’ transfer group ‘new’ sequences (1688ms) were encoded faster and with less variability than ‘old’ (1753ms) but the opposite pattern was found within the ‘switch’ group; ‘old’ sequences (1899ms) were encoded faster than ‘new’ (1907ms). The difference between ‘sequence type’ was not reliable (F(1,34) = 2.37, p > 0.05). Furthermore, there was no effect of ‘transfer group’ (F(1,34) = 1.39, p > 0.05) and there was no interaction between the factors (p > 0.05).

Additional analyses were performed on data from the switch transfer group only. There was no reliable difference in the time taken to encode old digit (1976ms), old motor (1874ms) and new sequences (1907ms; F = (2,34) = 1.14, p > 0.05).
These findings suggest that the planning involved at test is not facilitated by having previous experience with the exact same stimuli. The absence of facilitation may reflect the fact that forgetting of specific attributes of the stimuli occurred between acquisition and test or that global features of the stimuli are being learned.

4.3.3.5.4 RETENTION OF MOTOR COMPONENTS

Analysis of sequence execution was performed in order to assess retention of motor processes learned at acquisition. Execution time comprised the time taken to enter the 2nd, 3rd and the 4th keystroke. Table 4.3.3 shows the RT measures for each transfer group, for each sequence type.

Table 4.3.3 Mean median execution time (in ms, and SDs.) as a function of transfer group and sequence type

<table>
<thead>
<tr>
<th>RT Measure</th>
<th>Same</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Keystroke 2</td>
<td>New</td>
<td>298 (79)</td>
<td>280 (44)</td>
<td>403 (104)</td>
<td>388 (59)</td>
<td>379 (68)</td>
</tr>
<tr>
<td></td>
<td>Old</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keystroke 3</td>
<td>New</td>
<td>366 (97)</td>
<td>359 (86)</td>
<td>491 (181)</td>
<td>418 (104)</td>
<td>476 (163)</td>
</tr>
<tr>
<td></td>
<td>Old</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keystroke 4</td>
<td>New</td>
<td>266 (46)</td>
<td>260 (53)</td>
<td>412 (130)</td>
<td>413 (149)</td>
<td>372 (115)</td>
</tr>
<tr>
<td></td>
<td>Old</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A 2 x 2 ('transfer group' by 'sequence type') repeated measures ANOVA (across subjects) with an additional three-level factor of 'keystroke' was to test for differences on the execution time data. There was no effect of transfer group, but main effects of 'sequence type' (F(1,34) = 9.50, p < 0.001), old sequences were entered faster than new, and 'keystroke' (F(1,34) = 16.52, p < 0.001) were found. The main effect of keystroke reflected the increased time taken to enter the third keystroke. A significant interaction between sequence type and keystroke was found (F(2,68) = 4.10, p < 0.05), caused by the increased time taken to execute the third keystroke.

Data from the switch transfer group only, was analysed for the three sequence types.
There was no difference between the sequences (\(F(2,34) = 1.39, p > 0.05\)). An interaction between sequence type and keystroke was found, (\(F(4,68) = 4.30, p < 0.01\)), again reflecting the fact that within each of the sequence types, the latency for the 3rd keystroke was greater than the 2nd and 4th keystrokes.

In summary, with respect to encoding, or the perceptual processing of the sequences it would appear that following a retention interval, specific attributes of the sequences are not retained. This is supported by the finding that there was no disruption in encoding following the presentation of novel sequences and through manipulations of the keypad format.

Analysis of the execution time data however, reveals mixed results, in that differences do not arise as a consequence of changing transfer groups, but that there is a benefit from having previously entered stimuli per se. Individuals would appear to be retaining general aspects of how to perform the task, rather than using specific response strategies created at an earlier date.

### 4.3.3.6 RECOGNITION

In order to examine whether subjects in both transfer groups had explicit memory of old sequences, a measure of sensitivity to each sequence type, \(A'\), was calculated. The proportion of 'hits' (correctly recognised old sequences) and 'false alarms' (incorrectly recognised new sequences) was calculated for each group. These, along with the mean \(A'\) scores can be seen in Table 4.3.4.

<table>
<thead>
<tr>
<th>Transfer group</th>
<th>pHits</th>
<th>PFalse alarms</th>
<th>(A')</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>0.60</td>
<td>0.38</td>
<td>0.67</td>
</tr>
<tr>
<td>Switch</td>
<td>0.58</td>
<td>0.43</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Clearly there was no difference between the same and switch transfer groups in their
ability to discriminate between old and new sequences, the mean A’ scores being 0.67 for both. The accuracy of detection was above the chance level of 0.5). Both the same (t(16) = 5.95, p<0.001) and the switch transfer group (t(14) = 4.82, p<0.001) performed significantly better than chance, indicating reliable recognition of old sequences. The results imply that having typed a sequence previously facilitates memory for the stimuli regardless of whether the motor act changes and clearly implies that some specific attributes of the sequences are retained. That the differences do not emerge during the measurement of RTs suggests that motoric fluency does not contribute to recognition.

4.3.4 DISCUSSION
The pattern of learning following a massed practice acquisition schedule was examined. In line with expectations, an improvement in performance emerged throughout the practice session, subjects responding with greater speed following multiple presentations of the stimuli. Indeed learning was negatively accelerated, the amount of learning occurring during the early phases of the practice session being greater than the later stages. These findings again support the suggestion that of the task properties available to learn, the majority are done so during the initial stages of practice (Groeger, 2000). Those properties involved in the overall completion of the task were subsequently decomposed. Both planning the response and executing the sequences was facilitated using a massed practice regime.

The time taken to perceive the entire sequence and plan its response decreased throughout the acquisition session. As was demonstrated in the previous study this indicates an improvement in the ability to simultaneously plan and make the initial execution of the response (Singley and Anderson, 1989). Furthermore, the speed with which the motor response was made also decreased within the present experiment. Unlike previous work where the locus of change has been purely due to the planning component, with massed practice, the execution of the sequence was also enhanced within the present experiment. Decreases in the inter-keystroke interval were found may have arisen as a consequence of enhanced planning capabilities; spatial
awareness improved, resulting in easier execution of the sequence. Such findings have been reported where experienced typists have had to learn to re-map responses to a new keypad layout; decreases occur in both the time taken to plan the sequence and execute the response which suggests complete relearning of the task (Matias, MacKenzie and Buxton, 1996).

Thus, it is clear that learning is occurring. However, there appears to be a caveat to this in so far as the learning appears to be based on the representation of specific sequences. At acquisition, the final repetition of the sequences was entered faster than the first but between sequences, typing times differed. Not only did total times differ but the time taken to perceive the sequences, plan the response and subsequently execute the remainder of the sequence appeared to depend upon that specific sequence being typed. The results would appear to support Logan's (1991) idea that each sequence represents a separate instance of practice. The instance is only strengthened when an identical sequence is perceived and retyped. Typing a similar sequence does not lead to enhanced performance across the entire task; general features of the task appear not to be learned (c.f. Anderson, 1995). These findings would suggest that specific stimulus properties would be retained and would facilitate later performance if the same stimuli were presented.

As in the previous study, the purpose of the retention test in the present experiment was to examine whether representations of the stimuli were retained. However, influencing expectations was the finding that massed practice reportedly leads to deficits in responding (Adams, 1987). The results of the present experiment seem to suggest that performance does suffer following a retention interval. Response times increased during the retention interval. This must be interpreted as forgetting of the response representation. There was no post-rest decrement in performance (i.e. where the initial response spuriously increases the remaining response times, indicative of 'warming-up') and perhaps more conclusively, there was no difference in the time taken to respond to 'old' and 'new' sequences presented at test. These results suggest that forgetting of the 'response representation', i.e. the combination of the perceptual
and the motor components. This clearly raises questions of whether a specific instance of that sequence is retained.

The procedural reinstatement framework allowed a more detailed examination into whether the representation formed at acquisition contributed to performance at retention. Both the perceptual and the execution requirements of the task were manipulated (through the presentation of ‘new’ and ‘old’ sequences and the change in keypad formation, respectively). When tested indirectly, a dissociation was found between the component processes involved in responding. Altering the requirements of the task did not detrimentally affect the amount of planning involved in responding to the stimuli. There appeared to be no advantage from having previously practiced the task and the ease with which the stimulus was perceived.

It is not possible to conclude from these results that specific sequence representations were not formed at acquisition. However, such results suggest that Logan’s (1992) notion of obligatory encoding and retrieval of specific instances is not the best way in which performance at retention can be accounted for. Certainly the predictions made from procedural reinstatement are not supported. The mismatch between study and test is not detrimental to performance (c.f. Kolers and Roediger, 1984; Fendrich et al, 1995). It does appear that responding at retention is based on a global or general ability to perform the typing task (Anderson, 1995).

Accounting for the execution of the sequence appears to be more complex. While there was no deficit in performance as a consequence of changing the format of the keypad, an advantage was found for execution if the sequences had been previously practiced. This is interesting as it suggests opposing effects of learning a motor response. There is no difference in responding if the keypad format is transposed. However, if the sequences have been presented before, then they are executed faster. This suggests that reinstating the perceptual component facilitates execution and enables the performer to overcome deficits that may have been incurred through changing the motor response. This is a difficult finding to reconcile with expectations
and caution should be taken when trying to interpret it. Although not denying the possibility, it does not offer a convincing argument that specific properties of the sequences are being learned.

The findings that have emerged from the indirect tests of memory are somewhat unclear and do not support the notions of procedural reinstatement. A possible reason for this may be due to findings suggesting that massed practice leads to less effective learning (Adams, 1987). This was addressed more conclusively through examining performance on direct tests of memory. It was expected that massed practice would lead to less durable learning and as a consequence, a failure to recognise 'old' sequences. However, results revealed 'old' sequences were reliably discriminated from 'new', which puts a different perspective on the results of the indirect tests. Specific features of the stimuli appear to be retained and are not dependent on the speed or fluency with which they are perceived and executed. This raises questions about the possibility of floor effects occurring during practice, i.e. that response speed had reached an asymptote and explicit knowledge of the task was being developed. Clearly this has implications for the effects of procedural reinstatement; where reduced learning or the amount of practice available is less than ideal, reinstating the conditions between study and test may be more important.

One of the issues raised in the introduction that has not been addressed concerns whether distributed practice results in more effective learning and retention of material compared to massed practice. This will be addressed in the next section through an analysis of the data from the distributed (Study 1) and massed (Study 2) groups.
4.3.5 **COMPARISON OF THE MASSED AND DISTRIBUTED PRACTICE GROUPS**

To recap, opinions are divided regarding the issue of whether distributed practice leads to more effective durable learning than massed practice. Massed practice albeit attractive in terms of temporal duration often leads to less effective acquisition (Baddeley and Hitch, 1978); the findings at retention are even more unclear. While some research suggests that massing is a variable that only effects performance when massing is present (Mumford *et al*, 1994) others report the effects to be more pervasive (Adams, 1987).

In order to examine whether the type of practice received had an effect upon the way in which the task was learned and the way in which aspects of it were retained, the results of Studies 1 and 2 were compared. It was expected that distributed practice would lead to faster acquisition and furthermore, indexed by indirect and direct tests, better retention of the task. The analyses will be the same as those in the subsections reported above, but will include between subject variable of practice.

### 4.3.5.1 ACQUISITION

In order to examine whether there was an effect of practice upon the overall rate of learning, the RTs of both the massed and distributed practice groups were compared. It was hypothesised that RTs within the massed practice group would be faster than those within the distributed group.

The difference in time taken to enter the first and sixth repetition of the sequences was compared between groups. To recap, the mean median RTs for the first and sixth repetition was 2950ms and 2602ms, respectively for the massed group and 2786ms and 2456ms for the distributed group.

A 2 x 2 ('practice' by 'presentation') repeated measures ANOVA was performed on the subject's RTs. A main effect of 'presentation' was found ($F(1,38) = 68.068$, $p <$
0.001), supporting previous findings demonstrating that the sixth repetition was entered faster than the first. Furthermore, a main effect of 'practice' was found (F(1, 38) = 8.348, p < 0.01) indicating faster overall RTs within the distributed group. There was no interaction between 'presentation' and 'practice' (F(1,38) = 0.046, p = 0.831), however, which suggests that the RT of the distributed group were faster for both the first and the sixth sequence repetitions and that the rate of improvement between the groups did not differ across the acquisition session.

What did appear to differ between the practice groups was the amount of sequence information used from the first to the final repetition. RTs for each of the sequence pairs differed between the practice groups. Higher correlations were found within the massed group than the distributed, as Table 4.3.5 illustrates.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Massed (r)</th>
<th>Distributed(r)</th>
<th>Sequence</th>
<th>Massed(r)</th>
<th>Distributed(r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (4726)</td>
<td>.655*</td>
<td>0.386</td>
<td>11 (3753)</td>
<td>.909**</td>
<td>0.604*</td>
</tr>
<tr>
<td>2 (8267)</td>
<td>.636*</td>
<td>0.289</td>
<td>12 (8269)</td>
<td>.750**</td>
<td>0.404</td>
</tr>
<tr>
<td>3 (6284)</td>
<td>.745**</td>
<td>0.155</td>
<td>13 (7168)</td>
<td>.664*</td>
<td>0.398</td>
</tr>
<tr>
<td>4 (8167)</td>
<td>.418</td>
<td>0.552*</td>
<td>14 (7627)</td>
<td>.748**</td>
<td>0.030</td>
</tr>
<tr>
<td>5 (6726)</td>
<td>.636*</td>
<td>0.411</td>
<td>15 (1761)</td>
<td>.828**</td>
<td>0.494*</td>
</tr>
<tr>
<td>6 (4186)</td>
<td>.507*</td>
<td>0.315</td>
<td>16 (5824)</td>
<td>.838**</td>
<td>0.464*</td>
</tr>
<tr>
<td>7 (6826)</td>
<td>.787**</td>
<td>0.018</td>
<td>17 (1863)</td>
<td>.579*</td>
<td>0.248</td>
</tr>
<tr>
<td>8 (8417)</td>
<td>.822**</td>
<td>0.667*</td>
<td>18 (9157)</td>
<td>.748**</td>
<td>0.404</td>
</tr>
<tr>
<td>9 (9438)</td>
<td>.771**</td>
<td>0.484*</td>
<td>19 (8637)</td>
<td>.729**</td>
<td>0.562*</td>
</tr>
<tr>
<td>10 (5816)</td>
<td>.450</td>
<td>0.506*</td>
<td>20 (4375)</td>
<td>.695**</td>
<td>0.351</td>
</tr>
</tbody>
</table>

(*significant where p < 0.05; ** where p < 0.001).

It would appear therefore that the variance accounted for within the massed group is more than is accounted for within the distributed group, and can be explained by the knowledge that is formed about the sequence at the first repetition that is used again
4.3.5.1.1 Changes in the Rate of Learning

Results of the power functions fits were compared in order to examine differences in the rate of learning between the practice groups. The ‘fit’ of the curve was initially compared, using a paired t-test on fit for each sequence. The $r^2$ values did not differ as a function of practice ($t(19) = 1.184, p > 0.05$), which suggests that the power function did not offer a better account of the learning occurring during acquisition for one group compared to the other. Additional support for this is obtained when the values of the slope were compared (shown on Figure 4.3.7). There was no difference between the practice groups and the rate of learning that occurred ($t(19) = .507, p > 0.05$).

These results support the claim that there was no difference in the rate of learning depending upon the type of practice received during acquisition. Although a reliable difference between the sequence intercepts was found, ($t(19) = 7.640, p < 0.05$) this reflects the fact that the massed group entered the sequences more slowly than the distributed group, rather than the latter learning the sequences more effectively than the massed group.

![Figure 4.3.7](image-url) Mean slope values of the twenty sequences for the Massed and
Distributed practice groups.

The findings show that although the distributed group performed faster than the massed group there was no difference in the rate at which the subjects learned the task. Furthermore, as is evident from Figure 4.3.7, both groups respond differently to certain sequences. Although the curve of the massed group follows an overall upward trend, the distributed group did not follow this pattern. The variability in learning within the distributed practice group was greater than the massed. The main conclusion drawn here would be that the sequences are learned differently. The basis for these differences will be examined presently.

4.3.5.1.2 LEARNING OF THE PERCEPTION AND PLANNING COMPONENT

In order to examine whether the effect of practice contributed to any differences in planning performance, a 2 x 2 ('repetition' by 'practice') repeated measures ANOVA was performed on the encoding time data across groups. The results replicated those found for the total time analysis. A main effect of 'repetition' was found (F(1,38) = 51.161, p < 0.001) reflecting the fact that the sixth repetition was entered faster than the first. A main effect of 'practice' was also found (F(1, 38) = 27.508, p < 0.001), again indicating that the distributed group encoded the sequences faster than the massed group. The fact that there was no interaction between 'repetition' and 'practice' (F(1, 38) = 1.085, p > 0.05) suggests that the rate of improvement occurring across acquisition between the distributed and massed practice group did not differ.

This possibility was confirmed by examining the proportion of total time comprised by encoding time within each practice group, as illustrated on Figure 4.3.8.

For both the massed and the distributed practice groups, the pattern that emerged was virtually identical; encoding accounting for on average 52% and 51% of the total time, for each group respectively. However the curves clearly follows a downward trend, supporting the claim that the ability to perceive and plan a response improves with practice. Although the distributed practice group encoded faster, proportionally the
two groups were identical; the rate of encoding between the groups did not differ.

![Graph showing encoding time as a proportion of the total time within each practice group.](image)

**Figure 4.3.8** Encoding time as a proportion of the total time within each practice group.

### 4.3.5.1.3 Motor Response Component

The effect of practice upon execution times was examined using a $2 \times 2 \times 3$ (‘repetition’ by ‘practice’ by ‘keystroke’) repeated measures ANOVA. Unlike the previous RT measures, there was no overall main effect of repetition ($F(1, 38) = 2.802, p > 0.05$) supporting the contention that execution does not improve substantially with practice. This is further supported by the fact that there was no main effect of practice regime ($F(1, 38) = 0.604, p > 0.05$); receiving massed or distributed practice schedule does not effect motor responding. A main effect of keystroke was found ($F(1, 38) = 119.128, p < 0.001$) again reflecting the fact that the third keystroke took significantly longer to enter than the second or the fourth, suggesting additional processing, maybe not purely motor is used here.

An interaction was found between repetition and practice ($F(1, 38) = 22.016, p < 0.001$) which is shown on Figure 4.3.9. While the curve found for the massed practice group followed the expected trend, RTs decreasing with practice, execution time increased for the sixth repetition within the distributed practice group.
Changes in the rate of learning for both perceptual and motor components was more closely examined by assessing differences in the slope values obtained from the power function fits. Data from the first five and last five sequences were analysed. In order to ensure the execution of the sequences was not contaminated by planning time, the time taken for the fourth keystroke was used in the analysis.

The mean slope values for the first five and the final five sequences were compared for each of the practice groups. Table 4.3.6 shows that for both keystroke measures the slope flattened between the first and final sets of sequences, within each group⁹.

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⁹ That learning was possible was established by comparing the values of the slope to zero, the hypothetical situation where no learning is occurring. The time taken to encode the first five sequences was reliably different from (distributed: $t(33) = -2.71, p < 0.01$; massed: $t(35) = -5.454, p < 0.001$), as was the fourth keystroke (distributed: $t(33) = -4.218, p < 0.001$; massed: $t(35) = -2.276, p < 0.05$). For the last five sequences, within the massed group, none of the slope values were reliably different from zero suggesting an asymptote in responding at the end of acquisition. Within the distributed group, the rate at which the sequences were encoded was still reliably different from zero ($p < 0.05$), learning had reached an asymptote for Key 4. Thus learning slowed throughout the session.
Table 4.3.6 Mean slope values for the first and fourth keystrokes for the first and final five sequences presented for the massed and distributed practice groups.

<table>
<thead>
<tr>
<th></th>
<th>Distributed practice</th>
<th>Massed practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encoding (first five)</td>
<td>-0.0462</td>
<td>-0.05</td>
</tr>
<tr>
<td>Encoding (last five)</td>
<td>-0.0212</td>
<td>-0.016</td>
</tr>
<tr>
<td>Key 4 (first five)</td>
<td>-0.0288</td>
<td>-0.0118</td>
</tr>
<tr>
<td>Key 4 (last five)</td>
<td>-0.007</td>
<td>-0.0058</td>
</tr>
</tbody>
</table>

Paired t-tests were used to examine whether the slope values for each RT differed between the first and the final five sequences within each practice group. Within the distributed practice group the difference in the rate of encoding across subjects was reliable ($t(35) = 3.707, p < 0.01$) but for the fourth keystroke the difference was not reliable ($t(35) = -1.1412, p > 0.05$). This lends further support to the finding that while the planning component of the task improves the execution does not. For the massed group, reliable differences in the rate of encoding ($t(33) = 2.458, p < 0.05$) and the fourth keystroke was found ($t(33) = 4.638, p < 0.001$) across subjects. This suggests therefore that the planning and execution improves across the acquisition session. These results suggest that even in a well learned skill differences do exist between massed and distributed practice.

In summary an improvement in the ability to perceive the sequences and plan responses across the acquisition session was found and was greater within the distributed practice group than the massed. (Although it is important to realise that the rate at which response planning improves does not appear to be dependent upon the type of practice received). In contrast, for the motor component of the task, the time taken to execute the sequences did not differ as a consequence of practice.

4.3.5.2 RETENTION

The effectiveness with which material was retained was compared between the
practice groups. RTs from the subjects were analysed. To recap, it was hypothesised that there would be no differences in the performance of the two groups if massing was a variable that only effected performance while present. However, there would be a difference if distributed practice led to more durable learning; the distributed group would be more accurate in their recognition judgments.

A 3 x 2 (‘sequence set’ x ‘practice’) repeated measures ANOVA was used on the data. A main effect of sequence set was found (F(1, 38) = 29.952, p < 0.001) again reflecting the difference (i.e. significant decrease) in time taken to enter the ‘sixth repetition’ during acquisition and the two sets of sequences at test. There was no difference between the practice groups (F(1,38) = 3.610, p > 0.05) and there was no interaction between sequence set and practice group (F(1,38) = 0.011, p > 0.05).

Support for the above finding was obtained when the initial typing speed at acquisition was controlled for at retention. A 2 x 2 (‘sequence type’ by ‘practice group’) ANCOVA was performed on these data, the co-variate being the time taken to enter the first fifteen sequences during the acquisition phase. When initial speed was controlled for, there were no differences between the sequences (F(1,69) = 1.622, p > 0.05) or the practice groups (F(1,69) = .019, p > 0.05). There was also no interaction between sequence type and practice (F(1,69) = .005, p > 0.05).

Thus the type of practice received at acquisition did not appear to effect the time taken to enter the sequences following a retention interval. This does indeed support the claim that massing is a powerful performance variable affecting performance while the variable is present, hence not giving a clear indication of the learning that is occurring.

### 4.3.5.2.1 PERCEPTION AND PLANNING COMPONENT

The results of the massed and distributed practice groups and the time taken to encode

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10 The first fifteen sequences were the only sequences that were identical between the groups. These
and execute the sequences was compared. To recap the time taken to perceive and plan responses was faster in the distributed group than the massed group, whereas the latter executed the sequences at a faster rate (see Tables 4.2.2 and 4.2.3 for the massed group and Tables 4.1.2 and 4.1.3 for the distributed practice group).

A 2 x 2 ('sequence type' by 'practice') repeated measures ANOVA performed upon encoding time found a main effect of practice (F(1,69) = 6.279, p < 0.05), the sequences being executed faster in the distributed condition than the massed. Analysis was also performed on the data for each transfer group within each practice condition. Again main effects of practice were found for the 'same' transfer group (F(1,33) = 5.689, p < 0.05) indicating faster responding within the distributed practice group, but no effects were found for the switch transfer group (F(1,35) = 1.256, p > 0.05).

In order to ensure these differences in performance did not simply reflect the initial speed advantage of the distributed group at acquisition a 2 x 2 ('sequence type' by 'practice group') ANCOVA was performed on these data. The co-variate included in the analysis was the time taken to encode the first fifteen sequences. The main result indicated that there was no difference between the practice groups (F(1,69) = 0.007, p > 0.05). As for the total time taken to enter the sequences, the effects of massing practice appear to be found only when the material to be learned is being massed.

4.3.5.2.2 MOTOR RESPONSE COMPONENT

With respect to differences in the time taken to execute the sequences the same analysis was performed on the data. The effect of practice condition was the main result of interest. There was no difference in the time taken to execute the sequences depending upon whether they received massed or distributed practice (F(1, 70) = 0.007, p > 0.05). Furthermore, there was no difference between the practice conditions in terms of whether the motor requirements were the same (F(1, 33) =

were considered to provide the most accurate reflection of typing time.
1.553, p > 0.05) or were switched (F(1, 35) = 1.519, p > 0.05). Clearly the time taken to execute the sequences at acquisition was not affecting performance at retention.

4.3.5.3 RECOGNITION

The performance of both practice groups was compared with respect to their ability to respond to direct tests of memory. It has been proposed that distributing practice leads to more durable learning. However, the fact that massing practice appears to be a performance rather than a learning variable, suggests that there should be no difference in recognition performance between the two. To recap, $A'$ was used as an index of whether recognition of the sequences occurred at retention. Both the massed and the distributed practice groups detected previously typed sequences at a level above chance. However, there was no difference in accuracy between the groups ($t(69) = 2.647$, p > 0.05).

In summary therefore, there were no differences between the practice groups in terms of the perceptual and motor processing occurring during the testing session. The results of the present experiment suggest that generalised, more global response strategies were used at retention resulting in improvements in task performance as a whole and that specific representations of the sequences were not retained. Furthermore, the type of practice received did not influence how well the material was retained and subsequently used.

4.3.6 DISCUSSION

The main intention of this cross-study comparison was to test hypotheses that have been proposed to account for the differences between massed and distributed practice regimes. Although the findings are unclear (Baddeley, 1997), previous research has demonstrated that while massed practice leads to faster learning, distributed practice leads to more durable learning. Alternatively, distributed practice leads to fast, accurate acquisition and massing only effects performance when it is present.
Comparison of the groups at acquisition revealed that overall the distributed group responded faster than the massed group, a finding congruent with previous research (Baddeley and Hitch, 1978). Closer examination of the way in which particular components of the sequences were responded to found that the difference was due to the increased speed involved in the perception of the stimuli and the planning of responses within the distributed group. There was no difference between the groups and the time taken to execute the sequence. Receiving distributed practice appears to facilitate the ability to prepare the response. A potential reason for this may be due to the fact that transient performance variables effect massed performance to a greater extent than distributed.

It has been demonstrated that response planning and perception is the most effortful aspect of performance involved in the task. This component improves with practice regardless of the type of schedule received, however, the finding reported above suggests that planning is facilitated to a greater extent when practice is distributed. A potential reason for this concerns the way in which 'required effort' may interact with factors such as fatigue and belief in one's abilities. When the amount of effort required is great, individuals are more likely to perceive themselves as being unable to perform the task and are more likely to suffer from situational variables such as fatigue and boredom (Ackerman, 1991). Distributed practice by its very nature is less demanding upon the individual, the break in practice sessions enabling a rest from the task, consolidation of learning and knowledge of future task requirements (Mumford et al, 1994).

It is clear that there is a definite difference in the speed with which the task is performed. However, this comparison between studies extends previous research, such as that of Baddeley's by looking at the changes in the rate of learning between groups. There was no difference in the rate at which the task was learned depending upon the practice received. Although the massed group performed the task more slowly compared to the distributed group, the effectiveness with which they learned did not differ at acquisition; they simply took longer to asymptote. In examining the
rate of learning, these findings extend the work of Baddeley and Longman (1978). They too established that the massed practice group take longer to achieve the same level of performance as the distributed, but did not demonstrate that the rate of learning was equivalent between groups. Although such a finding has obvious implications for the planning of optimum acquisition phases the result also suggests that the effects of massing practice may be transient (Groeger, 2000).

Retention of the task was tested to examine this point further. Following a retention interval all subjects were required to participate in exactly the same test. There was no difference between the practice groups and the way in which they responded to the task. The amount of time spent planning to respond was less within the distributed practice group, but when initial typing speed was controlled for, the effect disappeared. There was no difference between the ability to execute the sequences and in terms of recognition of the sequences, again the practice regime undertaken did not effect the outcome. Both groups were able to distinguish the sequences reliably above chance level.

Thus, what was hinted at throughout acquisition was supported at retention. The detrimental effects of massing practice appear to be confined to the actual acquisition phase when a massed practice schedule is being employed (Adams and Reynolds, 1954; Groeger, 2000). In the present study, the durability of learning via massed practice is equivalent to that found with distributed practice.

### 4.3.7 Conclusions

Performance during the learning phase of the experiments was the main focus of attention in the present experiments. In both studies the results demonstrated that learning was negatively accelerated, with large initial gains followed by slower benefits from practice. Furthermore, the data from each subject to each sequence were best fitted to a power function. Thus the results supported established findings. With respect to which response component improved, differential effects were found within the studies. While consistent findings emerged with respect to the facilitation
of the time taken to perceive the stimuli and subsequently plan the response, i.e. a distinct improvement was found, mixed findings emerged for the execution of the motor response. When massed practice was given, execution improved. This was not the case with distributed practice. This suggests that continuous practice benefits this aspect of performance.

In terms of the underlying representation formed, it would appear that at acquisition, specific features of the stimuli relating to the encoding and the execution of the sequence are learned and are accessed each time the specific sequences is again presented. However, at retention, it would appear that some of this knowledge, notably that required to execute the sequences is forgotten. While a benefit was found for 'old' sequences when performance was tested using indirect tests, when the keypad format changed and thus the motor response, there was no disruption to performance. Thus, it would appear that global as well as specific knowledge is developed and facilitates performance. The results of the direct tests of retention would support this assertion; 'old' sequences were discriminated from 'new'.

Clearly, the type of practice received did not effect performance. There was no difference in the rate of learning between the groups and the retention of information did not differ. The results did not support the predictions from within the 'traditional' literature, i.e. slower but more durable learning with distributed practice, faster learning with massed. Rather they accord with a growing body of findings that fail to demonstrate such effects.

One effect that was not directly tested in the present studies was that of procedural reinstatement. Apart from the implicit benefit of having previously processed the sequences, manipulating the keypad formation and thus removing motor cues formed at study, did not have an effect upon performance. This finding is of greater significance given that subjects were still able to discriminate 'old' sequences from 'new' as per the direct tests. One reason for this may be due to the amount of practice received in the two studies. It is this issue which will be focussed on in the next
chapter. Namely, exploring the practice conditions under which the effects of 'procedural reinstatement' can be demonstrated.
5 THE EFFECT OF PRACTICE UPON PROCEDURAL REINSTATEMENT

5.1 SUMMARY
The experiments reported in the present chapter were designed to investigate whether manipulating the amount of practice given at study and the delay between study and test, had any effect upon the learning and retention of stimulus material. Results reported in the previous chapter demonstrated that the type of practice schedule employed, that is 'massed' or 'distributed', did not affect way in which the stimuli were learned. There was no difference in the rate of learning and at retention, both groups demonstrated explicit knowledge of the stimuli that had been learned. However, at retention there was no evidence of implicit learning; subjects responded at the same rate to both 'old' and 'new' sequences. This suggests that the learning that occurred was partly based upon the development of global response strategies which enabled subjects to transfer performance. A potential reason for this may have been due to the amount of practice given. The stimuli were 'overlearned' to the extent that while representations of specific sequences were formed, performance was still generalisable to similar stimuli. This issue was addressed in greater detail in Study 3.
5.2 STUDY 3: THE EFFECT OF REDUCED PRACTICE ON LEARNING AND RETENTION

5.2.1 INTRODUCTION
One of the main objectives of this thesis is to examine ways in which practice affects learning and how the material that is learned is represented at retention. In the previous chapter, it was demonstrated that manipulating the 'type' of practice received, that is, whether it is 'massed' or distributed', did not affect the extent to which the stimuli were learned or retained. It was hypothesised that distributed practice would be more effortful, but would result in more durable learning, while massed practice would lead to rapid acquisition of the task (Baddeley, 1997).

Retention of the stimuli was measured using both direct (recognition) and indirect (measurement of response times) tests of memory. There was no difference in performance as a function of practice. Furthermore, the results for both practice groups followed the same pattern; retention of the material learned was evident using direct tests of memory, but not when measured by indirect tests. Such findings are equivocal regarding the nature of the underlying representation formed during learning and, surprising given the relatively robust evidence for repetition effects (Marsolek and Field, 1999). Thus the results pose an interesting question; why the apparent dissociation between the memory tests - was it a consequence of the amount of practice received? In other words, did the practice received lead to the development of specific sequence knowledge in addition to facilitating general task based performance?

