Development And Representation Of
The Knowledge Acquired During
Incidental Sequence Learning

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ABSTRACT

Past research on sequence learning shows that exposure to a structured series of events under incidental learning conditions results in a dissociation between performance measures of learning and measures of conscious memory. A criticism directed to previous studies, however, was that the performance speed-up did not always reflect the type of knowledge that was being tested by the tasks of conscious memory. Thus, any observed dissociation was due to a methodological artefact rather than the existence of two independent knowledge bases. The main aim of the experiments reported in this thesis was to identify the type of information that is expressed in performance measures of sequence learning under incidental conditions. Experiments 1 and 2 tested whether practice with a complex sequential structure leads to learning of rules or learning of instances and supported an instance-based process of learning. Experiments 3 and 4 demonstrated the presence of higher order sequential effects in a response time task that may have contaminated the response time index of learning in previous studies. Experiments 5 and 6 examined whether sequence learning is based on an associative or a chunking mechanism and supported the latter mechanism. Experiment 7 demonstrated a correspondence between response times and recognition ratings for chunks. Finally, Experiment 8 examined the effect of contextual interference and arbitrary parsing of the sequence during practice, on both response times in a transfer phase and tasks of conscious memory. Results showed that a combination of low contextual interference and unfavourable parsing slowed down response time performance during transfer but did not affect recognition memory. Results from all experiments provided useful insights into the characteristics of a learning mechanism based on chunking and were evaluated in terms of proposed models of sequence learning.
To Solon
ΙΘΑΚΗ

Σα βγεις οιον πηγαίνει για την Ιθάκη,
να εύχεσαι να είναι μακρύς ο δρόμος,
γεμάτος περιπέτειες, γεμάτος γνώσεις...

...Πάντα στο νοῦ σου να έχεις την Ιθάκη.
Το φθάσεις εκεί είναι ο προορισμός σου.
Αλλά μην βιάζετε το ταξίδι διόλου.
Καλύτερα χρόνια πολλά να διαρκέσει και γέρος πιά να αράξεις οτι νηοι,
πλούσιος με όσα κέρδησες στον δρόμο,
μη προσδοκώντας πλούτη να σε δώσει η Ιθάκη.

Η Ιθάκη ο'έδωσε το ωφαίο ταξιδι.
Χωρίς αυτή δεν θα έβγαινες οσ το δρόμο.
Άλλα δεν έχεις να σε δώσει πια.

Κι αν πτωχής την βρής, η Ιθάκη δε σε γέλαε.
Είτε σοφός που έγινες με τόση πείρα,
ήθης θα το κατάλαβες οι Ιθάκες τι σημαίνουν.

Κ. Καβάφης

ΙΘΑΚΑ

When you set out for Ithaca,
pray that your journey be long,
full of adventures, full of wisdom....

...Have Ithaca always in your mind.
Arriving there is your aim.
But do not rush your journey in the least.
Better that it may last for many years,
and that you moor at that island, when you are old
and enriched by all you have gained on the way,
not expecting Ithaca to make you rich.

For Ithaca has given you that splendid journey.
Without her you would have not set out.
She has nothing more to give.

And if you find her poor, Ithaca has not deceived you.
As you have acquired such wisdom, so much experience,
you will have guessed what these Ithacas mean.

C. Kavafis
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<th>Description</th>
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<td>AR</td>
<td>Altered Rule</td>
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<tr>
<td>CI</td>
<td>Contextual Interference</td>
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<td>FOB</td>
<td>First Order Backward</td>
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<td>FC</td>
<td>Full Coverage</td>
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<td>M-er</td>
<td>Movement error</td>
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<td>MSe</td>
<td>Mean Square Error</td>
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<td>R-er</td>
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<td>Response Stimulus Interval</td>
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<td>Simple Recurrent Network</td>
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CHAPTER 1

Unconscious Learning:

Terms, Concepts And Methodology
1.1. INTRODUCTION

One theoretical issue that has received considerable attention in psychological research is whether learning is a unitary phenomenon or whether there are distinct types of learning that rely on independent mechanisms. For example, one widely accepted distinction that has been proposed by Ryle (1949) is between learning that leads to "knowing that" and learning that leads to "knowing how". Examples for each learning type can be found in two situations that probably almost all of us have encountered: learning a section from a history book and learning to ride a bicycle. In recent psychological terms, the former type of learning leads to declarative knowledge of historical facts while the latter type of learning leads to procedural knowledge of how to ride a bicycle (Anderson, 1976; Cohen & Squire, 1980).

The independence of declarative and procedural learning has been demonstrated in a study carried out on the famous amnesic patient H.M. (Milner, Corkin, & Teuber, 1968). H.M. was unable to learn lists of words or recognise faces of people he used to encounter every day. His inability to learn specific events, however, stood in sharp contrast to his intact ability to learn mirror tracing, a procedural task in which one traces a complex path while viewing the path through a mirror. H.M. improved at a normal rate with practice on mirror tracing, yet on each practice session he denied even having seen the task before. This dissociation between learning of specific episodes and learning of skills has since been replicated with a variety of different tasks. For example, amnesics have also been found to show intact learning of perceptual and cognitive skills that do not require performance of motor actions. These skills include reading mirror-inverted script (Cohen & Squire, 1980) and puzzle solving * (Brooks and Baddeley, 1976; see Schacter, 1987 for a review). Practice

* The dissociation of procedural and declarative learning has been further supported by
with these tasks involves the repeated performance of a series of operations and results in the ability to bring about some end result with maximum certainty and minimum outlay of time and energy (Guthrie, 1952).

One of the main differences underlying declarative and procedural learning is the ability to verbally articulate the acquired knowledge. While knowledge of events can be elicited in a verbal form, knowledge for procedures cannot. For example, physicists know that the rule for riding a bicycle is to turn the handlebars so that the curvature of the bike's trajectory is proportional to the angle of its imbalance divided by the square of its speed (Polanyi, 1964). It is unlikely, however, that a 7-year old cyclist knows this proposition as such. It is also unlikely that this proposition would assist someone who is learning how to cycle. At some level, this information must be represented in the memory system, but the representation appears to have a different form from the verbal description offered by a physicist. Polanyi (1964) used the term "tacit" to describe the memorial representation that underlies the ability to cycle and the term "explicit" for the verbal description of the underlying rule.

The independence of a tacit knowledge base not available for verbal report and an explicit knowledge base that is available for verbal report has been extensively studied by Reber (1965, 1967) who investigated the distinction between a conscious and an unconscious learning mode. In a pioneering study, Reber (1967) asked participants to memorise a series of letter strings. Unbeknownst to them these letter strings were generated by a complex set of rules specified by an artificial semantic-free grammar. Participants were then shown a set of novel strings, only half of which were generated by the grammar, a demonstration of exactly the opposite pattern of results by patients with basal ganglia damage. Butters, Heindel, and Salmon (1990) reported that these patients failed to learn a procedural task while at the same time their memory for the acquisition episode was intact.
and were asked to classify them as grammatical or non-grammatical employing any strategy, even mere guessing. Reber reported that performance on this task was above chance. However, although participants appeared to have acquired some knowledge of the grammatical rules during the memory task, verbal reports at the end of the experiment revealed that they were unable to describe any of the rules underlying the grammar.

Reber introduced the term implicit learning to characterise this learning process (Reber, 1965). He suggested that implicit learning produces a tacit knowledge base that is abstract and representative of the structure of the environment and that such knowledge is optimally acquired independently of conscious effort to learn (Reber, 1989). What is unique to implicit learning and was not captured by the term procedural learning is that the expression of the acquired knowledge during test does not require performance of the procedures employed during practice. The memory task which leads to knowledge of the grammar does not appear to have procedures in common with the classification task. Furthermore, the learning process is passive and unintentional: participants do not know about the grammar while they are trying to memorise the letter strings.

The existence of the unconscious learning process postulated by Reber (1989) is an intriguing possibility as it runs against our perceptions of learning as a conscious, effortful and laborious process. Not surprisingly, Reber's initial proposal has led to the development of ingenious methodologies that would establish the existence and investigate the properties of this special learning mode. This development has been particularly evident in recent years due to the parallel development of investigations of unconscious cognition in the area of perception and memory (Marcel, 1983a; Marcel, 1983b; Merikle & Reingold, 1990; Schacter, 1987). The majority of studies investigating implicit learning may be taxonomized into three main experimental paradigms: learning of artificial
grammars, learning to control complex dynamic systems, and learning of structured stimulus sequences. A brief description of some representative studies in each paradigm and a discussion of some methodological problems in the establishment of unconscious learning will be presented in the next sections.

1.2. IMPLICIT LEARNING: OVERVIEW OF MAIN EXPERIMENTAL PARADIGMS.

1.2.1. Artificial Grammar Learning

In artificial grammar learning experiments, stimuli are letter strings that are generated according to the constraints set by a finite state grammar. The grammar that has been used in the prototypical artificial grammar learning experiment (Reber, 1967) is presented in Figure 1.1. Grammatical strings are generated by following the arrows that connect the states of the grammar represented by the circles. Artificial grammars of this type are considered to be particularly suitable for implicit learning studies as they generate a large number of strings that can be used as stimuli, and their underlying formal structure is considered not to be within the domain of conscious memory for a typical participant. Furthermore, the fact that they define both authorised letters and permissible transitions between them allows a manipulation of these two factors independently; the same grammar could be used to generate strings from a different set of letters, and the same letters can be used in another grammar.
A typical finding in artificial grammar learning studies is that after a memorisation task, participants show above chance performance in a classification task. Furthermore, in the initial memory task, participants who study grammatical strings outperform participants who study randomly generated strings (Reber, 1967). Even a lay person would agree that it is highly unlikely that a participant asked to memorise a list of letter-strings would afterwards be able to give an accurate description of the underlying finite state grammar presented on Figure 1.1.

This has been confirmed by Reber and his colleagues who have repeatedly reported that participants are not able to accurately describe the rules of the grammar (Reber, 1967; Reber & Lewis, 1977; Reber & Allen, 1978; Reber, Kassin, Lewis & Cantor, 1980; Reber, 1989). Mathews et al. (1989) further elaborated on the issue of verbalisation and required participants to describe to other participants who had not studied the grammatical strings, how they made their classification decisions. Classification performance of the yoked participants was found to be above chance but significantly worse than that of the
experimental participants. When Dienes, Broadbent and Berry (1991) used similar verbal reports (obtained after the end of a classification task) to simulate classification performance, simulated correct classifications were considerably fewer than actual correct classifications. What is the basis, then, of the successful performance in the classification task?

According to one line of argument, classification performance is based on an unconscious knowledge base that is sensitive to the grammatical rules that underlie letter string generation. This unconscious knowledge is based on a rule induction mechanism that leads to the formation of abstract rules that are very similar to the ones defined by the grammar (Reber, 1967; Reber & Lewis, 1977; Reber & Allen, 1978; Reber et al., 1980; Reber, 1989). Reber (1993) uses the term abstract to describe a representation that:

"contains little, if any, information pertaining to the specific stimulus features from which it was derived; the emphasis is on the structural relationships among stimuli" (p.122).

Therefore, evidence for abstraction can be provided if learning of a set of stimuli shows positive transfer to superficially different stimuli that have the same underlying structure as the training set. In support of the abstract nature of the acquired knowledge, Reber (1969) showed that participants' successful recall of grammatical strings is attained even when they are asked to memorise a set of strings that are generated from the same grammar but from a new set of letters. Mathews et al. (1989; see also Brooks & Vokey, 1991; Whittlesea & Dorken, 1994) also reported above chance classification performance even when the letter strings are generated from a new letter set. Transfer was also found to occur from strings of letters to sequences of tones by Altmann, Dienes and Goode (1995). In this study, post-experimentally, participants denied knowing any
rules that they had transferred across the domains, and claimed that they were simply guessing.

However, an alternative explanation of the underlying learning mechanism in artificial grammar learning studies is that grammaticality judgements are based on a number of idiosyncratic rules developed by participants to perform both the memory and the classification task. Instead of the complex rules that underlie the structure of a typical grammar, participants may base their classification judgements on consciously accessible knowledge of short-sequences of letters and the position of these short-sequences within a string (Dulany, Carlson & Dewey, 1984; Mathews et al., 1989; Perruchet & Pacteau, 1990; Servan-Schreiber & Anderson, 1990; Dienes et al. 1991), or on the similarity of studied exemplars to the new grammatical stings (Brooks & Vokey, 1991; Vokey & Brooks, 1992).

For example, Dulany et al. (1984) asked participants during classification to underline that part of the string that made it grammatical, or that part that violated the rules if it was classified as non-grammatical. Dulany et al. reported that knowledge of the string parts that had been underlined by participants was sufficient to account for their classification performance without significant residuals. Perruchet and Pacteau (1990) and Dienes et al. (1991) provided evidence suggesting that participants are sensitive both to permissible bigrams and to the position of the bigrams within the string. Dienes et al. (1991) developed a sequential letter dependency task that required participants to complete stems that varied in length from zero letters upwards. They found that participants' performance was above chance on this task.

In summary, studies from artificial grammar learning suggest that successful classification performance is based on some idiosyncratic rules that can be
expressed when participants are directly probed (e.g. underline parts of the
string or write continuations of stems). Furthermore these rules do not appear to
have the complexity suggested by Reber and his colleagues. Recent findings
suggest that these learning may lead to behaviour revealing abstraction as there
is positive transfer to a different letter set or to a different stimulus modality.
There is still disagreement, however, on whether the acquired knowledge is
unconscious. Expressed knowledge that is characterised conscious by some
authors (e.g. Dulany et al., 1984; Perruchet and Pacteau, 1990) is characterised as
unconscious by others (e.g. Reber, Allen and Regan, 1985).

1.2.2. Control Of Complex Systems.

This experimental paradigm requires participants to interact with a complex
control system. It involves the manipulation of a number of causal variables in
order to achieve a desired value for some target variables. The relationships that
underlie the behaviour of the complex control system are determined by the
experimenter in the form of a set of linear equations. For example, in one of the
first complex system control studies, Broadbent (1977) used a transport control
task. Participants had to control the number of passengers using the bus and the
number of free parking spaces by manipulating the time interval between buses
and the parking fee. Behaviour of the system was based on two simultaneous
equations. Bus load increased linearly with the time interval between buses, and
the amount of space in the car park increased linearly with the parking fee.
Also, bus load increased linearly with car parking fee, and parking space
decreased linearly with time interval between buses. Participants had to learn to
control this system through a process of trial and error. They were not informed
about the underlying relationship of the initial and target variables but they
were allowed to try various combinations of the initial variables and see the
resulting effect on the target variables.
Other forms of the complex control task have included learning to make
decisions about a model of the British economy (Broadbent and Aston, 1978),
managing a sugar production factory, and interacting with a computer person
in order to achieve elicitation of a friendly attitude (Berry & Broadbent, 1984).
Although variables come from various real-life situations, relationships between
variables are usually arbitrary and apply only to the experimental task.
Participants have to learn these arbitrary relationships and any preconceptions
they have about the task may actually delay learning (Sanderson, 1989).

Initial complex control task studies mainly examined the relationship between
performance on the task and the ability to verbalise the underlying knowledge.
A robust finding was that skilled performance resulting from practice was not
always accompanied by ability to verbalise the underlying relationship between
the variables. Berry & Broadbent (1984) and Broadbent, FitzGerald & Broadbent
(1986) reported that improving the ability of participants to answer questions
about the task did not lead to improved task performance, unless performance
was accompanied by concurrent verbalisation (Berry and Broadbent, 1984).
Small improvements in subsequent task performance were found when
participants were presented with a variety of different types of verbal

When participants were asked to explain to other participants how to control
the system, a considerable difference emerged between the amount of time
needed to improve performance on the task and the amount of time needed to
acquire verbal knowledge that could be used by the yoked participants to
perform the task successfully. The former exceeded the latter up to moderate
levels of practice while at high levels of practice considerable verbal knowledge
appeared to develop (Stanley, et al. 1989; Sanderson, 1989). When similar verbal
instructions to yoked participants were used to develop computer simulations
of participants' control performance, it was found that, for the majority of them simulated performances were either equivalent to or better than actual performances (McGeorge & Burton, 1989).

Berry & Broadbent (1988) reported that instructions that directed participants to an explicit search for the underlying relationships improved performance of participants who performed an easy version of a control task and interfered with the performance of participants who were given a difficult version of the task. The easy and difficult versions of the tasks were created by manipulating the degree of saliency of the underlying relationship between the control system variables. Salience of the underlying task relationship was also found to affect the degree of verbalisation about the task (Berry and Broadbent, 1988). This was replicated in a study that manipulated saliency within the same task. When the system's output was determined simultaneously by a salient and a non-salient relationship, participants were found to develop verbal knowledge for the salient but not for the non-salient relationships (Berry & Broadbent, 1987a). On the basis of these findings Berry and Broadbent suggested that there are two different learning modes, a selective and an unselective mode that are employed in the salient and non-salient versions of the task respectively.

In order to test the independence of the two learning modes, a number of studies investigated whether the two modes are differentially affected by certain variables. For example, a sudden change of the underlying variable relationships while participants performed the task, and the addition of a concurrent memory distraction task (Hayes and Broadbent, 1988) were found to differentially affect the selective and unselective learning modes. Furthermore, these learning modes appeared to be distinct as these two variables affected them in opposite ways.
However, a failure to replicate the above finding by Green and Shanks (1993) indicated that the distinction between the selective and unselective mode of learning may not be an architectural one but one based on different levels of task difficulty. Green and Shanks (1993) suggested that non-salient relationships between variables are more difficult to acquire, and this was the cause of the differential effects of instructions and secondary task imposition obtained by Hayes and Broadbent (1988). Berry (1993; see also Berry & Broadbent, 1995) has pointed out that establishing the criteria to define saliency is problematic because there are no independent means of defining it in relation to particular tasks.

In summary, studies with complex control tasks have demonstrated a non-parallel development of performance gains and verbalizable knowledge. However, it is not yet clear whether this finding should be attributed to the existence of two distinct memory systems. Furthermore, control system knowledge was not found to transfer to dissimilar tasks with the same underlying equations (Berry & Broadbent, 1988; Squire & Frambach, 1990). Also, Marescaux, Luc, and Kamas (1989) found that participants could only give correct answers to verbal questions that involved specific situations they had previously experienced. This finding was further extended by Dienes and Fahey (1995) who found that participants performed best on old situations in which they had previously been successful. However, they also reported that this did not depend on correct recognition of the previous successful situations.

1.2.3. Sequential Structure Learning.

This experimental paradigm usually involves an indirect learning task that requires fast responses to sequences of stimuli. Unknown to participants, the stimulus sequence is structured. Learning of this structure is expressed in the
development of faster or more accurate motor responses. The most frequently used task in this paradigm is a typical choice response time task with a one-to-one mapping between an equal number of stimuli and responses. Participants are instructed to respond to a number of stimuli (ranging from three to six) usually presented in different spatial locations on a computer screen by pressing keys corresponding to the locations. The experiment starts with a lengthy practice session that involves the presentation of a structured stimulus sequence. Participants are simply told that the experiment is concerned with response times and that they are required to respond as fast as possible to the presented stimuli. Learning of the structure is established in two ways: (a) a greater response time speed-up for a group that practices with the structured sequence in comparison to a group that practices with a control pseudo-random sequence (b) a deterioration in performance when the group that practised with the structured sequence is transferred to a new (usually random) sequence.

As the experimental work presented in this thesis involves the sequence learning paradigm a detailed review of the studies in this paradigm will follow in chapters 2 and 3. The bulk of these studies can be categorised into those that have incorporated a complex sequential structure that is generated according to some general rules and those that have incorporated a short sequence repetition. The former studies were able to directly test both main aspects of the definition of implicit learning as proposed by Reber (1991), i.e. they were able to test whether the underlying knowledge base was both abstract and unconscious. Therefore, learning in these studies can be accommodated under the term implicit learning. On the other hand, studies that incorporated a short sequence repetition were only able to test whether the acquired sequence knowledge is available to consciousness. Therefore, these studies only test one aspect of the definition offered by Reber (1989) and cannot be accommodated under the term implicit learning.
This creates a difficulty in finding a term that would accommodate all sequence learning studies and this is reflected in the terminology used by different researchers. Lewicki and his colleagues (Lewicki, Czyzewska & Hoffman, 1987; see also Stadler 1989) use the terms "learning of complex procedural knowledge" while Kushner, Cleeremans and Reber (1991) use the term "implicit learning" for tasks similar to the ones used by Lewicki et al. (1987). On the other hand, Nissen and Bullemer (1987; see also Willingham, Nissen and Bullemer, 1989; Nissen, 1992), who employed simple sequence repetitions in a choice response time task, use the term "procedural learning" while researchers who have investigated the effect of a simple sequence repetition on tracking performance use the terms "prediction" or "anticipation".

What is common to all studies is that learning of a sequential structure takes place incidentally. Participants are not informed about the structure and they can meet the basic requirements of the task (i.e. responding to individual stimuli) without having to learn the sequential structure. Therefore, in the present thesis all of the above studies will be put under the general term "incidental sequence learning". All these studies test whether the sequence knowledge acquired under incidental conditions is available to consciousness. This test is usually carried out through extensive interviews at the end of practice or/and the use of a "generation" task, a task of the type introduced by Nissen and Bullemer (1987). Subsequent studies incorporated different versions of the generation task and there is currently a debate on which is the most appropriate task for the measurement of conscious sequence knowledge.

For example, in the Nissen and Bullemer (1987) study, the generation task required participants to press the key corresponding to where they thought the next target would appear rather than to the current target. The location of the targets followed the same repeating sequence presented in the Serial Response
Time (SRT) task. However, the target remained on the screen until participants pressed the correct key that corresponded to the next target in the sequence (generation-with-correction task). As this task provided feedback on the correct sequence of targets and presented the repeating sequence more than once, accuracy scores from the first sequence presentation and learning rate were examined separately.

On the other hand, Cohen, Ivry and Keele (1990) used a generation task that did not require participants to press the correct key before the next target was presented. Once they made a response, regardless of whether it was accurate or not, the next target in the sequence appeared. Therefore this generation task provided feedback on the repeating sequence but not a correction of responses (generation-with-feedback).

Perruchet and Amorim (1992) introduced a different version of the generation task that involved neither correction nor feedback. Participants were simply required to generate a series of 100 targets that resembled the series they saw in the response time task (free generation). Finally, Reed and Johnson (1994) required participants to generate a series of target locations after they had responded to two target locations from the repeating sequence (cued-generation). Results from studies that have used different versions of the generation task appear to be contradictory. In some cases this was due to methodological artefacts that will be elaborated in the detailed review of incidental sequence learning studies presented in the following chapters. However, as most of the controversy in incidental learning studies centres around methodological issues in the establishment of unconscious learning, these will be considered in some detail in the next section.
1.3. UNCONSCIOUS COGNITION: METHODOLOGICAL ISSUES.

1.3.1 Identifying criteria for consciousness

One of the main problems in empirical research on the cognitive unconscious is the lack of consensus on the operational definition of consciousness. Definitions of consciousness are rarely provided and experimental methodologies developed to establish unconscious cognition are never universally accepted. Consequently, valid demonstrations of unconscious cognition for some researchers are considered methodological artefacts by others.

Allport (1988) suggests that the problem with empirical investigations of consciousness is a conceptual one, as consciousness is not a unique, coherently conceptualised phenomenon. However, there appears to be a general consensus that investigations can take place before definitions are complete. Weiskrantz (1988) even suggests that a definition should be the end point rather than the starting point of research on consciousness. Empirical studies based on functional descriptions of different aspects of the phenomenon of consciousness may help ascertain whether there is an identifiable property in common between them and thereby direct us towards a coherent theory of consciousness.

However, as Allport (1988) suggests, a starting point should be the identification of some objective criteria that would reveal when we have an instance or a non-instance of the phenomenon under study. Allport proposes that a person is conscious of a situation, when able to choose an appropriate course of direct action in that situation (criterion I), when able to subsequently recall that situation (criterion II), and when able to confidently testify as to his or her awareness of that situation (criterion III).
The first criterion implies that consciousness may be expressed with behavioural indicators that are not necessarily verbal. For example, button presses in the serial response time task may be considered to be a way of saying "The stimulus on the rightmost location appeared right now". This is a speech act agreed between the participant and the experimenter (Marcel, 1988) and reveals awareness of the stimulus. The problem with criterion I, however, is that all types of behaviour can be taken as indicators of consciousness. Therefore, unconscious cognition appears to be automatically defined out of existence (Bowers, 1984).

One way of tackling this problem is to qualify different "kinds" of awareness in different behaviours and recognise that we may have awareness in respect to one category of behaviour but not another (Allport, 1988). Another solution may be to consider a behavioural act as a reliable indicator of consciousness only if a person says that he is not guessing (Marcel, 1988). In that case, awareness would be shown if both criteria I and III are satisfied. Or alternatively, as suggested by Allport (1988), we could identify consciousness as present when all three criteria agree.

It appears that identification of an instance of consciousness is not problematic. Problems, however, arise when we want to identify a non-instance of the phenomenon. Does satisfaction of only one out of the three criteria reveal unconscious behaviour? Would we be certain, for example, that lack of subjective reports of awareness, expressed in criterion III, indicate lack of awareness of an event? One problem with subjective reports is that it is difficult to know what criteria people use to decide whether they were conscious of an event. Merikle (1984) points out that subjective reports may reflect individuals' own theories of how events and experiences guide behaviour rather than a true presence or absence of conscious experience. Therefore, use of subjective
measures may just transfer the responsibility for the operational definition of consciousness from the experimenter to the participant (Merikle, 1984).

Another problem with criterion III is that it can only be a positive indicator of awareness. Someone may forget what they were conscious of even for those things in the immediate past (Marcel, 1988). The same asymmetry may also apply to criterion II, the memory criterion. Recall of past events can be an indicator of awareness, while failure to recall leaves us uncertain (Allport, 1988). Therefore, criteria II and III may be applied to indicate instances but not non-instances of the phenomenon of consciousness.

On the basis of the above considerations, how could Allport's criteria be applied to the SRT task? In this task, response time speed-up reveals that a direct action is taken on the basis of knowledge that stimulus A, for example, follows stimulus B. We can conclude that this knowledge is conscious, if participants are also able to confirm that they were responding on the basis of some regularities and are able to recall these regularities. If they are unable to do both of the above, we can not draw any definite conclusions on whether the knowledge was conscious or unconscious.

However, the above uncertainty is problematic for investigations of unconscious learning or unconscious cognition in general. These investigations require a methodology that would identify non-instances of the phenomenon of consciousness. In experimental practice, researchers have initially focused on identifying tasks that would provide separate indices of conscious and nonconscious behaviour. This identification has been based on functional definitions of consciousness and is, therefore, bound to suffer from the conceptual problems surrounding consciousness. Nonetheless, it provides a starting point and it has led to considerable methodological progress.
Two methodological tools, that have been developed in the study of unconscious perception and have mainly been used in investigations of unconscious learning, are dissociations and qualitative differences. These methodologies will be examined in the following sections.

### 1.3.2. Dissociations

In the frequently employed version of a dissociation, such as one advocated by Holender (1986) for unconscious perception, it has to be shown that stimulus information which is completely unavailable to consciousness is nevertheless perceived and capable of influencing higher-order decision processes. This demonstration requires a measure that indicates the availability of stimulus information to consciousness, and a measure that indicates the availability of stimulus information, independent of whether or not this information is available to consciousness. A dissociation is obtained if the first measure shows null sensitivity - does not reveal the presence of conscious knowledge - while the second measure reveals availability of stimulus information that influences behaviour.

Most incidental sequence learning studies have employed the above logic of dissociations. For example, speed-up in the SRT task is used as an index of acquired knowledge about sequential dependencies. This task is followed by extensive interviews or some version of the generation task to act as an index of conscious knowledge. If the conscious knowledge measures show null sensitivity, response time improvement is assumed to be based on unconscious knowledge.

One basic requirement for the employment of this methodology is the identification of the type of information that has been learned. Shanks and St
John (1994) stressed this point and proposed an Information criterion that should be satisfied by all studies investigating unconscious learning. The Information criterion states that the indices of conscious and unconscious knowledge should reveal exactly the same type of information. For example, if learning leads to the development of knowledge type A and the experimenter employs indices that test for conscious awareness of knowledge type B, null sensitivity of these indices does not provide evidence for unconscious learning.

This may sound too simple to be a serious methodological threat, especially if one considers learning of factual knowledge. Studies on implicit learning, however, are particularly prone to misinterpretations of this kind, as they involve learning of complex stimulus environments. An example may be found in the study carried out by Lewicki et al. (1988). This study was criticised by Perruchet, Gallego and Savy (1990) because Lewicki et al. (1988) conducted extensive interviews that probed for knowledge of the complex rules used for the generation of the stimulus series while the response time speed-up was caused by knowledge of simple event frequencies (both studies will be presented in detail in Chapter 2).

A second problem with the methodology of dissociations relates to the asymmetry of Allport's criteria II and III. Participants may be unable to report the sequential information that has driven their performance in the response time task because by the time they have to give their verbal reports they have forgotten both the acquired information and the fact that they were aware of it while performing the SRT task. A subsequent free recall test may be lacking the necessary contextual cues that would elicit participants' acquired knowledge.

Shanks and St John (1994) suggest that in order to minimise forgetting, tests for conscious knowledge should follow immediately after the learning episode.
They also propose a Sensitivity criterion, according to which an awareness test should be sensitive to the whole amount of conscious knowledge that is used in the indirect learning task. This can be accomplished if the two tests are as similar as possible in terms of retrieval context. The main difference should be that participants are encouraged to retrieve more conscious information in the awareness test.

According to the sensitivity criterion, a dissociation in the SRT task will be established if a response time measure reveals sensitivity to sequential structure while a generation task that immediately follows does not. In the generation task participants should be told that they have to generate the sequence they had seen before. However, satisfaction of the sensitivity criterion appears to be in disagreement with criterion I (Allport, 1988). The assumption that some behavioural indices reveal consciousness while others do not is especially problematic when the indices become very similar. In such a case, it becomes difficult to justify why some tasks measure conscious behaviour while others do not. This is reflected in the existing debate on whether the generation task is a valid indicator of conscious behaviour (Shanks & St John, 1994; Dienes & Perner, 1994).

An example of a similar debate can be found in the literature on discriminative responding in perception without awareness. According to Holender (1986), discriminative responses are based on intentionality and as intentionality is a fundamental indicator of awareness, discriminative responses reflect conscious processes. On the other hand, Marcel (1983a) suggests that:

"In attempting to make deliberate judgements based on information of whose external source one is unaware, it would seem that one makes use of relevant nonconscious information, if it is available, by relying passively on its effects (e.g. upon attention)
rather than being able selectively to retrieve it or be sensitive to it such that it can be the basis of an intentional choice. " (p.211).

This directly applies to the use of the response time task and the generation task in the SRT paradigm. The difference between the two tasks is that in one case participants respond to the presented target, while in the second case participants make a response to the next target before it is presented. Therefore, they are required to make a discriminative response that is intentional. According to Reingold and Merikle (1993), the real problem with this position is that the intentions of a participant cannot be directly observed or measured. Intentionality like awareness is a theoretical construct that should not be confused with the characteristics of empirical tasks. One solution to this problem is to follow Allport's (1988) suggestion and investigate whether knowledge of some regularities can be expressed in one task but not another without necessarily identifying tasks with conscious and non-conscious states.

An alternative methodology, the demonstration of qualitative differences, is considered next.

1.3.3. Qualitative Differences

The methodology of qualitative differences requires that a criterion that separates conscious from non-conscious processing is set a priori. However, this criterion is provisional and would only be accepted if it shown that the behavioural consequences of the two processes are qualitative different (Reingold and Merikle, 1993).

An example of a qualitative difference resulting from a conscious and an unconscious representation of the same event comes from visual masking. In visual masking experiments, words are presented for very brief durations and
are followed by a mask. Marcel (1980) has shown that when a polysemous word (palm) is masked, it facilitates processing of subsequent words related to all its meanings, irrespective of any biasing context. However, when such a word is not masked and is clearly above threshold, it facilitates processing only of one meaning that has been determined by a biasing context. This is an example of how degrading the presentation of a stimulus may lead to qualitative differences in subsequent processing.

Qualitative differences have also been demonstrated when the criterion for separating conscious and non-conscious processing was set by subjective reports. Cheesman and Merikle (1985) were the first to apply this criterion in visual masking. They suggested that when performance on a discrimination task that follows a subliminally presented word is at chance levels, stimuli are presented below an objective discrimination threshold. When performance, however, on the discrimination task is above chance while participants claim that they are performing at chance then stimuli are presented below a subjective discrimination threshold (Cheesman and Merikle, 1984, 1986; Merikle & Cheesman, 1986). It has been shown that words presented below a subjective threshold tend to be related to other words on the basis of semantic similarities, while when presented above a subjective threshold they tend to be related to other words on the basis of structural similarities (Groeger, 1984; Groeger, 1988).

The strength of the methodology of demonstrating qualitative differences is that it avoids the problems with the asymmetries found for Allport's criteria II and III. The fact that participants may be setting the subjective confidence threshold themselves, or that they may even rapidly forget whether they were conscious of a stimulus, becomes irrelevant. Demonstration of qualitative differences suggest that the subjective confidence criterion is a theoretically interesting criterion regardless of the above considerations (Reingold & Merikle, 1993).
Furthermore, identification of a large number of qualitative differences provides a method for defining and, perhaps, even for discovering non-arbitrary measures of consciousness.

In applying similar criteria in implicit learning, Berry and Dienes (1993) propose that knowledge is below an objective threshold if participants perform at chance on a range of specific questions or forced choice tests for which, in principle, they should have the knowledge to answer correctly (given their performance on the indirect learning task). On the other hand, knowledge is below a subjective threshold when participants believe that they are guessing while in fact they are performing above chance in either the indirect learning task or a subsequent forced choice test. This provides a basis for searching for qualitative differences.

However, demonstrations of qualitative differences are not without criticisms either. Holender (1986) suggests that observation of qualitative differences does not necessarily support the existence of two distinct underlying systems. He points out that there have been demonstrations of qualitative differences even when words were above a subjective threshold in both cases (Neely, 1977; Posner & Snyder, 1975). Therefore, qualitative differences may be found even when performance is based on a single underlying system. This suggests, that the search for qualitative differences may provide cut off points that are not necessarily related to a distinction between conscious and nonconscious processes.

1.4. Conclusion

Dissociations and qualitative differences are the two most common methodological tools that have been employed in previous studies on
unconscious learning. Neither methodology is free from criticisms and inherent problems which, as stated in the beginning of this section, are linked to the conceptual problems surrounding the phenomenon of consciousness. However, these studies have yielded a considerable body of experimental findings and have highlighted issues that need to be resolved before further progress is made. The two main issues that have been raised in previous studies are: a) identifying the exact type of information that has been learned during an indirect learning task and b) identifying tasks that could be used as valid indicators of conscious processing. While the latter issue requires considerable progress development of the theory pertaining to consciousness, the former can be tackled empirically.

The aim of this thesis is to address the former issue and systematically investigate the type of knowledge that develops in the incidental sequence learning task. A second aim is to cast light on whether various measures are valid and sensitive indicators of the acquisition of sequential information. Although the thesis does not directly address the issue of whether the information expressed in different tasks is conscious or unconscious, it still has relevance to previous studies that have identified different tasks with conscious or unconscious processing. Before the description of the present experiments, the next two chapters provide a review of previous experimental findings on incidental sequence learning.
CHAPTER

2

Incidental Sequence Learning:

Review Of Experimental Findings
2.1. INTRODUCTION

The first part of this chapter will deal with studies incorporating the methodology of single dissociations that have tested whether knowledge expressed in an indirect performance task is revealed in later generation and recognition tasks or verbal reports*. Studies that have used a complex sequential structure defined by some non-salient underlying rules or long distance contingencies and studies that have used a fairly simple structure based on the continuous repetition of a short sequence will be presented in separate subsections. The second part of the chapter will deal with studies that have investigated whether two separate learning modes can be identified by the methodology of qualitative differences. All these latter studies have examined the characteristics of sequence learning under conditions of attentional distraction.

2.2. ACQUIRED KNOWLEDGE EXPRESSED IN VERBAL REPORTS, GENERATION TASKS AND RECOGNITION TASKS

2.2.1. Complex Stimulus Sequences

2.2.1.1. Visual Search Task

Systematic work on learning of complex patterned stimulus sequences in visual search tasks was initiated by Lewicki and his co-workers. In an initial study (Lewicki, 1986b) participants were asked to view a succession of matrices of

* This review will not present studies carried out on special populations (i.e. amnesic patients). A detailed review of these studies is provided by Berry and Dienes (1993) and an extensive discussion of their relevance to the study of implicit learning is provided by Shanks and St John (1994).
digits and search for the location of a target within each frame. Some properties
of the displays, such as the pitch of the warning tone, or some subliminally
presented strings of letters, were systematically associated with the location of
the target character. These covariations were found to decrease participants' response latencies, although participants were not able to explicitly describe them.

Lewicki, Czyzewska, and Hoffman (1987), further elaborated on this initial finding by conducting a study that incorporated a highly complex pattern of stimuli. In this study participants had to react to the appearance of a digit character in one of four different quadrants of the computer screen by pressing a key that spatially corresponded with it. The whole sequence of trials was divided into blocks of seven trials. Each block consisted of six simple trials and a final complex trial in which the target was presented with a matrix of distractor digits. The location of the target on the complex seventh trial, was determined by the location of the target in four of the previous trials in the block according to a non-salient rule.

Analysis of response latencies indicated that participants had developed a sensitivity to these higher order contingencies. Participants became increasingly fast in responding to the seventh predictable trial. Furthermore, when at the end of practice the contingencies changed so that the target in the seventh trial appeared in the diagonally opposite location, response times showed an immediate increase. After the end of the practice session, Lewicki and his co-workers required participants to report the rules they were using to predict the final trials. None of the participants could correctly specify which four out of the six simple trials determined the final position of the target. Furthermore, none of the participants could report even one instance of the seven-trial sequences they had practised.
This finding was replicated by Stadler (1989) who incorporated a prediction task that was administered at the end of practice. In this prediction task participants were presented with the six simple trials and were asked to predict and generate the location of the target on the last seventh trial. Their prediction performance was found to be at chance levels. When participants were asked to give verbal descriptions of the bases of their performance, none of them reported that they used rules and expressed surprise when they were informed that the location of the target was determined by them. It appears that Stadler provided evidence for learning of some complex stimulus contingencies that are below both an objective threshold (defined by chance performance on the prediction task) and a subjective verbally reportable threshold.

A different explanation of Lewicki et al.'s (1987) results, however, has been proposed by Shanks and St John (1994; see also Cleeremans, 1993). A careful examination of Lewicki et al.'s sequences indicates that even the sixth trial on its own provided considerable information on the location of the target in the seventh complex trial. The appearance of the target in one of the quadrants in this last simple trial was linked to more frequent presentations of the target in two of the four possible locations. Knowledge of frequency of pairs of successive stimuli could have led to a considerable decrease in response times. This may have been attributed by Lewicki et al. (1987) to learning of the complex contingencies used to construct the 7-trial sequences.

As neither Lewicki et al. (1987) nor Stadler (1989) provided evidence that would rule out this possibility, they violated the information criterion. While verbal reports were directed towards complex contingency knowledge, participants may have been using much simpler information. Results from the generation task used by Stadler (1989), however, are still valid. Even if participants possessed knowledge of frequency of stimulus pairs, they were unable to
express it in the generation task. This suggests that predictive knowledge expressed in speeded responses does not transfer to a task that involves generating a target rather than responding to a target (see also Shanks & St John, 1994; Stadler, 1994).

2.2.1.2. Explicit Prediction Task

Kushner, Cleeremans and Reber (1991) demonstrated the development of sequence knowledge that is unavailable for verbal report when participants have to make explicit predictions about the successor of a series of trials. The stimuli appeared on three spatial locations that formed the vertices of an inverted, invisible triangle. A trial in this experiment consisted of six successive events. After a rapid presentation of a random series of five stimuli, participants were required to enter their prediction for the last stimulus by pressing one out of three response keys that corresponded to the three locations. Then the sixth stimulus appeared in its correct location. This location was determined by the spatial relationship between the second and the fourth stimuli. If they had been at the same location then the sixth stimulus appeared in location A. If they had been in a clockwise relation then the sixth stimulus appeared in location B, and if they had been in a counter-clockwise relation then the sixth stimulus appeared in location C. The locations of the first, third and fifth stimuli in the series were irrelevant for the prediction of the last target.

Kushner et al. (1991) reported that after 2,430 trials, prediction accuracy reached 45% which was above the chance level of 33%. In a second phase the sixth stimulus was shifted by one location: a sequence that ended on location A, now ended on location B, and so on. Participants' performance was at chance (33%) at the beginning of this phase but showed a gradual increase after 972 predictions. Finally in a third phase where the location of the sixth target was
random, participants performance remained around chance levels. Extensive post-experimental interviews revealed that participants were unable to describe the rules determining the location of the sixth target. When they were asked to rate each of the first five stimuli in terms of their relevance to the prediction task on a five-point scale, they did not show any preference to the crucial second and fourth stimuli. Kushner et al. (1991) suggested that knowledge of sequence regularities expressed in explicit predictions could not be articulated in verbal reports.

Perruchet (1994) elaborated on this finding and tested whether successful predictions during practice could be accounted by a mechanism that leads to abstraction of the relationship between the relevant events two and four, or by a mechanism based on memory for specific instances. In the initial training phase, Perruchet (1994) presented participants only with two thirds of the total number of the six-stimuli trials that could be generated according to the rule used by Kushner et al. (1991). Predictions to the remaining unpractised one-third of the trials that were introduced in a transfer phase revealed that participants based their performance on memory for specific instances rather than the rules used. This finding eliminates an explanation of successful performance on this task on the basis of unconscious knowledge of the rules employed. However, Perruchet (1994) confirmed that participants were unable to verbally describe which was the basis for their successful task performance.

2.2.1.3. Tracking Task.

A step-tracking task was incorporated by Harvey (1988) in a study that examined learning of a series of targets generated according to a second order autoregressive algorithm. In a step-tracking task, signals jump from one position of the screen to another and participants are asked to follow these
signals with a cursor. The step-tracking task used by Harvey (1988) involved an inter-stimulus interval between two successive signals and participants were specifically instructed to anticipate the next position of the target and use this interval to move towards this position.

Harvey (1988) reported that anticipatory performance improved with practice, but this improvement was restricted to the initial phases of practice. Participants appeared to learn how far they should move in order to be closer to the next signal, but they did not improve in the choice of correct direction for the next signal. Half-way through and at the end of practice, participants were also required to generate a series of signals that resembled the one they had to respond to. They were found to be able to reproduce series of the same form as the one produced by the track-generating algorithm used and this ability improved with practice. Knowledge expressed in the generation performance, however, was not found to correlate with anticipatory performance during the tracking task.

According to Harvey (1988) one possible explanation for this finding was that during the tracking tasks participants were using anticipatory heuristics that did not reflect the nature of the series of signals. This is supported by the fact that improvement in anticipation performance appeared fairly early in practice, when reliable knowledge of the series had not yet developed. It is also supported by a study carried out by Trumbo, Noble, Fowler and Porterfield (1968). Using a step-tracking task but with temporal uncertainty and predictable directions and amplitudes, Trumbo et al. (1968) found that participants tended to lag short intervals and to lead long ones. In other words, they responded with an interval near to the mean of the possible intervals. This enabled them to perform the task as well as possible on the average.
What is interesting, however, about Harvey's finding is that although participants gradually acquired more accurate knowledge of the stimulus series that was expressed in their generation performance, they did not appear to use this knowledge and change the basis of their anticipations. A possible reason for this may be that responding on the basis of this knowledge may not have led to more accurate anticipations and that a change in strategy was not, therefore, beneficial. This speculation, however, would need further investigation. One difference between the study carried out by Harvey and the studies that were presented before is that Harvey (1988) specifically instructed participants to try and anticipate the location of the next target. One possibility is that these instructions may have resulted in the enhanced knowledge of the sequence in the generation task.

2.2.1.4. Choice Response Time Task

Lewicki et al. (1988) attempted to provide evidence for the existence of unconscious complex rule learning in a choice response time task. A target letter was presented in one of the four quadrants of a computer screen. Participants had to respond as soon as the letter appeared on the screen by pressing one of four keys spatially corresponding to the four quadrants. The whole sequence of stimuli was divided into blocks of five trials. The first two locations of the target in these blocks were pseudo-randomly distributed so that the target was never displayed twice in the same location. The last three locations depended on the "movement" of the target between its two previous locations. The specific rules that were used changed between the third, fourth, and fifth presentation of the target within a block. For example, if the target moved horizontally from the first to the second trial, the movement from the second to the third was vertical. If the target moved horizontally from the second to the third, the movement from the third to the fourth was diagonal, and so forth.
Lewicki et al. (1988) reported that mean response latencies on the last three predictable trials were clearly differentiated from the mean response latencies of the first two, indicating that participants had acquired some knowledge of the complex rules that determined the target location. Furthermore, when these rules changed towards the end of practice, an increase in response times was evident only for the three predictable trials. This apparent demonstration of rule learning was not accompanied by verbal knowledge of the rules or even awareness of the existence of any rules: in an extensive post experimental interview, participants were not able to report even the fact that the stimuli followed a pattern.

Perruchet et al. (1990) replicated Lewicki et al.'s (1988) study but provided a different explanation for the observed pattern in the response latencies. A careful examination of the stimulus sequence revealed that the rules caused the selective occurrence of particular events in certain trials and not in others. For example, backwards stimulus movements, that were created by a return of the stimulus to the same location after it appeared in only one other location, although rare during the whole course of the stimulus series, were found to be quite frequent in the first two unpredictable trials. The first two unpredictable trials were also found to involve generally infrequent horizontal movements that did not appear at all in two of the last three predictable trials. Therefore, participants might have been slower to respond in the first two trials, just because of a decrease in the predictability of the stimulus movements in these trials.

Perruchet and his colleagues, using a more fine-grained analysis of data, tested whether these differences in the relative frequencies of events - which have been shown to affect response latencies (Hasher and Zacks, 1979) - could account for all the variations in the data. It was indeed found that the relatively simple
processing of frequency information could fully explain all of the results reported by Lewicki et al. (1988). Furthermore, some aspects of the results that were accounted for by the frequency learning hypothesis could not be explained by the rule learning hypothesis.

Perruchet et al. (1990), however, did not challenge the existence of some unconscious processes of knowledge acquisition. Their main criticism concerned the nature of this knowledge. They argued that the knowledge acquired was not complex or abstract and they rejected the hypothesis of unconscious abstraction put forward by Lewicki et al. (1988). Participants were not directly asked if they had noticed any infrequent movements and, as Perruchet et al. (1990) argue, any verbal reports on frequency of occurrence would have been rejected as irrelevant to the actual manipulation. It is not clear, however, whether the knowledge of frequencies of events that may have affected response times in Lewicki et al.'s (1988) stimulus series, could be expressed in verbal reports: Perruchet et al. (1990) did not directly test this alternative hypothesis.

Some insights on this question are provided by a study carried out by Cleeremans & McClelland (1991). They investigated the effects of extensive training (60,000 trials) on a six choice response time task. The sequence of stimuli was generated according to a "noisy" finite state grammar that defined the permissible transitions between six letters. Each of these letters corresponded to a stimulus location in the choice response time task. Random stimulus generation on 15% of the trials added noise to the structure of the sequence.

A general practice effect and an increasingly large difference between the grammatical predictable and random unpredictable trials was apparent in the
analysis of response times. Cleeremans and McClelland (1991) reported that participants' verbal reports revealed knowledge of some frequently occurring alternating patterns between two pairs of positions. These alternating patterns were created by two loops in the stimulus-generation grammar and were similar to the backwards movements in Lewicki et al.'s (1988) sequence. Therefore, participants were found to be able to report some frequent target movements, especially if they are salient. Cleeremans and McClelland (1991) also found that in a generation-with-feedback task accuracy of prediction was significantly higher for the grammatical than the ungrammatical trials.

Nonetheless, the researchers reported that overall prediction performance was very poor. After 450 trials of the generation task participants were able to predict correctly only 25% of the grammatical trials. The researchers suggested that the complexity of the experimental situation, the presence of noise and the number of different possible grammatical sub-sequences made it very hard for the participants to perform sufficient conscious processing of the material. However, it was not possible to determine whether there was a direct correspondence between the knowledge expressed in the response time speed-up and the knowledge expressed in the generation task or whether there was some residual knowledge that was expressed only in the response time task.

2.2.2. Repeated Stimulus Sequences

2.2.2.1. Tracking Tasks

Pew and Wickens (cited in Pew, 1974), were the first to provide some information on whether awareness is necessary for the development of fast responses in a pursuit tracking task that involves a repetition of the target movement. In their experiment, each trial was divided into three parts of 20 sec
each. The presented signal was generated by a random process. The first and last 20 sec of each trial were different samples of the random process. The middle 20 sec for each trial, however, was the same sample of the random process. Participants were not informed on this experimental manipulation. Performance on the middle segment, although initially the same as that on the other two segments, showed a faster rate of improvement with practice. When asked, three of five participants reported that they did not notice any repetition in the movement of the target, one reported that he noticed a repetition that was not localised and could occur anywhere in the trials, and one reported that he noticed that a repeated pattern occurred in two thirds of the trials. Pew and Wickens suggested that participants were not modifying their behaviour on the basis of reportable knowledge about the character of the repeated segment.

A similar finding was reported by Day and Marsden (1982) who also used a tracking task. They reported that as soon as the task was made repetitive, tracking lag started to drop and this was true whether the individual was aware of the repetition or not. Day and Marsden (1982) also examined differences in the motor performance of aware and unaware participants. They reported that participants who were not aware of the repetition reduced their tracking lag at a slower rate than the ones who were. Participants who were aware of the repetition adopted an anticipatory strategy as they produced considerably larger reductions in error and achieved tracking lags which approached zero.

Day and Marsden (1982) suggested that for aware participants an internal representation of the task was used to generate the movement. Responses were not driven by the external stimuli as aware participants were dispatching motor commands to the muscles in advance of target movements. Unaware participants, on the other hand, were responding to the external world, as is revealed by the fact that their tracking lag did not decrease past the limits of
their visual reaction time. It is interesting to note that when, at the end of the Day and Marsden's experiment, participants were asked to draw what they thought the task had been, many of them had to mentally replay their responses in order to draw them. Some even went as far as to perform the actual arm movements physically before putting pen to paper.

2.2.2.2. Choice Response Time Task

Nissen and Bullemer (1987) were the first to investigate incidental learning of a ten-trial repeating sequence in a choice response time task (or Serial Response time task: SRT). In their task a light appeared at one of four locations that were arranged on a horizontal line. Participants had to press a set of four keys that were directly below the positions of the lights. One group received a repeating 10-trial sequence and a control group received a random sequence. Nissen and Bullemer evaluated learning by measuring the degree of performance facilitation caused by the structured sequence in comparison to the random sequence. The "repeating group" indeed showed faster response times that were evident even after the seventh repetition of the 10-trial sequence. At the end of the experiment, the majority of participants reported that they had noticed a repeated pattern, while sub-groups of participants noticed it at different stages of practice.

Nissen and Bullemer (1987) argued that learning was not always accompanied by awareness, as performance improvement occurred fairly early in practice, when most of the participants were not aware of the repetition. This conclusion was based on participants' post experimental verbal reports. Verbal reports, however, have been criticised as failing to satisfy the sensitivity criterion. Furthermore, the considerable time delay between the interview and the first blocks of practice in Nissen and Bullemer's experiment, makes it unlikely that
participants could recall with satisfactory accuracy the exact time at which they had noticed the repetition.

Willingham, Nissen and Bullemer (1989) further elaborated on Nissen and Bullemer's (1987) initial finding. They trained participants on the SRT task and then asked them whether they had noticed a repeating sequence. Participants were grouped at the end of the experiment according to their verbally reported knowledge of the repeated sequence. Participants who did not notice any repeating sequence formed a no-knowledge group, participants who noticed part of the sequence but were unable to designate more than seven of the ten consecutive positions formed a poor-knowledge group, and participants who were able to designate all ten consecutive positions formed a full-knowledge group. Participants not being able to identify more than three consecutive positions, although reporting that they had noticed a pattern, were allocated to the no-knowledge group.

Response time performance of all groups was examined separately and Willingham et al. (1989) reported that all groups showed a substantial speed-up with practice. Their performance was significantly better when compared to the control group of Nissen and Bullemer's (1987) previous study. Also, the full knowledge group was found to respond significantly faster than the other two repeating sub-groups which did not differ.

In a second experiment, Willingham et al. (1989) administered the generation-with-correction task. Accuracy on the first presentation of the sequence and rate of improvement on this task were the variables of interest. The relation between response time speed-up and generation accuracy was investigated for different groups of participants who received increasing amounts of training. Based on data from two control groups, one that practised a random sequence and one
that performed the generate task without prior practice, a learning criterion was set for each group for both response times and generation accuracy. Three criteria were set at one, two and three standard deviations beyond the baseline means of the control groups.

