Abstract

Exposure to a repeating sequence of target stimuli in a speeded localization task can support both priming of sequence-consistent responses and recognition of sequence components. In 3 experiments with both deterministic and probabilistic sequences a novel procedure was used in which measures of priming and recognition were taken concurrently and it was asked whether these measures can be dissociated. In all 3 experiments, both measures were above chance at the group level and hence no evidence of a dissociation was observed. Experiment 4 tested the claim that amnesia leads to a dissociation between priming and recognition. Therefore, diazepam was administered to participants to induce a temporary period of amnesia, however, again no evidence of a dissociation between learning and awareness was reported. Taken together, the findings of Experiments 1-4 are compatible with a formal model in which priming and recognition are based on a single common memory variable. Experiments 5-8 sought to test Destrebecqz and Cleeremans’ (2001, 2003) claim that under certain circumstances, the expression of sequence knowledge cannot be brought under intentional control. In Experiment 5, participants were trained on either a deterministic or a probabilistic sequence and then they performed a free generation test under either ‘inclusion’ or ‘exclusion’ instructions. In contrast to Destrebecqz and Cleeremans’ findings, participants were capable of both expressing (inclusion) and avoiding expressing (exclusion) sequence knowledge. These results were confirmed in Experiment 6 with a more exact replication of Destrebecqz and Cleeremans’ methodology. In Experiments 7 and 8, participants performed trial-by-trial generation tests and free generation tests under both inclusion and exclusion conditions, after much longer periods of training than are usually employed. All the findings in Experiments 5-8 are consistent with the proposal that the expression of knowledge acquired during sequence learning is under intentional control, and therefore is explicit in nature.
"Entities are not to be multiplied beyond necessity."

William of Ockham, 14th century
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1 Review of the Literature on Implicit Sequence Learning

A distinction is commonly drawn between explicit (conscious) and implicit (unconscious) learning. Implicit learning is defined as non-episodic learning of complex information in an incidental manner without awareness of the material that was learned (Seger, 1994; Shanks & St. John, 1994). Explicit learning, in contrast, constitutes all learning that is accompanied by awareness. To demonstrate the existence and independence of an implicit learning mechanism in the laboratory, experimenters have used a variety of experimental procedures: artificial grammar learning (A. S. Reber, 1967), dynamic systems control (Berry & Broadbent, 1984), and the serial reaction time (SRT) task (Nissen & Bullemer, 1987). Broadly speaking, all of these paradigms involve indirectly exposing participants to complex sequential material and then assessing whether or not they learned the material. If they did learn it, then their awareness of the knowledge they acquired is measured. In section 1.1 of this review, the concept of implicit learning and its close relationship to the procedural/declarative distinction will be examined and then the SRT task will be described. This is a speeded target detection task that has repeatedly been used to try to demonstrate the existence of implicit learning (Cleeremans & McClelland, 1991; A. Cohen, Ivry, & Keele, 1990; T. Curran, 1997a; Destrebecqz & Cleeremans, 2001, 2003; Jiménez, Méndez, & Cleeremans, 1996; Knopman, 1991a; Nissen & Bullemer, 1987; Reed & Johnson, 1994; Willingham, Nissen, & Bullemer, 1989; Willingham, Nissen, & Hartman, 1989).

According to dissociation logic, to demonstrate implicit learning convincingly it must be shown that participants' performance on a task exceeds their awareness of the acquired knowledge. In section 1.2, the review will turn to the methods used to measure performance and awareness in sequence learning. For instance, the studies cited above indicate that performance on the SRT task exceeds awareness, but there has been some debate concerning the adequacy of the methodologies typically
employed by experimenters to ascertain the presence or absence of awareness (Perruchet & Amorim, 1992; Perruchet & Gallego, 1993; Shanks, Green, & Kolodny, 1994; Shanks & Johnstone, 1998, 1999; Shanks & St. John, 1994).

The tests commonly used to establish whether or not a participant is aware are often 'subjective' in the sense that participants decide the extent of sequence knowledge that they report. Some argue, therefore, that subjective tests may be 'insensitive' to all available conscious sequence knowledge. Section 1.3 will consider sequence learning experiments in which subjective tests have been employed (Nissen & Bullemer, 1987; Willingham et al., 1989). Following this, the discussion will turn to experiments in which 'objective' tests of awareness have been employed. In such procedures, a forced-choice test is used so the parameters of conscious report are set by the experimenter (and not the participants). Objective tests of awareness may therefore be more sensitive to awareness of sequence knowledge than subjective tests. When objective tests of awareness are used, existing evidence indicates that sequence learning is explicit (Shanks & Johnstone, 1999).

Another aspect of the methodology of sequence learning experiments that has been criticised is the measure typically used to establish that participants have acquired knowledge of sequential information. This measure will be the focus of section 1.4 of the review. The upshot of these criticisms is that in early experiments participants may not have acquired sequence knowledge at all; their improved performance on the SRT task was due to knowledge of simple event probabilities. Therefore, more recent techniques have been devised to overcome this difficulty (Reed & Johnson, 1994; Shanks et al., 1994).

One convincing study that revealed an implicit learning effect will be considered in section 1.4.1 of the review. In this study experimenters addressed the above methodological concerns by ensuring that that participants learned sequential information and by using objective tests of awareness (free generation and recognition tests) (Reed & Johnson, 1994). However, the implicit effect reported by Reed and Johnson has not been replicated by others (Shanks & Johnstone, 1999).

How do implicit and explicit learning systems interact? It is possible that knowledge
initially acquired without awareness gradually becomes conscious over repeated learning episodes. In section 1.5 of the review the discussion will look at experiments designed to investigate this possibility. For example, Perruchet and Amorim (1992), Perruchet, Bigand, and Benoît-Gonin (1997) and Shanks and Johnstone (1999) all demonstrated that learning after short periods of exposure to sequential material was explicit, therefore it is not true that implicit learning becomes explicit over time. Researchers have questioned whether the occurrence of implicit and explicit learning are mutually exclusive or whether they can both occur simultaneously (Willingham & Goedert-Eschmann, 1999). Evidence discussed in section 1.6 suggests that they can co-exist, although it is not certain that unaware participants were genuinely not aware in that experiment.

In the majority of sequence learning experiments, participants are repeatedly exposed to sequences of a specific length, which do not vary during the exposure phase. However, it is possible that when sequences are disguised during exposure, by the addition of noise, it is more likely that participants will learn the sequence unconsciously. Section 1.7 will consider experiments concerned with the learning of noisy or probabilistic sequences rather than fixed sequences (Cleeremans & McClelland, 1991; T. Curran, 1997a; Jiménez et al., 1996). One of these studies revealed that probabilistic sequence learning was explicit according to above chance performance on an objective test of awareness (Cleeremans & McClelland, 1991). The remaining studies revealed evidence in favour of implicit learning, although this evidence is not without some methodological concerns (Shanks & Johnstone, 1999).

It is possible that specific populations can provide evidence of implicit learning more convincingly than that provided by normal populations. For example it is claimed that the elderly learn probabilistic sequences implicitly (T. Curran, 1997a) and that amnesic individuals, who are impaired on explicit tasks, are capable of preserved implicit learning. Some argue that these claims constitute evidence that explicit and implicit systems are separable and depend on distinct brain regions (P. J. Reber & Squire, 1994, 1998). Section 1.8 will briefly examine this idea as an introduction to Chapter 3 of the thesis. It will be demonstrated in that section, and in greater detail in Chapter 3, that a large proportion of existing experiments using amnesic populations are plagued with the same methodological problems (discussed above).
that blight experiments with normal individuals. Therefore, it is possible to explain Reber and Squire's findings within a single system account (Shanks & St. John, 1994). In addition, studies looking at the particular brain regions involved in procedural learning will be described here (and again in Chapter 3). It is argued that individuals with damage to the basal ganglia such as patients with Huntington's and Parkinson's disease reveal impaired procedural learning. Moreover, the effects of amnesia on sequence learning can be modelled by administering drugs to temporarily induce periods of amnesia in normal participants. This technique, which allows the claim that learning during amnesia is implicit to be tested, is employed in Chapter 3.