One way of answering these questions is to examine the effects of over-learning and its effects upon the stimulus representation formed and retained following practice. It has long been established that in certain instances of perceptual-motor skill, the knowledge that is acquired can be highly specific but in other cases is far more general (Willingham, 1998). Keyboard and sequencing type tasks are a prime
example of this apparent contradiction (Bosman, 1994). Consider the action of typing a telephone number or a cashpoint PIN number. The sequence of digits is invariably entered in a single, fluid motion leading to a fixed and rigid motor pattern, 'rigidity' being a potential consequence of overlearning (Willingham, 1998). These actions appear to contrast with those required for transcription typing for which stored motor patterns have to be much more flexible; although associations may be created based upon the regularities and probabilities of certain letters co-occurring, the knowledge learned is more abstract in nature (Rumelhart and Norman, 1978).

Such divergence on perceptual-motor tasks that involve, at a fundamental level, the same input and output responses, implies that the stimulus-to-response mapping that occurs during learning influences the way in which knowledge is stored and retained; that is, whether knowledge represents learning of specific attributes of the stimuli, or whether more global (or general – the two terms will be used interchangeably within this thesis) features of the stimuli are learned (Marsolek and Field, 1999).

What are the 'global' or 'general' features of the stimuli, therefore? In the present series of studies, 'global features' are those common elements, or underlying regularities of a task that are learned and can subsequently used to facilitate performance upon analogous tasks (Cohen, Poldrack and Drake, 1997). Learning of general regularities has been hypothesised to enhance performance upon artificial grammar tasks (Reber, 1967) as well as tasks using problem solving paradigms that rely upon learning of transferable construction rules (Anderson, 1995). It is suggested that one of the reasons for such enhanced performance is due to the proceduralisation of knowledge (Anderson, 1995). Proceduralisation, however, has been traditionally thought of as occurring as a consequence of extended practice (Singley and Anderson, 1989). Extended practice, however, directly contradicting the above has also been proposed to lead to learning of specific elements of a task (Willingham, 1998).

The nature of the representation underlying 'specific' learning is said to be based upon the acquisition of 'wholes', or those parts which contain the distinctive information
most useful for differentially representing specific stimuli. Specific sequence learning involves mapping and integrating multiple ‘wholes’, such as the motor component and the perceptual component, to form an overall cohesive sequence representation (Marsolek and Field, 1996). The idea that ‘wholes’ are learned is theoretically attractive with respect to research that has been performed into the effects of overlearning (i.e., that knowledge becomes more rigid and inflexible; Holding, 1991). The notion of learning ‘wholes’ is in accordance with an Instance Theory view of skill acquisition, whereby a skill is learned as a consequence of experiencing repetitions of specific episodes of a task, i.e., all of the attributes of a particular stimulus are associated within an episode (Logan, 1992). With respect to the typing task, this view implies that every single word will have a separate representation stored in memory and thus should ultimately be recollected separately (Logan and Etherton, 1994).

Such a suggestion is supported when research into the typing of digraphs and trigraphs is examined. Digraphs and trigraphs are the language specific features of word production and formation (Gentner, 1983). However, these features can also be considered as the ‘underlying regularities’ of word sequences (Terzuolo and Viviani, 1980). Herein lies a conflict as it seems intuitively unlikely that digraphs can exist as both general and specific features of the sequences. It is worthwhile evaluating the literature from this point of view. Frequently occurring digraphs such as ‘th’ and ‘ch’ are typed faster than low frequency digraphs such as ‘tw’ suggesting some specific association between the letters (West and Sabban, 1982). Gentner, Larochelle and Grudin (1988) found the median inter-key-interval (IKI) for high frequency digraphs was 129ms, faster than that recorded for low-frequency digraphs (134ms) attributing the effects to peripheral movement practice. High frequency words were executed more often than low frequency words, with the consequence that they receive more practice and were executed more quickly. Clearly this suggests that the specific attributes of the words are learned.

Shaffer (1978) compared typing times for the same digraphs appearing in different words and found IKIs were different. For example, using the words ‘wink’ and
‘wintry’, he found that the time to type ‘wi’ in wintry was longer than in wink, but the effect was reversed for the time taken to type the digraph ‘in’. This was further investigated by Gentner (1982), who assessed the effect of context by examining whether the IKI increased or decreased between words. It was found that not only the preceding character but also the character two spaces before the context exerted an influence upon timing i.e. reduced or increased the IKI. More importantly, however, was the fact that this was irrespective of whether the preceding character was from the same or a different word. This again suggests that specific attributes, rather than general regularities of the word are learned.

However, more recently, it has been demonstrated that both general and specific learning can co-occur in certain circumstances. The effects have been demonstrated in studies using a similar paradigm to the present one, in which the perceptual - motor mapping of sequences presented between study and test has been manipulated. Poldrack, Selco, Field and Cohen (1999) reported a study in which a subset of a sequences complying to a rule based system was repeated within a list presented during training. ‘Sequence type’ was manipulated at test; ‘old’ sequences shown at training; ‘new’ sequences adhering to the same rules as ‘old’, but that had not been previously seen and ‘novel’ sequences, which did not follow the rule were presented. Results found that ‘new’ sequences were processed faster than ‘novel’, evidence to suggest that ‘general regularity’ learning occurred as the same underlying rule structure was learned from the ‘old’ sequences and applied to the new ones. ‘Specific’ learning was demonstrated as ‘old’ sequences were processed faster then ‘new’. It has since been proposed that independent learning systems subserve different types of learning (Keele et al, 1995; Marsolek and Field, 1999).

With respect to the previous study, therefore, the proposal that dual learning systems exist may account for the reported findings – i.e. explicit but no implicit effects. Although the sequences were explicitly identified as ‘old’, i.e. specific sequence knowledge, the typing times for unpracticed sequences were equal to those that had received practice, i.e. general regularity learning. In the previous chapter it was
suggested that subjects had learned the task to the extent that they were no longer reliant upon cues provided by the perceived time taken to enter the sequences. This in turn negated any effects of reinstating the 'procedural' component of the task. In the present experiment, overlearning will be prevented. The amount of practice will be reduced and the effect upon learning and memory examined. The hypothesis is straightforward; when the amount of practice is reduced, the amount of learning that occurs will also be reduced; it is proposed that learning will be ongoing at the end of the practice phase. It is hypothesised that general regularities of the sequences will not have been learned; subjects will be learning specific aspects of the sequences. Thus at retention, the more stimulus specific cues that are present from the learning phase, the better memory for the task will be, i.e. there will be a dissociation between both indirect and direct tests of memory. Manipulations in the response requirements of the task will detrimentally affect performance.

5.2.2 METHOD

5.2.2.1 PARTICIPANTS

Forty right-handed volunteers, 14 male and 26 female with a mean age of 21.4 years ($SD = 2.4$ years) participated in this experiment. Each subject was randomly assigned to one of four conditions upon arrival at the acquisition session, depending upon the keypad formation used ('calculator' or 'telephone' layout) and whether they would 'switch' or use the 'same' keypad at retention.

5.2.2.2 MATERIALS AND APPARATUS

Stimuli were presented using a P.C. and were typed using the numerically modified keypads (see Section 3.1).

Three sequence lists were used, one at acquisition, two at retention. The list presented at acquisition contained sixty-five sequences, twenty novel sequences repeated three times, as described. At retention, two lists were used, one for the same transfer group, one for the switch. The list contained forty sequences, 20 old and 20 new. For the switch group 10 were old motor, 10 were old digit.
Sequence lists can be seen in Appendix 1.

5.2.2.3 DESIGN

A mixed design was used. Within subjects factors at acquisition included 'repetition' and 'sequence'. At retention, a 2 (transfer group) x 2 (sequence type) mixed design was used. Participants either switched keypad formation ('switch' transfer group) or remained the same ('same' transfer group), creating a between-subject factor of 'transfer group'. A within-subject factor of 'sequence type' existed; sequences were either 'old' or 'new'. Independent variables of interest in this experiment, therefore, were 'transfer group' and 'list type', while dependent variables were response time and recognition decision.

5.2.2.4 PROCEDURE

As for the previous experiments participants were individually tested at both acquisition and retention. Instructions were presented on the computer screen at the beginning of the session; five practice trials were given before the acquisition list was shown. Subjects entered 60 sequences, 20 unique sequences repeated three times, using the keypad to the right of the keyboard. The organisation of the list is described in Section 4.2.2.2. Each consecutive sequence was invoked by pressing one of the function keys located horizontally at the top of the screen. After a one week interval subjects returned for the retention test. 40 sequences were presented, 20 'old' and 20 'new'. After each sequence was entered, a display appeared in the centre of the computer screen instructing participants to make a recognition response regarding the familiarity of the just-seen sequence. Responses were made using the blue-coloured function keys, where 'F1' corresponded to 'confident old' and F6 corresponded to 'confident new'. Following the recognition response the prompt was replaced by the next sequence. Subjects were thanked for their participation at the end of the experiment.
5.2.3 RESULTS
Data from both the acquisition and the retention phase were analysed and will be reported separately. Three response time (RT) measures were recorded, ‘total’, ‘encoding’ and ‘execution’ time. Each RT measure was measured to the nearest millisecond; mean median RTs will be reported. The unit of analysis was the participant.

5.2.3.1 ACQUISITION
At acquisition the main questions of interest was whether there was any evidence of overall learning; whether learning looked as if it was still occurring at the end of the practice phase; and as in previous experiments, whether the change in learning across the acquisition session was evident during the encoding component of the task, rather than the motor response component.

5.2.3.1.1 EVIDENCE FOR OVERALL LEARNING
In order to establish whether learning was actually occurring during acquisition, the overall speed up in responding was initially assessed. A paired t-test was used to compare the mean total time taken to enter the first (2842ms, SD = 469ms) and the third (2661ms, SD = 455ms) repetition of the sequences across subjects. A reliable difference between RTs was found ($t(39) = 6.126, p<0.001$); sequences were entered 7% faster upon the final repetition than the first.

RTs for individual sequences were subsequently analysed to see whether the speed-up was evident across all sequence repetitions. The total time taken to enter the first and the third repetition of each sequence is shown on Figure 5.2.1

RTs for each of the sequences are displayed. The actual sequence is displayed on the ‘y’ axis; the first sequence presented, ‘4726’ is located at the bottom of the axis, ascending to the twentieth sequence, ‘4375’, at the top of the axis.
Using a series of paired t-tests, twelve of the twenty sequences were entered reliably faster upon the third repetition than the first (p<0.05). There were no differences in the time taken to enter sequences 7 (6826), 16 (5824), 17 (1863) and 18 (9157), i.e where RTs were faster for the first rather than the third repetition, and differences were not found for sequences 19 (8637) and 20 (4375). The fact that the RTs were faster on the third presentation suggests that learning of the sequences and the responses is still occurring. It is worth noting that the above sequences do not have any distinguishing features that would result in them being learned differently from the remaining sequences. (For RTs, standard deviations and t-values, see Appendix 12).
In order to measure whether the information used to type the first repetition of the sequence was again used at the third repetition, Pearson’s product moment correlation coefficients were calculated. It was assumed that high positive correlations would indicate considerable overlap in informational terms; low correlations, indicating high variance would suggest that other information is being used to type the sequences. The mean coefficient ‘r’ was .54, ranging from .11 (sequence 16) to .73 for sequence 5. For sequences 1–15, all pairs were reliably positively correlated (p < 0.05), suggesting that the same information used to type the first and third repetition. For sequences 16–20, the correlations were not reliable; different sources of information were being used, supporting the contention that these sequences were still being learned.

These findings indicate that responding does improve over time; the time taken to enter the sequences decreases with practice. However, the findings also show that a uniform decrease in RTs does not occur across the sequences. Particular sequences were responded to differently, suggesting specific ‘sequence feature’ knowledge rather than general task-performance knowledge is developed. The fact that RTs for the final sequence repetitions are not related suggests that learning of the sequence representations is still occurring, however.

5.2.3.1.2 RESPONDING TO SEQUENCE COMPONENTS

Sequence responses were decomposed to reflect a planning component and an execution component in order to assess changes in the perceptual and the motor requirements of the task, respectively.

5.2.3.1.3 PERCEPTION AND PLANNING

The change in time taken to encode the sequences was used as an index of the planning involved in perceiving the sequence and subsequent initiation of a response based upon what is encoded. To recap, encoding time was the time taken to make the first keypress from the onset of the sequence upon the screen. The mean encoding
time for the first repetition of the sequences was 1428ms (SD = 333ms), reliably slower than the time taken to encode the third repetition (1325ms, SD = 300ms) of the sequences (t(19) = 5.982, p < 0.001).

In order to obtain a more detailed picture of the pattern of responding, changes in encoding were examined for each of the sequence pairs, as shown on Figure 5.2.2.

![Figure 5.2.2](image)

**Figure 5.2.2** Mean median encoding times (in ms) for the first and the third repetition of the sequences.

Figure 5.2.2 shows that apart from 7 (6826), 8 (8417) and 16 (5824), all sequences were entered faster on third presentation that first. The fact that these sequences all
begin with different numbers again suggests that it is not some property of the sequences that makes them inherently more difficult to encode.

The reliability of the differences was analysed using a series of paired t-tests. Thirteen pairs were reliably different (p < 0.05). There was no difference in the time taken to encode sequences 6, 7, 8, 12, 16, 17, 18 (p > 0.05). Based upon the same assumptions as the total time, using Pearson's product moment coefficients, reliable positive correlations were found for all sequence pairs (p < 0.05). The mean coefficient 'r' was .62, ranging from .25 (sequence 6) to .83 (sequence 18). This suggests therefore that some of the same type of information was used to encode the sequences from one repetition to the next. For those sequences that did not differ as per the t-test, the implication is that improvement in encoding has still to occur, i.e. that learning was still benefiting from practice at the end of the acquisition session.

5.2.3.1.4 MOTOR RESPONSE COMPONENT

Changes in motor responding were assessed by comparing the time taken to execute the final three digits of the sequence for the first and the third repetition. On the basis of previous findings, changes in execution were not expected. The mean RT for each of the keystrokes is shown on Table 5.2.1.

<table>
<thead>
<tr>
<th>RT measure</th>
<th>Repetition 1</th>
<th>Repetition 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keystroke 2</td>
<td>451 (178)</td>
<td>399 (152)</td>
</tr>
<tr>
<td>Keystroke 3</td>
<td>582 (231)</td>
<td>559 (213)</td>
</tr>
<tr>
<td>Keystroke 4</td>
<td>366 (112)</td>
<td>322 (111)</td>
</tr>
</tbody>
</table>

Keystrokes' 2 (t(39) = 3.896, p< 0.001) and 4 (t(39) = 3.968, p< 0.001) were executed reliably faster at the third repetition than the first, the proportional difference in time taken to execute the strokes being .90 and .88, respectively. However there was no
change in the time taken to execute the third digit of the sequence ($t(39) = 1.678$, $p > 0.05$) across the acquisition session (a 5% reduction in time between the first and the third repetition). Furthermore, Keystroke 3 took reliably longer to execute than 2 and 4 ($F(2, 78) = 54.287$, $p < 0.001$). This suggests that some sort of parsing mechanism is being used to respond to the sequence and it may be that the third keystroke requires increased perceptual processing compared to the second and fourth keystrokes.

5.2.3.1.5 SUMMARY
The main questions being asked at acquisition were whether there was an overall improvement in performance with practice; whether learning was still occurring at the end of the acquisition phase and where the improvement was occurring with practice. The difference in time taken to respond to the first and the final repetition of the sequences was used to measure improvement. On all RT measures, responding was faster at the end of practice than at the start. However, analysis of the sequence pairs indicated that learning was still occurring on certain sequence pairs. This suggests that facilitation from practice does not appear to lead to global performance benefits upon the task itself, rather specific sequence properties are learned. Furthermore, one of the aims of the experiment was to stop practice whilst learning was still occurring. The results indicate that this was successfully achieved.

5.2.3.2 RETENTION
At retention, both implicit and explicit effects of memory were measured in order to assess the durability and the specificity of learning at acquisition. Variables manipulated included the between subjects factor of ‘transfer group’ (‘switch’ / ‘same’); subjects either switched keypad formations or used the same format as at acquisition. ‘Sequence type’ was analysed within subjects. Sequences were either ‘old’ or ‘new’ (for the switch transfer group, ‘old motor’ and ‘old digit’ sequences
were measured). It was hypothesised that as a consequence of receiving diminished amounts of practice, there would be a performance benefit when the conditions at study and test matched. If subjects rely more upon the specific perceptual-motor cues provided by the previously practiced sequences then deficits in performance would be expected at retention where manipulations in task requirements are made.

On the implicit tests, RT measures taken included again ‘total’, ‘encoding’ and ‘execution’ time; on explicit tests of memory, accuracy of recognition was assessed using A’.

5.2.3.2.1 DURABILITY OF LEARNING

The durability of learning that occurred during acquisition was assessed using the total time taken to enter the entire sequence. Responding at retention was compared to that at acquisition. Time to enter the third repetition of sequences at acquisition 2580ms ($SD = 475ms$), was compared to the times of both the ‘old’ and ‘new’ sequences at retention using a series of paired t-tests. Using RTs across sequences. It was demonstrated that the third repetition was reliably faster than the time taken to enter both the ‘old’ ($t(39) = 3.832, p < 0.01$) and the ‘new’ sequences at test ($t(39) = 3.140, p < 0.01$). This suggests that forgetting of specific sequence attributes occurs between acquisition and test or, that a post-rest decrement in performance may be obscuring the true results.

1 The accuracy of keystroke responses for the same and switch conditions were found. For those who used the calculator, the percentage of errors made was 1.44% and 0.63%, respectively. For those who used the telephone, the error rate was 1.39% and 1.5% respectively. The modal error score was two digits incorrect out of 160; the range being from one to six. In terms of the mistakes made by the switch transfer group, all were due to the keypad manipulation, i.e. 7 typed instead of 1, rather than a non-specific error, which characterised those made by subjects in the same transfer group.
Table 5.2.2 shows mean RTs for each 'sequence type' within each 'transfer group'.

Table 5.2.2. Mean total time (in ms and SD), taken to enter each sequence type within each transfer group.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>New Sequences</th>
<th>Old Sequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>3052 (672)</td>
<td>2869 (594)</td>
</tr>
<tr>
<td>Same</td>
<td>2711 (391)</td>
<td>2631 (302)</td>
</tr>
<tr>
<td>Switch</td>
<td>3096 (774)</td>
<td>2883 (693)</td>
</tr>
</tbody>
</table>

A 2 x 2 ('sequence type' by 'transfer group') ANOVA was performed on the subject data. A main effect of 'sequence type' was found, 'old' sequences were entered 183ms faster than 'new' (F(1,38) = 188.37, p< 0.001). Within the 'same' transfer group, 'old sequences' (2631ms) were entered 80ms faster than 'new' (2711ms), the magnitude increasing for those who 'switched' (213ms). A main effect of 'transfer group' (F(1,38) = 5.76, p<0.05) was found, 'same' performing faster than 'switch'. Furthermore the interaction between 'transfer group' and 'sequence type' was reliable (F(1,38) = 8.40, p<0.01) indicating that 'new' sequences were entered more slowly within the 'switch' transfer group. This suggests that as the difference in requirements between study and test increases, the likelihood of experiencing a greater detrimental effect upon performance also increases.

Within the 'switch' transfer group only, RTs to 'old digit', 'old motor' and 'new' sequences were analysed. The analysis was performed in order to examine the relative contribution of perceptual and motor factors. 'Old motor' sequences (2826ms, SD = 215) were entered 116ms faster than 'old digit' sequences (2932ms SD = 206) which in turn were entered 120ms faster then 'new' sequences (3052ms, SD = 404). A main effect of 'sequence type' was found (F(2,38) = 91.09, p< 0.01), 'old' sequences were entered reliably faster than 'new'. There was no difference between 'old digit' and 'old motor' sequences (p> 0.05) which suggests that the reinstatement of either perceptual or motor factors facilitates subsequent typing times.
5.2.3.2 PERCEPTION AND PLANNING

The change in the amount of planning between acquisition and test was initially assessed by examining the difference in the time taken to encode the sequence. The mean time taken to encode the third repetition of the sequences at test was 1325ms ($SD = 300ms$), reliably faster than the time taken to enter both ‘old’ ($t(39) = 4.044, p < 0.01$) and ‘new’ sequences ($t(39) = 3.566, p < 0.001$). An increase in the time taken to plan the response was found between study and test. In order to verify whether this was due to a post-rest decrement in performance the planning time required for the sequences at test per se was examined. A $2 \times 2$ (sequence type by transfer group) ANOVA was performed on the data. RTs for ‘old’ and ‘new’ sequences within each transfer group are shown on Table 5.2.3.

Table 5.2.3 Mean encoding time (in ms and $SD$) for each sequence type and transfer group.

<table>
<thead>
<tr>
<th>Transfer Group</th>
<th>New Sequences</th>
<th>Old Sequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>1499 (326)</td>
<td>1454 (278)</td>
</tr>
<tr>
<td>Switch</td>
<td>1712 (514)</td>
<td>1574 (443)</td>
</tr>
</tbody>
</table>

Within the ‘same’ transfer group, ‘old’ sequences were encoded 45ms faster than ‘new’; within the ‘switch’ transfer group the difference was 138ms, ‘old’ sequences responded to faster than ‘new’. A main effect of ‘sequence type’ was found ($F(1,38) = 6.48, p < 0.05$), suggesting that the subjects retain a representation of the sequences that they have previously practiced.

However, although the ‘switch’ group took longer than the ‘same’ group to respond to both ‘new’ (213ms slower) and ‘old’ sequences (120ms slower), the effect of ‘transfer group’ only approached significance ($F(1,38) = 3.03, p = 0.09$). There was no interaction between ‘transfer group’ and ‘sequence type’ ($p > 0.05$).

Thus, the benefit in performance that has been found appears to be due to the perceptual encoding of the sequences rather than in the initiation of a motor response.
The fact that there is no difference between 'transfer group' supports this assertion; the manipulation of the keypad format does not have any effect upon performance at this stage.

Analysis was performed on the encoding times within the 'switch' transfer group only. Both 'old motor' and 'old digit' sequences (1568ms and 1587ms, respectively) were encoded reliably faster than 'new' (1712ms; F(2,38) = 3.83, p < 0.05). This suggests that the combined change in perceptual representation and motor layout was detrimental to perception and planning performance; a benefit to performance was obtained from reinstating either the perceptual (having previously seen the sequence) or the motor (knowing where to make the response) component. This was investigated further by examining the execution component of the sequence.

5.2.3.2.3 EXECUTION TIME

In order to examine whether there was a benefit from having previously executed the sequence, RTs at test only were examined. Execution times for each component keystroke (2, 3, and 4) are illustrated in Table 5.2.4.

Table 5.2.4. Execution times (in ms and SD), taken for each keystroke as a function of sequence type and transfer group.

<table>
<thead>
<tr>
<th>Keystroke</th>
<th>Sequence Type</th>
<th>Same</th>
<th>Switch</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>New</td>
<td>368 (88)</td>
<td>446 (179)</td>
</tr>
<tr>
<td></td>
<td>Old</td>
<td>344 (95)</td>
<td>431 (172)</td>
</tr>
<tr>
<td>3</td>
<td>New</td>
<td>497 (179)</td>
<td>519 (274)</td>
</tr>
<tr>
<td></td>
<td>Old</td>
<td>488 (172)</td>
<td>607 (224)</td>
</tr>
<tr>
<td>4</td>
<td>New</td>
<td>356 (099)</td>
<td>390 (234)</td>
</tr>
<tr>
<td></td>
<td>Old</td>
<td>342 (119)</td>
<td>337 (175)</td>
</tr>
</tbody>
</table>
Main effects of ‘sequence type’ (F(1,38) = 8.18, p = 0.007), ‘old’ sequences were executed reliably faster than ‘new’; of ‘transfer group’ (F(1,38) = 5.46, p = 0.025), the ‘switch’ transfer group took significantly longer to execute the sequences than the ‘same’ transfer group; and ‘keystroke’ (F(2,76) = 25.56, p < 0.005) reflecting the increased time taken to execute the third keystroke compared to the second and fourth was found. The absence of interactions in this set of analyses indicates that the pattern of responding was similar within both transfer groups for both sequence types.

Figure 5.2.3 shows the execution times for each sequence type within the ‘switch’ transfer group only. ‘Old’ sequences were, overall, executed faster than ‘new’, (F(2,38) = 13.08, p < 0.001). Newman Keuls post hoc tests found no differences between old motor and old digit (p > 0.05).

![Figure 5.2.3 Execution times (in ms) for the switch transfer group for each sequence type](image)

Again, the time taken to make the third keystroke (F(2,38) = 3.38, p < 0.05) was reliably different from the 2nd and the 4th. As for acquisition where it was suggested parsing of the sequences was occurring, this finding that the sequences have been retained as chunks of information and that the third keystroke requires additional processing compared to the second and the fourth.
In summary, the findings of the present study suggest that recapitulation of the study conditions at test does enhance performance where reduced amounts of practice are received. The fact that reinstatement of perceptual and motor components of the task facilitated performance upon indirect tests of learning supported this. Furthermore, the improved performance within the switch transfer group when task conditions were only partly reinstated provides further evidence for the benefit of having previously practiced the stimuli.

5.2.3.3 Recognition

As a direct test of the procedural reinstatement hypothesis an assessment of whether participants had formed any explicit memory for the stimuli a recognition judgement about the 'old' / 'new' status of the sequences was performed. It was hypothesised that under conditions of diminished practice that accuracy would be greater where the conditions between study and test remained the same. This would be due to the provision of more task related cues that could be used to facilitate performance. Accuracy of recognition was analysed by calculating the proportion of hits ('old' sequences correctly identified) and false alarms ('new' sequences identified as 'old') and subsequently $A'$.  

Table 5.2.5 shows that although the 'same' transfer group were more accurate in their detection of old sequences, this was offset by the higher number of false alarms. This is reflected in the $A'$ score, 0.56 for both groups.

<table>
<thead>
<tr>
<th>Transfer group</th>
<th>Hits</th>
<th>False Alarms</th>
<th>$A'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>0.49</td>
<td>0.36</td>
<td>0.56</td>
</tr>
<tr>
<td>Switch</td>
<td>0.39</td>
<td>0.28</td>
<td>0.56</td>
</tr>
</tbody>
</table>
The $A'$ scores were tested against a 'chance' level of .5 using a one-sample t-test. Within the 'same' transfer group performance was significantly better than chance ($t(18) = 2.11, p < 0.05$) but within the 'switch' group recognition was not different from chance performance ($t(15) = 1.47, p > 0.05$). Indeed, increased variability in the accuracy of discrimination (i.e. in the proportion of hits and misses) was found within the 'switch' group ($SE = 0.041$). Thus, it would appear that the manipulation in conditions between study and test is detrimental to recognition performance.

5.2.3.4 SUMMARY

Results at acquisition demonstrated a RT speed up with practice. The effect is a consequence of improvements in the time taken to plan and subsequently make the required response. Furthermore, as in previous studies the pattern of responding that emerged suggested that properties of particular sequences were being learned. The fact that an overall decrease in RTs was not found supports this.

At retention, reinstatement of the conditions between study and test led to improvements in speed and accuracy of responding. In terms of indirect tests, perceptual and motor factors were found to make separable contributions to performance. Enhanced performance resulted where the conditions overlapped entirely. With respect to direct tests, however, while there was evidence of reliable discrimination between old and new sequences within the 'same' transfer group, partial reinstatement of either the perceptual or the motor representation did not facilitate responding.

5.2.4 DISCUSSION

The aim of the present experiment was to examine whether reinstating the conditions between study and test facilitated performance under conditions of reduced practice. The study directly emanated from those reported in the previous chapter. In Studies 1 and 2 it was proposed that the amount of practice received enabled subjects to form explicit memories of the stimuli presented, despite there being no evidence of implicit
memory of the sequences; recognition of the stimuli was not dependent upon additional cues provided by perceived response time, as is typically expected (Schacter, 1992). In the present experiment the amount of practice given at acquisition was reduced. It was hypothesised that halving the amount of practice would prevent overlearning of the sequences and that as a consequence, reliance upon perceptual and motor cues formed during practice would increase. As a test of the procedural reinstatement paradigm, it was expected that when the perceptual representation and the motor requirement of the task differed between study and test, performance would suffer. Furthermore, the use of the procedural reinstatement paradigm allowed continued investigation into whether 'wholes' or alternatively 'global' attributes of the sequences were learned.

Although the main focus of the study was upon performance at retention it is important to demonstrate that the sequences were still being learned at acquisition. Although there was an overall speed up in responding throughout acquisition, this was not a general effect. Rather, supporting previous findings, specific sequences were 'learned' and responded to differently. When individual sequences were examined, it was found that only half of the sequences were entered faster when encountered at the final repetition rather than at the first. That response times to certain sequences did not improve with practice while with others they did suggests that learning was still occurring during acquisition. Lending strength to this assertion is the fact that the perceptual processing, or the 'encoding' of the stimuli had not improved for these sequences. One of the most widely reported findings, and one that has been demonstrated in the present thesis, is that encoding is the main beneficiary of practice; it is unlikely that this aspect of performance would not improve over time (Salthouse, 1986b; Anderson, 1995).

Performance at retention therefore can be considered in terms of how individuals adapt having learned under conditions of diminished practice. The implications of the results in terms of the procedural reinstatement argument will be initially examined. The procedural reinstatement argument proposes that the overlap between study and
test influences the success with which subsequent performance of that task is performed (Fendrich et al, 1991). In the present experiment this was hypothesised to interact with the amount of practice received; more specifically that a reduction in the amount of practice given would increase the dependence of perceptual and motor cues at acquisition. This hypothesis was supported.

In optimising both the number of contextual cues present at retention and the overlap in the processing requirements led to faster and more accurate responding. The results demonstrated that a mismatch in the conditions between study and test led to a decrement in performance. Through the manipulation of ‘sequence type’ and ‘transfer group’, it was evident via the indirect tests of memory that having previous practice with the stimuli facilitated subsequent performance; ‘old’ sequences were entered faster than ‘new’ and furthermore, were the benefit was greater when the keypad format remained the same. The results directly supported those of Fendrich et al (1991; 1995).

The findings also demonstrate that the benefit received from previous practice extends to both perceptual (i.e. the appearance of the sequences) and motor (the keypad formation used during typing) components of the task. This was clearly evident through the findings from the ‘switch’ transfer group, which revealed that both perceptual and motor aspects of performance contributed separately to successful retention performance; all ‘old’ lists were entered faster than ‘new’. This suggests that reinstating some component of the sequence can facilitate performance (i.e. the perceptual representation can compensate for the change in motor representation, and vice versa (Pashler, 1991)). However, the fact remains that when the entire conditions are reinstated optimum performance is promoted (Fendrich et al, 1995).

These are an interesting set of findings, when consideration is given to the hypotheses under investigation. In previous studies in the present thesis, using the same paradigm, but with the amount of practice doubled, the performance of the practice groups could not be differentiated as measured by indirect tests of memory. An
implication therefore, that the importance of the perceptual/motor cues that are reinstated increases when a diminished amount of practice has been received. A plausible suggestion is that under conditions of diminished practice, the more cues that are reinstated and the individual is able to use, the more effective subsequent performance will be.

Such a suggestion offers an interesting contribution to the proposal that 'sequence' wholes are learned during practice (Marsolek and Field, 1999). One of the underlying assumptions of this argument is that following practice, different components involved in performing the task are amalgamated into one representation. It is possible that the amount of practice received in the present experiment was insufficient to result in this amalgamation. Clearly if subjects were relying upon either the 'perceptual' or the 'motor' component in the present experiment, and at test these cues were unavailable, desultory performance would be expected, compared to a test where all cues are available. Such amalgamation of information makes intuitive sense when coupled with the notion that representations become more rigid as practice progresses (Holding, 1991).

The results of the direct tests of memory used within this experiment lend support to this argument. Using direct tests of memory it is evident that the subjects were able to explicitly recognise which of the sequences had been practiced previously. However, this finding emerged only for subjects who had performed entirely the same task between study and test. Where the perceptual / motor factors had been manipulated (i.e. the 'switch' transfer group) accuracy was no better than chance. This finding suggests at least two things. Firstly that the sequence representation formed is specific to that particular sequence, which clearly accords with a 'procedural reinstatement' view (Fendrich et al, 1991; Healy et al, 1995) in addition to a Logan-esque view of Instance learning (Logan, 1995). More interestingly, the finding again supports the assumption that sequence components are amalgamated to comprise a whole (Marsolek and Field, 1999). Recall that within the 'switch' transfer group, using indirect tests, the perceptual and motor components of the sequence separately
contributed to performance. In direct tests, where the conditions were switched, performance was no better than chance. The amalgamation of the parts to make a 'whole' was negated by the change in conditions and thus no benefit to performance was evident.