Results were similar for each criterion. As participants were given more experience with the response time task, both response time speed-up and generation accuracy increased. Also, response times were more likely to speed-up first; at every criterion level, of the subjects who exceeded it for only one of the two measures, a greater number exceeded the criterion level for response times rather than for generation accuracy. However, Willingham et al. (1989) suggested that there were cases where a criterion level was exceeded for generation accuracy but not for response times. For example, when response times were one standard deviation below the mean of the control group, the generation accuracy could be two standard deviations above that of the control group. On the basis of these results, Willingham et al. (1989) concluded that the two types of knowledge expressed in the response time and generation task are separable and independent.

Willingham et al.'s (1989) conclusion, however, has been challenged by Shanks, Green and Kolodny (1994) who suggested that the response time speed-up found by Willingham et al. (1989) may have been caused by an uncontrolled factor. Shanks et al. (1994) pointed out that the sequence used by Willingham et al. (1989) had unequal frequencies of stimulus occurrences and that this may have been the cause for the response time speed-up. In order to directly test this alternative account, they replicated Willingham et al.'s experiment. They incorporated an additional control group that practised with a pseudo-random sequence constrained to have the same number of presentations of each of the four stimuli per ten trials. They divided the repeating group into the no-
knowledge, some-knowledge and full-knowledge sub-groups used by Willingham et al. (1989) and they compared the performance of these sub-groups to the pseudo-random control group.

Shanks et al. (1994) found that only the full knowledge repeating group outperformed the pseudo-random control group. The other two groups did not exceed the level of performance that could be achieved on the basis of knowledge of stimulus frequencies. This finding invalidated Willingham et al.'s (1989) conclusions about the existence of an independent unconscious knowledge base that is expressed only in the response time task. Lack of correspondence between the two tasks may have been due to their differential sensitivity to different types of knowledge. Accuracy of generation mainly expresses knowledge of the exact sequence that has been practised and is therefore less likely to reveal knowledge of stimulus frequencies.

Further evidence against the conclusion of Willingham et al. about the existence of two independent knowledge bases was provided by Perruchet and Amorim (1992). Perruchet and Amorim (1992) compared a group that practised 20 repetitions of a 10-trial sequence, with a group that practised with a random sequence that excluded repetitions. In a later free generation task, participants were specifically instructed to generate the sequence of stimuli that was presented to them in the response time task. They also ensured that the free generation task was as similar as possible to the response time task by not providing feedback or correction to participants' generations.

Differences between the two groups were found for both response times and free generations. Participants in the group that practised with the repeating sequence were found to generate a greater number of sub-sequences that were part of the repeating sequence. In a item-by-item analysis of the sequence,
Perruchet and Amorim (1992) correlated response times to each stimulus position within the 10-trial sequence with the number of generated sub-sequences ending on that position. Correlations were carried out separately for generated sub-sequences of different lengths (these ranged from zero to eight). Significant correlations were found only for the three- and four-trial sub-sequences, which indicated that participants were able to predict subsequent stimuli on the basis of knowledge of the previous two or three trials. Furthermore, the most frequently generated sub-sequences were the ones that were easier to encode: e.g. runs of events.

In a second experiment, Perruchet and Amorim (1992) reduced the amount of practice with the response time task and used a recognition task where participants were presented with sequence components and were required to indicate on a four point scale whether they had encountered them in the previous phase. Even after just six repetitions of the sequence, participants were found to acquire knowledge of sub-parts of the sequence that was expressed in both the free generation and the recognition tasks. The striking finding, however, was that no differences were found between the experimental and the control groups on response times. The same finding was replicated in a third experiment that required participants to perform the response time task under attentional distraction. This finding suggested that response time speed-up follows the development of knowledge of parts of the sequence expressed in the generation task and the recognition task.

On the basis of their findings, Perruchet and Amorim (1992) rejected Willingham et al.'s (1989) conclusions about the existence of two independent knowledge bases. They suggested that conscious knowledge of parts of the sequence develops in parallel with response time improvement. What was the reason, however, for the inconsistency of their results with those of Willingham
et al.'s? First of all, Perruchet and Amorim (1992) pointed out that in Willingham et al.'s (1989) study, participants were not directed to the relationship between the response time task and the generate task. They were not given explicit instructions to reproduce the sequences that they had previously practised and consequently they may not have expressed the full amount of their conscious knowledge.

Furthermore, Perruchet and Amorim (1992) changed the level of analysis from the 10-trial repeating sequence to chunks of the sequence. They argued that the use of a trial-by-trial correction procedure in Willingham et al.'s (1989) generation task may have disrupted participants' performance and blocked the expression of participants' knowledge. If participants learn chunks of a few elements within the repeating sequence, the correction procedure would have made it difficult for them to recognise the beginning of the sub-sequence in order to generate its final components. Perruchet and Amorim (1992) used tasks that appeared to be more sensitive to participants' acquired knowledge than the generation-with-correction task used by Willingham et al. (1989).

The validity of Perruchet and Amorim's findings (1991) was tested by Willingham, Greeley and Bardone (1993) in an experiment that used a more extended learning period. Willingham et al. (1993) adopted Perruchet and Amorim's (1992) recognition test but also examined whether perceptual or motor fluency mediated performance on this test. Participants were presented with the old 16-trial sequence they had practised and four new 16-trial sequences. However, different groups of participants received three different versions of the recognition task. One version involved the same perceptual and motor characteristics of the response time task. Participants in this group saw and responded to the stimuli that were presented in the response time task. In the second version of the task, participants saw the same stimuli but were asked
not to respond to them. Finally, a third version had both perceptual and motor aspects of the task altered. Participants were presented with combinations of the number digits 1 to 4. They were told that these numbers corresponded to the spatial locations that were occupied by the target in the previous response time task and were required to base their recognition judgements on this analogy. Participants in the group that practised with the repeating sequence were found to be able to recognise the sequence they had practised. Furthermore, no difference emerged between the three sub-groups that had received the different versions of the task. This indicated that performance on this task was not mediated by perceptual or motor fluency.

Willingham et al. (1993) also sought to examine the demand characteristics of the post-experimental interviews. They required all participants, including those who claimed not to have seen a pattern, to answer questions about the sequence. Before the interviews all participants were informed that they had practised with a repeating pattern. This appeared to affect responses to the post experimental interview questions. About a quarter of the control group participants who had not seen a pattern, reported that they had developed a strategy based on a pattern and more than half of them reported that the stimuli were sometimes predictable. Willingham et al. (1993) concluded that differentiation between the verbal responses of the two groups occurs only when detailed questions about the nature of the sequence are asked. When directly asked, a greater number of experimental participants report that they are able predict the stimulus series and that this predictability is caused by a repeating sequence.

One of the specific questions participants had to answer was whether the stimuli followed a single repeating sequence or whether some stimuli were more probable than others. It is interesting to note that out of the 45 participants
in the repeating group, 30 said that there was a consistent pattern or that a repeating pattern was coming and going in the series, ten said that they had noticed differing stimulus probabilities and only three said that the sequence was random. This finding supports the criticisms directed at previous studies that have not asked participants whether they had learned parts of the sequence or stimulus probabilities. In this study the majority of participants reported both types of knowledge when they were directly asked.

In order to test whether response time speed-up is based on the same knowledge base that is expressed in the post-experimental questionnaire and the recognition task, Willingham et al. (1993) divided participants into an aware and an unaware group on the basis of these measures. To avoid the problem of misclassifying participants as unaware due to the lack of reliability of the conscious measures, they used very conservative criteria for their classification. Three interview questions and the recognition test were found to reliably distinguish participants in the repeating and the control groups. Participants who showed reliable sequence knowledge on at least one of these measures were allocated to the aware group.

Only two repeating group participants were found not to express any knowledge on all these measures, and these were allocated to the no-knowledge group. Response time comparisons indicated that these two participants showed a greater rate of improvement compared to the control group. This finding, according to Willingham et al. (1993), provides evidence for the development of unconscious knowledge of the sequence. This evidence, however, has been regarded as weak because it is based on data from only two participants (Perruchet & Gallego, 1993; Shanks & St John, 1994).
A thorough investigation of the nature of information that is being acquired by participants in a sequence learning experimental paradigm was done by Reed and Johnston (1994). The researchers point out a basic weakness in the methodology used in most studies that have tested for sequence learning through indirect performance measures. They suggest that the performance deterioration observed with transfer to a random sequence can not be safely attributed to learning of the practised sequence: the random sequence can differ from it in terms of simpler types of information.

Reed and Johnston (1994) specified five types of frequencies that, when learned, can cause a decline in performance with transfer to a random sequence. They are: (a) location frequency - the frequency with which each target location is represented within the sequence (b) transition frequency - the frequency with which each possible location transition occurs, (c) reversal frequency - the frequency with which backwards movements occur, (d) rate of full coverage (occurrence coverage) - the average number of targets encountered so that each possible location has been occupied at least once, and (e) rate of complete transition usage (transition coverage) - the average number of targets encountered so that each possible transition has occurred at least once. If these frequencies of simple events are not similar for the random and the practised sequence, then a deterioration in performance during the random transfer can reflect learning of simple event frequency information rather than learning of the sequence.

The above hypothesis was supported in Reed and Johnson's first experiment. A negative transfer effect was evident when participants responded to a random sequence after having practised a 96 trial sequence that differed from the random one on reversal frequency, rate of full coverage, and rate of complete transition usage. This negative transfer was not found when another group of
subjects was transferred to a new sequence that had similar simple event frequencies to the practised one.

Reed and Johnson (1994), however, provided further evidence for a dissociation between the knowledge expressed in the response time task and the knowledge expressed in a generation and a recognition task. They used a 12-trial sequence that contained equal number of stimulus occurrences and all possible stimulus transitions. Practice with this sequence could lead to performance savings only when at least three-trial sub-sequences were acquired. They trained a group of participants under conditions of divided attention as they wanted to minimise the development of any conscious knowledge of the sequence. After a lengthy practice session, they introduced a new-sequence that had exactly the same simple frequency information and differed from the practised one only on triplet information. They reported that this resulted in a reliable performance deterioration.

Reed and Johnson (1994) attributed the above finding to learning of triplets. They directly tested this by comparing response times to the last stimuli of triplets from the practised and transfer sequences that had the same first two trials and differed on the last trial. They reported that reliable differences were obtained for all comparisons. On the other hand, generation accuracy scores when participants were asked to predict the third stimulus after they were presented with the initial two stimuli of each triplet, as well as recognition ratings for the practised triplets, did not exceed chance levels.

Reed and Johnson's (1994) study fulfilled the Information Criterion as both the recognition and the generation task were directly testing the type of knowledge that supposedly led to performance improvement during the SRT task. Thus, if we consider the generation and the recognition tasks as tests of conscious
knowledge, it appears that their findings provide evidence for learning of three-trial sub-sequences that is not expressed in measures of conscious knowledge. However, a replication of their study by Shanks and Johnson (1995) - with a slight modification in the design - revealed that sequence knowledge was expressed in a generation task but was not expressed in verbal reports or in confidence ratings on the performance during the response time task.

2.3. EFFECTS OF ATTENTIONAL DISTRACTION

Availability of attentional resources has mainly been manipulated in studies that were designed to demonstrate qualitative differences between knowledge expressed in response times and knowledge expressed in generation tasks. All of these studies have investigated learning of a repeating short sequence. Although many of the conclusions drawn by researchers are invalidated by the demonstrated dependence of response times on simple frequency information (Reed and Johnson, 1994; Shanks et al. 1994), findings from these studies still provide useful information on the characteristics of incidental sequence learning. In the review that follows, findings of these studies will be evaluated in the context of the requirements set by the information criterion (Shanks and St John, 1994).

Nissen and Bullemer (1987) were the first to investigate the effects of attentional distraction produced by a tone-counting secondary task. Participants in the dual task condition had to perform the response time task while simultaneously attending to a series of low and high pitched tones that occurred in the inter stimulus intervals. They had to count the number of high pitched tones and report them at the end of the practice block. Attentional distraction was found to slow down response time performance and eliminate learning of the sequence: no reliable differences were found between the dual task repeating
and dual task random conditions. Furthermore, participants in the dual-
repeating condition did not seem to notice any repeated pattern in the stimuli. 
Lack of performance improvement was accompanied by lack of awareness of 
the repetitive pattern. This study failed to provide evidence for a qualitative 
difference between the two knowledge measures but, nevertheless, showed that 
full attention was needed for response time improvement to occur.

Cohen, Ivry and Keele (1990) used the same choice response time task and 
secondary tone counting task as the one used by Nissen and Bullemer (1987). 
Together with attentional availability they also manipulated the degree of 
ambiguity of the repeating sequence. They used various numbers of stimulus-
response alternatives and various sequence lengths and created three different 
types of sub-sequences: a unique structure type, in which every element was 
always followed by the same element and had a unique association with it (i.e. 
12345); an ambiguous structure type, in which there were no unique 
associations between elements: each stimulus could be followed by any other of 
the remaining stimuli (i.e. 123213); and a hybrid sequence type, in which there 
were both unique and ambiguous associations between the elements (i.e. 
12323).

In one experiment, two groups of participants performed an easy and a difficult 
version of the distraction task, while practising with different versions of a 5-
trial hybrid sequence. Two control groups that practised with a random 
sequence (with the restriction that no consecutive elements occurred in the same 
location) were also incorporated. Both repeating groups were found to 
outperform the corresponding control groups. The difficult version of the 
distraction task was found to slow down response times but it did not affect 
degree of learning expressed in the learning slope. In contrast to Nissen and 
Bullemes's (1987) finding, this experiment showed that sequence learning is
possible even under attentional distraction. According to Cohen et al. (1990), this was because the sequence was shorter in length than the one used by Nissen and Bullemer (1987), and also included unique pairwise associations that are easier to learn.

With respect to the generation-with-feedback task, no differences were found between the control groups and the repeating group that practised with the difficult version of the tone counting task. The group that practised with the easy version, however, showed reliable sequence knowledge during the first sequence presentation in the generation task. The two levels of attentional distraction were not found to affect learning rate in the response time task but were found to cause different levels of performance in the generation task.

Cohen et al. (1990) attributed the above differential effect to the existence of an unconscious knowledge base that is expressed in the response time task only. The generation task, on the other hand, expresses conscious knowledge of the sequence that is likely to be affected by the secondary task. This suggestion, however, must be treated with caution. The sequence used by Cohen et al. (1990) had differing probabilities of occurrence of both single stimuli and pairs of successive stimuli. Participants who received the difficult version of the response time task may have been responding on the basis of this information, and consequently any lack of sequence knowledge in the generation-with-feedback task may be irrelevant to their response time improvement.

In a subsequent experiment, different groups of participants practised with a unique, an ambiguous, and a hybrid type of sequence, under single and dual task conditions. There were five stimulus-response alternatives for the unique sequence and each one appeared once in the five-trial long unique sequence. Four stimulus-response alternatives were incorporated in a six-trial long hybrid
sequence while three stimulus-response alternatives were used for a six-trial long ambiguous sequence. In the ambiguous sequence all possible stimulus transitions appeared once and all possible stimulus locations appeared twice in each sequence presentation.

After approximately 1000 trials, the three groups were switched to a random sequence and after 200 trials, switched back to the repeating sequence. A deterioration in performance in the random sequence and an improvement in performance with the switch back to the structured sequence was evident for all groups that practised under single task conditions and indicated that the sequences had been learned. Under dual task conditions, however, this pattern was found only for the unique and hybrid sequences and not for the ambiguous sequence.

In the generation-with-feedback task that followed, results of the previous experiment were replicated for the hybrid sequence. On the other hand, no differences were found between the single and dual task groups that practised with the unique and the ambiguous sequences. Therefore, in the case of the ambiguous sequence, while only the single-task group expressed sequential knowledge in the response time task, both single and dual-task groups expressed similar amounts of sequence knowledge in the generation-with feedback task. It is interesting to note that both the ambiguous and hybrid sequences had equal numbers of stimulus presentations, and, furthermore, the ambiguous sequence had an equal number of presentations of all pairs of successive stimuli. Consequently, an insensitivity of the generation-with-feedback task to learning of differing event probabilities does not apply in this case.
Therefore, a question that immediately arises is why the generation-with-feedback task was insensitive to the differential amounts of sequence knowledge expressed by the single and dual task groups in the response time task in the case of the ambiguous sequence. A possible answer may be given by another finding reported by Cohen et al. (1990): although all participants practising under single task conditions with an ambiguous sequence reported awareness of the sequence, this did not translate into successful performance in the generation task. As Cohen et al. (1990) reported, generation accuracy was "less than perfect" even at the end of the generation task that involved 10 presentations of the sequence in which participants were provided with feedback on the correct responses. The generation-with-feedback task appears to be a less sensitive measure of awareness than verbal reports.

It is worth mentioning that this was one of the reasons that Perruchet and Amorim (1992) questioned the reliability of this test as a measure of conscious knowledge by pointing out to the procedural differences between this task and the response time task. If we accept this criticism, however, we still have to explain why this task appears to be sensitive to the acquired sequence knowledge in the case of the groups practising with the hybrid sequence. What is the difference between the hybrid and the ambiguous sequences that causes the differential sensitivity of the generation-with-feedback task?

A further test for the hypothesis of the existence of two independent knowledge bases was carried out by Curran and Keele (1993). They suggested that there are two separate knowledge bases developed by an attentional and a non-attentional mode. In the attentional mode of learning there is a parallelism between different levels of awareness and performance, and this might explain the demonstrated associations between learning and awareness in previous studies. However, a clear dissociation between performance and awareness is
expected for the non-attentional form of learning where awareness is neither necessary nor helpful for learning.

However, the terminology surrounding the attentional-nonattentional distinction is problematic (as has been stated by Curran and Keele themselves). It is impossible that a task, however simple, can be performed without any attentional requirements. Participants must in some sense attend to a visual stimulus to make a response. To overcome this problem, Curran and Keele (1993) argued that non-attentional learning may be defined as the learning process that takes place with the minimum attentional resources, and evidence for its existence may be provided if attentional availability qualitatively alters the pattern of results.

In support for their hypotheses, Curran and Keele (1993) manipulated the effect of awareness by making the learning task intentional for some participants and incidental for others. An intentional group that had received a description of the sequence before the beginning of practice was compared to an incidental group that received standard incidental instructions. Both groups practised without attentional distraction with a 6-trial hybrid sequence that involved four stimulus-response alternatives. Conscious knowledge was assessed by a questionnaire that required participants to give a description of the sequence they had practised.

On the basis of the responses to this questionnaire, participants in the incidental group were assigned to an aware and an unaware group. The unaware group included seven subjects who had not noticed a sequence and four subjects who had noticed a sequence but reported less than four successive stimuli. All participants in the intentional group were able to reproduce accurately the entire sequence. All three groups showed a performance deterioration when
transferred to a random sequence and a performance improvement when transferred back to the repeating sequence. Curran and Keele (1993) reported that the degree of response time improvement was greater for the intentional group. The aware sub-group showed a slower response time improvement, and finally the group that did not express knowledge of the repeating sequence showed an even slower improvement. This demonstrated that differing degrees of conscious sequence knowledge led to an analogous differentiation of response time performance.

Curran and Keele (1993), however, hypothesised that non-attentional learning would occur in parallel with attentional learning and would not be influenced by the resulting different degrees of awareness. In order to test this hypothesis, at the end of the single task practice, all groups performed the response time task under conditions of divided attention. After two blocks of practice with the random sequence they returned to the repeating sequence and then back again to the random sequence. The response time pattern on the Random-Sequence-Random blocks in this dual-task phase was expected to indicate the degree of non-attentional learning. It was indeed found that the three groups showed similar degrees of performance facilitation with transfer to the practised sequence and performance deterioration when they were transferred back to the random sequence.

In another experiment that employed the same hybrid sequence, similar degrees of sequence learning were expressed under dual task conditions for an incidental group that practised under dual task conditions throughout the session and an intentional group that started practice with single-task conditions and was later transferred to the dual task. However, when a 9-trial long ambiguous sequence was used, dual task conditions eliminated sequence learning. An exception to this dual-task effect on ambiguous sequence learning
was found for a sub-group of participants from the intentional single-task group. Participants in this sub-group reported that they had noticed the sequence during the final dual task phase.

The hybrid sequence type used by Curran and Keele (1993) involved different probabilities of occurrence of individual stimuli. In order to directly test whether the response time speed-up may have been caused by these differing probabilities, Curran and Keele (1993) separately calculated mean response times of different sub-sets of stimuli with low and high probabilities of occurrence. Response times for both types were found to differ significantly from mean response times to the random sequence. Thus, it appears that there is some type of sequence learning that may be expressed under attentional distraction which is not necessarily due to sensitivity to differing stimulus probabilities.

Curran and Keele (1993) suggested that attention activates some additional process or mechanism that changes the nature of learning and leads to representational differences. However, they also suggested that their findings could not rule out an alternative explanation, namely that the same system supports both attentional and non-attentional learning but full attention may provide additional retrieval cues that are blocked by distraction.

2.4. Conclusion

In summary, a number of studies that demonstrated a lack of correspondence between response times and verbally reportable knowledge or performance on a generation task have been invalidated because they failed to satisfy the Information criterion (Lewicki et al., 1988; Willingham et al., 1989). However, recent studies appear to show a considerable improvement in the methodology.
Researchers are now trying to establish exactly what is being learned with practice on the SRT task (e.g. Reed and Johnson, 1994; Shanks et al., 1994), as well as to test conscious knowledge with a range of tests, e.g. questionnaires, generation and recognition tasks etc. (Willingham et al. 1993). It may only be possible for a general consensus on the validity of demonstrations of unconscious learning to be achieved if strict criteria are set.

The evidence from studies incorporating the methodology of single dissociations suggests that, although knowledge expressed in response times may be unavailable for verbal report, it is usually available when more sensitive generation or recognition tasks are used (Perruchet and Amorim, 1992). However, there is a small number of studies that have demonstrated dissociations between the response time task and both a generation and a recognition task (Stadler, 1990; Reed and Johnson, 1994; Willingham et al., 1993).

Finally, studies that used the methodology of qualitative differences have not provided convincing evidence for the existence of two independent knowledge bases that are employed in the indirect response time task and in the direct recognition and generation tasks. However, there is some evidence that different learning mechanisms may be employed for different types of sequences (e.g. ambiguous, hybrid and unique) and depending on the presence or absence of attentional distraction. The alternative mechanisms that have been proposed for incidental sequence learning will be briefly reviewed in the next chapter.
CHAPTER

3

Mechanisms, Models And Locus

Of Incidental Sequence Learning
3.1. INTRODUCTION

The first part of this chapter will present studies that specifically examined the type of information that is being learned and the mechanisms underlying incidental sequence learning while the second part will present studies that tested whether learning is tied to the perceptual or the motor aspect of the response time task.

3.2. MECHANISMS OF LEARNING

Concerning the issue of the learning mechanisms and the resulting knowledge representation, there are three different proposals: a) that sequence learning is based on memory for chunks (Perruchet and Amorim, 1992; Perruchet, 1994), b) depending on the structure of the sequence and the availability of attentional resources, sequence learning is based either on a mechanism that learns associations between successive events or a mechanism that forms hierarchical representations of sub-parts of the sequence (Cohen et al., 1990; Keele and Jennings, 1992) and c) that sequence learning is based on an associative mechanism that learns covariations between a series of events (Cleeremans and McClelland, 1991; Frensch and Miner, 1994). These alternative mechanisms will be briefly discussed in the next subsections.

3.2.1. Memory for Chunks

Much of the debate on implicit learning studies comes from Reber's definition of learning as a process that leads to the development of abstract knowledge. Consequently one of the first questions to be addressed in implicit learning studies was whether knowledge is tied to specific instances that have been practised or whether it can be applied to new stimulus environments that obey
similar abstract rules. Two studies that directly addressed this issue in the incidental sequence learning paradigm did not provide evidence in favour of abstraction: Perruchet et al. (1990) provided evidence against a development of abstract knowledge in the task introduced by Lewicki et al. (1988), while Perruchet (1994) provided evidence against abstraction and in favour of a memory-based mechanism in the task introduced by Kushner et al. (1991; see chapter 2).

According to the instance memorisation account, - which stems from the exemplar-based model for categorisation (Medin & Smith, 1981; Medin & Schaffer, 1978; Medin & Florian, 1992) - performance in indirect learning tasks is based on memory for stored exemplars encountered during previous practice. Perruchet (1994b) further suggested that this memory-process is based on chunking and that knowledge of certain chunks of the stimulus material as well as sensitivity to the frequency of occurrence of the acquired chunks may fully account for the skilled performance that develops with exposure to a structured stimulus environment.

Evidence for learning of chunks has been provided in studies that have used a short sequence repetition where the structure of the sequence has precluded learning of abstract rules. For example, Nissen and Bullemer (1987) showed that the pattern in the response times to each one of the stimuli of the ten-trial repeating sequence revealed that participants learned two salient runs of the four alternative stimulus locations. A similar finding was reported by Perruchet and Amorim (1992) who have also shown that participants were able to generate and recognise chunks of the sequence.
3.2.2. Hierarchical and Associative Learning

Cohen et al. (1990) suggested that learning of chunks requires parsing of the sequence and the formation of a hierarchical representation of its sub-chunks. They also suggested that this process of parsing requires attention only when ambiguous sequences are learned. Learning of hybrid sequences does not require attention as the unique events in the sequence provide the beginning and endpoints for the sub-parts of the sequence that lead to a natural process of parsing. Also, when all associations in the sequence are unique, learning may be based on a simple associative mechanism that does not require attention. This proposal was supported by their finding that attentional distraction eliminated learning of ambiguous but not of unique and hybrid sequences.

Cohen et al. (1990), however, also noted that there is no empirical basis for distinguishing between their proposed account for the existence of the two different mechanisms and a second account, namely that all types of sequences are processed hierarchically but ambiguous sequences require a more complex "parsing" than unique sequences. Distraction would still have differential effects on the two types of sequences. This second account is in line with Perruchet and Amorim's (1992) findings. Perruchet and Amorim (1992) demonstrated learning of chunks of the sequence for both hybrid and ambiguous sequences, which suggests that a parsing mechanism is used for both types of sequences.

3.2.3. Learning of Covariations

On the other hand, Cleeremans and McClelland (1991) favoured a mechanism based on a process of optimising preparation for the next event on the basis of the constraints set by relevant features of the previous events in the sequence. This mechanism would rely on the development of knowledge of the stimulus.
contingencies in a gradually increasing temporal window of events. Cleeremans and McClelland (1991) obtained evidence for this mechanism in an experiment that examined learning of a complex sequence of events generated by an artificial grammar (see Chapter 2). In order to investigate the progressive development of predictive knowledge for grammatical trials that were intermixed with ungrammatical trials, they estimated the conditional probabilities of observing each letter as a successor to every grammatical path of length zero to four. They also estimated average response times for each successor to each grammatical path of length four separately for four successive experimental sessions. Response times from the different sessions were regressed on the five different conditional probabilities.

Results indicated that participants were responding on the basis of an encoding of the constraints imposed by previous elements of the sequence. Furthermore, probabilities based on one preceding trial were found to account best for the variability of the data during the initial practice sessions while probabilities based on two preceding trials were found to account best for the data during the whole course of practice. Probabilities based on three preceding trials affected response times especially towards the end of practice. However, even after 60,000 trials of practice, there was no evidence that participants discriminated between the different possible successors entailed by elements of the sequence four steps away from the current trial. The above results supported the proposed associative mechanism that acquires stimulus contingencies in an increasing temporal window of events.

An associative learning mechanism that learns covariations between successive events was also favoured by Frensch and Miner (1994) who argued that this mechanism is supported by recent studies that have demonstrated learning of ambiguous sequences even under attentional distraction (Keele & Jennings,
1992; Frensch, Buchner & Lin, 1994). Frensch and Miner (1994) adopted a general framework for learning proposed by Cowan (1988, 1993). According to this general framework, learning is supported by two functionally separable memory stores, long-term memory and short-term memory which is an activated subset of long term memory. Learning is also supported by a central executive that directs attention and controls voluntary processing. Attention may be directed to only a subset of short-term memory at any point in time.

Frensch and Miner (1994) proposed that conscious learning occurs only in the subset of short-term memory that is controlled by the central executive. The information that is in the focus of the central executive is more likely to be voluntarily retrievable and lead to awareness. On the other hand, unconscious learning involves activated information in the short-term memory store that is not necessarily within the focus of the central executive. Unconscious learning is achieved through a passive associative process that detects and stores covariational information. According to Frensch and Miner (1994) the unique prediction of this theoretical framework is that unconscious learning of covariations is achieved only if the participating pieces of information are simultaneously available in short term memory. Consequently short term memory capacity as well as the level of activation of the sequential information to be learned will affect unconscious learning.

Frensch and Miner (1994) provided support for this prediction by showing that activation level of stimulus information, operationalized as rate of presentation of the stimuli, affected sequence learning in the SRT task. They reported that reliable learning was obtained for an inter-stimulus interval (RSI) of 500 msec and not for an RSI of 1500 msec. Furthermore, this effect was obtained for both incidental and intentional instructions and for both single and dual-task practice conditions (for further discussion of Frensch and Miner's (1994) findings see
One possible reason for the inconsistent findings in previous studies may be that different studies examined learning of different sequential structures. Different types of sequence may lead to the employment of different learning mechanisms. For example, the complexity of the sequence used by Cleeremans and McClelland (1991) makes it unlikely that chunking or hierarchical encoding could be employed. On the other hand, a chunking process may be the most effective learning mechanism for the simple repetition of a six-trial sequence used by Perruchet and Amorim (1992). Useful insights into the feasibility of the above alternative mechanisms of sequence learning are provided by actual simulations using connectionist models (Keele and Jennings, 1992; Cleeremans and McClelland, 1991; Cleeremans, 1993). Results from these simulations will be examined in the next section.

3.3. Connectionist Models

3.3.1. Sequential Network (Jordan, 1986)

Keele and Jennings (1992) used the Sequential Network (see Figure 3.1) introduced by Jordan (1986) to model learning of a repeating sequence of events. This connectionist architecture can learn to predict the next event in a temporal sequence of events. The state units receive the stimulus at time t and the output units produce the stimulus at time t+1. At the first time step the current event is represented as a pattern of activation over the state units. This activation is propagated through the hidden layer to the output units which produce the next event in the sequence. Then the activation pattern for the next event is applied to the state units. Also, recurrent connections at the state units preserve part of their activation from the previous time-step. This new pattern
of activation is again propagated through the hidden units to the output units that produce the next event in the sequence. Therefore, predictions of subsequent events are based on the current event as well as a decaying trace of previous events in the sequence. The pattern of activation at the plan units is not necessary for the sequence prediction task.

Keele and Jennings (1992) examined the behaviour of this network as it was trained on unique, hybrid and ambiguous sequences. They showed that it learned unique and hybrid sequences faster than ambiguous sequences. This is also the pattern that has been found in the human experimental data (Cohen et al. 1990). They also implemented a process of parsing by setting the activation of the state units to zero at certain points in the sequence. These zero states
provided the boundaries to separate sub-parts of the sequence. This manipulation resulted in a speed-up of the learning process for the ambiguous sequences, which supported the argument that an attentionally demanding parsing process may underlie learning of ambiguous sequences. On the other hand, Keele and Jennings (1992) suggested that parsing of unique and hybrid sequences is not attentionally demanding because it is naturally provided by the unique elements in the sequence. The appearance of a unique event has an effect similar to setting the state units to zero.

Keele & Jennings (1992) also found that another mechanism that speeded up learning of ambiguous sequences. It involved applying different patterns of activation to the plan units for sub-parts of the sequence. The pattern of activation at the plan units may be described as an arbitrary representation of the sequence. As with the previous mechanism, this representational process is likely to require attention.

One problem, however, with the simulations on the sequential network is that the two processes of parsing and representation have to be provided to the network externally. The sequential network does not have a mechanism that decides which sub-parts of the sequence will be parsed or a mechanism that sets up different representations for each sub-part. According to Cleeremans (1993) these recoding strategies proposed by Keele and Jennings (1992) are more likely to be explicit. Cleeremans (1993) has shown that a different connectionist architecture, presented in the next section, can simulate the learning processes of ambiguous, unique and hybrid sequences without the need to posit the existence of those explicit processes.
3.3.2. **Simple Recurrent Network (SRN).**

Cleeremans and McClelland (1991) have applied the Simple Recurrent Network (SRN) introduced by Elman (1990) to the sequence learning task. This network consists of a standard three layered feed-forward fully connected network with an additional layer of context units that receives recurrent connections from the hidden layer (see Figure 3.2). The context layer serves as an input together with the input units and is fully connected with feed-forward connections to the hidden layer. With the use of the back propagation learning algorithm, this network can learn to predict an event that comes next in a temporal sequence of events.

Only one event is coded and presented at the input units at each time step. At time 1 (t1) the current event, together with the activation at the context units, is
propagated to the hidden units and produces the next event at the output units. The hidden units' activation is copied to the context units. At the next time step (t2) the next event is coded and presented to the input units. Both input and context units are then propagated to the hidden units and the predicted event is produced at the output units.

The hidden units provide a means of re-representing input so that it produces the target output (Hinton, McClelland & Rumelhart, 1986). In the SRN the activation at the hidden units may be described as an internal representation of the input-output predictive relationship. Consequently the hidden units re-represent the current stimulus input together with the previous internal representation that produced a prediction of the previous output. This prediction of the previous output, however, has also information about the prediction of the output before that. This internal representation, therefore, encodes history of previous predictions. The difference between the SRN and the sequential network is that while the sequential network uses history of previous events, the SRN uses history of previous representations of the input-output relationship produced at the hidden units.

Cleeremans and McClelland (1991) attempted to model data from their experiment that examined learning of a complex sequential structure produced by an artificial grammar. They showed that an SRN augmented with two additional mechanisms accounted for 81% of the variance of the human data. The first of these additional mechanisms was incorporated to account for the priming found when the same response is repeated in two successive trials. The second mechanism accounted for the priming found when short sequences of events are repeated in successive trials. The augmented simple recurrent network was trained for exactly the same number of trials as the human participants and achieved a similar performance level. Furthermore, at the
initial stages of training, it based its predictions on only one past stimulus, but
with more training it became gradually sensitive to the predictive information
provided by two and finally three past stimuli. The same pattern of results was
demonstrated by human participants.

Cleeremans (1993) also tested whether this network behaves similarly to human
participants when learning unique, hybrid and ambiguous sequences under
attentional distraction. He simulated learning of the sequence under attentional
distraction by adding random noise to the weights connecting the context and
the input units to the hidden units. This addition of random noise prevented
learning of the ambiguous sequences. He also tested whether adding random
noise only to the connections from the context units to the hidden units would
have a similar effect. This resulted in the abolition of learning of the ambiguous
sequences but did not affect learning of the unique and hybrid sequences.
Experimental results, however, have shown that unique and hybrid sequences
are also affected by attentional distraction which suggests that attentional
distraction may also interfere with the associative mechanism that relates the
current stimulus with the next one.

However, one problem with the SRN is that it will only learn a sequence if all
events are prediction-relevant (Servan-Schreiber, Cleeremans, & McClelland,
1991; Cleeremans, 1993). This is not the case, however, for the sequence used by
Kushner et al. (1991) or Lewicki et al. (1987). In Kushner et al.'s (1991) study the
target on the last trial was determined by the relationship between two events
that were intermixed with irrelevant events. Under these circumstances the SRN
did not succeed in learning the sequential dependencies in the material
(Cleeremans, 1993). A simpler connectionist architecture that is presented next
was found to succeed in this task of learning long-distance dependencies.
3.3.3. Buffer Network

The main characteristic of the buffer network is the use of a spatial metaphor for the representation of time. The specific architecture that was used by Cleeremans (1993) to simulate the Kushner et al. (1991) task is presented in Figure 3.3. This network has five identical pools of input units, each pool representing an event that takes place at a different time step starting from t (the current event) to t-5 (the event five time steps ago). On each time step the contents of the pool are copied to the previous one and a new element is presented to the current event pool. The contents of the pool corresponding to the most remote time step are lost. As with the previous architectures, the representations of events in the input pools are propagated through the hidden units to the output units that provide the prediction for the next event.

Cleeremans (1993) reported that this network was able to learn the
contingencies in the stimulus material used by Kushner et al. (1991). Performance was based on the development of strong connection weights from the relevant events (events two and four) to the hidden units. In contrast, connection weights from the irrelevant events (events one, three and five) to the hidden units were close to zero. Therefore, the network learned to ignore irrelevant events in the sequence. This characteristic resulted in positive transfer when the network was transferred to a variant of the rule that determined the location of the last target. In the transfer material, events two and four were still the ones that determined the location of the target. The location of the target, however, was moved by one step: if the target was in location A during practice it was on location B during transfer. The network showed very fast learning of the new material. One reason for that was that the mappings of the crucial events to the hidden units that re-represent the input remained the same; the network only needed to adjust the mappings from the internal representation to the output events.

Cleeremans (1994) tested the behaviour of the network when it was presented with new instances of the rule that were not encountered during the practice phase. This experimental manipulation was carried out by Perruchet (1994) with human participants in order to test whether learning was based on rule abstraction or on memory for specific instances. Results from the simulation were similar to results from human participants: both supported a memory-based account for learning.

However, Cleeremans (1994) argued that it was unlikely that the only process that operated in this task was a memory-based one. He suggested that knowledge based on raw memory was not consistent with the fast learning demonstrated with transfer to material that involved a shift in the target location. A memory-based process would predict gradual learning of the new
material and a similar rate of performance savings as the initially practised material. As both the network, however, and the human participants showed a much faster rate of learning with the new material, it is likely that initial learning was not just memory-based.

A number of limitations of buffer networks, that have been identified by Elman (1990), reduce their strength as psychologically plausible mechanisms for human learning processes. First of all, these networks are computationally expensive as they require a large number of input units in order to represent past events. The number of the additional input units that are needed is determined by the longest sequence of events that has to be learned. This, in turn, has the undesired consequence that when shorter sequences are learned some resources of the networks are wasted. However, regardless of these criticisms, the fact that the buffer network succeeded in simulating human data in the complex task introduced by Kushner et al. (1991) provides useful insights on the processes that may be in operation during incidental sequence learning.

3.4. LOCUS OF LEARNING

Incidental sequence learning has been expressed through the development of fast or accurate motor responses to a structured series of stimuli. One of the questions that have been addressed is whether participants learn the perceptual characteristics of the series or whether they learn the series of motor responses. These two alternatives constitute a perceptual and a response learning hypothesis respectively (Stadler, 1989). There are experiments that have provided evidence in favour of each of these hypotheses, as well as studies that have suggested that the locus of learning may be the mappings between stimuli and responses. Studies that have provided support for each one of these three alternatives will be presented separately in the next sections.
3.4.1. Perceptual Locus Of Learning

Poulton (1952) appears to have been the first to systematically investigate whether the development of anticipation in a tracking task that involves a repetition depends on the perception of the movement of the target. He tested the differences in proficiency associated with pursuit versus compensatory tracking. In pursuit tracking, both the perceptual input and the participants' movement output are displayed. In compensatory tracking, only the difference between the input and the participants' output is available (as tracking error). Pursuit tracking resulted in smaller tracking errors than compensatory tracking because it was only in this case that the participants were able to perceive the action of the target directly, and thus were able to learn the regularities of the target sequence. With compensatory tracking, the action of the target was masked by the actions of the control movements. This interfered with learning of regularities. Therefore, learning of the regularities in the movement of the target was facilitated by direct perception of the movement.

Stadler (1989) was the first to directly test whether learning of the structured sequence is based on the anticipation of the appropriate motor responses or on the anticipation of the location of the next target. He used the visual search task introduced by Lewicki, Czyzewska, and Hoffman (1987; see chapter 2). To test the perceptual learning hypothesis, he transferred participants to a task that involved the same responses but different perceptual displays; stimuli were moved into the inner corners of the appropriate quadrants. An increase in response times was found with perceptual transfer and suggested that learning is dependent on the perceptual characteristics of the task.

To test the response learning hypothesis, Stadler (1989) transferred participants
to a different response apparatus. The new apparatus kept the same square spatial arrangement of the response keys, but increased the distance between them. Also, participants were required to use the index and middle fingers of the right hand during training but were required to use the middle and index fingers of both right and left hands during transfer. Stadler (1989) reported a decrease in response time when participants were transferred to the new response requirements which suggested that learning was not based on response anticipation. However, although the above finding suggests that sequence learning is independent of the actual motor responses, response times in the transfer phase may have been speeded up by a factor that is unrelated to sequence learning. There is considerable evidence to suggest that choice reaction times are faster when two alternative responses are executed by fingers from different hands rather than fingers from the same hand (Kornblum, 1965; Reeve & Proctor, 1988; Alain, Taktak & Buckoltz, 1993). This may account for response time speed-up found by Stadler (1989).

Cohen et al. (1990) also tested whether the locus of learning in a dual-task situation is on the motor responses performed. A group of participants practised a structured sequence in a three choice reaction time task using the three fingers of one hand, each finger corresponding to a different stimulus location. Movement requirements were changed for half of the participants who were then asked to perform the task using one finger for all stimulus locations. The remaining participants were transferred to a random sequence while keeping the same response requirements. No deterioration in performance was found for the group that was transferred to different movement requirements, while performance of the group that was switched to the random sequence declined. This indicated that learning was not tied to the effector system used for the response during practice.
A slightly different approach was employed by Howard, Mutter and Howard (1992), who tested whether performance of the motor responses is necessary for the development of response time speed-up. They compared a "response" group that performed a serial response time task and an "observation" group that responded only to the first repetition of the presented sequence in each one of the eight blocks of practice and just observed the following repetitions. In a second experiment the observation group just observed the sequence during the first three blocks and responded to the initial trials of blocks four to eight. Both response and observation groups exhibited a similar degree of learning during the response time task, suggesting that responding to all trials is not a necessary condition for learning.

In a generation-with-correction task, the observation group achieved greater accuracy during the first cycles of sequence generation. The response group, however, showed a greater degree of improvement during the generation task and reached the same overall level of performance as the observation group by the last sequence presentation. It appeared that the requirements of the response time task for the response group hampered performance in the initial trials of the generation task. As Howard et al. (1992) state "Continued learning for the response group during the generation phase may reflect the need for an additional recoding of pattern knowledge into a form that could better support task demands" (p.1035). Howard et al. (1992) concluded that overt responses are not necessary for serial pattern learning to occur and that therefore learning may be based on the perceptual aspect of the repetition.

However, it may also be argued that the enhanced ability of the observation group to predict the sequence in the generation task indicates that this group may have been engaged in a more analytical mode of processing. This was in a way dictated by the requirements of the practice task. Participants were
instructed to "carefully observe" a sequence of stimuli and they had full attentional resources available. They still had to respond to this pattern for a few trials, which probably motivated them to attend to specific attributes of this sequence that would allow them to speed-up their responses.

On the other hand the response group did not have any reason to overtly analyse the spatial properties of the sequence of stimuli because their main task was to respond as fast as possible to each one of these stimuli. A representation of the sequence could only develop within the boundaries of the attentional resources left by the task requirements of overt responding. It may be the case that performance on the response time task is affected by both the development of fast selection and execution of the response movements and the development of sequential knowledge that allows preparation for following events. Consequently, Howard et al.'s (1992) results could be fully explained by a differential influence of these two processes on performance levels of the two groups rather than the account proposed by them based on a purely perceptual basis of learning in the response time task.

One study, however, that reported persuasive evidence to suggest that a repetition of responses is not required for sequence learning was carried out by Zießler (1994). In one experiment, participants had to respond to five different letters by pressing five corresponding keys in a matrix-scanning task. Each target letter was presented together with distractor letters, in a five by five matrix. The location of the target on the next trial was determined by the identity of the target letter in the previous trial according to some simple rules. Therefore, a target letter could follow any other target letter but it appeared in a predictable spatial location. Practice with this task did not involve a repetition of a series of motor responses as motor responses were determined by the letter identity which was random. Zießler (1994) reported that a group that practised
with the sequential dependencies between letter identities and the location of
the next target showed a performance speed-up compared to a control group
that practised with a random sequence of target locations. Therefore, Zießler
(1994) has shown that sequential dependency learning can occur without a
repetition of motor responses.

3.4.2. Response Locus Of Learning

Although Zießler's (1994) findings suggest that repetition of a series of motor
actions is not necessary for learning, some additional findings from the same
experiment suggest that another aspect of the response requirements, the
execution of different responses to different stimuli, may be crucial for the
development of learning. Zießler (1994) reported that a group of participants
that performed the same key pressing response rather than different responses
to four out of the five target letters did not show any performance savings when
compared to the control group. This led him to conclude that learning of the
target locations may be based on associative links between different responses
and the target location that followed them rather than between letter identities
and the target location that followed them.

One problem, however, with this interpretation is that associating different
responses to different targets may be the mediator for the process of associating
letter identities to subsequent locations. Selection of a different response for
each target may lead to a deeper encoding of the target identities which may be
crucial for the development of sequential knowledge. On the other hand,
performing the same response to the different target letters may not allow a
sufficient degree of letter differentiation and consequently may prevent learning
of the sequential dependencies. Although Zießler (1994) attempted to exclude
the hypothesis of identity-encoding in another experiment, results were not
conclusive and this hypothesis could not be excluded.

One experiment that supported a response locus of learning in a SRT task was reported by Nattkemper and Prinz (1993). In this experiment participants had to respond to eight different letters by pressing four response keys. Each key was allocated to two different letters. After participants practised with a repeating sequence of letters, some letters in this sequence were substituted with other letters that either required the same or a different motor response as the originally practised letters. Nattkemper and Prinz (1993) reported that response times were affected only when the new letters required a new motor response. This result indicated that sequence learning may be closely tied to a sequence of motor responses.

3.4.3. Learning Of Stimulus-Response Mappings

One study that provided evidence suggesting that the locus of learning may be on the stimulus-response mappings was reported by Willingham, Nissen and Bullemer (1989). They used a task that involved presentation of different colours of stimuli in different locations. One group practised a random sequence of colours that were presented in a repeating sequence of locations ("location" group). A second group practised a repetition of colours, that were randomly presented in different locations ("colour" group), and a third, control group practised with a sequence that was random, in both stimulus locations and colours. Responses were determined by the colour of the stimulus; the stimulus location was irrelevant to the task.

The "colour" group that received a repetition in colour (which was the stimulus that required a response) was the only one to show a significant improvement in performance when compared to the control group. Performance of the
"location" group did not differ from that of the control group. At the end of the experiment all participants performed a transfer task in which they had to respond to the location and not the colour of the target. The sequence of locations was the one used for the "location" group, while the sequence of the required motor responses was the one practised by the "colour" group. A positive transfer for the "location" group would have provided evidence for learning of perceptual characteristics of the stimulus series, while a positive transfer for the "colour" group would have provided evidence for learning of motor responses irrespective to the stimuli associated with them.

Willingham et al. (1989) reported that no group showed a positive transfer effect. This led them to the conclusion that what participants learn in these tasks is a series of condition-action statements mapping stimuli on to responses. The "location" group did not show sequential learning as the repetition was represented in neither the condition nor the action of the production rules. In contrast, the "colour" group showed sequential learning, as the dimension in which repetition occurred was represented in the production rules controlling performance. Performance of the motor sequence that was practised did not facilitate response times of the transfer task because it was performed in response to a different stimulus sequence. The findings reported by Nattkemper and Prinz (1993), however, suggest that if the same motor response is associated with two different stimuli, positive transfer may occur when one stimulus is substituted by the other. Therefore motor responses may be partly independent of the stimuli present in the repeating sequence.

Some interesting findings on the effect of the stimulus-response mappings on incidental sequence learning were reported by Hartman, Knopan and Nissen (1989). Hartman et al. (1989) tested whether sequence learning may occur for verbal stimuli. They reported that when participants were required to read a
sequence of words, no differences emerged between a group of participants that post-experimentally reported they were unaware of the repetition and a control group. (The control group practised with a pseudo-random sequence that controlled for stimulus frequencies). On the other hand, aware participants showed a reliable response time speed-up. When participants were required to respond by saying the semantic category to which each of the stimulus words belonged or to press buttons that corresponded to each word, both unaware and aware of the repeating sequence participants performed better than the control group. When participants had to respond verbally by indicating the location (north, south, east, west) of four stimuli, clear evidence of sequence learning was found for both aware and unaware participants who practised a repeating sequence.

According to Hartman et al. (1989) the above results demonstrate that the nature of the stimulus-response relation is a powerful factor in determining whether unconscious sequence learning will occur. Highly automated responses are less likely to lead to sequence learning without awareness. A possible explanation for this finding offered by Hartman et al. (1989) is that the manipulation of the relation between stimuli and responses may affect the amount of attentional resources that the participants devote to each stimulus-response pair, and that attention, mediated through effortfulness, plays a critical role in facilitating implicit learning.

Hartman et al. (1989) have also demonstrated that reliable response time speed-up may be found even when participants are classified as unaware on the basis of their verbal reports. However, as Shanks, Green and Kolodny (1994) have pointed out, participants who are classified as unaware on the basis of verbal reports show a small but consistent saving in their performance on a generation task. This was indeed the case in two of the experiments (exp. 2 and 3) reported
by Hartman et al. (1989): accuracy scores on the first sequence presentation in the generate task were 5% and 10% higher than those of the control group. Therefore, it may be the case that participants who were aware of parts of the sequence during the response time task but who were unable to recall it in verbal reports, were classified as unaware. What is interesting, however, is that unaware participants in the experiments that involved responding on the basis of stimulus categories showed a response time improvement, while unaware participants in the experiment that required naming words did not. This suggests that development of sequence knowledge is dependent on the performance of fairly arbitrary and not yet automated stimulus-response mappings.

3.5. Conclusion

Concerning the mechanisms in operation in incidental sequence learning, connectionist simulations suggest that learning may be based on some simple processes that learn covariations between successive events. However, experimental findings suggest that different mechanisms may be in operation for stimulus material of different levels of complexity.

Concerning the locus of learning in the serial response time task, experimental findings appear to be contradictory. However, there is evidence for negative transfer with a change of the perceptual characteristics of the stimuli (Stadler, 1989) and a change of the stimulus-response mappings (Willingham et al. 1989).

The experiments reported in the next chapter examined learning of a sequence that is complex enough to be acquired by a mechanism that learns long distance covariations and simple enough to be learned by a memory-based mechanism.
Also, they tested which aspect of the motor response is speeded up with practice. Therefore, rather than examining the locus of sequence learning, the next two experiments examined the locus of the response time speed-up.
CHAPTER

4

Rule Versus Instance Learning
4.1. INTRODUCTION

Initial studies on implicit learning appeared to lack rigorous methods of testing which learning mechanisms underlie participants' successful performance in the indirect learning tasks. Experimenters were keen to interpret any observed performance gains after practice with a complex stimulus environment as resulting from an abstract knowledge base that contained the same rules as those used to generate the stimuli (Reber, 1967, 1969; Lewicki, Hill & Bizot, 1988; but see Reber, 1993). Today, however, it is widely accepted that participants are not necessarily learning the exact rules used by experimenters but something much simpler that nevertheless allows them to deal successfully with the complex environment (Perruchet, Gallego & Savy, 1990; Perruchet 1994; Shanks, Green and Kolodny, 1994).

One clear demonstration of this was provided by Perruchet, Gallego and Savy (1990) in their replication of the study carried out by Lewicki, Hill and Bizot (1988; for a detailed description of both studies see Chapter 2). Perruchet et al. (1990) convincingly demonstrated that the response time pattern attributed to learning of some biconditional rules by Lewicki et al. (1988) was instead caused by learning the relative frequencies of some distinctive target movements. This methodological artefact invalidated Lewicki et al.'s conclusions concerning the development of unconscious learning of complex rules: Lewicki et al. (1988) tested for conscious knowledge of rules that did not actually cause the observed performance improvement. Although, according to Reber (1993), Perruchet et al.'s (1990) demonstration does not invalidate the fact that participants learned to respond to a complex stimulus array, it is debatable whether they were doing so independently of awareness of this structure: Lewicki et al. (1988) would have rejected verbal reports on relative frequencies of target movements as inappropriate.
4.1.1. Learning of Rules versus Learning of Instances.

One issue that is still unresolved by Perruchet et al.'s (1990) study concerns the exact nature of the underlying knowledge representation that caused the response time speed-up. For example, Perruchet et al. (1990) pointed out that horizontal target movements, as well as "backward" target movements* were infrequent during the whole series of trials. They also pointed out that the target covered all four alternative locations in four successive trials (full coverage (FC) movements) quite frequently in the series. Perruchet et al. (1990) suggested that sensitivities to the frequencies of these target movements could account for the complete pattern of results in Lewicki et al.'s experiment.

However, Perruchet's suggestion may still be compatible with an abstraction-based account for learning as participants may have developed knowledge of some general categories of physically different target movements. For example, a horizontal movement is found when the target moves from right to left and from left to right in both the upper and lower rows. This also applies to backward movements that can occur between any pair of locations, as well as to full coverage movements that can appear in a large number of different patterns (see Figure 4.1). As has been suggested by Reber (1993), learning of frequencies of these general movements may have resulted in the development of an abstract knowledge base, which, however, consisted of much simpler rules than the ones hypothesised by Lewicki et al. (1989).