It is plausible that brain-imaging data could provide tangible evidence for the existence of implicit learning. Section 1.9 will focus on evidence from positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) studies of sequence learning. Several experiments indicate that separate brain regions are associated with implicit and explicit learning (Berns, Cohen, & Mintun, 1997; Destrebecqz et al., 2003; Grafton, Hazeltine, & Ivry, 1995; Hazeltine, Grafton, & Ivry, 1997; Honda et al., 1998; Jenkins, Brooks, Nixon, Frackowiak, & Passingham, 1994; Maquet et al., 2000; Peigneux et al., 2000; Rauch et al., 1995; Rauch et al., 1997). Taken together, the findings suggest that implicit and explicit learning are mutually exclusive because entirely different brain regions are associated with explicit and implicit learning.

However, existing imaging studies are problematic because when experimenters claim to have achieved an effect of implicit learning, in truth, it is questionable that learning was implicit at all because the tests of awareness employed are often subjective. Further, implicit and explicit learning are typically measured at different times under different conditions, which means that it is difficult to establish whether an effect in favour of implicit learning is genuine evidence of implicit learning, or simply an effect of a more routine process like forgetting. In contrast, a recent fMRI study involved concurrent examination of implicit and explicit sequence learning. Interestingly, the same brain regions were found to underlie both kinds of learning (Willingham, Salidis, & Gabrieli, 2002). Therefore, it is not implausible that so-called implicit and explicit learning depend on a single conscious system.
One fundamental problem with the argument that all learning is explicit is the possibility that performance on objective tests of awareness may be contaminated by the presence of implicit knowledge. This problem implies that successful performance on these tasks cannot necessarily be taken as evidence against the existence of implicit learning. Such a possibility will be discussed in section 1.10, and evidence that recognition performance depends on at least 2 processes will be presented (Shanks & Johnstone, 1999). This theme will be continued in Chapters 2 and 3 in which a recognition test is used to assess awareness. In all experiments discussed, the analysis attempts to ascertain whether recognition performance is contaminated by implicit knowledge or whether all processes underlying recognition performance are entirely explicit.

The idea that objective tests can be contaminated by more than 1 process will be continued in section 1.11. Here, the possibility that another objective test of awareness (free generation) is dependent on both implicit and explicit processes will be examined. A method called the process dissociation procedure, initially developed by Jacoby (1991), will be discussed. In this procedure, the degree of control a participant holds over the expression of knowledge is used to separate the conscious and unconscious processes underlying performance. It is assumed that the expression of explicit knowledge is under participants' control but the expression of implicit knowledge is out of participants' control. Destrebecqz and Cleeremans (2001) adapted Jacoby's process dissociation procedure to sequential learning; they reported that performance on a particular explicit test of awareness (the free generation task) is sometimes contaminated by implicit knowledge. Furthermore, they demonstrated that under certain conditions a dissociation was produced between performance on a sequential learning task and awareness. To date this observation is one of the most convincing demonstrations of a dissociation between learning and awareness, and in Chapter 4 an attempt is made to replicate it.
1.1 Implicit learning and the serial reaction time task

1.1.1 Implicit learning

Is it possible that humans acquire information about which they are unaware, but which can nevertheless influence their future behaviour? Take skill learning for instance and in particular learning to ski. When a person learns to ski, their performance is influenced by several things: the words of their instructor, observations of other skiers careering down the ski slopes, and actual practice of going down several slopes in various weather conditions. A novice skier may fall over many times and perhaps may even twist an ankle until eventually they learn to remain upright and feel confident that they can tackle some fairly steep slopes. One day, they may end up competing in the winter Olympics! It is obvious that people can learn new skills and may become experts at them. Clearly there are many aspects of this learning about which a person is aware; for instance an expert skier may be able to verbalise a great deal of the information required to become a good skier, perhaps enabling them to teach other people how to ski. This type of information is without doubt a form of conscious knowledge and is known as explicit knowledge. Is it plausible that information can exist, which influences a person’s performance but is not reportable? Can any of this information be said to be unconscious?

Autonomic activities exist that indisputably are unconscious; for example, when a new born learns to regulate its heart beat, the process is automatic in the sense that the child has no capability of controlling their heart rate and is unaware of its adaptation. By the same token, the term ‘implicit learning’ refers to the learning of complex material by an unconscious cognitive system (A. S. Reber, 1967).

The idea that humans are capable of learning unconsciously is intuitively appealing. However, a long-established debate regarding whether or not learning can proceed independently of awareness (i.e., implicitly) is far from resolved. The claim that human learning can be unconscious has led to a polarisation of views: some propose that explicit and implicit learning depend on distinct systems (e.g. Ashby & Ell, 2002; Destrebecqz & Cleeremans, 2001; Manns, Clark, & Squire, 2002; P. J. Reber
& Squire, 1994, 1998; Willingham et al., 2002), whereas others reject the notion that learning can be implicit and argue that all human learning relies on a unitary explicit system (e.g. Dulany, 1997; Kinder & Shanks, 2001, 2003; Lovibond & Shanks, 2002; Perruchet & Vinter, 2002.; Shanks & Perruchet, 2002; Shanks & St. John, 1994; Shanks, Wilkinson, & Channon, 2003; Wilkinson & Shanks, in press).

With respect to sequence learning in particular, it has been reported that people can learn about complex sequential structures implicitly (T. Curran, 1997a; Destrebecqz & Cleeremans, 2001, 2003; Nissen & Bullemer, 1987; A. S. Reber, 1967, 1989; Reed & Johnson, 1994; Willingham et al., 1989). Such findings have led to the popular belief that humans are capable of ‘implicit’ learning. The present review will examine this evidence carefully, and include a discussion of the alternative view that human learning cannot be unconscious.

The distinction between implicit and explicit learning is closely related to the idea that within long-term memory, implicit (unconscious) and explicit (conscious) memory systems are separable (Tulving, 1985). Explicit memory encompasses both episodic memory (memory for autobiographical events) and semantic memory (memory for facts). Explicit memory is also known as declarative memory because the type of information involved is reportable. On the other hand, implicit memory refers to the expression of memory by performance rather than recollection. This includes skill learning, habit learning, priming and simple classical conditioning. Some researchers go as far as to say that all procedural or non-declarative knowledge is ‘implicit’ and that all declarative knowledge is ‘explicit’. In turn, it is argued that these forms of knowledge may well depend on distinct brain systems (Schacter & Buckner, 1998; Squire, 1992; Squire, Knowlton, & Musen, 1993).

However, others have argued that learning is always accompanied by awareness (Perruchet & Amorim, 1992; Perruchet et al., 1997; Perruchet & Gallego, 1993; Shanks & Johnstone, 1998, 1999; Shanks & St. John, 1994). They deny that the empirical reports to date have provided any robust evidence of unconscious sequence learning and this assertion is principally grounded in methodological concerns regarding early studies. Even in later studies, in which these concerns were addressed, proponents of this particular view believe that there is no necessity to
make a distinction between implicit and explicit learning because a single explicit system can still account for all of the empirical findings. Hence, it is argued that a single system view is the most parsimonious account (Shanks & Johnstone, 1999; Shanks & Perruchet, 2002; Shanks & St. John, 1994). It follows that learning would not necessarily involve separate implicit and explicit memory systems or brain regions and that procedural, episodic and semantic knowledge are all ‘explicit’ systems.