Thus the results of the present study suggest that the beneficial effects of 'procedural reinstatement' are evident under conditions of diminished practice. Clearly this implies that the amount of practice rather than the 'type' of practice does indeed influence retention performance in certain situations (c.f. Baddeley, 1997; Groeger, 2000). Well established findings that indicate the organisation of the practice schedule effects learning and retention to a greater degree than the number of trials participated in are not supported in the present experiment. Furthermore, the fact that a divergence on memory tests is evidently effected by the amount of practice given is very interesting. The findings of Studies 2 and 3 do not clarify the 'systems' versus 'processes' debate of memory at all. It would appear that the amount of practice has an effect upon whether disparate memory systems are evident, or not. This clearly is an extreme point of view and for this reason, warrants closer attention. In the following experiment a more sensitive assessment of the amount of practice given is conducted with the aim of clarifying whether retention does actually differ simply as a consequence of the amount of practice.
5.3 STUDY 4. A WITHIN-SUBJECTS COMPARISON OF THE WHETHER ‘AMOUNT OF PRACTICE’ AFFECTS SUBSEQUENT RETENTION OF INFORMATION.

5.3.1 INTRODUCTION
The aim of the present study is to present a more direct assessment of whether the amount of practice influences the way in which learned material is retained. Studies reported so far, in which the amount of practice has been manipulated, have shown differing effects at retention. To recap, the amount of practice given in Studies 1 and 2 was twice that given in the previous study (Study 3). In Studies 1 and 2, reinstating the study conditions at test did not lead to a facilitation in performance. While ‘old’ stimuli were not differentiated from ‘new’ using indirect tests, subjects were still able to recognise stimuli that had been previously seen. In Study 3, the practice was halved and the results differed dramatically; using indirect tests, subjects responded faster to stimuli that they had previously seen; performance was disrupted by the presence of novel stimuli. Furthermore, using direct tests, successful discrimination of ‘old’ and ‘new’ sequences was only apparent where the exact procedures used at study were reinstated.

The most parsimonious explanation for these disparate findings is that the amount of practice received has an influence upon subsequent performance. Increasing the amount of practice leads to improved retention in terms of the individual’s ability to discriminate between previously processed and previously unprocessed material, and also with respect to the ease with which ‘procedural’ performance can generalise to other similar tasks. Such practice effects would be expected on the basis of theories of skill acquisition, especially that espoused by Anderson (1992); here as the individual becomes more proficient in the task being learned performance is increasingly ‘proceduralised’, resulting in subsequent transfer of performance to other similar tasks. However, previous research has demonstrated that there is usually a
more complex relationship between practice and retention. It is not usually the case that the amount of practice *per se* is important (Groeger, 1997).

Indeed as was demonstrated in the previous chapter, a theoretical distinction has been drawn between 'massed' and 'distributed' practice. While the former is proposed to lead to rapid acquisition of the task, retention of the information is less effective than that found using a distributed practice regime (Adams, 1985). However, as reported in the previous chapter, there was no distinction in retention performance following the two types of practice. The only manipulation that has resulted in differential effects of practice is varying the amount given.

Throughout the experiments, direct and indirect tests of retention have been performed, tapping implicit and explicit effects of memory. Indeed, the differential effects of practice have arisen as a consequence of the retention tests used. One of the most prevalent debates within the literature at present concerns the extent to which these different types of memory are related (Richardson-Klavehn and Bjork, 1992; Gabrieli, 1995). On the one hand, it has been argued that 'implicit' and 'explicit' are different 'forms' of memory and are thus dissociable (Schacter, 1992). Alternatively, it has been suggested that implicit and explicit memory are the extremes of a continuum of awareness and that eliciting information depends upon the type of test used at retention (Blaxton, 1995; Kolers and Roediger, 1984). 'Testing' is the key issue for process theorists, who argues that the quality of the memory will be influenced by the match between study and test. Thus if a test fails to tap processes that were used at acquisition, memory will appear to fail (Tulving, 1985).

The results reported in the thesis thus far suggest that the 'process' theorists offer a more plausible account of how material is retained and should be tested. Importantly, the prevailing conditions at acquisition have to be taken into account when performing retention tests. Under conditions of diminished practice, reinstating the exact conditions between study and test facilitated performance and memory in Study 2. However, when the amount of practice was increased, at retention, an apparent
dissociation between what was retained emerged, depending on the test used, i.e. no implicit but explicit effects of memory. It may be that different learning conditions led to more powerful ‘explicit’ effects overriding the implicit effects.

Thus, in order to examine the stability of previous findings, the aim of the present experiment was to conduct a more sensitive within subjects comparison of the amount of practice. On the basis of previous findings it was expected that a difference in performance would be evident depending upon whether sequences were repeated three or six times. It was hypothesised that increased practice of specific sequences during study would result in an asymptote in performance and consequently greater ability to transfer learned aspects of the task to novel situations. Reduced practice was hypothesised to be insufficient to produce stability of learning; enhanced retention performance, indexed in terms of a benefit for ‘old’ over ‘new’ sequences, was expected to be dependent upon the contextual match between study and test.

More specifically, at retention, the effect of ‘transfer group’ was expected to have an effect upon performance due to the importance of reinstating the perceptual-motor cues formed. Within the ‘same’ group, i.e. where the same keypad formation was used between study and test, in terms of indirect tests, RTs to ‘old 6’ (i.e. those repeated at acquisition six times), ‘old 3’ (those repeated three times at acquisition) and ‘new’ sequences were not expected to differ; subjects could transfer what is learned to the novel stimuli without a decrement in performance. Within the ‘switch’ transfer group, ‘old 6’ and ‘new’ sequences were not expected to differ from each other however, RTs to ‘old 3’ stimuli were expected to suffer, due to the reduced amount of practice and the absence of perceptual-motor cues. With respect to the direct tests, ‘old 6’ sequences were expected to be distinguishable from ‘new’, but ‘old 3’ sequences would only be distinguishable from ‘new’ when the study-test conditions match. (i.e. performance within the ‘same’ transfer group was expected to be more accurate than that of the ‘switch’ group).
5.3.2 Method

5.3.2.1 Subjects
44 subjects, 29 female and 15 male, with a mean age of 20.4 years (SD = 1.35 years) participated in the study. Each was randomly assigned to one of four experimental conditions upon arrival at study, depending upon the stimulus list used at study.

5.3.2.2 Materials and Apparatus
The experiment was entirely P.C. based. Stimuli were presented upon a computer screen and responses were made using a modified computer keyboard. The keyboard was the same as that used in the previous experiments, with the keypad to the right of the board configured such that it resembled either a ‘calculator’ or a ‘telephone’ layout (see Figure 3.1, Section 3.2).

At ‘study’ four stimulus lists were used. Each list contained a total of ninety sequences. Of those ninety, only twenty were unique, 10 being repeated three times, 10 six times. Six blocks of sequences were presented in total. Each block of sequences contained five sequences repeated three times. The fourth and fifth block of sequences were repetitions of blocks’ 1 and 2. The blocks were counterbalanced across subjects; the structure of the blocks within the four lists was as follows:

- List A: 1 2 3 4 1 2
- List B: 2 1 4 3 2 1
- List C: 3 4 1 2 3 4
- List D: 4 3 2 1 4 3

At test, different lists were presented depending upon the lists used at study. ‘Test lists ’1a and ’1b’ were used where study lists’ ‘1’ and ‘2’ had been presented; ‘test list ’2A’ and ’2b’ where study lists’ ‘3’ and ‘4’ had been given. ‘Old’ sequences repeated either 3 or 6 times differed between the lists at test due to the block presentation at study. The lists were counterbalanced such that ‘old6’ sequences were presented within the first 20 sequences in the ‘A’ lists, and within the final 20 within the ‘b’ lists (clearly presentation was opposite for ‘old3’ sequences).
5.3.2.3 DESIGN
A mixed design was used. At acquisition, 'sequence set' was manipulated within subjects; sequences were presented either 'six times' or 'three times'. The variable of interest was the repetition of the sequences. First and final repetition were compared. The dependent variable was response time (RT) of which there were three measures: 'total', 'encoding' and 'execution' time.

At retention 'sequence type' (within subjects) and 'transfer group' (between subjects) were manipulated. 'Sequence type' comprised 'old6' (10 sequences), 'old3' (10 sequences) and 'new' (20) sequences. The 'old' sequence types were repetitions of those shown at acquisition. 'Transfer group' referred to the keypad used at retention that was either the 'same' as that used at acquisition, or was transposed to the alternative 'switch' layout.

5.3.2.4 PROCEDURE
The procedure followed was identical to that reported in the previous experiment. At study, subjects entered the laboratory and sat in front of the computer. Instructions were presented on the P.C. screen. Subjects were informed that they would be presented with a series of ninety, four-digit sequences which were to be typed as quickly as possible, with the right hand, and upon the modified keypad to the right of the keyboard.

A one-week retention interval separated study and test. Subjects returned to the laboratory. Instructions were again displayed on the computer. Subjects were informed that they would be presented with a series of forty, four-digit sequences, some of which were 'old', and some of which were 'new'. Subjects entered the sequences in the same manner as study, but following each sequence entry, were required to make a recognition decision regarding the 'old' / 'new' status of that sequence. Responses were made with the left hand, using specifically marked keys located horizontally at the top of the keyboard.

At the end of the experiment subjects were thanked for their participation.
5.3.3 RESULTS
Results will be reported for both the acquisition and the retention phases of the experiment. As in the previous studies both indirect and direct tests of retention were performed. On the indirect tests, three response time measures were taken: Total time, encoding time and execution time. The mean median time was measured to the nearest millisecond. Recognition of the sequences was measured using A'.

5.3.3.1 ACQUISITION
The aim at acquisition was to examine whether the sequences were being learned, in addition to whether sequences presented six times were responded to faster than those presented three times. The subject data was the unit of analysis.

5.3.3.1.1 EVIDENCE FOR OVERALL LEARNING
An initial assessment of whether an improvement in responding occurred throughout the acquisition session was performed by examining the ‘total’ time taken to enter the entire sequence. Table 5.3.1 shows the time taken to enter the first and the final repetition for sequences repeated three and six times.

Table 5.3.1. Mean time (in ms with SD) taken to enter the first and final repetition of the sequences

<table>
<thead>
<tr>
<th>Sequence set</th>
<th>First repetition</th>
<th>Final repetition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three</td>
<td>2642 (522)</td>
<td>2648 (663)</td>
</tr>
<tr>
<td>Six</td>
<td>2800 (479)</td>
<td>2522 (511)</td>
</tr>
</tbody>
</table>

Although sequences presented ‘three times’ were entered faster at the outset, there was no improvement over time; RTs were 6ms slower upon final presentation. Sequences presented ‘six times’ were entered 278ms faster at the end of the practice phase. A $2 \times 2$ (‘repetition’ by ‘sequence presentation’) repeated measures ANOVA
was used to analyse these data. A main effect of 'repetition' was found \((F(1, 42) = 12.05, p < 0.001)\), indicative of faster responding to the final repetition of the sequences. An effect of 'presentation' was not found, \((F(1,42) = .099, p > 0.05)\), however, which suggests that the response times across the two sequence sets did not differ. However, a significant interaction between 'repetition' and 'presentation' was found \((F(1, 42) = 14.997, p < 0.001)\), which gives a more accurate reflection of the data. The amount of improvement across the sequences repeated 'six times' was greater than those repeated three times. Although RT to the initial presentation of the sequences within the former set was slower, by the final presentation, RTs within the set were faster than RTs recorded for sequences presented three times.

The change in performance across sequences presented six times was more closely examined. The mean RT for sequences presented 'six times' at the third repetition was 2634ms \((SD = 471)\), faster than the equivalent RT recorded for sequences presented 'three times'. For sequences presented 'six times', a 6% gain in response times was found between the third repetition and the first; a 5% gain was found between the sixth and the third repetition, again reflecting that performance benefits from additional practice, but does so at a much diminished rate.

To summarise, sequences presented six times benefited more from practice than did those repeated three times. Whereas RTs significantly improved over time across the 'six repetition' set, there was no change across the 'three repetition' set. Within the 'six repetition' set, it is interesting to note that the most learning occurred during the first three presentations. The amount diminished during the last three repetitions. It is worthy of note, however, that the RTs to those sequences presented three times did not change, suggesting no, or little specific facilitation from the amount of practice received.

5.3.3.1.2 PERCEPTION AND PLANNING

Encoding time, or that taken to make the first keypress following the appearance of the sequence upon the screen was used as an index of the time taken to perceive the
stimulus and plan a response. Table 5.3.2 shows the time taken to encode the first and the final repetition of each sequence set.

**Table 5.3.2** Encoding times (in ms with SD) of the first and final repetition of the sequences repeated three or six times

<table>
<thead>
<tr>
<th>Sequence set</th>
<th>First repetition</th>
<th>Final repetition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three</td>
<td>1293 (509)</td>
<td>1289 (459)</td>
</tr>
<tr>
<td>Six</td>
<td>1425 (420)</td>
<td>1245 (500)</td>
</tr>
</tbody>
</table>

The RTs indicate that although encoding time was significantly slower for the first repetition within the 'six set' compared to the 'three set', (t(42) = 3.124, p < 0.05), the amount of improvement by the final repetition was greater for sequences presented six times (180ms versus 4ms difference).

A 2 x 2 ('repetition' by 'presentation') repeated measures ANOVA was performed on the data. Although main effects of both 'presentation' (F(1, 42) = 6.393, p < 0.05) and 'repetition' (F(1, 42) = 12.137, p < 0.05) were found, suggesting that encoding of the sequences presented 'three times' was faster than those presented 'six times' and also that the final repetition was encoded faster than the first, a significant interaction was also found (F(1, 42) = 10.142, p < 0.05). The interaction reflects the fact that although initially entered more slowly, the speed-up in responding was greater across sequences presented six times than for three.

The time taken to encode the third repetition of the sequences within the 'six' set was again examined. Unlike total time, encoding time was slower than the third repetition within the 'three' set, 1318ms ($SD = 404ms$) compared to 1289ms ($SD = 459ms$). However this is still a 107ms improvement across those sequences presented six times. Furthermore, the additional practice still facilitates responding; a 73ms difference between the third and the final repetition within the 'six set' is found. These results suggest that the time taken to plan a response does benefit from extended practice.
5.3.3.1.3 EXECUTION OF THE MOTOR RESPONSE COMPONENT

The time taken to execute the final three digits of the sequence was used as an index of the motor response requirements of the task. Three response time measures were analysed, therefore, 'keystroke 2', 'keystroke 3' and 'keystroke 4'. Table 5.3.3 shows execution times for the first and final repetition of the sequences within each set.

Table 5.3.3 Mean execution times (in ms, with SD) for the first and final repetition of the sequences within each set.

<table>
<thead>
<tr>
<th>Sequence set</th>
<th>Keystroke</th>
<th>First</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three</td>
<td>2</td>
<td>347 (127)</td>
<td>354 (151)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>579 (200)</td>
<td>566 (217)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>333 (137)</td>
<td>350 (290)</td>
</tr>
<tr>
<td>Six</td>
<td>2</td>
<td>385 (135)</td>
<td>340 (171)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>561 (207)</td>
<td>565 (221)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>314 (87)</td>
<td>298 (95)</td>
</tr>
</tbody>
</table>

The direction of results in Table 5.3.3 shows that while execution time decreases across repetitions for those sequences repeated six times, for sequences repeated three times, execution is slower at the final repetition. The difference in RTs tested using a 2 x 2 x 3 ('repetition' by 'presentation' by 'keystroke') ANOVA. Neither a main effect of 'repetition' (F(1, 42) = .396, p>0.05) nor 'presentation' was found (F(1, 42) = .656, p>0.05). Execution of the sequences did not differ as a function of whether they were repeated three or six times, or whether they were executed at the outset or the end of the practice session. A main effect of keystroke was found (F(2, 84) = 69.96, p<0.001) which reflected the increased time taken to enter the third keystroke in comparison to the second and fourth. None of the interactions were significant in the present analysis.
In summary, execution of the sequences did not change over the practice session. Whether the sequences were presented three or six times did not affect responding. This suggests that the motor component of the task is relatively stable. Encoding time however, did improve across the practice session, namely for those sequences presented six times. The results support propositions that the planning component benefits more from practice. How the amount of practice received effected retention will now be examined.

5.3.3.2 RETENTION

To recap, the aim at retention was to examine whether the amount of practice received influenced the effectiveness with which sequence knowledge was retained. Sequences presented ‘six times’ (old6), ‘three times’ (old3) and ‘novel’ sequences were compared (the variable of ‘sequence type’). In addition, half of the subjects performed the task using the ‘same’ keypad, half ‘switched’ (variable of ‘transfer group’). It was hypothesised that RTs to ‘old6’ sequences would not differ from those that were ‘new’, nor would there be any detrimental effect of the manipulation in the keypad. However, it was expected that ‘old3’ sequences would differ from those that were new and would be detrimentally affected by the change in keypad formation. Results are reported in terms of the three response time measures.

5.3.3.2.1 DURABILITY OF LEARNING

A 2 x 3 (‘transfer group’ by ‘sequence type’) repeated measures ANOVA was used to analyse the RTs for each of the sequence types, within each transfer group; RTs. Are shown in Table 5.3.4. A main effect of ‘sequence type’ was not found (F(2, 82) = .128, p > 0.05). The amount of practice did not influence the speed with which sequences were entered at retention.
Table 5.3.4 Mean total time (in ms with SD) for each of the sequence types within each transfer group.

<table>
<thead>
<tr>
<th>Transfer Group</th>
<th>Old 6</th>
<th>Old 3</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>2666 (712)</td>
<td>2690 (614)</td>
<td>2749 (679)</td>
</tr>
<tr>
<td>Switch</td>
<td>2933 (650)</td>
<td>3017 (597)</td>
<td>2934 (514)</td>
</tr>
</tbody>
</table>

Furthermore, there was no difference depending upon whether subjects switched keypad formation or used the same layout as at acquisition (F(1, 41) = 3.199, p > 0.05); the reinstatement or absence of perceptual motor cues did not effect responding.

5.3.3.2.2 PERCEPTION AND PLANNING

Encoding time was again used as an indication of the time required to perceive the sequence and plan a response. Table 5.3.5 shows the mean time taken to encode each of the sequence types, within each transfer group. The direction of the data suggests that all sequences are encoded faster within the ‘same’ transfer group than the ‘switch’. However, using a 2 x 3 (transfer group by sequence type) repeated measures ANOVA, it was found that these differences were not reliable.

There was no difference between the sequences (F(2, 82) = .071, p > 0.05) or the transfer groups (F(1, 41) = .874), p > 0.05), and there was no interaction between the variables (F(2, 82) = .204, p > 0.05).

Table 5.3.5 Mean encoding time (in ms with SD) for each sequence type within each transfer group

<table>
<thead>
<tr>
<th>Transfer Group</th>
<th>Old 6</th>
<th>Old 3</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>1517 (571)</td>
<td>1520 (469)</td>
<td>1502 (521)</td>
</tr>
<tr>
<td>Switch</td>
<td>1613 (436)</td>
<td>1634 (476)</td>
<td>1582 (459)</td>
</tr>
</tbody>
</table>
Again, manipulating the amount of practice did not have an effect upon retention performance, and reinstating the cues learned during practice did not confer any beneficial effect to the encoding of 'old' sequences. However, the fact that 'new' sequences were encoded at the same rate suggests a potential 'transferable' benefit from practice.

5.3.3.2.3 EXECUTION OF THE MOTOR RESPONSE

Table 5.3.6 shows the mean execution time for the final three digits of the sequences. It is evident that although the 'switch' transfer group performed the main motor response more slowly than the 'same' transfer group, the difference between the 'sequence types' was small.

Table 5.3.6 Mean execution time (in ms with SD) for each sequence type within each transfer group.

<table>
<thead>
<tr>
<th>Transfer Group</th>
<th>Keystroke</th>
<th>Old 6</th>
<th>Old 3</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>2</td>
<td>324 (111)</td>
<td>322 (95)</td>
<td>339 (120)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>420 (159)</td>
<td>439 (169)</td>
<td>415 (125)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>314 (83)</td>
<td>314 (74)</td>
<td>314 (62)</td>
</tr>
<tr>
<td>Switch</td>
<td>2</td>
<td>372 (155)</td>
<td>372 (170)</td>
<td>397 (514)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>482 (168)</td>
<td>528 (187)</td>
<td>524 (161)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>322 (87)</td>
<td>314 (67)</td>
<td>307 (53)</td>
</tr>
</tbody>
</table>

A 2 x 3 x 3 ('transfer group' by 'sequence type' by 'keystroke') repeated measures ANOVA was performed on the subject data. There was no main effect of 'sequence type' (F(2, 82) = .122, p > 0.05), having previously executed sequences did not lead to an advantage at retention where novel sequences were presented. Furthermore, the amount of practice received did not affect performance. A main effect of transfer group did not emerge (F(1, 41) = 4.657, p > 0.05); manipulating the response format did not influence the way in which the sequences were responded to and clearly there was no interaction between the variables (F(2, 82) = .037, p > 0.05). An effect of
'keystroke' was found ($F(2, 82) = 73.4, p < 0.001$), which reflects the fact that the third keystroke took longer to enter than the second or the fourth, again suggesting that additional processing of this component is required.

Again, the amount of practice received and the provision of previously learned perceptual-motor cues did not enhance performance when subsequently tested against novel stimuli. Performance is apparently transferring to novel components of the task, as indexed by the execution of novel sequences, but more importantly in the present experiment, the alternative keypad layout. It was expected that unfamiliar motor response would disrupt performance, especially under conditions of reduced practice. This was not found.

### 5.3.3.2.4 Recognition of Sequence Sets

To assess whether subjects could discriminate 'old' sequences from 'new', a recognition judgement about the sequences was made. The accuracy of judgements was analysed by calculating the proportion of 'hits' ('old' sequences correctly recognised as 'old') and false alarms ('new' sequences identified as 'old'). $A'$ was subsequently calculated from these measures.

Table 5.3.7 illustrates the proportion of 'hits' obtained for both 'old 6' and 'old 3' sequences, in addition to the proportion of false alarms. It is evident that the hit rate is higher for those sequences presented six times (i.e. 'old 6'), which means a greater number of these sequences were correctly recognised as 'old'. The $A'$ statistic confirms that 'old 6' sequences were recognised with greater accuracy than 'old 3' sequences. In order to test whether the sequences were being recognised at above chance level, a one-sample t-test was performed on the $A'$ scores for each of the sequences across subjects.
Table 5.3.7 Proportion of hits and false alarms, and $A'$ score obtained for ‘old 6’ and ‘old 3’ sequences.

<table>
<thead>
<tr>
<th>Sequences</th>
<th>Hits</th>
<th>False alarms</th>
<th>$A'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old 3</td>
<td>.43</td>
<td>.48</td>
<td>.108</td>
</tr>
<tr>
<td>Old 6</td>
<td>.53</td>
<td>.48</td>
<td>.662</td>
</tr>
</tbody>
</table>

The test value used in the analysis was 0.5. Both ‘old 6’ ($t(39) = 18.7$, $p < 0.01$) and ‘old 3’ ($t(41) = 26.2$, $p < 0.01$) were different from chance. However, the results suggest that responding to the sequences presented six times was above chance, while responding to sequences presented three times was below chance; indeed an independent samples t-test performed on the data found that the $A'$ scores were reliably different between sequences presented either six or three times ($t(80) = 32.1$, $p < 0.01$). It is worth noting that one of the reasons for this may be due to the fact that the ‘hit’ rate within the ‘old 6’ group was higher than that within the ‘old 3’ group, while the false alarm rate was the same between the groups; ‘old 6’ sequences were more accurately recognised. Thus in terms of the explicit tests of memory, it would appear that memory is more accurate when increased amounts of practice are received.

5.3.3.3 SUMMARY

At acquisition, the results demonstrated that the rate of improvement in responding was greater across those sequences presented six times than across those presented three times. Indeed, as has been demonstrated in previous studies, there was no change in performance when just three presentations of the sequences were given. Where an improvement did occur, it was in the perception and planning component of the sequence. Subjects made their initial response with increasing speed across the practice session. However, there was no change in the time taken to execute the sequence, motor responding did not differ as a function of the amount of practice received.
At retention however, in terms of indirect tests, although there was no difference between sequences presented six times (at study) and novel stimuli which was in line with predictions, there was also no difference between the sequences presented three times, and more importantly no difference between the transfer groups. The amount of practice received did not effect responding and furthermore, reinstating the perceptual-motor cues learned at acquisition did not facilitate subsequent performance when it was hypothesised they would, i.e. where practice was diminished.

Using direct tests, a difference was found in the accuracy with which old sequences were discriminated from new. Sequences presented six times were recognised with greater accuracy than those presented three times. Thus it would appear that the amount of practice received facilitated this aspect of responding.

5.3.4 DISCUSSION
The aim of the present experiment was to test the hypothesis that the amount of practice influences subsequent performance upon a task. The hypothesis was based on previous findings reported in this thesis in which differential effects upon indirect and direct tests of memory were found when the amount of practice received was manipulated. In the initial set of findings (Study 2) a benefit for having previously practiced specific stimuli was not found upon indirect tests, but was upon direct tests. In a subsequent study (Study 3) in which the amount of practice given was halved, indirect tests revealed a benefit for having previously practiced specific stimuli. However, upon direct tests, previously practiced stimuli were discriminated from new only when the exact procedures used to complete the task at acquisition were reinstated at test. It was expected therefore that the same pattern of responding would be evident using a more sensitive within subjects design.

One of the reasons for reducing the amount of practice given in Study 3 was to ‘cut-off’ practice essentially while the subject was still learning the task. It was hypothesised that the amount of practice given in Study 2 lead to overlearning of the task enabling subjects’ to transfer ‘procedural’ aspects of performance to other similar
stimuli yet retaining the ability to discriminate between what had and had not been previously processed. In the present experiment, there was evidence of learning across sequences presented six times at acquisition; changes in performance did occur across the first three repetitions and continued across the final three repetitions at a negatively accelerating rate. Furthermore, supporting previous findings, the locus of the learning was in the perception and planning component of the response; the motor response component did not change (Salthouse, 1986).

However, there was no change in performance across those sequences presented three times suggesting that typing of these sequences was not facilitated by practice. This finding supports the results reported in Study 3 where only certain sequences were responded to more quickly following the same amount of practice, i.e. benefited from practice. However, what is interesting about this finding is that learning did occur across the first three repetitions of those sequences presented six times. Why did this difference arise? It has been established in this and other experiments in the thesis that learning is negatively accelerated and diminishes rapidly. It may be in the present experiment that most of the knowledge required to perform the task was acquired during the first three repetitions of the task (i.e. the first half of practice for the six repetition set). On presentation of the ‘three repetition’ set therefore, the individual had knowledge of how to perform the task per se, i.e. had some global knowledge of the task, but not knowledge of the specific sequences. Thus some benefit to RTs were experienced, but the absence of change indicated that practice did not facilitate those specific sequences. The improvement in responding to the final three repetitions of the ‘six’ sequence set was thus a consequence of earlier practice.

The suggestion that there was global facilitation occurring is supported by the results at retention. At retention, therefore, the initial finding was to establish whether global aspects of the task were learned when ‘full’ practice (i.e. six repetitions) was received. This was examined in two ways; through a comparison of RTs for different sequence types and through comparing RTs for each transfer group.
In terms of sequence type, response times of sequences entered ‘six times’ did not differ from those that were entered ‘three times’, or those that were ‘new’. This supports the suggestion of global learning and that certain elements of the task are transferred between similar stimuli (Anderson, 1995). The fact that sequences presented ‘three times’ did not differ from either of the ‘old6’ sequences and new also supports this view. Rather than remaining impervious to the effects of alternative practice, at the retention test, the benefits of having previously practiced the task per se are evident.

Additional support for this suggestion comes from the finding that the performance between the transfer groups did not differ. The manipulation in the keypad format did not detrimentally affect responding to those sequences presented ‘three times’. Clearly the effects regarding the sequences presented three times were not hypothesised to occur. It was expected that the absence of perceptual-motor cues learned at acquisition would detrimentally affect responding to these sequences at retention. It was expected, in line with previous studies, that responding to these sequences would be dependent upon the presence of performance cues. However, it would appear that the additional practice received throughout the study session facilitated performance upon this sequence set. Such an assertion would be expected upon the basis of a ‘procedural’ account of learning (Anderson, 1995) but not one in which the specific properties of the sequences were the features that were learned (Logan, 1994; Fendrich et al, 1991).

Performance differences did emerge upon the direct tests, however. Recognition accuracy of those sequences presented ‘six times’ was reliably above chance level; recognition of those sequences presented ‘three times’ was not. This finding supports the notion that there is a dissociation between different types of memory ‘systems’ or ‘forms’. The recognition results are actually very interesting. For sequences repeated six times, a globally based facilitation from practice was found using indirect tests. However, discrimination of the sequences was found when retention was tested directly, which suggests that specific sequence representations are also learned. For
sequences presented three times, using indirect tests the same results emerged. However, using direct tests it was found that the subjects did not acquire sequence specific knowledge.

It would appear therefore, that the additional practice facilitated learning of the task upon a global basis, rather than the specific stimuli. The results suggest therefore that additional practice leads to strengthening of a specific response. Indeed it was demonstrated in the previous experiment that successful retention performance was dependent upon the reinstatement of the exact processing conditions used at study. Thus it would appear that receiving reduced amounts of practice results in a decreased capacity to perform a task; an individual can ‘get by’ in performing generalised aspects of the task, but not specifics. Clearly it would be advantageous to adopt a strategy whereby such deleterious effects could be overcome.

A feature of the present and the previous experiment that remained constant was the length of the retention interval. In terms of the studies presented so far in this thesis, it has been hypothesised that increasing the practice reduces the importance of reinstating the ‘study-test’ conditions while conversely, reducing practice increases this need. A factor that may interact with this may be the ‘length of retention interval’.

Recall that in the present study, there was evidence of ‘forgetting’ between study and test, as indexed by faster responding to the same sequences presented at acquisition and then again at retention. Clearly this suggests that as a consequence of the delay, there is a decay in the representation formed during acquisition; it is this which is hypothesised to increase the reliance upon the match between study and test. The issue that arises therefore concerns the effects of reducing the interval between study and test whilst maintaining the diminished practice conditions of the present study. Does the amount of practice interact with the length of the retention interval?
Given the results reported in the previous chapter in which 'overlearning' of the sequences was proposed to account for the absence of procedural reinstatement effects, would the reducing the interval between study and test have comparable effects under conditions of reduced practice? Or, is it simply the amount of practice *per se*? In attempting to answer these questions the processes that are believed to occur during the retention interval will be examined in the following study.
5.4 STUDY 5. THE EFFECT OF REDUCING THE INTERVAL BETWEEN STUDY AND TEST UPON RETENTION FOLLOWING DIMINISHED PRACTICE.

5.4.1 INTRODUCTION
In the opening Study (3) of this chapter it was suggested that when the amount of practice an individual receives is reduced, such that learning is ongoing at the end of a practice phase, subsequent successful performance upon that same task is influenced by the reinstatement of cues present at acquisition. Subjects in Study 3 responded faster to, in addition to recognising, previously seen and practiced stimuli. Where novel sequences were presented, or the format for responding changed, performance suffered; response times to novel stimuli increased. Such findings contrasted with those reported in the previous chapter (Studies 1 and 2). Following a regime in which twice as much practice was received, a response time deficit was not found when 'new' sequences were presented alongside 'old' and subjects maintained the ability to discriminate between the two types of sequence, apparently without any dependency upon the repetition of perceptual-motor cues.

The amount of practiced received thus appears to be a factor influencing 'what' and 'how' information is retained using this paradigm. Although such an explanation is intuitively appealing previous research has doubted that it is this factor per se, that leads to more effective learning (Adams, 1985). Rather, as was argued in the previous chapter, the 'type' of practice for example, is believed to exert a stronger influence upon retention performance (Groeger, 2000). The results of the studies reported in the previous chapter contradict these established findings; there was no difference in performance using the procedural reinstatement paradigm, depending upon whether a 'massed' or 'distributed' practice schedule was adopted. When the amount of practice was reduced, however, retrieval of the learned information appeared to become more effortful, or cue-dependent. These findings suggest that other variables exert an influence upon the way learned material is manifested at retention. It is hypothesised that one of these variables may be the 'length of retention interval'.
In order to establish whether the length of the retention interval may effect performance, the processes that occur during the delay must be examined; i.e. the processes of ‘forgetting’ and the implications for subsequent retrieval of information. Forgetting is defined as the loss in learned performance observed when time passes between learning and retention (Baddeley, 1997). The deterioration of memory performance over time is demonstrated by retention functions. Retention functions all show the same basic form; initial forgetting is rapid, followed by continued deterioration but at a much slower rate (Anderson, 1995). Thus in the case of the forgetting function, the delay produces smaller and smaller losses; as for the learning function, the forgetting function is negatively accelerated and is best described by a power function (Anderson, 1995).

A question relevant to the present study therefore, is how does the amount of practice affect the retention function? Research has demonstrated a systematic relationship between the degree of practice and the retention function (Anderson, 1995). When the amount of practice is manipulated such that more or less is received, following a retention interval, the underlying functions are approximately parallel; the effect of practice upon the retention function is to shift it up by a multiplicative factor; the materials are actually forgotten at the same rate (Wixted and Ebbesen, 1991).