The design of the Lewicki et al.'s (1988) study did not allow a test of this hypothesis or of an alternative one, namely that participants' performance was based on memorisation of specific instances of subsets of the whole series of trials. Therefore, one of the aims of the experiments presented in this chapter

* "Backward" movements occur when the target is displayed in the same location after covering only one other location (first order backward movement: FOB).
Figure 4.1 Two different instantiations of a first-order-backward (ABA, ADA) and a full coverage (BADC, BACD) movement of the target.

was to test these two alternative accounts using the task that was introduced by Lewicki, Hill and Bizot (1988).

### 4.1.2. Locus of Performance Speed-up

A second aim of the experiment was to examine which aspects of the motor-response show a speed-up after practice with a structured stimulus series. One possible locus of performance speed-up in the SRT task is the stimulus-response translation stage. Indirect support for a stimulus-response translation locus of learning comes from the finding that precueing two of the locations in a four-choice response time task speeds up the response translation phase for targets that are later presented in one of the two locations (Miller, 1982; Reeve & Proctor, 1984). Anticipating the location of the target in subsequent trials may essentially be an internally generated precueing of some target locations and
may lead to a similar effect.

Reeve & Proctor (1984; 1990) have shown that the translational facilitation during pre-cueing is based on spatial coding and is independent of the preparation of the specific movements carried out by the fingers. A similar conclusion has been drawn in an incidental sequence learning study by Cohen et al. (1990). They reported that a change in the effector system used for the response did not affect the expression of sequence learning. One possible explanation for this finding is that performance speed-up in the SRT task is based on knowledge of where in space subsequent stimuli or responses will occur.

An alternative locus of learning that may cause a performance speed-up is the development of an efficient motor programming process. According to Rosenbaum (1991), a motor program may be viewed as a functional state that takes place before movement initiation and allows preparation of particular movements or classes of movements. Although a motor program is believed to include specifications of the spatial direction of the movement, it also includes details on movement timing and force (Schmidt, 1975; Schmidt, 1988). However, the simple nature of the key pressing responses used in the SRT task does not allow an examination of the degree to which performance speed-up may also be due to a more accurate movement execution. This would only be evident if more complex movements with greater accuracy constraints were employed.

Finally, an alternative locus of performance speed-up may be a process of programming or planning a series of motor actions. This is relevant to the serial response time task if we suppose that participants load the motor programs for a whole series of subsequent responses. Although this process is unlikely to occur during initial practice with the sequence, it can not be excluded from the
later stages of practice. Various models have been proposed to describe how the elements in a serial response are organised prior to initiation. Essentially, the proposal is that there is some form of a motor buffer (Henry & Rogers, 1960; Henry, 1986; Ivry, 1986; Sternberg, Monsell, Knoll & Wright, 1978), into which the individual subprograms are loaded and from which they must be retrieved (after a search) and read out in order to execute the response. This results in a faster execution of the series, as movements may be programmed and executed in parallel.

This process is clearly demonstrated in skilled typewriting where there is a considerable amount of overlap between successive strikes. Films of typists' hands reveal that fingers do not wait passively until the previous keystrokes have been completed but rather both hands and fingers move continually and in parallel. This, in turn, results in very fast movements: a professional typist performs a keystroke in about 120 to 140 msec while choice reaction times for single letters are 300 msec (Viviani & Terzuolo, 1983). This parallel movement is only restricted by mechanical interference from previous keystrokes (Gentner, Grudin, & Conway, 1980).

The fact that almost all SRT studies have used key pressing responses from different fingers suggests that a faster and more efficient planning of a series of responses as well as a parallel movement execution may partly be responsible for the response time speed-up especially after extended practice. The facilitatory effect of practice in executing a series of movements is supported by evidence in typewriting that suggests that frequent words and bigrams are typed faster than infrequent words and bigrams (Fendrick, 1937; Gentner, Larochelle, & Grudin, 1988).

Trying to establish which of the above motor response aspects are speeded-up
by sequence learning appears to be problematic, especially when the task involves execution of single finger pressing movements. The all-or-none nature of these responses does not allow a separate examination of the effects of the different stages in the motor response. An alternative way to investigate this issue is to isolate and separately examine certain aspects of the response. This was attempted in the present experiments.

In order to eliminate a possible influence of a parallel movement programming and execution of a series of responses, keypresses by different fingers were substituted by a joystick movement that required use of the same effector system for each response. The joystick-control task involved a more demanding movement execution phase that had accuracy constraints. This increased the complexity of the movement requirements and was expected to de-emphasise the process of parallel programming of a series of separate movements for two reasons: (a) more complex movements or those that have longer movement times tend to pose greater programming demands before they are initiated (Henry & Rogers, 1960) (b) as the motor output buffer is believed to have limited capacity (Klapp, 1977; Rosenbaum, 1987; Sternberg et al., 1978), increasing the complexity of the movement would also be expected to reduce the number of movements that can be programmed in advance or even completely eliminate parallel pre-programming. Furthermore, the joystick-control task allowed a separate examination of a speed-up due to a more efficient movement execution and a speed-up due to a faster selection of the correct spatial location for the response.

4.2. EXPERIMENT 1

The task used in Experiment 1 involved moving a cursor from the centre of the screen towards four targets that appeared in the four quadrants of the screen.
Performance speed-up in this task was expected to be based on faster selection of the spatial location for the response and/or on faster execution of the movement towards the target. Selection of the spatial location was expected to be expressed in the time for movement initiation, while a more efficient motor programming was expected to be expressed in faster and more accurate movement execution. The joystick task allowed separate measurement of the time taken to initiate the movement and the time taken to execute the movement. Causes of any speed-up could therefore be identified.

The sequence used was generated by a rule similar to the one used by Lewicki, Hill and Bizot (1988). In order to directly test the extent to which a memory-based process could account for any performance speed-up, the stimulus sequence also involved a repetition. This allowed a direct comparison of the memory-based and the abstraction-based model. A number of possible ways that participants may have encoded the structure of the sequence were examined using a transfer paradigm. Detailed verbal reports were obtained at the end of the experiment in order to test whether any performance speed-up correlated with verbally expressed knowledge of regularities in the series. Also, a generation task tested whether knowledge acquired could be expressed when participants had to respond on the basis of their explicit predictions for the subsequent stimuli in the series.

4.2.1. METHOD

4.2.1.1. Subjects

30 right-handed undergraduate Psychology students from University College London participated in the experiment as part of a course requirement. They were randomly assigned to one of three groups, with the restriction that each
group contained the same number of men and women. Their mean age was 22.1 years and 9 of them were male. All participants were naive about the purpose of the experiment. They were asked to volunteer to participate in an experiment on motor skill learning.

4.2.1.2. Apparatus and Stimuli

The experiment was run on a Dell Personal Computer with a 386 microprocessor that was located in a artificially illuminated, quiet experimental room. The stimuli were presented on a VGA colour monitor and the responses were made via a joystick. The stimulus display consisted of a green area in the shape of an "X", presented on a blue background (Figure 4.2). The targets were yellow circles that appeared at the four edges of the X-shaped area. A cursor controlled via the joystick was used to intercept the target circles. A blue circle in the centre of the X-shaped area was the starting point for every response: the next target appeared only after the cursor was placed in this circle.

Each part of the "X" shape was 13.0 cm long, and 1.7 cm deep. The diameter of the target-circles was 0.7 cm while the diameter of the starting circle in the centre of the screen was 1.2 cm. Participants were seated approximately 60 cm away from the screen. The visual angle of the distance between the centre and each one of the targets was 5.2°, the visual angle of the vertical distance between two targets was 7.5°, and the visual angle of the horizontal distance between two targets was 6.1°.

4.2.1.3. Stimulus Conditions

The experiment included a practice phase that consisted of four blocks of 240 trials, a transfer phase that comprised one block of 240 trials, interviews about
3. The target was never displayed at the same location twice in a row (No-Repetition constraint).
2. The target never returned to the same location after being displayed in less than two other locations (No-FOB movement constraint).
3. The frequencies of the presentation of the target on each one of the four locations were equal.
As repetitions and FOB movements were excluded, all target movements involved either a full coverage of all locations or a return of the target to the same location after being presented in two other locations (second order backward movements: SOB, see Figure 4.3). The rule used to generate the rule-repeating sequence caused a lower frequency of FC movements in comparison to SOB movements. Therefore, another constraint for the generation of the pseudo-random repeating and non-repeating sequences was that the frequencies of both types of movements were equated with those of the Rule condition.

4.2.1.3.1.1. Rule Sequence

The 60-trial sequence that was used for the Rule condition consisted of 12 5-trial blocks. The last three targets in each one of these blocks were generated according to a rule that was adapted from Lewicki et al. (1988). This rule determined the succession of the horizontal, vertical and diagonal movements of the target as follows: a horizontal movement was always followed by a

![Diagram](image_url)

Figure 4.3. A full coverage and a second order backward movement of the target at the end of the sub-sequences ABCD and ABCA respectively. Locations A, B correspond to the upper row, from left to right while locations C, D correspond to the lower row also from left to right.
vertical one, a vertical movement by a diagonal one, and a diagonal one by a horizontal one. For example (see Figure 4.4), a horizontal movement of the target from location A to location B on the first two trials was followed by a vertical movement and so the target on the third trial appeared in location D. A vertical movement was followed by a diagonal and so the fourth target appeared in location A. The next movement of the target was horizontal and the last target appeared in location B.

The first two locations of the target in each 5-trial block were pseudorandomly generated according to the general constraints. As there were four possible locations for the first presentation of the target and each one of these initial locations could be followed by either of the three remaining locations, there were 12 (4 X 3) possible combinations for the first two target locations. Each one of these combinations was followed by the locations determined by the "movement succession" rule.

The rule used in the present experiment is simpler that the one used by Lewicki et al. (1988). In the present experiment the same "movement succession rule" determined the generation of the last three trials of each 5-trial block, while in
the study carried out by Lewicki et al. (1988) a different "movement succession rule" was in operation on each one of the third, fourth and fifth trials in a 5-trial block. For example, in the sequence used by Lewicki et al. (1988) a horizontal movement from the first to the second trial was followed by a vertical movement, while a horizontal movement from the second to the third trial was followed by a diagonal movement and so on. The use of the same rule for all three trials in the present experiment equalises frequencies of horizontal, diagonal and vertical movements within a sequence. The inequality of frequencies of target movements in the Lewicki et al. (1988) sequence that was criticised by Perruchet et al. (1990) is therefore eliminated in the present experiment. The only movement frequency inequality in the present sequence is found between SOB and FC movements: SOB movements are more frequent. This inequality, however, is controlled in the pseudo-random sequence.

Furthermore, the sequence used by Lewicki et al. (1988) did not involve any repetition: it consisted of a random succession of the 12 5-trial sequences that were generated by the rule. In the present experiment, the succession of the 12 5-trial blocks within the 60-trial repeating rule sequence was pseudo-random and the general constraints of non-repetition and non-FOB movement were not violated anywhere in the series. Therefore, there were no repetitions or FOB movements from the transition of one 5-trial block to the next.

4.2.1.3.1.2. Pseudorandom Repeating and Non-repeating Sequences

The pseudorandom sequences for the Repeating and Control group were generated according to the general constraints. The same 60-trial sequence was continuously repeated for the Repeating group while a 960-trial sequence that did not involve any repetition was presented to the control group. In the non-repeating pseudo-random sequence, frequencies of presentation of each target
were equalised for every 60 trials. Also, frequencies of FC and SOB trials were approximately equal to those of the Rule and Repeating sequence for every 60 trials.

The last 60 trials of the non-repeating 960-trial sequence were the 60-trial sequence that was repeated in the Repeating condition. This allowed a direct comparison of the two groups, in order to test for any performance gains due to the repetition of the sequence. The exact sequences that were used can be found in Appendix 2.

4.2.1.3.2. Transfer

The transfer block consisted of 240 trials divided into four blocks of 60 trials that were designed to test specific hypotheses about the knowledge that participants had acquired during practice with the repeating sequences. An outline of the sequences for each group in the test block is shown in Table 4.1.

On the first 60-trial sub-block the Rule group was transferred to the Repeating group's sequence, while the Repeating and Control groups were transferred to Rule Group's sequence. On the last 60 trials of the transfer block, the Rule and

<table>
<thead>
<tr>
<th>Group</th>
<th>Practice</th>
<th>Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>960 trials</td>
<td>60 trials</td>
</tr>
<tr>
<td>Rule</td>
<td>Rule</td>
<td>Rep</td>
</tr>
<tr>
<td>Repeating</td>
<td>Rep</td>
<td>Rule</td>
</tr>
<tr>
<td>Control</td>
<td>Pseudo-R</td>
<td>Rule</td>
</tr>
</tbody>
</table>
Repeating groups were switched back to their practised sequences, while the Control group was tested on the Repeating group's pseudo-random 60-trial sequence. These trials were designed to test whether participants acquired knowledge of specific instances found in the repeating sequences.

The second and third 60-trial sub-blocks were designed to investigate the type of knowledge acquired by the Rule group. The first aim was to test whether any performance improvements of the Rule group could be attributed to rule learning. The 12 5-trial blocks that created the rule sequence were reordered in a Same Rule (SR) transfer 60-trial sequence. This sequence kept the specific rules of target succession but changed the order of presentation of the twelve 5-trial blocks. If the Rule group learned the movement succession rules used to generate the stimuli it would be expected to show positive transfer to this reordered rule sequence. Although an alternative explanation for any performance savings on this sequence could be memory for the 5-trial sub-sequence, findings from Perruchet et al. (1990) suggest that this is unlikely to be the case. Perruchet et al. (1990) reported that there was no evidence that participants were separating the sequence into the 5-trial blocks generated by the rules.

The second aim was to test whether participants acquired knowledge of rules of partial validity rather than the movement succession rule or any specific parts of the sequence. For example, a characteristic of the sequence generated by the rule was that on the last two trials of each 5-trial block the target always moved in a SOB movement. Although frequencies of SOB movements have been controlled in the non-repeating sequence, participants might have learnt that at least two SOB movements occur every five trials. Although this characteristic of the rule sequence could have been reproduced in the control sequence by chance, it was not as regular as in the rule sequence.
how are participants warned about the occurrence of a predictive trial?
In order to test this possibility a transfer 60-trial sequence was generated so that the movement succession rule changed while the SOB movement repetition remained the same. This transfer sequence was generated in a similar way to the Rule sequence except that the succession of movements on the last three trials was altered: a horizontal movement was always followed by a diagonal one and a diagonal movement was always followed by a vertical one. This altered rule still causes the target to move in a SOB pattern on the last two trials of each 5-trial block. Therefore, a greater performance decrement found for the transfer sequence generated by the altered rule, compared to the transfer sequence generated by the original rule, would provide evidence for rule learning rather than learning of simple frequency information concerning sequences of FC and SOB movements.

The Altered Rule (AR) sequence and the re-ordered Same Rule (SR) sequence were presented after the initial 60 trials of the transfer experimental block to all groups. Order of presentation of the SR and AR sequences was counterbalanced in each of the three stimulus conditions.

4.2.1.3.3. Prediction

The last experimental block was intended to test whether participants could predict the next target while responding to the repeating sequence. This block included three repetitions of the rule sequence for the Rule group, and three repetitions of the pseudo-random sequence for the Repeating and the Control groups. Twenty "guess" trials, which required a target choice by the participants, were pseudorandomly distributed so that there were never fewer than five targets and never more than 20 targets between two successive guess trials. Five guess trials occurred for each spatial location. For the Rule sequence, each one of these five trials corresponded to each one of the five serial positions
in the 5-trial blocks.

4.2.1.4. Procedure

The experiment lasted approximately one hour. Participants were tested individually. At the beginning of the experimental session, they completed a hand preference questionnaire. They were then seated in front of the computer screen and were given written instructions about the task (Appendix 3). The stimulus display and the target circles were presented on the screen while participants read the instructions. They were instructed to use the joystick to move the cursor that appeared on the screen and intercept the yellow circles that appeared at the edges of the X-shaped area as fast as possible. They were informed that only one target would appear at a time and that the target would appear only after they had placed the cursor in the blue circle at the centre of the screen. This circle was supposed to be their "base". They were asked to move only within the boundaries of the green X-shaped area, and they were informed that a beep would sound every time their cursor left the green X-shaped area. After each response they had to return back to their base and wait for the appearance of the next target.

After reading the instructions, participants initiated 20 training trials by pressing the space bar of the computer keyboard. Each trial consisted of the presentation of the target, its interception by the cursor, and the return of the cursor into the circle at the centre of the X-shape. The main experimental session consisted of five blocks of 240 trials (four practice blocks and one transfer block). After each block, participants had to wait at least ten seconds before they could initiate the next block. The first target of each block appeared after the cursor was placed in the base.
After the end of the fifth block, participants were asked increasingly specific questions about the task (Appendix 4) and their verbal reports were recorded. After the interviews, participants were given verbal instructions about the last part of the experiment which involved a small change in the procedure. They were told that for most of the trials their task remained unchanged: they had to intercept the target that appeared in one of the four spatial locations. In some of the trials, however, the target would appear on all four locations simultaneously. On these trials they had to intercept the target that they believed was the most probable one to appear on this trial. They were encouraged to respond quickly and to try not to think about the task.

4.2.2. RESULTS

Total Movement time from the presentation of the target to its interception by the cursor was divided into a Response time measure and a Movement Execution measure. Response time was the time it took participants to leave the base and enter the correct side of the X-shape after the presentation of the target. Movement execution time was the time it took participants to intercept the target after they had left the base and entered the correct side of the X-shape. The analysis was carried out on both variables to investigate the effect of sequence learning on both aspects of the motor response.

Error scores for both initial responses and movement execution were also examined. A response error was recorded whenever participants moved in the wrong direction after the presentation of the target. Movement error was measured separately on each trial and was the total amount of time spent outside the X-shape boundaries while the cursor was moving towards the target.
4.2.2.1. Practice

Medians for every ten trials were calculated for both Response times (RT) and Movement times (MT). Mean values of the twelve medians* for every 120 trials were entered into the analyses. Total number of response errors (R-er) and mean movement time errors (M-er) for every 120 trials were also calculated and were entered into the analyses. Means and standard deviations for all five measures are presented in Table 4.2.

Results of the evaluation of the assumption of normality were satisfactory for movement time and response time scores, but not for accuracy scores. As there were large individual differences in accuracy scores, with some participants having particularly large scores while others having scores close to zero, the distributions were flat. After a square root transformation of the data, the skewness and kurtosis of the distributions were satisfactory. However, the same results were obtained from the analyses of both the transformed and the original scores. For clarity of presentation only the analyses of the original scores will be reported.

Inspection of the means reveals that the Rule group participants show greater variability in their movement time and response time scores, and that both the Rule group and the Repeating group have higher movement errors and slightly higher response errors than the Control group. Also, response errors are especially large at the beginning of practice. At the end of practice participants move to the wrong direction at about 20% of the trials. These large error scores are probably due to the highly sensitive joystick controlled cursor. Even fine

* Median response times are influenced less by unusually slow or fast responses than mean response times. Therefore means of medians would show less variability due to random variation than means of 120 trials.
### Table 4.2. Means (M) and Standard Deviations (SD) for Movement time (MT), Movement error (M-er), Response Time (RT), and Response errors (R-er) for each group on each one of the practice blocks. (Rep: Repeating, C: Control).

<table>
<thead>
<tr>
<th></th>
<th>Blocks of 120 trials</th>
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<th></th>
<th></th>
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<th></th>
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<td>3</td>
<td>4</td>
<td>5</td>
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<tr>
<td>MT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>431</td>
<td>412</td>
<td>406</td>
<td>391</td>
<td>354</td>
<td>355</td>
<td>350</td>
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<tr>
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<td>121</td>
<td>88</td>
<td>115</td>
<td>106</td>
<td>108</td>
<td>83</td>
</tr>
<tr>
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<td>545</td>
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<td>404</td>
<td>382</td>
<td>366</td>
<td>331</td>
<td>322</td>
<td>310</td>
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<tr>
<td>SD</td>
<td>83</td>
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<td>71</td>
<td>50</td>
<td>63</td>
<td>43</td>
<td>41</td>
</tr>
<tr>
<td>C M</td>
<td>517</td>
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<td>424</td>
<td>419</td>
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<td>378</td>
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<tr>
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<td>56</td>
<td>46</td>
<td>50</td>
<td>45</td>
<td>53</td>
</tr>
<tr>
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</tr>
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<td></td>
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<td></td>
</tr>
<tr>
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<td>295</td>
<td>280</td>
<td>284</td>
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<tr>
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<td>32</td>
<td>41</td>
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<td>39</td>
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<tr>
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<td>279</td>
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<td>269</td>
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<td>267</td>
</tr>
<tr>
<td>SD</td>
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<td>41</td>
<td>32</td>
<td>38</td>
<td>25</td>
<td>34</td>
<td>28</td>
<td>34</td>
</tr>
<tr>
<td>C M</td>
<td>310</td>
<td>303</td>
<td>299</td>
<td>292</td>
<td>298</td>
<td>296</td>
<td>286</td>
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<td>22</td>
<td>31</td>
<td>29</td>
<td>26</td>
<td>35</td>
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<tr>
<td>R-er</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rule M</td>
<td>36</td>
<td>31</td>
<td>27</td>
<td>29</td>
<td>24</td>
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<tr>
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<td>13</td>
<td>13</td>
<td>12</td>
<td>13</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td>Rep M</td>
<td>30</td>
<td>24</td>
<td>26</td>
<td>22</td>
<td>23</td>
<td>25</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>SD</td>
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<td>11</td>
<td>15</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>6</td>
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<td>7</td>
<td>6</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>
movements of the hand may cause the cursor to move in the wrong direction. Therefore, number of response errors depends on the skill of joystick control.

A three (Group: Rule vs Repeating vs Control) X eight (Practice: eight blocks) analyses of variance with repeated measures on the last factor was conducted on RT and MT. The assumption of homogeneity of variance covariance matrices was violated in the analyses and the degrees of freedom for the F test were adjusted by multiplying them by the average of the Greenhouse-Geisser epsilon and Huynh Feldt epsilon (Levine, 1991). Adjusted degrees of freedom will be reported for all following analyses that violated this assumption.

Both analyses revealed a reliable main effect of Practice (RT: F(7,189)= 10.26, MSe= 365, adjusted df 2,56 p<0.01, MT: F(7,189)= 51.35, MSe= 2290, adjusted df 3,90 p<0.01) but no significant interaction between Group and Practice. Similarly, analyses of Response errors and Movement errors revealed a main effect of Practice (R-er: F(7,189)=8.81, MSe= 34.1, p<0.0001, M-er: RT: F(7,189)=10.57, MSe= 227, adjusted df 3,94 p<0.01) and no interaction between Group and Practice.

The above findings suggest that neither the Rule nor the Repeating group learned the repeating sequences that were practised. Even when the two repeating groups were separately compared to the Control group there was no evidence for sequence learning. There was a significant interaction between Group and Practice only for the Rule versus Control group comparison on Movement error scores. However, this was due to larger error scores for the Rule group at the beginning of practice that gradually reduced and reached the level of the Control group at the end of practice.

A comparison of the two pseudo-random groups was also carried out on the
final 60-trial block. The two groups responded to the same pseudo-random 60-trial sequence at the end of the fourth practice block. For all measures, independent group t-tests on mean of medians for this last block failed to reach significance.

4.2.2.2. Transfer

Median scores for every ten trials were calculated for Movement time and Response time measures and means of the six medians for every 60 trials were entered into the analyses. Total number of response errors and mean number of movement errors for every 60 trials were also calculated and entered the analyses. Means and standard deviations for all measures are presented in Table 4.3 while mean Response times are represented graphically in Figure 4.5.

The Rule and Repeating groups were separately compared to the Control group with a two (Group) X four (Transfer sub-block) analysis of variance that was carried out for all measures. The following orthogonal a priori contrasts were tested:

a) whether Rule group participants acquired any specific knowledge of the succession of horizontal, vertical and diagonal movements: rule learning would be supported if the Rule group showed performance savings on the SR sequence compared to the AR sequence,

b) whether Rule group participants acquired any knowledge of the regularity in the occurrence frequencies of the FC and SOB target movements: movement frequency learning would be supported by a faster performance of the Rule group to the SR and AR sequences in comparison with the first pseudo-random transfer sequence in the block, and
c) whether learning was based on memory for instances of the repeating sequences; instance learning would be supported by performance savings only on the final practised sequence for both the Rule group and the Repeating group as compared to the Control group.

The interaction between the contrasts and the Grouping factor tests the above hypotheses. The contrast coefficients for the three comparisons are presented in Table 4.4. The comparison of the Rule group with the Control group on response times revealed a reliable interaction between Group and the third contrast that tested instance learning ($F(1,18)= 9.4, MSe= 112, p<0.006$).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Group</th>
<th>60-trial transfer sub-blocks</th>
<th>Pseudo-R or Rule</th>
<th>Same Rule</th>
<th>Altered Rule</th>
<th>Practised sequence</th>
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<tr>
<td>MT</td>
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<td>354 (69)</td>
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<td>340 (57)</td>
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<tr>
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<tr>
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<td>21 (15)</td>
<td>16 (15)</td>
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</tr>
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<td></td>
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</tbody>
</table>
Transfer and Return blocks

![Graph showing mean response times for the four 60-trial sequence of the transfer block for the Rule, Repeating and Control groups.](image)

Figure 4.5. Mean response times for the four 60-trial sequence of the transfer block for the Rule, Repeating and Control groups.

None of the other contrasts reached significance while the main interaction effect was marginally significant ($F(3,54)=2.71$, $MSe=161$, $p<0.054$). When the groups were compared on each one of the transfer blocks, no reliable differences emerged. This finding suggests that participants in the Rule group had acquired some knowledge that was not based on either the rule structure of the practised sequence or on movement sequential information. None of the analyses of the other measures supported the hypotheses tested by the contrasts.

Table 4.4. Coefficients for the contrasts testing "Rule learning", "Movement Frequency Learning" and "Instance learning".

<table>
<thead>
<tr>
<th>Contrasts</th>
<th>60-trial sequence</th>
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<tr>
<td></td>
<td>Transfer</td>
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<tr>
<td>Rule learning</td>
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<tr>
<td>Frequency learning</td>
<td>2</td>
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<tr>
<td>Instance learning</td>
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</table>
A two (Group) X four (Transfer sub-block) analysis of variance with repeated measures on the last factor was also carried out to compare the Repeating group with the Control group. If instances of the sequence were learned, the Repeating group would be expected to show similar response times on the first three blocks and a faster performance on the last practised block. The interaction between Group and the third contrast that tested the above hypothesis was reliable for the Response time measure \( (F(1,18) = 10, \text{MS}e = 84, p<0.005) \). The main interaction between Group and Block was marginally reliable \( (F(3,54) = 3.32, \text{MS}e = 125, p<0.058) \). Simple effects analyses revealed that the two groups significantly differed on the last practised block \( (F(1,18) = 5.02, \text{MS}e = 1089, p<0.038) \). None of the other measures produced any significant effects.

### 4.2.2.3. Prediction Task

A measure of the probability of correct prediction was calculated by dividing the total number of correct predictions by 20 which was the total number of "guess" trials. Means and standard deviations for the three groups are presented in Table 4.5. The Rule and Repeating groups were not found to outperform the Control group.

One confounding factor, however, that influenced the prediction scores for all groups was noticed by the experimenter and was mentioned by participants during the experimental session. On the guess trials participants tended to move to locations B and C more frequently, because these locations were

<table>
<thead>
<tr>
<th>Group</th>
<th>Rule</th>
<th>Repeating</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of correct prediction</td>
<td>Mean</td>
<td>0.38</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.13</td>
<td>0.11</td>
</tr>
</tbody>
</table>
associated with the easiest movement. As all participants were right-handed, moving in the up right and the left down spatial location could be executed by just flexing the wrist, while moving up-left and down-right could only be executed by moving the whole arm. This movement execution bias, combined with the instructions that encouraged participants to respond to the guess trials "quickly and without thinking", resulted in a bias in target selection. The mean numbers of generations of each target location are presented in Table 4.6. The most preferred location was B, followed by C, then D and A. Although this differential ease in movement execution could not affect group comparisons in all previous analyses as target locations were equally frequent in all conditions, it affected and distorted generation scores.

4.2.2.4. Verbal Reports

The post-experimental interviews revealed that the majority of participants in all groups did not notice any repeating sequence or any regularity in the way the targets were presented. Most participants seemed surprised when asked whether they had noticed a pattern in the target series. They replied that they did not even attempt to look for a pattern, as they were paying attention to the actual movement execution.

Table 4.6. Mean number of generations (total = 20) of each one of the target locations for all three groups (SD: standard deviation, Min: Minimum, Max: Maximum).

<table>
<thead>
<tr>
<th>Target Location</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.0</td>
<td>1.5</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>B</td>
<td>8.0</td>
<td>2.6</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>5.7</td>
<td>2.4</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>D</td>
<td>3.3</td>
<td>2.0</td>
<td>0</td>
<td>7</td>
</tr>
</tbody>
</table>
However, three participants from the Rule group, four participants from the Repeating group and four participants from the Control group reported that they had noticed that some movement patterns tended to appear twice before the target moved in a different pattern. The exact verbal reports of these participants are presented in Table 4.7. Most participants could not recall the exact patterns that tended to be repeated although a few mentioned triangle patterns that characterise SOB movements.

It appears that a similar type of knowledge of immediate repetitions of some patterns is expressed by participants in all three groups. This knowledge appears to be based on the general constraints that applied to all sequences. Even the control sequence, for example, had a higher proportion of SOB movements and this resulted in the regularity of pattern repetition that was also found in the other sequences. Therefore, this knowledge was not sufficient to account for the performance savings found for the two groups that practised with a repetition. This especially applies to the Rule group, as this group showed faster performance with the rule sequence when it was compared to a transfer sequence with exactly the same structure in terms of SOB movement repetition. Therefore, it seems that this performance saving was based on memory for some specific sub-sequences which were unique to the practised 60-trial repeating sequences and which the majority of participants were unable to recall when interviewed.

In order to examine whether this verbally expressed knowledge of pattern repetitions was associated with greater performance savings on the last practice sub-block or the transfer block, mean response times were estimated separately for knowledgeable and non-knowledgeable participants in each group for all four 60-trial sub-blocks of the transfer block. These means are presented in Table 4.8.
Table 4.7. Verbal reports of participants who noticed some target movement patterns.

RULE GROUP
- I do not remember a specific sequence. When I was doing it I was noticing some periodical movements, but I do not remember at all now.

- I noticed that there was a sequence to the left. Up left, Down left and Up right and then Up left again, Down left and Up right. This was a small sequence that was repeated more than once within a part. I became aware of it after it happened for a couple of times.

- The stimuli were coming in threes for a few times and then they could change. I attempted to anticipate the location of the next target and I think I was successful sometimes.

REPEATING GROUP
- Sometimes you could predict which target would come next, but then it changed again. For example, it covered Up left, Up right, Down left and then the same again. It did that for a couple of times and then changed again.

- At times I was trying to anticipate. I could concentrate on a location and I would know that it was going to be there. I could be in a triangle going to the same locations and then I would change to the other one.

- Sometimes I felt that the targets were appearing in a certain order but then it seemed to get random again.

- I was anticipating the next target. It worked quite well. There was some kind of pattern, it was easier when they were in pattern but I could not tell you what the pattern is.

CONTROL GROUP
- I noticed sometimes it seemed to go in a square, other times in a triangle. When there was a pattern it was obviously easier. And when the pattern stopped I would make a mistake because I would assume that it would continue.

- You tend to get a pattern repeated and then it changes. In some parts I could tell - I do not know why - which patterns were the new ones and which would come next.

- It sometimes repeated in threes, like it could go in the same sequence twice.

- Sometimes the targets seemed to be coming in an order. Sometimes they were coming in threes and then they seemed to go round.
Inspection of the means reveals that both sub-groups show a performance speed-up at the last practice block. However the knowledgeable participants were generally faster in all sub-blocks and this actually resulted in a smaller response time reduction at the last block. In order to test whether this speed-up was reliable, all knowledgeable participants from both repeating groups (n=7) were compared to the control group using a two (Group: Control vs Repeating with knowledge) X four (Transfer: four sub-blocks) analysis of variance with repeated measures on the last factor. The interaction between group and sub-block and between group and the sub-block contrast that tested for instance learning were not reliable. However, the Group main effect approached significance (F(1,15)=3.79, MSe= 52.2, p<0.07) and the two groups were reliably different on the last practice sub-block (F(1,15)=5.52, MSe= 1338, p<0.033).

Table 4.8. Means and Standard Deviations (in brackets) for Response Time for the sub-groups with and without pattern repetition knowledge within each practice group and on each one of the 60-trial transfer sequences and the final practised sequence. In the shaded part, response times for the groups with and without knowledge have been pooled for the two repeating groups. Response times for all participants of the Control group are presented for comparison (Pseudo-R: Pseudo Random, Rep.: Repeating, C: Control).

<table>
<thead>
<tr>
<th>Knowledge of repetitions</th>
<th>Group</th>
<th>60-trial Transfer sub-blocks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pseudo-R /Rule</td>
</tr>
<tr>
<td>With</td>
<td>RL</td>
<td>289 (34)</td>
</tr>
<tr>
<td></td>
<td>RP</td>
<td>300 (21)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>305 (12)</td>
</tr>
<tr>
<td>Without</td>
<td>RL</td>
<td>281 (61)</td>
</tr>
<tr>
<td></td>
<td>RP</td>
<td>244 (32)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>276 (36)</td>
</tr>
<tr>
<td>Without</td>
<td>RL, RP</td>
<td>294 (28)</td>
</tr>
<tr>
<td>With</td>
<td>RL, RP</td>
<td>260 (46)</td>
</tr>
<tr>
<td>Both</td>
<td>C</td>
<td>293 (27)</td>
</tr>
</tbody>
</table>
In order to examine whether the non-knowledgeable participants from both groups showed a reliable performance speed-up, they were also compared to the Control group with a similar analysis. This analysis revealed a significant Group by sub-block interaction \( (F(3,63)=3.44, \text{MSe}= 165, p<0.022) \) as well as a significant interaction between the Group factor and the sub-block contrast that tested for instance learning \( (F(1,21)=17.6, \text{MSe}= 87, p<0.0001) \).

Therefore, participants who did not express any knowledge of repeated patterns show clear evidence for a memory-based speed-up. On the other hand, those who expressed knowledge of repeated patterns show a general speed-up to both new and old sequences. This suggests that the verbally reported knowledge results in the development of a general strategy that may facilitate responses to all transfer sequences. On the other hand, it seems the memory-based speed-up is independent of verbally expressed knowledge of the repetition.

### 4.2.3. DISCUSSION

In this experiment, participants who practised with a repeating sequence did not demonstrate performance savings when compared to a control group that practised with a pseudo-random sequence. Performance savings were found, however, when participants were returned to the practised sequence after they had been transferred to new sequences.

This finding indicates that learning was a memory-based process and it is in line with Perruchet's (1994) recent demonstration that a memory process is responsible for learning the sequential structure introduced by Kushner, Cleeremans, and Reber (1991) in an explicit prediction task. Also, the fact that no positive transfer was found to a new sequence that just re-ordered the 12 5-
trial sub-sequences that made up the repeating sequence suggests that the specific instances learned were of a greater length than or of a different form from the 5-trial sub-sequence units that made up the sequence. Speed-up was probably caused by recognition of longer sub-sequences that may have been embedded in two or even three 5-trial blocks.

This speculation is supported by participants' verbal reports. A small number of participants from all three groups reported that the sequence included some immediate repetitions of certain triplets. These repetitions were caused by a higher proportion of SOB target movements. Successive SOB movements resulted in the presentation of the target in the same three locations more than once. Re-ordering of the 5-trial blocks that made up the sequence would not eliminate the triplet repetition effect, but would cause a change in the triplets that were immediately repeated. Therefore, the lack of positive transfer to a sequence that re-ordered the 5-trial blocks could be explained if participants had learned instances of triplets that were repeated.

However, verbal reports revealed that, although some participants from both repeating groups could recall that they were aware of some pattern repetitions during practice, they were unable to describe any specific instances of the repeated patterns. Furthermore, knowledge of pattern repetition was expressed even by participants from the Control group and resulted in a general performance speed-up to both new and practised sequences in the transfer block.

On the other hand, the selective performance speed-up on the last practised sub-block was found even for participants who did not verbally express any knowledge about the regularities in the practised sequence. This indicates that a memory-based performance speed-up may be dissociated from verbally
reported knowledge. However, it was not possible to determine whether the knowledge that guided performance during the indirect learning task could have been recalled in a more sensitive memory task. The generation scores in the present experiment were distorted by a the differential response execution rates for the four alternative target locations. Therefore, it was not possible to make a proper assessment of whether participants could recall instances of the sequence when given enough retrieval cues.

Concerning the locus of motor response speed-up, results suggest that memory for sequences speeds up movement initiation but not movement execution. Therefore, it is likely that performance speed-up is related to a faster selection of the spatial location of the next target (see also Cohen et al. 1990). Furthermore, the fact that evidence for performance savings was not very strong may be attributed to the attentionally demanding nature of the task. Indeed, participants reported that the movement execution phase was tiring and demanding*.

An additional factor that may have affected sequence learning in the present task was the time-consuming nature of the responses required by the task. This caused a slower rate of stimulus presentation in comparison with the keypressing tasks used in previous studies. In the present task at least 1.5 seconds elapsed before the next target was presented. Recent findings by Frensch and Miner (1994; see also Frensch, Buchner & Lin, 1994) have shown that a similar rate of stimulus presentation prevented simultaneous representation of subsequent stimuli in short term memory, and eliminated sequence learning in a keypressing task. Therefore, the lack of robust sequence learning in this

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* The fact that this may have slowed down the development of reliable sequence learning is supported by the finding that attentional distraction is more likely to affect the ambiguous sequence used in the present experiment (Nissen & Bullemer, 1987; Cohen et al., 1990; Curran & Keele, 1991; Cleeremans, 1993).
experiment may also have been due to this factor. Nevertheless, it appears that, even under conditions of attentional distraction and a slow rate of stimuli presentation, some memory-based sequence learning is possible.

One issue that arose from this experiment concerns the nature of the underlying knowledge representation. For example, it is not clear which instances were learned by participants. It is also not clear whether the pattern repetition effect that was mentioned in the verbal reports was independent of the memory-based process of learning. These issues were investigated in Experiment 2.

4.3. EXPERIMENT 2

The sequences used in Experiment 2 had a higher proportion of SOB trials than those used in Experiment 1. This resulted in a greater number of repetitions of the same triplets. A transfer paradigm was used that tested whether: a) knowledge of these repetitions could be expressed in a sequence that had similar structural characteristics but used different instances of triplets and b) whether negative transfer would be observed when the transfer sequence included a smaller number of triplet repetitions.

Furthermore, as the validity of the prediction task used in Experiment 1 was reduced by the differential ease in executing the four alternative responses, Experiment 2 involved a prediction task that controlled for this factor. The prediction task involved keypresses rather than the use of the joystick. It was similar to the task used by Perruchet and Amorim (1992) and was designed to provide greater sensitivity for testing memory for specific instances.

Finally, in Experiment 2, the response task remained the same except that accuracy constraints for the movement towards the target were eliminated.
So, joystick during task but keyboard during prediction?
Participants were no longer required to move within certain boundaries. They were just required to hit the target as fast as possible. This was expected to reduce the attentional requirements of the response execution and result in a faster rate of stimulus presentation that would facilitate learning of the sequence. Participants were also instructed to be accurate in terms of the selection of the direction of the target. This was to encourage the development of a preparation strategy as well as to decrease errors in response selection.

4.3.1. METHOD

4.3.1.1. Subjects

36 right-handed participants were randomly assigned to three groups, with the restriction that each group contained the same number of men and women. Their ages ranged from 19 to 39 years and 12 of them were male. Participants were volunteers who were paid £2 for their participation or first year students of the Psychology department of University College London whose participation was part of a course requirement. All participants had normal or corrected-to-normal vision and were naive about the purpose of the experiment. They were asked to volunteer to participate in an experiment on motor skill learning.

4.3.1.2. Apparatus and Stimuli

The experiment was run on a DELL personal computer with a VGA colour monitor, that was located in an artificially illuminated, quiet experimental room. Participants were presented with a green rhombus on a blue background. The rhombus was located at the centre of the screen and contained the same blue circle that was used in the previous experiment as the starting point for every
Chapter 4  
*Rule versus Instance Learning*

4.3.1.3. Stimulus Conditions

The stimulus sequences that were used in this experiment followed the same general constraints that applied to the sequences used in Experiment 1. Furthermore, frequencies of occurrence of all possible combinations of two successive targets were approximately equal in each sequence.

Two groups of participants practised with a repeating 60-trial sequence that

Figure 4.6. The target circles in the four quadrants of the screen, and the starting circle within the rhombus shape at the centre of the screen.

response (Figure 4.6). The distance between the centre of the blue circle and each side of the rhombus was 4.5 cm while the length of each side of the rhombus was 1.7 cm. The targets were yellow circles that had a diameter of 1.0 cm and were presented in exactly the same locations that were used in Experiment 3.

As there was no X-shape in this experiment, the locations were now defined as the four quadrants of the screen. Participants were seated approximately 60 cm away from the screen. The visual angle of the distance between the target and the centre of the screen, and the horizontal and vertical distances between two targets were the same as those reported in Experiment 1.
contained 47 SOB trials and 13 FC trials*. Therefore all sequences involved a large number of triplet repetitions of certain triplets. A Control group practised with four different 60-trial sequences. One of them was the sequence used for the two Repeating groups while the remaining three had exactly the same simple frequency information as the repeating sequence.

A Practice phase comprised nine blocks of 120 trials. Each block was made up of two repetitions of the same 60-trial sequence for two Repeating groups. For the Control group each 120-trial block also contained two repetitions of a 60-trial sequence, but a different sequence was presented in each successive block. However, there were only four different sequences that were presented to the Control group which were matched on simple frequency information. Therefore blocks 5 to 8 were exactly the same with blocks 1 to 4. The final ninth practice block involved the fifth and sixth presentation of the Repeating 60-trial sequence for all groups. An outline of the sequences presented in each block for the three groups can be found in Table 4.9.

After the Practice phase that involved a total of 1080 trials, the three groups were transferred to three new sequences. The first Repeating group was

<p>| Table 4.9. The 60-trial sequences presented twice in each one of the nine 120-trial practice blocks, for the Repeating 1 (REP 1), Repeating 2 (REP 2) and Control groups. (R: Repeating, C1: Control 1, C2: Control 2, C3: Control 3). |
|---------------------------------|---------------------------------|</p>
<table>
<thead>
<tr>
<th>Group</th>
<th>Blocks of 120-trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>REP 1</td>
<td>R  R  R  R  R  R  R  R  R</td>
</tr>
<tr>
<td>REP 2</td>
<td>R  R  R  R  R  R  R  R  R</td>
</tr>
<tr>
<td>CONTROL</td>
<td>R  C1  C2  C3  R  C1  C2  C3  R</td>
</tr>
</tbody>
</table>

* A large proportion of SOB trials is associated with a large occurrence coverage value. This is the average number of trials that are needed for the target to cover all four locations (Reed & Johnson, 1994; see chapter 2).
transferred to a new 60-trial sequence that had exactly the same simple frequency information as the practised sequence (frequency information A). The second Repeating group and the Control group were transferred to two new sequences that had smaller numbers of SOB trials (frequency information B and C respectively). All three groups responded to two presentations of the transfer sequences and were then returned to two presentations of the original practised repeating sequence for the last 120 trials. Simple frequency information of the repeating and transfer sequences is presented in Table 4.10 while an outline of the stimulus conditions is represented in Table 4.11. The exact sequences used and their frequency information can be found in Appendix 5.

**Table 4.10.** Proportion of SOB movements and values for Occurrence Coverage and Transition Coverage (the average number of trials so that all transitions are presented at least once) for the 60-trial transfer sequences that differed in Simple Frequency Information (A, B and C) (All sequences had equal number of target frequencies and transition frequencies and excluded repetitions and FOB movements).

<table>
<thead>
<tr>
<th>Simple Frequency Information for every 60 trials</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of Triangle trials</td>
<td>78%</td>
<td>65%</td>
<td>38%</td>
</tr>
<tr>
<td>Occurrence Coverage</td>
<td>8.85</td>
<td>6.5</td>
<td>5.4</td>
</tr>
<tr>
<td>Transition Coverage</td>
<td>36.4</td>
<td>32.6</td>
<td>20.35</td>
</tr>
</tbody>
</table>

**Table 4.11.** Frequency information in Practised and Transfer sequences for the three groups. The two Repeating groups practised with a repetition of a 60-trial sequence and the Control group with four different 60-trial sequences. All groups responded to two repetitions of a new 60-trial sequence during Transfer.

<table>
<thead>
<tr>
<th>Group</th>
<th>Simple Frequency Information</th>
<th>Practice</th>
<th>Transfer</th>
<th>Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeating-1</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Repeating-2</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>A</td>
<td>C</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>
4.3.1.4. Procedure

The experiment lasted approximately one hour. All participants were tested individually. At the beginning of the experimental session they were seated in front of the computer screen and were given written instructions about the task (Appendix 6). They were instructed to intercept the target with the joystick-controlled cursor as fast as possible, return back to their base, and wait for the next target to appear. After the appearance of the target they were required to move towards its direction and exit from the side of the green rhombus that corresponded to the target. If the cursor was in one of the wrong quadrants after the presentation of the target, a beep sounded to indicate an error. Every block of trials was initiated after participants had placed the cursor in the base and every target appeared after participants had returned back to the base.

After reading the instructions, participants initiated 20 training trials by pressing the space bar of the computer keyboard. There were 11 blocks of 120 trials and there was a short interval between them. At the end of each block participants were given feedback on their mean response times, movement times and the total number of errors. They had to wait at least ten seconds before they could initiate the next block.

They then proceeded to the last part of the experiment which involved a generation task. Instructions for this task appeared on the computer screen. They were asked to generate a series of 100 trials that resembled the series of trials they had encountered during practice. They were told that they were not required to reproduce an exact series of 100 trials but to try to produce at least sub-series of trials that they had seen before. In this generation task, the response of the participants was changed. Instead of using the joystick, they had to use the middle and index fingers of their left and right hand and press the
4,5,1 and 2 keys of the numeric keypad on the computer keyboard. These four keys corresponded spatially to the four quadrants of the screen. After participants pressed a key, a target appeared on the screen at the location matching the location of the key. This target remained on the screen until participants pressed a key again.

4.3.2. RESULTS

4.3.2.1. Response Time Task

The total time from the presentation of the target to its interception by the cursor was divided into a Response time measure and a Movement execution measure. Response time was the time it took participants to exit the rhombus shape after the presentation of the target. Movement execution time was the time it took participants to intercept the target after they exited the rhombus shape. Median scores were calculated for every 10 trials and mean values of the 12 medians in each 120-trial block were entered into the analyses. Total numbers of response errors in every 120 trial block were also analysed. Means and standard deviations for the three measures are presented in Table 4.12.

As can be seen in Table 4.12 performance of all groups on block 10 (the transfer block) is similar to both block 9 and block 11 that presented the practised sequence. Therefore, in this experiment there is no evidence of either instance learning or learning of simple frequency information. This was confirmed by a three (Group) X three (Block: Practised, Transfer, Practised) analysis of variance that was carried out for all measures. Neither the main effect of Block nor the interaction between Group and Block were reliable.
### Table 4.12

Means (M) and Standard Deviations (SD) for Response time (RT), Movement Time (MT) and Response errors (R-er) for the Repeating-1 (RP-1), Repeating-2 (RP-2) and Control groups (Shading denotes the transfer block).

<table>
<thead>
<tr>
<th>Block</th>
<th>RT</th>
<th>MT</th>
<th>R-er</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RP-1</td>
<td>RP-2</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>M</td>
<td>357</td>
<td>383</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>86</td>
<td>96</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>344</td>
<td>362</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>94</td>
<td>54</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>353</td>
<td>346</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>129</td>
<td>69</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>330</td>
<td>338</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>108</td>
<td>57</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>313</td>
<td>323</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>109</td>
<td>56</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>311</td>
<td>315</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>110</td>
<td>46</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>303</td>
<td>317</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>118</td>
<td>45</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>301</td>
<td>314</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>97</td>
<td>46</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>298</td>
<td>308</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>81</td>
<td>45</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>293</td>
<td>311</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>74</td>
<td>37</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>289</td>
<td>308</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>73</td>
<td>45</td>
</tr>
</tbody>
</table>
4.3.2.1.1. Triplet-Repetition Effect

Although there was no evidence for learning of instances in this experiment*, a more specific test for the triplet repetition effect was carried out for the first Repeating group. This group was transferred to a sequence with exactly the same simple frequency information as the practised sequence. The practised and transfer sequences for this group had exactly the same number of triplet repetitions; they only differed in the triplets that were repeated. For example both sequences started with three repetitions of one triplet that were followed by five repetitions of another triplet and three repetitions of a third triplet. However, for the practised sequence, the first three repeated triplets were ABD, CBA, and DBC while for the transfer sequence they were DAC, BAD, and CAB. The same applied to all following triplet repetitions until the end of the sequence.

The structure of the two sequences allowed a test of whether any evidence of a triplet repetition effect is independent of memory of specific instances, in this case triplets. If participants acquire simple frequency information only and develop general expectations for triplet-repetitions then facilitation should be similar for both practised and transfer triplets. If, on the other hand, the repetition effect is dependent on memory for the specific triplets that were practised, then it should be evident only for the practised sequence.

It was initially necessary to test whether participants showed faster responses to

* Results from Experiments 3 and 4, that are reported in the next chapter, suggest that response times to FC trials are faster than response times to SOB trials in a keypressing task. If this was also the case in the present joystick task then the lack of performance deterioration during the transfer block for the Repeating-2 and the Control group could have been caused by the lower proportion of SOB trials in the transfer sequences. However, when response times to FC and SOB trials were compared, it was found that they did not differ in this joystick task. Therefore, the lack of performance deterioration during transfer could not be attributed to this effect.
the triplet repetitions and whether any such effect was due to practice and not to a general facilitation effect. Therefore, median Response times and Movement execution times were calculated for the first, second and third presentation of a triplet in blocks 2 and 10 and 11. However, as each triplet included different targets and different targets were associated with different movement times, target location was controlled for.

Calculation of medians was based on responses to targets that were part of three different repeated triplets and appeared in the same locations for both the practised and the transfer sequence. Median scores for the practised sequence blocks were based on two responses to target A in triplet CBA, two responses to target C in triplet DCA and two responses to target A in triplet DAB. Median scores for the transfer block were based on two responses to target A in triplet BAD, two responses to target C in triplet CBD and two responses to target A in triplet CDA. All three targets that were used for the calculation of scores were also preceded by the same target in both the practised and transfer sequence. This served to eliminate any effect of movement execution that was unrelated to a repetition and transfer effects. Means and standard deviations for Response time and Movement execution times for the first, second and third presentation of the triplets in blocks 2, 10 and 11 are presented in Table 4.13.

A three (Repetition: First, Second and Third triplet presentation) X two (Block: 2 vs 11) analysis of variance with repeated measures on both factors was initially carried out to test whether there is a repetition effect and whether it is evident after practice with the sequence. For response times, the main effect of repetition was not reliable and the interaction between block and repetition was marginally reliable for the linear trend of repetition (F(1,11)= 4.6, MSe= 1310, p<0.054). When the repetition effect was examined separately for block 2 and block 11, a reliable linear trend as well as a main effect was obtained for block 11
only (linear: \(F(1,11)=7, \text{MSe}= 1299, p<0.022, \) main: \(F(2,22)= 5.1, \text{MSe}= 909, p<0.015\)).

When movement execution times were examined, both the main effect of repetition (\(F(2,22)=3.88, \text{MSe}= 4660, p<0.036\)) and the linear trend of repetition (\(F(1,11)=5.9, \text{MSe}= 5936, p<0.033\)) were reliable. Also the interaction between Block and the repetition effect was reliable (\(F(2,22)=10.56, \text{MSe}= 5952, p<0.001\)). Block interacted with both the linear (\(F(1,11)=10.49, \text{MSe}= 6217, p<0.008\)) and the quadratic trend of repetition (\(F(1,11)=10.62, \text{MSe}= 5687, p<0.008\)). When the repetition effect was examined separately for block 2 and block 11, both the main effect and the linear and quadratic trends of repetition were reliable for block 11 only (main effect: \(F(2,22)=12.7, \text{MSe}= 5360, p<0.0001\), linear trend: \(F(1,11)=13.7, \text{MSe}= 7137, p<0.003\), quadratic trend: \(F(1,11)=10.7, \text{MSe}= 3582, p<0.007\)). As can be seen in Table 4.13 a movement time speed-up for the first and second repetition of the triplet is only found in block 11.