1.1.2 Dissociation logic

Implicit learning has proven to be rather a difficult phenomenon to pin down in the laboratory. Quintessentially, evidence for implicit learning relies on the demonstration of a dissociation between participants’ performance on a task and their awareness of the knowledge upon which this performance is based. If participants can be shown to perform well on a learning task whilst at the same time performing poorly on a test of awareness, this finding is good evidence that they have learned implicitly. Ideally, performance on the learning task is above chance, while awareness is at chance.

However, it is well documented that the adoption of dissociation logic can often be fraught with methodological problems. The first problem concerns the nature of the test of awareness employed, which should 1) be sensitive enough to pick up knowledge about the task that may be held with low confidence by the participant. 2) test knowledge upon which performance was based (i.e. which was acquired during the learning phase) 3) be uncontaminated by implicit knowledge.

The second problem concerns the time at which performance and awareness are measured, for example, if awareness is measured a considerable time after performance, a dissociation may be observed which is simply the result of the fact that before the onset of the test phase, participants have forgotten the information they used to perform the task. The above methodological issues will be discussed in more detail in this thesis.
1.1.3 The serial reaction time task

One paradigm that has been widely used to examine the existence of implicit learning is the SRT task. This is a speeded target detection task devised by Nissen and Bullemer (1987) and subsequently adopted and modified by many others (Cleeremans & McClelland, 1991; Destrebecqz & Cleeremans, 2001; Frensch, Lin, & Buchner, 1998; Honda et al., 1998; Jiménez et al., 1996; Perruchet & Amorim, 1992; Perruchet et al., 1997; P.J. Reber & Squire, 1994, 1998; Reed & Johnson, 1994; Shanks & Johnstone, 1998, 1999; Stadler, 1995; Willingham, Greely, & Bardone, 1993). Participants are typically shown four boxes (1-4) on a computer display and on each trial a target appears in one of the boxes (see Figure 1.1). Participants must respond as quickly as possible to the target by pressing the appropriate key on a keyboard; they typically perform around 1200 trials or 12 blocks of 100 trials. Unknown to the participants, for the majority of the training blocks the targets appear in a pre-determined sequence of box locations, commonly about 12 locations in length (e.g., 3-4-2-3-1-2-1-4-3-2-4-1). The sequence cycles during the training stage and reaction times are measured. In one of the final training blocks a different sequence is introduced and if RTs are greater for this transfer block than for the preceding sequence blocks, then it can be inferred that participants learned the sequence on which they were trained. This learning is assumed to lead to response priming whereby expectancy of the impending target location leads to faster responses; in the transfer block such expectancies are violated and hence RTs are longer.

Once it has been established that participants have demonstrated sequence learning, it is possible to see whether the knowledge underlying this learning is 'implicit' or 'explicit'; a variety of tests of awareness have been devised for this purpose. The case for implicit learning depends crucially on the validity of the tests used to index awareness; therefore, the precise form of these tests has been debated at length. A common distinction is drawn between subjective and objective tests, where the former require the participant to report his/her state of awareness whereas the latter demand some forced-choice discrimination.

For example, one way to measure explicit sequence knowledge is by a direct free
recall test. It has been claimed that participants who demonstrate learning of a sequence subsequently perform poorly at free recall of the sequence, leading to the conclusion that learning was implicit (Nissen & Bullemer, 1987; Willingham et al., 1993). However, free recall has been criticized on the basis that it may be an insensitive or biased test of awareness (Shanks, in press; Shanks & St. John, 1994). Alternatives such as recognition, generation, and prediction tests have therefore been devised.

![Figure 1.1 Stimuli typically employed in the SRT task. In this case, boxes 1-4 (left to right) correspond to keys V, B, N, M on a standard QWERTY keyboard and participants must respond as quickly as possible to the target (X) by pressing the corresponding key.](image)

**1.2 Verbal report is a subjective test of awareness**

**1.2.1 Evidence for implicit learning of sequences**

One of the most obvious methods of measuring the extent of participants' explicit sequence knowledge is simply to ask them to recall the information they have learned. For instance, in Nissen and Bullemer's (1987) seminal study, 1 group of participants was trained for 4 blocks of 100 trials on a 10-item pre-determined sequence (4-2-3-1-3-2-4-3) and another group was trained for 8 blocks on a completely random sequence. In this example, participants were required to carry out a secondary tone counting task during the training phase in the hope that dividing their attention would increase the chances they may learn the sequence implicitly. Although the sequence group clearly demonstrated accelerating RTs during training compared to the controls, 11 out of the 12 participants could not report the presence of a sequence at all. Likewise, in other studies (A. Cohen et al., 1990; Knopman &
1. Review of the Literature on Implicit Sequence Learning

Nissen, 1991; Willingham et al., 1989; Willingham et al., 1989), accelerating RTs for participants trained on a sequence occurred, combined with an apparent inability to verbally report this sequence at the end of the experiment.

Another way to elicit subjective reports of awareness is for participants to attempt to generate the sequence that they were trained on and then give a "metacognitive" assessment of their confidence in their generation accuracy. For instance, Shanks and Johnstone (1998) initially trained participants on sequences before getting them to freely generate those sequences. Participants who reported that they were guessing in this test nonetheless generated their training sequence far better than would be expected by chance (see section 1.13 for further discussion of how such subjective measures of awareness have been developed).

Verbal report is not always above chance at a group level. For example in an experiment conducted by Willingham et al. (1993), a verbal report measure revealed that sequence learning was explicit. In this study, participants were trained on 5 blocks of 100 trials in either a random or a sequence group. After the training stage all participants were required to generate their knowledge of the sequence by reporting it verbally to the experimenter. The sequence group were capable of good verbal report performance.

1.2.2 Individual differences

Upon closer inspection of their data, Willingham et al. (1993) calculated that control participants in a group trained on a random sequence produced by chance a median of 3 correct locations when asked to "recall" sequences. Moreover, 17 out of 45 participants from the sequence group performed worse than the control participants. The experimenters suggested that these particular participants had acquired no explicit knowledge of the sequence. Hence the reaction time decrease during training demonstrated by these participants can be explained by an implicit learning effect in this subgroup of participants. Willingham et al.'s (1993) claim for implicit learning is based upon the intuitive assumption that individual differences exist in the sample population. In other words, given a particular group of participants, most people may learn explicitly but a few people will learn implicitly. On face value,
this individual participant analysis revealed evidence supporting the existence of implicit learning that would not otherwise have been apparent when making comparisons at the group level.

Willingham et al.’s (1993) analysis consisted of taking the whole group’s performance on the implicit measure (RT) and dichotomising this data to determine those participants who performed poorly and those who performed well. Likewise, the group’s performance on the explicit measure was divided according to above or below chance levels. Perruchet and Gallego (1993) observed that most participants either fell into the subgroup defined by good RT performance and above chance explicit test performance or into the subgroup defined by poor RT performance and below chance explicit task performance. They argued however that it is statistically inevitable that there will be some additional participants who either performed poorly on the RT measure and well on the explicit measure or showed good performance on the RT measure and below chance performance on the explicit test. Perruchet and Gallego (1993) suggested that the problem with relying on sub-group data is that a preliminary condition for obtaining a perfect correlation is perfect reliability of measures and this condition is highly unrealistic in psychological investigations. Perruchet and Gallego (1993) pointed out that the measures are especially prone to error variation which could produce the pattern of results described above. This raises the possibility that Willingham et al. (1993) concluded erroneously that they demonstrated implicit sequence learning in a small sub-group of participants. According to Perruchet and Gallego (1993), the data reported by Willingham et al. (1993) do not provide reliable evidence of implicit learning because they were based upon a statistical artefact. Therefore the group level association originally observed between verbal report and sequence learning should continue to be taken as evidence that learning occurred explicitly.