The pattern of forgetting therefore is likely to be highly similar across a range of situations. A question that remains however, concerns what it is that causes information to be forgotten. Mechanisms responsible for forgetting such as ‘trace decay’, whereby information is eroded by the passage of time (Anderson, 1995) ‘interference’ from other information (either retro- or proactively; Underwood, 1957) and fragmentation of information (Bower, 1967) have all been proposed to account for the processes underlying forgetting.

One of the proposed arguments is that the passage of time creates a mismatch between both the internal and the external contextual cues present during the learning
experience, decreasing the likelihood that target material will be retrieved (Bouton, 1993). In a study demonstrating such effects, groups of subjects were shown line drawings of objects, 1, 3, 9 or 18 times and were subsequently asked to identify each of the original drawings from a number of distractors – ten ‘similar’ objects shown alongside each of the targets. Participants were tested immediately, two hours, two days, or two weeks after seeing the original drawings.

Subjects were more accurate and faster at identifying targets when the test was closer to the study phase; accuracy also increased with the amount of practice received. Unsurprisingly maximum practice (18 trials) coupled with an immediate test resulted in near perfect accuracy. When minimum practice (one trial) was combined with immediate testing an accuracy rate of 60% was achieved, equating to performance observed where 18 trials of practice were combined with a two week delay (i.e. the most practice and the longest delay). Accuracy decreased where one practice trial was experienced and testing was two weeks later (Bahrick, Clark and Bahrick, 1967). In accordance with the predictions that would derive from the power function, the result suggests that there is a trade-off between the amount of practice received and the length of the retention interval.

An alternative account of forgetting is that of ‘retrieval failure’ (Tulving, 1985). This theory corresponds well with the procedural reinstatement framework and is clearly reminiscent of the ‘processing’ view of memory (Blaxton, 1995). The underlying idea of retrieval failure is that at any one time there is more information stored that can be reported. Experiments incorporating ‘recall’ and ‘recognition’ paradigms illustrate this; rates of recollection, in which the subject directly recalls something they have processed, are usually significantly lower than rates of recognition where there is a ‘sense’ of having processed a stimulus before (Mandler, 1980). The key notion is that rather than decaying, information is always ‘available’, but not readily ‘accessible’ (Tulving, 1985).
A major factor influencing the 'availability' of material is the presence of appropriate retrieval cues (Tulving, 1985). To identify 'appropriate retrieval cues' the 'encoding specificity principle' must be examined (Tulving and Osler, 1968). The principle assumes that an appropriate retrieval cue is one which was encoded at the time of learning. Clearly a major point of contention is the testability of this principle. The premise that if a stimulus is retrieved then it has been encoded, if it is not, then it has not been encoded, is inherently circular. Furthermore, there is also an implication with the principle that cues will facilitate performance to the extent that the individual needs them - if there is little or no forgetting (and hence no retrieval failure) then the necessity for cues will become redundant.

Indeed, this suggestion, in combination with the results reported earlier by Bahrick et al (1967) provides the rationale for the forthcoming experiment. To recap, halving the amount of practice received but maintaining a one-week retention interval (Study 3) resulted in increased forgetting of the original stimuli and subsequent performance differences on both indirect and direct tests of memory. Subjects responded more accurately to stimuli that they had previously seen, however this was contingent on the availability of the perceptual-motor cues encoded at acquisition being present at retention. In Studies 1 and 2 these cues were not necessary to facilitate discrimination of previously seen stimuli.

In the present experiment it is expected that reducing the delay between study and test will decrease the necessity for ensuring precise overlap between study-test conditions. As with the Bahrick et al experiment, it is expected that the shorter retention interval will compensate for the reduced amount of practice given. The implication from the retention function is that there will be less forgetting due to the shortened delay (i.e. one hour compared to one week); retrieval failure will not be expected and hence the provision of perceptual-motor cues at retention will not be necessary. In order to examine whether this is indeed the case, the time taken to respond to 'old' and 'new' sequences will be tested; a response time difference will not be expected. However, it is expected that subject's will be able to distinguish between 'old' and 'new'
sequences when tested directly. Such a finding will support the idea that retrieval cues are not always necessary when testing retention.

5.4.2 METHOD

5.4.2.1 SUBJECTS

51 volunteers, 14 males and 37 females with a mean age of 20.5 years, participated in this experiment. Each was randomly assigned to one of four conditions upon arrival at the acquisition session, depending upon the format of the keypad used (‘calculator’ / ‘telephone’) and at retention which ‘transfer group’ they performed the task in (‘switch’ / ‘same”).

5.4.2.2 MATERIALS AND APPARATUS

Three stimulus lists were used in the present experiment, one during the acquisition phase and two during the retention test. Lists were identical to those shown in Study 3 (see Appendix 1) and consisted of either sixty (acquisition) or forty (retention), four-digit sequences.

At acquisition, 60 sequences were presented in total, 20 novel sequences repeated three times. Sequences were presented in four blocks, each block containing three repetitions of five sequences, i.e. one block would follow the pattern: $a, b, c, d, e, a, b, c, d, e, a, b, c, d, e, a, b, c, d, e$. The second, third and fourth blocks followed in the same manner.

At retention, 40 sequences were presented, 20 ‘old’ and 20 ‘new’. The sequences were randomly mixed with the constraint that within any a group of eight sequences, four ‘old’ and four ‘new’ were shown.

The lists were presented on the P.C. and sequences were typed using the modified numeric keypads as described in Section 3.2.

5.4.2.3 DESIGN AND PROCEDURE

The design of the experiment was identical to that used in Study 3 (see section 5.2.2).
The procedure was identical to Study 3 apart from the length of the retention interval. One hour separated study from test.

5.4.3 RESULTS
The results for the acquisition session will be presented prior to those for the retention session. At acquisition the aim was to establish whether learning had occurred across the session and whether different components of the sequences had been learned differently. The unit of analysis was the RTs of the subjects. At retention, the durability of learning was assessed and further investigation of the specificity of learning was performed. The main aim of the experiment was to establish the effect of reducing the retention interval and whether the subjects could distinguish between the sequences. Both indirect and direct tests of memory were used.

5.4.3.1 ACQUISITION

5.4.3.1.1 EVIDENCE OF LEARNING
In order to assess whether practice was benefiting performance it was established whether there was a speed up in responding across acquisition. A paired t-test was used to compare the mean total time taken to enter the first (2887ms, SD = 556ms) and the third (2685ms, SD = 567ms) repetition of the sequences. A reliable difference between RTs was found ($t(50) = 4.619$, $p < 0.001$), the third repetition being entered on average 7% faster than the first.

RTs for individual sequences were subsequently analysed to see whether the decrease in RT was consistent across all sequences, or whether responding differed between particular sequences. The total time taken to enter the first and the third repetition of each sequence is shown on Figure 5.4.1.
Twelve of the sequence pairs were reliably different between repetitions (using paired t-tests, where p < 0.05). There were no differences in the time taken to enter sequences 5 (6726), 7 (6826), 9 (9438), 12 (8626), 16 (5824), 18 (9157), 19 (8637), 20 (4375); (p > 0.05). It is worth noting that as was found in Study 3, there is nothing 'peculiar' about these sequences that may have contributed to the absence of learning effects, i.e. the repetition of the same digits within these sequences; the repetition of the digit '6' in sequences 5, 7 and 12 may have added to RT, but this seems unlikely due to the fact that the other sequences do not contain repeating digits. It is interesting to note that four of those sequences were amongst the final sequences presented, suggesting diminished benefits from practice, or asymptotic responding by the end of the acquisition phase.
Pearson's product moment correlation coefficients were subsequently calculated to examine the variance between repetitions for each of the sequence pairs. To recap it was assumed that high correlations would suggest that information used at the first repetition was again being used at the third repetition. RTs for all sequence pairs were positively correlated (p < 0.05), only the coefficient for sequence 5 was not reliable (p > 0.05). The mean coefficient 'r' was .50, ranging from .24 (sequence 5) to .73 for sequence 19. This finding suggests that there is a certain amount of shared variance between the first and the third repetition of each of the sequence pairs, i.e. that the same 'information' is used when typing specific sequences. The t-test results which show reliable differences suggests that practice is having a specific, facilitative effect.

Overall the findings indicate that responding does improve over time, the time taken to enter the sequences decreasing with practice. However, the results suggest that although individual sequences are responded to differently and furthermore, that specific aspects of those sequences are learned across the practice session. However, as in the previous experiment (Study 3), the results again appear to suggest that learning is still ongoing at the end of the practice phase.

5.4.3.2 PERCEPTION AND PLANNING

The change in time taken to encode the sequences was measured and used as an index of the planning involved in responding. To recap, encoding time was the time taken to make the first keypress from the onset of the sequence upon the screen. The mean encoding time for the first repetition of the sequences was 1473ms (SD = 351ms), 8% greater and reliably slower than the time taken to encode the third repetition (1366ms, SD = 356ms) of the sequences (t(50) = 5.077, p < 0.001).

The differences in RT for each of the sequences were examined and are shown on Figure 5.4.2. Paired t-tests were performed on these data; reliable differences were found for ten sequence pairs only (p < 0.05). Eight of the ten pairs that were not reliably different were presented in the second half of the list. This suggests that
practice leads to stability of encoding. However, Figure 5.4.2 shows that although following a downward trend, encoding has not settled by the final sequence presentation.

![Figure 5.4.2 Mean median encoding times (in ms) for the first and the third repetition of the sequences.](image)

Pearson’s product moment correlation coefficients found that apart from sequence 1, all coefficients were reliably positively correlated (p < 0.05) again suggesting that some of the information used to encode the first repetition was again used to encode the third repetition. The mean coefficient ‘r’ was .56, ranging from .20 (sequence 1), to .75 for sequence 19. Indeed the correlation between repetitions of sequence 2 was also very low (.23) which suggests that the fact that these sequences were presented at the beginning of the list had a detrimental effect upon performance.

The results echo those of the ‘total time’ findings. Although there is an overall speed-up across repetitions, closer examination reveals that performance has not changed by
the third repetition for half of the sequences. Specific sequences are being learned differently. Within each sequence, however, it would appear that the same 'encoding type' of information is being strengthened with each presentation. The fact that responding has not levelled off by the end of the practice session suggests that learning is still ongoing. The pattern of the results is again very similar to those reported in Study 3, in terms of the time taken and the nature of responding.

5.4.3.2.1 MOTOR RESPONSE EXECUTION

The change in motor responding was assessed by comparing the time taken to execute the final three digits of the sequence. The mean RT for each of the keystrokes performed is shown on Table 5.4.1.

Table 5.4.1 Mean median execution times (in ms and SDs) for the first and third repetition of the sequences.

<table>
<thead>
<tr>
<th>RT measure</th>
<th>Repetition 1</th>
<th>Repetition 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keystroke 2</td>
<td>448 (148)</td>
<td>415 (139)</td>
</tr>
<tr>
<td>Keystroke 3</td>
<td>575 (109)</td>
<td>557 (262)</td>
</tr>
<tr>
<td>Keystroke 4</td>
<td>395 (137)</td>
<td>346 (104)</td>
</tr>
</tbody>
</table>

The difference in time taken to execute the third repetition of the sequences as a proportion of the first was calculated. A 6%, 3% and 9% reduction in RT was found for Keystrokes 2, 3 and 4, respectively. Keystrokes' 2 ($t(50) = 2.766, p < 0.01$) and 4 ($t(50) = 2.956, p < 0.001$) were executed reliably faster at the third repetition than the first, but there was no change in the time taken to execute the third digit of the sequence ($t(50) = .649, p > 0.05$). Keystroke 3 also took reliably longer to execute than 2 and 4 ($F(2, 104) = 52.854, p < 0.001$). This again suggests that some sort of parsing mechanism is being used to respond during the task (as in Study 3), and at the parsing boundary, i.e. the third keystroke, the facilitative effect of practice upon motor and perceptual performance does not occur to the same extent to pre- or post boundary performance.
In summary, the results at acquisition support the previous experiments in that there is an improvement in performance with practice and the facilitation is for both the planning and the motor response components of the sequences. Again specific properties of the sequences appear to be learned as response times differed between the sequences. However it is worth noting that for certain sequences pairs there was no difference in responding between the first and third repetition. This may be due to the amount of practice given; it was insufficient to result in any improvement.

5.4.3.3 Retention

The durability and 'nature' of the learning that occurred during acquisition was initially examined through an analysis of the total time taken to enter the sequences. Using a paired t-test, it was found that the mean time taken to enter the third repetition of the sequences at acquisition (2685ms, SD = 567ms) was not different from the time taken to enter 'old' sequences (t(50) = 1.192, p > 0.05), but was reliably faster than the time taken to enter 'new' sequences at test (t(50) = 3.090, p < 0.05) as Table 5.4.2 illustrates. A lasting RT advantage was found at test for having previously typed the sequences, a finding that has not previously been demonstrated.

The effect of prior practice was more closely examined by examining performance at retention only. A 2 x 2 ('sequence type' by 'transfer group') repeated measures ANOVA was performed on the data. Table 5.4.2 shows the time taken to enter each type of sequence within both transfer groups. There was no difference between the 'transfer groups', (F(1,52) = 1.61, p > 0.05), indicating that the change in the motor response format does not detrimentally effect performance. A main effect of 'sequence type' was found (F(1,52) = 28.25, p < 0.001); the time taken to enter 'old' sequences ('same': 2616ms; 'switch': 2680ms) was reliably faster than the time taken to enter 'new' ('same': 2658ms; 'switch': 2730ms).
Table 5.4.2. Mean total times (in ms) as a function of sequence type and transfer group

<table>
<thead>
<tr>
<th>Transfer group</th>
<th>New (SD)</th>
<th>Old (SD)</th>
<th>Old digit (SD)</th>
<th>Old motor (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>2658 (364)</td>
<td>2616 (328)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Switch</td>
<td>2730 (532)</td>
<td>2680 (436)</td>
<td>2731 (471)</td>
<td>2608 (401)</td>
</tr>
</tbody>
</table>

Within the ‘switch’ transfer group only, Table 5.4.2 shows that the benefit received for ‘old motor’ sequences was greater than that for ‘old digit’. This suggests that retention was facilitated by reinstatement of the motor representation rather than the perceptual representation. The fact that there was no interaction between the variables suggests that the subjects responded to each of the sequence types in the same way.

5.4.3.3.1 PERCEPTION AND PLANNING

The encoding time data were analysed in order to examine in greater detail whether prior practice facilitated perception and planning of responses, i.e. the perceptual representation of the sequences was retained. The initial comparison made was between the time taken to encode the third repetition of the sequences at acquisition and the sequences at test. Sequences at acquisition (1366ms, SD = 356ms) were encoded reliably faster than ‘new’ sequences at test ($t(50) = 2.205, p<0.05$) but were not different from the same, or ‘old’ sequences at test ($t(50) = 1.645, p>0.05$) as illustrated in Table 5.4.3.

Table 5.4.3. Mean encoding times (in ms) as a function of sequence type and transfer group.

<table>
<thead>
<tr>
<th>Transfer group</th>
<th>New (SD)</th>
<th>Old (SD)</th>
<th>Old Motor (SD)</th>
<th>Old Digit (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>1476 (346)</td>
<td>1478 (341)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Switch</td>
<td>1488 (412)</td>
<td>1466 (389)</td>
<td>1429 (356)</td>
<td>1498 (419)</td>
</tr>
</tbody>
</table>

This expands previous findings by suggesting that the planning component of the sequences is facilitated by prior experience with the stimuli and again suggests that
specific features of the stimuli are learned and retained; retention of specific sequence information has not been previously demonstrated for encoding time. Examining performance at test only, therefore can clarify further the role of perceptual processes in responding.

A 2 x 2 (‘sequence type’ by ‘transfer group’) repeated measures ANOVA was used on the encoding time data. Table 5.4.3 shows encoding times for ‘old’ and ‘new’ sequences within both transfer groups. Neither a main effect of ‘transfer group’ (F(1,52) = 0.06, p > 0.05) nor of ‘sequence type’ (F(1,52) = 0.01, p > 0.05) was found. Manipulating the perceptual representation or the motor response requirement did not impede the perception and planning involved in the initial execution of the sequence, suggesting that responses were not made on the availability of perceptual cues.

For the switch transfer group only, a statistically significant difference was found in the time taken to encode ‘old motor’ sequences in comparison to ‘new’ and ‘old digit’ (F(1,27) = 12.19, p = 0.002). This result suggests that regardless of whether the response format changed (i.e. the keypad was not the same as was practiced upon) maintaining the same motor action enhances the speed of responding; initial responding is not simply based upon the perceptual cues provided by the stimuli, but rather by knowing the location of the key to be pressed. This is examined in greater detail in the following section.

5.4.3.3.2 EXECUTION TIME

In order to examine whether changes in execution time occurred between acquisition and test, component keystroke times for the third repetition at acquisition were compared to ‘old’ and ‘new’ sequences presented at test. The sequences presented at test regardless of type, were entered reliably faster than the third repetition at acquisition (p > 0.05). This result was unexpected in light of previous findings, but it is worth noting that the interval in the present experiment was much shorter than usual, i.e. one hour compared to one week. (For t-values see Appendix 13).
The specificity of the knowledge acquired was further examined by assessing execution performance at test only. Table 5.4.4 shows each component keystroke time for each sequence type within transfer groups. Data were analysed using a 2 x 2 (‘sequence type’ by ‘transfer group’) ANOVA, with the additional three level factor of ‘keystroke’ (representing each of the component keystrokes). Main effects were not found for ‘sequence type’ (F(1,52) = 0.68, p = 0.415), or ‘transfer group’ (F(1,52) = 2.62, p = 0.112). These results suggests that although motor response patterns specific to certain sequences were learned, cues provided from previously seen sequences were generalised to other similar sequences.

The only reliable effect that was found was for keystroke (F(2,104) = 34.70, p = < 0.001) and reflected the difference in time taken for the third keystroke in comparison to the fourth. This finding supports the notion of ‘parsing’, suggesting that the third keystroke requires additional processing compared to the remaining keystrokes.

Table 5.4.4. Mean median execution times (in ms) for the switch transfer group as a function of sequence type.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Key 2</th>
<th>Key 3</th>
<th>Key 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>New</td>
<td>380 (182)</td>
<td>523 (142)</td>
<td>312 (143)</td>
</tr>
<tr>
<td>Old</td>
<td>346 (160)</td>
<td>505 (121)</td>
<td>287 (172)</td>
</tr>
<tr>
<td>Old digit</td>
<td>351 (68)</td>
<td>503 (94)</td>
<td>294 (93)</td>
</tr>
<tr>
<td>Oldmotor</td>
<td>373 (63)</td>
<td>528 (112)</td>
<td>296 (87)</td>
</tr>
</tbody>
</table>

With respect to the switch transfer group only, there was no difference between the execution times for each of the sequence types.

In summary, there was no RT benefit from having previously encoded and executed previously seen sequences in the present study. There did appear to be a benefit afforded to the way in which novel sequences were responded to however. It would appear that having received previous practice in executing the sequences allowed generalisation of performance to other similar sequences.
5.4.3.4 RECOGNITION

In order to examine whether subjects had any explicit memory for the sequences they entered, recognition accuracy of old sequences was analysed. On the basis of signal detection theory hit and false alarm rates of 'old' sequences were calculated. The mean probability of hits, that 'old' sequences were correctly recognised as old, for the 'same' transfer group was 0.53; for false alarms, the probability of 'new' sequences being incorrectly recognised as old, was higher at 0.63. For the 'switch' transfer group, the probability of hits was 0.54, the probability of false alarms was 0.59.

$A'$ was calculated from these data. For the 'same' group, mean $A' = 0.67$, for the 'switch' group, $A' = 0.65$. In order to verify whether discrimination was occurring at a level greater than chance, the results were tested using a one-sample t-test, with a criterion level of .5. Detection of 'old' sequences was reliably greater than chance for both the 'same' transfer group ($t(28) = 7.68, p < 0.001$) and the 'switch' group ($t(26) = 6.93, p < 0.001$). There were no reliable differences between the two groups in their ability to recognise the sequences.

Thus, both groups demonstrated recognition memory for 'old' sequences. Furthermore, the fact that responding did not differ as indexed using indirect tests of memory, suggests that the subjects were not using perceptual-motor cues to facilitate retrieval. It would appear that reducing the retention interval facilitates recognition of the sequences.

5.4.3.5 SUMMARY

Findings at acquisition indicated that the subjects were learning the task and furthermore, were learning specific properties of the sequences. Pearson's correlation coefficients demonstrated that the knowledge acquired when performing the task upon immediate presentation was used for later (i.e. the third) presentations of specific sequences. When responding to the sequence components was examined, in terms of
encoding, the sequences were encoded differently, but the shared variance between first and the third repetition of the specific sequences was high, suggesting that the same encoding 'information' was being used on the two occasions. The same pattern of findings emerged for the execution time data. In addition, using t-test analysis it was demonstrated that only half of the sequence pairs (i.e. the first and the third repetition) were responded to differently at the third repetition. However, rather than suggesting RTs had reached asymptote, the inter-sequence variability suggests that the sequences were still being learned at this stage. Essentially, the results of the present study parallel those found in the previous study, in which the same amount of practice was given.

Both indirect and direct tests of retention were performed. The indirect tests measured RTs to 'old' and 'new' sequences as well as measuring the effect of a manipulation in the keypad format used to enter the sequences. For each of the RT measures, the initial measurement was whether forgetting of the sequences had occurred during the retention interval. There was no difference between RTs for those sequences shown at both study and test. This is the first demonstration of this finding so far in the thesis, and in terms of the present study, the first indication of support for the idea that subjects may not rely upon perceptual-motor cues to facilitate retrieval performance.

Indeed, results relating to encoding and execution time did not show a difference in performance upon the critical measures of 'sequence type' and 'transfer group'. Where the manipulations in task requirements had been made, performance, measured in terms of RTs, did not suffer.

The effects of the manipulations were demonstrated on the direct tests of memory. Both of the transfer groups were able to discriminate those sequences that they had previously seen, from those that were new. Thus despite the apparent absence of perceptual-motor cues which, as was demonstrated in Study 3, may have implicitly facilitated performance, recognition of stimuli occurred in the present study. In line
with the hypothesis under investigation this may be attributable to the reduced retention interval.

5.4.4 DISCUSSION
The aim of the present experiment was to examine whether, under conditions of diminished practice, reducing the time interval between study and test would have a beneficial effect upon retention of the stimuli. The rationale for the present study emerged from the findings of the previous studies. To recap, in Studies 1 and 2, it was demonstrated that manipulating the conditions (i.e. removing retrieval cues) between study and test did not detrimentally affect performance; subjects were able to recognise previously seen sequences. However, when the amount of practice was reduced, and the retention interval of one week was maintained, performance suffered when retrieval cues were absent.

These results suggest that the amount of practice contributed to the differential findings, an intuitively appealing idea. Such an idea is not theoretically robust (Adams, 1985) but, a separate body of literature has demonstrated that the length of the retention interval in combination with the amount of practice is an important factor to consider when assessing retention (Bouton, 1993). In the present study therefore, it was hypothesised that the potential cost of reducing the amount of practice given would be offset by a reduction in the interval between study and test.

The demonstration that learning was occurring and that the subjects would indeed have potential information to retrieve was established at acquisition. Learning of the sequences was occurring and furthermore, the results are comparable to those reported in Study 3, whereby specific sequences were being learned differently from others and that improvement within sequences differed over the study session. Not only does this demonstrate that the way in which the sequences were learned is relatively robust, such results allow more definitive conclusions to be drawn about the effects of manipulating the retention interval.
The aim of reducing the retention interval was to examine whether subjects would make use contextual cues when retrieving information. This aim was based on an understanding of the proposed effect of delaying retention performance. It has been argued that the delay between study and test leads to forgetting of what was learned (Baddeley, 1997) It has been proposed that this results in 'unavailability' of information on the one hand, for example, forgetting due to interference (Underwood, 1957), or alternatively that information is available, but not always accessible; access depends upon the presence of retrieval cues (Tulving, 1985). The presence of retrieval cues in this study was manipulated through varying the overlap between experimental conditions at study and then at test. Furthermore, it was expected that reducing the retention interval would increase the likelihood of retrieval cues being used and hence information retrievable.

On the basis of indirect tests subjects did not respond differently to, in terms of perceiving, planning and executing, 'old' sequences that had been previously practiced at acquisition and 'new' sequences. This initially suggests therefore that the perceptual-motor cues associated with 'old' stimuli were not facilitating performance upon these sequences. It was evident that the subjects were learning specific attributes of the stimuli through the results found for performance at acquisition, however, these attributes were not used at test. Conversely, it appeared as though subjects were without awareness, generalising their knowledge to other similar sequences at test.

What this may suggest therefore is that the retrieval cues may have been used, but rather than providing a facilitative effect for previously seen sequences, the benefit of having previously practiced the stimuli was due to the transfer of performance to other similar, i.e. 'new' stimuli. Thus retrieval cues may have been used at test, but the 'transfer' element of the task may have obscured the effect. Results of the direct tests illuminate this.
Direct tests used in the present study were those of sequence 'recognition'; subjects had to discriminate 'old' sequences from 'new'. The use of direct tests in conjunction with indirect tests clearly enables a stronger challenge about the presence of retrieval cues. To recap, in the present experiment, it was hypothesised that reducing the retention interval would negate the need for retrieval cues. Indirect tests illustrated that cues provided by the presence of 'old' sequences were not used, or were perhaps obscured by the ability of subjects to transfer elements of performance. Using direct tests, it was demonstrated that subjects were still able to discriminate 'old' sequences from 'new'. That is, subjects had explicit knowledge of specific sequences and, unlike Study 3 in which the retention interval was one week rather than an hour, were able to demonstrate such knowledge in the absence of cues.

Thus, the results lend support to the claim that the length of the retention interval does affect performance. Indeed, the present results are comparable to those reported by Bahrick et al (1967) in which differential effects were found when the amount of practice was manipulated alongside the length of retention interval. The findings of the present study (no difference upon indirect tests, but differences on direct tests) were also reported in Studies 1 and 2 where double the amount of practice was given with a longer retention interval. Clearly such findings echo those reported by Bahrick et al (1967) where they demonstrated minimum practice (one trial) combined with immediate testing equated to performance where 18 trials of practice was combined with a two week delay (i.e. the most practice and the longest delay). Again the result suggests that there is a trade-off between the amount of practice received and the length of the retention interval; too little practice with too much delay appears to increase the necessity for the presence of appropriate retrieval cues to facilitate retention performance.

Before concluding the discussion element of this study and summarising the overall conclusions about the findings reported in this chapter a closer examination of the relationship between 'retention interval' and the 'amount of practice' will be performed. A cross study comparison of Study 3 and Study 5 will now be conducted.
5.5 **STUDY 5B A COMPARISON BETWEEN STUDY 3 AND STUDY 5. ASSESSING THE EFFECT OF A REDUCTION IN RETENTION INTERVAL FOLLOWING REDUCED PRACTICE.**

5.5.1 **INTRODUCTION**
The main reason for performing the experiments reported in the present chapter was to examine further the conditions under which reinstating the context between study and test and thus the perceptual-motor cues present at acquisition, facilitates performance at retention. It was found that under conditions of reduced practice (Study 3) an increased reliance upon the reinstatement of 'retrieval cues' emerged. However, in the previous study (Study 5) where the same amount of practice was given but the retention interval was reduced, the dependency upon such retrieval cues was not found. One of the reasons for this finding may be due to the rate at which the information is forgotten following practice. It has been suggested that although the rate of forgetting does not differ depending upon the amount of practice received, clearly testing performance at an earlier stage following the same amount of practice would result in improved retention performance. This was tested in the following study, which is based upon a reanalysis of the data from Studies 3 and 5. A direct, exploratory comparison of responding at retention will be performed in order to obtain a deeper insight into the effects of reducing the retention interval.

5.5.2 **METHOD**
Section 5.2.2 details the design and procedure for Study 3. Section 5.4.2 details the design and procedure used in Study 4.

5.5.3 **RESULTS AND DISCUSSION**
Data from the retention phases only were analysed. Analysis was performed on the data for each of the RT measures, using the subjects as the unit of analysis.
5.5.3.1 **Overall Time Taken to Respond to Sequences**

A 2 x 2 (‘sequence type’ by ‘study’) repeated measures ANOVA was performed on the ‘total time’ data to obtain an indication of whether, overall, RTs were faster within either of the studies. Table 5.5.1 illustrates the RTs for each sequence type found within each study.

**Table 5.5.1.** Mean total time (in ms with SD), taken to enter each sequence type within each transfer group across studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>Group</th>
<th>New</th>
<th>Old</th>
<th>Old digit</th>
<th>Old motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Same</td>
<td>2711 (391)</td>
<td>2631 (302)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>Switch</td>
<td>3096 (774)</td>
<td>2883 (693)</td>
<td>2932 (206)</td>
<td>2826 (215)</td>
</tr>
<tr>
<td>5</td>
<td>Same</td>
<td>2658 (364)</td>
<td>2616 (328)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>Switch</td>
<td>2730 (532)</td>
<td>2680 (436)</td>
<td>2731 (471)</td>
<td>2608 (401)</td>
</tr>
</tbody>
</table>

As expected a main effect of ‘sequence type’ was found (F(1, 92) = 28.059, p < 0.001), ‘old’ sequences were typed faster than ‘new’. The more interesting finding was the effect of ‘study’, which approached significance (F(1, 92) = 3.546, p = 0.06). The direction of the results indicate that the sequences were entered faster by participants in Study 5, that is where the retention interval was reduced. There was no interaction between ‘sequence type’ and ‘study’ (F(1, 92) = 1.741, p > 0.05); the pattern of responding across the sequences was the same within each study.

The ‘total time’ data for each of the transfer groups across studies were analysed. A 2 x 2 (‘sequence type’ by ‘study’) repeated measures ANOVA was performed on the data from the ‘same’ transfer group. A main effect of ‘sequence type’ was found (F(1, 44) = 6.22, p < 0.05), the ‘old’ sequences entered faster than the ‘new’. However, there was no difference between the studies (F(1, 44) = 0.182, p > 0.05). The temporal delay between the test did not affect the time taken to respond when the conditions between study and test overlapped. This is further supported by the results of a 2 by 2 (‘sequence type’ by ‘study’) ANCOVA. The time taken to enter the first fifteen sequences at acquisition was included as the covaried out of the analysis.
There was no difference between the studies and the time taken to respond \((F(1, 43) = .581, p > 0.05)\). These findings suggest that reducing the interval between study and test does not influence subsequent retention performance when the conditions at study and thus the retrieval cues are reinstated at test.

The analyses were repeated on data from the 'switch' transfer group. A main effect of 'sequence type' \((F(1, 46) = 24.653, p < 0.001)\) was found, 'old' sequences were entered faster than 'new'. A main effect of 'study' was also found \((F(1, 46) = 4.579, p < 0.05)\). Subjects who performed the task following a shorter interval (i.e. Study 4), responded faster than those receiving a longer interval (Study 3). A 2 x 2 ANCOVA using the time taken to enter the sequences at acquisition as the covariate was performed on these data. A main effect of 'study' was again found \((F(1, 42) = 4.303, p > 0.05)\). Thus, it would appear that reducing the retention interval has a beneficial effect upon performance when retrieval cues are absent or are manipulated in some way, reducing their utility.

Encoding times within the 'same' transfer group were examined between studies. RTs for each of the sequence types within each of the studies are shown in Table 5.5.2.

<table>
<thead>
<tr>
<th>Study</th>
<th>Group</th>
<th>New</th>
<th>Old</th>
<th>Old digit</th>
<th>Old motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Same</td>
<td>1499 (326)</td>
<td>1454 (278)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>Switch</td>
<td>1712 (514)</td>
<td>1574 (443)</td>
<td>1587 (492)</td>
<td>1568 (427)</td>
</tr>
<tr>
<td>5</td>
<td>Same</td>
<td>1476 (346)</td>
<td>1478 (341)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td></td>
<td>Switch</td>
<td>1488 (412)</td>
<td>1466 (389)</td>
<td>1429 (356)</td>
<td>1498 (419)</td>
</tr>
</tbody>
</table>

Using a 2 x 2 ANOVA, neither a main effect of 'sequence' \((F(1, 44) = 1.142, p > 0.05)\) nor of 'study' \((F(1, 44) = .00, p > 0.05)\) was found. There was no interaction between the variables \((F(1, 44) = 1.428, p > 0.05)\). With respect to the 'switch'
transfer group, a main effect of ‘sequence type’ was found (F(1, 46) = 7.139, p < 0.05), ‘old’ sequences were encoded faster than ‘new’. There was no main effect of ‘study’ (F(1, 46) = 3.546, p > 0.05) and there was no interaction between the factors (F(1, 46) = 3.090, p > 0.05).

Thus in terms of the time taken to perceive and respond to the initial representation of the sequences there was no difference depending upon whether the retention interval was one hour or one week.

The time taken to execute the sequences was subsequently analysed, RTs are shown in Table 5.5.3.