In order to examine whether the repetition effect is evident only for the practised as compared to the transfer sequence, a three (Repetition: First, Second

| Table 4.13. Mean response times and standard deviations (in parentheses) for the selected targets in the first presentation (PR), the first repetition (R1) and the second repetition (R2) of the triplet. |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Initial practice block | Transfer block | Final practice block |
| (Block 2) | (Block 10) | (Block 11) |
| RT PR | 334 (65) | 301 (71) | 314 (52) |
| R1 | 348 (119) | 295 (79) | 292 (67) |
| R2 | 340 (81) | 292 (92) | 275 (66) |
| MT PR | 283 (107) | 259 (155) | 310 (107) |
| R1 | 347 (163) | 192 (69) | 176 (82) |
| R2 | 303 (112) | 207 (73) | 182 (76) |
and Third triplet presentation) X two (Block: Transfer, Practice) analysis of variance with repeated measures on both factors was carried out initially for response times. The interaction between the linear trend of Repetition and Block was marginally significant \((F(1,11)= 4.7, MSe= 589, p<0.053)\). Simple effect analyses revealed that the linear trend of Repetition was not significant for block 10 \((p<0.6)\) which was the transfer block. Therefore there is an indication that learning of simple frequency information, which in this case is expressed in frequent repetitions of triplets, is associated with memory for the specific instances that were practised. However, this learning is not very strong and does not produce an overall reduction in times to the practised sequence relative to the new transfer sequence.

A different pattern of results emerged for movement execution time. The interaction between block and repetition failed to reach significance even for the simple linear and quadratic effects of repetition. Therefore it appears that a linear trend is evident for both transfer and practised sequence. However, when the repetition effect was examined separately for block 10 it failed to reach significance.

### 4.3.2.2. Free Generation Task

No differences were found between the two Repeating groups and the Control group on the number of generations of the triplets that were the repeating sequence. Furthermore, no differences were found between the number of generated triplets that were practised and number of generated triplets that were not practised by the two Repeating groups. Table 4.14 presents the mean number of generations of the triplets that were in the repeating sequence and of the triplets that were in the transfer sequence that was presented to the Repeating-1 group.
Participants from the Repeating-1 group generated sequences with simple event frequency information that was similar to that in the practised sequences. However, it appears that the change in simple frequency information for the Repeating-2 and the Control groups when the transfer sequences were introduced biased participants towards generating a smaller number of SOB trials and, consequently, triplet repetitions than the Repeating-1 group. Mean number of SOB trials for each one of the groups is shown in Table 4.15.

A one-way analysis of variance tested the difference between the three groups on both measures. A special contrast was applied to the Grouping factor to compare the Repeating-1 group that practised with the same simple frequency information throughout with the other two groups. The difference between the groups was reliable for both measures (SOB trials: $F(1,33)=4.43$, $MSe= 469$, $p<0.043$), Triplet repetitions: $F(1,33)=4.44$, $MSe= 349$, $p<0.043$).

Table 4.14. Mean number of generations of the triplets found in the Practised Repeating and the Transfer (for the Repeating-1 group) sequence for the Repeating-1 (RP-1), Repeating-2 (RP-2) and Control groups.

<table>
<thead>
<tr>
<th>Triplet type</th>
<th>Group</th>
<th>RP-1</th>
<th>RP-2</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single triplet</td>
<td>Practised</td>
<td>21</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>generations (3 trials)</td>
<td>Transfer</td>
<td>23</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>Double-triplet</td>
<td>Practised</td>
<td>6</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>generations (6 trials)</td>
<td>Transfer</td>
<td>7.5</td>
<td>3</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Table 4.15. Number of generations of SOB movements and triplet repetitions for the Repeating 1, Repeating 2 and Control groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>SOB Trials</th>
<th>Triplet Repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeating-1</td>
<td>50 (25)</td>
<td>26 (22)</td>
</tr>
<tr>
<td>Repeating-2</td>
<td>33 (21)</td>
<td>13 (17)</td>
</tr>
<tr>
<td>Control</td>
<td>34 (17)</td>
<td>12 (14)</td>
</tr>
</tbody>
</table>
4.3.3. DISCUSSION

This experiment provided evidence for learning of instances of triplets that were repeated in the practised sequence. A speed-up was found for response times to the first and second repetition of these instances. It appears that the first triplet presentation served as the cue that led to an expectancy for a repetition of this triplet. This repetition speed-up, however, was not strong enough to cause a reliable difference in overall response time scores.

Furthermore, this repetition effect affected both response times and movement times. However, the response time speed-up was only found for the practised sequences while the movement time speed-up was found for both practised and new triplets. It may be the case that general knowledge for triplet repetitions allows a more efficient movement execution while memory for specific instances allows a faster movement initiation towards the target location. This speculation, however, would require further investigation.

Knowledge of specific instances was not found to be expressed in a subsequent free generation task. This finding could be interpreted as evidence that this triplet knowledge was applied unconsciously in the response time task. However, there is at least one argument against such an interpretation. A response time speed-up was found only after the first presentation of the acquired triplet. Therefore the generation task may have lacked the contextual cues that would elicit this triplet knowledge. It may be the case that a cued-generation task presenting different triplets and requiring participants to generate continuations for these triplets would be sensitive enough to reveal the acquired knowledge.

Performance on the generation task also revealed that participants acquire
simple frequency information from the sequence. The two groups that received a transfer sequence with a smaller proportion of SOB trials than the practised sequence generated a smaller number of SOB trials and a smaller number of immediate triplet repetitions. This finding also revealed that generations were more likely to be influenced by the recent past rather than by the characteristics of the sequence throughout the whole course of practice.

4.4. GENERAL DISCUSSION

4.4.1. Rule versus Instance Learning

Results from both experiments suggest that participants developed fast response times for specific instances that they had encountered during practice. This supports the memory-based model proposed by Perruchet (1994). There was no evidence either for learning of the deterministic rules that were used to generate the sequence or for learning of regularities in the sequence of general target movements (Experiment 1). Instead, participants appeared to encode the stimulus series in a much simpler way than the one hypothesised when the study was designed: as repetitions of certain patterns or/and frequencies of target movements.

Concerning the issue of awareness, results in the present experiments can not be conclusive: there was only weak evidence for the development of sequence knowledge in the response time task and the tests of conscious knowledge may not have been sensitive enough to reveal the knowledge that was acquired. However, results were conclusive in terms of a dissociation of verbally expressed knowledge and the memory-based process that leads to a performance speed-up. Participants in Experiment 1 who did not report any regularity or repetition in the sequence nevertheless showed instance-based
speed-up.

### 4.4.2. Response Locus Of Learning

Results from both experiments suggest that learning of specific instances in a practised sequence speeds up the time taken to initiate a movement towards the direction of the target but not the time taken to execute the movements. As time to initiate the movement towards the direction of the target reflects the stimulus-response translation stage, the present finding is consistent with findings of previous studies. For example Willingham et al. (1989) failed to find positive transfer with the introduction of a new set of stimuli that required the practised sequence of motor responses. On the other hand, Nattkemper and Prinz (1993) obtained positive transfer when they substituted a subset of the stimuli within the practised sequence with a new set of stimuli that were mapped on to the same responses as the original stimuli. Results from these studies taken together suggest that sequence learning affects the stimulus-response translation stage. In Willingham et al.'s study, participants had to deal with a completely new stimulus-response translation during transfer, while in Nattkemper and Prinz's (1993) study participants had already formed the mapping between the new stimuli and the spatial locations because it was the same as the one between the practised stimuli and the new locations.

Furthermore, the finding that sequence learning does not speed-up the movement execution phase explains why a change of the movement execution requirements of the task after practice with a sequence does not eliminate any observed performance speed-up. A lack of negative transfer was reported by Cohen et al. (1990) when they altered the movement requirements in a key-pressing task. However, Cohen et al. (1990) suggested that a movement execution effect may have been obtained if more complex movements were
required for the response. Results from the present experiments suggest that this is unlikely to be case: even with the fairly complex movements used in the present experiments, there was no speed-up in the movement execution phase.

One of the problems, however, with both Experiments 1 and 2 that undermine the validity of the above speculations is the lack of a reliable speed-up in response time and movement time after practice with the sequence. The speed-up that was caused by the reintroduction of the practised sequence after a transfer sequence in Experiment 1 was the only reliable evidence that revealed sequence learning. However, this evidence was not obtained in Experiment 2 even though the elimination of movement accuracy constraints in this experiment was expected to make the task less attentionally demanding and to increase the rate of stimulus presentation.

A possible factor that may have eliminated the evidence for sequence learning in Experiment 2 was the introduction of accuracy constraints on the first movement towards the direction of the target. Although this resulted in the expected reduction of response errors, it also resulted in a general response time slow-down. In order to avoid response errors, participants may have been particularly careful to control the cursor when they were moving towards the base. This attentionally demanding movement requirement was probably even more detrimental to learning than the accuracy constraints imposed on movement execution in Experiment 1. Or, alternatively, it may be the case that the accuracy constraints on the initiation of the movement prevented the expression rather than the development of sequence knowledge. For example, participants may have acquired parts of the sequence but did not express this knowledge as movement initiation had accuracy constraints. This hypothesis, however, would require a direct test.
4.5. Conclusion

In summary, results from both Experiment 1 and 2 support a memory-based process of learning. It appears that the repetition of certain sub-sequences within the series facilitated encoding and memorisation of instances that, in turn, speeded-up the initiation of the movement towards the location of the target. However, one problem with Experiments 1 and 2 was that the sequence length that was used (60-trials) did not allow the identification of the exact sub-sequences that were acquired. An item-by-item analysis that would reveal the exact instances that were acquired could not be carried out due to the presence of a confounding factors that may have affected response time comparisons (i.e. sequential effects, movement execution effects etc.). On the other hand, these confounding factors are easier to control when a shorter sequence is used. Therefore, the experiments that follow were designed to investigate the memory process that underlies sequence learning when the stimulus series involves the repetition of a short sequence. Furthermore, in order to avoid the response complexities present in the joystick task all the following experiments used a simple key-pressing task that imposes minimum response requirement on participants. However, investigating learning of a short sequence repetition require the identification of a valid index of learning each one of the stimuli in the sequence. Therefore, it was initially necessary to examine the influence of sequential effects that are present in choice response time tasks and that may affect the item-by-item response time comparisons that can be performed on a short repeating sequence. This was the aim of the experiments presented in the following chapter.
CHAPTER

5

Sequential Effects

In The Serial Response Time Task
5.1. INTRODUCTION

The importance of establishing the exact type of knowledge that leads to a performance speed-up in order to test whether this knowledge is conscious is encapsulated in Shanks and St John's (1994) Information Criterion. Recent demonstrations of the violation of this criterion in some SRT studies have raised concerns about the validity of response times as measures of sequential structure knowledge. For example, Shanks et al. (1994) have shown that the response time improvement attributed by Willingham et al. (1989) to learning of a 10-trial sequence was caused by learning of probabilities of stimulus occurrences. This demonstration challenged Willingham et al.'s (1989) conclusions that participants in their study acquired unconscious knowledge of sequential structure.

Reed and Johnson (1994) have further elaborated on this potential methodological artefact. They identified different types of simple frequency information that may be acquired with exposure to a series of stimuli and that may therefore lead to a response time speed-up. They have shown that a difference just in simple event frequencies between the practised and transfer sequence may be sufficient to cause a performance deterioration, similar to the one used as evidence for sequence learning. This finding suggests that unless researchers are careful to select transfer sequences that are matched with the repeating sequences on simple frequency information, response times will not be valid measures of sequential knowledge.

Another methodological issue that has been raised by Perruchet and Amorim (1992) and that is especially relevant to studies that have incorporated a sequence repetition, is that the acquired knowledge may be very specific and
limited to certain sub-parts of the sequence. Consequently, unless subsequent conscious knowledge tests are sensitive to sub-sequence knowledge, experimenters may erroneously conclude that the acquired sequence knowledge was unavailable to consciousness (Perruchet & Amorim, 1992).

One methodological tool that has been used to determine the exact type of information that has been acquired and caused the response time speed-up is a trial-by-trial comparison of each one of the stimuli in a repeating sequence with stimuli from a control sequence. This comparison reveals which transitions or which sub-parts of the sequence have been acquired. For example, on the basis of the response time pattern from a trial-by-trial comparison, Nissen and Bullemer (1987) suggested that participants may have learned two salient stimulus runs in the sequence. A similar suggestion was made by Perruchet and Amorim (1992) who have further shown that subsequent explicit memory tasks were sensitive to knowledge of the sub-parts of the sequence revealed by a trial-by-trial comparison.

A trial-by-trial response time comparison was also employed by Reed and Johnson (1994) with a 12-trial sequence that had equal frequencies of stimulus occurrences and included all possible combinations of pairs of successive stimuli. This sequence is described as a Second Order Conditional (SOC) because each stimulus may only be predicted on the basis of at least two previous stimuli. Practice with a repetition of this SOC sequence would lead to a response time improvement if at least triplets of stimuli are learned. In order to verify this assumption, Reed and Johnson compared response time to the last stimulus of each one of the 12 different triplets of the repeating sequence with response time to the last stimulus of transfer control triplets. The transfer control sequence was matched with the practised sequence on simple frequency
information, and furthermore the control triplets contained exactly the same first two stimuli; they only differed on the last stimulus. All comparisons were found to be significant, which suggested that participants had learned all triplets of stimuli.

However, one factor that may invalidate the trial-by-trial response time comparison is the presence of short term sequential effects that affect choice response times. These sequential effects may be either first order, if the response time is affected by the immediately preceding stimulus, or higher-order if the response time is affected by stimuli earlier in the sequence (Soetens, Boer & Hueting, 1985). First order sequential effects are expressed as a response time speed-up when the same stimulus is immediately repeated and the inter-stimulus interval is short. This repetition effect has been attributed to an automatic facilitation process. Most sequence learning studies have excluded repetitions in order to avoid this effect.

When the inter-stimulus interval is long, sequential effects may be based on participants' strategies and a priori expectations for the appearance of certain stimuli (Bertelson, 1961; Kirby, 1976). For example, with two stimulus response alternatives participants tend to expect alternations rather than repetitions. With more than two stimulus response alternatives, if a pair of stimuli is immediately repeated, participants will be faster to respond to the last stimulus of the pair in the second presentation. This suggests that a comparison of response time to the last trial in the sequence ABABAB may not lead to pure measure of learning as this response time may be facilitated by the pair repetition.

Sequential effects have not always been controlled in incidental sequence learning studies, although their influence was demonstrated by Cleeremans and
McClelland (1991) in their simulation of human response time performance with a connectionist model. A simple recurrent network (see Elman, 1990; Cleeremans, Servan-Schneiber & McClelland, 1989) successfully modelled human response times to a sequence determined by an artificial grammar, but did so only when it was augmented with mechanisms that produced both first and higher order repetition effects. However, although these higher order repetition effects may be relevant to hybrid short sequences (e.g. ABABCD) they are not relevant to the SOC sequence that was used by Reed & Johnson (1994). This sequence did not include repetitions of pairs or triplets of events.

An SOC sequence, however, may be affected by another higher order effect. Hyman (1953) was the first to report that, in a serial response time task, response times to a stimulus are affected by the number of alternative stimuli that intervene between its previous and current occurrence. He reported that the function relating response times to the number of intervening stimuli is parabolic. They reach a maximum when there are one or two intervening trials before the presentation of the same stimulus, and then go down again. This response time facilitation when there are three or more intervening trials may be explained in terms of participants' verbal reports that stimuli which have not appeared for some time in the series are expected to be more likely to occur next (Hyman, 1953).

An alternative explanation for this effect is that an inhibitory process that slows response times to a presented stimulus peaks after one or two intervening stimuli. This is supported by research investigating inhibitory processes in visual orientation. Posner and Cohen (1984) have shown that reaction time to a stimulus that is preceded by a cue is slower when the cue is presented in the same rather than in a different location with the target stimulus. This inhibition
occurs if the target stimulus is presented at least 300 msec after the cue and is described as "inhibition of return" because attention returns back to the cued location. Inhibition of return has also been demonstrated in tasks that have not used cues but have required a single manual response to four stimuli presented in different locations (Maylor and Hockey, 1985).

If this sequential effect is present in the serial response time task, trials with a smaller number of intervening stimuli before the target is presented in the same location would be expected to be slowed down due to inhibition of return. For example, response times to the last trial of the sequence ABC would be faster than response time to the last trial of the sequence ABA which is a first order backward trial (FOB). Similarly, response time to the last trial of the sequence ABCD, which is a full coverage trial (FC), would be faster than response time to the last trial of the sequence DBCD, which is a second order backward trial (SOB). If this is the case, then a trial-by-trial comparison may be affected by higher order sequential effects that are independent of any learning effect. This may be so even for an SOC sequence. The experiments reported in this chapter examined whether these higher order sequential effects are present in a four choice response time task with a high stimulus response compatibility that is most typical of incidental sequence learning studies.

5.2. EXPERIMENT 3

Two different stimulus response spatial arrangements have been used in sequence learning studies. In the most commonly used one (Nissen & Bullemer, 1987), the stimuli are arranged in a line, while in the one used by Lewicki et al.
Figure 5.1. Movement of the target in the sub-sequences ABC, ACB, ABCA and ACBA for the line and the square spatial arrangement. In the line spatial arrangement, letters A, B, C, D correspond to the spatial locations from left to right. In the square spatial arrangement letters A, B correspond to the upper row from left to right while letters C, D correspond to the lower row also from left to right.

(1988) and Perruchet et al. (1990) the stimuli are arranged in a square. If inhibition of return is to be investigated, the square spatial arrangement appears to be preferable. Every triplet of stimuli involves a shift in the direction of attention in the square spatial arrangement but not in the line spatial arrangement.

For example, as shown in Figure 5.1, triplets ABC and ACB involve a more or
less similar shift in the direction of attention in the square spatial arrangement, while only triplet ACB involves a shift in the direction of attention in the line spatial arrangement. Furthermore, the sub-sequences ABCA and ACBA that involve a return of the target to the position occupied three trials before, involve comparable directional shifts in the square spatial arrangement. In the line spatial arrangement, however, a directional reversal occurs only in the transition CA in the first sub-sequence and only in transition CB in the second sub-sequence.

This makes the comparison of sub-sequences that have a different number of intervening trials more complex in the case of the line spatial arrangement. The advantage of the square spatial arrangement is that response times on the last stimulus may be pooled and compared to response times to stimuli that involve a greater number of intervening trials. Therefore, this arrangement was used in the present studies. Each trial was coded on the basis of its distance from the previous occurrence of the same stimulus. A repetition of the same stimulus had a distance of 1 (D1), the last trial of a first order backward movement (e.g. ABA) had a distance of 2 (D2) and so on.

If trials with small distances are associated with longer response times, then mean response time to a sequence that has a greater number of small distance trials should be larger. This should be evident even at the beginning of practice when learning of the sequential structure is unlikely to develop. If this is the case, then transfer to a sequence with a higher proportion of small distance trials may also increase response times. This increase may be unrelated to learning of either sequential structure or simple frequency information.

The first aim of this experiment was to compare response times to stimuli that
were associated with different distances from their last occurrence. The second aim was to examine whether the presence of small distances would affect mean response times to a sequence at the beginning of practice. Two groups practised with 14 repetitions of a 32 trial sequence. The sequence practised by one of the groups did not include any repetitions (D1 trials) or first-order backward movements (D2 trials) while the sequence practised by the other group included all distances.

5.2.1. METHOD

5.2.1.1. Subjects

56 right-handed undergraduate psychology students from Goldsmiths' College, University of London volunteered to participate in the experiment. All participants had normal or corrected to normal vision and were randomly assigned to two groups.

5.2.1.2. Apparatus and Stimuli.

The experiment was run on Personal Computers with 386 microprocessors. The target stimulus was a white circle that appeared on a black background on the four different quadrants of a VGA colour monitor. The four equally-sized quadrants of the screen were clearly separated by one horizontal and one vertical line (Figure 5.2). The radius of the circle stimulus was 1.0 cm. The distance between the circle stimulus and the vertical and horizontal line was 2.5 cm. The visual angle of the distance between two targets that were in the same vertical or horizontal line was 5.7°, while the visual angle of two diagonal elements was 7.9°. Participants used the 4, 5, 1 and 2 keys on the numeric
The target remained on the screen for 500 msec or until a response was made (if the response was slower that 500 msec). The next target appeared 300 msec later. If participants did not respond in less than 1500 msec after the presentation of the target, the response was recorded as missing and the next target appeared.

Two different 32 trial sequences were used for the two groups (Appendix 7). The sequences were randomly generated with the constraint that they had an equal number of occurrences of the four stimuli. Furthermore, one of the sequences did not include any D1 or D2 trials. This sequence was generated with the constraint that it had an equal number of SOB and FC movements (16 SOB and 16 FC). The sequence that included D1 and D2 trials had five repetitions, four FOB movements, 8 SOB movements and 15 FC movements.
5.2.1.3. Procedure

The experiment was conducted in the Psychology Laboratory of Goldsmiths' College. Participants were tested individually in laboratory cubicles. They were seated approximately 50 cm from the screen. They were told that the experiment investigated reaction times and were instructed to respond as fast as possible to the targets appearing on the screen by pressing the corresponding response keys.

The experimental session comprised two blocks of 224 trials separated by an interval. Participants could initiate the second block after at least 10 seconds had elapsed. Each block involved seven repeated presentations of the stimulus sequence.

5.2.2. RESULTS

The analyses will be presented in three sections: the first section presents analyses of the Long Distance group that practised with a sequence that did not include any D1 or D2 trials; the second section presents analyses of the Short Distance group that responded to the sequence that included D1 and D2 trials; the last section presents a comparison of the two groups.

5.2.2.1. Sequence with Long Distance Trials.

Median response times for each one of the 32 positions of the sequence were calculated for each participant. The first presentation of the sequence on the first block was excluded from the analysis as it provided the necessary sequential context for the later presentations of the sequence. The 32 means across all
participants are presented in Figure 5.3. It is apparent that there is considerable response time variability. Response times for each stimulus in the sequence were plotted against distance to test whether their relationship is linear (Figure 5.4).

The relationship appears to be linear up to distance 6. Response time, however, on the trial that had the largest distance score 9 appears to be very slow. Figure 5.3 shows that the trial that corresponds to distance 9 follows a series of five D3 trials. This repetition of D3 trials in which the target appears to move in a triangle may bias the participants to expect a similar movement and, therefore, slow them down when a different movement type is presented. If this effect is reliable then a quadratic trend appears to describe the relationship between response times and Distance better. However, as there was only one observation for distance 9, this response time score was excluded as an outlier.

The rest of the scores may be fitted by both a linear and a quadratic model. The linearity appears to be due to the difference between D3 and D4 trials. There is no apparent difference between D4 and D5 trials. As there are only four stimulus alternatives in the task, this response time pattern indicates that participants develop strong expectancies for the appearance of the target on the fourth remaining location, without being sensitive to the number of intervening trials from the last occurrence of the target to this location.

In order to test this alternative source of response time variability, trials were coded according to the type of movement of the target that occurred over the previous three trials plus the current one. The two alternative movement types are second order backward movements (SOB) or full coverage movements (FC).
Sequential Pattern for Long Distances (D>2)

Figure 5.3. Median response times for the 32 serial positions of the Long Distance Sequence

Distance Effect (D>2)

Figure 5.4. Plot of response times for each stimulus in the sequence against Distance.
It has to be noted that the Distance measure not only distinguishes SOB and FC trials but also breaks down the FC trials on the basis of how far back in time the stimulus appeared. For example, in the case of the sub-sequence D A B C D, Distance would have a value of 4 for the last FC trial, while in the case of the sequence D A B C A D, Distance would have a value of 5 for the last FC trial.

The comparison of Distance and type of stimulus movement would reveal whether participants' expectations are mainly based on Distance from previous presentation or on type of target Movement. In the first case, number of intervening trials would be a better predictor of response time variability and the difference between two successive trials should not be affected by whether they were SOB and FC or whether they were both FC trials with different distances. In the second case Movement type would be a better predictor of response times and response time variability for distances that are larger that 4 would be expected to be small. Finally, it may be the case that response times show a speed-up up to a distance of 4, but then are actually slowed down. In this case, response times should be predicted by both the linear and a quadratic effect of Distance.

In order to test the above alternatives both the linear and quadratic trend of Distance and Movement type were used as predictors in a multiple regression analysis that investigated the sources of response time variability. However, as Movement type and Distance were highly correlated (.9), two separate hierarchical multiple regression analyses were used in order to avoid the potential problem of multicollinearity (Howell, 1987). Furthermore, as response time on the previous trial may also affect response time on the current trial, this variable was also used as a predictor.
When response times were regressed on Distance in the first analysis, the model accounted for 40% of the variability (Adjusted $R^2=0.38$, $F(1,29)=19.8$, $p<0.0001$). When the quadratic effect of Distance was entered ($Distance^2$) the explained variability increased to 50% (Adjusted $R^2=46\%$, $F(2,28)=14.2$, $p<0.0001$). This increase was significant ($F(1,28)=5.6$, $p<0.05$). Finally, when response time on the previous trial was entered, the variability explained by the model increased to 62% (Adjusted $R^2=0.52$, $F(3,27)=15.1$, $p<0.00001$). This increase was also significant ($F(1,27)=8.85$, $p<0.01$).

When Response time on the previous trial, however, was the only predictor, the model accounted for only 0.06% or the variance which indicated that this variable contributes to the model only when the linear and quadratic effects of Distance are taken into account. On the other hand, the linear and quadratic effects had equal weighting as both accounted for the same amount of variance when entered at the first step.

When response time was regressed on Movement type, 53% of response time variability was explained (Adjusted $R^2=0.52$, $F(1,29)=33.9$, $p<0.00001$). When Response time on the previous trial was entered in the equation the amount of response time variability accounted by the model increased to 63% (Adjusted $R^2=0.60$, $F(2,28)=24.2$, $p<0.00001$). This increase was significant ($F(1,28)=7.26$, $p<0.05$). As with the previous analysis, this variable contributes to the model only when Movement type is taken into account.

Both Movement type and Distance account for a large proportion of response time variability. In a further analyses, response times to D3 trials were excluded and the effect of distance was used as a predictor just for FC trials. It was found that the linear effect of Distance accounted for only 2% of response time
variability which indicates that the variability accounted by Distance in the initial analysis was mainly due to the difference between the D3 and D4 trials.

In order to test whether Movement time is a better predictor of response times than the linear effect of Distance, a t-test was applied to the correlation coefficients between Distance and response times and between Movement time and response times. As the two coefficients are not independent, the t-test was calculated with the formula devised by Williams (1959; see also Howell, 1987, p. 243). The difference between the two correlation coefficients just failed to reach significance (t(26)=1.49, p<0.1). A similar t-test was also calculated to compare the correlation coefficient between response times and Movement type and the multiple correlation coefficient between response times and the predicted response time scores from the model that included both the linear and quadratic trends of Distance. The difference between the two correlations was not significant (p<0.5).

The fact that Movement type accounts for the same proportion of variance as both the linear and quadratic effects of Distance suggests that the simple coding of Movement type provides an alternative way to control for the sequential effects that are present in a serial response time task. For example, it is easier to match two sequences on SOB and FC movements, than to match two sequences on the distance of each individual trial.

Finally, in order to examine the higher order sequential effects suggested by the slow response time to the D9 trial that followed a series of D3 trials, a further analysis was performed. Median response times for FC trials that followed either two successive FC trials or two successive SOB trials were calculated. Similarly, median response times for SOB trials that either followed two SOB or
Movement Repetition Effect

![Graph showing movement repetition effect](image)

**Figure 5.5.** Mean Response times of FC and SOB Movements when the two preceding trials were of the same or different movement type.

two FC trials were calculated. These scores were entered into a two (Movement type: SOB vs FC) X two (Same vs Different movements on previous 2 trials) analysis of variance with repeated measures on both factors. Means are presented in Figure 5.5. Both the effect of Movement type ($F(1,27)=11.99, MSe=372, p<0.002$) and the effect of Same/Different preceding movements ($F(1,27)=10.47, MSe=155, p<0.003$) were significant. Response times were faster when the two previous movements were the same as the one in the current trial. This effect was similar for the two movement types as the interaction between the two variables was not significant.
5.2.2.2. Sequence with Short Distance Trials

The sequential pattern of response times for the sequence that included repetitions and FOB movements is presented in Figure 5.6 while Figure 5.7 shows a plot of response times against Distance. Inspection of the plot reveals that a linear trend describes response times up to Distance 6, while response times for the whole set of distances appear be better explained by a quadratic trend.

A hierarchical multiple regression was used to investigate the sources of the response time variability. Response times were initially regressed on Distance. This was found to account for 33% of their variability (Adjusted $R^2=0.31$, $F(1,29)=14.7$, $p<0.00001$). When the quadratic effect of Distance was entered into the model there was no reliable increase in the explained response time variability. Similarly, response time on the previous trial was not found to contribute to the model (accounted variability increase = 1%). When just the FC trials were predicted from distance the variability accounted by the model was not significant ($R^2=20%$).

The effect of movement type was also examined by comparing Repetitions, First order backward movements (FOB), SOB and FC trials. In this sequence, SOB and FC trials required that the stimuli that appeared on the three preceding trials were different from each other. For example the last trial of the sub-sequence CAABBC and other similar trials were excluded.

As the remaining 20 data points were too few to carry out a multiple regression analysis, median response times for each movement type were calculated for
Figure 5.6. Median response times for the 32 serial position of the Long Distance Sequence

Figure 5.7. Plot of Response times against Distance.
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Figure 5.8. Mean response times for Full Coverage, SO-Backward, FO-Backward and Repetition trials.

Movement Type

<table>
<thead>
<tr>
<th>Movement Type</th>
<th>Mean Response Time (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Coverage</td>
<td>380</td>
</tr>
<tr>
<td>SO-Backward</td>
<td>400</td>
</tr>
<tr>
<td>FO-Backward</td>
<td>440</td>
</tr>
<tr>
<td>Repetition</td>
<td>460</td>
</tr>
</tbody>
</table>

Each participant. Means of these medians for each type of trial are presented in Figure 5.8. A one way analysis of variance with Movement type as a repeated measures factor was carried out. The homogeneity of variance covariance assumption was violated in this analysis, and the degrees of freedom of the F test were adjusted by multiplying them by the average of the Greenhouse Geisser epsilon and Huynh Feldt epsilon (Levine, 1991). The obtained F value was still larger than the critical F value for the adjusted degrees of freedom (F(1,27)=30.99, MSe= 84.8, p<0.01).

Post hoc pairwise comparisons revealed that FC trials were significantly faster than all other types (FC vs SOB t(27)=8.84, p<0.0001, FC vs FOB t(27)=12.37, p<0.0001, FC vs Rep t(27)=4.8 p<0.0001). Also, SOB trials were significantly faster than FOB (t(27)=6.94, p<0.0001). The other comparisons did not reach the
critical probability level 0.012 needed to control the inflated type I error. However, there is clearly a facilitation effect for Repetitions that does not exceed that found for FC trials. It is likely that this pattern of response times results from a mixture of automatic and subjective expectancy influences that are both facilitatory and inhibitory.

Finally, as with the previous analysis, the difference between the correlation coefficients of Movement type and response times and of Distance and response times was not significant.

5.2.2.3. Comparison of Sequences

One question that this experiment addressed concerned the effect of the presence of short distance trials on the mean response time to a sequence of stimuli. Therefore, median response times were calculated for every 32 trials. Means of these medians were calculated for each block and were entered into a two (Group: Long Distances vs Short Distances) X two (Block: 1 vs 2) analysis of variance with repeated measures on the last factor. The two groups did not differ and practice with the task did not decrease response times.

Although FOB trials were found to be slower than SOB and FC trials and Repetitions slower than FC trials, this did not slow the mean response time to the sequence that included FOB trials and repetitions. Participants who responded to the long distance sequence did not seem to use the information entailed by the absence of repetitions and FOB trials (i.e. the fact that the alternatives for the next stimulus were only two, the ones that did not appear in the two preceding trials).
A comparison of the two groups on the FC and SOB trials could provide some insights into this finding. A two (Group) X two (Movement type: FC vs SOB trials) analysis of variance with repeated measures on the last factor was carried out. Means for each Movement type for the two groups are presented in Figure 5.9. A significant Group by Movement type interaction ($F(1,54)=8.81$, $MSe= 56.1$, $p<0.004$) revealed that, although the two groups responded similarly to FC trials, the group that practised with Long Distances was slower to respond to SOB trials. Therefore, it seems that the presence of Repetitions and FOB trials leads to expectations that reduce the inhibition for the SOB trials.
5.2.3. DISCUSSION

This experiment showed that Movement type influenced response times: the full coverage trials showed faster response times than any other movement type. Furthermore, a continuous run of trials with the same Movement type biased expectations towards the continuation of the run with the same movement.

However, the presence of repetitions and first order backward movements in the sequence did not lead to a higher overall mean response time during the initial stages of practice. This may be explained by the fact that response times to second-order-backward movements showed a speed-up in the short distance sequence in comparison to the long-distance sequence. This in turn suggests that the presence of repetitions or first-order backward movements reduces the inhibitory effect that slows responses to second-order backward movements. However, it is not clear whether the different pattern of results in the short distance sequence is due to the presence of Repetitions or the presence of first-order backward movements. This was further investigated in Experiment 4.

5.3. EXPERIMENT 4

Repetitions were excluded from both sequences in this experiment. One group practised with a sequence that did not include any first order backward movements and another group practised with a sequence that included first order backward movements. Results from this experiment should have greater relevance to previous sequence learning studies, because the majority of them have excluded stimulus repetitions. Also, a non-repeating 240-trial sequence was used in order to provide a greater range for Distance than was possible
with the previous 32-trial sequence. Finally, the short-distance group responded
to exactly the same long distance sequence as the other group in the last 30 trials
of the block so that the two groups could be directly compared on exactly the
same sequence.

5.3.1. METHOD

5.3.1.1. Subjects

40 right-handed undergraduate psychology students from University College
London and Goldsmiths' College, University of London participated in the
experiment. All participants had normal or corrected to normal vision and were
randomly assigned to two groups.

5.3.1.2. Apparatus and Stimuli

The experiment was run on Personal Computers with 386 microprocessors.
Stimuli and responses were the same with those in Experiment 1.

Two 240-trial non repeating sequences were presented to the two groups. Both
sequences excluded repetitions of the same stimulus, while one of the sequences
also excluded FOB movements. The sequences were randomly generated with
the constraint that each stimulus occurred an equal number of times in every
block of 60 trials. The sequence without FOB movements included
approximately equal numbers of SOB and FC trials (127 SOB and 103 FC) while
the sequence with FOB movements included 68 FOB movements, 58 SOB
movements and 104 FC movements. The exact sequences are presented in
Appendix 7.
5.3.1.3. Procedure

The experiment was run in laboratory cubicles in University College London and Goldsmiths' College. Participants practised two blocks of 120 trials separated by an interval. Everything else in the procedure was the same with Experiment 1.

5.3.2. RESULTS

The analyses will be presented in three sections. The first section presents analyses of the group that practised a sequence that did not include FOB trials. The second section presents analyses of the group that practised with a sequence that included FOB trials. The last section presents a comparison of the two groups.

5.3.2.1. Sequence without First-Order-Backward Movements

The first five trials from each block were excluded from the analysis because they provided the sequential context for the following stimuli in the sequence. Mean response times for the remaining 230 serial positions were calculated from the scores of all participants. A plot of response times against Distance is shown in Figure 5.10. The plot reveals a clear difference between response times to distances 3 and 4 which suggests that response times are mainly influenced by the movement of the target.

A hierarchical multiple regression was used to investigate the sources of response time variability. Distance was the first variable to enter the model. It accounted for 6% of response time variability (Adj $R^2=5\%$, $F(1,228)=14.8,$
Distance effect (D>2)

Figure 5.10. Plot of response times against Distance.

p<0.0002). When the quadratic effect of distance was entered the model accounted for 14% of the variability (Adj. R²=13%, F(2,227)=18.9, p<0.0001) and this increase was significant (F(1,227)=21, p<0.01). When response time on the previous trial was entered the accounted variability increased to 22% (Adj R²=21%, F(3,226)=21.8, p<0.00001). This increase was also significant (F(1,226)=23, p<0.01). Both the quadratic effect of Distance and response time on the previous trial were reliable predictors only after the linear effect of Distance had been entered into the model. When they were the first variables to enter the model the explained variance was not reliable.

In a separate analysis, Response times were regressed on to Movement Type. The amount of variance accounted by Movement Type (SOB vs FC) was 18%
(Adj. $R^2= 18\%$, $F(1,227)=51.4$, $p<0.0001$). When response time on the previous trial was entered, the model accounted for 26% of response time variability (Adj. $R^2= 25\%$, $F(2,226)= 39.8$, $p<0.0001$) and this increase in the explained variance was significant ($F(1,226)=23.3$, $p<0.01$).

It is clear that Movement type has a significant effect on response times and accounts for a greater proportion of their variability than both the linear and quadratic effects of Distance. In order to test the difference between the correlation coefficient between response times and Movement type and the multiple correlation coefficient between response times and the predicted response time scores from the model that included both the linear and quadratic trends of Distance, a t-test for non independent $r$s (Williams, 1959; Howell, 1987, p. 243) was calculated. The difference between the two correlations was reliable ($t(223)=1.71$, $p<0.05$) which showed that in this non-repeating sequence the simple encoding of Movement type is a better predictor of response time variability than Distance.

However, it also appears that response times are slowed down in long distance trials. This was supported by the significant quadratic trend of Distance. As in the previous experiment this may be caused by a preceding run of SOB movements that biases participants towards a continuation of that run. In order to test whether response times are affected by sequences of Movement type, each trial was coded according to whether the two previous stimuli had the same Movement type as it or a different Movement type from it. This variable was then entered into the multiple regression along with the previous variables. When the two preceding movements were different from each other, trials were excluded from the analysis. Therefore the multiple regression analysis was based on the remaining 93 trials.
Movement type and response time on the previous trial were entered into the model at the first step and accounted for 26% of response time variability (Adj. $R^2=25\%$, $F(2,90)=16.3$, $F<0.0001$). However, when similarity or difference of movement type on the two previous trials was entered at step 2 and its interaction with movement type were entered at step 3, the increase in the response time variability that was thereby explained was not significant.

5.3.2.2. Sequence with First-Order-Backward Movements.

The first five trials from each block were excluded as before and median response times were calculated for the remaining 230 trials. A plot of response times against distance is presented in Figure 5.11. As can be seen in the plot, there is a clear linear trend for the D3, D4 and D5 trials while the relationship between response times and distance becomes noisy for long distances.

In a hierarchical multiple regression analysis, Distance was entered first and accounted for 3% of response time variability (Adj $R^2=2\%$, $F(1,228)=7.8$, $F<0.0056$). When the quadratic effect was entered in the next step, the model accounted for 14% of response time variability (Adj. $R^2=13\%$, $F(2,227)=19.5$, $p<0.0001$) and this increase was significant ($F(1,227)=30$, $p<0.01$). When Response time on the previous trial was entered, the model accounted for 19% of response time variability (Adj $R^2=18\%$, $F(3,226)=18.09$, $p<0.0001$) and this increase was also significant ($F(1,226)=13.1$, $p<0.01$). However, when the quadratic effect of Distance entered the model first, the explained variance (3%) was not significant, which suggests that this effect contributes to the model after the linear trend is accounted for. Also, when only D2, D3 and D4 trials were included in the analysis, Distance accounted for 11% of response time variability (Adj. $R^2=11\%$, $F(1,152)=20.6$, $p<0.0001$).
In a separate analysis, the effect of Movement type was investigated. FC trials that had an FOB movement in the preceding 3 trials were excluded from the analysis. Movement type was encoded in two dummy variables as a combination of 1, 0 and -1. The first variable tested the difference between SOB and FC trials, while the second variable tested the difference between SOB and FOB trials.

Response times were regressed on to these two variables and the model accounted for 26% of their variability (Adj $R^2=25\%$, $F(2,183)=32.5$, $p<0.0001$). Both dummy variables contributed to the model ($t=7.7$, $p<0.0001$ and $t=5.5$, $p<0.0001$ respectively). When response time on the previous trial was entered the variance that was explained increased to 29% (Adj $R^2=28\%$, $F(3,182)=25.9$) and this increase was significant ($F(1,182)=9.6$, $p<0.05$). Means of the three types of Movement are represented in Figure 5.12.
In order to compare the regression models based on Movement type and Distance, response times were regressed on Distance only for the 183 trials that were used in the Movement type analysis (this subset excluded all trials that had an FOB movement in the preceding three trials). This analysis revealed that Distance accounted for a larger proportion of variance in this subset of trials than in the analysis that included all 229 trials. The linear trend of Distance accounted for a reliable 13% of the variance (Adj. $R^2=12\%$, $F(1,184)=27.86$, $p<0.001$). The quadratic trend of Distance contributed to an additional reliable 10% of the variance ($F(1,183)=24.3$, $p<0.01$). The difference between the correlation coefficients produced by the two models in this subset of trials was not significant. However, this analysis revealed that an additional source of response time variability is the influence of FOB trials on the subsequent trials and that this influence may affect the relationship between response times and Distance.
5.3.2.3. Comparison of Sequences

A simple regression analysis was used to test whether the two groups differed on all trials. Mean response time for the group that responded to a sequence without SOB trials was 370 msec (sd: 32) while for the group that responded to SOB trials was 405 msec (sd: 35). The simple regression revealed that the difference between the two groups was reliable ($R^2=21\%$, Adj $R^2=21\%$, $F(1,458)=125, p<0.0001$).

The same analysis was repeated but only for the last 25 trials of each block that involved the same sequence for both groups. Mean response time for the long distance group was 367 msec (sd: 30) while for the short distance group 391 msec (sd: 31). Group accounted for 14% of response time variability ($F(1,98)=17.19, p<0.0001$). The way the two groups responded to Movement type (which was either SOB or FC) was also investigated. Movement type was entered into the model and the variability explained by both variables increased to 25% (Adj $R^2=23\%$, $F(2,97)=16.5, p<0.0001$). This increase was significant ($F(1,97)=13.6, p<0.01$). Finally when the interaction between Group and Movement Type was entered, the increase in the amount of the explained variability was not significant. Both groups responded to SOB and FC trials in a similar way.

5.4. GENERAL DISCUSSION

Results from both Experiment 3 and 4 have shown that response times to backward movements of the target are slower than response times to full coverage movements. It was also found that a series of trials of the same Movement type biased expectations towards a continuation of the same movement but only in Experiment 3. This finding in a way just confirms the
presence of the facilitatory effect for higher-order repetitions in the present task. For example, a series of SOB movements is produced when a series of three target locations is repeated (i.e. triplet repetition). The fact that a similar effect was not present in Experiments 1 and 2 in the previous chapter suggests that this effect requires the fast rate of stimulus presentation characteristic of the present keypressing task, so that a series of previously presented targets are still active in short term-memory. Also, the fact that the same effect was not present in Experiment 4 that involved a non repeating sequence suggests that this effect may not be present when movement repetition characteristics are variable and random.

There was also an indication that the difference between second-order backward movements and full coverage trials is affected by the presence of short distance trials in the sequence. However, the fact that a reduction in the difference between these two movements was found when the sequence involved both repetitions and FOB movements (Experiment 3) and not when it involved FOB movements only (Experiment 4) suggests that the presence of repetitions is crucial for this effect. It is possible that an expectation for repetitions reduced the inhibitory effect that slowed response times to SOB trials. Alternatively, the different pattern of results in Experiments 3 and 4 may have been caused by the higher degree of statistical structure of the sequence in Experiment 4 (i.e. the repetition of a 32-trial sequence). Participants in Experiment 3 who practised with Long Distances may have been particularly biased towards FC movements and this may have resulted in a greater inhibition of SOB movements.

Whatever the reason of the differential pattern of results in the two Experiments, both have confirmed the presence of higher order sequential
effects that cause a slow down of responses to backward movements. These sequential effects may result from a mixture of automatic facilitation and subjective expectations. It is not possible to determine their relative contribution from the present experiments. For example, slow responses to backward movements may be attributed to an automatic attentional effect of inhibition of return. The fact that there is no difference between Distance 4 and Distance 5 trials may have been due to the dissipation of this effect with time. Differences between backward and full coverage trials may alternatively be attributed to subjective expectations that are determined by the number of the stimulus-response alternatives. Participants may expect the stimulus to cover all alternative locations.

Whatever the exact process that results in these sequential effects, the crucial finding is that they are present in the Serial Response time task and may therefore influence a trial-by-trial response time comparison. For example, a comparison of a first-order-backward movement from the repeating sequence (that is associated with slow response times) with a full coverage movement from a control sequence (that is associated with fast response times) may fail to reveal a reliable response time difference because the measure of learning was contaminated by the presence of sequential effects. Also, a comparison of a practised full coverage trial with an unpractised backward trial may reveal a reliable difference that was due to the movement type effect. As mentioned in the introduction this directly applies to the trial-by-trial comparison carried out by Reed and Johnson in order to confirm that all transitions in the SOC sequence had been learned. Before valid conclusions are drawn from this comparison it has to be ensured that either sequential effects were not present in the task or that they have been controlled for.
Sequential effects may also invalidate conclusions on how a sequence is encoded or organised. For example, Perruchet and Amorim (1992) performed a trial-by-trial response time comparison which was based on the difference between response times on each one of the serial positions of a repeating sequence and mean response times of corresponding stimuli in a pseudo-random sequence. They reported that only a subset of these comparisons reached a significance level: when response times to the sequence ABCBC were examined, reaction to stimulus C was faster in the third rather than the fifth serial position while reaction to stimulus B was faster in the second rather than the fourth serial position. According to Perruchet and Amorim (1992) this indicated that participants learned the three element chunk ABC or CAB. Cohen and Curran (1993) supported Perruchet and Amorim's claim by pointing out that both of these chunks are anchored by the unique element A in the sequence.

However, the experiments reported here indicate that the differences between the serial positions could be attributed to the presence of first order backward movements at serial positions 4 and 5. As we have seen, these are likely to elicit slower responses. Although the explanations offered by Perruchet and Amorim (1992) and Cohen and Curran (1993) may still be valid, they would have a greater support if higher order sequential effects were eliminated before the comparisons were made.

5.5. Conclusion

Experiments 3 and 4 demonstrated that response times are faster to full coverage movements and slower to first- or second-order backward movements of the target. This difference, which may be caused either by subjective
expectations or by the attentional mechanism of inhibition of return, is likely to contaminate the trial-by-trial response time comparisons that have been used as an index of learning in previous sequence learning experiments. The present findings show that this index will be valid if these higher order sequential effect are controlled for.
CHAPTER

6

Associative Learning Versus Chunking
6.1. INTRODUCTION

According to Cohen, Ivry and Keele (1990) two different learning mechanisms may be in operation in the incidental sequence learning task. One mechanism learns simple associations between adjacent events. This mechanism is employed when every event in the sequence is uniquely associated with the following event and prediction of the next target may be unambiguously determined by the current target. A second learning mechanism forms a hierarchical representation of the sequence by parsing it into sub-parts. This mechanism is required for learning of ambiguous sequences in which each event may be followed by a number of different events and, therefore, predictions have to be based on a series of preceding trials.

The main experimental finding that supported the postulation of these two learning mechanisms was that attentional distraction differentially affected learning of sequences with and sequences without unique transitions: while it just slowed down learning of the former it completely eliminated learning of the latter (Nissen & Bullemer, 1987; Cohen et al., 1990). According to Cohen et al. (1990) attentional distraction is more likely to block the employment of a hierarchical mechanism rather than an associative mechanism.

A connectionist simulation by Keele and Jennings (1992) provided some insights into the nature of the attentionally demanding mechanism that underlies learning of ambiguous sequences. Keele and Jennings (1992) have used the sequential network (see chapter 3) to simulate sequence learning and reported that learning of ambiguous sequences was facilitated when the state of the network was set to zero at certain serial positions. They argued that this manipulation resulted in an arbitrary division of the sequence into sub-parts; the "zero" states served as the boundaries that defined the sub-parts. Another
manipulation that resulted in a facilitation of learning of ambiguous sequences was based on providing different arbitrary representations for sub-parts of the sequence. According to Keele and Jennings (1992), both of the above manipulations are likely to require the employment of attention.

However, recent studies have shown that learning of ambiguous sequences can take place even under conditions of attentional distraction (Reed and Johnson, 1994; Shanks and Johnson 1995). Although attentional distraction delays the development of a performance speed-up, it does not completely eliminate learning of ambiguous sequences. This suggests either that a parsing process is not necessary for learning ambiguous sequences, or that a parsing process still takes place under attentional distraction.

The first alternative was favoured by Cleeremans (1993). Cleeremans (1993) simulated learning of an ambiguous sequence with a simple recurrent network (see chapter 3). This network initially learns associations between two successive events and gradually becomes sensitive to a larger temporal window of events. Cleeremans (1993) showed that the effect of attentional distraction on learning of ambiguous sequences was successfully modelled when noise was added to the connection weights of the network. Therefore, he concluded that the parsing process proposed by Keele and Jennings (1992) was not strictly necessary for learning of ambiguous sequences.

On the other hand, Perruchet and Amorim (1992) supported the second alternative, namely that learning based on parsing may occur even under attentional distraction. They have shown that reliable knowledge of sub-parts of an ambiguous sequence may develop even at the initial stages of practice under conditions of attentional distraction. However, Perruchet and Amorim (1992) have also found that the acquired sub-sequence knowledge was expressed in a
recognition and a free-generation task but not in the response time task. This suggested that the development of conscious sub-sequence knowledge may even precede a response time speed-up. Perruchet and Amorim (1992) favoured a memory-based model and suggested that response time speed-up is based on memory of some psychologically relevant chunks of the sequence (see also Perruchet, 1994).

One problem with the memory-based model proposed by Perruchet (1994) is that it lacks a detailed description of the process that determines which chunks will be learned (Cleeremans, 1994). It is not clear, for example, how a sequence is divided into chunks, or which aspect of a chunk makes it psychologically relevant and therefore more likely to be acquired. A detailed description of this process, however, could be provided by the Competitive Chunking model, a computational model that was developed by Servan-Schneider and Anderson (1990) for artificial grammar learning.

The main underlying principle of Competitive Chunking is that both memory and perception are based on a process of chunk formation. Chunks retrieved from memory are used to perceive environmental stimuli. This perception process is based on a constant competition between different chunks. Which chunk will eventually win the competition is determined by a strength parameter which is a composite measure of how often and how recently a chunk has been used in the past. A similar strength accumulation process underlies the formation of new chunks. The finding that participants in Experiment 2 learned instances of repeated triplets may be explained by the strength accumulation property of the CC model. Repeated triplets are more likely to stand out in the perception process as they accumulate strength with every immediate repetition. How plausible is this chunking process, however, in learning of the 12-trial ambiguous sequence introduced by Reed and Johnson? (1994; see
This sequence was generated with the constraint that it included an equal number of stimulus occurrences and all possible stimulus transitions. Therefore, all transitions between the four alternative stimuli occur once. This results in the exclusion of any repetitions of small chunks that may facilitate a chunking process. Furthermore, the fact that, in this sequence, each stimulus has a unique association with the two previous stimuli appears to favour the employment of an associative learning mechanism. This mechanism would just have to store the associations between a pair of successive events and the event that follows. Therefore, anticipation of subsequent events would be based on a simultaneous representation of three rather than two stimuli.

This associative mechanism was favoured by Reed and Johnson (1994). In order to test whether the response time speed-up during practice was caused by triplet knowledge, they compared response times of all stimuli in the sequence with response times to those in a control sequence. They found that all comparisons showed reliable differences which, as they suggested, confirmed that participants had acquired all possible triplets in the sequence. Also, when Reed and Johnson administered tests for conscious sequence knowledge, they found that participants could not generate the last stimulus of a triplet or recognise triplets from the repeating sequence. This indicated that the triplet knowledge that caused the response time speed-up was unconscious.

However, it may be the case that participants' response time speed-up was not caused by learning of all possible triplets. As was suggested in the previous chapter, the trial-by-trial comparison carried out by Reed and Johnson may have been invalidated by the presence of sequential effects. It is likely that at least some of the response time comparisons reached significance because a full
coverage movement from the practised sequence was compared with a backward movement from the transfer sequence.

Furthermore, even if Reed and Johnson's response time comparisons were valid, it may still be the case that participants had not learned all possible triplets. Reliable differences for all serial-positions were used as evidence for the employment of an associative mechanism. However, these are also compatible with a chunking process. If such a process was in operation, then at the beginning of practice participants' knowledge units may have had the form of a small number of sub-chunks that were longer than three trials. According to the Competitive Chunking model, chunking takes place even at later stages of learning as elementary chunks form higher-order complex chunks (see also Newell and Rosenbloom, 1981). Extensive practice with a sequence may, therefore, result in the organisation of the initially learned chunks into larger hierarchical memory representations. In this case one lower order chunk may serve as the cue for the prediction of the initial stimuli of the chunk that follows. This will eventually result in fast response times to all serial positions of sequence. However, in this case participants' knowledge does not necessarily consist of all possible triplets in the sequence.

Therefore, both the associative mechanism and the chunking mechanism predict that a reliable speed-up should be found for all stimuli in the sequence after extensive practice. On the other hand the two mechanisms lead to different predictions about the response time pattern for the serial positions of the sequence at the initial stages of learning. The associative mechanism predicts that learning of all associations would occur at a similar rate, and therefore all serial positions should show a similar response time speed-up. On the other hand, a memory-based chunking process predicts that a response time speed-up will only be evident for the last stimuli of the learned sub-chunks and therefore
only for a subset of the serial positions.