1.2.3 The sensitivity criterion

Although performance on tests like verbal report is oftentimes at chance at the group level, and this does establish that, in at least one sense, sequence learning can be implicit, there may be a rather more mundane explanation. As many authors have
pointed out (Merikle, Smilek, & Eastwood, 2001; Reingold & Merikle, 1990; Shanks & St. John, 1994), an adequate test of awareness must be exhaustive, meaning that it must be sensitive to all of the conscious knowledge that the participant possesses. The exhaustiveness criterion is widely recognized to constitute a problem for tests of awareness like verbal report because there is little to guarantee in such tests that participants have reported all available knowledge. For instance, a verbal report test is based upon participants' introspection regarding their reportable knowledge of the information they learned; it is plausible that participants' verbal reports may be influenced by response biases. A participant may systematically claim not to have learned stimuli that they have partially learned or even fully learned (Kunimoto, Miller, & Pashler, 2001). In this sense, the verbal report test is 'subjective' in nature and can lead participants to withhold conscious knowledge about which they lack confidence. If that happens, then a measure of RT performance during the training stage may dissociate from a measure of verbal report simply because the former is more sensitive to conscious knowledge. All the apparent dissociations between RT performance and awareness could merely reflect the insensitivity of the verbal awareness tests when compared to more sensitive tests of RT performance.

1.3 The difference between subjective and objective tests of awareness

As described above, verbal report tests are subjective because they require the participant to make a decision about whether or not they will report available knowledge to the experimenter. Therefore the particular report criterion employed is decided entirely by the participant.

In an objective test, participants' awareness is indexed by their forced response to external environmental cues rather than by their introspective accounts. In this sense, the adoption of an objective test transfers the definition of awareness out of the hands of the participant and into the hands of the experimenter (Kunimoto et al., 2001). In an objective test, the participant must perform a task and their performance can then be measured as either correct or incorrect. For example, rather than asking people to describe their knowledge of a sequence, it is possible to ask them to generate key
presses that conform to the sequence they learned. The accuracy of these responses can be used as an index of awareness (free generation task). Participants undergoing the free generation task may have no subjective idea that they know anything about the sequence they encountered previously. Nevertheless, if they perform at an above chance level on the free generation task, they would be classified as aware. In essence, an objective measure of awareness is defined as a test in which the participant is instructed to try to access conscious information, but which can be performed at above chance levels even when the participant believes that they are guessing.

Researchers on both sides of the debate concerning the existence of implicit learning agree that objective tests are a more sensitive method of establishing whether or not participants are aware than verbal report. There is absolutely no doubt that participants' verbal reports about training sequences in SRT task experiments fail to incorporate all of the information and serial dependencies that can be detected chronometrically in their primed key presses (Shanks & Johnstone, 1998; Willingham et al., 1993). However, if participants can be shown by some priming measure to possess knowledge of sequential structure, but fail to perform above chance on an objective test then it is hard to argue that this is simply a problem of sensitivity or exhaustiveness.

1.3.1 Evidence for implicit learning using the generate task as a measure of awareness

One objective test of awareness called the generate task was developed by Willingham et al. (1989) to measure participants' ability to generate sequence chunks. It was believed that this test is more sensitive than verbal report because it is capable of indexing fragmentary knowledge held with low confidence. In the generate task participants are trained as usual on a sequence of key presses and subsequently are given a specific cue and asked to generate the next item. In Willingham et al.'s (1989), experiment participants were trained for 4 blocks of 100 trials on a repeating 10-item sequence under single task conditions. Following training, they performed a verbal report test in which they were asked questions like
Did you ever notice any pattern or repeating sequence?" In addition, they completed 2 blocks of 110 trials of the generate task in which they were given a stimulus as usual but were told to press the key corresponding to where they thought the next stimulus would appear. The stimulus remained present until the participant made the correct response and then appeared at the correct location so they received feedback regarding the accuracy of their responses during the test phase.

Based on verbal report task performance, participants were assigned post-hoc to 3 subgroups; no knowledge, some knowledge and full knowledge. Willingham et al. observed that RTs in the no knowledge group decreased significantly compared to controls during the training phase. As for the results of the generate task, because the task involved supplying the participants with feedback on their accuracy, this gave them the opportunity to learn the sequence during the test phase and consequently, only the first 10 trials of the first test block were analysed. Willingham et al. reported that the no knowledge group was unable to generate significantly more correct responses than a control group who did not receive training on a sequence. For instance, accuracy rates were 38.7% for the control group and 42.6% for the no knowledge group. In contrast, the some knowledge group achieved 62.4% correct and the full knowledge group 77.5% correct during the first ten trials. This appears to be robust evidence that the no knowledge participants learned the sequence implicitly.

In the studies considered thus far, experimenters adopted either single or dual task conditions with the aim of manipulating participants' attention and most studies have involved training participants on a 10-item repeating sequence. A. Cohen et al. (1990) conducted a study to investigate under what conditions (i.e., dual or single task), people learn particular sequences implicitly. Again A. Cohen et al. used the generate task performance as their index of participants' awareness. In this experiment, participants were trained on a repeating pattern containing either 5 or 6 elements and there were 5, rather than the usual 4 target locations on the computer screen. In the unique sequence group, participants were trained on a 5-item sequence of key presses with the constraint that the sequence could be coded as a set of paired associations. For example the sequence 1-4-5-3-2 is unique because participants can learn it by forming specific associations between 1 and 4, 4 and 5, 5 and 3 and so on.
In the ambiguous sequence group, participants were trained on a 6-item sequence of key presses. In this case, it was specified that participants should not be able to code the sequence in pairs and instead should have to learn at least 2 sequence locations before they can predict the third one. For instance, in the ambiguous sequence 1-3-2-3-1-2 it is necessary to learn 1-3 to predict location 2 in the first triplet of the sequence because location 3 is later followed by location 1. Participants were trained under both single and dual task conditions for 8 blocks of 100 sequence trials, followed by 2 blocks of 100 random trials and 2 blocks of sequence trials. At test, participants underwent 100 trials of the generate task. In this case, participants were shown 2 targets and asked to generate a response for the next location of the sequence. The stimulus was displayed until the participants made a response, then the stimulus was displayed at its correct location whether the participants' response was correct or not. Again this feedback offered the opportunity for participants to learn during the test phase so A. Cohen et al. were restricted to analysing the first 4 cycles of the sequence rather than the complete test data.

Participants trained with unique sequences under dual task conditions were able to learn the sequence and were not aware of this, as indexed by their generate task performance (A. Cohen et al., 1990). Moreover, when participants were trained under single task conditions, they learned both unique and ambiguous sequences and again this was accompanied by poor performance on the generate task. A. Cohen et al. drew several conclusions from these findings. Firstly, they argued that only unique sequences, and not ambiguous ones, could be learned under dual task conditions and this could be achieved implicitly. Secondly, ambiguous sequences could be learned under single task conditions and again this could be achieved implicitly. A. Cohen et al. posited 2 separate learning systems for dual and single task learning respectively suggesting that these are qualitatively different systems. More important for the purposes of this review it was suggested that these systems are both capable of learning sequence information implicitly.