Table 5.5.3 Execution times (in ms with SDs) for each of the sequence types, across studies (Study 3 top half of the table, Study 5, bottom half)

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Same Key 2</th>
<th>Key 3</th>
<th>Key 4</th>
<th>Switch Key 2</th>
<th>Key 3</th>
<th>Key 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>New</td>
<td>368 (88)</td>
<td>497 (179)</td>
<td>356 (99)</td>
<td>446 (179)</td>
<td>519 (274)</td>
<td>390 (234)</td>
</tr>
<tr>
<td>Old</td>
<td>344 (95)</td>
<td>488 (172)</td>
<td>342 (119)</td>
<td>431 (172)</td>
<td>607 (224)</td>
<td>337 (175)</td>
</tr>
<tr>
<td>Old digit</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>337 (72)</td>
<td>563 (86)</td>
<td>298 (42)</td>
</tr>
<tr>
<td>Old motor</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>344 (44)</td>
<td>514 (69)</td>
<td>312 (41)</td>
</tr>
<tr>
<td>New</td>
<td>328 (178)</td>
<td>420 (123)</td>
<td>289 (89)</td>
<td>380 (182)</td>
<td>523 (142)</td>
<td>312 (143)</td>
</tr>
<tr>
<td>Old</td>
<td>306 (109)</td>
<td>396 (148)</td>
<td>277 (97)</td>
<td>346 (160)</td>
<td>505 (121)</td>
<td>287 (172)</td>
</tr>
<tr>
<td>Old digit</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>351 (68)</td>
<td>503 (94)</td>
<td>294 (93)</td>
</tr>
<tr>
<td>Old motor</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>373 (63)</td>
<td>528 (112)</td>
<td>296 (87)</td>
</tr>
</tbody>
</table>

Within the ‘same’ transfer groups, a main effect of ‘sequence type’ was found (F(1, 44) = 8.9, p < 0.05), indicating that ‘old’ sequences were entered faster than ‘new’. A main effect of keystroke was found (F(2, 88) = 31.407, p < 0.001), which reflected the time taken to execute the third keystroke compared to the second and the third. Most importantly however, a main effect of ‘study’ was also found (F(1, 44) = 6.119, p <
0.05), reflecting the fact that the sequences were executed faster following a shorter retention interval.

The findings were replicated within the 'switch' transfer group. A main effect of sequence was found (F(1, 46) = 14.456, p < 0.001), 'old' sequences were executed faster than 'new'. A main effect of 'keystroke' was found (F(2, 92) = 32.827, p < 0.001). A main effect of 'study' was also found (F(1, 46) = 7.081, p < 0.05). Execution of the sequences was faster where the interval between study and test was shorter. None of the interactions were significant which illustrates that the way in which the sequences were executed was the same across the studies.

The comparison between the findings from the above studies suggest that overall, there is a less of a performance decrement when the time between study and test is reduced. Clearly this is intuitively appealing simply due to the fact that there is less time for forgetting to occur. However, upon closer examination it would appear that this does depend upon the subsequent match between conditions at study and then at test.

When performance conditions were reinstated at test there was no difference in RTs between the study groups. The length of time spent away from the task following practice did not affect subsequent performance. This suggests that the overlap in conditions provided enough cues for enhanced performance. This is supported by the fact that within the 'switch' transfer groups, when testing followed a one-week interval a RT decrement was found when compared to performance following a one-hour interval. Increasing the interval between study and test therefore appears to exacerbate the effects of decreasing the available contextual cues.

The 'aspect' of performance most detrimentally affected by the retention interval appears to be the motor response component of the task. There was no difference in RTs at all for encoding. However, the increased interval of one week detrimentally affected motor responding. What this suggests is that the perceptual, encoding and
planning phases of the response remain relatively stable over time and are subject to less decay than the motor aspects in this context.

The main finding of interest with respect to the execution of the sequences is that regardless of whether the contextual cues are present or absent, when the retention interval increases performance suffers. Again this is intuitively appealing: the execution of the sequence is the physical part of the task requiring increased levels of practice and is more likely to decay over time (Welford, 1987). A detrimental effect does not arise as a consequence of switching the motor requirements of the task. This lends support to the claims above, that there is a period within which the response becomes increasingly specific. Following a one-hour interval this does not happen, responses are easily adaptable to other similar response patterns. However, to maintain levels of responding over time the availability of contextual cues becomes more important.

5.6 CONCLUSIONS
The experiments reported in the present chapter were designed to investigate whether manipulating the amount of practice given at study and the delay between study and test, had any effect upon the learning and retention of stimulus material.

In Study 3, the amount of practice given was halved compared to that given in Studies 1 and 2. This was designed to inhibit learning of the stimuli consequently increasing the reliance upon the presence of stimulus specific perceptual and motor cues at retention. That is, it was hypothesised that under these circumstances the effects of procedural reinstatement would be evident. The results supported the predictions. It was demonstrated that subjects relied upon specific knowledge formed during acquisition, to perform at retention. An underlying global representation of how to perform the task was not developed. However, this effect does appear to be due to the amount of practice that was given.
In Study 4 a more sensitive within-subjects' design was used, where participants were presented with either three or six repetitions of the sequences. It was hypothesised that sequences presented three times would be distinguished from new only when the processing conditions at learning were reinstated at test. This was not found. There was no difference in performance at retention depending upon the amount of practice received. It would appear that the increased practice upon the additional sequences facilitated the development of global response strategies.

The final experiment reported the effects of reducing the retention interval in conjunction with experiencing reduced practice. This study was conducted to examine whether reducing the delay between study and test decreased the necessity for ensuring precise overlap between study-test conditions. It was expected that the shorter retention interval would compensate for the reduced amount of practice given. Indeed, this was the case. Responding to old and new sequences was indistinguishable suggesting that responding was occurring on a global basis, i.e. that performance was transferring to similar aspects of the task. However, this was coupled with the finding that the capacity to discriminate previously seen material was retained. This suggests therefore a dissociation between implicit and explicit knowledge. More specifically, demonstration of the latter is not dependent upon the former.

Thus with respect to the effects of procedural reinstatement are evident, it would appear that the learning conditions exert a strong influence over the situations in which they are exhibited. Thus far it would appear that the effects are found when learning is degraded in some way. In the following chapter this notion will be extended. The difficulty of the to be learned material will be examined.
6 TASK DIFFICULTY AND THE EFFECTS UPON LEARNING AND RETENTION

6.1 SUMMARY
The studies reported in this final empirical chapter investigate further the conditions under which learned information transfers to different situations. One of the objectives of this thesis has been to investigate the premise, associated with the procedural reinstatement argument, that enhanced performance at retention will be evident to the extent that the conditions at study and test overlap. However, thus far the effects of procedural reinstatement have only been demonstrated when learning conditions are degraded in some way, suggesting that under these conditions, retention of the task is dependent upon appropriate retrieval cues. The first study reported in the present chapter uses a slightly modified version of the procedural reinstatement paradigm. The familiarity of the stimulus response associations is manipulated. It is expected that this will increase the difficulty of learning the task and thus increase the dependency upon contextual cues at retention and reduce the likelihood of transfer of performance.

In the second study reported, a final manipulation will be made to the intra-list organisation of the practice schedule. Either a ‘blocked’ or a ‘spaced’ practice regime will be undertaken. This will enable a test of ‘procedural reinstatement’ as well as that of ‘contextual interference’ (CI). By increasing task difficulty, CI is hypothesised to reduce the necessity of procedural overlap between study and test. Clearly this is at odds with procedural reinstatement. Thus, the final experiment will allow further investigation into the idea that procedural reinstatement effects arise as a consequence of a response strategy used under deleterious learning conditions.
6.2 STUDY 6 DOES TASK DIFFICULTY INFLUENCE PROCEDURAL REINSTATEMENT EFFECTS?

6.2.1 INTRODUCTION
In the previous chapter the aim of the studies was to examine the conditions which resulted in the demonstration of procedural reinstatement effects. The results of Study 3 indicated that under conditions of reduced practice, enhanced retention performance was evident only when the perceptual-motor cues that were used at study were made available at test. When such retrieval cues were unavailable, caused by a manipulation in the stimuli and the response requirement of the task, performance suffered. The results were interpreted as evidence for the heightened importance of appropriate retrieval cues following adverse learning conditions. Indeed, in a follow-up study (Study 5) it was demonstrated that the effects of such adverse learning conditions could be ameliorated when the interval between study and test was reduced. Following on from this it is arguable that the effects of procedural reinstatement may be transient, only being demonstrated when learning of the task is in some way difficult or incomplete.

The present study seeks to explore this notion further. More specifically, the 'familiarity' of stimulus-response pairings and the effect upon learning and retention will be examined. It was asserted in Chapter 2 of the thesis that individuals in Western society have pervasive experience of performing typing actions (Trewin and Pain, 1999). Such experience involves typing numeric digit strings upon specific keypad layouts, i.e. entering telephone numbers and cashpoint PIN numbers on the respective layouts (Willingham, 1998). The action of typing a number sequence is highly familiar to most people (Clegg, 1998).

Clearly, in terms of the present studies, this has implications for the experiential abilities of those participating. Under circumstances in which extensive practice has
been previously experienced, the capacity to respond to the numeric four-digit strings incorporated in the preceding studies may have been relatively easy following a certain level of laboratory based practice. It is for this reason that the present study sought to examine the efficacy with which individual’s could associate unfamiliar stimuli with a ‘familiar’ response.

In order to understand how ‘familiarity’ may affect learning and retention of material, the processes that occur during transcription typing, i.e. when the stimuli and the response format are familiar and congruent, will be examined. Transcription typing is a complex cognitive task, composed of intertwined perceptual and motor processes. At least two major tasks must be performed during copy typing, encoding of visual text and the subsequent translation of this into a sequence of corresponding manual keypresses (Inhoff and Wang, 1992). These two features must be successfully coordinated in order to ensure the availability of encoded text for continuous legible manual output (Salthouse, 1986b).

The differences in performance when novel perceptual-motor associations are ‘being learned’ and ‘are learned’, respectively, is demonstrated through an examination of inexperienced and experienced individual’s ability. Inexperienced individuals typically reach typing speeds of about 30 wpm and average error rates of 34%; experienced transcription typists with about 10,000 hours of practice reach rates of up to 80 wpm, with error rates of 0.3% (Bosman, 1994). Clearly there is a massive discrepancy in the respective ability to co-ordinate perceptual-motor responding. These results demonstrate that the effort expended at the outset of learning novel associations is very high.

In addition to these ‘co-ordinating’ demands, typing is also affected by the ‘to-be-typed’ material (Salthouse, 1986a). Although studies have demonstrated that certain semantic effects exert little influence on performance, for example typing passages of prose in a native or foreign language (Gentner et al, 1988), deterioration in performance has been demonstrated when transcribing of non-words has been studied.
These findings suggest that some form of language processing is involved in typing but it may not extend to units larger than the word (Salthouse, 1986a).

Indeed, an explanation for the detrimental effects of having to process random letter strings is provided by understanding 'lexicality'. Word formation and thus production, respect language specific features of digraphs and trigraphs; words must be pronounceable by the speakers of the language and in most cases correspond to an entry in the mental lexicon (Viviani and Laissard, 1996). Word frequency effects illustrate this point. High frequency words are typed faster than low frequency words which in turn are typed faster than nonwords (West and Sabban, 1982). Gentner, Larochelle and Grudin (1988) found the median IKI for high frequency digraphs was 129ms, faster than the time recorded for low-frequency digraphs (134ms). These frequency effects were initially attributed to movement practice or, peripheral factors; high frequency words were executed more often than low frequency words, with the obvious consequence that they receive more practice. However the lexical processing that is required prior to the motor response clearly has an effect upon the speed with which digraphs are responded to. Clearly the use of random letters in the present study will have a detrimental effect upon the individual’s ability to process the stimuli (Terzuolo and Viviani, 1980).

One point to emerge from the typing literature concerns practice and transfer of movements such as used in the typing of digraphs reported above. More specifically, whether the actual act of making a typing response transfers and facilitates other typing actions. This issue of motor transfer was investigated by Bosnian (1994) who assumed that extensive experience upon a typing task would generalise to another similar motor task. A choice reaction time task assessing the latencies required to type two consecutive keystrokes was employed. Two indices of performance were measured: The 'initial latency', sensitive to the duration of translation or encoding and other pre-execution factors, and the 'IKI', which is more sensitive to execution processes.
For the typing task, subjects entered 60 digraphs, 30 using both hands and 30 using two fingers of the same hand. For the choice reaction time task subjects were presented with the letters 'L' and 'R' on the computer screen which were paired with the actual keys 'Z' and '/', respectively. Subjects had to type the corresponding key when the letters appeared. It was hypothesised that the typing related experience would facilitate performance on the choice reaction time task.

Two opposing predictions based on the two timing latencies were made with respect to transfer between the tasks. In terms of the IKIs, it was hypothesised that transfer between the two tasks would be found. In contrast, with respect to the initial latency measure, no transfer (or difference) was predicted. The main reason for this divergence is that executing successive keys is more similar between the tasks than the encoding and production of the initial response, i.e. having to learn novel stimulus response mappings in the choice reaction time rather than being able to press the 'known' key. Regression analysis indicated a difference in the initial latency time for the two tasks, which suggests that the actual motor processes that are involved in the execution of typing transfer while the encoding processes do not. This could be due to the similarity and the highly practiced nature of the action (Salthouse, 1986b).

These results can be understood in terms of an account of transfer provided by Shea and Morgan (1979). Although using a different paradigm, Shea and Morgan (1979) demonstrated that previous practice does enable transfer, depending upon the complexity of the practice received. Practice upon a simple task will enable performance to transfer to a similar simple task (i.e. the execution component of the Bosman task). However, practice will not facilitate transfer of performance to a more difficult aspect of the task; i.e. encoding new stimulus-response associations. While many similar ‘typing’ like actions may have been performed previously, as we have seen throughout the thesis, the encoding component of an action is much more attention demanding due to the fact that not only is the stimulus perceived, but preparation for responding also occurs (Salthouse, 1988).
This issue of transfer will be investigated in the present experiment through a manipulation in the stimulus-response mappings required to perform the task. It has been acknowledged that individual’s have pervasive experience of typing, and more specifically of typing four-digit numeric strings. However, as has been reported, the typing of random letter strings is not well practiced, and furthermore is difficult to learn (Terzuolo and Viviani, 1980). Moreover, it is expected that this difficulty will be compounded by having to learn to associate letters with a response format that is incongruent to the task; letters are usually typed using the QWERTY keypad; numbers are usually typed using the keypad to the right of the keyboard.

Thus, task difficulty will be assessed by manipulating the familiarity of the stimuli and the associated response and subsequently examining it’s effect upon learning and retention of the material. The procedural reinstatement paradigm will be used, but will incorporate an initial ‘familiarisation’ period. Participants will be provided with an opportunity to learn the stimulus response mappings, i.e. single letter digits will be typed. Half of the participants will subsequently be required to learn different stimulus-response mappings to perform the main study phase. This will allow an initial exploratory investigation into the participant’s ability to transfer performance. The acquisition phase will be examined further in order to assess whether the sequences are learned and whether the initial familiarisation phase has lasting effects upon performance. Finally retention performance will be examined to obtain a more conclusive picture of whether transfer occurs or whether the effects of procedural reinstatement will be evident under these circumstances. It is hypothesised, due to the unfamiliarity of the stimulus response mappings that reliance upon perceptual-motor cues at acquisition and hence the procedural reinstatement effects will be demonstrated.
6.2.2 METHOD

6.2.2.1 SUBJECTS

40 individuals participated in this experiment, 17 males and 23 females. The age range was 18 to 42 years, mean age 24 years. All subjects were right handed and were tested individually.

6.2.2.2 MATERIALS AND APPARATUS

Stimuli were presented on a P.C screen and were entered using one of two modified keypads, the layouts of which can be seen on Figure 6.2.1.

Seven lists of sequences were used during three stages of the experiment:

- **Pre-study**
  
  One list of 180 single letters. The list contained 20 repetitions of the nine consonants shown on 1a, Figure 6.2.1 (the far left panel).

- **Study**
  
  Two lists were used, each containing 120 four letter sequences. One of the lists contained sequences comprised of the letters upon grid '1A', Figure 6.2.1; the second list was comprised of the stimuli on grid '2A' of Figure 6.2.1. Of the 120 sequences, 20 were unique, the remainder were repetitions of these twenty. Sequences were presented in four consecutive blocks, each block containing five unique sequences repeated six times, i.e followed the pattern: $a,b,c,d,e, a,b,c,d,e, a,b,c,d,e$, until all six repetitions were presented.

```
R S W
L N P
F G H
```

`1a. Training layout`

```
F G H
L N P
R S W
```

`1b. (switch)`

```
B T D
J V K
Q C M
```

`2a. Alternative layout`

```
Q C M
J V K
B T D
```

`2b. (switch)`

**Figure 6.2.1.** Keypad layouts used throughout the experiment; 'switch' layouts were presented at 'Test' only.
• Test

Four lists comprising 20 ‘old’ and 20 ‘new’ sequences were used at test. Two lists were designed for subjects who used the ‘same’ keypad and two for those who ‘switched’ (see Figure 6.2.1). For subjects in the ‘switch’ condition, 10 ‘old motor’ (same motor pattern as study, different perceptual representation) and 10 ‘old digit’ (same perceptual representation, different motor pattern) sequences were presented alongside ‘new’ sequences.

6.2.2.3 Design

A mixed design was used, incorporating both within and between subjects’ factors. Subjects were assigned to one of two conditions at study depending on whether the keypad upon which the ‘pre-study’ phase was used, or whether the alternative format was used. This created a two level between subjects factor of ‘keypad’ (‘familiar’ versus ‘unfamiliar’). In order to assess the learning that occurred and whether there was any difference in responding, response times (RTs) to different sequences ‘repetitions’ were recorded.

At test, subjects used either the ‘same’ keypad as at study, or ‘switched’ to a transposed format, creating a between subjects factor of ‘transfer group (‘switch’ versus ‘same’). ‘Sequence type’ was manipulated within subjects; responding to ‘old’ and ‘new’ sequences was measured. Within the ‘switch’ transfer group responding to ‘old motor’ and ‘old digit’ sequences was measured. Dependent variables measured were RTs (to the nearest millisecond) and recognition decisions, measured using $A'$.

6.2.2.4 Procedure

The experiment was divided into two temporally distinct phases, ‘study’ and ‘test’. Stimuli were presented and entered using a P.C. at both phases. Subjects were informed at study, that they would be participating in a sequence entry task. The phase commenced with a ‘training’ period in which 180 individual letters were presented consecutively, in the centre of the P.C. screen. Subjects were required to
enter the digits as quickly and accurately as possible, with their right hand, using the modified keypad to the right of the keyboard.

The second part of the 'study' phase followed immediately. Subjects were assigned to one of two groups, half used the same keypad layout as 'pre-study', half used a novel layout incorporating different letter stimuli (see arrangement 2a., Figure 6.2.1). Both groups entered 120 four-letter sequences, again using their right hand and the modified keypad. The perceptual representation of each of the twenty sequences differed between the groups due to the different letter stimuli but the motor pattern remained the same. The study phase took fifteen minutes to complete.

A retention interval of one week separated study from test. At test, subjects were assigned to one of two conditions, 'switch' or 'same'. Half of the subjects from each study condition, 'familiar' and 'unfamiliar', used either the 'same' keypad layout as at study, or 'switched' to an alternative layout. (see arrangements 1a and 2a, and 1b and 2b, Figure 6.2.1 for the 'same' and 'switch' layouts, respectively). Each group were presented with a stimulus list containing 40 sequences, twenty of which were 'old', twenty of which were 'new'. Subjects were instructed to enter the sequences as quickly and accurately as possible. After each of the sequences had been entered, subjects were required to make a recognition decision about that sequence. Subjects had to indicate whether they thought the sequence was 'old' or 'new' by using the function keys at the top of the keyboard. After each response was made, the next sequence appeared. The test phase took ten minutes to complete. Upon completion of the experiment, subjects were thanked for their participation.

6.2.3 RESULTS
Data were obtained from each of the three stages of the experiment. At study and test three RT measures were analysed: Total time, encoding time and execution time. Mean median RTs are reported, each measured to the nearest millisecond. In addition, accuracy of recognition at test was measured using $A'$. Results will be
reported for each consecutive stage of the experiment.

6.2.3.1 Pre-study

180 single letters were entered during the ‘pre-study’ phase in order to familiarise subjects with the keypad layout and to establish a base rate level of performance. The mean time taken to enter each of the letters was 1017ms. RTs were divided, ad hoc, based upon the two groups created during the ‘study’ phase of the experiment. The times were then compared in order to eliminate the possibility of artifactual differences being present between the groups.

Mean entry time for subject’s ultimately using the ‘same’ keypad during ‘pre-study’ and ‘study’ was 1043ms ($SD = 160ms$); for those who switched, entry time was faster at 973ms, ($SD = 128ms$). This difference was not reliable ($F(1, 36) = 2.595, p > 0.05$) indicating that the typing ability of both groups was equivalent at the outset of the study and any subsequent differences found between the groups were due to experimental manipulations rather than being artifactually based.

6.2.3.2 Study

Two conditions were compared at study. The ‘familiar’ group used the same keypad layout as the pre-study phase, the ‘unfamiliar’ group used an alternative keypad upon which different stimuli were presented. On the basis of this manipulation it was expected that the ‘familiar’ group would show a RT advantage at the outset of the practice session. It was also expected however, that the pattern of responding within the ‘unfamiliar’ group would be the same as the ‘familiar’ group at the end of the practice phase. Overall sequence entry (total time) was examined prior to responding to different sequence components, i.e. the time taken to plan and execute the response, respectively.
6.2.3.2.1 OVERALL SEQUENCE ENTRY

The overall time taken to enter the sequences was assessed using the ‘total’ time measure. Timing commenced at the onset of the sequence upon the screen and ceased at the final keypress. RTs for each of the sequence repetitions were analysed. Table 6.2.1 shows the mean time taken to respond within each of the training groups.

Table 6.2.1 Mean total time (in ms with SD) for each sequence repetition for each training group.

<table>
<thead>
<tr>
<th></th>
<th>Repetition 1</th>
<th>Repetition 2</th>
<th>Repetition 3</th>
<th>Repetition 4</th>
<th>Repetition 5</th>
<th>Repetition 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familiar</td>
<td>3580</td>
<td>3472</td>
<td>3374</td>
<td>3351</td>
<td>3259</td>
<td>3275</td>
</tr>
<tr>
<td></td>
<td>(704)</td>
<td>(734)</td>
<td>(642)</td>
<td>(721)</td>
<td>(703)</td>
<td>(682)</td>
</tr>
<tr>
<td>Unfamiliar</td>
<td>3379</td>
<td>3422</td>
<td>3396</td>
<td>3274</td>
<td>3225</td>
<td>3147</td>
</tr>
<tr>
<td></td>
<td>(567)</td>
<td>(623)</td>
<td>(572)</td>
<td>(648)</td>
<td>(555)</td>
<td>(572)</td>
</tr>
</tbody>
</table>

The data were analysed using a 6 x 2 (‘repetition’ by ‘sequence’) repeated measures ANOVA. It is evident that within both groups, RTs decreased across the study phase; 305ms and 232ms difference between the first and final repetition within the ‘familiar’ and ‘unfamiliar’ group respectively. A main effect of repetition was found, indicating that RTs became reliable faster over the study session (F(5, 205) = 4.373, p < 0.01).

In order to test whether the training received in the pre-study phase of the experiment affected responding, RTs were compared between training groups. There was no main effect of ‘training’ (F(1, 41) = 0.179, p > 0.05). However, there was an interaction between the ‘training’ and ‘repetition’ (F(5, 205) = 3.06, p < 0.01), which reflects the diverging RTs at repetition 5 to 6; while the ‘unfamiliar’ group continued to speed up, the ‘familiar’ group’s responses slowed. Thus, initial familiarisation with the response format and stimuli had no effect upon performance, neither facilitating responses where the format remained the same, nor impeding performance where the
response requirements changed.

The time taken to enter each of the sequence repetitions within the four blocks was examined in order to obtain a more detailed view of responding. Table 6.2.2 illustrates that there was no consistent pattern of responding to repetitions within any of the four blocks across training groups. Although the interaction between 'block' and 'repetition' was significant ($F(15, 615) = 3.682, p < 0.001$) this did not reflect the fact that response times for each repetition of the sequence decreased across the blocks, rather, that responding was different across the repetitions within the blocks. There was no interaction between the three variables ($p > 0.05$).

Table 6.2.2 Mean total times (in ms with SD) for each sequence repetition within each block, for each training group.

<table>
<thead>
<tr>
<th>Rep1</th>
<th>Trained Group</th>
<th>Untrained Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block 1</td>
<td>Block 2</td>
<td>Block 3</td>
</tr>
<tr>
<td>Rep1</td>
<td>3312</td>
<td>3676</td>
</tr>
<tr>
<td>(659)</td>
<td>(897)</td>
<td>(815)</td>
</tr>
<tr>
<td>Rep2</td>
<td>3559</td>
<td>3374</td>
</tr>
<tr>
<td>(840)</td>
<td>(809)</td>
<td>(677)</td>
</tr>
<tr>
<td>Rep3</td>
<td>3315</td>
<td>3309</td>
</tr>
<tr>
<td>(739)</td>
<td>(927)</td>
<td>(874)</td>
</tr>
<tr>
<td>Rep4</td>
<td>3229</td>
<td>3092</td>
</tr>
<tr>
<td>(682)</td>
<td>(769)</td>
<td>(683)</td>
</tr>
<tr>
<td>Rep5</td>
<td>3182</td>
<td>3168</td>
</tr>
<tr>
<td>(748)</td>
<td>(815)</td>
<td>(826)</td>
</tr>
<tr>
<td>Rep6</td>
<td>3177</td>
<td>3070</td>
</tr>
<tr>
<td>(746)</td>
<td>(680)</td>
<td>(815)</td>
</tr>
</tbody>
</table>

In terms of the total time, although there was a decrease in RT across the study session within both of the training groups, there was no difference in the speed with which responses were made between the groups. Familiarisation did not effect
responding.

6.2.3.2 PERCEPTION AND PLANNING

The time taken to perceive the stimuli and initiate a response was compared between groups. Encoding time, which measured the latency between sequence onset on the screen to first keypress was analysed. It was hypothesised that encoding time would be faster for the ‘familiar’ group at the outset of practice. Table 6.2.3 illustrates the time taken to encode each repetition between training groups.

Table 6.2.3 Encoding time (in ms, with SDs) for each sequence repetition across training groups.

<table>
<thead>
<tr>
<th></th>
<th>Rep 1</th>
<th>Rep 2</th>
<th>Rep 3</th>
<th>Rep 4</th>
<th>Rep 5</th>
<th>Rep 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familiar</td>
<td>1740</td>
<td>1700</td>
<td>1650</td>
<td>1630</td>
<td>1630</td>
<td>1620</td>
</tr>
<tr>
<td></td>
<td>(499)</td>
<td>(456)</td>
<td>(443)</td>
<td>(461)</td>
<td>(432)</td>
<td>(428)</td>
</tr>
<tr>
<td>Unfamiliar</td>
<td>1490</td>
<td>1510</td>
<td>1490</td>
<td>1460</td>
<td>1470</td>
<td>1440</td>
</tr>
<tr>
<td></td>
<td>(451)</td>
<td>(406)</td>
<td>(411)</td>
<td>(380)</td>
<td>(346)</td>
<td>(371)</td>
</tr>
</tbody>
</table>

Although the direction of results shows that encoding was faster within the ‘unfamiliar’ group, there was no difference between the training groups \( (F(1, 41) = 1.971, p > 0.05) \). A main effect of ‘repetition’ was found \( (F(5, 205) = 8.396, p < 0.001) \), indicating that the repetitions were responded to differently. The interaction between ‘repetition’ and ‘group’ was not reliable \( (F(5, 205) = 0.80, p > 0.05) \); both groups responded in the same way across the sequence repetitions. The RTs for each repetition were more closely analysed within blocks. As for the total time, neither the interaction between block and repetition \( (F(15, 615) = 1.654, p > 0.05) \), nor the interaction between block, repetition and group \( (F(15, 615) = 1.208, p > 0.05) \) was reliable. Thus receiving training did not have any effect upon the speed with which the sequences were perceived. Switching to an alternative keypad format did not detrimentally affect performance. However, it is worth noting that the direction of results was not expected.
6.2.3.2.3 EXECUTION OF THE MOTOR RESPONSE

Execution time was based upon the time taken to enter the final three letters of the sequence. Again, it was hypothesised that the familiarisation with the keypad layout would facilitate performance for the 'familiar' group. Table 6.2.4 shows the overall time taken to execute each repetition of the sequences for each of the keystrokes, by each of the groups.

Table 6.2.4 Mean execution time (in ms with SD) of each sequence repetition as a function of group.

<table>
<thead>
<tr>
<th>Group</th>
<th>Key</th>
<th>Rep 1</th>
<th>Rep 2</th>
<th>Rep 3</th>
<th>Rep 4</th>
<th>Rep 5</th>
<th>Rep 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familiar</td>
<td>2</td>
<td>467</td>
<td>477</td>
<td>449</td>
<td>407</td>
<td>435</td>
<td>422</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(250)</td>
<td>(260)</td>
<td>(207)</td>
<td>(216)</td>
<td>(263)</td>
<td>(241)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>714</td>
<td>680</td>
<td>678</td>
<td>674</td>
<td>691</td>
<td>650</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(284)</td>
<td>(298)</td>
<td>(293)</td>
<td>(295)</td>
<td>(324)</td>
<td>(299)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>361</td>
<td>383</td>
<td>362</td>
<td>337</td>
<td>314</td>
<td>319</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(133)</td>
<td>(159)</td>
<td>(137)</td>
<td>(106)</td>
<td>(84)</td>
<td>(98)</td>
</tr>
<tr>
<td>Unfamiliar</td>
<td>2</td>
<td>519</td>
<td>540</td>
<td>550</td>
<td>519</td>
<td>505</td>
<td>489</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(266)</td>
<td>(266)</td>
<td>(284)</td>
<td>(262)</td>
<td>(264)</td>
<td>(234)</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>757</td>
<td>736</td>
<td>702</td>
<td>686</td>
<td>687</td>
<td>692</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(232)</td>
<td>(258)</td>
<td>(235)</td>
<td>(256)</td>
<td>(278)</td>
<td>(269)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>423</td>
<td>443</td>
<td>442</td>
<td>412</td>
<td>391</td>
<td>382</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(197)</td>
<td>(234)</td>
<td>(219)</td>
<td>(214)</td>
<td>(191)</td>
<td>(185)</td>
</tr>
</tbody>
</table>

Although there was no main effect of 'group', (F(1, 41) = 0.597, p > 0.05), the direction of results show that the 'familiar' group executed the sequence faster than the 'unfamiliar' group. An effect of 'repetition' was found (F(5, 205) = 9.647, p < 0.001), however, it is clear from Table 6.2.4 that this reflects the repetitions were executed inconsistently, rather than showing the speed up expected across repetitions. There was no interaction between the variables, 'repetition' and 'group' (F(5, 205) =
1.821, p > 0.05) indicative of the fact that inconsistent responding was found across both groups.

6.2.3.2.4 SUMMARY

The results from the study phase indicated that there was no benefit received from the pre-study familiarisation phase of the experiment. Having processed the stimuli to-be-presented, did not facilitate performance. Subjects in the 'familiar' group had formed perceptual representations of the stimuli as well as motor-response mappings; the spatial layout of the keypad was practiced upon. However, the unfamiliar group performed equally well, in planning and making an initial response, as well as executing the entire sequence.

6.2.3.3 RETENTION

Subjects were tested in one of two 'transfer group' conditions, depending upon whether the 'same' keypad layout was used at study, or whether the alternative 'switch' format was used. This manipulation was incorporated in order to assess the extent to which previous motor experience facilitated retention of stimuli. In order to separately examine the impact of having previously seen the stimuli, a mixture of 'old' and 'new' sequences were entered at test. It was hypothesised that 'old' sequences would be entered faster than 'new', and also that the 'same' transfer group would enter sequences faster than the 'switch' group. Both indirect and direct tests of memory were used to measure retention of the material. For the indirect tests, the three response time measures were again taken. Recognition of the sequences was assessed using $A'$.  

6.2.3.3.1 OVERALL RESPONDING AT RETENTION

The total time taken to enter the sequences was used to obtain an initial measure of how subjects responded to the sequences. Table 6.2.5 shows the total time taken to enter 'old' and 'new' sequences by subjects in both conditions.
Table 6.2.5 Mean total time (in ms with SD) for ‘old’ and ‘new’ sequences within both transfer groups.

<table>
<thead>
<tr>
<th></th>
<th>New</th>
<th>Old</th>
<th>Old digit</th>
<th>Old motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>3504 (559)</td>
<td>3402 (522)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Switch</td>
<td>4204 (726)</td>
<td>4072 (829)</td>
<td>4000 (877)</td>
<td>4171 (508)</td>
</tr>
</tbody>
</table>

It is evident that the ‘same’ transfer group responded faster than the ‘switch’ group to both ‘new’ and ‘old’ sequences, the difference between the groups being 700ms and 670ms, respectively. A 2 x 2 (‘transfer group’ by ‘sequence type’) repeated measures ANOVA was used to analyse the data. A main effect of ‘transfer group’ was found (F(1, 36) = 10.27, p<0.01). ‘Old’ sequences were also entered reliably faster than the ‘new’ sequences (F(1, 36) = 8.28 , p<0.01). The interaction between sequence type and keypad condition was not significant (F(1, 36) = 0.143, p>0.05) indicating that the pattern of responding within the transfer groups did not differ. Thus the results indicate that when perceptual and motor conditions from study to test match, retention is enhanced.