One study that examined the representation of sequence knowledge at the initial stages of learning was carried out by Perruchet and Amorim (1992). This study has provided evidence in favour of the memory-based chunking process. However, as was pointed out by Reed and Johnson (1994), the sequence used by Perruchet was shorter and therefore easier to learn than the 12-trial SOC sequence they employed. The fact that the structure of their sequence may have facilitated the development of conscious sequence knowledge of chunks was also supported by Perruchet and Amorim's (1992) finding that reliable conscious knowledge of chunks developed even before a response time speed-up was evident. Is learning of chunks also responsible for the response time found for the longer 12-trial ambiguous sequence used by Reed and Johnson (1994)? Experiment 5 was designed to answer this question.

6.2. EXPERIMENT 5

In the present experiment the sequence used was similar to the 12-trial SOC sequence used by Reed and Johnson (1994). Participants in a Repeating group practised with 120-trial blocks that comprised ten repetitions of the 12-trial sequence. Participants in a Control group practised with a 120-trial sequence that had the same simple frequency information (as described by Reed and Johnson, 1994) as the repeating sequence as well as similar proportions of full coverage, first-order and second-order backward movements. Furthermore, in order to eliminate the influence of long term sequential effects from the trial-by-trial comparisons between the groups, the control sequence included two successive presentations of the repeating sequence so that the two groups could be compared on exactly the same stimulus sequence.
The amount of practice required for the emergence of sequence learning was roughly estimated on the basis of three previous studies. First, Reed and Johnson (1994) found reliable learning of the same sequence after 136 sequence repetitions, but this was under conditions of divided attention. The present experiment aimed to examine participants' knowledge of the sequence in a transfer test at the initial stages of learning under conditions of full attentional availability so the number of sequence repetitions had to be smaller.

Second, Perruchet and Amorim (1992), who also tested for conscious knowledge in the initial stages of learning, reported that a reliable response time improvement for a hybrid 10-trial sequence was evident after 10 repetitions. However, as their hybrid sequence is likely to be easier to learn than the present ambiguous sequence, the number of sequence presentations in the present experiment should be larger.

Finally, Willingham, Greeley and Bardone (1993) reported that learning of a 16-trial sequence under conditions of full attentional availability was evident after 25 sequence repetitions. Apart from the difference between the present sequence and the type of sequence used in Willingham et al.'s study, the present study also used a Control group that had some exposure to the Repeating sequence. Therefore, reliable response time differences between the two groups should be evident after a larger amount of practice. On the basis of these studies it was estimated that 50 sequence repetitions would be sufficient for the development of sequence learning in the present experiment. In addition, both groups were given initial training with the response time task using a non-repeating sequence. This ensured that the response time reduction during the five blocks that involved the sequence repetition would be a pure measure of sequence learning for the Repeating group and simple frequency information learning for the Control group.
At the end of practice participants were required to perform the free-generation task introduced by Perruchet and Amorim (1992). There is some disagreement in the literature on whether performance on this task is contaminated by unconscious sequence knowledge (Cohen & Curran, 1993; Willingham, Greeley & Bardone, 1993). However, it was considered to be the most appropriate task for the purposes of the present experiment as it allows estimation of generation scores for each serial position. This, in turn, allows estimation of measures of association between response times and generation scores for each serial position.

6.2.1. METHOD

6.2.1.1. Subjects

34 undergraduate psychology students from University College London and Goldsmiths' College served as subjects. They were paid £2 for their participation. They were 14 men and 25 women and their mean age was 21.3 years. All participants had normal or corrected to normal vision and were naive about the purpose of the experiment. They were asked to volunteer to participate in an experiment that measured response time. They were randomly allocated to a Repeating and to a Control group.

6.2.1.2. Stimulus Conditions

The 12-trial sequence that was repeated for the Repeating group contained three presentations of each stimulus location and all possible stimulus transitions. The exact sequence and the target movements associated with each serial position are presented in Figure 6.1.
Figure 6.1. Target locations for the 12-trial Repeating sequence (uppercase characters) and Movement type of the target on each trial (lowercase characters, fc: full coverage, sob: second-order backward, fob: first-order backward).

The 120-trial sequence that was repeated for the Control group contained two instances of the Repeating sequence shown in Figure 6.1 and eight new 12-trial sequences that had the same event frequency information as the Repeating sequence. These sequences also had exactly the same succession of higher order target movements as the Repeating sequence. Serial positions /1, 3, 6,7,8,10,11/ in each sequence were FC trials, serial positions /2,4,9,12/ in each sequence were SO-backward trials and serial position 5 in each sequence was an FO-backward trial. Four of these new sequences were presented at the beginning and the other four at the end of 120 trial block. The middle 24 trials of the block consisted of the two presentations of the Repeating sequence. This allowed a direct comparison of the two groups on exactly the same sequence on the middle 24 trials of each block (Appendix 8).

6.2.1.3. Procedure

The experiment was run on Dell IBM compatible PCs equipped with 33 cm colour monitors and lasted approximately 30 minutes. All participants were tested individually in experimental cubicles. Instructions about the task were presented on the computer screen. A cross divided the screen into four equal quadrants and participants were presented with the stimuli which were white circles appearing in one of the four screen quadrants. They were instructed to use the keys 4, 5, 1, 2, of the numeric keypad for their response. These keys corresponded spatially to the screen quadrants. They were asked to use their
right index finger for the two left keys and the right middle finger for the two right keys and to respond as fast as possible when a circle appeared in one of the quadrants by pressing the key corresponding to the quadrant.

The response time task started with two training blocks of 120-trials that comprised a non-repeating sequence. This sequence was generated with the restriction that all possible target locations and all possible transitions had equal frequencies. The training blocks were followed by five 120-trial Practice blocks using the experimental material described above. At the end of each block participants were given feedback on their mean response time and their total number of errors. After each block, they had to wait at least 10 sec before they could initiate the next block by pressing a key on the keyboard.

After the end of the fifth Practice block participants were given new instructions about the generation task. They were asked to generate a series of 100 trials that resembled the series of trials they had encountered during the previous response time task. They were told that they were not expected to reproduce an exact series of 100 trials but to generate at least sub-series of trials they had seen before. They were instructed to use the same fingers and the same response keys they used in the previous response time task.

The first trial in the generation task started with a circle appearing in the upper left quadrant of the screen. Participants were asked to press the key that corresponded to the location of the next target. When participants pressed a key, a circle appeared on the screen in the location matching the location of the key. This circle remained on the screen until participants pressed a key again. At the end of the experiment subjects were debriefed and thanked for their participation.
6.2.2. RESULTS

6.2.2.1. Response Time Task.

Mean error rates ranged from 2% to 4% and no differences between the groups emerged on any of the blocks. Consequently only results from the response time analysis will be reported.

Median response times of correct responses were calculated for every 12 trials. Means of the 10 medians from each one of the five blocks were submitted to a two (Group: Repeating vs Control) X five (Practice: block 1 to 5) analysis of variance with repeated measures on the last factor. Polynomial contrasts were applied to the Practice factor to test the linear and quadratic trends. Means for the two groups are presented in Table 6.1 and are represented graphically in Figure 6.2.

Groups did not differ overall as there was no significant main effect of Group. Performance of both groups improved with practice. This was supported by a significant main effect of Practice (F(4,128)=20.06, MSe= 178, p<0.001) and a significant linear trend for Practice (F(1,32)=52.15, MSe= 260, p<0.001). The data also suggested that response times of the repeating group tended to improve with a faster rate.

The Group by Practice interaction was marginally significant (F(4,128)=2.20, MSe= 178, p<0.072) and the interaction of Group by the linear trend of Practice was significant (F(1,32)=6, MSe= 260, p<0.02). Simple effects analysis showed that the Control group was substantially slower on the fourth (F(1,32)= 4.86, MSe= 716 p<0.035) and the fifth block (F(1,32)= 6.41, MSe= 787, p<0.016).
In order to compare the two groups on each one of the 12 serial positions (SP) of the repeating sequence, average response times for each one of the stimuli in the middle two repeating sequences of the last block were calculated. All responses that were larger than 1000 msec were excluded and substituted by the corresponding response time of the other sequence. Means of the two groups are presented in Table 6.2 while Figure 6.3 presents means and positive

**Table 6.1.** Mean response times (M) and standard deviations (SD) for the five blocks of trials for the Repeating and Control group.

<table>
<thead>
<tr>
<th>Group</th>
<th>Practice block</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeating</td>
<td>M</td>
<td>359</td>
<td>346</td>
<td>343</td>
<td>332</td>
<td>324</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>23</td>
<td>18</td>
<td>23</td>
<td>21</td>
<td>23</td>
</tr>
<tr>
<td>Control</td>
<td>M</td>
<td>367</td>
<td>357</td>
<td>358</td>
<td>352</td>
<td>349</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>40</td>
<td>34</td>
<td>35</td>
<td>30</td>
<td>32</td>
</tr>
</tbody>
</table>
differences between the two groups.

There is a considerable response time variability across the 12 serial positions and a large part of it may be attributed to the differences between FC, SOB and FOB trials. The FOB trial at serial position 5 elicits the slowest responses, and is followed by SOB trials at Serial positions 2, 4, 9 and 12. FC trials elicit fast responses except from serial position 6 that immediately follows the first-order backward movement CAC. There is also some variability in the differences between the two groups on the 12-Serial positions with the Repeating group being noticeably faster at serial positions 11 and 3.

Table 6.2. Mean response times and standard deviations (in brackets) for the 12 Serial positions of the two middle repeating sequences of block 5 for the Repeating and Control groups.

<table>
<thead>
<tr>
<th>Serial</th>
<th>Spatial Target</th>
<th>Group</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td></td>
<td>Repeating</td>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>324 (74)</td>
<td>352 (63)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>356 (46)</td>
<td>358 (63)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>290 (52)</td>
<td>343 (62)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>374 (62)</td>
<td>381 (71)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>407 (51)</td>
<td>428 (79)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>374 (65)</td>
<td>413 (62)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>293 (50)</td>
<td>325 (73)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>320 (64)</td>
<td>344 (67)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>372 (87)</td>
<td>391 (69)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>325 (72)</td>
<td>332 (100)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>266 (56)</td>
<td>336 (68)</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>374 (66)</td>
<td>390 (77)</td>
<td></td>
</tr>
</tbody>
</table>
Figure 6.3. Average response times for each serial position of the two middle repeating sequences of the last block. Bars represent the difference between the two groups.

A two (Group: Repeating vs Control) X twelve (Serial Position: 1 to 12) analysis of variance with repeated measures on the last factor revealed that the two groups significantly differed on the middle repeating sequences ($F(1,30)=4.97$, $MSe=13653$, $p<0.033$). Response times were affected by the serial position as indicated by a significant serial position main effect ($F(11,330)=11.68$, $MSe=3814$, $p<0.001$). However, the two groups responded similarly to the twelve serial positions as the Group by Serial Position interaction was not significant.

Simple effects analyses were also carried out on each one of the 12 serial positions. The family wise error rate for all comparisons was set to 0.1 and therefore the pairwise error rate for each comparison was set to 0.008. The analyses revealed that the groups significantly differed on Serial Position 11.
Figure 6.4. Stimulus "Movements" that end on Serial Positions 11 and 3 (s: start, e: end).

(F(1,30)= 10.02, MSe= 3934, p<0.002). However, group differences exceeded the 0.05 probability level on Serial position 3 (F(1,30)= 6.64, MSe= 3329, p<0.022). What is characteristic of serial position 11 (SP11) is that it is the end of a run of all possible stimulus locations and that the target moves through the two diagonals (Figure 6.4). A similar "diagonal run" ends in SP3.

6.2.2.2. Free Generation Task.

Table 6.3 shows the totals, means and standard deviations of the number of generations of all the possible 3-, 4-, 5- and 6-trial sub-sequences found in the repeating sequence. The Repeating Group consistently generated more repeating sub-sequences, but the difference between the groups did not reach statistical significance.

In order to test whether participants learned parts of the Repeating Sequence, the two groups were compared on each one of the 3-, 4-, 5- and 6-trial individual sub-sequences of the repeating sequence. While almost all participants from both groups generated the 3- and 4-trial sub-sequences at least once, substantially fewer participants generated the 5- and 6-trial sub-
sequences at least once which resulted in markedly skewed distributions of total number of generations. Consequently, t-tests on the total number of generated sub-sequences were used only for the 3-trial and the 4-trial sub-sequences that had been generated by at least 9 participants from each group. The chi-square test or the Fisher's exact test on the number of participants from each group who generated at least one sub-sequence was used for the rest of the 4-, and all 5- and 6-trial sub-sequences.

Table 6.4 shows the total number of generations for each group and for each sub-sequence that end on the 12 serial positions of the repeating sequence. The Control group outperformed the Repeating group on generations of the 3-trial sequence ABC at SP3 and the 5-trial sub-sequence ACDBA at SP8 (t(24)=-2.29, p<0.031 and chi = 5.84, p<0.01 respectively). The 4-trial sub-sequence DCBD at SP12 (Fisher's exact p<0.058), and the 5-trial sub-sequence DCBDA at SP1 was generated by a greater number of Repeating group participants (Fisher's exact p< 0.051). The Repeating group generated more 4-trial sub-sequences ADCB that ended in serial position 11 but the difference between the groups did not

<table>
<thead>
<tr>
<th>Sequence length</th>
<th>Group</th>
<th>Total</th>
<th>Mean(SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-trial</td>
<td>R</td>
<td>668</td>
<td>39.2 (8)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>647</td>
<td>38 (7.75)</td>
</tr>
<tr>
<td>4-trial</td>
<td>R</td>
<td>311</td>
<td>18.2 (7.5)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>270</td>
<td>15.8 (5.4)</td>
</tr>
<tr>
<td>5-trial</td>
<td>R</td>
<td>148</td>
<td>8.7 (4.9)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>113</td>
<td>6.6(3.1)</td>
</tr>
<tr>
<td>6-trial</td>
<td>R</td>
<td>66</td>
<td>3.8 (3.7)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>37</td>
<td>2.1 (2.2)</td>
</tr>
</tbody>
</table>
Table 6.4. Mean number of generated 3-, 4-, 5-, and 6-trial sub-sequences that end on the 12 serial positions of the repeating sequence, for the Repeating (R) and Control (C) groups (in parentheses: no of subjects who generated the sub-sequence at least once).

<table>
<thead>
<tr>
<th>Last trial</th>
<th>Serial position</th>
<th>Spatial location</th>
<th>Group</th>
<th>Length of sequences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>A</td>
<td>R</td>
<td>3.3 (16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>2.5 (16)</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>B</td>
<td>R</td>
<td>2.7 (17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>3.5 (16)</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>C</td>
<td>R</td>
<td>2.4 (17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>3.8 (16)</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>A</td>
<td>R</td>
<td>2.9 (16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>2.9 (16)</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>C</td>
<td>R</td>
<td>2.7 (10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>1.5 (13)</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>D</td>
<td>R</td>
<td>3.1 (16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>3.1 (16)</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>B</td>
<td>R</td>
<td>3.9 (16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>4.8 (17)</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>A</td>
<td>R</td>
<td>4.5 (17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>5.0 (17)</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>D</td>
<td>R</td>
<td>4.8 (16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>4.1 (17)</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>C</td>
<td>R</td>
<td>3.9 (17)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>2.7 (15)</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>B</td>
<td>R</td>
<td>4.0 (16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>2.8 (16)</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>D</td>
<td>R</td>
<td>3.4 (15)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td>2.3 (15)</td>
</tr>
</tbody>
</table>
reach statistical significance (t(32)=1.83, p<0.076).

It appears that there is no correspondence between the response times and number of sub-sequence generations. Repeating group participants outperform the Control group only for serial positions 1 and 12. However, due to the large number of comparisons performed, two reliable differences could be expected just by chance.

A similar picture emerged when response times were correlated with number of generated sub-sequences. Mean response times for the last block and response time differences between blocks were correlated with total number of generations of 3-, 4-, 5-, or 6-trial sub-sequences. All correlations were unreliable and ranged from 0.01 to 0.035. Response times on each one of the Serial Positions were also correlated with the generated 3-, 4-, 5- or 6-trial sub-sequences that ended on each one of the serial positions. The highest correlations found were -0.57 and -0.50 for the response times to SP1 and SP12 and the 3-trial generated sub-sequences that ended on these serial positions. Only the first one reached significance (p<0.01). All other correlations were non-significant and ranged from 0.01 to -0.37. However, as with the group comparisons described in the previous analysis, given the large number tests carried out one reliable effect is to be expected by chance.

### 6.2.2.3. Free Generation and Response Times

The lack of correspondence of the results from the response time task and the generation task suggests that there is a dissociation of the knowledge expressed in the two types of tests. However, it may be the case that this finding is due to the different sensitivity of the two tasks to the acquired sequence knowledge. If there is no correspondence between the two tasks then
it should be possible to show that at least a few participants that did not express any knowledge in the generation task expressed reliable knowledge in the response time task. In order to test this, the Repeating group was divided into a sub-group of participants who expressed substantial sequence knowledge in the free generation task and a sub-group of participants who did not. Similar divisions have been employed in previous SRT studies (Willingham et al. 1989; Willingham et al. 1993) with the purpose of testing whether the knowledge that develops in the response time task is unconscious. Evidence for unconscious learning is taken to be present if it is shown that participants who express no knowledge of the sequence in the generation task show reliable learning in the response time task.

In order to test the reliability of the above method of testing dissociations between unconscious and conscious knowledge as well as to attain some insight into the length of the sub-sequences that were learned, a number of divisions on the basis of different sub-sequence lengths were carried out. These divisions were based on the total number of generated sub-sequences ending on all serial positions of the sequence and on the number of generations of sub-sequences that ended on the serial positions that were associated with fast response times (SP11 and SP3). These two types of divisions will be presented in separate sections.

6.2.2.3.1. Group Division on the Basis of Total Generation Scores.

Four different divisions were initially made on the basis of the scores on the total number of generations of sub-sequences of different lengths. The cut off point was the mean plus one standard deviation of the Control group on each one of these measures. The resulting sub-groups were compared with the Control group on response times on the last block of trials and the response
time difference between the last block and the first block of practice. Table 6.5 presents the results of the four different divisions of the Repeating group.

For both measures, the divisions on the basis of the 3-, 4- and 6-trial sub-sequences resulted in sub-groups with similar scores. Furthermore, differences between the Repeating sub-group that expressed substantial sequence knowledge in the generation task (R-K) and the Control group were not reliable. On the other hand, the Repeating sub-group that did not express substantial sequence knowledge in the generation task (R-NK) group significantly differed from the Control group on block 5 response times ($t(28)=2.33$, $p<0.027$, $t(26)=2.08$, $p<0.048$ and $t(28)=2.33$, $p<0.027$ for the 3-, 4-, and 6-trial sub-sequence division respectively).

Table 6.5. Mean response times on block 5 and mean difference response times between block 5 and block 1 that resulted from the 4 divisions on the basis of the total numbers of 3-, 4-, 5- and 6-trial generated sub-sequences. The asterisk denotes that the comparison with the Control group was significant (in parentheses: number of participants in each group and SD for response time scores).

<table>
<thead>
<tr>
<th>Division on sub-sequence length</th>
<th>Group</th>
<th>Mean RT on Block 5</th>
<th>Difference RT Block 5- Block 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-trial</td>
<td>R-K (4)</td>
<td>324 (30)</td>
<td>39.4 (19)</td>
</tr>
<tr>
<td></td>
<td>R-NK (13)</td>
<td>324 (21) *</td>
<td>34.0 (21)</td>
</tr>
<tr>
<td>4-trial</td>
<td>R-K (6)</td>
<td>323 (23)</td>
<td>39.4 (22)</td>
</tr>
<tr>
<td></td>
<td>R-NK (11)</td>
<td>325 (23)*</td>
<td>32.9 (19)</td>
</tr>
<tr>
<td>5-trial</td>
<td>R-K (5)</td>
<td>316 (19)*</td>
<td>41.5 (24)</td>
</tr>
<tr>
<td></td>
<td>R-NK (12)</td>
<td>328 (24)</td>
<td>32.0 (19)</td>
</tr>
<tr>
<td>6-trial</td>
<td>R-K (4)</td>
<td>324 (30)</td>
<td>33.0 (20)</td>
</tr>
<tr>
<td></td>
<td>R-NK (13)</td>
<td>324 (21)*</td>
<td>35.0 (21)</td>
</tr>
<tr>
<td></td>
<td>C (17)</td>
<td>349 (32)</td>
<td>18.0 (24)</td>
</tr>
</tbody>
</table>
In contrast, the division on the basis of the 5-trial sub-sequences resulted in a R-K group that was faster than the Control group \((t(20)=-2.11, p<0.048)\) on response times in the final block. However, when the R-K group from this division was compared to the Control group on all blocks of trials, the interaction between group and practice failed to reach significance. Furthermore, differences between the R-NK group and the Control group just failed to reach significance on the last practice block \((p<0.06)\) and were significant for the response time comparisons on Serial positions 3 and 11. This suggests either that participants in the R-NK group show some degree of unconscious learning or that the division on the basis of total generation scores may have allowed some participants with considerable knowledge of a few sub-parts of the sequence to be allocated in the R-NK group. The second alternative will be examined in the following section.

What this pattern of results demonstrates, however, is that the establishment of the length of sub-sequences that are learned in the response time task is necessary before divisions into groups with and without explicit knowledge are carried out. Divisions on the basis of different sub-sequence lengths may lead to different conclusions about whether the two tests tap the same or different types of knowledge. The results also suggest that knowledge of 5-trial sub-sequences may be crucial for the performance speed-up in the response time task.

### 6.2.2.3.2. Group Division on the Basis of Sub-sequence Knowledge

Another division of the repeating group was carried out on the basis of the generations of the parts of the sequence that ended on serial positions 3 and 11 which showed the greater response time differences. The division was carried out 4 times, separately on the basis of the generated 3-, 4-, 5-, and 6-trial sub-
sequences. The cut-off point was the mean plus one standard deviation of the control group on all measures. Participants who scored less than the cut-off point on generated sub-sequences of the same length that ended on SP3 and SP11 were allocated to the No-Knowledge Repeating sub-group. The sub-groups that resulted from the four different divisions were compared to the Control group on response times in the last block of trials and difference scores between the last and the first block of trials. Results from the comparisons are presented in Table 6.6.

The divisions of the repeating group on the basis of the 3-trial and 6-trial sub-sequences resulted in sub-groups that had almost the same response times on the last practice block and produced a significant difference between the R-NK

<table>
<thead>
<tr>
<th>Sub-sequence length</th>
<th>Group</th>
<th>Mean RT on Block 5</th>
<th>Difference RT Block 5- Block 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-trial</td>
<td>R-K</td>
<td>327 (28)</td>
<td>36 (18)</td>
</tr>
<tr>
<td></td>
<td>R-NK</td>
<td>323 (21) *</td>
<td>34 (21)</td>
</tr>
<tr>
<td>4-trial</td>
<td>R-K</td>
<td>315 (27) *</td>
<td>42 (19) *</td>
</tr>
<tr>
<td></td>
<td>R-NK</td>
<td>334 (12)</td>
<td>27 (19)</td>
</tr>
<tr>
<td>5-trial</td>
<td>R-K</td>
<td>314 (28) *</td>
<td>47 (21) *</td>
</tr>
<tr>
<td></td>
<td>R-NK</td>
<td>333 (12)</td>
<td>24 (11)</td>
</tr>
<tr>
<td>6-trial</td>
<td>R-K</td>
<td>324 (37)</td>
<td>37 (23)</td>
</tr>
<tr>
<td></td>
<td>R-NK</td>
<td>324 (31) *</td>
<td>34 (20)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>349 (32)</td>
<td>18 (24)</td>
</tr>
</tbody>
</table>
group and the Control group. However, the two sub-groups that resulted from the division on the basis of the 4-trial and 5-trial sub-sequences showed the expected pattern of results.

The 4-trial R-K group significantly differed from the Control group on response times on the last block of trials ($t(24)=2.63$, $p<0.015$) and on difference scores ($t(24)=2.47$, $p<0.021$) while no differences were found for the R-NK and the Control groups. Similarly the 5-trial R-K group significantly differed from the Control group on both response times ($t(24)=2.55$, $p<0.018$) and difference scores ($t(24)=2.87$, $p<0.009$).

This finding furthers supports the speculation that knowledgeable participants may be acquiring information about 5-trial and even 4-trial sub-sequences. Three-trial and 6-trial sequences did not differentiate between participants with and without sequence knowledge using either the division on the basis of total generation scores or using the division on the basis of the Serial position scores. The finding that generation of four and 5-trial sub-sequences is crucial for differentiating between fast and slow participants may indicate that, for the present ambiguous sequence, this is the minimum sub-sequence length that can be used in an anticipatory manner. Also, the length of the learned sub-sequences should not be isolated from the stimulus movement patterns that may have been learned. Both anticipated serial positions in the present sequence were the end of a 5-trial diagonal run that started and ended on the same stimulus.

As two serial position lengths appeared to be reliable in separating participants who showed response time improvement and those that did not, membership of the R-K and R-NK groups was determined anew. Participants who exceeded the cut-off point on either the 4- or the 5-trial generated sub-
sequences were allocated to the R-K group. This division resulted in the allocation of ten participants to the R-K and seven participants to the R-NK group. Mean response times for the two new sub-groups and the Control group for all blocks of trials are presented in Table 6.7 and Figure 6.5. Only the R-K group significantly differed from the Control group (t(25)=2.5, p<0.02) on response times on the last block of trials. The response time difference means were 45 (sd: 20) for the R-K and 21 (sd: 8) for the R-NK sub-groups and again only the R-K group significantly differed from the Control group (t(25)=2.85, p<0.004).

A two (Group: Repeating vs Control) X five (Practice: blocks 1 to 5) analysis of variance on response times revealed no significant effects for the comparison of the R-NK group to the Control group apart from the effect of Practice which indicated that both groups improved with practice. The same analysis comparing the R-K group with the Control group revealed a significant Group by Practice interaction (F(4,100)= 3.48, MSe= 191, p<0.011) and a significant Group by the linear trend of Practice interaction (F(1,25)= 9.8, MSe= 270, p<0.004). As is shown in Figure 6.5, only the Repeating group that expressed knowledge of the sub-sequences in the generation task showed improvement in response times in the last block of trials. Simple effects analysis revealed that the difference between the R-K group and the Control group was reliable on block 5 (F(1,25)=6.23, MSe= 270, p<0.02).

Analysis of response times on each one of the 12 serial positions indicate a similar pattern of results. Means and standard deviations are presented in Table 6.8. No differences emerged between the R-NK and the Control group on any of the Serial Positions, while the R-K group significantly differed from the Control group on SP3 (t(25)= 2.13, p<0.043), SP11 (t(25)= 3.96, p<0.001) and also SP7 (t(25)= 2.3, p<0.03).
Figure 6.5. Mean response times for the five blocks of practice for the R-K (10), R-NK (7) and Control groups.

Table 6.7. Means and Standard Deviations for the R-K (10) and R-NK (7) groups and the Control group and for the five practice blocks of trials.

<table>
<thead>
<tr>
<th>Group</th>
<th>Practice block</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-K (10)</td>
<td>M</td>
<td>363</td>
<td>346</td>
<td>343</td>
<td>329</td>
<td>318</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>29</td>
<td>17</td>
<td>26</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>R-NK(7)</td>
<td>M</td>
<td>354</td>
<td>346</td>
<td>343</td>
<td>336</td>
<td>333</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>12</td>
<td>21</td>
<td>18</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Control</td>
<td>M</td>
<td>367</td>
<td>357</td>
<td>358</td>
<td>352</td>
<td>349</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>40</td>
<td>34</td>
<td>35</td>
<td>30</td>
<td>32</td>
</tr>
</tbody>
</table>
6.2.3.3. Correspondence of Generation Scores and Response Times

One of the reasons for dividing the Repeating group into a sub-group that expressed sequential knowledge in the generation task and a sub-group that did not, was that differences between the Repeating and the Control group were more likely to be reduced if one of the tasks shows less sensitivity to the acquired knowledge. However, if there is a direct correspondence between the response time task and the generation task, then reliable differences are more likely to be observed for both tasks when comparisons are carried out only for the R-K group. Although the selection of this group was bound to lead to reliable differences at least for the generated 4- and 5-trial sub-sequences at serial positions 3 and 11, this group also showed a reliable response time

Table 6.8. Mean response times and standard deviations (in brackets) for the 12 serial positions of the middle Repeating sequences of block 5 for the R-K, R-NK and the Control groups.

<table>
<thead>
<tr>
<th>Serial Position</th>
<th>Spatial Location</th>
<th>R-K (Mean)</th>
<th>R-NK (Mean)</th>
<th>Control (Mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>325 (93)</td>
<td>316 (33)</td>
<td>352 (63)</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>341 (61)</td>
<td>363 (28)</td>
<td>358 (63)</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>285 (57)</td>
<td>297 (43)</td>
<td>343 (62)</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>358 (74)</td>
<td>394 (41)</td>
<td>381 (71)</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>393 (47)</td>
<td>420 (54)</td>
<td>428 (79)</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>366 (76)</td>
<td>381 (46)</td>
<td>413 (62)</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>271 (42)</td>
<td>319 (48)</td>
<td>325 (73)</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>309 (66)</td>
<td>346 (59)</td>
<td>344 (67)</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>351 (90)</td>
<td>388 (83)</td>
<td>391 (69)</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>326 (89)</td>
<td>315 (35)</td>
<td>332 (100)</td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>238 (51)</td>
<td>303 (34)</td>
<td>336 (68)</td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>359 (74)</td>
<td>392 (46)</td>
<td>390 (77)</td>
</tr>
</tbody>
</table>
difference for serial position 7. This serial position did not reach significance when all Repeating group participants were compared to the Control group. Therefore, in order to test whether generation differences would now match response time differences, the two groups were compared on all serial position generation scores. Table 6.9 summarises the results from the analyses.

The R-K group was found to outperform the Control only for SP10 (3-trial t(25)=2.34, p<0.028, 4-trial t(25)=2.15, p<0.041), SP11 (3-trial t(25)=2.34, p<0.027, 4-trial t(25)=3.45, p<0.002, 5-trial t(25)=3.05, p<0.005) and SP1 (5-trial Fisher exact p<0.04). Exactly the opposite pattern is found for SP6 (4-trial Fisher's exact p<0.02), SP7 (5-trial Fisher's exact p<0.041), and SP8 (5-trial Fisher's exact p< 0.006) where the Control-group outperforms the R-K group.

Table 6.9. Mean scores for the generated sub-sequences that showed significant differences between the R-K (10) and Control (17) group (in parentheses number of participants who generated the sub-sequence at least once).

<table>
<thead>
<tr>
<th>Spatial location</th>
<th>Sequence length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>1. A</td>
<td>R-K</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>6. D</td>
<td>R-K</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>7. B</td>
<td>R-K</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>8. A</td>
<td>R-K</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>10. C</td>
<td>R-K</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>11. B</td>
<td>R-K</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>
It is worth noting that, although the R-K group was faster to respond to SP7 in the response time task, none of the participants generated even one 5-trial sub-sequence that ended on SP7. Furthermore there is no correspondence between response times and generation scores even for serial position 3, one of the positions used to determine group division.

This finding of lack of correspondence between the two tasks was further investigated by inspecting the generation scores of each one of the participants in the R-K group. This inspection revealed that eight out of the ten participants that were allocated to the R-K group had exceeded the cut-off scores for SP11 while only three out the ten had exceeded the cut-off score for SP3 (one participant had exceeded the cut-off score for both serial positions).

When generation scores for SP7 were also examined, it was found that only one participant had exceeded the cut-off score for this serial position. This may explain why only generation scores on SP11 showed significant differences. As only a total of four participants expressed considerable knowledge of serial positions 3 and 7, this did not lead to reliable generation differences.

In order to further investigate this point, the four participants who expressed knowledge for serial position 3 and 7 at the generation task were excluded from the R-K group, and the remaining six participants (R-K-SP11) were compared to the Control group. If there is a direct relationship between response times and generation scores these six participants should not show fast responses on serial positions 3 and 7.

The mean response time on the last block of trials for the sub-group that showed knowledge of SP11 (R-K-SP11) was 306 (sd: 26) and significantly different from the Control group's mean (t(21)=2.92, p<0.008). Similarly, the
response time difference score was 43 (sd: 17) and significantly different from the Control group's difference score ($t(21)=2.23$, $p<0.037$). Mean response times of the R-K-SP11 group and the Control group on each Serial position are shown in Table 6.10. The two groups reliably differed on SP3 ($t(21)=2.49$, $p<0.021$), SP6 ($t(21)=2.66$, $p<0.015$), SP7 ($t(21)=2.06$, $p<0.05$) and SP11 ($t(21)=3.04$, $p<0.006$). Table 6.11 shows corresponding generation scores for the four serial positions that showed response time differences. As can be seen in Table 6.11, these six participants do not generate any sub-sequences that ended on Serial positions 3, 6 and 7. Their knowledge about these serial positions reduced response times but was not expressed in the generation task.

Table 6.10. Mean response times and standard deviations (in brackets) for the 12 Serial positions of the two middle repeating sequences of block 5 for the R-K(SP11) and Control group.

<table>
<thead>
<tr>
<th>Serial Position</th>
<th>Spatial Location</th>
<th>R-K(SP11)</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>333 (82)</td>
<td>352 (63)</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>335 (56)</td>
<td>358 (63)</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>269 (35)</td>
<td>343 (62)</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>357 (46)</td>
<td>381 (71)</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>407 (48)</td>
<td>428 (79)</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>337 (66)</td>
<td>413 (62)</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>266 (24)</td>
<td>325 (73)</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>343 (63)</td>
<td>344 (67)</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>340 (83)</td>
<td>391 (69)</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>304 (77)</td>
<td>332 (100)</td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>249 (29)</td>
<td>336 (68)</td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>362 (38)</td>
<td>390 (77)</td>
</tr>
</tbody>
</table>
Table 6.11. Mean generation scores of the R-K (SP11) and the Control group. (Asterisks denote a reliably larger number of generations).

<table>
<thead>
<tr>
<th>Serial Position</th>
<th>Group</th>
<th>3-trial</th>
<th>4-trial</th>
<th>5-trial</th>
<th>6-trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>R-K(SPII)</td>
<td>1.5 (6)</td>
<td>0.8 (5)</td>
<td>0.1 (1)</td>
<td>0.0 (0)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.8 (16)*</td>
<td>2.0 (12)</td>
<td>0.5 (8)</td>
<td>0.1 (2)</td>
</tr>
<tr>
<td>6</td>
<td>R-K(SPII)</td>
<td>1.6 (6)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.1 (16)</td>
<td>0.6 (7)</td>
<td>0.2 (2)</td>
<td>0.05 (1)</td>
</tr>
<tr>
<td>7</td>
<td>R-K(SPII)</td>
<td>2.5 (6)</td>
<td>1.0 (5)</td>
<td>0.0 (0)</td>
<td>0.0 (0)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4.8 (17)*</td>
<td>2.5 (14)</td>
<td>0.5 (6)</td>
<td>0.2 (2)</td>
</tr>
<tr>
<td>11</td>
<td>R-K(SPII)</td>
<td>6.0 (6)*</td>
<td>4.5 (6)*</td>
<td>3.5 (6)*</td>
<td>0.8 (4)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>2.8 (16)</td>
<td>1.2 (12)</td>
<td>1.1 (10)</td>
<td>0.3 (6)</td>
</tr>
</tbody>
</table>

6.2.3. DISCUSSION

The present experiment investigated the response time pattern to the serial positions of an SOC sequence (Reed and Johnson, 1994), when learning - expressed in response times - was just beginning to emerge. It was found that participants were particularly fast in responding to a few serial positions, which indicates that they learnt a few sub-parts of the sequence.

Knowledge expressed in the response time task was not found to correspond to knowledge expressed in a free-generation task when traditional methods of testing were used: correlations between the two tests were weak and a group division on the basis of total generation scores on all 12 serial positions resulted in groups that expressed very similar degrees of learning in the response time task.

In contrast, a clear response time differentiation was achieved when the group
division was made on the basis of generations of 4- and 5-trial chunks that ended on the serial positions that elicited reliable group differences in response times. Participants who did not generate these chunks did not show reliable response time improvement with practice. This indicates that the knowledge that leads to response time improvement is very specific and limited to a few sub-parts of the sequence (see also Perruchet & Amorim, 1992).

The fact that this specific knowledge reduces response times but does not significantly increase total generation scores may be explained by a difference in the sensitivity of the measurement scale of the two tasks. Although the acquired knowledge is sufficient to reduce mean response times in a block of trials, it is not sufficient to increase mean generation scores for the simple reason that the two tasks measure this knowledge in different ways (see also, Shanks, Green & Kolodny, 1994). This provides another demonstration of the importance of establishing the type of information that leads to the response time improvement before testing whether this information may be expressed in a subsequent generation task (Shanks & St John, 1994).

It was also found that different participants learned different parts of the sequence. This was because the present ambiguous sequence was not easily separated into well defined and salient chunks. Perception of this sequence is more likely to be based on a competition between different chunks with approximately similar strengths. According to the competitive chunking model (Servan-Schreiber & Anderson, 1990), the first "winners" are more likely to accumulate strength faster and direct the learning process to different parts of the sequence. Therefore, different chunks are likely to be learned by different participants.
The response time pattern obtained also suggests that the formation of chunks may have been affected by the presence of two repeated diagonal target movements. For example, a response time speed-up was found for serial position 11 which was the end of a diagonal target movement that followed another diagonal movement at serial position 9. Furthermore, a diagonal movement follows at serial position 1 and another at serial position 3 that also showed a response time speed-up. One explanation of this finding may be that the target movements on serial positions 11 and 3 are the first to accumulate strength due to the immediate repetition of the diagonal movements. This account requires that participants encode general target movements and that this encoding may facilitate the formation of chunks. Serial position 11, for example, does not involve the repetition of the same instance - as was the case with the triplet repetitions in Experiment 2 - but the repetition of the movement that characterised the previous instance.

An alternative explanation, that does not require such influence from general target movements, is that the two repeated diagonal movements facilitate the encoding of the 4-trial sub-sequence they are associated with and that this allows the formation of a memorial representation for this specific 4-trial instance. In that case, the first diagonal movement is the trigger that elicits an expectation for the second. This explanation is supported by the fact that a response time speed-up was associated with generation of the four- and five-trial chunks.

On the other hand, the response time speed-up found for serial positions 6 and 7 could be explained by a learning mechanism implemented by the sequential network (Keele & Jennings, 1992). The sequential network predicts that a response time improvement should initially be found for the serial positions that follow unique events in the sequence. If the sequence does not involve
unique events - as is the case in the present ambiguous sequence - then an external parsing process should set some arbitrary anchor points that would serve the same function as the unique events and thereby facilitate learning of the sequence. The speed-up on serial positions 6 and 7, however, suggests that even in an ambiguous sequence the parsing process may not be arbitrary. These serial positions immediately follow the only first-order backward movement that appears in the sequence. This event may be considered unique and likely to serve as a parsing point. Therefore, in an ambiguous sequence that does not include any unique stimuli, a parsing process may be facilitated by unique events that are now defined by a series of two or more stimuli.

However, there was still some evidence for a lack of correspondence between response times and generation scores even when each serial position was separately examined. A sub-group of participants who showed fast responses to four serial positions generated sub-sequences for only one of them. This finding may have different interpretations depending on whether the free-generation task is taken to measure conscious or unconscious knowledge.

If we assume that the free-generation task measures conscious sequence knowledge, then the above finding provides evidence for unconscious learning. The sub-group of participants who showed learning of four parts of the sequence possessed conscious knowledge for only one of them and unconscious knowledge for the remaining three. Furthermore, as the sub-sequence that was generated showed the most reliable response time differences, we may even suggest that sequence knowledge is initially unconscious and may later become conscious. According to this hypothesis, a generation task given at a later stage of practice would be expected to reveal conscious knowledge for all four sub-sequences.
An alternative explanation is that participants possess conscious knowledge for all four sequence parts. However, as with free recall tasks, the generation task is not sensitive to low confidence knowledge and did not express knowledge that was just beginning to develop. Only knowledge of sub-sequences on serial position 11 managed to exceed the confidence threshold required by the generation task. According to this hypothesis, a more sensitive recognition task would reveal that participants have conscious knowledge of all sub-parts of the sequence. This possibility is investigated in the experiments presented in the following chapter.

Finally, if we assume that the generation task expresses unconscious knowledge, it is difficult to explain why it reveals knowledge of one sub-sequence only. The only explanation would be that, as with conscious knowledge, there may be low-confidence unconscious knowledge that is not expressed in another unconscious task. However, such an explanation suggests that there is no real difference between the expression of conscious and unconscious knowledge and implies that there is no real potential value for a conceptual distinction between conscious and unconscious processes. According to Merikle (1992): "... the distinction is much more significant and interesting if conscious and unconscious processes lead to qualitatively different consequences than if unconscious processes are simply quantitatively weaker versions of conscious processes." (p. 794).

6.3. Conclusion

This experiment demonstrated that learning of an ambiguous SOC sequence when attention is freely available is based on a parsing process. It also showed that determining the exact type of information that causes a response time speed-up is crucial when testing for a dissociation of knowledge expressed in two different tasks. Results also suggested that sub-sequence knowledge may be
expressed in the response time task but not in the generation task. This last finding, however, requires further investigation.
CHAPTER

7

Expression Of Sequence Knowledge

In Explicit Memory Tasks
7.1. INTRODUCTION

Both the sequential network proposed by Keele and Jennings (1992), and the memory-based framework proposed by Perruchet (1994) predict that, at the beginning of sequence learning, response time speed-up should be evident only for a subset of the serial positions of the sequence. According to the memory-based framework, response time improvement should initially be found for the last stimuli of some salient chunks memorised by participants. Experiment 5 suggested that participants learn 4- or 5-trial parts of the sequence that start and finish with a diagonal target movement. These parts may be considered to be salient.

On the other hand, the sequential network proposed by Keele and Jennings (1992) predicts that response time improvement should initially be found for the serial positions that follow the points that define the sequence sub-parts. In a hybrid sequence these points are provided by the unique events while in the present ambiguous sequence they are set arbitrarily. Experiment 5 suggested that participants develop expectations for the stimuli that follow the only first-order backward movement that appears in the sequence. Therefore, this movement may serve as a unique event that facilitates parsing.

One question that arises, however, is whether this hypothetical encoding of diagonal or backward movements is conscious. Are participants aware of the presence of these movements when responding to the sequence and are they able to report post-experimentally that they have noticed "diagonal" or "back and forth" target movements? According to the competitive chunking model (Servan-Schreiber and Anderson, 1990), the contents of the chunks may be available to consciousness but their strength and support may well not be. Furthermore, even if participants are not able to describe any target movements,
they may be able to recognise the specific instances that were presented in the SRT task. They may also be aware that their performance was driven by some type of knowledge or they may be aware that they were successfully anticipated the next stimuli in the response time task; in other words they may have metaknowledge of their knowledge (Berry & Dienes, 1993). These issues were investigated in the following experiment. Participants' knowledge about the sequential structure was tested with a questionnaire with multiple choice and open-ended questions and a recognition task that presented sub-parts of the sequence.

Also, the competitive chunking model suggests that initially created chunks are later organised into higher order chunks. Therefore, two successive chunks may, after extensive practice, be perceived as one higher order chunk. In order to investigate how initially acquired knowledge of chunks develops at a later stage of learning, participants in the next experiment received a greater amount of practice with the sequence.

Finally, another aim of Experiment 6 was to investigate the length of the acquired sub-parts of the sequence. Experiment 5 provided some evidence that participants learn 4- and 5-trial chunks. However this evidence was indirect as it was based on an observed close correspondence between the response time task and the generation task. This evidence suggests but does not prove that the two tasks express exactly the same type of knowledge. It may be the case that knowledge expressed in the generation task is not the only type of knowledge that facilitates performance in the response time task. For example, an associative mechanism that learns triplets may operate in parallel with a chunking mechanism but it is only the chunking mechanism that is expressed in the generation task. Also, a possible delay in the knowledge expressed in the two tasks may invalidate the conclusions drawn from Experiment 5. It is
therefore necessary to carry out a direct test on the length of the acquired chunks that lead to a speed-up in the response time task.

7.2. EXPERIMENT 6

In the serial response time task, Repeating group participants are expected to speed-up response times if they anticipate the location of the next target and initiate their response earlier than participants in the Control group. If anticipations are based on knowledge of triplets, the two groups should show similar response times to the first two trials of the triplet and differ only on the third trial. In effect, the beginning of the triplet would serve as a probe and the final stimulus of the triplet as the target. Similarly, if participants learn 4-trial sequences, the first three stimuli would not elicit any group differences while the final stimulus would.

In order to test directly whether participants are basing their response time improvement on knowledge of triplets or knowledge of 4-trial sub-sequences, the Repeating and Control groups could simply be compared on the last stimulus of all possible triplets or 4-trial sub-sequences in the practised sequence. There are two issues, however, that need to be considered at this point. First, it may be the case that participants learn a triplet initially, but then extend their knowledge to the stimulus that immediately follows that triplet. In that case they would be expected to show fast response times to both the third and the fourth stimulus of a presented 4-trial chunk. Therefore, conclusions about the length of sub-sequences learned by participants should be based on the estimation of the minimum number of trials needed before they show a response time speed-up for the first time.

Second, all sub-sequences being tested would have to be presented separately. If
the sub-sequences are presented one after the other in a continuous sequence, there is no control over the length of the preceding sub-sequence that may serve as a probe for the next target. To provide this control, some type of interference should be used so that the tested triplets or 4-trial sub-sequences are not influenced by preceding trials. The present experiment was designed to test whether interfering with the represented information in short-term memory would provide a means of isolating sub-sequences in the SRT task. The importance of the information represented in short-term memory for the sequence learning task was demonstrated by Frensch and Miner (1994). They showed that, under certain practice conditions, a spatial digit span measure correlated with response time improvement. Furthermore, a slow rate of stimulus presentation reduced the amount of information represented in short-term memory and when this amount was not sufficient to specify subsequent events, sequence learning was prevented. Interference with the information represented in short-term memory may, therefore, provide a means of preventing anticipation of subsequent stimuli.

In order to interfere with the information represented in short term memory in the SRT task, an irrelevant display could be presented between successive stimuli. Previous research suggests that presentation of irrelevant displays - either dynamic or static - while performing a task that requires representing spatial information in short-term memory is detrimental to performance (Logie, 1986; Toms, Morris and Foley, 1994). Therefore, an irrelevant display presented in the inter-trial interval in the response time task could interfere with the representation of the preceding series of trials and could prevent anticipation of the next target. If this manipulation proved successful, then presenting this irrelevant display after series of trials of different lengths would provide control over the number of successive trials that are simultaneously represented in short-term memory. This would provide a means of testing which is the
minimum number of trials that have to be represented in memory so that successful anticipations of the next target are possible.

The present experiment examined whether presenting an irrelevant display after every three trials would interfere with the expression of the acquired sequence knowledge. This would directly test whether participants acquire associations between a stimulus pair and the subsequent stimulus. A Repeating group practised the same 12-trial sequence used in Experiment 5, but received nine rather than five blocks of 120 trials. An irrelevant display was introduced on block 8 and was presented after every three successive stimuli. The irrelevant display consisted of a large number of circles randomly scattered on the screen. It was hypothesised that this display would interfere with short-term memory of the preceding trials and that this would prevent anticipations based on more than two successive stimuli.

If the interference introduced in block 8 proves successful, prediction of the last stimulus in an uninterrupted triplet must be based on the preceding two stimuli. If response time differences between the Repeating and the Control group dissipate when the irrelevant display is introduced, then it may be concluded that response time improvement is based on knowledge of 4-trial or longer sub-sequences.

7.2.1. METHOD

7.2.1.1. Subjects

Forty-four undergraduate psychology students from Goldsmiths' College, University of London, participated in the experiment. Their participation was part of a course requirement. They were 11 men and 33 women and their
mean age was 24.3 years. All participants had normal or corrected to normal vision and were naive about the purpose of the experiment. They were asked to participate in an experiment that measured reaction time.

7.2.1.2. Stimulus Conditions

7.2.1.2.1. Response Time Task

A Repeating group and a Control group practised nine blocks of 120-trials. The 12-trial sequence used in Experiment 5 was repeated 90 times for the Repeating group. The pseudo-random 120-trial sequence that was used in Experiment 5 was repeated nine times throughout practice for the Control group.

The target stimuli were the same circles used in Experiments 3, 4 and 5. A target remained on the screen for at least 400 msec or until a response was made (if the response was slower than 400 msec). If participants did not respond within 1500 msec, the response was recorded as missing. The next target appeared 400 msec later.

An irrelevant display (ID) was presented after approximately one third of the trials in block 8. This ID consisted of the four target stimuli, and a large number of circles that were randomly scattered on the screen. The cross that divided the screen in four quadrants was visible at all times. In order to prevent familiarisation with the ID, different numbers of circles were scattered in an area of one of three different sizes around the centre of the screen: 40 circles were scattered into half the screen area; 50 circles were scattered into three quarters of the screen area; and 60 circles were scattered into the whole screen. The size of the screen area that was covered with circles was randomly
chosen on each presentation of the ID. The ID appeared immediately after the stimulus disappeared and remained visible for 250 msec. 400 msec later the next target appeared.

The ID was presented after three successive targets, four consecutive times. The fifth ID presentation followed after only one target. For example, starting from the first target of the block, the first four interference screens were presented immediately after target 3, target 6, target 9 and target 12. The next ID was presented after target 13 and the next four were presented after target 16, target 19, target 22, and target 25. This was repeated until the end of the block and ensured that all possible triplets of the 12-trial sequence were presented. In total, 37 non-interrupted triplets were presented in block 8. Both groups saw the ID after exactly the same numbers of trials.

7.2.1.2.2. Recognition Task

In the recognition task participants were presented with 3- and 6-trial chunks. A comparison of the recognition ratings in the two sub-sequence lengths should provide some information on the optimal testing conditions for recognition memory. Participants in Experiment 5 appeared to have acquired 4- and 5- trial sub-sequences. If recognition memory depends on perception of the whole chunk that has been acquired, then participants would be more likely to recognise 6- rather than 3-trial chunks. This is because 6-trial sub-sequences are more likely to include the complete 4- or 5- trial acquired chunks. Furthermore, as participants in this experiment received a greater amount of practice in comparison to those in Experiment 5, they may acquire chunks that are longer than 4- or 5-trials.

Twenty-four 3-trial sub-sequences and twelve 6-trial sub-sequences were
separately presented in two blocks of trials in the recognition task. Half of the sub-sequences in each block were part of the Repeating sequence (Old for both the Repeating and the Control group) while the other half were part of the pseudo-random control sequence (Old for the Control group but New for the Repeating group). All sub-sequences are presented in Table 7.1.

7.2.1.3. Procedure

The experiment was run on Dell IBM compatible PCs equipped with 33 cm colour monitors and lasted approximately 40 minutes. All participants were tested individually in experimental cubicles. The instructions about the task were the same as in Experiment 5. The practice session consisted of nine blocks of 120 trials. Blocks were separated by a short interval and participants could initiate the next block after at least 10 seconds had elapsed.

At the end of each block participants were given feedback on their mean response time and number of errors. After the end of block 9, they were asked to fill in a questionnaire with multiple choice and open ended questions about

<table>
<thead>
<tr>
<th>3-trial sub-sequence</th>
<th>6-trial sub-sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Old</td>
</tr>
<tr>
<td>ABC</td>
<td>BAD</td>
</tr>
<tr>
<td>BCA</td>
<td>ADC</td>
</tr>
<tr>
<td>CAC</td>
<td>DCB</td>
</tr>
<tr>
<td>ACD</td>
<td>CBD</td>
</tr>
<tr>
<td>CDB</td>
<td>BDA</td>
</tr>
<tr>
<td>DBA</td>
<td>DAB</td>
</tr>
</tbody>
</table>
the sequence of stimuli presented in the response time task (Appendix 9). They were asked whether the targets were predictable, whether they had attempted to anticipate the next target, whether they believed that their anticipations were successful and whether they had noticed a repeating sequence. They were also asked to write down any sequences they could remember from the response time task. They were given the diagram in Figure 7.1 that numbered each location and were asked to write the sequence as a series of numbers. Finally, they were asked whether some locations were more frequent than others and whether they had noticed any frequent or distinctive target movements.

After they had completed the questionnaire they were given instructions about the recognition task. Half of the participants performed the recognition block with the 3-trial sub-sequences first and the recognition block with the 6-trial sub-sequences later; the other half received the two recognition blocks in the opposite order. In the recognition task, participants were presented with each sub-sequence and were instructed to respond to the targets exactly as they had done in the response time task. They then had to give their recognition rating on a 9 point scale from 1 (I am sure I have not seen the sequence before) to 9 (I am sure I have seen the sequence before). They could see the sub-sequence as many times as they wished before they typed their recognition rating. It was stressed that they had to make the recognition judgements on the basis of the sequences they had seen in the initial response time task. At the end of the experiment participants were debriefed and
7.2.2. RESULTS

7.2.2.1. Response Time Task.

Error scores on each block of 120 trials ranged from 1% to 3% and were at similar levels for both groups. Consequently only response time analyses will be reported. Median response times of correct responses were calculated for every 12 trials. Means of the 10 medians from each one of the nine blocks were submitted to a two (Group: Repeating vs Control) X nine (Practice: block 1 to 9) analysis of variance with repeated measures on the last factor. Figure 7.2 and Table 7.2 present the means of the two groups on all blocks of trials. As the assumption of homogeneity of variance-covariance matrices was violated in this analysis, the degrees of freedom for the F values that tested the main effect of Practice and the interaction between Group and Practice were adjusted by multiplying them with the average of the Greenhouse Geisser epsilon and Huynh Feldt epsilon (Adjusted degrees of freedom will also be used for all following analyses that did not satisfy the homogeneity of variance-covariance matrices assumption).