At this point, a mention should be made of the claim that implicit learning can proceed normally under conditions of divided attention whereas explicit learning is impaired by resource demanding tasks (Frensch et al., 1998). A comprehensive review of the literature dealing with this claim was conducted by Goschke (1997).
addition, Shanks and Channon (2002) recently presented strong evidence against this view, demonstrating that implicit and explicit learning are both impaired in parallel under conditions of divided attention.

Reed and Johnson (1994) reported further evidence to support the existence of implicit learning. Participants were trained on a 12 item sequence of target locations for 17 training blocks of 100 sequence trials and on the 18th training block a different 12 item sequence was introduced. Response latencies (RTs) decreased over training and dramatically increased on the transfer block. Notice that transfer to a new sequence on the 18th block allowed a within-participants measure of sequence learning (an improvement on the usual between-group design). In this instance a significant RT difference between the sequence blocks and the transfer block is evidence that participants learned the sequence.

In the cued generation condition, participants were trained as above on a sequence of target locations, and at test, they were told that the targets had followed a specific sequence. Then they were given 24 pairs of sequence locations and were asked to generate the next 10 sequence locations for each pair. In the cued generation control condition, participants were trained on a non-repeating sequence and then asked to perform the cued generation task to provide a baseline for comparison. Each pair of sequence locations corresponded to 1 of the possible 12 pairs in a sequence and performance was measured by counting how often the first key press corresponded to the correct location. Cued generation performance was not significantly different between the 2 groups but was numerically lower in the cued generation condition compared to the cued generation control condition. It was concluded that participants in the cued generation condition were capable of learning the sequence and their performance on the explicit measure was no better than chance, suggesting that they learned the sequence implicitly.

1.3.2 Problems with the methodology of studies

In response to A. Cohen et al.'s (1990) proposal that learning occurred implicitly, Perruchet and Amorim (1992) highlighted some methodological concerns with the 'generate task' that was employed as the test of awareness in A. Cohen et al.'s study.
The first problem concerns the nature of the information that the test is designed to measure. For instance, during the test phase, A. Cohen et al.'s instructions did not mention the reproduction of prior sequences; this means that in this sense their test was indirect. According to Schacter (1987), who chooses to make the distinction between implicit and explicit knowledge on the basis of the nature of instructions participants are given, it follows that that this makes the generate test a test of implicit rather than of explicit knowledge.

The second problem with the generate test concerns its sensitivity. Perruchet and Amorim (1992) argued that even if participants successfully guess what they are supposed to do, the introduction of the correction procedure makes the task insensitive. The generate test is both a difficult and unfamiliar procedure, leading to the possibility of participant confusion. Moreover, because the correction procedure adopted actually provides information about the sequence, this leads to the possibility that participants could learn during the test phase. To eliminate this possibility, the amount of trials that A. Cohen et al. could analyse was reduced to the first 10 and it is hardly surprising that in this case participants were deemed unaware of the sequence. Under these circumstances the generate task is probably not a sensitive procedure, even though it was originally devised to overcome the sensitivity issue.

1.3.3 Free generation task and recognition test

To overcome problems associated with task sensitivity, 2 further objective tests of awareness have been devised: the free generation task and the recognition test. These tests will be discussed in detail and they are both employed in the experiments presented in this thesis. In the free generation task, devised by Perruchet and Amorim (1992), participants were trained as usual on a sequence of key presses, and at test, they generated a series of key presses for 100 trials. In this case, participants were required to include in their responses any patterns they could remember from the sequence. If participants generated significantly more of the trained sequence than controls, then they were deemed to be ‘aware’. As mentioned previously, this task is a forced choice task because participants must generate at least 100 trials,
whether or not they think they have learned a sequence. It is also an intentional task because participants are told specifically about the presence of a sequence during the training phase, and are then asked to reproduce it.

In the recognition test devised by Perruchet and Amorim (1992), following a period of training on a sequence, participants were presented with several test sequences consisting of sequence chunks. Half of the chunks were part of the training sequence and the remainder of the chunks were novel. Participants were required to respond to the test chunks as before, then following each test chunk, to give a recognition rating based on whether or not they recognised the chunk from the training stage. If participants are capable of discriminating between old and new test chunks then they are classified as aware of the sequence. One advantage of the recognition test is that the retrieval context is identical to the learning context. Furthermore, a forced-choice old/new response is required.

1.3.4 Evidence against implicit learning using objective measures of awareness

The free generation and recognition tests have been adopted in several studies to test the claim that learning can be implicit. This claim was previously supported by evidence from earlier studies in which insensitive tests of awareness were employed. Perruchet and Amorim (1992) used Nissen and Bullemer's (1987) version of the sequence-learning task to train participants on a sequence of key presses. Hence participants were trained for 10 blocks of 100 trials on either a 10-item sequence taken from Nissen and Bullemer (1987) or on a random sequence. Following the training stage, participants performed a free generation task. Participants responded faster to sequence trials compared to random trials and this difference appeared after the second block of 100 trials. Perruchet and Amorim calculated specific RT savings between each sequence position and RTs for random trials when they appeared in each sequence position. They demonstrated that only certain locations showed a significant RT saving. Similarly, they calculated the amount of the sequence that was generated by sequence and random groups respectively. Interestingly, RTs were shorter for trials that ended in the most frequently generated 3 and 4 trial sequences, suggesting that in this case the measure of performance correlated well with the
In addition, Perruchet and Amorim looked at the evidence for implicit learning reported by A. Cohen et al. (1990). Recall that A. Cohen et al. observed implicit learning of unique sequences under dual task conditions. In Perruchet and Amorim’s experiment, participants were trained under dual task conditions for 4 blocks of 100 trials in either a unique sequence group or a random pattern group and then they underwent recognition and free generation tasks rather than the generate task. In contrast to A. Cohen et al.’s study, participants were capable of good performance on both free generation and recognition tests.

1.4 Problems identified with the indirect measure of learning

In addition to the question of which test of awareness is the best to employ, the indirect measure of learning has also been scrutinised in the literature. In the majority of studies, experimenters compare RTs for sequence blocks with RTs for random blocks to ascertain whether learning has taken place. Usually, improved performance for sequence compared to random blocks has been taken as evidence of sequential learning. However Shanks et al. (1994) and Shanks and St John (1994) pointed out that the observed disruption caused by the introduction of random trials may not be attributable to the learning of a sequence as suggested, but merely to learning simple event probabilities. Recall that implicit learning is defined as unaware, unintentional learning of complex sequential information, so if such a claim is correct then the majority of studies have not demonstrated implicit sequence learning.

To illustrate, Shanks et al. pointed out the following: if participants are trained on a fixed sequence 4n2-3-1-3-2-4-3-2-1 compared with a completely random sequence, the stimuli in the fixed sequence are not equi-probable; 3 locations appear twice and 1 location appears 3 times, whereas in the random sequence all 4 locations appear equally often. This means the participants would be able to predict which stimuli are most probable in the training sequence, and their good performance may be based on
this information, rather than on the learning of a complex sequence. It was proposed that the best comparison should actually be with a pseudo-random sequence, in which the stimuli occur with probabilities similar to the training sequence. Shanks et al. (1994) demonstrated their point with an experiment. Firstly, a sequence group was trained for 4 blocks on the 10-item sequence used by Willingham et al. (1993): 4-2-3-1-3-2-4-3-2-1. A random group was trained for 4 blocks on random trials and the only constraint was that there should be no repetitions in the random trials. Finally, a pseudo-random group was trained for 4 blocks on a matched sequence. Following training, all participants underwent a verbal report task and participants in the sequence group were classified based on their verbal report performance into no-knowledge and full-knowledge groups. If the no-knowledge group learned implicitly, it was predicted that the RT difference or speed up between the first and fourth blocks should be greater for the no-knowledge participants than the pseudo-random group. However there was no significant difference between the means of the 2 groups; hence it could be concluded that the no-knowledge group did not learn any sequential information. Furthermore, the difference between the no-knowledge and the random groups was significant, suggesting that in this case, the learning of simple event probabilities rather than complex sequence information caused the difference between RT acceleration.