Data from the ‘switch’ transfer group only was examined to see whether there was a difference between ‘old motor ‘ and ‘old letter’ sequences in comparison to ‘new’. Table 6.2.5 shows that a greater advantage was obtained from the reinstatement of the perceptual, rather than motor representation; ‘old motor’ sequences (4171ms) took longer to enter than ‘old letter’ (4000ms). Although the difference between the three sequence types was reliable (F(2, 36) = 3.848, p < 0.05), post hoc analysis found that ‘old letter’ sequences were entered reliably faster than ‘old motor’ and ‘new’ (p< 0.05).

At this stage, the results suggest that when the study-test conditions are manipulated, reinstating the motor pattern does not facilitate retention to the same extent as reinstatement of the visual representation. Reinstating the motor component elicits performance which is equivalent to presenting completely new stimuli. Analysis of the perceptual and the motor component of the sequences is examined further in the
following sections.

6.2.3.3.2 PERCEPTION AND PLANNING OF RESPONSES

Retention of the perceptual component of the sequence was examined further through analysis of the encoding time data. To recap, encoding time reflected the time taken to make the first keypress from the onset of the sequence upon the screen. The mean encoding time taken to enter each sequence type by each of the keypad conditions is shown in Table 6.2.6.

Table 6.2.6 Mean encoding time (in ms with SD) as a function of sequence type and keypad condition.

<table>
<thead>
<tr>
<th></th>
<th>New</th>
<th>Old</th>
<th>Old Letter</th>
<th>Old Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>1777 (469)</td>
<td>1718 (405)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Switch</td>
<td>1980 (446)</td>
<td>1903 (417)</td>
<td>1879 (489)</td>
<td>1975 (272)</td>
</tr>
</tbody>
</table>

Although the direction of results suggest the 'same' transfer group encoded the sequences faster than the 'switch' group, the difference was not reliable (F(1, 36) = 1.74, p > 0.05). With respect to sequence type, 'old' sequences were encoded reliably faster than 'new' (F(1, 36) = 9.53, p < 0.01). Again the interaction between sequence type and keypad condition was not significant (F(1, 36) = 0.182, p > 0.05) which suggests that the encoding of the sequences was the same between the group.

Within the 'switch' transfer group only, 'old letter' sequences were encoded 96ms faster than 'old motor' sequences and 101ms faster than 'new'. Again the difference between the sequences was reliable (F(2, 36) = 3.953, p < 0.05); post hoc analysis found the difference between the 'old letter' and the remaining sequences different (p < 0.05). The fact that 'old letter' sequences are encoded faster is intuitively appealing given that the perceptual representation does not change from study, whereas for the 'old motor' and 'new' sequence, the representation does change.
6.2.3.3 MOTOR RESPONSE EXECUTION

Execution time comprised three separate RT measures for each of the final three digits of the sequence. Figure 6.2.2 illustrates the time taken to make these responses within each keypad condition.

![Figure 6.2.2 Mean execution time (in s) as a function of sequence type and transfer condition.](image)

For each keystroke it is evident that each movement was executed faster within the 'same' condition than the 'switch'. Indeed the difference between the transfer groups was reliable ($F(1, 36) = 14.975, p < 0.001$), suggesting that reinstating the motor component has a greater effect when the actual execution of the sequence is performed. With respect to sequence type, the 'old' sequences were again executed faster than 'new'. A main effect of sequence type was found ($F(1, 36) = 3.848, p < 0.05$). The interaction between sequence type and transfer group was not significant ($F(1, 36) = 0.824, p > 0.05$); the pattern of responding to 'old' and 'new' sequences did not differ depending upon the keypad used.
CHAPTER SIX

Figure 6.2.2 also shows that the response time latency for the third keystroke was greater than either the second or the fourth. The difference between the keystrokes was reliable \((F(2, 72) = 35.249, p < 0.001)\) and the lack of significant interaction between the variables \((F(2, 72) = 1.22, p > 0.05)\) was indicative of the fact that the pattern of responding did not differ as a function of transfer group.

Data from the switch condition were again separately analysed in order to examine whether there was a difference in the execution of both types of old sequence and new. Table 6.2.7 shows the mean execution times for each keystroke, for each sequence type.

<table>
<thead>
<tr>
<th></th>
<th>New</th>
<th>Old Letter</th>
<th>Old Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keystroke 2</td>
<td>682 (332)</td>
<td>633 (292)</td>
<td>649 (324)</td>
</tr>
<tr>
<td>Keystroke 3</td>
<td>867 (342)</td>
<td>863 (355)</td>
<td>831 (208)</td>
</tr>
<tr>
<td>Keystroke 4</td>
<td>545 (208)</td>
<td>530 (211)</td>
<td>497 (200)</td>
</tr>
</tbody>
</table>

Although 'new' sequences were executed more slowly than both types of 'old', the difference between the response times was not significant \((F(2, 36) = 1.129, p > 0.05)\).

6.2.3.4 RECOGNITION

Of the 40 sequences presented at test, 20 were 'old' and 20 were 'new'. Accuracy of recognition decisions of both the switch and the same keypad conditions were analysed in order to ascertain whether subjects' had explicit knowledge of the stimuli. \(A'\), a measure based upon the principles of signal detection theory, was used to examine this.

Table 6.2.8 shows the proportion of hits and false alarms for each group. It is evident that the proportion of false alarms for both groups were higher than the proportion of
hits, i.e. sequences correctly recognised as 'old'. The $A'$ scores for both groups were 0.53, which is reliably better than chance ($t(13) = 3.87, p = 0.001$) and would seem to suggest that some explicit knowledge of the sequences exists. The fact that the proportion of false alarms is greater than the proportion of hits, however, suggests that this result should be interpreted with some caution.

Table 6.2.8 Hit, false alarm rates and $A'$ scores of both keypad conditions.

<table>
<thead>
<tr>
<th>Transfer group</th>
<th>Proportion hits</th>
<th>Proportion false alarms</th>
<th>$A'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>.44</td>
<td>.56</td>
<td>.53</td>
</tr>
<tr>
<td>Switch</td>
<td>.45</td>
<td>.55</td>
<td>.53</td>
</tr>
</tbody>
</table>

6.2.3.5 SUMMARY

During the initial 'pre-study' phase of the experiment, it was established that there was no prior differences in the typing ability of the subjects and that any subsequent differences between the 'familiar' and the 'unfamiliar' groups of subjects would be due to experimental manipulations. During the actual study phase, although there was evidence of learning, RTs to the six repetitions of the sequences decreasing with practice, this was not influenced by prior training. There was no difference between the groups depending upon whether the 'familiar' or unfamiliar' keypad was used. This was found for all three RT measures. Indeed, the direction of results indicated that subjects using the 'unfamiliar' layout were encoding and executing the sequences faster than those using the same layout.

At retention, subjects switched keypad or used the same as at acquisition to assess transfer of performance. It was found that subjects responded more quickly to sequences that they had previously seen and furthermore, an advantage was found where the response requirements remained the same between study and test. The detrimental effect of switching the keypad layout was evident during the execution stages of the task. Subjects were able to encode the sequences at the same rate regardless of whether they had switched formation, but their performance was upset.
during the execution stage. Direct tests of retention were also performed. Both the 'same' and the 'switch' transfer groups were able to discriminate 'old' sequences from 'new' at a level above chance. This suggests that as well as the implicit knowledge being sensitive to specific task features, explicit knowledge of specific sequence attributes is also retained.

6.2.4 DISCUSSION

The present experiment sought to establish whether familiarity of stimulus response mappings would have an influence upon performance at learning, transfer and retention. More specifically, the aim of the experiment was to examine whether having to learn unfamiliar stimulus-response locations would increase the dependency upon the presence of appropriate retrieval cues and thus result in minimal transfer performance. The experiment therefore was a test of the procedural reinstatement paradigm, further examining whether the effects were due to a response strategy used by individual's when faced with difficult learning / retention situations.

Transfer of performance was initially examined between the 'pre-study' and the study phase of the experiment. All of the participants were 'familiarised' with the perceptual representation and spatial layout of single stimuli during pre-study. At the study phase proper, subjects were presented with the stimuli in four-digit sequences and furthermore, half of the participants switched keypad formation thus necessitating learning of new stimulus-response mappings. It was expected that this latter manipulation would result in a disruption to performance. This was not the case. At this stage of the experiment, where new associations had to be made between stimuli and responses, they were achieved with apparent ease.

A simple explanation for the lack of disruption may be due to the time between the two phases. The fact that the pre-study and the study phases followed immediately after one another suggests that there may not have been any consolidation of the processes demanded by the first task, thus diminishing any potential effects of interference from this earlier learning. An more complex explanation is adapted from
an argument made by Shea and Morgan (1979), who stated that task difficulty may interact with the observed amount of transfer. Essentially, if practice upon a simple task is undertaken it is argued that one would expect performance to transfer to another similar simple task. However, performance would not transfer to a more difficult task. In terms of the present study, therefore, perhaps the move from performing a one-letter typing task to performing a four-letter typing task in which the demands of the planning / execution component is increased, then this would constitute a move from a simple to a difficult task.

Clearly this shift in requirements from a ‘one-letter’ to a ‘four-letter’ task is the same for both the ‘familiar’ and the ‘unfamiliar’ groups in this study. The fact that there is no difference between the groups therefore, may not be due to the ability of the ‘unfamiliar’ group to transfer, but rather because of the inability of the ‘familiar’ group to transfer performance from a one to four-letter task. It is worth speculating, that if this were the situation, then maybe the ‘unfamiliar’ group were actually at an advantage; they were required to completely relearn stimulus response mappings to perform the ‘study’ task, therefore maybe this requirement removed a source of interference due to the complete change in response.

Further investigation into the ability of the participant to transfer the different elements of performance was conducted between study and test. In this experiment it was hypothesised that performance would not transfer at this phase. This was due to the incorporation ‘difficult to learn’ stimulus-response mappings effecting an increase in the overlap between procedures used at study and then again at test. In previous studies reported in this thesis, findings suggest that procedural reinstatement effects are transient, apparent only when the material to-be-learned has been done so under degraded learning conditions, or has been difficult or idiosyncratic in some way. Performance at retention is dependent upon the presence of appropriate retrieval cues. It was hypothesised in the present experiment that the novel stimulus-response mappings would increase ‘difficulty of learning’ and hence performance at retention would be dependent upon the procedures used at study being reinstated at test.
The predictions in this instance were supported. Procedural reinstatement effects were demonstrated; manipulations in both 'transfer group' and 'sequence type' had an effect upon performance. That is, when previously seen sequences were retyped at test, a response time advantage was evident compared to novel sequences. Similarly when the same response format was used between study and test, enhanced retention performance was found. Furthermore, the locus of the facilitation appeared to be in the motor component of the task. Whilst there were no differences in the time taken to encode the sequences between the transfer groups, i.e. the time taken to perceive the sequences and make the initial response, there was a difference in the time taken to execute the remaining motor response.

This is an unexpected finding. Results (in this thesis and elsewhere, e.g. Salthouse, 1986; Bosman, 1994) have demonstrated that the facilitation from practice is mostly in the encoding stage of the response; the execution phase remains largely unaffected. Therefore transfer would be expected primarily from the latter but not from encoding. The fact that there was facilitation from neither of the components therefore, implies that in the present experiment, there is a greater amount of disruption or additional effort required to re-orientate to the novel keypad formation to make the appropriate motor response. This may be because letters, rather than digits are being used. Recall that digit orientations comprise both the telephone and the calculator layout and thus arguably have some intrinsic familiarity within Western society. Thus retrieval cues provided by the motor and the perceptual component (especially with regard to 'old' sequence representations) of the sequences were apparently used at test. When such cues were not present performance suffered.

Clearly then when measured indirectly, transfer of performance between study and test was not evident. However, when direct tests of retention were employed, there was evidence that subjects were discriminating old sequences from new. Both groups of subjects were performing above the chance level. This finding again supports the contention that the information learned seems to be highly specific and furthermore, is
elicited only in the presence of appropriate retrieval cues. Again this supports the contention that procedural reinstatement effects are likely to be seen not only when learning is disrupted in some way, but also when novel stimulus-response mappings have to be learned, especially when an element of the mapping is usually associated with performing a highly practiced task such as typing number sequences. As was suggested in Study 3, procedural reinstatement appears to be a 'transient' strategy which depends upon the learning conditions that are promoted at study.

Thus, two important findings emerge from this experiment. The first relates to the procedural reinstatement effects and reiterates the point made above. The effects appear to arise as a consequence of a strategy that is adopted when the demands placed on the individual during learning are high; i.e. when unfamiliar or 'difficult' material is being learned. The dependence upon contextual cues at retention is high; little transfer occurs between the stimuli presented. The second point concerns the performance exhibited at the learning stage of the experiment. An unexpected, unclear finding emerged regarding the processing that was occurring between the pre-study and the study phase of the experiment. Essentially, this was that performance transferred readily despite a manipulation in the response requirements of the task. An argument made earlier to account for these effects was adapted from the Shea and Morgan (1979) proposal regarding task difficulty, i.e. that the difficulty of the task increased to the extent that regardless of the previous practice (pre-study), both groups were set back to the equivalent performance levels at study.

One way in which this issue can be taken further is by manipulating the organisation of the practice given; the procedural reinstatement paradigm allows an elegant way of doing this. In the final experiment of this thesis, the issue of 'contextual interference' will be investigated.
6.3 STUDY 7: BLOCKED VERSUS SPACED PRACTICE AND THE EFFECT UPON LEARNING

6.3.1 INTRODUCTION
In the previous study it was examined whether familiarity had an effect upon learning and retention of stimulus material. Rather than presenting subjects with numeric digit sequences which are encountered frequently in today’s society (Trewin and Pain, 1999), the stimuli in Study 6 comprised of random consonant strings. It was argued that having to process unfamiliar material, such as letter strings, would require more effort than processing numeric sequences (see Gentner et al, 1988), and as a consequence, successful retention performance would depend upon the overlap between conditions at study and test. The results supported these predictions; the effects of ‘procedural reinstatement’ as espoused by Fendrich et al (1991, 1995) were demonstrated.

An unexpected finding emerged during the study phase of the experiment, however. Here, all of the sample participated in a pre-study ‘familiarisation’ phase in which single stimuli were responded to. During the ‘study’ phase proper in which four-letter sequences were entered, half of the sample were required to use a different keypad format to perform the task. Thus, in addition to increasing the amount of perceptual planning and motor responding required to complete the task, for half of the group, (the ‘unfamiliar’ condition) the stimulus response mappings had to be re-learned. It was predicted that responding would be worse within the ‘unfamiliar’ group due to the relearning required. This was not found; manipulating the response requirement did not effect performance at study.

A potential explanation for this result was derived from an argument proposed by Shea and Morgan (1979), which suggests that the switch from performing an easy to a more difficult task detrimentally affects performance regardless of other manipulations. Thus in the previous study the shift from entering ‘one letter’ to a
sequence of letters would have overridden the effect of changing the keypad in task requirements. Clearly this is a speculative and 'adapted' explanation for the findings of the previous study. However, the procedural reinstatement paradigm does afford quite an elegant way of examining the theoretical proposals of Shea and Morgan (1979), whose findings were principally based upon an experiment in which the organisation of the practice schedule was manipulated. More specifically, whether practice was 'blocked' or 'spaced' within a learning trial.

As the name suggests, in a situation in which 'blocked' practice is given, the learner experiences all of the identical elements of the task before being presented with any alternative variations. Under conditions of 'spaced' practice the presentation of different elements is varied and unpredictable; at it's extreme, spaced practice is essentially randomised (Battig, 1972). Blocking or spacing trials within a practice list determines whether the task will be acquired rapidly or more slowly (Proctor and Dutta, 1996). Blocking trials in which the same operation is consistently performed is proposed to lead to faster acquisition of that operation; the learner is assumed to predict which stimuli will be presented and can thus rely upon anticipatory responding throughout the trials. Randomising trials negates such responding; a different, unpredictable response is required upon each trial which consequently has a deleterious effect upon responding (Lee, 1998).

A study in which the effects of 'blocked' and 'random' practice were demonstrated was reported by Pollock and Lee (1997). The experimental task involved a modification of the American game 'Crokinole' (Kelly, 1988). Subjects, using their middle finger were required to propel a wooden disc towards an elastic barrier, causing the disc to rebound and hit a target goal. Three elastic barriers, each located such that a different striking force and angle was required for the disc to hit the target goal were used. The location of the barriers formed the three variations of the acquisition task. The goal was a circular hole located in the centre of the board. A series of five concentric circles surrounded the goal as a measure of performance error.
Ninety practice trials were performed at acquisition. Subjects in the 'blocked' group practiced the three variations in three consecutive blocks of thirty trials. Subjects in the 'random' condition performed the three variations in sets of fifteen trials; five of each variation were presented with no more than three repetitions of the same variation occurring within a set. Scores of one to six were given depending upon where the block landed, six being the goal and one being the circle farthest from the goal. Results demonstrated that the blocked group performed more accurately than the random group, i.e. the disc was 'on target' on more trials, supporting an account that consistency of practice facilitates acquisition (Pollock and Lee, 1997). As a caveat to this however, it is worth noting that when children performed the task, the effects of practice were not evident. It was argued that the children found the task more difficult to acquire from the outset, thus negating any practice effects.

The effects of blocked and random practice have not only been established at acquisition. When tested, random practice rather than blocked practice leads to more successful retention. A classic study demonstrating the effects of random practice upon motor skills was performed by Shea and Morgan (1979). Subjects were required to complete a task that involved knocking down six pegs with their right hand. The pegs could be knocked in one of three specific sequences. Practice was either blocked so that each sequence group was practiced prior to the onset of practice for the others (i.e. all of the practice for the first, the second and then the third), or random.

Following a retention interval of either ten minutes or ten days, regardless of whether the test trials were random or blocked, the group who received random practice during acquisition performed the task faster and more accurately than the blocked group. Indeed in the Pollock and Lee (1997) study referred to above, subjects performed tests of 'transfer' and 'retention'. At transfer, ten test trials were undertaken in which subjects were required to perform the task from a different starting position on each occasion. At retention, fifteen randomly ordered trials were performed, five trials at
each of the three ‘barrier’ positions. In both situations the random group were more accurate, i.e. on target, compared to the blocked group.

Thus, the results suggest that receiving random practice engages the learner in greater movement planning processes which facilitates subsequent transfer and retention (Lee and Magill, 1985; Immink and Wright, 1998). This effect of experiencing what is essentially greater interference during acquisition but demonstrating enhanced retention performance has been termed ‘contextual interference’ (CI) and once again demonstrates how practice and retention are fundamentally interleaved (Lee and Magill, 1985). ‘Contextual interference’ (CI) is defined as the “effect on learning of the degree of functional interference found in a practice situation when several tasks must be learned and are practiced together” (Magill and Hall, 1990, p 244). ‘Functional interference’ therefore, facilitates learning; the question remains as to how.

It has been proposed that the relationship between acquisition and retention relies upon establishing whether the variations of the skill being practiced are controlled by the same, or different underlying motor programs (Schmidt, 1991). It has been proposed that CI effects will only be evident where motor programs differ, or where blocked practice is followed immediately by random practice and subtle changes in the task requirements become more noticable (Lee and Magill, 1985). Thus a task requiring different motor programs is more difficult to perform than one in which the response requirement is always the same or differs only through an alteration of a within task parameter. Increasing task difficulty through restructuring the response requirement in a more overt way undoubtedly increases the effort required to perform the task and thus the level of CI experienced (Lee, 1998).

Two explanations of the CI effect have been proposed, the first based upon the principles of elaboration and distinctiveness (Battig, 1972; Shea and Morgan, 1979), the second upon reconstruction of the action plan required to perform the task (Magill and Hall, 1990). The ‘elaboration benefit’ explanation is based upon the operation of
'inter-task' and 'intra-task' mechanisms and the subsequent differential use of multiple and variable encoding processes that lead to conditions of high CI. 'Multiple' processing concerns the number of different strategies that must be employed in order to perform the task, while 'variability' refers to the fact that the learner does not know when one rather than another response strategy is required (Shea and Morgan, 1979).

Under conditions of blocked practice on any trial, only intra-task processing occurs. The learner focuses purely upon the requirements of the specific task in hand and does not make any reference to extant knowledge structures. Random practice however also involves inter-task as well as intra-task processing. It is hypothesised that responses made upon each trial must be kept in working memory to serve as a guide as to the appropriateness of the subsequent response. New representations subsequently created result in additional information being incorporated into knowledge structures which in turn result in a more detailed task representations (Shea and Zimny, 1988). Thus the between task comparisons (i.e. random practice) result in more distinct and elaborate representations of each of the components (Shea and Morgan, 1982).

The alternative 'action plan reconstruction' hypothesis (Lee and Magill, 1985) relies on the premise that successful responding is initially based upon the formation of an action plan, a motor program of the response and details of the parameters required for successful execution of the task (Newell, 1979). It is the extensive retrieval practice that ensues when a particular trial is re-experienced during acquisition that is the key to understanding successful retention. Under conditions of high CI (i.e. random practice), details of the action plan constantly change due to the variation of the interpolated trials. A consequence of embarking upon novel variations is 'forgetting' of the previous response (e.g. Jacoby, 1978). However, this is combined with a concurrent increase in the amount of effortful processing which ultimately facilitates performance as the learner tries to resolve the problem by regenerating the old action plans (Lee and Magill, 1985).
This is the fundamental point of the theory. The learner actively tries to reconstruct what they have performed previously so that at retention each different presentation or aspect of the skill does not distract them. Under conditions of blocked practice forgetting of each sequence presentation is more likely as this regenerative process does not occur. The motor program remains in WM requiring little variation in response planning and practice required to complete the task. The learner is passive almost, simply going through the motions of the task in order to complete it (Magill and Hall, 1990).

One of the most important implications of the CI effect, implicit in both of the theoretical stances reviewed is that reinstating the specific encoding conditions is not a prerequisite for successful retention (McDermott and Roediger, 1996). Clearly this is contrary to suggestions proposed by proponents of the procedural reinstatement argument (Fendrich et al, 1991; Blaxton, 1995). The conflicting ideas appear to be based around what the learner is able to transfer from one situation to another. Whilst CI seemingly enhances transfer of performance, it has been established that ‘specificity of learning and retrieval’ is the key association with procedural reinstatement.

The aim of the present study is to investigate whether the effects of CI can be demonstrated using the sequence entry paradigm. In the present experiment, the practice at study will be ‘blocked’ or ‘spaced’. In line with reported effects of manipulating the ‘organisation’ of the practice schedule, it is predicted that the group following a ‘blocked’ practice schedule will acquire the task more quickly than those receiving ‘spaced’ practice. That is, faster responding to the sequences should be evident, in both the time taken to encode and execute the sequences by the blocked group.

At retention, again in line with CI effects, the main prediction is that faster responding will be found within the ‘spaced’ group. Subjects in this group should be able to
transfer their performance more readily to novel sequences, due to the experience of
'non-anticipatory' responding.

Regarding the effects of procedural reinstatement, in the present experiment there
should be no supporting evidence. It is stated that the encoding conditions are not a
pre-requisite for successful retention performance; the fact that multiple different
responses are being practiced should facilitate the transfer of performance from old to
new sequences. With respect to recognition, the hypotheses are simply exploratory.
There are no studies within which results of direct tests have been reported. However,
due to the elaboration / reconstruction elements proposed in the theoretical accounts
of CI, it is hypothesised that recognition within the spaced group will be more
accurate than the blocked. Thus, the effects of both CI and procedural reinstatement
will be investigated.

6.3.2 Method

6.3.2.1 Subjects

40 individuals participated in the study, 17 males and 23 females, with a mean age of
23.8 years (SD=2.53 years). Each subject was individually tested and had no prior
knowledge of the experiment.

6.3.2.2 Materials and Apparatus

The experimental set-up used in the previous experiments was used. Instructions to
the subject and the stimuli were presented on the P.C. screen. Subject's responded
using one of two modified keyboards. On each of the keyboards, all keys apart from
the 'numeric keypad' and 'function keys 1 to 6' were concealed. The keys on the
numeric keypad corresponded to the layout shown on Figure 6.1. The six function
keys were covered with blue coloured stickers, the intensity and depth of colour
increasing from 'light' to 'navy' blue and corresponding to the prompt which
appeared on the screen after each sequence had been entered. The keypad and the
function keys were used to enter the sequence and make the recognition response, respectively.

<table>
<thead>
<tr>
<th>R</th>
<th>S</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>F</td>
<td>G</td>
<td>H</td>
</tr>
</tbody>
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<th>F</th>
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<tr>
<td>L</td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>R</td>
<td>S</td>
<td>W</td>
</tr>
</tbody>
</table>

**Figure 6.3.1** Representation of the keypad layouts used during the experiment.

Eight stimulus lists were used, four at study, four at test. At study, each list comprised 120 four letter sequences; 20 unique sequences repeated six times. Within each list, sequences were presented in either four or eight ‘blocks’, as detailed below.

**List A and List B**
Eight successive blocks of sequences were presented. Each block contained five sequences repeated three times following the pattern: a,b,c,d,e, a,b,c,d,e, a,b,c,d,e, before progression to the next block. Blocks 5 to 8 were repetitions of blocks’ 1 to 4 (1 corresponding to 5, 2 to 6, 3 to 7 and 4 to 8). Presentation of the blocks was counterbalanced within List B in order to reduce order effects.

**List C and List D**
Four successive blocks of sequences were presented. Each block contained five sequences repeated six times; all six repetitions of the sequences were presented before the next block commenced. There was no repetition of the blocks. The order of the blocks was counterbalanced within List D in order to reduce order effects.

**Test**
Four lists of forty sequences were used; two lists for the ‘same’ condition, two for the ‘switch’. All lists comprised twenty ‘old’ sequences (i.e. all of the sequences presented during study) and twenty ‘new’ sequences, in a pseudo-random order. Within the lists presented to the ‘switch’ group, of the ‘old’ sequences ten were ‘old digit’ sequences (same perceptual representation, different motor pattern) and ten ‘old motor’ sequences (same motor pattern, different perceptual representation).
Two lists were used for each group to reduce order effects; the first and second halves of the list were swapped between lists.

All stimulus list can be seen in Appendix 1.

6.3.2.3 DESIGN

A mixed design was used, incorporating both within and between subjects' factors. The organisation of the sequence lists was manipulated at study. Sequences repetitions were either ‘blocked’ into four, or were ‘spaced’ across eight blocks creating a between-subjects factor of ‘practice group’. The within-subjects factor measured was ‘repetition’ of the sequences. All subjects were presented with six repetitions.

At test, the keypad formation used to enter the sequences was manipulated, creating a between subject factor of ‘transfer group’; subjects participated in either a ‘switch’ or ‘same’ keypad condition. Within-subjects, ‘sequence type’ was measured as responses were made to both ‘old’ and ‘new’ sequences.

Three response time (RT) measures were taken at both study and test: ‘Total’, ‘encoding’ and ‘execution’ time. In addition, at test recognition accuracy of the sequences was measured using $A'$, a non-parametric technique based on the principles of signal detection theory which does not assume equal variance between signal and noise.

6.3.2.4 PROCEDURE

The experiment consisted of two phases, ‘study’ and ‘test’. Subjects performed the task individually in laboratory conditions on both occasions. The procedure followed was the same as that described in previous experiments.

At study, subjects were informed, via the P.C., that they would be participating in a digit entry task in which 120 four-letter sequences were to be entered using the right
hand and the keypad to the right of the keyboard. Subjects pressed the 'return' key to begin. Five practice trials were provided before the experimental trials commenced. A four-letter sequence appeared, horizontally in the centre of the computer screen. A highlight covered the first digit, prompting the subjects to press the appropriate key. The highlight moved through the sequence with each keypress, regardless of whether the keypress was correct or incorrect. After the entire sequence had been entered, a prompt corresponding to the blue-coloured function keys located at the top of the keyboard appeared on the screen. Subjects were asked to press any one of these keys with their left hand for the next sequence to appear. This procedure was repeated until all 120 sequences had been entered. A prompt thanking the subjects for their participation signified the end of the study phase of the experiment.

Subjects were tested under the same laboratory conditions one week later. As before, all instructions were presented upon the computer. Subjects were informed that they would be presented with 40 four-letter sequences some of which were 'old' (i.e. presented at acquisition), some of which were 'new'. The sequences were entered as at study. Following each sequence entry, a recognition judgement regarding the 'old' / 'new' status of the sequence was required. The recognition judgement was made using the blue coloured keys at the top of the keyboard, the anchors for the judgement being 'definitely old' and 'definitely new'. Responses were made using the left hand and once made, the next sequence appeared. The procedure was repeated until all forty sequences had been entered.

It was made clear at both study and test that the subject was required to complete the task as quickly and accurately as possible. Specific instructions can be seen in the Appendices Appendix 3).

6.3.3 RESULTS
Results will be reported in two main sections, the first detailing those of the study session, the second the test phase. At both study and test, three RT measures were taken: 'total' time which referred to that taken to enter the entire sequence from its
onset on the screen until the final keypress; ‘encoding’ time, which reflected the time taken to make the first keypress following the onset of the sequence on the screen; and finally, ‘execution time’, which was the time required to enter the final three digits of the sequence. The mean median RT is reported throughout this section, to the nearest millisecond.

6.3.3.1 STUDY

Of interest at study was whether the manipulation in the intra-list organisation of the sequences effected the rate at which subjects learned and responded. Either a ‘blocked’ or ‘spaced’ practice schedule was followed in which all repetitions of sequences were presented before the next novel batch, or different interleaving sequences were presented before practice of previously repeated sequences was completed, respectively. RTs to sequence ‘repetitions’ (i.e. the first and last) were analysed to measure the improvement in performance with practice. It was expected that greater savings in RT would be evident where sequences were ‘blocked’, due to the consistency in practice received.

Error rates, i.e. the number of letters incorrectly entered, were examined before any analysis took place. Within the ‘spaced’ list, the error rate was 1.38%; for the ‘blocked’ list the error rate was 1.34%. The total number of digits within each list was 480, therefore the error rate was very small and consequently no data were omitted from analysis.

6.3.3.1.1 EVIDENCE FOR OVERALL LEARNING

Overall learning was assessed by examining the ‘total’ taken for the entire sequence to be entered. The effect of ‘practice’ upon learning was initially examined by comparing the first repetition of the sequences to the final repetition; the mean RTs are illustrated in Table 6.3.1.
Table 6.3.1 Mean median total time (in ms with SDs) for the first and the final repetition of sequences within each practice group.

<table>
<thead>
<tr>
<th></th>
<th>Blocked</th>
<th>Spaced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repetition 1</td>
<td>Repetition 6</td>
</tr>
<tr>
<td>Time</td>
<td>3739 (949)</td>
<td>3227 (874)</td>
</tr>
</tbody>
</table>

Total time data were analysed using a 2 x 2 (‘practice’ by ‘repetition’) repeated measures ANOVA. Despite the improvement in the ‘blocked’ group, there was no overall difference in performance between the groups (F(1, 35) = 1.175, p > 0.05). As expected, there was a difference between the repetitions (F(1, 35) = 68.7, p < 0.001), the final repetition being entered more rapidly than the first. There was no interaction between the variables (F(1, 35) = .020, p > 0.05); the pattern of responding across the repetitions did not differ between the groups.

The effect of ‘practice’ was more closely examined by analysing the mean time taken to respond to the first and the final repetition of sequences contained within each of the sequence blocks. As illustrated in Table 6.3.2 for each of the sequence ‘sets’, responding was faster from the outset within the ‘spaced’ group. However, the important feature to note is the improvement in RT between groups.

Within the ‘blocked’ group for each of the four respective sequence ‘sets’ (shown in Table 6.3.2) the proportional change was .87, .86, .84, .87 between the first and the sixth repetition. Between each set an increase from the sixth repetition to the first repetition of the following set was found indicative of specific learning.

---

2 The important feature to note about these RTs is that for the ‘blocked’ group the sixth repetition is experienced before the subject moves onto the next sequence set (i.e. all sequences 1 - 5 are entered before sequences 6 - 10, which are entered before 11-15 and 16-20), thus specific sequences are being practiced in large chunks. However, for the ‘spaced’ group, all of the sequences, 1 - 20 are entered before the sixth repetition of sequences 1 - 20, so different sequences are receiving practice. For the chronological order of sequence repetitions, RTs should be read across columns in Table 6.3.2 for the ‘blocked’ group, but down columns for the ‘spaced’ group.
Table 6.3.2 Mean RT (in ms with SD) for the first and final repetition of each sequence set for each of the practice groups.