There was a significant main effect of Practice (F(8,336)=38.4, MSe= 640, adj. df F(4,178)=3.48, p<.01) as well as a significant Group by Practice interaction (F(8,336)=3.63, MSe= 640, adj. df F(4,178)=3.48, p<0.01). In order to ensure that the Repeating group showed reliable learning of the sequence by block 8, when the ID was introduced, a two (Group: Repeating vs Control) X seven (Practice: block 1 to 7) analysis of variance with repeated measures on the last factor was carried out.
Figure 7.2. Mean response times for the nine practice blocks of trials, for the Repeating and the Control group.

Table 7.2. Mean response times and standard deviations (SD) for the nine blocks of 120 trials for the Repeating and the Control groups. Block 8 that is shaded included the irrelevant display.

<table>
<thead>
<tr>
<th>Block</th>
<th>Repeating</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>1</td>
<td>402</td>
<td>39</td>
</tr>
<tr>
<td>2</td>
<td>379</td>
<td>46</td>
</tr>
<tr>
<td>3</td>
<td>369</td>
<td>49</td>
</tr>
<tr>
<td>4</td>
<td>365</td>
<td>51</td>
</tr>
<tr>
<td>5</td>
<td>349</td>
<td>42</td>
</tr>
<tr>
<td>6</td>
<td>348</td>
<td>51</td>
</tr>
<tr>
<td>7</td>
<td>320</td>
<td>43</td>
</tr>
<tr>
<td>8</td>
<td>401</td>
<td>64</td>
</tr>
<tr>
<td>9</td>
<td>318</td>
<td>43</td>
</tr>
</tbody>
</table>
Both groups showed a response time speed-up with practice \((F(6,252)=31.48, MSe=549, p<.0001)\) but the Repeating group showed a greater rate of improvement: the interaction between Group and Practice and the interaction between Group and the linear trend of Practice were significant \((F(6,252)=3.56, MSe=549, \text{ adjusted df (3, 136), } p<0.025, \text{ and } (F(1,42)=6.7, MSe=1482, \text{ adjusted df (1,22), } p<0.025 \text{ respectively})\). Simple effects analysis revealed that the two groups significantly differed on block 7 \((F(1,42)=10.18, MSe=1653, p<0.003)\).

As can be seen in Figure 7.2, both groups are slowed down and show similar response times when the ID is introduced in block 8. However, this response time pattern may be due to at least three factors: a) a short term disruptive effect that slows response times to the trials that immediately follow the ID, b) a long-term disruptive effect that prevents anticipation of the last stimuli of the 4-, 5- or 6-trial sub-sequences that were learned by participants or c) both of the above.

In order to test these alternative accounts for the response time pattern shown in Figure 7.2, mean response times were calculated for the trials that immediately followed the ID ("interference trials") and for the last trials of the triplets that were not disrupted by an ID ("triplet trials"). These two scores were calculated for block 8 and block 1 for comparison. If a short term effect slowed down responses to the trials immediately following the ID, the difference between the "interference" and the "triplet" trials should be larger for block 8 than for block 1. Mean response times for the two Trial types and the two blocks are presented in Figure 7.3 and Table 7.3.

A two (Group: Repeating vs Control) X two (Block:1 and 8) X two (Trial-type: "interference" vs "triplet") analysis of variance with repeated measures on the
last two factors was carried out. There was a significant main effect of Trial type (F(1,42)=81.46, MSe= 590, p<0.0001) as well as a significant interaction between Block and Trial type (F(1,42)=135, MSe= 519, p<0.0001). Interference trials elicited slower response times during block 8 as compared to block 1, while the opposite was the case for triplet trials. Simple effects of Block were

Table 7.3. Mean (M) response times for the "Interference" and "Triplet" trials, for blocks 1 and 8 and for the Repeating and the Control group (standard deviations (SD) are in brackets).

<table>
<thead>
<tr>
<th>Trial type</th>
<th>Block 1</th>
<th>Block 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Triplet</td>
<td>Interference</td>
</tr>
<tr>
<td>Group</td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Repeating</td>
<td>412 (40)</td>
<td>405 (42)</td>
</tr>
<tr>
<td>Control</td>
<td>414 (68)</td>
<td>407 (73)</td>
</tr>
<tr>
<td>Pooled</td>
<td>413 (55)</td>
<td>406 (59)</td>
</tr>
</tbody>
</table>
Figure 7.4. Mean response times for the triplet trials in blocks seven, eight and nine for the Repeating and the Control groups.

significant for both trial types (F(1,42)= 15.29, MSe= 1993, p<0.0001 and F(1,42)= 36.3, MSe= 1111, p<0.0001 respectively). This finding confirmed that the disruption during block 8 was partly caused by the short term disruptive effect of the ID. The main effect of Group and the interaction between Group and the other variables was not reliable.

In order to eliminate the short term disruption caused by the ID, the following analysis was performed on mean response times for the "triplet" trials only. The two groups were compared on the last three blocks of Practice. A reliable slow down on block 8 would test whether the irrelevant display also prevented the successful anticipations that speeded up response times for the Repeating group. Response times for both groups on the three blocks of trials are presented in Figure 7.4 and Table 7.4.
A two (Group: Repeating vs Control) X three (Blocks 7, 8, 9) analysis of variance with repeated measures on the last factor was carried out on mean response times of "triplet" trials. It was expected that response times for the Repeating group on the three blocks would follow a quadratic trend and that group differences would be evident only on blocks 7 and 9. This prediction was confirmed as the critical interaction between Group and Block was significant (F(2,84)=9.6, MSe=688, adjusted df critical F(1,73)=6.85, p<0.01). This was due to the interaction between group and the quadratic trend of block (F(1,42)=14.16, MSe=931, adjusted df (1,36), p<0.01). The analysis also revealed a significant main effect of Block (F(2,84)=9.74, MSe=688, adjusted df (1,73), p<0.01) which was due to the quadratic trend (F(1,42)=12.8, MSe=931, adjusted df (1,36), p<0.01). Simple effects analysis revealed that the two groups significantly differed only on block seven (F(1,42)=4.79, MSe=1686, p<0.034). Their difference on block 9 was marginally significant (F(1,42)=3.74, MSe=1898, p<0.06).

The Repeating group shows a response time increase of 38 msec from block 7 to block 8 and a response time decrease of 45 msec from block 8 to block 9. The Control group shows a response time decrease of 5 msec in both cases. The response time pattern of the Control group suggests that their final "triplet" trials were not affected by the short term disruptive effect evident for the "interference" trials that immediately follow the ID. The Control group responded similarly to the "triplet" trials whether the ID was present or not.

Table 7.4. Mean (M) response times for the "triplet" trials on blocks seven, eight and nine for the Repeating and the Control groups (Standard Deviations (SD) in brackets.

<table>
<thead>
<tr>
<th>Group</th>
<th>Block 7</th>
<th>Block 8</th>
<th>Block 9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>M (SD)</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Repeating</td>
<td>340 (42)</td>
<td>378 (52)</td>
<td>333 (56)</td>
</tr>
<tr>
<td>Control</td>
<td>367 (39)</td>
<td>362 (42)</td>
<td>358 (35)</td>
</tr>
</tbody>
</table>
Furthermore, the dissipation of group differences on block 8 indicates that participants in the Repeating group based their response time speed-up on knowledge of sub-sequences that were longer than 3-trials. Two successive targets did not provide the necessary context for successful anticipation of the following target.

7.2.2.1.1. Comparison of Full Coverage and SO-Backward Trials in the Interference block.

An additional question that may be raised in the present experiment is whether the ID interfered with the inhibition of backward movements demonstrated in Experiments 3 and 4. Second-order backward movements and full coverage movements are determined by four successive trials. If a response time difference between them dissipates for the triplet trials in block 8, it would be fair to conclude that the irrelevant display completely blocked the continuous perception of the sub-sequence comprising the trial that preceded the irrelevant display and the three trials that followed it.

Mean response times for the FC and SOB "triplet" trials were calculated for block 8. These scores were entered into a two (Group: Repeating vs Control) X two (Movement type: FC vs SOB) analysis of variance with repeated measures on the last factor. Means are presented in Table 7.5 and represented graphically in Figure 7.5. The main effect of Movement type was significant (F(1,42)=19.19, MSe= 600, p<0.0001). Participants are faster to respond to FC and slower to respond to SOB trials. However, there was also a significant interaction between Group and Movement type (F(1,42)=10.11, MSe= 600, p<0.003).

The difference between the two Movement types was significant only for the Repeating group (F(1,42)= 28.58, MSe= 600, p<0.0001) (See Figure 7.5). When the
same analysis was repeated on scores from block 1, the difference between the two types of Movement was confirmed ($F(1,42)=22.08$, $MSe= 655$, $p<0.0001$), while the interaction between Group and Movement type failed to reach significance.

The inhibition of SOB trials persisted despite the interference caused by the ID but only for the Repeating group. Response times were affected by the context provided by the three previous trials only for participants in the Repeating group. One possible explanation for this finding is that participants in the

<table>
<thead>
<tr>
<th>Group</th>
<th>Block 8</th>
<th>Block 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FC</td>
<td>SOB</td>
</tr>
<tr>
<td>Repeating</td>
<td>354 (55)</td>
<td>394 (61)</td>
</tr>
<tr>
<td>Control</td>
<td>353 (41)</td>
<td>359 (49)</td>
</tr>
<tr>
<td>Pooled</td>
<td>354 (48)</td>
<td>376 (57)</td>
</tr>
</tbody>
</table>

Table 7.5. Mean response times for the FC and SOB triplet trials in block 8 and 1 for the Repeating and Control groups (Standard deviations in brackets).
Repeating group had developed an anticipatory strategy that allowed them to forecast trials that were further into the future. This strategy, however, resisted the interference caused by the irrelevant display only for expectations of general target movements; it did not do so for anticipations based on the acquired sequence knowledge. Or alternatively, it may be the case that anticipations on the basis of sequence knowledge require a uninterrupted perception of a larger number of trials than is required for the backward movement inhibition. However, this speculation would require further investigation.

7.2.2.1.2. Comparison of Serial Positions in Blocks Seven and Nine.

In order to find out which Serial positions were learned by the Repeating group, average response times for each one of the stimuli in the two middle repeating sequences of block 7 and 9 were calculated. All responses that were longer than 1000 msec were excluded and substituted by the corresponding response time of the other sequence. A two (Group: Repeating vs Control) X twelve (Serial position) analysis of variance with repeated measures on the last factor was carried out separately for each block. A similar analysis was not carried out for block 8 as response times to the 12 serial positions were likely to be affected by the irrelevant display. Mean response times for both blocks are presented in Figure 7.6.

The two groups significantly differed on the two middle repeating sequences of block 7 (F(1,39)=4.93, MSe= 28572, p<0.032). The Serial Position main effect was significant (F(11,330)=9.9 , MSe= 4807, adjusted df 8,234 p<0.05). The Group by Serial Position interaction was also significant F(11,429)= 2.34, MSe= 4968, adjusted df (9,343) p<0.025) which indicated that group differences were greater on a subset of the serial positions.
Figure 7.6. Average response times for each serial position of the two middle repeating sequences of blocks 7 and 9. Bars represent the difference response times between the two groups.
Simple effects analyses were carried out on each one of the Serial Positions. Group differences reached the adjusted probability level 0.008 that would control for inflated type I error only for serial position 3. However, all comparisons that reached the significance level 0.05 are presented in Table 7.6.

Participants in the repeating group appear to have learned the diagonal movement that end on serial positions 3 and 11, the backward movement at serial position 5 and the serial positions that follow the backward movement.

The same analysis was also carried out for block 9. Only the main effect of Serial Position was reliable in this analysis ($F(11,451=17.72, MSe= 4662$, adjusted df $(9,360), p<0.01$). The main effect of Group was marginally significant ($p<0.06$). Simple effect analysis showed that group differences reached the unadjusted

<table>
<thead>
<tr>
<th>Serial Position</th>
<th>Spatial Location</th>
<th>$F(1,39)$</th>
<th>MSe</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>9.52</td>
<td>6461</td>
<td>0.004</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>4.63</td>
<td>6365</td>
<td>0.038</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>4</td>
<td>6901</td>
<td>0.050</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>4.16</td>
<td>3788</td>
<td>0.048</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>6.47</td>
<td>9142</td>
<td>0.015</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>7.17</td>
<td>3996</td>
<td>0.011</td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
probability level 0.05 only for serial positions 7 \( (F(1,41)= 5.88, \text{MSe}= 6094, \ p<0.02) \) and 11 \( (F(1,41)= 4.65, \text{MSe}= 4768, \ p<0.037) \).

The Serial Position analyses suggest that the Interference block results in a small disruption in the expression of sequence knowledge even when the ID is removed in the following block. For example, while the Group by Serial Position interaction is significant in block 7, it is not in block 9. This is because the variation in response time differences between the two groups on each serial position is reduced. However, when serial positions from both block 7 and 9 were entered into the same analysis only for the Repeating group, the interaction between block and serial position failed to reach significance which suggests that any such effect is small.

7.2.2.2. Questionnaire Responses

The first three questions asked participants whether they thought the target appeared predictably or randomly (Q1), whether they attempted to anticipate the location of the next target (Q2a) and whether they thought their anticipations were successful (Q2b). Tables 7.7 and 7.8 present the alternative responses to these questions and the number of participants in each group that selected them.

As can be seen in Table 7.7, a greater number of participants from the Repeating group believed that the targets were predictable. The chi square test for this comparison just failed to reach statistical significance \( (\chi^2(1)=3.2, \ p<0.07) \). Almost all participants in both groups report that they had attempted to anticipate the location of the next target \( (\chi^2(1)=29.4, \ p<0.01) \). However, a greater number of participants from the Repeating group believed that their anticipations were successful most of the times. The chi square test for
this comparison also just failed to reach statistical significance (chi square(1)=3.2, p<0.07).

Question 3 (Q3) asked participants whether they thought the targets followed a repeating sequence. There were three alternative responses to this question: a) there was a repeating sequence that appeared continuously, b) a repeating sequence came and went and c) there was no repeating sequence. The majority of participants in both groups believed that a repeating sequence came and went (17 participants in the Repeating group and 18 participants in the Control group, chi square(1)=15.3, p<0.01). Only three participants from the Repeating group believed that the repeating sequence was continuous.

Responses of participants to the next question (Q4), that required them to write down any sequences they could remember from the response time task,

<table>
<thead>
<tr>
<th>Table 7.7. Number of participants from the Repeating and Control group who selected each of the two alternative responses in Question 1.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Repeating</td>
</tr>
<tr>
<td>Control</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 7.8. Number of participants from the Repeating and Control group who selected each of the alternative responses in Questions 2a and 2b.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q2a: Anticipated the location of the target:</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Group</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Repeating</td>
</tr>
<tr>
<td>Control</td>
</tr>
</tbody>
</table>
revealed that they tended to break down the sequence into 4-trial chunks. Out of the 84 sub-sequences that were written down by all participants, 69 were written as 4-trial chunks while the remaining 14 were 5-trial or longer. Only 13 out of the 44 participants in both groups reported a 5-trial or longer sub-sequence (chi square (1)=7.36, p<0.05). Also, there was only one 3-trial sub-sequence reported by one of the Repeating group participants and this was the backward movement CAC.

The final two questions in the questionnaire required participants to write down any movements of the target that appeared to be frequent or distinctive. Only five participants from both groups reported that diagonal target movements were both frequent and distinctive, while only one participant from the Repeating group reported the CAC triplet as distinctive. Half of the participants from both groups did not fill in the final two questions, arguing that they had not noticed any frequent or distinctive target movements. The majority of those who completed the last two questions wrote down the same sub-sequences they had already reported in Question 4.

The number of reported 4-trial chunks that were part of the repeating sequence was calculated for all three questions that required reporting of sub-sequences. The accuracy score that resulted did not differentiate between the Repeating and the Control group. Twenty-three accurate 4-trial sub-sequences were generated by 10 participants from the Repeating group while nine accurate 4-trial sequences were generated by six participants in the Control group. This difference was not reliable.

Number of reported sub-sequences was broken down according to the Serial position of the last trial of the sub-sequence. Only sequences that ended on Serial Positions 1, 3, 7, 8 and 11 were reported by both groups. Both groups
showed a bias towards full coverage trials as all these reported sub-sequences end at full coverage trials. Table 7.9 shows the number of participants who generated each one of these sub-sequences from the two groups. The greater differences are found for Serial Positions 7 and 11. However, only the chi square test on serial position 7 was reliable (chi square (1)=6.9, p<0.008).

The majority of reported 4-trial chunks that were not part of the Repeating sequence ended on FC trials. Table 7.10 shows the total number of generated FC, SOB and FOB trials that were not part of the Repeating sequence. The FC trials are further broken down in those with a diagonal target movement, those with a "Z" movement and those with a "move-around" movement of the target.

In parentheses are the number of participants in each group who reported a sub-sequence with these movements at least once. The difference between diagonal movement and the other full coverage movements was not reliable.

Table 7.9. Number of participants from the Repeating and Control group who generated sub-sequences that ended on Serial Positions 1, 3, 7, 8 and 11.

<table>
<thead>
<tr>
<th>Serial Position</th>
<th>1</th>
<th>3</th>
<th>7</th>
<th>8</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeating</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Control</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 7.10. Number of generated FC, SOB and FOB target movements that were not part of the Repeating sequence for the Repeating and the Control group (In parentheses: number of participants who generated these movements at least once).

<table>
<thead>
<tr>
<th>Movement type</th>
<th>FC</th>
<th>SOB</th>
<th>FOB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diagonal</td>
<td>Z</td>
<td>Around</td>
</tr>
<tr>
<td>Repeating</td>
<td>15 (9)</td>
<td>9 (6)</td>
<td>3 (3)</td>
</tr>
<tr>
<td>Control</td>
<td>17 (11)</td>
<td>10 (8)</td>
<td>5 (4)</td>
</tr>
</tbody>
</table>
The two groups were found to differ only on the FOB trials; these were reported by a greater number of Control group participants (chi(1)=3.6, p<0.05).

When participants were asked whether some locations were more frequent than others, 21 answered yes. Approximately half of the participants from both groups believed that one or two locations were more frequent than others.

### 7.2.2.3. Recognition Ratings

In order to compare the two groups on the recognition task, mean recognition ratings were calculated for the old and new 3-trial and 6-trial sub-sequences. The difference scores between old and new sequences for both sub-sequence lengths were entered into a two (Group: Repeating vs Control) X two (Order: 3-trial first vs 6-trial first) X two (sub-sequence length: 3 vs 6) analysis of variance with repeated measures on the last factor. No reliable main effects or interactions emerged from the analysis. Mean difference scores for both groups and all conditions are presented in Table 7.11.

<table>
<thead>
<tr>
<th>Length of sub-sequence</th>
<th>3-trial</th>
<th>6-trial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First</td>
<td>Second</td>
</tr>
<tr>
<td>Repeating</td>
<td>0.66(0.9)</td>
<td>0.45(1.4)</td>
</tr>
<tr>
<td>Control</td>
<td>0.09(0.9)</td>
<td>0.2(0.5)</td>
</tr>
</tbody>
</table>

Table 7.11. Mean difference recognition ratings (standard deviations in brackets) for the 3-trial and 6-trial sub-sequences for the Repeating and Control groups. Mean recognition ratings for both sub-groups that received the two sub-sequence lengths in a different order are shaded.
However, when the difference scores of the Repeating group were compared with the chance score of zero that would be expected if participants were unable to separate old from new sub-sequences the difference was reliable for the 3-trial sub-sequences ($t(21)=3.47$, $p<0.05$).

In order to test whether recognition performance matched the response time speed-up on each one of the serial positions, recognition ratings of the Repeating group were examined separately for each sub-sequence. Scores were compared against the score of 5 that was the middle score of the 9-point rating scale and indicated uncertainty on whether the sequence was presented during the response time task. Mean recognition ratings of the Repeating group for the sub-sequences that end on each serial position as well as $t$-values for the reliable differences are presented in Table 7.12. Participants gave high recognition ratings to triplets that end on serial positions 2, 6, 7, 9, 10 and 12. Table 7.12 also presents the serial positions that showed reliable group differences for the response time comparison (with a "*" in the SP column).

Participants failed to recognise most of the 6-trial sub-sequences. They only recognised the 6-trial chunk that ends on SP9 which also showed a reliable response time difference. However, inspection of the pattern of reliable differences for the triplet recognition ratings suggests that participants tend to recognise the triplets that precede the serial positions that show a reliable response time difference. For example, serial positions 2, 6, 7, and 10 that show reliable recognition differences precede serial positions 3, 7, 8 and 11 that show reliable response time differences.

In order to confirm that recognition of triplets is related to fast response times to the stimuli that follow these triplets rather than to the last stimuli of the triplets, an additional analysis was carried out. Two different recognition indices were
obtained and analysed separately. The first measure was obtained by subtracting
the mean recognition ratings of the new triplets from the mean recognition
ratings of the old triplets that preceded the serial positions that showed reliable
response time differences (preceding triplet measure). The second index was
obtained by subtracting mean ratings to new triplets from mean ratings to old
triplets that ended on the serial positions that showed significant differences
(same triplet measure).

A comparison of the Repeating group with the Control group was carried out
for both measures. The only measure that showed a reliable difference between
the groups was the "preceding triplet" measure ($t(42)=2.38, p<0.022$). The mean
of the Repeating group on this measure was 0.89 (sd: 1.3) while the mean of the

<table>
<thead>
<tr>
<th>SP</th>
<th>3-trial Mean (SD)</th>
<th>t(21)=</th>
<th>6-trial Mean (SD)</th>
<th>t(21)=</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BDA 5.00 (2.74)</td>
<td></td>
<td>DCDAB 4.00 (2.12)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>DAB 6.91 (2.31)</td>
<td>3.82 *</td>
<td>DCDBAB 5.36 (2.72)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>ABC 5.91 (2.64)</td>
<td></td>
<td>CBDBC 5.36 (2.72)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>BCA 5.50 (2.77)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>CAC 5.27 (3.13)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>ACD 6.68 (2.78)</td>
<td>2.80 *</td>
<td>ABCACD 5.50 (2.39)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>CDB 6.41 (2.68)</td>
<td>2.43 *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>DBA 5.27 (3.07)</td>
<td></td>
<td>CACDBA 4.68 (2.57)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>BAD 5.23 (2.62)</td>
<td></td>
<td>ACDBAD 6.05 (2.42)</td>
<td>2.01 *</td>
</tr>
<tr>
<td>10</td>
<td>ADC 6.27 (2.62)</td>
<td>2.26 *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>DCB 5.09 (2.78)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>CBD 6.59 (2.26)</td>
<td>3.24 *</td>
<td>BADCBD 5.50 (2.48)</td>
<td></td>
</tr>
</tbody>
</table>
Control group was 0.01 (sd: 1.0). Corresponding means for the "same triplet" measure were 0.25 (sd: 1.5) for the Repeating group and 0.14 (0.9) for the Control. The "preceding triplet" measure was the only recognition index that revealed a reliable difference between the Repeating group and the Control group. This finding can be taken as support for the response time analysis. In order for participants to develop expectancies for the following trial and to speed-up their response time, they must be able to recognise the triplet that precedes the fast trial.

7.2.2.4. Correspondence between Response Times and Reportable Knowledge.

A division of the Repeating group on the basis of their explicit knowledge was also attempted. The only measures that appeared to reliably distinguish between participants in the Repeating and Control group were the "preceding triplet" recognition ratings, Questions 1 and 2b in the questionnaire (although marginally), and report of the 4-trial chunk that ends on Serial position 7. Participants who did not express sequence knowledge via all these measures were allocated to the No-Knowledge group and this group was compared to the Control group. This comparison would test whether a response time speed-up is evident even in the complete absence of reportable knowledge about the sequence. The cut-off score for the "preceding triplet" recognition measure was set to be the mean plus one standard deviation of the Control group. Only five participants from the Repeating group met all four criteria for inclusion in the No-Knowledge group.

When these five participants were compared to the Control group, they showed no evidence of sequence learning. Means for the two Repeating sub-groups and the Control group are presented in Table 7.13 and in Figure 7.7.
Figure 7.7. Mean response times for the nine blocks of Practice for the Repeating-Knowledge, Repeating-No Knowledge and the Control groups.

Table 7.13. Mean response times and standard deviations (SD) for the nine blocks of 120 trials for the two Repeating groups and the Control group. Block 8 that included the irrelevant displays is shaded.

<table>
<thead>
<tr>
<th></th>
<th>R-N</th>
<th>R-NK</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>400 (42)</td>
<td>409 (32)</td>
<td>404 (72)</td>
</tr>
<tr>
<td>2</td>
<td>375 (49)</td>
<td>393 (33)</td>
<td>383 (53)</td>
</tr>
<tr>
<td>3</td>
<td>359 (47)</td>
<td>403 (45)</td>
<td>379 (48)</td>
</tr>
<tr>
<td>4</td>
<td>356 (53)</td>
<td>397 (31)</td>
<td>373 (46)</td>
</tr>
<tr>
<td>5</td>
<td>340 (39)</td>
<td>380 (38)</td>
<td>375 (44)</td>
</tr>
<tr>
<td>6</td>
<td>337 (50)</td>
<td>384 (37)</td>
<td>370 (40)</td>
</tr>
<tr>
<td>7</td>
<td>308 (40)</td>
<td>358 (31)</td>
<td>359 (37)</td>
</tr>
<tr>
<td>8</td>
<td>393 (64)</td>
<td>427 (62)</td>
<td>399 (44)</td>
</tr>
<tr>
<td>9</td>
<td>309 (42)</td>
<td>350 (34)</td>
<td>352 (34)</td>
</tr>
</tbody>
</table>
As there was a small number of Control group participants that reported that the targets were predictable and that they successfully anticipated the location of the next target, it may have been the case that positive responses were produced by the demand characteristics of the experiment rather than knowledge about the sequential structure. Therefore, a division of both the Repeating and the Control groups was carried out on the basis of responses to Questions 1 and 2a only. The aim of this division was to test whether these two questions were valid measures of sequence knowledge.

Six participants from the Repeating group and 14 participants of the Control group who believed that the targets were not predictable and that their anticipations were rarely successful were allocated to a No-Knowledge group. The remaining participants were allocated to a Knowledge group. This division resulted in four sub-groups, as both the Repeating and the Control group were divided on knowledge and no-knowledge sub-groups. Means for all sub-groups on block 7 are presented in Table 7.14 and graphically represented in Figure 7.8. Means for block 1 are also presented for comparison. A two (Practice group: Repeating vs Control) X two (Knowledge vs No Knowledge group) randomised block analysis of variance confirmed that the Repeating Group differed from the Control group ($F(1,40)=4.04, MSe= 1363, p<0.05$).

However, the main finding of the analysis was that the Knowledge group significantly differed from the No-Knowledge group ($F(1,40)=9, MSe= 1363, p<0.005$). The interaction between Practice group and Knowledge group was not reliable. However, simple effects analyses showed that a reliable difference between the Repeating and the Control was present only for the knowledgeable participants ($F(1,40)=12.12, MSe= 1363, p<0.001$). Also a reliable difference between the knowledge groups was found only for the Repeating group participants ($F(1,40) =16.39, MSe= 1363, p<0.0001$).
Figure 7.8. Mean response times on block seven for the two Knowledge groups for the Practice and Repeating groups.

This analysis showed that participants who had not noticed a repeating sequence and believed that their anticipations were rarely successful did not show evidence for sequence learning in their response times. Therefore, responses to these two questions do not appear to be influenced by demand characteristics of the experiment.

Table 7.14. Mean response times and standard deviations (in parentheses) for blocks 7 and 1 and for the two Knowledge and two Practice groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Knowledge</th>
<th>Block 7</th>
<th>Block 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Repeating</td>
<td>Knowledge</td>
<td>305 (38)</td>
<td>360 (28)</td>
</tr>
<tr>
<td>Control</td>
<td>No</td>
<td>348 (47)</td>
<td>365 (30)</td>
</tr>
</tbody>
</table>
7.2.3. DISCUSSION

The main finding from Experiment 6 is that sequence knowledge was not expressed in response times when an irrelevant display was presented during the inter-trial interval after every third target. Repeating group participants were unable to anticipate the location of the next target after they had seen an uninterrupted sequence of two targets. This finding demonstrates that, in the present experiment, response time speed-up was based on perception of a continuous series of more than two targets. This was supported by the results from the recognition ratings analysis. Participants gave higher recognition ratings to the triplets that preceded those serial positions that showed a reliable group difference on response times.

Therefore, it appears that, at this stage of learning, participants associate a triplet with the stimulus that follows it. The fact that they do not associate pairs of stimuli with the stimuli that follows them may be due to a bias in perceiving the temporal sequence of events in chunks of four. This bias was revealed when participants were asked to free recall parts of the sequence: the majority of chunks that were reported were four trials long. Therefore, in the present experiment, organisational or encoding biases appeared to be stronger than the structural characteristics of the sequence. Although participants could have learned the second-order conditional associations in the sequence, they did not do so.

It was initially hypothesised that a reliable between-group difference in the recognition ratings would be found for the 6-trial but not for the 3-trial sub­sequences. However, the recognition task elicited a reliable group difference only for the "preceding triplet" measure. The fact that participants were unable to recognise the acquired chunks when they were embedded in longer chunks
of 6-trials, or unable to recognise the triplets that ended on the serial positions that showed reliable group differences, suggests that encoding operations during the test phase are crucial for successful recognition performance. Although the 6-trial sub-sequences probably included the sub-chunks participants had learned, they did not elicit higher recognition ratings because the beginnings and ends of the presented sub-sequences were not the ones that defined the acquired chunks. Also, although participants recognised the first triplet of the acquired 4-trial chunk, they did not recognise the last triplet of the same chunk - probably because they never encoded this last triplet as a unit. This indicates that participants are unable to recognise parts of the sequence unless they are presented with the exact sub-sequences they have encoded during practice.

Responses to the Questionnaire showed that participants only report FC movements of the target. Furthermore, approximately half of the sequences they report are FC sequences that are not part of the Repeating sequence. Does this finding suggest that participants have learned general abstract full coverage target movements? Perruchet and Gallego (1994) suggested that participants' performance in a test phase may lead to the expression of abstract knowledge because of abstractive operations that take place during test rather than during practice. For example, in artificial grammar learning studies, after a memory task, participants are told about the existence of the underlying grammar and are asked to classify new strings as grammatical or non-grammatical. Perruchet and Gallego (1994) suggested that, in order to deal with the requirements of the classification task, participants may develop abstract knowledge through the manipulation of specific recollected information.

A different process may have been in operation in Experiment 6. In this experiment participants were asked to recall specific episodes from the response
time task and came up with sub-sequences that were similar to the ones encountered in terms of the movement pattern of the target. Probably, due to their inability to recall specific sub-sequences, they relied on knowledge of general target movements. In order to further investigate this finding the next experiment tested whether participants would also be biased towards the movement patterns of the acquired sub-sequences when they are required to recognise rather than recall the 4-trial sub-sequences.

7.3. EXPERIMENT 7

In the present experiment, the recognition task only included 4-trial sub-sequences. Furthermore, all sub-sequences that were presented ended on the trials that showed reliable response time speed-up in Experiments 5 and 6. The recognition task included a set of new 4-trial sub-sequences that contained target movements that were symmetrical transformations of those in the old sub-sequences and a set of new sub-sequences with target movements that were not symmetrical transformations of those in the old sub-sequences. If participants learn target movements rather than (or as well as) specific sub-sequences, then recognition rating should be higher for the symmetrically transformed sequences. Furthermore, Experiment 7 included a free-generation task in order to test directly whether this task is less sensitive than the recognition task and less able to elicit low confidence sequential knowledge.

7.3.1. METHOD

7.3.1.1. Subjects

32 undergraduate psychology students from University College London and Goldsmiths' College served as subjects. They were paid £2 for their
participation. They were 14 men and 18 women and their mean age was 22.6 years. All participants had normal or corrected to normal vision and were naive about the purpose of the experiment. They were asked to volunteer to participate in an experiment that measured reaction time.

7.3.1.2. Stimulus Conditions

The same 12-trial sequence used in Experiments 5 and 6 was repeated 70 times throughout the seven practice blocks for the 16 participants of the Repeating group. The same 120-trial sequence that was used in Experiments 5 and 6 was repeated seven times throughout practice for the 16 participants of the Control group.

The sub-sequences that were used in the recognition task are presented in Table 7.15. Only six out of the sixteen 4-trial sequences were presented in the response time task. These sub-sequences ended on the serial positions that were found to show reliable speed-on in Experiments 5 and 6 (SP 3, 5, 7, 9, 11, 1). Two sets of six new sequences were taken from the control sequence. The first set was chosen so that each new sequence was matched with an old one on the stimulus movement pattern. The pattern was a symmetrical transformation of the pattern in the corresponding old sequence. For example, the first old sequence and the first new sequence of the first group cover all four locations and the stimulus moves in a square (see Table 7.15). Similarly, the second sequence from both groups move in the two diagonals. The second set of the new sequences were randomly chosen from the control sequence.

7.3.1.3. Procedure

The experiment was run on Dell IBM compatible PCs equipped with 33 cm
colour monitors and lasted approximately 35 minutes. All participants were tested individually in experimental cubicles. The instructions about the task were the same as in Experiment 5 and 6. The practice session consisted of seven blocks of 120 trials. After the end of the seventh block participants were given new instructions about the next task. Half of them performed a generation task first and a recognition task later and the other half received the two tasks in the opposite order. It was stressed that they had to generate sub-sequences from the initial response time task and make their recognition judgements on the basis of the sequences they had seen in the initial response time task. The generation task was similar to the one described in Experiment 5, except that participants were asked to generate a series of 120 (rather than 100) trials.

In the recognition task participants were presented with 18 4-trial sub-sequences. They were instructed to study each sub-sequence and then give it a recognition rating on the same 9 point scale that was used in Experiment 6. In contrast to the previous experiment, the recognition task did not require responding to each one of the stimuli in the sub-sequences. This change was

<table>
<thead>
<tr>
<th>Type of sequence</th>
<th>Old</th>
<th>New-1</th>
<th>New-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACDB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADCB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DABC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCAC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DBAD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CBDA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7.15. Old, New-1 and New-2 4-trial sub-sequences that were presented in the recognition task.
introduced because participants in the previous experiment complained that they were distracted by responding to the stimuli; some even stopped responding in the middle of the task.

Participants were informed that only one-third of the sequences they would see had been presented to them before. They could see the sequence as many times as they wished before they typed in their recognition rating. At the end of the experiment participants were debriefed and thanked for their participation.

7.3.2. RESULTS

Error scores on each block of 120 trials ranged from 1% to 6% and were at similar levels for both groups. Consequently only response time analyses will be reported. The order of the memory tests was not found to interact with any of the other factors and, as it was not expected to influence the results of the response time task, it was excluded from all subsequent analyses.

7.3.2.1. Response Time Task

Median response times of correct responses were calculated for every 12 trials. Means of the 10 medians from each one of the seven blocks were submitted to a two (Group: Repeating vs Control) X seven (Practice : block 1 to 7) analysis of variance with repeated measures on the last factor.

Groups did not differ overall as the main effect of group was not significant. Practice facilitated performance for both groups as revealed by a significant main effect (F(6,180)=18.32, MSE= 507, p<.001). Both the linear (F(1,30)=39.5, MSE= 1100, p<0.001) and the quadratic (F(1,30)=4.9, MSE= 704, p<0.034)
PrACTICE

blocks of 120 trials

Figure 7.9. Mean response times for the seven blocks of 120-trials, for the Repeating and Control groups. Trends of Practice were significant.

However, the Repeating Group showed a sharp performance improvement in the last two blocks of practice (Figure 7.9). This was supported by a significant Group by Block interaction ($F(6,180)=2.42$, MSe = 507, $p<0.028$). The interaction between group and the linear and quadratic trends did not reach statistical significance. Simple effect analysis revealed that the two groups significantly differed on block 6 ($F(1,30)=4.27$, MSe = 1965, $p<0.048$) and block 7 ($F(30)=8.46$, MSe = 1932, $p<0.007$).

In order to compare the two groups on the 12 stimuli of the repeating sequence, average response times for each one of the stimuli in the two middle
repeating sequences of block 7 were calculated. All responses that were longer than 1000 msec were excluded and substituted by the corresponding response time of the other sequence. A two (Group: Repeating vs Control) by twelve (Serial position) analysis of variance with repeated measures on the last factor was carried out.

The two groups significantly differed on the two middle repeating sequences (F(1,30)=8.7, MSe= 25056, p<0.006). The assumption of the homogeneity of variance-covariance matrices was violated in this analysis. Therefore degrees of freedom were adjusted by multiplying them by the average of Greenhouse-Geisser epsilon and Huynh-Feldt epsilon. The serial position main effect was significant (F(11,330)=9.9 ,MSe= 4807, adjusted df 8,234 p<0.05). The group by serial position interaction was also significant F(11,330)= 2.11, MSe= 4807, adjusted df (8,234) p<0.05) which indicated that group differences were greater

Figure 7.10. Average response times for each serial position of the two middle repeating sequences of the last block. Bars represent the difference response times between the two groups.
on certain trials (see Figure 7.10).

Simple effects analyses were carried out on each one of the Serial Positions. All comparisons that reached the probability level 0.05 are presented in Table 7.16. Groups differed on serial positions 3, 7, 8 and 9. Participants in the repeating group appear to have learned all four stimuli that follow the first-order backward movement CAC as well as the diagonal movements that end on serial positions 1 and 3.

Table 7.16. Mean response times (standard deviations (SD) in parentheses) for the 12 serial positions of block 7, F values, Mean Square Error (MSe) and probability levels for the serial positions that showed significant group differences. Serial positions that reached the 0.008 probability level are shaded. (SP: Serial position).

<table>
<thead>
<tr>
<th>Block 7</th>
<th>Repeating</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>Target</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>301 (74)</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>336 (59)</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>268 (34)</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>337 (71)</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>420 (131)</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>303 (144)</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>248 (101)</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>290 (69)</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>303 (91)</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>336 (91)</td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>299 (103)</td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>381 (85)</td>
</tr>
</tbody>
</table>
Finally, as the Repeating group reliably differed from the Control group on block 6, it was possible to examine how the response time pattern changed with further practice. A comparison of the two groups on all twelve serial positions of block 6, revealed reliable differences only for SPs 1 and 3 (see Table 7.17). Also a speed-up was beginning to develop for SP6 (p<0.09). It appears that all serial positions that followed SP5 developed the speed-up that is evident in block 7 almost in parallel. Furthermore, the large standard deviations that are associated with the serial positions that follow the backward movement CAC for both blocks suggest that a few participants had probably learned this chunk by block 6 but a larger number had acquired it by block 7.

Table 7.17. Mean response times (standard deviations (SD) in parentheses) for the 12 serial positions of block 6. F values, Mean Square Error (MSe) and probability level for the serial positions that showed significant group differences.

<table>
<thead>
<tr>
<th>Block 6</th>
<th>Repeating</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>Target</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>312 (86)</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>342 (75)</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>283 (82)</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>379 (71)</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>398 (72)</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>344 (100)</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>293 (109)</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>291 (89)</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>330 (113)</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>344 (133)</td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>311 (119)</td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>398 (119)</td>
</tr>
</tbody>
</table>
7.3.2.2. Free Generation Task

Order of the generation task did not affect the results of the analyses. Therefore, Order was excluded for all reported analyses (Separate comparisons of the two Repeating sub-groups that received the generation task in a different order are presented in Appendix 10).

Group comparisons were conducted on each one of the 3- and 4-trial sub-sequences of the repeating sequence while the chi-square test or the Fisher's exact test was used for the 5- and 6-trial sequences. Table 7.18 presents the means of the groups. All significant differences are shaded.

A significant difference was found for the sequences SP6 (3-trial $t(30)=2.8$, $p<0.009$, 4-trial chi-square (1)=4.5, $p<0.03$), and SP7 (3-trial $t(30)=2.64$, $p<0.013$, 4-trial $t(30)=3.03$, $p<0.005$). The analyses of the 5-trial sub-sequences revealed significant differences between the Repeating and the Control group on SP6 (Fisher's exact, $p<0.008$), SP7 (chi square (1)=6.3, $p<0.01$), and SP8 (chi square (1)=6.3, $p<0.01$). The two groups also differed on the number of generated 6-trial sub-sequences that ended on SP7 (Fisher's exact, $p<0.02$).

The significant differences mainly appear on the serial positions that showed the greater response time differences. Serial positions 1, 3 and 9, however, showed significant response time differences without any corresponding differences between the two groups on number of generated sub-sequences.

Also, total generation scores for each sub-sequence length were correlated with mean response times from block 6 and 7 and difference response times between the last and the first block. None of the correlations reached statistical
Table 7.18. Mean scores of generated 3-, 4-, 5-, and 6-trial sub-sequences that end on the 12 serial positions of the repeating sequence, for the Repeating (REP) and Control (C) groups (in parentheses: number of participants who generated the sub-sequence at least once; significant differences are shaded).

<table>
<thead>
<tr>
<th>Last trial</th>
<th>Length of sequences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>SP</td>
<td>Group</td>
</tr>
<tr>
<td>1. A</td>
<td>REP</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>2. B</td>
<td>REP</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>3. C</td>
<td>REP</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>4. A</td>
<td>REP</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>5. C</td>
<td>REP</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>6. D</td>
<td>REP</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>7. B</td>
<td>REP</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>8. A</td>
<td>REP</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>9. D</td>
<td>REP</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>10. C</td>
<td>REP</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>11. B</td>
<td>REP</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>12. D</td>
<td>REP</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>
significance. Negative results were also found when response times to each serial position were correlated to number of generated sub-sequences that terminated on these serial positions.

### 7.3.2.3. Recognition Task

Mean scores were calculated for the Old, New-1 and New-2 sequences that were presented in the recognition task and the difference scores between the Old and New-1 and between the Old and New-2 mean recognition ratings were entered into a two (Group: Repeating vs Control) X two (Pattern of new sequences: symmetrical vs asymmetrical) analysis of variance with repeated measures on the last factor. The Repeating group was expected to show higher scores overall. Furthermore, higher scores for the asymmetrical-new than the symmetrical-new sequences would show that the knowledge acquired during the response time task was also based on the movement patterns of the stimuli. A main effect of group and a significant Group by Pattern interaction would confirm the above hypotheses. Means and standard deviations are presented in Table 7.19.

Order of the task was not found to interact with any of the other variables. The main effect of Group was significant (F(1,30)=9.19, MSE= 2.97, p<0.005) with the Repeating group outperforming the Control group on both types of sequence. None of the other effects were significant. The Repeating group showed some

<table>
<thead>
<tr>
<th>Sequence Type</th>
<th>Group</th>
<th>Symmetrical</th>
<th>Asymmetrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repeating</td>
<td>1.2 (1.5)</td>
<td>1.3 (1.7)</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>-0.2 (0.9)</td>
<td>0.2 (1.5)</td>
<td></td>
</tr>
</tbody>
</table>

Table 7.19. Mean (standard deviations in parentheses) recognition difference scores between the old and symmetrical new and the old and asymmetrical new sub-sequences.
recognition of the sequences that were practised in the response time task and recognition ratings for new sub-sequences were not affected by the movement of the target.

### 7.3.2.4. Correspondence between Response Times, Generation and Recognition

Results from Experiment 5 suggested that knowledge expressed in the response time task is not expressed in the free-generation task. Participants in that experiment did not generate sub-sequences for all serial positions that showed a response time speed-up. However, one problem with interpreting that finding is that the generation task may not be sensitive to low confidence knowledge that is just developing. Knowledge that fails to be expressed in a generation task may be expressed in a more sensitive recognition task. This hypothesis can be directly tested here because the present experiment incorporated both types of task.

Participants in the present experiment were found to anticipate SPs 6, 7, 8, and 9 that followed the first-order backward movement CAC as well as SPs 1 and 3. Inspection of the generation scores on these SPs revealed a sub-group of participants (n =10) that exceeded the mean score plus one standard deviation of the Control group on the 4- and 5-trial sub-sequences that ended on SPs 1, 6, 7, 8, and 9 but did not do so for SP 3. Therefore, it was possible to test whether this sub-group of participants showed a dissociation of knowledge expressed in the response time task and the recognition task for SP 3. Table 7.20 presents average response times for the 12 serial positions of the sequence on block 7, and the results from the statistical analyses. As can be seen in the table, this sub-group does show a reliable speed-up on SP 3.

However, when recognition ratings were examined, it was found that half
participants from this group recognised the 4-trial sub-sequence that ended on SP3. Four of them gave a rating of 9 and one of them gave a rating of 7. These five participants - who also exceeded the recognition difference mean score plus one standard deviation of the Control group - were excluded from the group. The remaining participants (n= 5) were then compared with the Control group on all serial positions. Mean response times and the results of the analyses are shown in Table 7.21. As is shown in the table, although these five participants show reliable differences for SPs 7, 8 and 9 they do not do so for SP3. Therefore there is a correspondence between the recognition and the response time tasks.

Table 7.20. Mean response times (standard deviations (SD) in parentheses), F values, Mean Square Error (MSe) and probability levels for the serial positions (SP) that showed significant group differences on block 7 for the Repeating-K sub-group.

<table>
<thead>
<tr>
<th>SP</th>
<th>Target</th>
<th>R-K (10) Mean (SD)</th>
<th>Control Mean (SD)</th>
<th>F(1,24)=</th>
<th>MSe=</th>
<th>p&lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>323 (70)</td>
<td>355 (53)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>322 (70)</td>
<td>345 (42)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>265 (41)</td>
<td>313 (52)</td>
<td>6.04</td>
<td>2388</td>
<td>0.022</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>344 (63)</td>
<td>355 (61)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>428 (127)</td>
<td>446 (76)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>312 (154)</td>
<td>406 (48)</td>
<td>5.18</td>
<td>10438</td>
<td>0.032</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>257 (104)</td>
<td>347 (84)</td>
<td>5.84</td>
<td>8540</td>
<td>0.024</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>284 (79)</td>
<td>341 (59)</td>
<td>4.45</td>
<td>4565</td>
<td>0.046</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>318 (112)</td>
<td>402 (89)</td>
<td>4.49</td>
<td>9711</td>
<td>0.045</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>330 (75)</td>
<td>363 (78)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>309 (123)</td>
<td>335 (62)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>407 (94)</td>
<td>384 (64)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 7.21. Mean response times (standard deviations (SD) in parentheses), F values, Mean Square Error (MSe) and probability levels for the serial positions that showed significant group differences in block 7. (SP: Serial position).

<table>
<thead>
<tr>
<th>SP</th>
<th>Target</th>
<th>R-K (5) Mean (SD)</th>
<th>Control Mean (SD)</th>
<th>F(1,24)</th>
<th>MSe=</th>
<th>p&lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>303 (63)</td>
<td>355 (53)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>341 (83)</td>
<td>345 (42)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>274 (44)</td>
<td>313 (52)</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>372 (60)</td>
<td>355 (61)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>357 (133)</td>
<td>446 (76)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>331 (163)</td>
<td>406 (48)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>257 (53)</td>
<td>347 (84)</td>
<td>4.99</td>
<td>6256</td>
<td>0.038</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>256 (30)</td>
<td>341 (59)</td>
<td>9.31</td>
<td>2994</td>
<td>0.007</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>307 (81)</td>
<td>402 (89)</td>
<td>4.47</td>
<td>7681</td>
<td>0.048</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>326 (107)</td>
<td>363 (78)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>358 (162)</td>
<td>335 (62)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>432 (101)</td>
<td>384 (64)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7.4. GENERAL DISCUSSION

In Experiment 7 participants were found to recognise the 4-trial sub-sequences that ended on the serial positions that showed reliable response time differences between the Repeating and the Control group. Furthermore, sub-sequence knowledge was very specific: recognition ratings to new sequences that had target movements that were symmetrical with those in the old sequences were not higher than ratings to new sequences that did not have this relationship with the old sequences. Participants did not show any bias in falsely recognising new sequences with symmetrical target movements as old. This suggests that reporting of chunks that were not part of the repeating sequence but had similar
target movements to the acquired sub-sequences was caused by the requirements of the free-recall task incorporated in Experiment 6. It appears that general target movements were used as cues in the recall task and that this resulted in reporting sub-sequences that were not part of the practised sequence but had similar target movements to the acquired sub-sequences.

Another finding that is relevant to the above speculation is that participants from the Control group generated a higher number of first-order backward movements than participants in the Repeating group (Experiment 6). As the proportion of first-order backward movements was the same in both conditions, the above result appears to be due to the fact that the Repeating sequence included only one instance of first-order backward movements while the Control sequence included several different instances of first-order backward movements. This suggests that practice with different instances of a movement is necessary for the development of a general movement representation that can be used as a cue in a free recall task.

This explanation is in line with findings in artificial grammar learning. In a study by Reber and Allen (1978), participants who were asked to memorise a small number of letter strings appeared to base performance on an exemplar-based representation. When they were asked to rapidly peruse a large number of exemplars, they appeared to develop abstract representations. Therefore, procedures used during learning may have a dramatic effect on whether the knowledge representation is abstract or exemplar-based. On the other hand, in the present experiments abstraction is only revealed in the more demanding recall task, where participants have to find cues in order to recall practised sequences.

Experiment 7 also revealed that sequential knowledge that is not expressed in
the free-generation task is expressed in a recognition task. Therefore, the lack of correspondence between response times and generation scores that was observed in Experiment 5 may be attributed to the fact that the generation task is not as sensitive as the response time task or the recognition task in eliciting sequence knowledge. However, results from both Experiments 6 and 7 also suggest that a recognition task is a sensitive measure of sequence knowledge only when the presented sub-sequences are the ones that have been encoded during the response time task. Reliable recognition performance was revealed for 4-trial chunks that ended on the serial positions that showed a response time speed-up and for the 3-trial chunks that preceded these serial positions. These findings support the speculation that participants learn 4-trial chunks and that the first triplet of an acquired chunk is used as a cue for the prediction of the last stimulus of the chunk.

Responses to the Questionnaire revealed that participants were actively anticipating the next targets during the response time task. Furthermore, a greater number of participants from the Repeating group thought that the sequence involved a repetition and that their anticipations were successful most of the time. These two statements were found to reliably distinguish participants who showed a response time speed-up from those who did not. Therefore, in the present experiment there is no indication that sequence knowledge develops without the intention to learn or that participants lack metaknowledge of their knowledge. Participants were actively anticipating the next stimuli and were aware that their anticipations were successful. If we apply Allport's (1988) three criteria to the present results, participants' sequence knowledge was conscious because (I) they took direct action on the basis of their knowledge in the response time task (II) they showed reliable recognition of sub-parts of the practised sequence and (III) their subjective reports revealed awareness of the acquired knowledge.
It is worth noting that the question that asked whether participants noticed the presence of a repeating sequence was a fairly reliable predictor of group membership and the response time speed-up during practice. However, this was not the case in the study reported by Willingham et al. (1993). In their experiment participants were willing to report that they had noticed a repeating sequence regardless of whether they had practised with the sequence. Willingham et al. (1993), however, informed both the Control and the Repeating group participants that the stimuli followed a repeating sequence before administering the questionnaire and so they may have introduced demand characteristics that affected their results.

Also, results from the present experiment suggest that although the sequence involved equal target location frequencies, the majority of participants believed that a few target locations were more frequent than others. This implies that verbal reports on target frequencies may not reflect actual target frequencies.

Concerning the organisation of the acquired sequential information, it was confirmed that participants learned the chunks that included two diagonal target movements as well as the chunk that followed the backward movement CAC. If we assume that the first order backward movement serves as a unique event, the sequential network (Keele & Jennings, 1992) may account for the process that underlies learning of the stimuli that follow it. According to this model, the presence of a unique event facilitates the learning process because it provides a unique context that carries over to subsequent events and facilitates discriminability between repeated events in the sequence. A prediction that derives from this model is that if the unique event is removed, subsequent events will no longer be discriminated and therefore accuracy in prediction will drop.
Results in the present experiment, however, do not support such a prediction. Questionnaire responses revealed that the 4-trial chunk that followed the CAC backward movement was the only one that was reported by significantly more participants from the Repeating than from the Control group. The fact that this chunk was not reported as a continuation of the CAC sub-sequence suggests that a unique movement does not necessarily facilitate an associative learning mechanism. It may serve as a demarcation point that facilitates encoding and therefore learning of the chunk that follows.

One problem with the above speculation is that it is based on results from the paper and pencil free recall task. As was mentioned previously, performance on this test may be affected by factors unrelated to the process of sequence encoding and learning, i.e. encoding of general target movements. Therefore, the effect of the presence of backward movements was further investigated in Experiment 8.