To ensure that participants were learning more than simple event probabilities Reed and Johnson (1994) adopted 2 matched sequences in their study. Second order conditional sequence A was (3-1-4-3-2-4-2-1-3-4-1-2) and second order conditional sequence B was (4-3-1-2-4-1-3-2-1-4-2-3). Similar to A. Cohen et al.'s ambiguous sequences, these sequences are known as second order conditional or SOC sequences because it is only possible for participants to predict the third item in each triplet of the sequence from the preceding 2 items. Therefore, in sequence A above, if a participant is exposed to 3-2, they should be able to predict 4. However if they are exposed to 1, then there are 3 possible consequent items 4, 3, or 2. The sequences are equated with respect to certain properties: location frequency (each location occurred 3 times), first order transition frequency (each location was preceded once by each of the other 3 locations), repetitions (no repetitions in either sequence), reversal frequency (one, e.g. 1-2-1, for each sequence) and rate of full coverage.
Now consider again the dissociation between learning on the SRT task and performance on the cued generation task demonstrated by Reed and Johnson (1994) and discussed in section 1.3.1. A major problem with this experiment was identified by Shanks and Johnstone (1998) who argued that Reed and Johnson's particular choice of sequences created conditions that made it inevitable for the indirect test of performance to show more of a difference than the direct test of awareness. Recall, in the study conducted by Reed and Johnson, 1 group of participants was trained for 17 blocks on SOCA following which they were transferred to SOCB on the 18th block (increase in RT was the indirect measure of learning). In contrast, for the cued generation control group, participants were trained on a non-repeating sequence (not a SOC sequence) and tested on SOCA. For example the indirect group who were trained on SOCA saw 12 specific triplets and learned that the probability that 4-3 is followed by 2, is 1. Suddenly when they were transferred to SOCB this expectation was violated and the participants' RT performance was disrupted. However in the case of the cued generation control group, they saw a non-repeating sequence that contained many more than 12 possible triplets, so the probability that they saw a given triplet was always less than 1. As a result, the cued generation control group was much more likely to generate a triplet from the SOCA sequence they had not seen than if they had been trained on SOCB. So the cued generation control group who were trained on a non-repeating sequence was not an appropriate control to use. It was suggested that the best control would be a group trained on an entirely different SOC sequence.

Shanks and Johnstone (1998) arranged for their cued generation control group to be trained on SOCB first so both the implicit and explicit tests of sequence knowledge were based on sequences that had no overlap in terms of SOC sequence information. They used a cued prediction task, where participants were given 1 trial and asked to predict the following 95 trials. Feedback was given, as the target did not move to the next location until the participants' response was correct. In the first experiment, participants were allocated to one of 3 conditions: cued prediction (trained on SOCA and tested on SOCA, indirect (trained on SOCA and transferred to SOCB) or cued prediction control (trained on SOCA and tested on SOCB). As predicted, RTs increased on transfer for the indirect group but the cued prediction test group was
able to predict significantly more of the sequence than the cued prediction controls. So Reed and Johnson's results are a methodological artefact, rather than strong evidence for the existence of implicit learning. Moreover, in their second experiment Shanks and Johnstone (1998) demonstrated that participants were capable of above chance free generation of the sequence under single task conditions.

Another study by Shanks and Johnstone (1999) attempted to investigate free generation under dual task conditions to see if dividing participants' attention would lead to implicit learning of the sequence. In their first experiment, participants were trained for 14 blocks on either SOCA or SOCB. The 15th block was a different sequence (either SOCA or SOCB). Finally, participants were told to freely generate 96 key presses trying to include all they could remember of the sequence. Counterbalancing of the training sequences across participants allowed transfer from SOCA triplets to SOCA triplets to be compared and vice versa for SOCB triplets, and free generation ratios were calculated for each possible triplet. Overall, transfer and free generation were found to be in parallel. However, it could be the case that a few participants were doing so well at free generation that they skewed the group mean so Shanks and Johnstone (1999) looked at the distribution of the free generation ratios and found it to be normally distributed demonstrating this was not the case in this study.

At this point, it can be concluded that the majority of evidence in favour of implicit learning of sequences can be rejected on the basis that experimenters failed to employ tests of awareness that meet the sensitivity criterion. When sensitive tests of awareness were employed, experimenters have reported a correlation between learning and awareness at a group level (Perruchet & Amorim, 1992; Shanks & Johnstone, 1999; Willingham et al., 1993; Willingham et al., 1989). In addition, apparent evidence for implicit sequence learning can be further rejected on the basis that in the majority of studies, experimenters failed to establish that participants learned more than simple probabilities during the training phase (Shanks et al., 1994; Shanks & Johnstone, 1998).
1.4.1 Evidence for implicit learning and a failure to replicate

Recall that in Reed and Johnson’s (1994) experiment, participants were trained on a SOC sequence of target locations over 17 training blocks and during the 18th transfer block a different SOC sequence was introduced, and therefore the transfer block constituted an indirect test of learning. Response latencies decreased over training and dramatically increased on the transfer block. As mentioned previously, this pattern of RTs is evidence that learning of the sequence had occurred. In a second experiment, awareness of the sequence was assessed using an objective test. Participants were trained as before and then underwent a recognition test in which they were asked to respond to several test items that were either old chunks of the training sequence or new chunks of a different sequence, and then were asked to rate the chunks on a scale of 1-4 (where 1 indicated definitely old and 4 indicated definitely new). It was reported that recognition performance was at chance. Taken together, the results represent a dissociation between implicit and explicit learning, which was achieved at a group level, and with consideration of the sensitivity criterion. Therefore the findings were apparently excellent evidence for implicit learning.

Given the convincing evidence in favour of the existence of implicit learning presented by Reed and Johnson (1994), Shanks and Johnstone (1999) attempted a replication of their findings. In their study participants were trained under conditions of divided attention on a 12-item SOC sequence of key presses for a total of 17 training blocks of 100 trials and on block 15, participants were transferred to a pseudo-random SOC block. Again, they performed a recognition test in which they had to discriminate between old and new test sequences. In contrast to Reed and Johnson’s findings, it was reported that participants learned the trained sequence (priming) and that they were also capable of discriminating between old and new test chunks. This represents a direct failure to replicate Reed and Johnson’s findings, suggesting that in this instance learning did not occur independently of awareness.

The circumstances under which participants were trained in Shanks and Johnstone’s experiment were identical to Reed and Johnson’s study with the only exception that Reed and Johnson’s participants were not rewarded for taking part, whereas in
Shanks and Johnstone's study, they were. Arguably, undertaking a recognition task involves greater cognitive effort on the part of the participant than does undertaking the RT training blocks. Hence, the presence or absence of participant motivation could account for the apparent discrepancies between the recognition data, because feasibly low motivation is likely to influence the outcome of a discrimination judgement (the explicit measure) far more than the RT task (the implicit measure). Furthermore, the recognition test was conducted after the RT task, which may have led participants to be comparatively less motivated by that stage. Therefore, an apparent dissociation between performance and awareness reported by Reed and Johnson may well be explained by the absence of participant motivation, rather than by the existence of implicit learning.