<table>
<thead>
<tr>
<th>Sequence set</th>
<th>Blocked Group</th>
<th>Spaced group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repetition 1</td>
<td>Repetition 6</td>
</tr>
<tr>
<td>sl - s5</td>
<td>3991 (547)</td>
<td>3490 (769)</td>
</tr>
<tr>
<td>s6 - s10</td>
<td>3831 (693)</td>
<td>3328 (604)</td>
</tr>
<tr>
<td>s11 - s15</td>
<td>3903 (764)</td>
<td>3287 (641)</td>
</tr>
<tr>
<td>s16 - s20</td>
<td>3659 (613)</td>
<td>3186 (647)</td>
</tr>
</tbody>
</table>

For the ‘spaced’ group the proportional change was .92, .90, .87, .90 across sets. Table 6.2 indicates that RTs do not change across the first repetition of the sequence sets, but by the sixth repetition, all RTs have improved.

A 2 x 4 x 2 (‘repetition’ by ‘sequence set’ by ‘practice group’) repeated measures ANOVA was performed on the sequence data. There was no effect of ‘practice’ (F(1, 35) = 1.159, p > 0.05); ‘blocking’ or ‘spacing’ the practice did not have an effect upon performance. Again a main effect of ‘repetition’ emerged (F(1, 35) = 67.66, p < 0.001), the sixth repetition being entered faster than the first. Furthermore, a main effect of ‘sequence set’ was found (F(1, 35) = 2.948, p < 0.05) which suggests that responding differed as a function of the sequences presented within each of the blocks. However, ‘Sequence set’ did not interact with either ‘practice group’ (F(3, 105) = 1.373, p > 0.05) or ‘repetition’ (F(3, 105) = .786, p > 0.05) suggesting that it was the presentation of novel stimuli that elicited differential responding per se.

Thus the practice received as a consequence of the organisation of the sequences within the list, did not effect the speed with which subjects responded to the sequences. There was an overall speed-up in responding across the sequences, as would be expected from receiving practice upon the task. It is apparent that the effect of practice is not just a general one. Differential responding emerged between the four sequence sets, which suggests that novel perceptual-motor processes have to be learned for each sequences. Notably within the ‘blocked’ practice group, following the
entry of each of the sequence sets, RTs increased upon the presentation of novel sequences. This suggests therefore that certain specific elements of the sequences are being learned. This will be examined more closely in the following sections.

6.3.3.1.2 Perception and Planning

The effect of the intra-list organisation upon the planning component of the response was examined through looking at changes in encoding time across the study session. As for the total time, the first and the final repetition of the sequences was initially examined; RTs are illustrated in Table 6.3.3. Again, a benefit in encoding time was expected for the ‘blocked’ practice group compared to the ‘spaced’.

Table 6.3.3 Mean encoding time (in ms with SD) for the first and the final repetition of the sequences, for both practice groups.

<table>
<thead>
<tr>
<th></th>
<th>Blocked</th>
<th>Spaced</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repetition 1</td>
<td>Repetition 6</td>
</tr>
<tr>
<td>Time</td>
<td>1708 (312)</td>
<td>1608 (526)</td>
</tr>
</tbody>
</table>

Using a 2 x 2 (‘repetition’ by ‘practice’) repeated measures ANOVA it was demonstrated that encoding improved reliably across sequence ‘repetitions’ (F(1, 35) = 5.724, p < 0.05). However, there was no difference between the ‘practice groups’ (F(1, 35) = 1.404, p > 0.05) and no interaction between the variables (F(1, 35) = .599, p > 0.05) which indicates that the same pattern of encoding emerged between the groups, across the repetitions; organisation of the list did not affect the rate at which sequences were perceived and responses planned.

The manipulation in practice and its effects upon encoding were more closely examined by looking at the time taken to respond to each of the sequences presented in the different blocks. Again, the important feature to note is the differential amounts of practice each of the sequences had received within each group. Table 6.3.4 shows each of the RTs.
The time taken to encode the sixth repetition of the sequences as a proportion of the first was calculated for each of the sequence sets (reported in Table 6.3.4) to obtain an approximation of the respective 'encoding' change over time. Within the 'blocked' group, proportions of .93, .89, .92, .85 were found indicative of a planning improvement with practice. Again however, there was a disruption in encoding when novel sequence sets were presented.

Table 6.3.4 Mean encoding time (in ms with SDs) for the first and final repetition of the sequences contained in each block.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Blocked Group Repetition 1</th>
<th>Repetition 6</th>
<th>Spaced group Repetition 1</th>
<th>Repetition 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>s1 - s5</td>
<td>1778 (426)</td>
<td>1666 (552)</td>
<td>1623 (248)</td>
<td>1731 (457)</td>
</tr>
<tr>
<td>s6 - s10</td>
<td>1704 (500)</td>
<td>1526 (455)</td>
<td>1538 (288)</td>
<td>1426 (322)</td>
</tr>
<tr>
<td>s11 - s15</td>
<td>1681 (493)</td>
<td>1558 (407)</td>
<td>1449 (289)</td>
<td>1594 (263)</td>
</tr>
<tr>
<td>s16 - s20</td>
<td>1682 (472)</td>
<td>1444 (393)</td>
<td>1569 (315)</td>
<td>1480 (471)</td>
</tr>
</tbody>
</table>

For the 'spaced' group, proportions of 1.06, .92, 1.10, .94. were obtained. The fact that improvement in responding was not found for half of the sequences suggests that the interleaving practice is having a detrimental effect upon the ability to perceive the sequence, plan and subsequently make the response.

A 2 x 4 x 2 ('repetition' by 'sequence set' by 'practice group') repeated measures ANOVA was performed on the subject data. Of particular interest was the effect of 'set', which allowed an examination of the effect of interleaving practice. A main effect of 'set' was found (F(3,105) = 8.529, p < 0.001) which illustrates that the perceptual processing and planning required is different across sequences sets. There was no interaction between 'set' and 'practice group' (F(3, 105) = 1.509, p > 0.05), which suggests that encoding of the sequences did not differ depending upon whether practice was 'blocked' or 'spaced'. 'Set' did interact with 'repetition' (F(3, 105) = 3.561, p < 0.05), however, which is likely due to the increase in encoding time within
the 'spaced' practice group within sets' 1 and 3, rather than systematic differences between the two variables.

Thus in terms of encoding the stimuli, the results showed that the way in which the practice is organised does not have an influence upon performance; that is, processing and initiating a response to a consistent perceptual representation does not afford an advantage over perceiving and planning 'inconsistent' responses. That is practicing an entire set of sequences prior to practicing novel sequences results in the same pattern of learning as receiving practice upon different, interleaving sequence sets. Receiving practice on the sequences per se appears to be responsible for the RT speed-up found.

6.3.3.1.3 MOTOR EXECUTION

'Execution' time, or that taken to enter the final three digits of the sequence was used as an index of the improvement, or otherwise, in motor responding across the practice session. Table 6.3.5 illustrates the time taken to execute the first and final repetitions.

Table 6.3.5 Mean execution time (in ms with SDs) for the first and final repetition of the sequences, between practice groups.

<table>
<thead>
<tr>
<th></th>
<th>Blocked</th>
<th></th>
<th>Spaced</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repetition 1</td>
<td>Repetition 6</td>
<td>Repetition 1</td>
<td>Repetition 6</td>
</tr>
<tr>
<td>Keystroke 2</td>
<td>574 (241)</td>
<td>477 (232)</td>
<td>562 (313)</td>
<td>454 (250)</td>
</tr>
<tr>
<td>Keystroke 3</td>
<td>823 (238)</td>
<td>762 (249)</td>
<td>866 (178)</td>
<td>676 (280)</td>
</tr>
<tr>
<td>Keystroke 4</td>
<td>473 (200)</td>
<td>358 (146)</td>
<td>387 (184)</td>
<td>308 (100)</td>
</tr>
</tbody>
</table>

The direction of the results indicate that all of the RTs improved across the practice session. A 2 x 2 x 3 ('repetition' by 'practice group' by 'keystroke') repeated measures ANOVA performed on these data found that the way in which practice was organised did not effect execution of the sequences (F(1, 35) = .592, p > 0.05). Practice did increase the speed with which the repetitions were executed, however
(F(1, 35) = 41.56, p < 0.05). An interaction between the variables was found (F(1, 35) = 12.17, p < 0.01) which was due to the increased time taken to execute the fourth keystroke within the 'blocked' group compared to the 'spaced'. This RT did appear to be artificially inflated however, as clear RT gains were evident by the sixth repetition. As has been found throughout the studies, a main effect of keystroke was found (F(2, 70) = 52.467, p < 0.001), which reflects the increased time taken to execute the third keystroke in comparison to the second and third.

The effects of manipulating the practice schedule upon execution were more closely examined using a 2 x 4 x 2 ('repetition' by 'set' by 'practice group') repeated measures ANOVA. A main effect of 'set' was found (F(3, 105) = 32.2, p < 0.001, the different groups of sequences repeated within the list being executed differently. There was no interaction between 'set' and 'repetition' (F(3, 105) = 0.033, p > 0.05) suggesting that the sequences were executed in the same manner across repetitions, but an interaction between 'set' and 'practice group' was found (F(3, 105) = 22.87, p < 0.001).

![Figure 6.3.2 Overall execution time (in ms) for each sequence set within practice groups.](image)

Figure 6.3.2 Overall execution time (in ms) for each sequence set within practice groups.
Figure 6.3.2 illustrates this interaction. While the overall execution time did not differ within the ‘blocked’ group, execution differed within the ‘spaced’ group. The first and second sets of sequences were executed more slowly within the spaced group than the blocked, but sets’ three and four were executed faster.

Thus it appears that although the execution of the sequences improved across the study phase, this was not due to the intra-list organisation of the sequences. There was no difference in execution depending upon whether practice had been ‘blocked’ or ‘spaced’.

6.3.3.4 SUMMARY

It would appear that manipulating the organisation of the list such that practice was either ‘blocked’ into four specific sets of sequences, or was ‘spaced’ so that different stimuli were practiced before repetition of previously seen sequences practice did not have an effect upon the speed with which the responding occurred. The time taken to perceive the stimuli and plan the response did not differ depending upon whether the perceptual representation and the initial motor response to be made remained constant or changed with greater frequency. Furthermore the execution of the sequences did not differ as a function whether practice was ‘blocked’ or ‘spaced’. Responding to the presentation of relatively unpredictable sequences does not appear to differ from responding to the presentation of sequences in which consistent responding is required.

6.3.3.2 TEST

The main hypotheses under investigation at test was to examine whether intra-list organisation of the stimuli at study effected retention of the material, i.e. whether retention of learned material was different, or worse following ‘blocked’ practice rather than ‘spaced’. In addition, the effect of reinstating perceptual-motor cues that were present at study was also investigated at test through the manipulation of
sequence type' and 'transfer group'. Both 'old' and 'new' sequences were presented at test and furthermore, the keypad format was manipulated such that half of the subjects within each practice group performed the task using a transposed layout. In line with the predictions of CI it was expected that there would be no difference between the groups. The effect of the keypad manipulation was analysed separately from the practice group. Both indirect and direct tests of memory were conducted at test; DVs were RTs and recognition decisions, respectively.

Error rates for each of the 'transfer groups' were initially examined; an error was classified as any incorrect keypress out of the possible 160 keypresses required. The mean percentage of errors made within the 'same' test condition was 1.7%; within the 'switch' group it was 1.9%; there was no difference between the groups (p > 0.05). As error rates were low all data were included in the analysis.

6.3.3.3 ORGANISATION OF PRACTICE

In order to examine whether the organisation of the practice given had an effect upon retention performance, total time data from each of the 'practice groups' were analysed using a 2 x 2 ('practice' by 'sequence type') repeated measures ANOVA. Analysis was performed within each of the transfer groups (i.e. 'same' or 'switch'). It was hypothesised that those receiving a 'blocked' practice schedule would show worse retention performance than 'spaced', due to the interleaving of sequences facilitating generalisability and transfer of performance.

Table 6.3.6 shows the mean RTs of each 'transfer group' within each 'practice group' for each 'sequence type'. For those subjects who used the 'same' keypad as at study, although the 'spaced' group appeared to respond more slowly than the 'blocked' group to 'new' sequences responding did not differ between the groups (F(1, 19) = .277, p > 0.05). A main effect of 'sequence type' was found (F(1, 19) = 6.280, p < 0.05) indicative of faster responding to sequences that had been previously seen.
Table 6.3.6 Mean median total time (in ms with SD) for each transfer group for each sequence type as a function of practice received.

<table>
<thead>
<tr>
<th>Practice group</th>
<th>New</th>
<th>Old</th>
<th>Old Motor</th>
<th>Old Digit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same – blocked</td>
<td>3583 (771)</td>
<td>3503 (721)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Same – spaced</td>
<td>3823 (609)</td>
<td>3597 (562)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Switch – blocked</td>
<td>3522 (743)</td>
<td>3487 (793)</td>
<td>3641 (839)</td>
<td>3221 (752)</td>
</tr>
<tr>
<td>Switch – spaced</td>
<td>3826 (692)</td>
<td>3791 (581)</td>
<td>3777 (493)</td>
<td>3730 (.662)</td>
</tr>
</tbody>
</table>

There was no interaction between ‘sequence type’ and ‘practice group’ (F(1, 19) = 1.435, p > 0.05), despite the increased time taken to respond to ‘new’ sequences within the ‘spaced’ group.

Data from the ‘switch’ transfer group were subject to the same analyses. Although the direction of results suggested that the ‘blocked’ group responded faster than the ‘spaced’, the effect was not reliable (F(1, 17) = .913, p > 0.05). Furthermore, unlike those in the ‘same’ transfer group, there was no difference between the sequences, ‘old’ sequences were entered at the same rate as ‘new’ (F(1, 19) = .382, p > 0.05). This suggests therefore that the removal of perceptual-motor cues used at practice detrimentally affects performance. The interaction between ‘sequence type’ and ‘practice’ was not reliable (F(1, 19) = .00, p > 0.05) which suggests comparable responding between both practice groups to all of the sequences.

The effect of manipulating the ‘transfer groups’ was subsequently examined; RTs are shown in Table 6.3.7.

Table 6.3.7 Mean median total time (in ms with SD) for each test condition as a function of sequence type

<table>
<thead>
<tr>
<th>Condition</th>
<th>New</th>
<th>Old</th>
<th>Old Motor</th>
<th>Old Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>3724 (679)</td>
<td>3562 (624)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Switch</td>
<td>3746 (723)</td>
<td>3668 (681)</td>
<td>3721 (643)</td>
<td>3527 (733)</td>
</tr>
</tbody>
</table>
The direction of the means indicate that responding was faster within the ‘same’
group than the ‘switch’ and that ‘old’ sequences were entered faster then ‘new’. A 2 x
2 (‘sequence type’ by ‘transfer group’) repeated measures ANOVA was performed on
the data. ‘Old’ sequences were entered reliably faster than ‘new’ within both transfer
groups (F(1, 34) = 6.094, p < 0.05). However, a main effect of ‘transfer group’ was
not found. There was no reliable difference between the ‘same’ and the ‘switch’
groups (F(1, 34) = 0.032, p > 0.05). The interaction between ‘sequence type’ and
‘condition’ was not significant (F(1, 34) = 2.584, p > 0.05).

The contribution of perceptual and motor cues were examined further by looking at
responding from within the ‘switch’ group only. Table 6.3.7 shows ‘old letter’
sequences were entered faster than ‘old motor’ which were entered faster than ‘new’.
A main effect of ‘sequence type’ was found (F(2, 36) = 3.743, p < 0.05); planned
comparisons revealed ‘old letter’ sequences were different from the others; ‘new’
(3746ms) and ‘old motor’ (3721ms) did not differ. Thus, the results suggest that
perceptual rather than motor information is retained.

Thus the organisation of the practice schedule did not affect retention performance;
there was no support for the hypothesis that the ‘spaced’ group would perform faster
at retention than the ‘blocked’. However, there was a benefit of receiving ‘old’
sequences compared to ‘new’ suggesting that there is a benefit to reinstating
perceptual-motor cues that were used at acquisition. Closer analysis of the transfer
groups seemed to suggest that the benefit was for the reinstatement of perceptual cues;
there was no difference in responding between the transfer groups, (where the motor
response requirement was altered) and within the switch transfer group only, no
differences between ‘old motor’ and ‘new’ sequences.

6.3.3.3.1 PERCEPTUAL PLANNING

The time taken to encode the sequences was used as an index of the time spent
perceiving the sequence and planning a response. The same analyses were performed
on the encoding time data. Table 6.3.8 shows the encoding times for each of the
'practice groups', further decomposed into the two 'transfer groups'. Analyses will be reported for the 'same' transfer group initially.

Although responding was slower within the 'spaced' group, 'practice' did not have an effect upon responding to each of the sequences ($F(1, 19) = .594, p > 0.05$); planning time required to respond to the sequences did not differ depending upon the organisation of the practice received. Furthermore, within the 'same' transfer group, there was no effect of 'sequence type' ($F(1, 19) = .395, p > 0.05$); having had previous practice in responding to a specific stimulus did not facilitate subsequent responding to that stimulus. There was no interaction between the variables ($p > 0.05$).

**Table 6.3.8 Encoding time (in ms with SD) within each transfer group, for each sequence type as a function of practice**

<table>
<thead>
<tr>
<th></th>
<th>New</th>
<th>Old</th>
<th>Old Motor</th>
<th>Old Digit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same - blocked</td>
<td>1772 (510)</td>
<td>1733 (501)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Same - spaced</td>
<td>1982 (527)</td>
<td>1889 (428)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Switch – blocked</td>
<td>1745 (462)</td>
<td>1755 (412)</td>
<td>1851 (514)</td>
<td>1690 (349)</td>
</tr>
<tr>
<td>Switch - spaced</td>
<td>1752 (482)</td>
<td>1786 (348)</td>
<td>1833 (304)</td>
<td>1754 (413)</td>
</tr>
</tbody>
</table>

The findings reported above were replicated within the switch transfer group. The organisation of the practice schedule did not affect the way in which sequences were subsequent encoded. And, having previously processed the sequences did not facilitate subsequent response planning ($p > 0.05$).

Encoding times for each sequence type within each 'transfer group' are shown in Table 6.3.9. A clear pattern of responding to the sequences did not emerge. 'Old' sequences within the 'same' test condition were entered faster than 'new'; the reverse was found within the switch transfer group.
Table 6.3.9 Mean median encoding times (in ms with SD) for each transfer group as a function of sequence type

<table>
<thead>
<tr>
<th>Condition</th>
<th>New</th>
<th>Old</th>
<th>Old Motor</th>
<th>Old Digit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>1903 (516)</td>
<td>1827 (446)</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Switch</td>
<td>1718 (463)</td>
<td>1772 (379)</td>
<td>1865 (429)</td>
<td>1745 (385)</td>
</tr>
</tbody>
</table>

A main effect of 'sequence type' was not found (F(1,34) = 0.611, p > 0.05). The difference between the two transfer groups was not reliable (F(1, 34) = 0.453, p > 0.05). However it is worth noting that the direction of results was not expected, the 'switch' group encoding faster than the 'same'. Again there was no significant interaction between 'sequence type' and transfer group' (F(1, 34) = 2.583, p > 0.05).

Analysis performed upon data from the 'switch' group revealed that there was no reliable difference between the different sequence types (F(2, 36) = 2.766, p > 0.05).

Thus, the way in which the practice is organised does not facilitate perceptual planning and initiation of a response. Furthermore, there is no benefit of having previously perceived the stimulus. Given the findings reported above it is interesting that the perceptual and the motor components do not differ; a stronger perceptual representation would be expected during the encoding phase of the study. Thus there is no effect of CI and no effect of procedural reinstatement.

6.3.3.3.2 MOTOR RESPONSE EXECUTION

Practice did not have an effect upon performance at retention; there was no difference between the 'blocked' and the 'spaced' group and the time taken to execute the sequences (F(1, 35) = .532, p > 0.05). There was no difference between execution of 'old' and 'new' sequences (F(1, 35) = .497, p > 0.05).
Analysis was performed on the data between the transfer groups. Table 6.3.10 illustrates the execution time of each keystroke within the ‘same’ and ‘switch’ transfer groups.

Table 6.3.10 Mean median execution times (in ms with SD) for each ‘transfer group’ as a function of ‘sequence type’

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Key 2</th>
<th>Key 3</th>
<th>Key 4</th>
<th>Key 2</th>
<th>Key 3</th>
<th>Key 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>New</td>
<td>437 (20)</td>
<td>759 (26)</td>
<td>417 (13)</td>
<td>484 (32)</td>
<td>955 (29)</td>
<td>386 (18)</td>
</tr>
<tr>
<td>Old</td>
<td>453 (20)</td>
<td>713 (25)</td>
<td>353 (10)</td>
<td>518 (30)</td>
<td>726 (25)</td>
<td>371 (15)</td>
</tr>
<tr>
<td>Old motor</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>532 (34)</td>
<td>798 (23)</td>
<td>416 (21)</td>
</tr>
<tr>
<td>Old digit</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>547 (28)</td>
<td>661 (26)</td>
<td>347 (13)</td>
</tr>
</tbody>
</table>

Overall ‘old’ sequences were executed faster and with less variation than ‘new’; a main effect of ‘sequence type’ was found (F(1, 34) = 7.723, p < 0.01). There was no difference between the two transfer groups (F(1, 34) = 0.378, p > 0.05) and the time taken to execute the sequences. Furthermore, there was no difference in the execution of the different sequence types within the ‘switch’ transfer group (p > 0.05). A main effect of ‘keystroke’ was found (F(2, 34) = 46.723, p < 0.001) reflecting an increased difference in the time taken to enter the third digit of the sequence compared to the second and fourth.

These results are clearly mixed. There appears to be a benefit from having previously executed the sequences, however, there is no difference between the transfer groups. This implies that benefits to performance are being obtained through the reinstatement of both perceptual and motor cues, but that the former are exerting more influence than the latter.

6.3.3.3.3 SUMMARY

The findings do not lend support to the CI effect. There was no difference in
performance at test as a consequence of the practice received; the 'blocked' and the 'spaced' group encoded and executed the sequences in the same way. Spacing practice at acquisition such that a greater variety of sequences were presented preventing subjects from relying upon anticipatory responding did not facilitate performance at retention where a range of sequences, both new and old were presented. However, there was an advantage for having processed old sequences. Although there was no difference in the way old sequences were initially perceived and responded to (i.e. encoded), there was a benefit in the execution of the sequences. Although this suggests that it is the retrieval of motor cues that is facilitating performance, it actually looks as though the perceptual cues are having a greater facilitative effect; within the 'switch' transfer group, 'old letter' sequences were executed faster than new.

Thus, while there is no effect of CI, there does appear to be a beneficial effect of reinstating cues that were used at acquisition. These findings were not expected.

6.3.3.4 RECOGNITION

Explicit tests of memory were performed on the data on the basis of the 'practice' received at study and also in terms of the 'transfer group' at test. Subjects were required to make a recognition judgment regarding the 'old' / 'new' status of the sequence immediately after entering the sequence. Recognition accuracy was measured using $A'$; Table 6.3.11 shows the proportion of false alarms, hits and the $A'$ statistic for both the 'blocked' and the 'spaced' practice groups.

Table 6.3.11 Proportion of 'hits' and 'false alarms' and $A'$ for the 'blocked' and 'spaced' practice group.

<table>
<thead>
<tr>
<th>Practice group</th>
<th>Hits</th>
<th>False alarms</th>
<th>$A'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocked</td>
<td>.57</td>
<td>.51</td>
<td>.62</td>
</tr>
<tr>
<td>Spaced</td>
<td>.53</td>
<td>.46</td>
<td>.64</td>
</tr>
</tbody>
</table>
In order to test whether subject’s were performing above the level of chance, $A'$ for each of the groups was compared, using a one-sample t-test against a .5 test level. Both the ‘blocked’ ($t(19) = 5.699, p < 0.01$) and the ‘spaced’ group ($t(18) = 7.695, p < 0.01$) were reliably higher than chance performance. It is evident that the ‘blocked’ group more accurately identified a higher proportion of the ‘old’ sequences as ‘old’, but mistakenly identified more ‘new’ sequences as ‘old’ than the ‘spaced’ group. However, recognition accuracy did not differ between the groups ($t(37) = 0.585, p > 0.05$). Thus, the manipulation in the organisation of the practice schedule did not affect subsequent explicit memory of the sequences.

Analysis was also performed on the data of the two ‘transfer groups’. This was performed in order to examine whether the manipulation in response requirements had a detrimental effect upon recognition accuracy. Table 6.3.12 depicts the proportion of hits and false alarms found for the ‘same’ and the ‘switch’ test conditions.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Hits</th>
<th>False alarms</th>
<th>$A'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>.58</td>
<td>.46</td>
<td>.63</td>
</tr>
<tr>
<td>Switch</td>
<td>.53</td>
<td>.51</td>
<td>.62</td>
</tr>
</tbody>
</table>

Within both transfer groups, the proportion of hits was greater than the proportion of false alarms, indicating that more decisions were correct than incorrect. Again a series of one sample t-tests were performed on the $A'$ data in order to examine whether the subjects were performing greater than chance (test level of 0.5). Both the ‘same’ ($t(20) = 6.925, p < 0.001$) and the ‘switch’ ($t(17) = 6.216, p < 0.001$) group performed significantly better than chance. However, there was no difference in accuracy between the test groups ($t(37) = 0.212, p = 0.833$).

It is evident that regardless of the practice received at study, or the manipulations performed at test, subjects are still able to accurately discriminate those sequences that they have previously processed. Again the effects of CI were not supported. The
'spaced' group were no more accurate than the 'blocked' group in their recognition performance. In addition, however, the effects of procedural reinstatement were not demonstrated. Both the 'same' and the 'switch' transfer groups demonstrated accurate recognition of the sequences, largely in the absence of the effects of indirect effects of memory.

6.3.4 DISCUSSION
The present experiment was designed to assess whether the organisation of the practice schedule, and as a consequence the 'contextual interference' effect would have an impact upon performance using the digit entry paradigm. The hypotheses that were tested stemmed directly from the evidence supporting CI. At study, it was expected that subject's receiving 'blocked' practice would perform faster than those receiving 'spaced' practice. At retention the reverse was expected. Improved performance, measured both indirectly and directly was expected from the 'spaced' group. Furthermore, there was expected to be no facilitation from the reinstatement of cues provided at study and then again at test.

The results did not support these predictions. At study, there was no difference between the practice groups and the learning that occurred; both groups entered the sequences at the same speed. Such results suggest that consistency in presentation does not facilitate learning of the digit entry task. The repetition of the same perceptual representation and thus the execution of the same motor response for an extended period of time does not afford any advantages over repeating different stimuli. Given the nature of the task and that responding occurs upon a defined spatial layout these results are somewhat surprising. Clearly reconciling such findings to established CI effects is paramount.

Two diverging views can account for the results. Perhaps the simplest explanation relies upon findings which have shown that 'blocked' / 'spacing' effects are not always present when the task being performed is considered 'difficult'. Recall that the organisation of the practice schedule did not effect responding when children
performed the ‘Cronikole’ task used by Pollock and Lee (1997). It was argued that
the task was difficult for the children to acquire per se, thus negating any practice
effects. Indeed such ‘difficulty’ effects have been reported elsewhere; the assertion is
that under difficult performance conditions, a speed-accuracy trade-off enters the
equation and the benefit of perceiving and responding to consistently presented
stimuli is offset (Wulf and Schmidt, 1989).

An alternative explanation of the null findings is derived from the idea that the
formation of different motor programs have an effect upon the way in which stimuli
are responded to (Schmidt, 1978). To be more specific, it is argued that a task
requiring the formation different motor programs is more difficult to perform than one
in which the response requirement is always the same or differs only through an
alteration of a within task parameter. The absence of effects at study therefore would
suggest that the although responses required in the present study differed, the only
alteration to the response was ‘made’ to a within task parameter. It follows therefore
that due to the fact that the response requirement was not restructured in an overt way,
the effort level required to perform the task and thus the level of CI experienced was
minimal (Lee, 1998).

Examination of the results at retention offer support for the latter view. The
expectation that the ‘spaced’ group would show enhanced retention of the task was
not supported in this experiment. There was no difference in the speed with which the
‘blocked’ and ‘spaced’ group responded to previously seen and previously unseen
material and furthermore, it was apparent that on tests of recognition, both groups
demonstrated the ability to discriminate ‘old’ sequences from ‘new’. Although this
result was unexpected, when considered with the results at study, again the idea that
the motor program was not sufficiently different seems to offer a plausible
explanation of the findings. The stimuli that were presented at test, despite the fact
that they differed perceptually and hence motorically to those at study, were
essentially responded to in the same manner. It would appear that the spatial
representation of the sequence did not differ to the extent that a different motor
program was developed. (It is worth noting that these findings have interesting implications for theories of skill acquisition and whether the learning that is occurring is proceduralised or is maintained on an episodic basis. Thus far the results would suggest that a ‘proceduralisation’ account is more appropriate).

Clearly the results do not lend support to the CI effect or the explanations proposed to account for the effects. The ‘elaboration benefit’ explanation is based upon the operation of ‘multiple’ and ‘variable’ encoding processes that lead to conditions of high CI, i.e. the number of and the unpredictability of the different strategies that must be employed in order to perform the task, respectively (Battig, 1972; Shea and Morgan, 1979). When responding under conditions of random practice responses made upon each trial are proposed to be kept in working memory to serve as a guide as to the appropriateness of the subsequent response. New representations subsequently created result in additional information being incorporated into knowledge structures which in turn result in a more detailed task representations hence longer acquisition but better retention (Shea and Zimny, 1988). The fact that there was no difference in the time taken to encode or execute those sequences presented to the ‘spaced’ group suggests that the processing occurring at both study and test was not different between the groups.

The alternative ‘action plan reconstruction’ hypothesis (Lee and Magill, 1985) relies on the premise that successful responding is initially based upon the formation of an action plan, a motor program of the response and details of the parameters required for successful execution of the task (Newell, 1979). This hypothesis tends to support the assertion that in the present experiment motor programs were not sufficiently different as to incur CI. The reconstruction account suggests that the extensive retrieval practice that ensues when a particular trial is re-experienced during acquisition is the key to understanding successful retention. Under conditions of high CI (i.e. random practice), details of the action plan constantly change due to the variation of the interpolated trials. The learner actively tries to reconstruct what they have performed previously so that at retention each different presentation or aspect of the skill does
not distract them. Under conditions of blocked practice forgetting of each sequence presentation is more likely as this regenerative process does not occur. The results do not suggest that these processes were occurring under either of the conditions.

However, the claim made in the CI literature regarding the reinstatement of study conditions at test does appear to have some support in this study, i.e. that the overlap between study and test does not lead to enhanced retention performance (Magill, 1998). It was demonstrated in the present experiment that manipulating the response requirement imposed on the subject did not detrimentally affect performance. Again it may be asserted that the findings were due to the motor programs underlying the response and the fact that programs changed within parameter boundaries only. Indeed, this argument may be asserted when discussing the lack of support given to the procedural reinstatement hypotheses. Conclusive evidence for the benefit of reinstating perceptual motor cues was not provided partly because the cues were not needed. That the motor program parameters did not change meant that learning could be transferred to novel exemplars of the type of stimuli used in the study. The findings that there were no differences upon the indirect tests of memory but recognition accuracy of the stimuli was reliable supports this assertion.

In conclusion, the results do not demonstrate CI effects. There was no advantage found at study for blocking the sequences into consistently presented groups. Furthermore, at retention the expected benefit for the 'spaced' practice group was not evident. The most plausible explanation for the results is that during acquisition, motor programs were formed enabling the subject's to respond to all of the sequences presented. Upon the presentation of novel stimuli, changes in the motor programs occurred within the parameters of the existing programs. There was no overtly different response requirement needed to execute the sequence. Indeed, this suggestion also offers a plausible account (in this and with respect to the previous studies) for why the reinstatement of perceptual-motor cues formed at acquisition was not necessary for accurate responding at retention. The results of the present
experiment support the assertion that only when learning is 'difficult' does the reliance upon perceptual cues increase.

6.4 CONCLUSIONS

The aim of the present chapter was to examine how manipulations in task difficult effected learning. In Study 6 a straightforward manipulation of the stimulus-response mappings was performed; subjects were required to type random letter strings using a keypad usually reserved for typing numbers. It was expected that such a manipulation would increase the effort required to learn the task and as a consequence would increase the dependency upon the presence of retrieval cues at test. This assertion followed from the suggestion made in the previous chapter in which it was demonstrated that degrading the learning conditions led to such a dependency. Indeed, this prediction was supported. At retention the reinstatement of specific perceptual-motor processing cues facilitated performance; there were no transfer effects. Again the results supported the assertion that procedural reinstatement effects appear to arise as a consequence of a strategy that is adopted when the demands placed on the individual during learning are high.