7.5. Conclusion

Results from the present experiments suggest that the response time task and a recognition memory task tap the same knowledge base. Another way of testing this, however, is to examine whether some variables differentially affect the two types of tasks. Experiment 8 was designed to test whether manipulating the conditions of practice during the response time task would differentially affect the response times and the measures of memory employed in Experiment 7.
CHAPTER

8

Contextual Interference and Parsing Effects
8.1. INTRODUCTION

A robust effect that has been demonstrated in a variety of studies investigating learning is that a high degree of contextual interference impairs performance during acquisition but facilitates retention and transfer. This effect was first demonstrated by Battig (1972, 1979) for paired-associate learning of verbal material. Battig manipulated contextual interference - or intra-task interference as he initially called it - by increasing the similarity of items to be learned or by varying the processing requirements from trial to trial. He found that interference during initial practice impaired performance during acquisition but facilitated subsequent transfer and retention.

Battig attributed the benefit of practice under high contextual interference to the different strategies employed by the learner at different times throughout the practice session. This results in more distinctive and elaborate memory representations that facilitate retention. Since the initial report by Battig, the contextual interference effect has been demonstrated in a number of different tasks like learning of movement sequences (Shea and Morgan, 1979; Shea and Zimny, 1983: Lee and Magill, 1983), classification based on rules (Hiew, 1977), problem solving (Carlson and Yaure, 1990), and learning of logical rules (Schneider, Healy, Ericsson, & Bourne, 1995).

The first study that tested the effect on learning of movement sequences was carried out by Shea and Morgan (1979). Participants in this study had to practice knocking down three out of six barriers, as fast as possible, in three different sequences and in response to an appropriate stimulus light. Under the high contextual interference condition, the three variations of this task were randomly intermixed across trials. Under the low contextual interference condition, practice of the three variations was blocked: all practice trials on one
variation were completed before the next one was introduced. The random schedule was expected to cause higher contextual interference by virtue of the inter-trial shifts in the cognitive processing required for the planning and execution of each task variation.

Shea and Morgan (1979) confirmed Battig’s observation. The blocked schedule decreased movement times during acquisition but impaired performance in two retention and two transfer tests. Shea and Morgan (1979) advocated the original explanation for the effect offered by Battig, while Shea and Zimny elaborated further on Battig’s original suggestions. According to Shea and Zimny (1983) high contextual interference conditions facilitate simultaneous representation of a number of tasks in working memory. Thus, there is an increased opportunity for comparisons between different tasks and this results in more elaborate and distinctive representations in long term memory.

Lee and Magill (1983) replicated Shea and Morgan’s (1979) and Shea and Zimny’s (1983) findings and also reported that the effect of high contextual interference was found even when the order of the task variations was predictable. A group that practised the three tasks in a fixed serial order and could anticipate which one would follow, showed similar performance to a random group. The crucial factor that facilitated retention and transfer was performance of a different movement pattern on each trial.

Lee and Magill (1983) related the contextual interference effect to the "forgetting" view proposed by Jacoby (1978; Cuddy and Jacoby 1982) to explain the "spacing of repetitions" effect in the learning of verbal material. Jacoby (1978) suggested that the cause of the spacing effect is the process of "effortful" as opposed to "effortless" remembering. More is learned when constructing the items in working memory as opposed to just holding the items in working
memory (Cuddy and Jacoby 1982). In the paradigm used by Lee and Magill, in a blocked condition, the plan can remain in working memory over a number of trials and need not be reconstructed each time. However, in a random condition, previously encoded information about one task variation is partially forgotten due to the intervening trials and has to be reconstructed.

Further support for the action plan reconstruction view was provided by Carlson and Yaure (1990) who studied learning of Boolean logic functions. Participants learned outputs to single equations and were transferred to a problem solving task that required them to chain several equations together to find a solution. Results of two experiments showed the benefit of a random practice schedule. Carlson and Yaure (1990) argued that reinstatement of a processing plan on each practice trial is a requirement for development of successful and efficient access to this plan. Random access is an important constraint in problem solving and random practice facilitates fast and reliable access to problem specific information. This proposal was also supported by Schneider, Healy, Ericsson and Bourne (1995) who investigated contextual interference in a task that required learning logical rules.

What is characteristic of the above studies is that they involved tasks that required either explicit memorisation or explicit learning of rules. For example, in rule learning studies, participants either had to discover and verbalise classification rules (Hiew, 1977) or had to memorise logical rules in order to apply them in a subsequent task (Schneider et al., 1995). In the motor skill learning studies, participants had to memorise the movement patterns associated with the different stimulus lights before practice began. Although illustrations of the movement sequences were on display during the acquisition trials, optimal performance could only be achieved if participants retrieved the movement pattern from memory. Therefore, memorisation of these patterns
was critical for successful performance.

On the other hand, in motor skill learning studies, participants are usually not informed about the retention and transfer tests that follow practice. As far as participants are concerned, the experimenters are interested in the accurate and fast execution of a series of movements; memorising movement patterns is important only to the degree that it serves this purpose. However, the unexpected retention test that follows is essentially a memory task as participants are not presented with the movement diagram. They are only presented with the stimulus light and are told to perform the movement pattern associated with it. Therefore, the performance measures at retention that have been used to demonstrate contextual interference reflect both skilled movement execution and memory for the movement patterns.

One study that separated the effect of skilled motor performance and memory for movement patterns was carried out by Shea, Morgan and Ho (cited in Shea and Zimny, 1983). The tasks performed by participants were similar to the ones used by Shea and Morgan (1979), except that participants tapped touch sensitive disks instead of knocking barriers down. Together with the usual performance measures, Shea, Morgan and Ho (1983) also obtained scores from paper and pencil recognition and recall tests of retention. They reported that a high degree of contextual interference facilitated performance on both memory tests but this facilitation was greater for the recall test.

A contextual interference manipulation could be applied in the incidental sequence learning task. In contrast to the previous studies that have focused on learning of motor-sequences, the demand characteristics of this task do not encourage memorisation of the sequence. Nevertheless participants acquire chunks of the sequence and anticipate next events on the basis of this
knowledge. If speed-up on the last trials of a chunk is based on an active reconstruction of the chunk in working memory, then, as with previous studies, learning under high contextual interference conditions should result in better retention and transfer. In the present SRT task the 12-trial repeating sequence could be separated into two sequences (A and B). A high degree of contextual interference could be created by interchanging the two sequences after a small number of repetitions e.g. A A A B B B A A A B B B. A low degree of contextual interference could be created by interchanging the two sub-sequences after a larger number of repetitions e.g. A A A A A B B B B B B.

Certain predictions concerning the effect of contextual interference during practice could be derived from the connectionist models that have been used for implicit sequence learning. Horak (1992) has shown how a connectionist model that learns a simple force-distance mapping provides a parsimonious account of the contextual interference effect in terms of properties inherent in a parallel distributed network. The learning process of the network may be visualised as a search for the optimal weight configuration in a multi-dimensional space. This optimal weight configuration is the one that minimises the error in the output. In the case of the sequence learning task, a large number of repetitions of one sub-sequence variation would bias the weights of the network towards a "local" solution for this sequence and lead to a faster reduction in error in prediction. An increase in error rate would be evident when the other sequence is introduced. Adjustments of the weights for the second sequence would again be local and this would lead to partial forgetting of the first sequence. On the other hand, a faster transition from one sub-sequence to the next would lead to a slower, more laborious learning process but to a global fit for both sequences.

Now consider what will happen when two groups are later presented with the whole sequence. Essentially the two sub-sequences are interchanged after only
one repetition, e.g. A B A B. The contextual interference group should be faster with this transfer sequence and show a greater improvement with practice due to a more favourable weight configuration. Furthermore, this group would have received a greater amount of practice on the transition from one sequence to the next and would be expected to show smaller error scores on the predictions of the first stimuli of each sequence. Therefore, in line with previous findings, a connectionist network predicts that contextual interference would facilitate performance during transfer.

A connectionist network, however, does not make any predictions concerning the effect of the two practice schedules on recall and recognition which, in this paradigm, are tests of conscious knowledge. A prediction that the group with high contextual interference would show better memory for the practised sequences appears counterintuitive. If anything, a high degree of contextual interference would be expected to make the structure of the sub-sequences less salient and discourage the development of conscious knowledge. For example, Berry and Broadbent (1988) showed that tasks that are difficult and high in complexity discourage the development of conscious verbalisable knowledge of the underlying relationships between the variables. On the other hand, a low degree of contextual interference would be expected to facilitate explicit encoding of the sequences especially if they are short. Furthermore, as the low contextual interference condition involves a larger number of immediate sub-sequence repetitions, the strength of the chunks that are formed are likely to increase faster than in the high contextual interference condition.

Therefore, if it is found that the high contextual interference group outperforms the low contextual interference group after transfer to the 12-trial repeating sequence while the opposite is found for the memory tasks, we would have evidence suggesting that there is no direct correspondence measures of
conscious memory and response times. This result would even suggest that a variable that facilitates performance in the response time task does not necessarily increase performance in tests of conscious memory.

8.2. EXPERIMENT 8

The present experiment tested the effect of contextual interference in the incidental sequence learning task. The SOC 12-trial sequence used in the previous experiments was broken down into two 6-trial sequences. In the low contextual interference condition, six repetitions of the first 6-trial sequence were presented before the second 6-trial sequence was introduced. In contrast, in the high contextual interference conditions the second 6-trial sequence was introduced after only three repetitions of the first one. An initial practice phase with the two sub-sequences was followed by a transfer phase with the 12-trial repeating sequence.

Practice with the two sub-sequences was expected to influence parsing of the whole sequence, when it is introduced in the transfer phase. The two sub-sequences that result from the division of the 12-trial repeating sequence are hybrid sequences with both unique and ambiguous transitions. For example, if the 12-trial sequence is broken in the middle, the first part ABCACD has two unique transitions at serial positions 2 and 6, and four ambiguous transitions. Practice with this sequence may lead to parsing based on the unique elements that will differ from the parsing when the whole ambiguous 12-trial sequence is practised.

Furthermore, findings from previous experiments in the present thesis suggested that practice with the 12-trial SOC sequence may lead to parsing on the basis of certain distinctive movements of the target. A "back and forth"
movement, for example, may serve as a unique event that facilitates learning of
the stimuli that follow. In the present experiment the importance of this
distinctive movement could be examined by dividing the sequence at different
serial positions. For example, the sequence could be divided immediately after
the backward movement. If this movement is important for learning of the
stimuli that follow, this division would be expected to disrupt the response time
speed-up found for these stimuli when the whole sequence is re-introduced
during transfer. The response time speed-up in the transfer phase would
indicate whether this manipulation affected parsing of the sequence. Therefore,
the present experiment compared the response time pattern that resulted from
two different divisions of the 12-trial sequence: one that separated the unique
backward movement (FOB) from the following events and one that did not.

8.2.1. METHOD

8.2.1.1. Design

Two groups practised with two 6-trial sub-sequences under Low or High
Contextual Interference conditions. Furthermore, these groups were divided in
two Parsing sub-groups that practised with different 6-trial sub-sequences.
Those were produced by dividing the 12-trial sequence at different serial
positions.

The practice phase included five blocks of 120 trials and it was followed by a
transfer phase that included two blocks of 120 trials with the 12-trial repeating
sequence. The same generation task and recognition task that were used in
Experiment 7 followed the response time task for all participants. This
allowed a comparison of the groups in the present experiment with the
Repeating group and the Control group of Experiment 7. These groups
practised the 12-trial repeating sequence and the pseudo-random control sequence throughout the seven blocks of trials.

8.2.1.2. Subjects

64 undergraduate psychology students from University College London and Goldsmiths' College served as subjects. They were paid £2 for their participation. They were 19 male and 45 female and their mean age was 22.7 years old. All participants had normal or corrected to normal vision and were naive about the purpose of the experiment. They were asked to volunteer to participate in a experiment that measured reaction time.

8.2.1.3. Stimulus Conditions

The 12-trial sequence was divided at serial position 6 for the first Parsing group and at serial position 2 for the second Parsing group (see Table 8.1). The first division will be labelled Middle parsing and would be expected to disrupt learning of the trials that follow the CAC backward movement as participants would practice the sub-sequence CACDAB rather than CACDBA which is found in the 12-trial sequence* . The second division will be labelled Quartile parsing and is not expected to disrupt learning of the stimuli that follow the CAC backward movement.

In the Low Contextual Interference condition, participants practised with six continuous repetitions of each 6-trial sub-sequence in each practice block. In the High Contextual Interference condition participants also practised with a

* Although the first stimulus that follows the CAC backward movement is the same for both groups, results from Experiment 7 suggested that participants may be learning the three-trial chunk that follows this movement. If this is the case then the two groups are expected to learn two different chunks.
total of six repetitions of each 6-trial sub-sequence in each block. However, they practised three continuous repetitions of one sequence that were followed by three continuous repetitions of the other sequence.

The middle 24 trials in each 120-trial practice block included two repetitions of the 12-trial sequence. This was to introduce a degree of unpredictability of the sequential structure that would discourage participants from employing explicit anticipation strategies. Table 8.2 shows the practice schedule in each block for the Low and High Contextual Interference groups.

The total number of trials when the 6-trial sub-sequences and the 12-trial sequences in each block are added up is 96. The remaining 24 trials to give a total of 120 for each block were filler sub-sequences that were drawn from the

<table>
<thead>
<tr>
<th>Parsing</th>
<th>12-trial Sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle</td>
<td>A B C A C D / B A D C B D</td>
</tr>
<tr>
<td>Quartile</td>
<td>A B / C A C D B A / D C B D</td>
</tr>
</tbody>
</table>

Table 8.2. Practice schedule in each 120-trial block for the Low and High Contextual Interference groups. The two 6-trial sub-sequences are denoted as A and B while the whole 12-trial sequence is denoted as AB.

<table>
<thead>
<tr>
<th>Contextual Interference</th>
<th>120 trial block</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Within first 48 trials</td>
</tr>
<tr>
<td>Low</td>
<td>6 X A</td>
</tr>
<tr>
<td>High</td>
<td>3 X A, 3 X B</td>
</tr>
</tbody>
</table>
12-trial sequence. These were placed in two locations within each block:

a) between the sub-sequence repetitions and the two 12-trial repetitions. This allowed a smooth transition from the sub-sequence to the whole sequence and vice versa. The length of these fillers varied and depended on the sub-sequence that was repeated. For example, if the sub-sequence ended on serial position 8, the filler that allowed the transition to the middle 12-trial sequence consisted of the sub-sequence from serial positions 9 to 12.

b) filler short sequences at the beginning and at the end of the 120-trial sequence. The length of these fillers was set so that the total number of trials in each block was 120.

All filler sequences were part of the 12-trial sequence. The order of sub-sequence presentation for both the low Contextual interference (CI) and high CI groups was counterbalanced. Half of the participants in each group received sub-sequence A first and the other half received sub-sequence B first. The exact sequences that were used in each condition are presented in Appendix 11.

8.2.1.4. Procedure

The instructions about the task were the same as in Experiment 7. The response time task lasted for seven blocks of 120 trials. After the end of the seventh block participants were given new instructions about the next task. Half of the them performed a generation task first and a recognition task later and the other half received these two tasks in the opposite order. It was stressed that they had to generate sub-sequences from the initial response time task and make the recognition judgements on this basis too. At the end of the
experiment participants were debriefed and thanked for their participation.

8.2.2. RESULTS

The results are divided into three main sections that present analyses of the response time task, the generation task and the recognition task. Each section examines the effect of Contextual Interference and Parsing and compares the Contextual interference and Parsing sub-groups with the Repeating group and the Control group of Experiment 7.

8.2.2.1. Response Time Task.

8.2.2.1.1. Response Times to the Practice and Transfer Blocks

None of the variables affected error scores which ranged from 3% to 5% in each 120-trial block. Consequently only response time analyses will be reported. Order of the memory test was not found to interact with any of the other factors and, as it was not expected to influence response times, it was not included in the following analyses.

Median response times of correct responses were calculated for every 12 trials. Means of the 10 medians from each one of the seven blocks were submitted to a two (Parsing: Middle vs Quartile) X two (Contextual Interference: Low vs High) X seven (Blocks) analysis of variance with repeated measures on the last factor. Mean response times and standard deviations on each block for all Parsing and Contextual Interference sub-groups are presented in Table 8.3.

There was a significant main effect of Block (F(6,360)=38, MSe= 17442, p<0.0001) and a significant interaction between Contextual Interference and Block
(F(6,360)=5, MSe= 2292, p<0.0001). Response times for the Contextual interference groups are presented in Figure 8.1. Contextual interference was expected to affect response times both in the initial blocks that involved practice with the two sub-sequences and in the final transfer blocks but to do so in

Table 8.3. Response times on each 120-trial block for the Contextual Interference and Parsing sub-groups and for the Control group and the Repeating group of Experiment 7. (M: mean , SD: Standard deviation). Pooled response times for the two Contextual Interference groups that are presented in Figure 8.1 are shaded.

<table>
<thead>
<tr>
<th>Group</th>
<th>Block</th>
<th>Practice</th>
<th>Transfer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 2 3 4 5</td>
<td>6 7</td>
</tr>
<tr>
<td>LOW CI</td>
<td>Middle M</td>
<td>376 347 355 353 341</td>
<td>343 333</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>50 48 45 43 42</td>
<td>46 43</td>
</tr>
<tr>
<td></td>
<td>Quartile M</td>
<td>367 340 331 330 316</td>
<td>328 323</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>45 51 46 41 34</td>
<td>41 37</td>
</tr>
<tr>
<td></td>
<td>Pooled M</td>
<td>371 344 343 342 328</td>
<td>335 328</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>47 49 47 43 40</td>
<td>44 39</td>
</tr>
<tr>
<td>HIGH CI</td>
<td>Middle M</td>
<td>367 358 351 344 337</td>
<td>324 308</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>56 38 45 50 45</td>
<td>50 43</td>
</tr>
<tr>
<td></td>
<td>Quartile M</td>
<td>359 348 339 323 326</td>
<td>305 305</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>38 37 35 36 35</td>
<td>31 36</td>
</tr>
<tr>
<td></td>
<td>Pooled M</td>
<td>363 353 345 333 332</td>
<td>315 307</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>47 37 40 44 40</td>
<td>42 39</td>
</tr>
<tr>
<td>Control</td>
<td>M</td>
<td>398 371 353 364 360</td>
<td>357 357</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>54 50 39 46 36</td>
<td>43 36</td>
</tr>
<tr>
<td>Repeating</td>
<td>M</td>
<td>378 346 348 342 342</td>
<td>325 312</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>53 43 59 56 51</td>
<td>44 49</td>
</tr>
</tbody>
</table>
When the analysis was carried out on the initial five practice blocks no main effect or interaction involving contextual interference emerged. However, when the analysis was carried out for the last three blocks that included the last sub-sequence practice block and the two whole-sequence transfer blocks, the interaction between Contextual Interference and Block was significant (F(2,120)= 11.2, MSe= 285, p<0.0001). A priori contrasts tested the difference between block 5 and blocks 6, 7 and between block 6 and block 7. The interaction between Contextual interference and the first contrast was significant (F(1,60)=18, MSe= 355, p<0.0001) indicating that the High Contextual Interference group showed faster performance than the Low Contextual Interference group after transfer to the 12-trial sequence blocks. Simple effects analysis revealed that the difference between the two groups reached a
significant level only on the last transfer block \(F(1,160)=4.67, \text{MSE}=1609, p<0.035\). The difference on the first transfer block just failed to reach significance \(F(1,60)=3.62, \text{MSE}=1873, p<0.062\).

There was also a significant interaction between Parsing group and the second contrast which compared the two transfer blocks \(F(1,60)=4.42, \text{MSE}=215, p<0.04\). Simple effects analysis revealed that a reliable performance speed-up from the first transfer block to the second was evident only for the Middle Parsing group \(F(1,60)=12.65, \text{MSE}=215, p<0.001\). However, as shown in Table 8.3 this group was slower in the first transfer block and achieves the performance level of Quartile group only in the last block.

Results indicate that a high degree of contextual interference facilitated performance when the whole sequence was introduced in blocks 6 and 7. Also the Middle Parsing group reached the level of Quartile group only in the second transfer block. Therefore, practice with the Quartile sub-sequences caused a similar performance facilitation for both transfer blocks while practice with the Middle sub-sequences caused a gradual facilitation from the first to the second transfer block.

In order to test whether the four sub-groups showed reliable learning of the whole repeating sequence, they were separately compared to the Control group. The only sub-group that did not show a reliable speed-up in comparison to the Control group was the Low-CI Middle parsing group. All other groups showed reliable evidence for sequence learning (a detailed analysis is presented in Appendix 12). Also as shown in Table 8.3, both High Contextual Interference sub-groups actually achieved slightly faster response times in the second transfer block than the Repeating group that practised with the 12-trial sequence throughout. However, when all four sub-groups were compared to the
Figure 8.2. Separation of the sequence for the Middle and Quartile Parsing groups. Serial positions that were not practised by the two groups due to the repetition of the 6-trial sub-sequences are in bold characters.

Repeating group, no reliable differences emerged for any of the comparisons.

8.2.2.1.2. Comparison of Serial Positions in the Transfer Blocks.

The response time pattern over the 12 Serial positions of the sequence was expected to differ for the two Parsing groups. Figure 8.2 shows the serial positions that received limited practice by the two Parsing groups due to the repetitions of the 6-trial sub-sequences.

Serial positions 3, 4, 5 and 9, 10 and 11 were not practised by the Quartile group while serial positions 1, 2, 3 and 7, 8 and 9 were not practised by the Middle group. Apart from serial positions 3 and 9 that were not practised by either group, the rest should show group differences when the transfer 12-trial sequence is introduced. Table 8.4 shows the mean response times of the two Parsing groups on each Serial Position for the middle Repeating sequences of blocks 6 and 7. Mean response times of the Control and Repeating groups from
Experiment 7 are also presented for comparison.

A two (Parsing group) X two (Contextual Interference group) X 12 (Serial positions) X two (Block 6, 7) analysis of variance with repeated measures on the last two factors was carried out on the average response times for the two middle repeating sequences. As with the analysis on mean response times for the whole block, a significant Parsing by Block interaction also emerged in this analysis ($F(1,53)=4.45, \text{MSe}= 7819, p<0.04$). This was due to the greater speed-up observed for the Middle Parsing in comparison to the Quartile Parsing group from the first to the second transfer block. However, a reliable three-way

<table>
<thead>
<tr>
<th>Group</th>
<th>Serial</th>
<th>Location</th>
<th>Middle</th>
<th>Quartile</th>
<th>Control</th>
<th>Repeating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>330 (84)</td>
<td>307 (68)</td>
<td>355 (53)</td>
<td>301 (74)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>342 (96)</td>
<td>330 (73)</td>
<td>345 (42)</td>
<td>336 (59)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>287 (70)</td>
<td>324 (79)</td>
<td>313 (52)</td>
<td>268 (34)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>379 (74)</td>
<td>376 (81)</td>
<td>355 (61)</td>
<td>337 (71)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>361 (72)</td>
<td>385 (91)</td>
<td>446 (76)</td>
<td>420 (131)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>371 (102)</td>
<td>376 (70)</td>
<td>406 (48)</td>
<td>303 (144)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>293 (72)</td>
<td>279 (50)</td>
<td>347 (84)</td>
<td>248 (101)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>337 (83)</td>
<td>288 (64)</td>
<td>341 (59)</td>
<td>290 (69)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>340 (80)</td>
<td>360 (81)</td>
<td>402 (89)</td>
<td>303 (91)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>330 (94)</td>
<td>315 (60)</td>
<td>363 (78)</td>
<td>336 (91)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>284 (66)</td>
<td>294 (73)</td>
<td>335 (62)</td>
<td>299 (103)</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>373 (67)</td>
<td>353 (69)</td>
<td>384 (64)</td>
<td>381 (85)</td>
<td></td>
</tr>
</tbody>
</table>
interaction between Contextual Interference, Parsing group and Block
\(F(1,53)=4.18, \text{MSe}=7819, p<0.046\) suggested that this greater speed-up for the Middle group was only found for one of the Contextual interference sub-groups. Simple effects analyses revealed that only the High-CI Middle group achieved the fast response times by the last transfer block \(F(1,23)=6.89, \text{MSe}=8713, p<0.015\). The Low-CI Middle group did not.

There was also a significant Parsing group by Serial position interaction \(F(11,583)=3.26, \text{adj. df (9,495) MSe}=5167, p<0.01\). Simple effects analyses were carried out for all 12 serial positions. The Middle group outperformed the Quartile group on Serial position 3 \(F(1,53)=8.6, \text{MSe}=8047, p<0.005\), while the Quartile group outperformed the Middle group on Serial position 7 \(F(1,53)=4.64, \text{MSe}=4847, p<0.036\) and Serial position 8 \(F(1,53)=12.4, \text{MSe}=6740, p<0.001\).

The differences on serial positions 7 and 8 were as predicted. On the other hand, no difference was predicted for serial position 3 as neither group practised with the transition between the last and first serial positions of the sequence. However, the Middle group did receive practice with the 4-trial chunk DABC that ends on SP3 but did so in a different context. This chunk was part of the first Middle 6-trial sub-sequence. A repetition of this 6-trial sequence resulted in an alternation between the backward movement CAC and the chunk DABC (see Table 8.1). Therefore it appears that acquired chunks may elicit fast response times even when they are presented in a different context from the one in which they were originally practised. Although in the 6-trial practised sequence the chunk DABC immediately followed the movement CAC, in the 12-trial sequence DABC it appears seven trials after CAC. Nevertheless, the Middle group recognised this chunk and speeded up responses to the last stimulus in it.
A comparison of each one of the Parsing groups with the Control group revealed the expected pattern of results. A summary of the reliable differences on each serial position is presented in Table 8.5, while a more detailed description of the analyses is presented in Appendix 13.

As can be seen in Table 8.5 the Middle group learns serial positions that include 9, 10 and 11 while the Quartile group learns serial positions that include 5, 6, 7 and 8. These were the parts of the sequence that were practiced by the two groups. It seems that the association of CAC with the chunk DABC during practice for the Middle group interferes with learning of the new chunk DBA that follows CAC in the whole repeating sequence. Furthermore, the speed-up for the series of three trials that follow the triplet DBA on serial position 8 for

<table>
<thead>
<tr>
<th>SP</th>
<th>Stimulus</th>
<th>Middle</th>
<th>Quartile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td></td>
<td>*p&lt;0.020</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>*p&lt;0.034</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>*p&lt;0.001</td>
<td>*p&lt;0.011</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td></td>
<td>p&lt;0.051</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td></td>
<td>*p&lt;0.001</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td></td>
<td>*p&lt;0.002</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>*p&lt;0.031</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>p&lt;0.052</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>*p&lt;0.021</td>
<td>*p&lt;0.008</td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
the Middle group is found because this triplet was followed by the same stimuli in the second 6-trial sub-sequence that was practised by this group (see Table 8.1). On the other hand the Quartile group shows the response time pattern found for the Repeating group in Experiment 6. It learns the stimuli that follow the backward movement CAC and the diagonal movements at serial positions 11 and 1. Clearly the chunks that were formed during practice affect the encoding of the sequence during transfer.

8.2.2.2. Free Generation Task

In order to test whether the level of Contextual interference during practice affects subsequent generation of the repeating sequence, sequences generated by the two groups were compared for each one of the Serial Positions of the sequence. The difference between them did not reach significance for any of the comparisons.

The four sub-groups were also compared to the Control group in order to test whether they showed reliable sequence knowledge. Order of explicit test was not found to affect the results so it will not be included in the reported analyses. Mean generation scores and number of participants that generated at least one sub-sequence for each serial position are shown in Tables 8.6 and 8.7. Sub-sequences that were generated significantly more times by the sub-groups than by the Control group are shaded and marked with an asterisk. Exact values for the statistical tests and probability levels can be found in Appendix 14.

Results appear to be consistent. All sub-groups generate more sub-sequences that end on the last trial of the alternation CAC and the trials that follow it. The Middle Low-CI sub-group outperforms the Control group, however, only on the
Table 8.6. MIDDLE PARSING GROUP: Mean number of generated sub-sequences for each Serial Position (in parentheses: number of participants who generated the sub-sequence at least once). SP: Serial Position, SL: Stimulus location, LCI: Low Contextual Interference, HCI: High Contextual Interference. Three comparisons are expected to reach significance by chance.

<table>
<thead>
<tr>
<th>SP</th>
<th>SL</th>
<th>Group</th>
<th>Length of generated sub-sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>LCI</td>
<td>2.8 (14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>4.3 (15)</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>LCI</td>
<td>3 (13)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>4.3 (16)</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>LCI</td>
<td>3.8 (14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>4.4 (16)</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>LCI</td>
<td>3.6 (16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>3.2 (14)</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>LCI</td>
<td>3.6 (14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>4.1 (14)*</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>LCI</td>
<td>4.1 (15)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>5.2 (16)</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>LCI</td>
<td>5.1 (14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>5.6 (16)</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>LCI</td>
<td>4.8 (15)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>5.6 (16)</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>LCI</td>
<td>3.8 (14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>5 (16)</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>LCI</td>
<td>4.3 (14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>4.1 (15)</td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>LCI</td>
<td>3.5 (15)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>3.6 (15)</td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>LCI</td>
<td>2.6 (13)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>3.7 (14)</td>
</tr>
</tbody>
</table>
Table 8.7. QUARTILE PARSING GROUP: Mean number of generated sub-sequences for each Serial Position (in parentheses: number of participants who generated the sub-sequence at least once). SP: Serial Position, SL: Stimulus location, LCI: Low Contextual Interference, HCI: High Contextual Interference. Three comparisons are expected to reach significance by chance.

<table>
<thead>
<tr>
<th>SP</th>
<th>SL</th>
<th>Group</th>
<th>Length of generated sub-sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>LCI</td>
<td>3.5 (14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>4.5 (15)</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>LCI</td>
<td>4.1 (14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>3.6 (16)</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>LCI</td>
<td>3.2 (15)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>2.4 (14)</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>LCI</td>
<td>2.9 (15)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>3.3 (14)</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>LCI</td>
<td>2.3 (13)*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>4.8 (14)</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>LCI</td>
<td>4.9 (16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>5.4 (16)</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>LCI</td>
<td>5.3 (14)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>2.8 (14)</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>LCI</td>
<td>4.3 (16)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HCI</td>
<td>3.7 (13)</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>LCI</td>
<td>3.8 (16)</td>
</tr>
</tbody>
</table>
5-trial sub-sequences that end on SP6. These results parallel the response time results. The Middle Low-CI sub-group was the only group that did not show reliable performance savings on the response time task.

The Middle High-CI sub-group outperforms the control group on SP5, SP6, SP7 and SP3. The Quartile Low-CI group outperforms the Control group on the sub-sequences that end on SP5, SP6, and SP7. Finally the Quartile High-CI group outperforms the Control group on sub-sequences that end on SP5, SP6, SP7 and SP8. These results support the argument that the backward movement in the sequence provides a parsing point that facilitates learning of subsequent events. It even appears that the frequency of generation of the sub-sequences around the backward movement CAC is related to the response time speed-up. All sub-groups, apart from the Middle Low-CI, generated these sub-sequences and also showed a reliable response time speed-up.

Furthermore, the Middle High-CI group was found to generate the serial positions that follow CAC although initial practice with the Middle 6-trial sub-sequences was expected to interfere with learning these serial positions (see Table 8.1). It seems that, by the end of practice, this group managed to overcome the expectancies for the chunk DABC that followed CAC during practice and associate CAC with the new chunk DBA that is found in the 12-trial repeating sequence. On the other hand, the fact that the Middle Low-CI group did not express any knowledge of the 12-trial repeating sequence either during the response time task or in the generation task may be due to a combined effect of unfavourable parsing and low contextual interference during practice.

The relationship between response times and generation performance was also examined. Total number of generated sub-sequences was correlated with mean response times for blocks 6 and 7 and with difference response times between
the first and the last block. Also, mean response times for each serial position of the 12-trial sequence in the last practice block were correlated with the number of generated sub-sequences that ended on that serial position. In order to increase the power of the test, correlations were computed for all participants in the Contextual interference and Parsing sub-groups as well as in the Repeating group. This amounted to a total of 80 participants (correlation coefficients computed separately for each sub-group are reported in Appendix 15).

The correlations between response time differences and generation scores were very low (0.1) and will not be reported. However, when generation scores and response times on each serial position were examined, reliable correlations were found for the 3-trial and 6-trial sub-sequences on SP1 (r= 0.29, p<0.01, r= 0.29, p<0.01 respectively) and 3-trial sub-sequences on SP6 (r= 0.31, p<0.01). Table 8.8 shows the correlation coefficients between mean response times for the last two blocks and the total number of generated sub-sequences that matched sub-sequences in the repeating sequence.

8.2.2.3. Recognition Task

Six out of the twelve new sub-sequences that were presented in the recognition task were excluded from the analyses as they included triplets that were part of initially practised 6-trial sub-sequences for both parsing conditions. The mean

| Table 8.8. Correlation coefficients between total number of correctly generated sub-sequences and mean response times in blocks 6 and 7 for 80 participants. |
|------------------|------|------|------|------|
|                  | 3    | 4    | 5    | 6    |
| Block            |      |      |      |      |
| 6                | -0.26* | -0.20 | -0.20 | -0.19 |
| 7                | -0.31* | -0.28* | -0.26* | -0.27* |
recognition rating for the remaining six were subtracted from the mean rating for the Old sub-sequences. The difference scores were entered into a two (Parsing: Middle vs Quartile 1) X two (Contextual Interference: High vs Low) analysis of variance. (Order of the recognition test was not found to interact with any of the other factors and will not be reported in the following analyses.) Means and standard deviations for the difference recognition ratings are presented in Table 8.9.

There were no differences between any of the factors. Each one of the sub-groups was also compared to the Control group to establish whether they showed reliable recognition performance. There was a significant main effect of Group only for the comparison between the Middle Low-CI and the Control group (F(1,30)=8.06, MSe= 1.12, p<0.008). The reliable recognition performance for the Repeating group that was found in Experiment 7 was also found in the present analyses with the new recognition scores (F(1,30)=4.53, MSe= 2.03, p<0.042).

The reliable recognition performance of the Middle Low-CI group is the only indication that a low contextual interference condition may facilitate memory

Table 8.9. Means and standard deviations (in brackets) of the Difference recognition scores for the Contextual Interference and Parsing sub-groups, the Control group and the Repeating group from Experiment 7.

<table>
<thead>
<tr>
<th>CI</th>
<th>Parsing</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Middle</td>
<td>1.2 (0.8)</td>
</tr>
<tr>
<td></td>
<td>Quartile</td>
<td>0.6 (1.0)</td>
</tr>
<tr>
<td>High</td>
<td>Middle</td>
<td>0.8 (1.5)</td>
</tr>
<tr>
<td></td>
<td>Quartile</td>
<td>0.6 (1.4)</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>0.1 (1.2)</td>
</tr>
<tr>
<td>Repeating</td>
<td></td>
<td>1.2 (1.6)</td>
</tr>
</tbody>
</table>
for the practised sub-sequences. On the other hand, this group did not express any sequence knowledge during the response time task or during the generation task. This suggests that reliable recognition memory for sub-sequences is not a sufficient condition for the development of a reliable performance speed-up. Although the Middle Low-CI group recognised parts of the sequence, it could not utilise this knowledge during the transfer phase of the response time task. It may be the case that this group employs an explicit strategy during practice that facilitates recognition but that is detrimental to response time performance during transfer.

The four Parsing and Contextual Interference sub-groups were also compared with the Control group on each one of the six old sub-sequences. A difference score was calculated by subtracting the mean recognition rating to the new sub-sequences from the recognition rating to each one of the old sub-sequences. Table 8.10 summarises the results of the analyses (F values and probability levels are presented in Appendix 16). The reliable comparisons with the Control group are shaded, while the reliable comparisons with the chance score of zero

Table 8.10. Difference recognition ratings for each one of the Old sub-sequences, for the CI and Parsing sub-groups, and the Repeating and Control groups from Experiment 7. Shading denotes a reliable difference from the Control group and an asterisk denotes a reliable difference from the chance score of zero. ML: Middle Low-CI, MH: Middle High-CI, QL: Quartile-Low CI, QH: Quartile High-CI, R: Repeating, C: Control groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>SP7</th>
<th>SP11</th>
<th>SP3</th>
<th>SP5</th>
<th>SP9</th>
<th>SP1</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML</td>
<td>-0.3 (2.9)</td>
<td>2.4 (1.1)*</td>
<td>1.6 (1.5)*</td>
<td>1.2 (3.3)*</td>
<td>1.2 (2.3)</td>
<td>1.1 (2.5)</td>
</tr>
<tr>
<td>MH</td>
<td>-1.2 (2.6)</td>
<td>1.7 (2.4)*</td>
<td>0.2 (2.1)</td>
<td>1.9 (2.7)*</td>
<td>0.6 (2.8)</td>
<td>0.5 (2.6)</td>
</tr>
<tr>
<td>Q L</td>
<td>0.4 (3.2)</td>
<td>1.4 (2.1)*</td>
<td>1.1 (2.0)</td>
<td>1.7 (2.2)*</td>
<td>0.2 (2.6)</td>
<td>-0.2 (2.8)</td>
</tr>
<tr>
<td>Q H</td>
<td>-0.8 (2.8)</td>
<td>0.4 (2.7)</td>
<td>0.08 (2.6)</td>
<td>2.7 (1.7)*</td>
<td>1.4 (2.1)*</td>
<td>0.02 (2.6)</td>
</tr>
<tr>
<td>R</td>
<td>1.6 (3.3)</td>
<td>0.5 (3.6)</td>
<td>1.6 (3.0)</td>
<td>1.7 (3.5)*</td>
<td>-0.1 (2.7)</td>
<td>1.8 (2.6)*</td>
</tr>
<tr>
<td>C</td>
<td>-1.7 (2.7)</td>
<td>0.8 (2.5)</td>
<td>0.0 (2.7)</td>
<td>1.0 (2.7)</td>
<td>0.5 (2.7)</td>
<td>0.2 (1.8)</td>
</tr>
</tbody>
</table>
are marked with an asterisk.

As can be seen in Table 8.10, all groups exceed the chance score of zero for the SP5 sub-sequence that ends on the first order backward movement CAC and all groups, apart from the Middle High-CI group, outperform the Control group on at least one sub-sequence.

Recognition ratings on each one of the Old 4-trial sub-sequences were also correlated with response times and with the number of generated sub-sequences for the last stimulus in the recognition sub-sequence. Recognition ratings for the sequence that ended on SP7 correlated with both response times on that serial position (-0.29, p<0.1) and with the number of generated 4-trial sub-sequences (0.3, p<0.01) that ended on that position. Also, recognition ratings for the sequence that ended on serial position 11 correlated with number of generated 3-trial sub-sequences on that serial position (0.27, p<0.01).

8.2.3. DISCUSSION

Experiment 8 showed that, compared to practice under conditions of low contextual interference, practice with two 6-trial sub-sequences under conditions of high contextual interference leads to faster performance to a transfer 12-trial sequence that consists of the two sub-sequences. This finding is in line with the predictions from connectionist models that have been applied to sequence learning as well as with findings from studies that tested the effect of contextual interference with different experimental paradigms (Battig, 1972, 1979; Shea and Morgan, 1979; Shea and Zimny, 1983; Lee and Magill, 1983; Hiew, 1977; Carlson and Yaure, 1990; Schneider et al. 1995).
However, in contrast with previous findings, a high degree of contextual interference during practice did not facilitate performance on recall and recognition memory tests. For example, Shea, Morgan and Ho (cited in Shea & Zimny, 1983) have reported that a high degree of contextual interference during practice with three different movement sequences facilitated memory for sequences that were introduced during a later transfer phase. In the present experiment a different pattern of results emerged. The Middle Low Contextual Interference sub-group was the only one that showed reliable recognition performance for sub-parts of the transfer sequence. On the other hand, this sub-group was the only one that did not show reliable response time and free generation performance for the 12-trial transfer sequence.

This obtained dissociation of the knowledge expressed in the three tasks suggests that reliable recognition memory for sub-parts of the sequence does not necessarily translate into fast performance in the response time task. Also, the reliable speed-up during the response time task is not necessarily accompanied by reliable recognition performance. A possible explanation for the latter finding is that the sub-sequences presented in the recognition task did not elicit the acquired sequence knowledge that allowed a performance speed-up, because participants were encoding the sequence in a different way during practice. As we have seen in Chapter 7, reliable recognition performance will only be expressed if the sub-sequences presented in the recognition task match the ones that were encoded during practice. This explanation is supported by the fact that the sub-groups that showed reliable performance speed-up showed above chance recognition performance for a subset of the sub-sequences that were presented in the recognition task.

Also, a possible explanation for the finding that reliable recognition performance may not be accompanied by reliable response time performance, is
that structural characteristics of the 12-trial transfer sequence may prevent identification of the sub-sequences that were acquired during initial practice with the 6-trial sub-sequences. If participants are unable to identify the beginning of an acquired chunk, they would also fail to show a speed-up for the final stimuli of this chunk.

The above speculation is partly supported by the finding that a first-order backward movement influenced encoding and organisation of the sequence. It was hypothesised that this movement serves as a parsing point that facilitates learning of the chunk that follows. Results provided some support for this prediction: the Middle parsing group learned the chunks that followed the first-order backward movements in the 6-trial practice sub-sequences. This was expressed in fast response times during transfer to these chunks although they did not follow the first-order backward movements that they were associated with during practice. Furthermore, learning of the chunk that followed the backward movement CAC during practice also resulted in negative transfer for the new chunk that followed the same backward movement in the transfer sequence.

However, the response time pattern to the stimuli that follow the CAC backward movement also suggests that this movement may serve as an event that provides a unique context for the following stimuli and facilitates learning of associations between successive stimuli. This is the learning process implemented by the sequential network (Keele & Jennings, 1992). This process was supported by the observed response time speed-up to all stimuli of the chunk that follows CAC for the repeating group of Experiment 7 that practised the 12-trial sequence throughout. A response time speed-up, however, is only found for the last stimulus of this chunk when it is presented in a transfer sequence and does not follow the backward movement it was originally
It is worth noting that only the Middle High Contextual Interference sub-group managed to associate the first order backward movement CAC with the new chunk that was presented during transfer and that this was also the only Middle sub-group that showed a reliable response time speed-up in the last block. It may be the case that, unless an anchor point is identified, sub-sequence knowledge will not be expressed in a performance speed-up. This may explain why the sub-group that showed reliable recognition performance did not show reliable response time speed-up: the employment of a strategy of optimising preparation for the next event on the basis of sub-sequence knowledge may only be possible when the sequence is optimally parsed and the acquired chunks can be identified.

8.3. Conclusion

Experiment 8 showed that perfect transfer will be shown if sub-parts of a sequence are practised under conditions of favourable parsing and high contextual interference but no transfer will be shown when practice involves a combination of unfavourable parsing and low contextual interference conditions.

Although Experiment 8 demonstrated a dissociation of the knowledge expressed in the response time task and the knowledge expressed in a recognition memory task, this finding can not be unequivocally taken as evidence in favour of the existence to two independent knowledge bases that support performance in the two tasks. It may be the case that the recognition task accesses the same knowledge base used for the response time task but only does so if recognition memory is tested with the same chunks that have been
formed by participants during practice. The fact that the present experiment manipulated parsing during practice suggests that learning of different chunks in the two parsing conditions may have caused the lack of correspondence between the response time task and the recognition task. Nevertheless, as the dissociation was found only under a combination of parsing and contextual interference conditions during practice, a further investigation of this finding would not be amiss.
CHAPTER

9

General Discussion
9.1. Overview Of Main Experimental Findings

The first two experiments in the present thesis tested whether practice with a repeating sequence that was generated according to some non-salient rules would lead to learning of rules, learning of regularities of target movements or learning of specific instances of the repeating sequence. Results suggested that learning was based on memory for instances and they were in line with those reported by Perruchet et al. (1990) and Perruchet (1994). A memory-based process of learning appeared to be facilitated by the immediate repetitions of certain sub-chunks of the sequence (i.e. triplet repetitions). On the other hand verbally expressed knowledge of regularities in the practised sequence did not accompany this memory-based speed-up. Rather, verbally expressed knowledge resulted in a performance facilitation even to new sequences that involved the same regularities that were present in the old sequences.

Experiments 3 and 4 demonstrated the influence of higher-order sequential effects on response times in the SRT task. This influence may contaminate an item-by-item analysis of the practised repeating sequence and may invalidate conclusions about the type of sequential information that was acquired. Experiments 5, 6, 7 and 8 were designed to control for these sequential effects and to investigate in some detail the development of sequence knowledge when participants practice with a short repeating sequence.

Experiment 5 tested whether a response time speed-up develops in parallel for all serial positions of the Second Order Conditional 12-trial sequence introduced by Reed and Johnson (1994). It was found that, during the initial stages of practice and under conditions of full attentional availability, a speed-up occurs only for a subset of the serial positions in the sequence. This finding suggests that participants developed knowledge of selected chunks in the sequence
rather than knowledge of the associations between all possible pairs of stimuli and the stimulus that follows (second order conditional information). Further evidence in favour of this conclusion was obtained in Experiment 6 which tested directly whether the length of the acquired sub-sequences was greater than three trials. In Experiment 6, the presentation of a random pattern of circles in the inter-trial interval after every three targets was found to eliminate the response time speed-up of the Repeating group. It was therefore concluded that successful anticipation of the next target was based on the perception of sub-sequences longer than three-trial.

A correspondence between performance in the response time task and a free-generation task was found in Experiment 5 only when knowledge of sub-parts of the sequence were examined. However, a detailed analysis showed that there was some residual knowledge of chunks that was expressed in the response time task but not in the generation task. Experiment 7 showed that this was due to the insensitivity of the generation task: a recognition task of 4-trial sub-parts of the sequence was sensitive even to the sub-sequence knowledge that was not expressed in the generation task. Response time performance was also found to be accompanied by metaknowledge: fast participants were aware that their anticipations in the response time task were successful and that there were regularities in the stimulus-series (Experiment 6).

Finally, practising two 6-trial sub-sequences under conditions of high contextual interference resulted in perfect transfer to the 12-trial sequence that consisted of the two 6-trial sub-sequences (Experiment 8). Also, practising under a combination of low contextual interference and unfavourable parsing conditions led to a reliable recognition performance of sub-parts of the transfer sequence which was not accompanied, however, by a reliable performance speed-up during transfer. This pattern of results suggest that there is no direct
correspondence between the processes that allow a performance speed-up in the response time task and recognition memory for sub-parts of the sequence.

9.1.1. Development and Representation of Sequence Knowledge.

The chunking process that was in operation in the present series of experiments appeared to be determined by some easily encoded target movements. Participants acquired full coverage movements of the target and especially those that included two diagonal movements. They also acquired a chunk that followed the unique first-order-backward movement of the target. In the former case, the chunk involved a repetition of a horizontal-diagonal movement sequence followed by another horizontal-diagonal movement sequence. While in the latter case the backward-movement involved a (vertical) movement repetition that occurs only once in the sequence. Therefore, it may be suggested that learning of the sequence is based on a decaying memory trace of previous events - similar to the one modelled by the buffer network - but on an encoding of both target movements and identities of the four different stimuli. For example, if a network is presented with movement as well as stimulus identity information, the horizontal-diagonal-horizontal sequence will be expected to develop strong connections with the diagonal movement that follows, and the vertical-vertical pair will be expected to develop strong connections with the stimuli and the movements that follow. Thus, learning of subsequent stimuli will be facilitated.

Encoding of target movements could indeed partially account for the observed response time speed-up to the serial positions of the 12-trial SOC sequence if predictions were based on a context of two previous movements of the target. If this was the case, however, the question that arises is why should two previous movements rather than two previous stimuli be used to predict subsequent
targets. Second order conditional movement information can only predict a subset of the stimuli in the sequence while second order conditional stimulus identity information can be used to predict all stimuli in the sequence. It is difficult to explain why a mechanism should favour the former over the latter.

An alternative account is that, rather than using target movement information to predict subsequent stimuli, a mechanism may use movement information as an aid in a process of parsing and chunk-formation. For example, diagonal movements are longer than the vertical and horizontal movements which are of equal length. Therefore a diagonal movement may serve as a natural anchor point that will facilitate the formation of a chunk. The same applies to the backward movement which is unique because it occurs only once in the present sequence and because it is inhibited by the attentional mechanism of inhibition of return. The uniqueness of the backward movement may explain the different pattern of response times that is caused by the diagonal and backward movement influence. While the diagonal chunks showed a speed-up only to their final stimulus, the chunks that followed a unique event showed a speed-up to both their final and initial stimuli. In the former case the first triplet of the chunk served as a cue for the prediction of the last stimulus while in the latter case the backward movement served as the cue for the prediction of the following chunk.

The employment of a chunking mechanism is also supported by the observed positive transfer when the chunk that followed the backward target movement during practice was presented after a different sequential context during transfer. In this case a speed-up was found only for its last stimulus (Experiment 8) which suggests that the chunk was acquired independently of the context it was associated with. Furthermore, knowledge of chunks will not
be expressed unless some anchor points that facilitated their encoding are identified (Experiment 8).

These results support a hybrid model that involves both a process of learning associations between events - similar to the one modelled by the sequential network - and a process of parsing and learning of chunks. Learning of associations will develop between unique events (even if these events are target movements) and the ones that follow them. Furthermore, the formation of chunks depends on a natural parsing of the sequence on the basis of unique events, while the acquired chunks are not necessarily associated with the previous context. Finally, expression of sequence knowledge depends both on knowledge of chunks and on optimal parsing of the sequence so that the acquired chunks can be identified.

One question that is raised by the observed influence of target movements on the learning process is whether participants acquired specific instances of the practised sequences or specific instances as well as the general abstract movements that characterised them. It was found that the Repeating group that practised with only one instance of an FOB movement generated a reliably smaller number of FOB movements than the Control group which practised with different instances of FOB movements. This was so despite the fact that the proportion of this movement type in relation to the other movements in the practised sequences was similar for both groups. On the other hand, a bias towards chunks with the same target movements was found when participants were asked to write on a piece of paper instances of the sequence they could recall from the practice phase. They were found to report full coverage movements of the target that were not necessarily part of the practised sequence, a behaviour which reveals abstraction.
These two findings suggest that variability of the movement instances during practice facilitates recall of instances of the specific movement type and that knowledge of instances may lead to behaviour that reveals abstraction. Practice of instances of the same movement may strengthen the representation of the general movement which may be used as a cue in a demanding recall task. On the other hand, this abstraction phenomenon was not observed in the more sensitive recognition task. Participants in Experiment 7 recognised the exact instances they had practised and did not show any bias for new instances with symmetrical movement patterns. The requirements of different memory tasks may therefore lead to different operations that may, in turn, lead to behaviour that reveals abstraction in one case but not in another.

9.2. Implications, Limitations And Suggestions For Further Research

The main aim of the experimental work in this thesis was to identify the type of knowledge that is acquired during incidental learning of sequences of events. The above aim stemmed from a current controversy on the validity of the methods and tests used to establish the existence of unconscious learning. Identification of the exact type of information that was learned in an indirect learning task is required in order to specify the optimal testing conditions that would reveal whether this knowledge is expressed in tasks of conscious memory. The present results support Perruchet's (1994; see also Perruchet & Amorim, 1992; Perruchet and Gallego, 1993) suggestion that tasks of conscious memory should be directed to psychologically relevant sub-parts of the sequence.

This conclusion directly applies to the study carried out by Reed and Johnson (1994). For example, the tests of cued-generation and recognition of triplets employed by Reed and Johnson (1994) may not have been valid measures of the
acquired sequence knowledge. As was argued in Chapter 6, Reed and Johnson's demonstration of a reliable performance speed-up for all stimuli in the sequence does not necessarily entail that an associative learning mechanism was in operation. If the trial-by-trial comparisons were carried out when higher order chunks had been formed, a chunking process may have resulted in a similar finding (see Chapter 6).

However, one argument against the above suggestion is that a chunking process could not have been in operation in Reed and Johnson's (1994) experiment as they tested learning under conditions of attentional distraction. As Cleeremans (1993) has suggested, any implicit learning task is likely to involve both a gradual sensitivity to the regularities in the material that may be considered an implicit process as well as the use of explicit memory for specific items, active hypothesis testing etc. It may be the case (as Reed and Johnson (1994) have argued) that practice under conditions of attentional distraction prevents conscious learning of some salient sub-parts of the sequence and allows the employment of an associative learning mechanism.

There are two arguments against this possibility. First, the fairly simple processes that may underlie encoding of parts of the sequence suggest that a chunking process is not necessarily attentionally demanding. For example, chunks may be formed by a natural parsing process provided by the unique events in the sequence that serve as anchor points. The employment of this simple mechanism may also account for the delay of learning caused by the presence of a secondary task without the need to assume that different mechanisms are in operation under conditions of full attentional availability and under attentional distraction. Performance of a concurrent task is likely to prevent a constant parsing of the sequence and result in the perception of different chunks of the sequence every time it is presented. Strength
accumulation of the chunks that compete for the perception process is therefore expected to slow down. This effect was recently demonstrated by Stadler (1995).