1.5 Does implicit knowledge lead to explicit knowledge?

Some experimenters assume that explicit knowledge arises from implicit knowledge. For example Pascual-Leone, Grafman, and Hallet (1994) conducted a positron emission tomography (PET) scan of participants' performance on the SRT task, and they attempted to distinguish between different stages of learning by assuming that implicit learning occurs before explicit learning. According to this logic, it could be argued that in the studies that have employed a long training period, participants might learn implicitly to begin with, but that awareness is measured after learning becomes explicit. For example, in the study conducted by Shanks and Johnstone (1998), participants were trained for 16 blocks of a sequence. Perhaps the participants would have revealed an implicit learning effect and performed poorly on the explicit test if the experiments had assessed awareness after fewer blocks.

However, this claim was refuted by Perruchet and Amorim (1992), who trained participants for only 60 trials or 6 repetitions of the 10-item sequence following which they did both a recognition and a free generation task. Even after this tiny amount of training, participants were able to generate the ending 4 trial sequence of the 10-item sequence. In addition, participants were able to recognise this and other portions of the sequence. Perruchet and Amorim concluded that tests of free recall and recognition of sequence components show that reliable explicit knowledge was
acquired after an amount of practice that was hardly sufficient to improve mean motor performance. Again, Perruchet, Bigand, and Benoit-Gonin (1997) reported that after short periods of learning e.g. 2 blocks of 80 trials, and under various manipulations, recognition was possible even when RT improvement was not revealed. Finally, Shanks and Johnstone (1999) demonstrated that participants trained on 4 sequence blocks of 96 trials, followed by transfer block, did not produce a negative transfer effect (i.e. no priming was demonstrated). However the results did reveal above chance generation of certain triplets from the sequence on which they were trained. These findings run counter to the claim of antecedence of performance changes over explicit knowledge.

1.6 Can implicit and explicit learning occur in parallel?

Evidence from several brain imaging studies (Grafton et al., 1995; Hazeltine et al., 1997; Honda et al., 1998; Rauch et al., 1995) indicate that implicit learning is dependent on separate brain regions and that essentially implicit and explicit learning are distinct systems (see section 1.9 of this review for a discussion of this evidence). Moreover, these brain-imaging studies suggest that implicit and explicit learning are mutually exclusive and they do not occur in parallel. Willingham and Goedert-Eschmann (1999) set up an elegant experiment designed to discover whether participants instructed to learn a sequence explicitly prior to training were also able to learn the sequence 'implicitly' at the same time. 2 groups of participants were trained for 3 blocks of 72 trials of a SOC sequence, followed by a transfer block that was composed of either a mixture of the whole 12 item sequence and pseudo-random trials for half of the subjects or only of pseudo-random trials for the other half. One group of participants (explicit group) was informed of the presence of a sequence before training and were specifically told to learn it and given encouragement by the presentation of the numerical target position throughout the training phase. The other group of participants (implicit group) were not told about the existence of a sequence and were not provided with any sequence cues during the training stage. At the end of the experiment participants were required to provide a confidence rating of the likelihood that they were in the group who had seen a mixture of sequence and random trials during the transfer block. Finally, they were required to
generate 13 key presses conforming to the sequence on which they were trained. Willingham and Goedert-Eschmann reported that both groups of participants were capable of significant RT savings between the random and the sequence trials (in the transfer block), providing good evidence that both groups learned the sequence. In addition, according to the confidence rating data, both groups were not capable of identifying whether or not they had been exposed to the sequence during the transfer block, suggesting that participants were unaware of the presence of a sequence in the transfer block. However, participants in the explicit group were capable of above chance generation of the sequence, indicating they had developed reliable explicit knowledge of the sequence. Participants in the implicit group were not able to perform above chance on the generation test.

Willingham and Goedert-Eschmann argued that participants in the explicit group acquired both implicit and explicit knowledge in parallel and this allowed them to on the one hand develop RT savings for sequence versus random trials in the absence of accurate confidence rating data (implicit knowledge), while on the other hand they were able to perform well on the generation test (explicit knowledge). Willingham and Goedert-Eschmann suggested that this is reliable evidence that implicit and explicit knowledge are separable but they are not mutually inhibitory. It was concluded that participants in the implicit group learned the sequence in the absence of awareness.

However, perhaps the rating test (where participants had to retrospectively determine the presence of a sequence during the transfer block) was less sensitive than the generation test employed in this study. This would have been more likely in the explicit group who were cued to encode the sequence as a series of digits during the training phase, and it is not surprising that these participants were subsequently able to generate the sequence well in the recall test. Participants in the implicit group, who were not cued to encode the sequence as a string of digits, would have found both the rating and recall tasks equally difficult, and it is possible that these tests were not sensitive enough to measure awareness accurately in this group. Therefore, the conclusion that any of these participants learned implicitly is, at the very least, open to question.
1.7 Probabilistic sequence learning

So far the review has addressed studies in which deterministic sequences were employed, which means that the sequences were composed of fixed contingencies, 10-12 items in length, e.g. 3-1-4-3-2-4-2-1-3-4-1-2. It has been shown that participants learn such fixed sequences consciously, as indexed by objective measures. But how do participants perform when a degree of noise is added to the sequence? It has been hypothesised that this should encourage participants to be less aware of the existence of the sequence and, therefore, to learn it implicitly. For instance, in a seminal study reported by Cleeremans and McClelland (1991), participants were extensively trained on a noisy sequence. In this case, participants were trained on sequences composed of 1-6 target locations and each location corresponded to a letter generated by an artificial grammar. The trials either corresponded to the grammar (predictable trials), or 15% of the time they did not (unpredictable trials). After considerable practice (60,000 exposures), participants responded to the grammatical targets more quickly than the ungrammatical ones, demonstrating that they had acquired a complex body of procedural knowledge about the sequential structure of the material. In addition, verbal report was poor but as already discussed, this is not an especially sensitive measure of awareness. In Experiment 2, participants were trained on even more complex sequences generated by a larger artificial grammar. In this case, the sequences were 13 target locations in length and again after extensive practice participants demonstrated procedural knowledge of the sequence. However, following training participants performed above chance on the generation task, indicating that the knowledge acquired in this study was explicit.

In a similar study, Jiménez et al. (1996) set out to examine probabilistic sequence learning followed by performance on the generate task. Participants performed 20 blocks of 155 trials for 20 sessions on a 6 choice reaction time task. Again the sequence was composed of 15% random and 85% structured trials and the structured trials were generated by a simple finite state grammar. Following training, participants performed 465 generate task trials. In this case, the experimenters followed the method of Cohen et al. (1990), so the participants were given a stimulus
and asked to predict the next target location. When participants gave an incorrect response they were shown the correct location and Jiménez et al. justified this use of feedback by pointing out that it is less likely for participants to learn during the test phase when a sequence is probabilistic.

Over the training phase, grammatical and ungrammatical items were compared. For instance, if a target in the sequence (t) was normally followed by t1, the RT of t1 was compared with the RT of an item which followed t, but which was not t1. Jiménez et al. selected some grammatical and non-grammatical items, of 3 different contextual lengths for analysis. These were either of length 1 (1st order, e.g. D-A), length 2 (2nd order, e.g. DC-A) or of length 3 (3rd order, e.g. DBE-A). Overall, grammatical items were executed more rapidly than non-grammatical items, suggesting that people were able to learn about the structure of the material. However this was restricted to the items of lengths 1 and 2 but was not true for items of length 3, evidence that people can only learn the constraints set by 2 previous trials.