Study 7 extended the investigation into task difficulty through a manipulation of the practice schedule. The manipulation involved 'blocking' or 'spacing' the practice within the schedule. In line with typical 'CI' effects it was hypothesised that spacing practice would increase the difficulty of learning the task while blocking practice would facilitate acquisition. Furthermore, it was expected that the 'memorability' of the stimuli would increase as a consequence of the spaced practice and would thus negate the need for the reinstatement of specific encoding cues. In line with the arguments arising from CI it was hypothesised that the effects of procedural reinstatement would not be found. The results partly supported this assertion. Responding at retention was not dependent upon the reinstatement of cues; again the results suggest that global properties of the sequences are learned facilitating performance upon the task as a whole. However, the extent to which this was due to the effects of CI is questionable. There was no difference in performance as a function of the practice received, either at acquisition or at retention. It was suggested
that a potential reason for the null findings was that novel motor programs were not formed when responding to different stimuli and thus the effort required during subsequent processing was insufficient to incur CI effects. It would again appear that the amount of practice *per se* in this instance was enough to facilitate global responding.
7 GENERAL DISCUSSION

7.1 SUMMARY
The present chapter will review the findings of the experimental studies reported in the thesis, investigating the commonalities and the differences that have been reported between studies as well as integrating the findings into the existing literature. The series of experiments reported in general sought to examine the ways in which stimuli are learned and retained. A specific methodology derived from the 'procedural reinstatement' paradigm (Fendrich et al, 1991) was used to study this. The methodology was chosen because it allowed an elegant way of manipulating the performance conditions at study and at test and subsequently the measurement of the effects of these manipulations. Furthermore, the methodology also broadened the type of measurement of retention typically used in studies of this sort through the incorporation of both indirect and direct tests.

The central themes of this thesis included the way in which 'practice' affected learning and retention of material; whether the learning was characterised by the acquisition of 'global task based' knowledge, or rather 'sequence-specific' knowledge; the extent to which what is learned transfers to other similar tasks; whether retention of material is influenced by the overlap between procedures used at study and at test; and whether evidence suggests that two distinct rather than one continuous memory system exists. What has been learned about each of these issues from the experiments reported in this thesis will be presented.

7.2 THE EFFECTS OF PRACTICE
The effects of practice upon learning and retention were examined in different ways. Practice 'style' was manipulated in the experiments reported in Chapter 4; the effects of receiving either a 'massed' or 'distributed' practice schedule was examined. The 'amount' of practice was manipulated in Chapter 5, and finally, the effects of 'blocking' and 'spacing' the practice schedule was examined in Chapter 6. With each
manipulation different effects were predicted. Before commencing the discussion of each manipulation, one very important point worth noting is that the effects of practice was negatively accelerating in all of the studies. That is as the amount of practice increased, the gains that were obtained became smaller. Indeed as was demonstrated in Chapter 4, when curves were fitted, the function that best accounted for the data was the characteristic power function. Thus, convincing evidence was provided that the subjects were actually learning how to perform the task. It is worth noting at this point that the effect was found despite the fact that the sample used would have undoubtedly had keyboard experience; individuals were learning a task that was not unusual. Thus, these results provide a sound basis from which to interpret the practice manipulations.

7.2.1 DISTRIBUTED AND MASSED PRACTICE
Studies 1 and 2 (Chapter 3) examined the effects, both at 'study' and at 'test', of distributing and massing the practice schedule upon learning of the digit entry task. Contradictory findings have emerged from the literature. It has been asserted that while massed practice leads to faster learning, distributed practice leads to more durable learning (Adams, 1985). However, contradictory findings also indicate that distributed practice leads to rapid acquisition, whilst 'massing' is a transient variable effecting performance only while it is present, i.e. there are no detrimental effects at retention (Baddeley, 1997; Groeger, 2000). A comparison of the results of Study 1, which explored the effects of distributing practice and Study 2, which incorporated massed practice enabled these predictions to be tested.

At acquisition, overall, the distributed group responded faster than the massed group, a finding congruent with previous research (Baddeley and Hitch, 1978). The locus of the advantage was due to the increased speed in the perception of the stimuli and the planning of responses within the distributed group; there was no difference between the groups and the time taken to execute the sequence. Receiving distributed practice thus appears to facilitate the ability to prepare and plan the response during learning, i.e. the most effortful aspect of the task. A potential reason for this concerns the way
in which 'required effort' may interact with transient factors such as fatigue (from continuous practice upon very repetitive tasks) and belief in one's abilities (Mumford et al, 1994; Ackerman, 1991). Distributed practice by its very nature is less demanding upon the individual in terms of the concentration upon practicing one element within a session. The results thus support previous work indicating that the break in practice sessions offers a rest from the task which may enable consolidation of learning and knowledge of future task requirements (Mumford et al, 1994).

However, the results also demonstrated that despite the speed difference between the groups, there was no difference in the actual rate at which the task was learned; the 'massed' group simply took longer to reach the same level of performance as the 'distributed'. In examining the rate of learning, these findings extend the work of Baddeley and Longman (1978), who examined response times per se. Such findings have obvious implications for the planning of optimum acquisition phases, but clearly should also be interpreted in the context of retention before decisions are made (Groeger, 2000).

Following a retention interval, subjects from both the massed and distributed practice groups were required to participate in exactly the same test. At retention it was initially demonstrated that the time spent planning the response was less within the distributed group than within the massed, suggesting that learning within the former group was indeed more durable. However, when initial typing speed was controlled for, i.e. the rate at which they were responding at acquisition, the effect disappeared, performance within the groups was the same. There was no difference between the groups and the ability to execute the sequences and in terms of recognition of the sequences, again the practice regime undertaken did not effect the outcome. Both groups were able to distinguish the sequences reliably above chance level.

Thus, the detrimental effects of massing practice appear to be confined to the actual acquisition phase when a massed practice schedule is being employed (Adams and Reynolds, 1954; Groeger, 2000). In the present study, the durability of learning via
massed practice was equivalent to that found with distributed practice. Clearly the implication for these findings regarding the acquisition of the typing skill is that the type of practice engaged in is not an influential factor in determining the rate at, or the success with which the skill is learned and retained. The results do imply that practice can be tailored to suit the demands of the particular learner.

7.2.2 'BLOCKED' AND 'SPACED' PRACTICE
The intra-list organisation was manipulated in Study 7 in order to examine the effects of 'blocking' and 'spacing' practice upon learning and retention of the stimulus material. Differential effects are hypothesised to occur at 'study' and 'test' with each regime. Blocked practice has been found to lead to faster acquisition of the task compared to spaced practice, but spaced practice is hypothesised to benefit retention of the material (Magill and Hall, 1990). The effect is believed to occur due to 'contextual interference', or experiencing and responding to different items before reprocessing previously seen and processed items (i.e. spaced practice).

In the present experiment the organisation of the stimulus list did not effect either learning or retention of the material. There was no contextual interference effect. At study, there was no difference between the practice groups and the learning that occurred; both groups entered the sequences at the same speed. Such results suggest that consistency in presentation, i.e the repetition of the same perceptual representation and thus the execution of the same motor response for an extended period of time does not facilitate learning of the digit entry task in a way which is more successful than presenting sequences in a random order.

The most plausible explanation for these findings is derived from the idea that responding to stimuli is governed by the formation of different motor programs (Schmidt, 1978). It is argued that a task requiring the formation different motor programs at each encounter with a stimulus is more difficult to perform than one in which the response requirement is always the same or differs only through an alteration of a within task parameter; i.e. the situation where the response required is
not 'significantly' different from a previous response. The absence of effects at study therefore would suggest that the although different responses were required in the present study differed, the alteration in performance occurred within a task parameter. It follows therefore that as the response requirement was not restructured in an overt way, the effort level required to perform the task and thus the level of CI experienced was minimal (Lee, 1998).

Indeed, in drawing a comparison between the tasks used in the present study and those in which the effects of CI are usually demonstrated, it is evident that the tasks usually require the learner to perform more overt motor movements for example requiring the performer to make some sort of ballistic movement to reach targets or hit goals, i.e. when the physical requirements of the tasks change upon a trial to trial basis (Magill, 1998). Clearly the motor movements in the studies reported here do not require such overt intra-task changes thus resulting in an absence of effects.

The results at retention support this view. The expectation that the ‘spaced’ group would show enhanced retention of the task was not supported in this experiment. There was no difference in the speed with which the ‘blocked’ and ‘spaced’ group responded to previously seen and previously unseen material and furthermore, it was apparent that on tests of recognition, both groups demonstrated the ability to discriminate ‘old’ sequences from ‘new’. Although this result was unexpected, when considered with the results at study, again the idea that the motor program was not sufficiently different seems to offer a plausible explanation of the findings. The stimuli that were presented at test, despite the fact that they differed perceptually and hence motorically to those at study, were essentially responded to in the same manner. It would appear that the spatial representation of the sequence did not differ to the extent that a different motor program was developed.

Thus the results support the notion that motor programs must alter beyond task parameters for the effects of contextual interference to be evident. However, a question that clearly remains unresolved concerns the extent to which tasks must
differ before the effects of contextual interference must be shown? When does the
motor program required to respond change? In terms of the present methodology, this
could be examined by altering the keypads used to respond to stimuli within practice
sessions, i.e. responding using the keypad, followed by responding on the actual
'letter keyboard'. In making small alterations one could establish the threshold at
which the effects are found. Indeed, using the acquisition of typing skill as an
example, assessing the rate at which people learn to type a particular passage of prose,
i.e. presenting to-be-typed sentences in a blocked or random order would be an
appropriate would of testing where this 'threshold' may lie. Clearly there is more
effort required to type using a QWERTY keypad than a three by three keypad. Thus
this manipulation may have an effect with the task itself.

7.2.3 THE 'AMOUNT' OF PRACTICE
In Study 3, the amount of practice that was given was reduced compared to that given
in Studies 1, 2 and 7, in which 'practice' manipulations were made (see above
sections). The methodology used in all of these experiments was used in Study 3;
subjects learned the task and then participated in a retention test in which they were
required to enter and discriminate between 'old' and 'new' sequences. It was
hypothesised that reducing the amount of practice would lead to greater dependency
upon the presence of 'appropriate retrieval cues', i.e. procedural cues that were
present at study and again at test.

When the amount of practice was reduced, a distinct advantage was demonstrated
when the response requirements between study and test were the same, i.e. when
'old' rather than 'new' sequences were responded to and when the same response
format was used. It was suggested from these results that when learning is interfered
with in some way, in this case when practice is diminished, reinstating the conditions
between study and test takes on additional importance for the learner. The rationale
for this suggestion is due to the fact that the learner becomes increasingly dependent
upon the presence of appropriate retrieval cues, i.e. those that were present at learning
to facilitate performance at retention. The simple implication of these findings is that
performance will suffer when insufficient practice is received. This will undoubtedly apply across a broad range of tasks, not just typing.

7.3 TRANSFER AND GLOBAL VERSUS STIMULUS SPECIFIC REPRESENTATIONS OF LEARNING

In this thesis, learning was characterised according to whether 'specific' features of the stimuli were learned or rather whether 'general', or more 'global' attributes were learned. As the labels suggest, it was hypothesised that whilst specific feature learning would facilitate performance on specific exemplars of the learned stimuli, 'global' learning would result in the ability to perform upon similar types of task that shared the same underlying processes, i.e. positive transfer performance would be evident. Thus with global learning, the action of typing sequences in general would be facilitated with practice rather than typing certain sequences per se. The initial examination of the nature of learning was ascertained at 'study', where responding to specific sequences and repetitions was examined.

Throughout all of the experiments, during the study phase, response times improved with practice indicative of a facilitation from practice. Closer examination of the individual sequences, however revealed that the time taken to respond to certain stimuli differed, and furthermore, components of specific sequences were entered at relatively faster or slower rates. Overall, the total time taken to respond to each of the stimuli differed across the learning phase. However, in terms of the component response times, the locus of specificity appeared to be in the amount of 'planning' required to respond. Encoding was used as an index of the time taken to perceive the sequence, plan the response and subsequently make the initial keypress. However, the implication is that within the encoding component, the generation of the motor plan occurs. This is supported by the absence of differences in the execution component of the sequences.

Thus, the effort required to perform the task (in terms of perceiving and planning)
appears to be an influential part of performance, influential in terms of whether responding is specific to the stimuli or was more general. The results suggest that during encoding the entire sequence response was planned and clearly the required time differs depending on the sequence shown. Once the initial movement is made and keypress typed, the difference diminishes as the subject ‘goes through the motions’ of executing the final three digits.

The absence of difference in the execution times between sequences supports this. Furthermore, within each sequence, a consistent finding to emerge was that the third keystroke took longer to execute than the second or the fourth. Although this suggests that parsing and therefore some additional planning is occurring during execution, the fact that the response time for keystroke three is significantly lower than encoding time, suggests that some planning for this response has already occurred and thus there is less to plan. The increase in time taken to respond here may be a reflection of the ‘implementation’ or ‘initiation’ of plan that has already been made. One question arising from these results, concerns the extent to which learning is occurring within the execution component of the task. Clearly there is no change in execution, thus the possibility may arise that on this aspect of the task, performance is due to transfer of previous typing ability. This suggestion is appealing from the point of view of learning to type and can be tested by presenting a typist with a selection of phrases to be typed. Compared to previously typed material, it would be predicted that the time taken to encode the novel sentence would increase, the time taken to plan and subsequently initiate the response would also increase as the specific properties of that sentence were processed. However, a difference in the time taken to actually execute the sequence would not be expected as the actions at this stage represent the global ability of being able to type. It would be expected that previous typing experience would transfer and facilitate performance in novel situations.

Overall it would appear that the results at ‘study’ suggest that both general and specific sequence learning occurs and thus lends support to arguments for the existence of two separable ‘specific’ and ‘general’ learning systems (Marsolek and
Responding at retention was examined in order to gauge whether general or specific learning was occurring and furthermore to obtain an idea of the extent to which performance transferred to similar tasks. To recap, the typing times of sequences presented at retention were examined in terms of whether they had been previously seen and typed. In five out of the seven experiments conducted, there was positive transfer to novel stimuli from sequences that had been previously processed; i.e. there was no difference between typing times for 'new' and 'old' sequences at test. Despite the fact that specific sequences were entered faster or more slowly at study, following a retention interval subjects responded in the same way, i.e. there was no difference in typing times to all stimuli. Clearly such findings do not accord with the procedural reinstatement account of retention which asserts that a benefit should be found for previously practiced stimuli in comparison to new.

A possible explanation for such transfer tends towards an account of skill acquisition and transfer offered by Anderson (1995). During the study phase and continuing during the retention interval the knowledge acquired is consolidated, associations between different response patterns strengthened and consequently the task becomes proceduralised (Anderson, 1995). Clearly this facilitates performance upon the original task in addition to enhancing performance upon related tasks. An additional result that supports such an assertion is the fact that subjects were able to discriminate between old and new sequences when direct tests of retention were used. Knowledge of previous experiences is enhanced, but does not retroactively interfere with the acquisition of similar types of task requiring the same sorts of responses.

The above argument could equally hold for those studies in which performance did not transfer, i.e. where the learning conditions were made more effortful by reducing the amount of practice received and increasing the difficulty of the task, and a performance advantage was found for previously practiced stimuli. The argument would simply be that performance did not reach a state where performance became
proceduralised. However, it is interesting to note that in these studies the findings are better accounted for by a Logan-esque view of skill acquisition. That is performance is based upon the encoding of specific instances of the stimuli, rather than any form of general learning of the underlying properties. Practice leads to the eventual accumulation of episodic traces in memory and it is the speed with which these memories are retrieved that is the influential factor in retention performance; the greater number of traces, the likelihood of successful retrieval will increase (Logan and Etherton, 1994). Clearly however, the fact that transfer and general regularity learning occurs in the remaining experiments detracts from this theoretical position.

Thus the degree of transfer that occurs is influenced by the practice received during the study phases of the experiments. As has been mentioned this has important implications for the procedural reinstatement view of retention performance.

7.4 THE EFFECTS OF ‘PROCEDURAL REINSTATEMENT’

The ‘procedural reinstatement’ paradigm was used throughout this thesis and was derived from the work of Fendrich et al (1991). The paradigm was used because it provided an ideal way of assessing the effects of manipulations upon learning in addition to retention (retention being the only aspect of performance assessed by Fendrich). The predictions made about the retention of material were thus directly testable under all of the different learning conditions used in our experiments.

To recap, the main premise of the procedural reinstatement argument is that performance at retention is dependent upon the extent to which the procedures used at study and test overlap (Fendrich et al, 1992; 1995). This was tested in all of the experiments specifically through manipulations in ‘sequence type’ and ‘transfer group’. On the basis of Fendrich's findings and preceding work (e.g. Kolers and Roediger, 1985) it was expected that findings in the present experiment would support this premise. However, throughout the experiments inconsistencies emerged; the effects were demonstrated under certain conditions but not others. What is interesting however, is noting the conditions under which the effects were found.
CHAPTER SEVEN

The effects of procedural reinstatement, i.e. finding a response time and a recognition advantage for 'old' stimuli and when using the 'same' keypad format between study and test, was demonstrated in two studies. The first was where the amount of practice received at study was reduced; the second was where 'unfamiliar' stimuli were presented. A distinct benefit to performance was found in these experiments when study-test conditions matched. The link between these experiments is that the learning conditions were intentionally made more difficult in comparison to the other studies. In Study 3 (Chapter 5) a diminished amount of practice was received compared to previous studies, thereby decreasing the amount and quality of learning. In Study 6 (Chapter 6) performing the task required learning of new stimulus-response associations. At retention, in both studies the presence of appropriate retrieval cues facilitated responding when both indirect and direct tests of retention were used.

Under 'enhanced' learning conditions, i.e. where the amount of practice given was sufficient to result in stability of performance; where 'familiar' stimulus response mappings were used (i.e. numbers and a telephone or calculator keypad) under such conditions and where the retention interval was reduced to counter the effects of reducing the practice, retention performance was less dependent upon the reinstatement of previously performed procedures. Thus the effects of procedural reinstatement may thus be seen as the consequences of performing under poor, or difficult learning conditions. The learner's retention performance is governed more by the specific stimuli that have been seen previously; responding to similar stimuli actually interferes with performance suggesting that performance has not transferred. Again the assertion from the results reported in this thesis is that as a learner's performance becomes more proficient upon a task with practice, they become more adept at responding in similar types of situations.

The results of Study 4 support this assertion. Recall that presentation of the stimuli were varied such that sequences were repeated either six or three times. It was hypothesised that at test, responding to stimuli presented three times would be
facilitated only in the presence of appropriate retrieval cues. This was not the case. Responding was no different when the response requirements changed between study and test on indirect tests. However, on direct tests, it was demonstrated that subjects could not discriminate between previously processed and novel sequences. Thus it would appear that certain aspects of performance are facilitated by practice from similar types of task at a ‘global’ level (thus enhancing transfer), but others require practice upon the specific element being learned. Implications for the typing skill clearly echo statements that were made above regarding the transfer of the actual ability to perform the motor component of the task. It would be expected that where additional practice is received, there would be some sort of compensation through transfer to situations in which novel actions had to be performed.

7.5 ‘SYSTEMS’ VERSUS ‘PROCESS’ VIEWS OF MEMORY
One final aspect of performance upon which the results impact concerns the debate surrounding the subject of whether memory is a unitary phenomenon or rather, is comprised of separable memory ‘systems’. This issue was not directly explored in the experiments, but both ‘indirect’ and ‘direct’ tests of retention were used thus the results can be extrapolated and applied to this argument. ‘Process-based’ theorists argue that the degree to which an individual is successful at retrieval and is therefore said to have a ‘memory’ for an event, is governed by the type of processing that occurs during acquisition of the task and the way in which it is later tested (Roediger, Weldon and Challis, 1989). Alternatively, it has been proposed that ‘implicit’ and ‘explicit’ memory systems exist (Schacter, 1992). Implicit memory effects can be observed without the learner referring to a specific episode; explicit memory effects are reliant upon such overt recollection (Schacter, 1992). That is, the learner can have a memory for an event yet remain unaware that it is influencing performance. Evidence for implicit memory is found on tests measuring response times while recognition and recall paradigms are used to measure explicit memory.

The findings of the present series of experiments do not provide conclusive support for one viewpoint over another. As was highlighted in the preceding section
regarding procedural reinstatement effects, where the conditions at learning were more effortful, it appeared that recreating processing conditions at test facilitated performance such that 'old' stimuli were not only processed faster than 'new', but were also correctly identified as old, i.e. were 'recognised'. Clearly these findings are consistent with the 'process' based view of memory and indeed suggest that all information is potentially retrievable. However, the findings from the remaining studies are more problematic to interpret.

In studies where the 'organisation' of the practice schedule was manipulated, i.e. those for which individual's received extended amounts of practice, indirect tests show no evidence that any of the material had been retained, however, when direct tests were used, it was found that individual's could discriminate previously seen sequences from novel stimuli. This result can be interpreted as supporting both the 'process' and the 'systems' view. In terms of the process view it can simply be argued that the recognition test was the appropriate test to use, while measuring response times was in this instance inappropriate. Clearly this is a somewhat tautologous argument however. As for the systems view, equally, one can argue that if the systems are indeed separable, then demonstration of one 'aspect' of memory, i.e. the implicit or explicit component is not dependent upon the presence of the other.

It is apparent from the results of the studies reported that explicit effects are present in the absence of implicit effects. This perhaps is the most conclusive supports for the proposal that two different forms of memory exist. Furthermore, the results of the experiment demonstrate 'direct' effects in the absence of indirect, but never indirect effects in the absence of direct effects, i.e. implicit without explicit effects. Clearly such findings are problematic for the 'process' view. If memory were indeed based upon a continuum of awareness, then presumably implicit effects should always be evident prior to explicit. This is clearly not in evidence in the present series of studies. Furthermore, the fact that procedural reinstatement effects were not found in the studies detracts from the view of memory as a 'continuum'.

7.6 CONCLUSION

The main finding to emerge from this thesis supported the assertion that practice is the *sine qua non* (Annett, 1991) of skill acquisition. However, it was also demonstrated that it was not the way in which practice was given, i.e. the style or the organisation that was the fundamental factor in effecting learning, rather it was the *amount* of practice that was important. Receiving a certain level of practice appeared to facilitate the acquisition of global knowledge of the task, improving performance in general and enhancing performance upon similar types of task. Such practice also resulted in the acquisition of sequence specific knowledge which led to an ability to discriminate between previously processed and novel material. When reduced practice was given, dependency upon exact retrieval cues increased, i.e. those perceptual-motor cues that were present during acquisition, limiting the extent to which practice facilitated performance. Establishing the amount of practice that leads to the acquisition of both types of knowledge across a range of tasks, is thus a challenge for future research.
8 REFERENCES


9 APPENDICES

CHAPTER 3

APPENDIX 1 SEQUENCES USED IN STIMULUS LISTS

APPENDIX 1A ACQUISITION LISTS USED IN STUDIES 1, 2, 3, AND 5

<table>
<thead>
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Study 1: Two sessions of practice. Within each session each block was repeated three times before presentation of the consecutive block.

Study 2: One session of massed practice. Six repetitions of each block were shown, the next block being presented after all repetitions were presented.

Study 3 and 5: Three repetitions of each block shown.

APPENDIX 1B RETENTION LISTS USED IN STUDIES 1, 2, 3, AND 5

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### APPENDIX 1C ACQUISITION LISTS USED IN STUDY 4

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### APPENDIX 1E ACQUISITION LIST USED IN STUDY 6

**‘Familiar’ group**

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### APPENDIX 1F RETENTION LIST USED IN STUDY 6

Lists presented to the ‘Same’ transfer group

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Lists presented to the ‘Switch’ transfer group

APPENDIX 1G ACQUISITION STIMULI USED IN STUDY 7

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288
### APPENDIX 1H RETENTION STIMULI USED IN STUDY 7

#### Test 1 list

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'Test 2' was the above list but with the last 20 sequences presented first

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'Test 4' list comprised the last 20 sequences presented first.

**APPENDIX 2 INSTRUCTIONS GIVEN TO SUBJECTS**

**ACQUISITION**

'You will be presented with \( n \) digit / letter sequences. Using your right hand and the keypad to the right of the keyboard, your task is to enter the sequences as quickly and accurately as possible. Once you have entered the entire sequence, the prompt shown below will appear. Using your left hand press any one of the coloured keys located at the top of the keyboard. The next sequence will then appear. Repeat this procedure until you have entered all of the sequences. Remember to complete the task as quickly and accurately as possible. You will be given five practice trials before you start. Press RETURN to begin'.

Upon completion of the practice trials:

'You are now ready to proceed with this part of the experiment. Press RETURN to begin'.

**RETENTION**

'You will be presented with 40 digit / letter sequences. Using the keypad to the right of the keyboard, your task is to enter the sequences as quickly and accurately as possible. After entering each sequence, the prompt shown below will appear. You will then be required to make a recognition judgement about the sequences using the coloured keys at the top of the keyboard. If you think the sequence is OLD press the WHITE key. If you think the sequence is NEW, press the DARK BLUE key. The next sequence will then appear. Please complete the task as quickly and accurately as possible. Press RETURN when you are ready to begin'.

**APPENDIX 3 FORMULAE USED TO CALCULATE \( A' \)**

\[
A' = 0.5 + (H - F)(1 + H - F)/[4H(1 - F)]
\]
If performance is below chance such that $H<F$, the equation must be modified to:

$$A' = 0.5 + \frac{(F - H)(1 + F - H)}{4F(1 - H)}$$

(from: Macmillan and Creelman, 1991)

### APPENDIX 4

#### $R^2$, SLOPE AND INTERCEPT VALUES FOUND FOR EACH OF THE SEQUENCES TYPED IN STUDY 1

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Rsquare</th>
<th>Intercept</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.348</td>
<td>2.883</td>
<td>-0.080</td>
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<tr>
<td>2</td>
<td>0.444</td>
<td>2.898</td>
<td>-0.047</td>
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<td>0.300</td>
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<td>-0.039</td>
</tr>
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<td>4</td>
<td>0.404</td>
<td>3.044</td>
<td>-0.176</td>
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<tr>
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<td>0.233</td>
<td>2.572</td>
<td>-0.028</td>
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<td>2.591</td>
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<td>0.322</td>
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<td>-0.060</td>
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<td>0.405</td>
<td>3.142</td>
<td>-0.153</td>
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<td>0.279</td>
<td>2.796</td>
<td>-0.176</td>
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<td>0.278</td>
<td>2.869</td>
<td>-0.026</td>
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<td>11</td>
<td>0.291</td>
<td>2.540</td>
<td>0.045</td>
</tr>
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<td>0.244</td>
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<td>-0.042</td>
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<td>3.028</td>
<td>-0.103</td>
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<tr>
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<td>2.372</td>
<td>-0.015</td>
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<tr>
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<td>0.184</td>
<td>2.488</td>
<td>0.048</td>
</tr>
<tr>
<td>17</td>
<td>0.319</td>
<td>2.427</td>
<td>-0.038</td>
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<td>0.296</td>
<td>2.860</td>
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</tr>
<tr>
<td>19</td>
<td>0.354</td>
<td>2.937</td>
<td>-0.148</td>
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</table>

### APPENDIX 5

#### MEDIAN ENCODING TIMES (IN MS) FOR REPETITION 1 AND 6, T-VALUES AND PEARSON’S $r$ IN STUDY 1

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Rep. 1 (in ms)</th>
<th>Rep. 6 (in ms)</th>
<th>t-value</th>
<th>Pearson’s $r$</th>
</tr>
</thead>
<tbody>
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<td>1428</td>
<td>3.118*</td>
<td>.311*</td>
</tr>
<tr>
<td>2</td>
<td>1492</td>
<td>1186</td>
<td>3.385*</td>
<td>.602**</td>
</tr>
<tr>
<td>3</td>
<td>1396</td>
<td>1070</td>
<td>.579</td>
<td>.418*</td>
</tr>
<tr>
<td>4</td>
<td>1566</td>
<td>1237</td>
<td>3.172*</td>
<td>.361*</td>
</tr>
<tr>
<td>5</td>
<td>1390</td>
<td>954</td>
<td>3.382*</td>
<td>.601**</td>
</tr>
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<td>1377</td>
<td>1140</td>
<td>2.790*</td>
<td>.535*</td>
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<tr>
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<td>1076</td>
<td>3.500*</td>
<td>.460*</td>
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<td>1137</td>
<td>1.442</td>
<td>.509*</td>
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<td>1325</td>
<td>1374</td>
<td>1.332</td>
<td>.497*</td>
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<td>1500</td>
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<td>3.463*</td>
<td>.635**</td>
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<td>.558**</td>
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### APPENDIX 6 PROPORTIONAL SEQUENCE ENTRY TIME BETWEEN ACQUISITION AND RETENTION

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<th>Massed Time</th>
<th>Acquisition</th>
<th>Retention</th>
<th>Massed Time</th>
<th>Acquisition</th>
<th>Retention</th>
</tr>
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<td></td>
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<td>1152</td>
<td>1.953*</td>
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<td></td>
</tr>
<tr>
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<td>1376</td>
<td>1526</td>
<td>1.788*</td>
<td>.422*</td>
<td></td>
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<td>1234</td>
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<td>1363</td>
<td>1225</td>
<td>.255</td>
<td>.444*</td>
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<td></td>
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<td>1363</td>
<td>1028</td>
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<td>.671**</td>
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<td></td>
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<td>1221</td>
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<td>.716**</td>
<td>.161</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>1424</td>
<td>1333</td>
<td>1.989*</td>
<td>.608**</td>
<td>.362</td>
<td>.161</td>
</tr>
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<td>20</td>
<td>1245</td>
<td>1146</td>
<td>.362</td>
<td>.608**</td>
<td>.362</td>
<td>.161</td>
</tr>
</tbody>
</table>

(significant where p < 0.05; where p < 0.001)

**Time taken to enter the fourth repetition as a proportion of the third during acquisition and the new sequences as a proportion of the sixth repetition during.**

### APPENDIX 7 CORRELATION COEFFICIENTS AND ASSOCIATED SIGNIFICANCE VALUES FOR SEQUENCES TYPED ON THE SIXTH REPETITION DURING ACQUISITION AND THEN AGAIN AT TEST IN STUDY 1 AND 2

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Pearson's r Massed</th>
<th>Spearman's rho Massed</th>
<th>Pearson's r Distributed</th>
<th>Spearman's rho Distributed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>.040</td>
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<td>-.132</td>
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<td>.103</td>
<td>-.250</td>
<td>.176</td>
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<td>8</td>
<td>-.247</td>
<td>-.324</td>
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<td>.208</td>
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### Appendix 8: Mean median total time (in ms) and SDs, correlation coefficients and t-values for the first and sixth repetition of each sequence within Study 2.

<table>
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<th>Sequence</th>
<th>Rep 1</th>
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<th>Rep.6</th>
<th>SD.R6</th>
<th>Pearson's r</th>
<th>Spearman's rho</th>
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<td>.110</td>
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<td>-.272</td>
</tr>
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<td>-.132</td>
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<td>-.243</td>
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<td>1099</td>
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<td>-.162</td>
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<td>2466</td>
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<td>-.313</td>
<td>-.368</td>
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<td>2325</td>
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<td>2539</td>
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### Appendix 9: Power function fits for each sequence collapsed across subjects in Study 2

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<tr>
<th>Sequence</th>
<th>Rsquare</th>
<th>Intercept</th>
<th>Slope</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>-0.075</td>
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<tr>
<td>Sequence in rank order</td>
<td>Intercept</td>
<td>Sequence in rank order</td>
<td>Slope</td>
</tr>
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<td>-----------</td>
<td>------------------------</td>
<td>--------</td>
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APPENDIX 11  MEDIAN ENCODING TIMES (IN MS) FOR REPETITION 1 AND 6, T-VALUES AND PEARSON'S R SHOWING CORRELATIONS BETWEEN RTs IN STUDY 2

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Rep. 1 (in ms)</th>
<th>Rep. 6 (in ms)</th>
<th>t-value</th>
<th>Pearson's r</th>
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<td>.695**</td>
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<td>3.585*</td>
<td>.766**</td>
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<td>.486*</td>
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<td>.510**</td>
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<td>.643**</td>
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<td>.603**</td>
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<td>1.432</td>
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<td>1251</td>
<td>1.047</td>
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(significant where p < 0.05; where p < 0.001)

CHAPTER 5

APPENDIX 12  TOTAL TIMES, WITH SD, T-VALUES AND PEARSON'S R FOR EACH OF THE SEQUENCES WITHIN STUDY 3

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APPENDIX 13  ENCODING TIMES WITH $SD$, T-VALUES AND PEARSON'S $r$ FOR EACH OF THE SEQUENCES WITHIN STUDY 3

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APPENDIX 14  TOTAL TIMES, WITH $SD$, T-VALUES AND PEARSON'S $r$ FOR SEQUENCES REPEATED THREE TIMES WITHIN STUDY 4

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### APPENDIX 15 Total times, with SD, t-values and Pearson's r for sequences repeated six times within Study 4

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### APPENDIX 16 Total times, with SD, t-values and Pearson's r for each of the sequences within Study 5

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### APPENDIX 17 Encoding times with SD, t-values and Pearson's r for each of the sequences within Study 5

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