Second, Shanks and St John (1994; see also Shanks and Johnson, 1995), reported that learning of an SOC sequence under conditions of attentional distraction led to above chance performance in the first sequence presentation of a generation-with-correction task. One explanation for this finding may be that the generation-with-correction task is more likely to reveal knowledge of longer than 3-trial sub-sequences than the cued generation task used by Reed and Johnson. While Reed and Johnson examined accuracy of generation on the basis of two successive stimuli, the generation-with-correction task reveals accuracy of generations on the basis of longer sequences of stimuli.

However, determination of whether a chunking mechanism or a slower associative or covariational learning process is in operation in learning the SOC ambiguous sequence under attentional distraction would require a direct experiment test (e.g. the presentation of the irrelevant display that was employed in Experiment 6 of the present thesis). Only this direct test would justify the choice of valid measures of conscious knowledge: one limitation of the present work is that it lacked this direct test.

The irrelevant display introduced in Experiment 6 may also be used to test whether there is correspondence between the knowledge expressed in the response time task and the knowledge expressed in tasks of conscious memory. For example, results from the present experiments suggest that participants recall and recognise 4-trial chunks from the repeating sequence (see also Perruchet and Amorim, 1992). If the irrelevant display is to be used as a tool for testing the sub-sequence length that is acquired by participants, it has to be shown that presentation of an irrelevant display every four trials will not
eliminate any response time speed-up caused by practice. Furthermore, as reliable recognition performance was found for the sub-sequences that showed a reliable speed-up on their last stimuli, the irrelevant display should isolate only these sub-sequences. If the response time speed-up on the last stimulus of these 4-trial sub-sequences is not eliminated when the irrelevant display is introduced, we would have evidence suggesting that the same knowledge base underlies the response time task and the recognition task. If, however, the response time speed-up is eliminated even after presentation of uninterrupted 4-trial sub-sequences, we would have evidence supporting a dissociation. Furthermore, if the response speed-up is not eliminated when the irrelevant display is presented after six stimuli while at the same time a recognition task of 6-trial sub-sequences reveals chance memory performance, then we would have evidence suggesting that two different processes are in operation in the response time and the recognition tasks.

Preliminary evidence in favour of a dissociation was obtained in Experiment 8 where a direct memory task dissociated from speed-up in the indirect response time task. However, this preliminary evidence would require a replication and further elaboration. It may have been the case, for example, that practice with the 6-trial sub-sequences resulted in a completely different encoding of the sequence and consequently learning of different chunks than the those acquired when the 12-trial sequence is practised throughout. Therefore, the fact that reliable performance speed-up was not accompanied by reliable recognition performance may have been due to an incomplete testing of recognition memory. This problem can be overcome if recognition memory is tested with all possible sub-sequences the sequence may be parsed into.

On the other hand the finding that reliable recognition memory is not accompanied by a reliable performance speed-up reveals the importance of
optimal parsing of the sequence for the expression of the acquired knowledge in
a response time speed-up. It also reveals that a pure memory process is not the
only process that is in operation during incidental sequence learning. Although
this finding would require a replication, it does not support Perruchet's (1994)
argument that any orienting task that would elicit a strategy of memorisation of
instances would lead to successful performance on an indirect learning task.
This is in line with Shanks and St John's (1994) proposal that the underlying
process in incidental sequence learning would best be characterised as a
instance/fragment distributed encoder rather than an instance memoriser.
Examples of distributed encoders are the connectionist models that appear to be
the best candidates for implicit learning.

The learning processes modelled by connectionist architectures are relevant to
the issue of knowledge representation in implicit learning and more specifically
to the comparison between the abstract and instance-based knowledge that has
been the cause of much debate. For example, Cleeremans (1994) argues
questions concerning direct comparisons between these two types of knowledge
representation may be ill-posed because connectionist model simulations reveal
that they may be points on a continuum. Connectionist networks develop
internal representations that may be characterised either as storage of exemplars
or as an encoding of common properties of many instances. Some factors that
determine the type of the representations developed are the number of hidden
units or the structure of the training set. For example, a small number of hidden
units does not allow memorisation of a large number of instances. Therefore the
network would only show learning if it develops representations that capture a
few general structural properties of the material.

Cleeremans (1994) has shown how connectionist networks learn to isolate the
features of the material that are relevant and the features that are not. This
simple operation may be treated as an abstraction as it can be applied to and facilitate learning of new material. Furthermore, although connectionist models are generally considered to develop representations that are very much based on the surface features of the material, there are some promising findings that suggest that connectionist models may show transfer to stimuli with a different physical instantiation (Dienes, Altmann, Gao, & Goode, 1995; Altmann, Dienes & Goode, 1995).

Today, the confrontation between the abstractionist and the fragment-based processes of learning appears to be less intense than it was during initial research on implicit learning. For example, the abstractionist view as suggested by Reber (1993) is:

"The essential argument of the abstractive view is that with continued exposure to exemplars... subjects encode the display deeply and set out a representation that captures the patterns of covariation between the various stimulus types that are displayed. The key feature that differentiates this view from the others... is that the hypothesised mental content consists not of the instantiations of specific physical forms, but of abstract representations of these forms."

Also:

"... there are reasons for suspecting that the processes may be captured by connectionist models that build up representations from the patterns of covariations among stimulus elements" (p 121).

Today, there appears to be a general agreement with Reber's argument that connectionist models may capture the process that underlies implicit learning (Cleeremans, 1993, 1994; Shanks and St John, 1994, Dienes & Berry, 1993). For example Shanks and St John argue:
"We have suggested that knowledge of instances or fragments is represented across a large number of weights in a parallel processor. This distributed processor system is best characterised by Dienes's and Cleeremans & McClelland's connectionist models..." Also "... distributed processors can perform a great deal of abstraction from a corpus of instances." (p. 439).

Therefore, there is also a general agreement that implicit learning is a process based on learning of instances that, however, may lead to behaviour that reveals abstraction. There is still disagreement, however, on which aspects of the knowledge representation are available to consciousness and which are not. For example, Perruchet (1994) argues that there is no evidence for an unconscious learning process that leads to abstract knowledge, while Shanks and St John (1994) argue that there is no evidence for an unconscious learning process whatsoever. They suggest that a more promising distinction is between rule learning - based on hypothesis testing - and instance memorisation. On the other hand, as we have seen above, Reber (1993) believes that an unconscious instance memorisation process leads to an abstract representation.

Although connectionist and computational models do not have much to say about the problem of consciousness, they may implement processes that give new directions to the questions we asked about consciousness. For example, a process modelled by MINERVA 2, a computational model developed by Hintzman (1986), suggests that asking about the development of abstract knowledge representation may be irrelevant. Essentially the MINERVA 2 model shows how abstract concepts can be acquired in a system that stores only episodic traces. According to this model, a probe that is presented in primary memory activates all traces in secondary memory that are similar to it. This results in a resonant state in which only the common properties of the traces stand out and what appears in consciousness is abstraction. Furthermore, the
MINERVA 2 model suggests that when a probe is presented in primary memory, an echo from the secondary memory is produced and returns to primary memory. Echo intensity depends on the total amount of activation triggered by the probe and forms the basis of judgements of familiarity. The greater the correlation between the features of a probe and a trace in memory, the greater the activation of the trace.

This model may be relevant to the present suggestion that sequence learning may lead to behaviour that reveals abstraction in a recall test but not in a recognition test. The presentation of probe in a recognition memory task results in an echo with intensity that is likely to lead to an accurate familiarity judgement. On the other hand, a recall memory task lacks the presentation of the probe that would activate the related memory traces. In a recall task participants are expected to attempt to activate all memory traces that were associated with the practice episode. This is likely to produce a resonant state in which only the common properties of the traces stand out and therefore lead to behaviour that reveals abstraction i.e. generation of sequences that were not practised but had similar target movements with the practised ones. On the other hand, if memory traces of some exemplars do not share common properties with others, they are not likely to be recalled. This can explain the lack of recall of the first-order-backward movement by the Repeating group.

Could this account also be applied to findings from artificial grammar learning that have supported the development of abstract knowledge? Evidence for abstraction was provided by requiring classifications of grammatical strings generated from a new set of letters or in a different physical form (i.e. tones). Participants showed above chance performance in these tasks. In both types of experiment, new probes were presented in primary memory. These probes could not activate any trace in the secondary memory. Therefore, classifications
had to be based on recall of previously encountered grammatical strings. It is highly likely that participants who are presented with a sequence of tones and are asked to classify them on the basis of the strings of letters they have previously studied will attempt to recall the previously encountered letter strings. If recall results in an activation of the common properties of the previously encountered strings, then this attempt to recall is likely to facilitate the classification judgements of new strings that match the activated common properties.

A prediction that derives from the above hypothesis is that abstraction will be revealed only when there is an attempt to recall previously encountered instances. If the new stimuli are presented in a different context and participants fail to realise the relevance of the previous study phase to the new task, then positive transfer will not occur. Another prediction from the above hypothesis is that transfer to new material will be evident only if the study phase included instances with common properties so that a resonant state based on those properties can be created.

One problem with the above prediction is identifying the common properties in a set of strings. This would require, as suggested by Reber (1993), a careful examination of participants' behaviour in an attempt to reveal their mental representations. But are the common properties in a set of strings actively or consciously encoded when the study strings are initially encountered or when the new strings are presented?

This question has been addressed by Perruchet (1994), who suggests that abstract behaviour may result from conscious hypothesis testing and from encoding during test. Another possibility, however, is that encoding of common properties may be an automatic consequence of encountering both the study
and the test stimuli. For example, in Experiment 6 of the present thesis, none of the participants verbally described the movements of the target that appeared to influence their response times (i.e. diagonal or backwards). On the other hand in Experiment 1, only participants who verbally reported frequent movements of the target showed positive transfer to new sequences that had similar movements. Participants who had verbal knowledge were obviously able to manipulate this knowledge and apply it to a new situation. This may be captured by the hypothesis-testing strategy that Shanks and St John (1994) contrast with use of the distributed instance/fragment encoder.

A similar argument appears to have been made by Clark and Karmiloff-Smith (in press). Clark and Karmiloff-Smith (in press) argued that the current generation of connectionist models are "first order" models: they contain only implicit knowledge. First order models have three characteristics. First, learning is purely example-driven. The network does not learn by manipulating its own representations independently of the input to determine if it can find a more elegant solution. Second, knowledge of rules in such networks is emergent. They do not depend on symbolic expressions which stand for the element of a rule. Third, first-order networks have no self-generated means of analysing their own activity so as to form symbolic representations of their own processing.

Future research is likely to show whether the above properties that are not captured by distributed encoders require a distinct learning mode or whether more complex distributed encoders can accommodate the processes required for a manipulation of their own representations. Finally, future models and research are likely to reveal better ways of addressing the questions about consciousness.
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MA: MIT Press.


A second prediction the derives from Frensch and Miner's (1994) theoretical framework, namely that a short-term memory measure would correlate with a response time index of learning, was only partially supported by their findings. Significant correlations were only found under intentional learning conditions in one experiment and under conditions of attentional distraction in another experiment when the RSI was 500msec but not when it was 1500msec. Frensch and Miner (1994) suggested that it only was under these conditions that participants reached their short-term memory capacity limits and that this was a necessary condition for significant correlations between short term memory and a response time index of learning to be obtained.

These findings, however, appear to run against the proposal that a passive associative mechanism is responsible for sequence learning as they reveal a direct correspondence between intention to learn and the amount of information that is represented in short term memory. According to Frensch and Miner (1994), conscious intention to learn should affect the amount of information represented in the central executive but not the amount of information represented in short-term memory. If, as Frensch and Miner (1994) also suggest, the response time measure is an index of learning of covariations in short term memory, then correlations between short-term memory and response times should be similar under both incidental and intentional instructions. Instead, it seems that there is a direct relationship between intention to learn (and therefore the amount of information represented in the central executive) and sequence learning expressed in response times.

Furthermore, Frensch and Miner suggested that a secondary task would interfere with implicit learning only if it requires the activation of information in
long term memory that is identical to the information activated in the primary task. Therefore, the addition of the tone counting task (Nissen & Bullemer, 1987) while performing the SRT task should interfere with the amount of information represented in the central executive but "implicit learning should not be affected" (Frensch and Miner, 1994 p. 98). However, the finding that the addition of the tone counting task in Frensch and Miner's experiment was necessary in order to obtain significant correlations between the response time index of learning and short-term memory capacity, suggests that the tone counting task employs the same resources that are used for learning of sequential information. Therefore, the response time index is a measure of learning that employs the same resources with the tone-counting task.

To summarise, the results of Frensch and Miner (1994) suggest that sequence learning that is expressed in response times requires simultaneous activation of the sequential information in short term memory. Also that the amount of sequential information that is represented in short term memory - and therefore acquired - depends on rate of stimulus presentation, intention to learn and the addition of a secondary tone-counting task. However, the influence of all of these factors depends on the type of sequence that is being learned. Intentional instructions were found to influence the relationship between response times and short-term memory for a 10-trial sequence while attentional distraction influenced the same relationship for a shorter 6-trial sequence.
APPENDIX 2

RULE SEQUENCE

DCADC BDABD ACBAC DABDA CDBCD ABDAB
CADCA BCDBC DBCDB ADCAD BACBA CBACB

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
</table>

SOB movements: 40
FC Movements: 20

PSEUDO RANDOM REPEATING SEQUENCE

ABCAD CBDCA DCBDA DBCBD ACDAC DACBA
DBCDA BDCBA CBDCB ACDAB DABDA BCADC

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
</table>

SOB movements: 39
FC Movements: 21
PSEUDO RANDOM NON-REPEATING SEQUENCE

FIRST BLOCK-1

A B D C A B C D B C D A C D B C A B C A B D C B A D B
A D B A D C A D C A B C A B D A C B A C D A C D A B D C B D

Frequencies of occurrence in a 60-trial sequence

Stimuli
A: 15
B: 15
C: 15
D: 15

Transitions
AB: 7  AC: 4  AD: 4
BA: 4  BC: 6  BD: 5
CA: 6  CB: 3  CD: 6
DA: 4  DB: 5  DC: 5

SOB movements: 37
FC Movements: 20

FIRST BLOCK-2

C A D B A C B A D C A D B C D B C A D B A D C A D C B D A C
D A C B A C B A C B A D B C D B C A B C D B C D A B D A B D

Frequencies of occurrence in a 60-trial sequence

Stimuli
A: 15
B: 15
C: 15
D: 15

Transitions
AB: 3  AC: 5  AD: 7
BA: 6  BC: 6  BD: 3
CA: 5  CB: 5  CD: 5
DA: 4  DB: 7  DC: 4

SOB movements: 40
FC Movements: 20
**FIRST BLOCK-3**

ACDACDBACBADBADBCDBADBA

CDACBDBCDBAABCABCADACBACBDCBDA

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transitions</td>
<td>AB: 2</td>
<td>AC: 9</td>
<td>AD: 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BA: 6</td>
<td>BC: 2</td>
<td>BD: 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CA: 2</td>
<td>CB: 8</td>
<td>CD: 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DA: 7</td>
<td>DB: 5</td>
<td>DC: 4</td>
<td></td>
</tr>
</tbody>
</table>

SOB movements: 39
FC Movements: 21

**FIRST BLOCK-4**

DCADBDBCABDABCADBCABCDABADBA

CDACDBCAABCABCADBACBDBADCBABCABAD

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transitions</td>
<td>AB: 5</td>
<td>AC: 5</td>
<td>AD: 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BA: 5</td>
<td>BC: 8</td>
<td>BD: 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CA: 6</td>
<td>CB: 2</td>
<td>CD: 7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DA: 4</td>
<td>DB: 8</td>
<td>DC: 2</td>
<td></td>
</tr>
</tbody>
</table>

SOB movements: 38
FC Movements: 22
### SECOND BLOCK-1

CABCD BCD ABD A BCAC DCDCAC B DABDCADC BCD ABCDBCA
BDABDCADCBADBADBA DCBADBDACBA

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 16</th>
<th>B: 16</th>
<th>C: 13</th>
<th>D: 15</th>
</tr>
</thead>
</table>

SOB movements: 36
FC Movements: 21

### SECOND BLOCK-2

CDABDC BDCB DACBACBAC DABDABCABDA
CDABCDBADBADCABCDBCADBCADCA

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
</table>

SOB movements: 36
FC Movements: 24
### SECOND BLOCK-3

| DC | A | D | C | A | D | B | C | DB | C | A | B | C | D | A | B | D | A | B | D | C | A | B | C | A |

**Frequencies of occurrence in a 60-trial sequence**

**Stimuli**
- A: 15
- B: 15
- C: 15
- D: 15

**Transitions**
- AB: 10
- AC: 2
- AD: 4
- BA: 1
- BC: 10
- BD: 4
- CA: 8
- CB: 0
- CD: 7
- DA: 6
- DB: 5
- DC: 3

SOB movements: 41

FC Movements: 19

### SECOND BLOCK-4

| CA | D | C | B | A | C | D | A | C | D | B | C | A | B | C | D | A | B | D | A | B | C | D | B | C |

**Frequencies of occurrence in a 60-trial sequence**

**Stimuli**
- A: 15
- B: 15
- C: 15
- D: 15

**Transitions**
- AB: 3
- AC: 4
- AD: 7
- BA: 5
- BC: 5
- BD: 5
- CA: 6
- CB: 6
- CD: 3
- DA: 4
- DB: 6
- DC: 6

SOB movements: 38

FC Movements: 22
THIRD BLOCK-1

BADBCDBADBAABCACDADCDBCDABDABCB
CDACBACBDAABCACDADCADCDBADBC

Frequencies of occurrence in a 60-trial sequence

| Stimuli | A: 15 | B: 15 | C: 15 | D: 15 |
| Transitions | AB: 5 | AC: 8 | AD: 3 |
| BA: 6 | BC: 7 | BD: 2 |
| CA: 1 | CB: 3 | CD: 10 |
| DA: 8 | DB: 7 | DC: 0 |

SOB movements: 37  
FC Movements: 20

THIRD BLOCK-2

DBCABCBDCBDAABCACDADCBCDABCDACD

ABCDBCDBADCBADBAADBACDBC

Frequencies of occurrence in a 60-trial sequence

| Stimuli | A: 15 | B: 15 | C: 15 | D: 15 |
| Transitions | AB: 6 | AC: 6 | AD: 3 |
| BA: 4 | BC: 6 | BD: 5 |
| CA: 4 | CB: 4 | CD: 7 |
| DA: 7 | DB: 5 | DC: 3 |

SOB movements: 39  
FC Movements: 21
# Third Block-3

**Sequence:**

\[
\text{DABDCBDCBDAADCBACBABCABDCBDCB}
\]

**Sequence:**

\[
\text{ADCADBBDCAADADAABCABADBCABCDACBADABCA}
\]

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
</table>

|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|

SOB movements: 38
FC Movements: 22

# Third Block-4

**Sequence:**

\[
\text{CADCBDCBDAADBADBCBACDADABDA}
\]

**Sequence:**

\[
\text{BDACDBCAABCABDCBDCABCDACBDADBCA}
\]

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
</table>

|-------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|

SOB movements: 39
FC Movements: 21
FOURTH BLOCK-1
ACDBCDBCABCABCABDACDBCBCABCA
DCAABCDADBCADCBDCADADBACBAD

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
</table>

SOB movements: 37
FC Movements: 20

FOURTH BLOCK-2
BADBCADCBACDBCDBCADBBCADACDADB
CDBCDABDBBDCBACDACDABCACBDA

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
</table>

SOB movements: 38
FC Movements: 22
FOURTH BLOCK-3

CBADBADCAABCDBADBACBCADBADCAD
CADCBCADCDDBCABCDACDBCDBCDBD

Frequencies of occurrence in a 60-trial sequence

Stimuli

A: 15
B: 15
C: 15
D: 15

Transitions

AB: 4  AC: 5  AD: 7
BA: 7  BC: 5  BD: 3
CA: 5  CB: 5  CD: 5
DA: 3  DB: 6  DC: 5

SOB movements: 40
FC Movements: 20

FOURTH BLOCK-4

ABCDADCBCADCBDBACDBCDBADDACDACA
DBCDABDCBACBDCBACDABDABADCAD

Frequencies of occurrence in a 60-trial sequence

Stimuli

A: 15
B: 15
C: 15
D: 15

Transitions

AB: 6  AC: 5  AD: 4
BA: 3  BC: 3  BD: 8
CA: 3  CB: 7  CD: 4
DA: 9  DB: 1  DC: 7

SOB movements: 38
FC Movements: 22
Total number of frequencies for the 960 practice trials for the Control sequence:

Stimuli
- A: 241
- B: 240
- C: 238
- D: 241

Transitions
- AB: 89  AC: 75  AD: 76
- BA: 72  BC: 94  BD: 74
- CA: 81  CB: 65  CD: 91
- DA: 86  DB: 86  DC: 69

SOB movements: 624
FC Movements: 336

RULE TRANSFER SEQUENCE

BCDBCDABDABDABDABDCADCADCADCABDAB
CDBCDABCADBDCADCBACBACBAC

 Frequencies of occurrence in a 60-trial sequence

Stimuli
- A: 15
- B: 15
- C: 15
- D: 15

Transitions
- AB: 5  AC: 4  AD: 6
- BA: 6  BC: 5  BD: 4
- CA: 5  CB: 4  CD: 5
- DA: 4  DB: 5  DC: 6

SOB movements: 41
FC Movements: 19
OPPOSITE RULES SEQUENCE

A D B A D C A B C A B D C B D C B A C D A C D A
B C A B C D B A D B C D A C D B A D B A D C B D C A B

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOB movements</td>
<td>39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FC Movements</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX 3

INSTRUCTIONS

The "motor skill learning" experiment you are participating in, involves the use of a joystick and the control of a cursor. Four target stimuli will appear in the x-shape that is presented in front of you, and you are required to move the cursor to these targets and intercept them as fast as possible. One target will be presented at a time.

The cursor should always be in the x-shape's boundaries while you move. After you intercept a target, you have to move the cursor to the circle in the centre of the x-shape, which is supposed to be your base, and wait until the next target stimulus appears.

Both reaction time, movement time and movement error - that is the time spent outside the x-shape's boundaries - will be recorded, so try to be as fast and as accurate as possible.

The experimenter studies motor skill learning and is interested in the improvement of your performance throughout the experimental session. The session will last for approximately 60 minutes. The experiment is divided in six parts, and there is a short interval between them.

Thank you for your cooperation
APPENDIX 4

INTERVIEW QUESTIONS

1. Have you noticed anything special about the task or the stimuli?

2. Have you noticed any regularities in the sequence of the targets? Did the circles appear randomly or predictably?

3. Did the circles appear in a repeating sequence? Did the sequence appear continuously or did it come and go?

4. Did you attempt to take any advantage of the regularities you have noticed in order to anticipate subsequent events?
APPENDIX 5

REPEATING SEQUENCE

D A B D A B D A B D C B A C B A C B A C B A D B C D B
C D A C D A B D A B D C A D C A D C A D C A D C A B C D B C

Stimuli
A: 15
B: 15
C: 15
D: 15

Transitions
AB: 6 AC: 4 AD: 5
BA: 5 BC: 5 BD: 5
CA: 5 CB: 5 CD: 4
DA: 5 DB: 4 DC: 6

SOB movements: 47
FC Movements: 13

CONTROL 1

A B C A B C A B C A D C B D C B D C B D C B A C D A C
D A C D A B C A B C A D B A D B A D B A D B C D A C D

Stimuli
A: 15
B: 15
C: 15
D: 15

Transitions
AB: 5 AC: 4 AD: 6
BA: 5 BC: 6 BD: 4
CA: 5 CB: 5 CD: 5
DA: 4 DB: 5 DC: 5

SOB movements: 47
FC Movements: 13
CONTROL 2

CDACDACDADBADBADBADBADBADBADBADBADBADBADBADBADBAD

BCABCDACDADCBDCBDCBDCBDCBDABCAB

Stimuli

|   | A: 15 | B: 15 | C: 15 | D: 15 |

Transitions

|   | AB: 4 | AC: 5 | AD: 5 |
|   | BA: 6 | BC: 5 | BD: 4 |
|   | CA: 4 | CB: 5 | CD: 6 |
|   | DA: 5 | DB: 5 | DC: 5 |

SOB movements: 47
FC Movements: 13

CONTROL 3

BCDBCDBDCA DCA DCA DCA DCA DCBDA BD

ABDACBCDBA CBA CBA CBA CBA CDA BDA

Stimuli

|   | A: 15 | B: 15 | C: 15 | D: 15 |

Transitions

|   | AB: 5 | AC: 5 | AD: 5 |
|   | BA: 5 | BC: 4 | BD: 5 |
|   | CA: 4 | CB: 6 | CD: 5 |
|   | DA: 6 | DB: 4 | DC: 5 |

SOB movements: 47
FC Movements: 13
TRANSFER 1

CDACDACBABDBABDDABDADBACBACB
BCABCDACDABDBDDBCDBCDBCDBCDBCAB

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
</table>

SOB movements: 47
FC Movements: 13

TRANSFER 2

DCADCBABDABACBACDADBACDADBABDAB
CADCABCDBDCDBDABCADBACBACBACB

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
</table>

SOB movements: 40
FC Movements: 20
TRANSFER 3

A B C A D C B A D B C A B D A C B A C B D A B D C A D B

A C B D A C B A D B C A B D A C B D C A D B C D A C B D C

Frequencies of occurrence in a 60-trial sequence

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>A: 15</th>
<th>B: 15</th>
<th>C: 15</th>
<th>D: 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transitions</td>
<td>AB: 4</td>
<td>AC: 6</td>
<td>AD: 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BA: 4</td>
<td>BC: 5</td>
<td>BD: 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CA: 4</td>
<td>CB: 6</td>
<td>CD: 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DA: 6</td>
<td>DB: 5</td>
<td>DC: 4</td>
<td></td>
</tr>
</tbody>
</table>

SOB movements: 23
FC Movements: 37
APPENDIX 6

INSTRUCTIONS

The motor skill learning experiment you are participating in involves the use of a joystick and the control of a cursor. Four target stimuli will appear on the screen and you are required to move the cursor to these targets and hit them as fast as possible. One target will be presented at a time.

After you hit a target, you have to move the cursor to the circle in the centre of the screen, which is supposed to be your base, and wait until the next stimulus appears. When it appears you have to exit rhombus shape in the centre of the screen from the "gate" that corresponds to the circle. If you do not you will get an error message (beep).

Response times, movement times and errors - that is number of times you exited from the wrong "gate" - will be recorded, and will be presented to you at the end of each block of trials.

The experimenter studies motor skill learning and is interested in the improvement of your performance throughout the experimental session. The session will last approximately 55 minutes. The experiment is divided in 12 parts, and there is a short interval between them.

Thank you for your cooperation.
APPENDIX 7

EXPERIMENT 3

SEQUENCE WITH LONG DISTANCE TRIALS \((n=32)\)

ABCDBADCABCADCBDBACDBADCB

SEQUENCE WITH SHORT DISTANCE TRIALS \((n=32)\)

ABDACCADABCAABCDDBADBDACDCCB

EXPERIMENT 4

SEQUENCE WITHOUT FIRST-ORDER BACKWARD MOVEMENTS \((n=240)\)

DCABDADCBDBACDABCDBDBCAABACDB

CABACDABCBACDBACDBABCACDBACDB

DCABCDADCBACDBACDBAABCADBCACB

ACDABABCADCBDBACDBACDBACDBACB

DCADBADCDBDCAADACDBDCABDCACBACB

DCADBADCDBDCAADACDBDCABDCACBACB

SEQUENCE WITH FIRST-ORDER BACKWARD MOVEMENTS \((N=240)\)

CABACDABCBDCDBADADABDADABDADBAC

CDCBCDCAADCBACDBACDABCACDBACDB

ACDABABCABCBDCBCACDBACDBACDBACB

DACDBBCBCACACBACDADBCACBACB

BABCACBCDBDCBCACDBACDBACDBACB

BABDCBCACDADABDADBDDBCACBACB

DABCDBACDABDDBDDBDCAACDCAACB
CONTROL SEQUENCE \( n=120 \)

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

5: A B C A C D B A D C B D | REPEATING
6: A B C A C D B A D C B D | SEQUENCE

7: A D C A C B D A B C D B
8: C A B C B D A C D B A D
9: C B A C A D B C D A B D
10: A C D A D B C A B D C B
APPENDIX 9

RESPONSE TIME QUESTIONNAIRE

1. In the previous response time task did the circles appear
   Randomly or Predictably?

2. Did you attempt to anticipate the location of the next circle?
   Yes    No

   If yes, were you successful?
   Most of the times    Rarely    No

3. Were the circles appearing in a repeating sequence?
   a. Yes there was a repeating sequence that appeared continuously
   b. There was a repeating sequence but it came and went
   c. There was no repeating sequence; the circles appeared randomly

   If you have noticed a sequence could you describe it?

   Below is a diagram of the response time task screen with the four circle locations numbered. Please write a sequence of numbers that correspond to the sequence of locations you have noticed in the response time task. For example, if you have noticed that the circles appeared counter-clockwise starting from location 2 write: 2134

   Please write down the longest sequence (or sequences) you have noticed

   Sequence: _______________________________
4. Were some circle locations more frequent than others?

   Yes   No

   if yes which ones?

5. Did you notice any distinctive movements of the circles?

   Yes   No

   If yes can you describe them? (Either describe them in words or draw them, or write a series of numbers that correspond to the locations below)

   1   2
   3   4

6. Were some movements of the circles more frequent than others?

   Yes   No

   If yes, can you describe them? (Either describe them in words or draw them, or write a series of numbers that correspond to the locations below)

   1   2
   3   4

Please ask the experimenter to set up the final part of the experiment
APPENDIX 10

Experiment 7 Results

Generation task

Table A1 shows the means and standard deviations of the number of generations of all the possible 3-, 4-, 5- and 6-trial sub sequences found in the repeating sequence for the two repeating sub-groups that received the generation task in a different order and for the Control group.

Table A1. Total number of generated sub-sequences that were part of the Repeating 12 trial sequence for the R-Gen, R-Rec, Repeating (R) and Control (C) groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean(SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-trial</td>
<td></td>
</tr>
<tr>
<td>R-Gen</td>
<td>57 (14)</td>
</tr>
<tr>
<td>R-Rec</td>
<td>49 (8)</td>
</tr>
<tr>
<td>Pooled R</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>52 (14)</td>
</tr>
<tr>
<td>C</td>
<td>49 (8)</td>
</tr>
<tr>
<td>4-trial</td>
<td></td>
</tr>
<tr>
<td>R-Gen</td>
<td>33 (18)</td>
</tr>
<tr>
<td>R-Rec</td>
<td>26 (12)</td>
</tr>
<tr>
<td>Pooled R</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>29.5 (15)</td>
</tr>
<tr>
<td>C</td>
<td>21.3 (7.9)</td>
</tr>
<tr>
<td>5-trial</td>
<td></td>
</tr>
<tr>
<td>R-Gen</td>
<td>19.3 (16)</td>
</tr>
<tr>
<td>R-Rec</td>
<td>13.8 (10)</td>
</tr>
<tr>
<td>Pooled R</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>16.6 (13.7)</td>
</tr>
<tr>
<td>C</td>
<td>9.3 (5.2)</td>
</tr>
<tr>
<td>6-trial</td>
<td></td>
</tr>
<tr>
<td>R-Gen</td>
<td>11.2 (14.8)</td>
</tr>
<tr>
<td>R-Rec</td>
<td>7.8 (8)</td>
</tr>
<tr>
<td>Pooled R</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>9.5 (11.7)</td>
</tr>
<tr>
<td>C</td>
<td>3.6 (3.1)</td>
</tr>
</tbody>
</table>
Both Repeating sub-groups generate more repeating sub-sequences than the Control group. A Group (Repeating vs Control) X (Order : generation first (R-Gen) vs recognition first (R-Rec)) analysis of variance was carried out for each one of the four scores. None of the analyses revealed significant main effects or interactions although the main effect of group approached the critical probability level for the 4, 5 and 6-trial sub-sequences (p<0.072, 0.06, 0.069 respectively).

Similar analyses of variance were conducted on each one of the 3- and 4-trial sub-sequences of the repeating sequence while the chi-square test or the Fisher's exact test was used for the 5- and 6-trial sequences both for the comparison of the Repeating group with the Control group and for the comparison of each sub-group with the Control group.

Table A2 presents the means of the groups and the results of the analyses. A star "*" indicates a significant main effect of group. In the case of the three and four-trial sequences, a star followed by the letter I "*I" indicates that there was a significant interaction between Group and Order of the explicit test and no main effect of group. A main effect of group was found for the sequences that end on SP6 (3-trial F(1,28)=8, p<0.008, 4-trial F(1,28)=5.5, p<0.025), and SP7 (3-trial F(1,28)=6.6, p<0.016, 4-trial F(1,28)=8.7, p<0.006). Both sub-groups outperformed the Control group on the number of generated sub-sequences that ended on these serial positions which were among the ones that showed the greater Response times differences.

The R-Gen group outperforms, however, the R-Rec group on the 3-trial sub-sequences on SP10, SP11 and SP12 and the 4-trial sub-sequences on SP10 and SP11 (Group X Order interaction : F(1,28)=4.9, p<0.034, F(1,28)=5.5, p<0.025, F(1,28)=4.2, p<0.049, F(1,28)=4.1, p<0.051, F(1,28)=5.03, p<0.033 respectively).
These serial positions were not associated, however, with significantly faster responses of the Repeating group which indicates that this knowledge did not facilitate performance during the response time task.

The analyses of the 5-trial sub-sequences revealed significant differences between the Repeating and the Control group on SP6 (Fisher's exact, p<0.008), SP7 (chi square (1)=6.3, p<0.01), SP8 (chi square (1)=6.3, p<0.01), while the two groups also differed on the number of generated 6-trial sub-sequences that ended on SP7 (Fisher's exact, p<0.02).

When the two explicit order sub-groups were separately compared with the control group, both were found to show significant differences that were not necessarily on the same sub-sequences. In Table A2 the star in parenthesis "(*)" is used when the corresponding sub-group significantly differed from the Control group.

Sub-group differences are found on sub-sequences that also show main group differences. Also, the R-Rec sub-group is found to differ from the Control group on an equal number of sub-sequences with the R-Gen group. The significant differences mainly appear on the serial positions that showed the greater response time differences.

It can be concluded that the Repeating group expresses some knowledge of parts of the Repeating sequence in the generation task even when this task is performed after a recognition task. Serial position 9, however, showed significant response time differences without any corresponding differences between the two groups on number of generated sub-sequences.
Table A2. Mean scores of generated 3, 4, 5, and 6-trial sub sequences that end on the 12 serial positions of the repeating sequence, for the R-GEN and R-REC) and Control (C) groups (in parenthesis number of subjects that generated the sub-sequence at least once; *: significant main effects; *1: significant interactions for the 3 and 4-trial sequences; (*) significant simple effects between the corresponding sub-group and the Control group).

<table>
<thead>
<tr>
<th>Last trial</th>
<th>Spatial location</th>
<th>Group</th>
<th>Length of sequences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>1. A 1</td>
<td>R-GEN</td>
<td>2.2 (7)</td>
<td>1.3 (5)</td>
</tr>
<tr>
<td></td>
<td>R-REC</td>
<td>4.1 (7)</td>
<td>1.5 (4)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4.5 (14)</td>
<td>1.8 (13)</td>
</tr>
<tr>
<td>2. B 2</td>
<td>R-GEN</td>
<td>3.8 (8)</td>
<td>1.3 (5)</td>
</tr>
<tr>
<td></td>
<td>R-REC</td>
<td>3.7 (6)</td>
<td>1.1 (4)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.9 (16)</td>
<td>1.3 (13)</td>
</tr>
<tr>
<td>3. C 3</td>
<td>R-GEN</td>
<td>5.2 (8)</td>
<td>3 (8)</td>
</tr>
<tr>
<td></td>
<td>R-REC</td>
<td>3.5 (6)</td>
<td>2.2 (4)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4.3 (16)</td>
<td>1.9 (13)</td>
</tr>
<tr>
<td>4. A 1</td>
<td>R-GEN</td>
<td>4.7 (8)</td>
<td>1.8 (7)</td>
</tr>
<tr>
<td></td>
<td>R-REC</td>
<td>3.1 (7)</td>
<td>0.6 (4)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4.9 (15)</td>
<td>1.7 (12)</td>
</tr>
<tr>
<td>5. C 3</td>
<td>R-GEN</td>
<td>2.3 (5)</td>
<td>1.5 (3)</td>
</tr>
<tr>
<td></td>
<td>R-REC</td>
<td>4.1 (7)</td>
<td>1.6 (4)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>1.3 (10)</td>
<td>0.4 (5)</td>
</tr>
<tr>
<td>6. D 4</td>
<td>R-GEN</td>
<td>5 (8)</td>
<td>1.5 (4)</td>
</tr>
<tr>
<td></td>
<td>R-REC</td>
<td>6.5 (8)</td>
<td>3 (7) (*)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.1 (15*)</td>
<td>0.5 (5) *</td>
</tr>
<tr>
<td>7. B 2</td>
<td>R-GEN</td>
<td>6.3 (8)</td>
<td>4.1 (8)</td>
</tr>
<tr>
<td></td>
<td>R-REC</td>
<td>7.5 (7)</td>
<td>4.8 (7)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4 (16*)</td>
<td>1.6 (10) *</td>
</tr>
<tr>
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<td>R-GEN</td>
<td>5.2 (8)</td>
<td>4.1 (8)</td>
</tr>
<tr>
<td></td>
<td>R-REC</td>
<td>6.5 (8)</td>
<td>4.2 (7)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>5 (16)</td>
<td>2.4 (14)</td>
</tr>
<tr>
<td>9. D 4</td>
<td>R-GEN</td>
<td>6.7 (8)</td>
<td>2.2 (7)</td>
</tr>
<tr>
<td></td>
<td>R-REC</td>
<td>4.1 (8)</td>
<td>2.8 (6)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>5.8 (16)</td>
<td>2.2 (13)</td>
</tr>
<tr>
<td>10. C 3</td>
<td>R-GEN</td>
<td>7 (8)</td>
<td>4.8 (8)</td>
</tr>
<tr>
<td></td>
<td>R-REC</td>
<td>2.6 (7)</td>
<td>1.8 (6)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4.9 (15*)</td>
<td>3.1 (14)*</td>
</tr>
<tr>
<td>11. B 2</td>
<td>R-GEN</td>
<td>8 (8)</td>
<td>5.8 (8)</td>
</tr>
<tr>
<td></td>
<td>R-REC</td>
<td>2.2 (7)</td>
<td>1.1 (4)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>4.6 (15*)</td>
<td>3 (14)*</td>
</tr>
<tr>
<td>12. D 4</td>
<td>R-GEN</td>
<td>2.5 (7)</td>
<td>1.2 (4)</td>
</tr>
<tr>
<td></td>
<td>R-REC</td>
<td>3.1 (8)</td>
<td>0.8 (4)</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3.6 (15*)</td>
<td>0.9 (10)</td>
</tr>
</tbody>
</table>
APPENDIX 11

MIDDLE LOW CONTEXTUAL INTERFERENCE

B A D C B D
A B C A C D A B C A C D A B C A C D
A B C A C D A B C A C D A B C A C D
B A D C B D
A B C A C D B A D C B D
A B C A C D A B C A C D
B A D C B D B A D C B D B A D C B D
B A D C B D B A D C B D B A D C B D
A B C A C D

6-trial sub-sequences in opposite order

B A D C B D A B C A C D
B A D C B D B A D C B D B A D C B D
B A D C B D B A D C B D B A D C B D
A B C A C D B A D C B D
A B C A C D B A D C B D
A B C A C D B A D C B D
A B C A C D
B A D C B D B A D C B D B A D C B D
B A D C B D B A D C B D B A D C B D
A B C A C D A B C A C D A B C A C D
A B C A C D A B C A C D A B C A C D
B A D C B D A B C A C D

MIDDLE HIGH CONTEXTUAL INTERFERENCE

A B C A C D B A D C B D
A B C A C D A B C A C D A B C A C D
B A D C B D B A D C B D B A D C B D
A B C A C D B A D C B D
A B C A C D B A D C B D
A B C A C D
B A D C B D B A D C B D B A D C B D
B A D C B D B A D C B D B A D C B D
A B C A C D A B C A C D A B C A C D
A B C A C D A B C A C D A B C A C D
B A D C B D

6-trial sub-sequences in opposite order

A B C A C D
B A D C B D B A D C B D B A D C B D
A B C A C D A B C A C D A B C A C D
B A D C B D
A B C A C D B A D C B D
A B C A C D B A D C B D
A B C A C D B A D C B D
A B C A C D A B C A C D A B C A C D
B A D C B D B A D C B D B A D C B D
A B C A C D B A D C B D

6-trial X 3
filler
6-trial X 3
filler
12-trial
6-trial X 3
6-trial X 3
filler
6-trial X 3
filler
12-trial
6-trial X 3
6-trial X 3
filler
6-trial X 3
filler
6-trial X 3
filler
6-trial X 3
filler
QUARTILE LOW CONTEXTUAL INTERFERENCE

B A D C B D A B
C A C D B A C A C D B A C A C D B A
D C B D
A B C A C D B A D C B D
A B C A C D B A D C B D
A B C A C D B A
D C B D A B D C B D A B D C B D A B
D C B D A B D C B D A B D C B D A B
C A C D

6-trial sub-sequences in opposite order

B A
D C B D A B D C B D A B D C B D A B
D C B D A B D C B D A B D C B D A B
C A C D B A D C B D
A B C A C D B A D C B D
A B C A C D B A D C B D
A B
C A C D B A C A C D B A C A C D B A
C A C D B A C A C D B A C A C D B A
D C B D A B C A C D

QUARTILE HIGH CONTEXTUAL INTERFERENCE

A B
C A C D B A C A C D B A C A C D B A
D C B D A B D C B D A B D C B D A B
C A C D B A D C B D
A B C A C D B A D C B D
A B C A C D B A
D C B D A B D C B D A B D C B D A B
C A C D B A C A C D B A C A C D B A
D C B D

6-trial sub-sequences in opposite order

A B C A C D B A
D C B D A B D C B D A B D C B D A B
C A C D B A C A C D B A C A C D B A
D C B D
A B C A C D B A D C B D
A B C A C D B A D C B D
A B
C A C D B A C A C D B A C A C D B A
D C B D A B D C B D A B D C B D A B
C A C D B A D C B D
APPENDIX 12

In order to test whether the four sub-groups showed reliable learning of the whole repeating sequence, they were separately compared to the control group with a two (Group) X seven (Practice: 7 blocks) analysis of variance with repeated measures on the last factor. The Low-CI/Middle sub-group did not show reliable sequence learning as the interaction between Group and Practice was not significant. Simple effects analyses did not show any significant difference between the two groups on the last blocks. The High-CI/Middle sub-group showed reliable sequence learning: the Group by Practice interaction was significant ($F(6,180)=3.93$, $MSe=462$, $p<0.001$). Group differences reached significance only on the last block ($F(1,30)=11.86$, $MSe=1630$, $p<0.002$).

There was a significant main effect of group and no interaction between group and practice for the comparison between the Low-CI/Quartile sub-group and the Control group ($F(1,30)=5.40$, $MSe=10782$, $p<0.02$). The two groups significantly differed on block 5 ($F(1,30)=12.16$, $MSe=1266$, $p<0.002$) and block 7 ($F(1,30)=6.64$, $MSe=1379$, $p<0.015$).

Finally, there was both a significant main effect of Group ($F(1,30)=8.45$, $MSe=8806$, $p<0.007$) and a significant interaction between Group and Practice ($F(6,180)=3.56$, $MSe=443$, $p<0.002$) for the High-CI/Quartile sub-group. This group differed from the Control group on all three final blocks of practice (block 5: $F(1,30)=6.82$, $MSe=1308$, $p<0.014$, block 6: $F(1,30)=15.13$, $MSe=1448$, $p<0.001$, block 7: $F(1,30)=16.14$, $MSe=1334$, $p<0.0001$).
APPENDIX 13

Each one of the sub-groups was compared to the Control group with a two (Parsing group) X two (Group) X 12 (Serial positions) X two (Block 6, 7) analysis of variance with repeated measures on the last two factors carried out on the average response times for the two middle repeating sequences. The Middle group did not differ from the Control group on the last block of trials (p<0.068). However, the Group by Serial position interaction was significant (F(11, 462)= 2.73, MSe= 4464, adj df (8,364) p<0.01). The Quartile group significantly differed from the Control (F(1, 41)= 6.95, MSe= 38973, p<0.012). Also the Group by Serial Position interaction was significant (F(11, 451)= 2.75, MSe= 4992, adj df (8,356) p<0.01). Results from the Simple effects analyses are presented in Table A3 while average response times for each serial position are presented in Table A4.

Table A3. Serial positions that showed reliable differences between the Parsing groups and the Control group. Comparisons that reached the probability level 0.05 are denoted by a star " * ", while those that reached the adjusted 0.008 probability level are shaded.

<table>
<thead>
<tr>
<th>SP</th>
<th>MIDDLE</th>
<th>QUARTILE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F(1,42)=</td>
<td>MSe=</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>5.81</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>4.79</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>13.55</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>4.05</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>10.85</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>4.98</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>3.99</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>5.76</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>7.71</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>12.04</td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>10.85</td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>7.02</td>
</tr>
</tbody>
</table>
Table A4. Mean response times and standard deviations (SD) for the 12 serial positions of blocks 6 and 7, for the four Parsing and Contextual Interference sub-groups and the Repeating and Control groups of Experiment 7.

<table>
<thead>
<tr>
<th>Serial Position</th>
<th>Spatial Location</th>
<th>Group</th>
<th>Control</th>
<th>Middle LCI</th>
<th>Middle HCI</th>
<th>Quartile LCI</th>
<th>Quartile HCI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Repeating</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>1</td>
<td>A</td>
<td>306</td>
<td>60</td>
<td>363</td>
<td>59</td>
<td>350</td>
<td>84</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>339</td>
<td>52</td>
<td>347</td>
<td>48</td>
<td>371</td>
<td>73</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>276</td>
<td>49</td>
<td>327</td>
<td>62</td>
<td>296</td>
<td>75</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
<td>358</td>
<td>60</td>
<td>366</td>
<td>53</td>
<td>381</td>
<td>84</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>409</td>
<td>71</td>
<td>440</td>
<td>76</td>
<td>363</td>
<td>67</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>323</td>
<td>110</td>
<td>404</td>
<td>60</td>
<td>385</td>
<td>83</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>270</td>
<td>99</td>
<td>334</td>
<td>75</td>
<td>318</td>
<td>66</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>290</td>
<td>65</td>
<td>345</td>
<td>73</td>
<td>343</td>
<td>70</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>316</td>
<td>89</td>
<td>393</td>
<td>78</td>
<td>350</td>
<td>59</td>
</tr>
<tr>
<td>10</td>
<td>C</td>
<td>340</td>
<td>94</td>
<td>358</td>
<td>68</td>
<td>335</td>
<td>60</td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>305</td>
<td>104</td>
<td>331</td>
<td>56</td>
<td>304</td>
<td>62</td>
</tr>
<tr>
<td>12</td>
<td>D</td>
<td>390</td>
<td>84</td>
<td>389</td>
<td>71</td>
<td>386</td>
<td>62</td>
</tr>
</tbody>
</table>
APPENDIX 14

Independent group t-tests were carried out for the number of generated 3-trial sub-sequences. The chi-square test or the Fisher’s exact probability test was carried out for all other sub-sequences as they were generated at least once by less than 9 subjects in each group.

Results appear to be consistent. All sub-groups generate more sub-sequences that end on the last trial of the alternation CAC and the trials that follow it. The Middle Low CI sub-group outperforms the Control group only on the 5-trial sub-sequences that end on SP6 (Fishers exact p< 0.02). The Control group, however, outperforms this sub-group on the 3-trial sub-sequences that end on SP9 (F(1,28)=4.5, MSe= 6.5, p<0.042), the 4-trial sub-sequence that ends on SP8 (F(1,28)=6.1, MSe= 1.4, p<0.019) and the 5 and 6-trial sub-sequences that end on SP1 (chi(1)=7.5, p<0.005 and Fisher’s exact p<0.01 respectively).

The Middle High-CI sub-group outperforms the control group on SP5 (3-trial: F(1,28)=9.7, MSe= 6.1, p<0.004), SP6 ( 4-trial : chi sq(1)= 8, p<0.004), SP7 (4-trial, Fishers exact p<0.008, 5-trial : chi sq(1)=4.8, p<0.02, 6-trial: Fisher exact p<0.01) and SP3 (5-trial : chi sq(1)=6.3, p<0.01). The control group does not outperform this sub-group on any of the generation scores.

The Quartile Low CI group outperforms the Control group on the sub-sequences that end on SP5 (3-trial: F(1,28)=16, MSe= 6.5, p<0.0001, 4-trial: chi sq (1)=8.1, p<0.004), SP6 (4-trial: chi sq (1)=8.1, p<0.001, 5-trial: Fisher’s exact p<0.008) and SP7 (5-trial: chi sq (1)=4.8, p<0.02, 6-trial: Fisher’s exact p<0.05). However, the Control group outperforms this sub-group on SP4 (3-trial: F(1,28)=8.1, MSe= 6.1, p<0.008, 4-trial: chi sq (1)=6.1, p<0.01)
Finally the Quartile High CI group outperforms the Control group on sub-sequences that end on SP5 (3-trial: $F(1,28)=5.6$, $MSe=5.2$, $p<0.024$), SP6 (4-trial: $\text{chi sq (1)=4.5, } p<0.03$), SP7 (5-trial: $\text{chi sq (1)=4.8, } p<0.02$) and SP8 (6-trial: $\text{chi sq (1)=5.2, } p<0.02$).
All correlations were calculated separately for each group. For the Middle High/CI group response times on SP2 correlated with number of generated 3-trial sub-sequences on this serial position (-0.77, p<0.001) while response times on SP3 correlated with both 3 and 4-trial sub-sequences (-0.60, -0.67 respectively p<0.01).

For the Quartile Low-CI group response times on SP8 correlated with number of generated 3-trial sub-sequences that end on this serial position (-0.64, p<0.01). The Quartile High-CI group showed significant correlations for SP6 and SP7. Response times on SP6 correlated with number of generated 3- and 4-trial sub-sequences (-0.58, -0.67 respectively, p<0.01) while those on SP7 correlated with number of generated 6-trial sub-sequences (-0.72, p<0.001). Finally this group also showed a significant relationship between improvement of response times from the first to the last practice block and total number of generated 4-trial sub-sequences (0.58, p<0.01).

It has to be noted, however, that these significant correlations came out of 60 correlation coefficients that were calculated for each group. A few correlations are expected to reach significance due to chance. Furthermore the power of the correlations is very low as they are based on 16 pairs of observations only.
Table A5. F values, Mean Square Error and probability levels for the statistical comparisons that showed reliable recognition differences (CI: Contextual Interference, Rep.: Repeating).

<table>
<thead>
<tr>
<th>Group</th>
<th>Comparison vs Control</th>
<th>Comparison vs Chance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle</td>
<td>SP11 F(1,30)=5.1, MSe=3.9, p&lt;0.03</td>
<td>SP3 F(1,30)=4.4, MSe=5.1, p&lt;0.047</td>
</tr>
<tr>
<td>Low CI</td>
<td>SP3 F(1,30)=4.2, MSe=5.1, p&lt;0.047</td>
<td>SP5 F(1,30)=4.2, MSe=9.5, p&lt;0.047</td>
</tr>
<tr>
<td>Middle</td>
<td></td>
<td>SP11 F(1,30)=9.2, MSe=6.1, p&lt;0.005</td>
</tr>
<tr>
<td>High CI</td>
<td></td>
<td>SP5 F(1,30)=9.3, MSe=7.6, p&lt;0.005</td>
</tr>
<tr>
<td>Quartile</td>
<td>SP5 F(1,30)=4.2, MSe=9.2, p&lt;0.048</td>
<td>SP11 F(1,30)=7.5, MSe=5.6, p&lt;0.01</td>
</tr>
<tr>
<td>Low CI</td>
<td></td>
<td>SP5 F(1,30)=9.9, MSe=6.3, p&lt;0.004</td>
</tr>
<tr>
<td>Quartile</td>
<td>SP5 F(1,30)=4.2, MSe=5.4, p&lt;0.049</td>
<td>SP5 F(1,30)=20.5, MSe=5.4, p&lt;0.001</td>
</tr>
<tr>
<td>High CI</td>
<td></td>
<td>SP9 F(1,30)=5.1, MSe=6.0, p&lt;0.03</td>
</tr>
<tr>
<td>Rep.</td>
<td>SP7 F(1,30)=9.5, MSe=9.5, p&lt;0.004</td>
<td>SP5 F(1,30)=6.1, MSe=10.1, p&lt;0.019</td>
</tr>
<tr>
<td></td>
<td>SP1 F(1,30)=3.9, MSe=5.3, p&lt;0.056</td>
<td>SP1 F(1,30)=7, MSe=5.3, p&lt;0.013</td>
</tr>
</tbody>
</table>