Regarding generate task performance, it was observed that participants generated above chance levels of correct responses, indicating that this learning was not implicit. Moreover, a similar analysis was conducted on the generate data as was conducted on the RT data, and Jiménez et al. looked at the probability of participants generating grammatical and non-grammatical sequence chunks of length 1, length 2 or length 3. It was reported that participants generated significantly more grammatical items than ungrammatical items of lengths 1 and 2, but this effect was not significant for items of length 3. On the whole, the findings are consistent with the theory that people learned no more than second order contingencies, and this learning was explicit in nature.

Interestingly, Jiménez et al. conducted a finer grained analysis of the data, to investigate whether participants used the same knowledge to perform the indirect RT task and the generate task, or whether different knowledge was used to perform the indirect task, which was not reflected by the generate task. Jiménez et al. looked at the distribution of generation probabilities for the last element of the selected paths, and at the RT accuracy for each probability. Then, the experimenters compared these learning distributions, by computing their correlation, and compared that with
the actual distribution of conditional probabilities of the experimental stimulus.

Strikingly, Jiménez et al. showed that large effects of sequence learning are exclusively expressed through reaction time, but not through generate task performance. For example, for items of Length 1, it was reported that there was some knowledge about the statistical structure of the material that was exclusively expressed by the generate task (accounting for about 5\% of the variance of conditional probabilities). However, the percentage of variance explained exclusively through the indirect measures was higher and amounted to over 20\%. A similar pattern of results was obtained for items of length 2. According to Jiménez et al., this result suggests that at least some of the learning observed in their experiment can be described as implicit.

There is one major problem with Jiménez et al.'s claim for the existence of implicit learning identified by Shanks and Johnstone (1999) who underlined that to interpret Jiménez et al.'s data as evidence for implicit learning, it must be assumed that participants adopted the same response rules in both the indirect and direct tests. However, the performance targets of the indirect and direct tests were different. For example, recall in Jiménez et al.'s indirect RT test, participants were required to respond to probabilistic sequences generated by an artificial grammar, and the resulting profile of priming observed during the indirect test would be distributed across all possible target locations. However, the conditional probability of each sequence location varied throughout the training stage and, by pure chance, a participant may have been exposed to significantly more of 1 sequence location during training, and have had relatively little exposure to another. Therefore, in the generate task when participants were required to produce sequence locations, it is possible that they were more likely to produce locations with the highest conditional probability during the training phase (i.e., those which they thought were most likely) in favour of those sequence locations, for which the conditional probability of appearing in the training phase was low. The resulting profile of generate task performance would be distributed across only a few of the most likely target locations rather than all possible locations. If participants do "overmatch" when they perform generate tasks then this behaviour would produce a pattern of results similar to that described by Jiménez et al. Furthermore, it would not need to be explained by
appealing to separate implicit and explicit systems.

1.7.1 How do the elderly learn probabilistic sequences?

The ability to learn implicitly has been conceptualised as a robust phenomenon, whereas explicit learning is viewed as a more fragile entity, vulnerable to interference by processes like dividing attention, or aging. For example, Curran (1997a) hypothesised that the elderly would be able to learn second order conditional or SOC sequences implicitly, but in addition, they would be impaired at learning first order conditional sequences explicitly. In the study a probabilistic version of the SRT task was employed, with the hope that it would disguise the presence of sequences to the participants. Hence, one group of elderly and a second group of young individuals were trained on noisy sequences. The sequences employed were a SOC sequence (i.e. 1-4-2-3-4-1-3-2-4-3) that was interspersed with random trials, and a first order predictive sequence (i.e. 1-2-1-4-2-3-4-3-1-4-2-3) that was also interspersed with random trials. Participants were trained for 9 blocks of 120 trials and each block was arranged so that random and sequence trials were mixed as follows: RSSRSSR.

Following the training stage, participants performed 2 recognition tests. In the first test, they were required to distinguish between whole sequences 12 items in length and distractor sequences. As a departure from the typical recognition test method, the test sequences were presented as strings of digits, rather than as target locations. In the second recognition test, participants were required to distinguish between sequence chunks of 4 items in length and similar distractor chunks, and again these chunks were presented as strings of digits. Curran compared RTs for random trials with RTs for sequence trials, and reported that old and young participants were capable of learning the SOC sequences, as indexed by a significant RT difference between random and sequence trials. Moreover, Curran demonstrated that young individuals were capable of learning the first order predictive sequences, but old participants were not able to learn these sequences. Both elderly and young individuals performed at chance on the recognition tests for the SOC sequences, suggesting that participants learned SOC sequences implicitly. It was reported that
recognition performance for the first order predictive sequences was at chance for the young individuals, whereas the old individuals performed significantly above chance on this measure. It is not clear why the elderly individuals demonstrated above chance recognition of the first order sequences, when they appeared to show no learning during the training stage.

The most important claim is that learning was implicit, indicated by the recognition performance of individuals in this study. It is possible that the particular method used to measure recognition was insensitive, because participants were given recognition test items in the form of digit strings. Perhaps this method is significantly more difficult than the usual recognition test, because it does not require a motor response from the participant. As pointed out by Shanks and St John (1994), if a test of performance is easier than a test of awareness, then the experimenter runs the risk of comparing a sensitive measure of performance with an insensitive measure of awareness.

1.8 Neuropsychological and psychopharmacological evidence for the existence of implicit learning and its underlying brain regions

It is widely believed that amnesic individuals with damage to the medial temporal lobe (MTL) region of the brain, including the hippocampus, provide evidence of implicit learning because they appear to show a selective deficit in explicit knowledge (assessed by generation and recognition tests) combined with normal implicit learning (P.J. Reber & Squire, 1994, 1998). Therefore, according to a multiple systems view, the MTL and related structures underlie explicit learning whereas implicit learning depends on different neural networks.

However, the claim that procedural learning remains unaltered in MTL amnesics is debatable. For instance, MTL amnesics show deficits in sequence learning that indicate that priming is not always normal in these individuals (T. Curran, 1997b). Moreover, amnesic individuals with damage to the hippocampus have been shown to be impaired at a visual search task which requires sequential learning but which also
specifically involves contextual cue learning (Chun & Phelps, 1999). Hence, it remains to be shown that the implicit/explicit distinction correctly characterizes the difference between spared and impaired learning processes in amnesia.

Squire (1992) proposed that skill learning is dependent on the integrity of the basal ganglia. This claim is supported by several findings that have suggested that sequence learning is altered in individuals with disorders involving lesions of the basal ganglia. For example, individuals with Huntington's disease (Knopman & Nissen, 1991; Willingham & Koroshetz, 1993) and Parkinson's disease (Doyon et al., 1997; Doyon et al., 1998; Ferraro, Balota, & Connor, 1993; Jackson, Jackson, Harrison, Henderson, & Kennard, 1995; Pascual-Leone et al., 1993; Westwater, McDowall, Siegert, Mossman, & Abernethy, 1998) are impaired at procedural learning.

In neuropsychological studies, one problem is that sample sizes are often very small leading to low experimental power. Another problem is that brain damage is usually heterogeneous within samples. To overcome these difficulties, experimenters can model organic amnesia by using pharmacological manipulations to induce a period of temporary amnesia in normal participants (H.V.Curran, 1999). A small number of studies have been conducted to investigate sequence learning where drug-induced amnesic participants have been employed, and the evidence suggests that procedural learning remains intact. However, the issue of whether learning was implicit/explicit has not yet been thoroughly examined (Bishop, Curran, & Lader, 1996; Knopman, 1991b; Nissen, Knopman, & Schacter, 1986; Volkerts, Van Laar, Verbaten, Mulder, & Maes, 1999).

The introduction to Chapter 3 provides a more detailed discussion of the issues summarised in this section.
1.9 Brain regions activated during sequence learning

Both positron emission tomography (PET) (Berns et al., 1997; Destrebecqz et al., 2003; Doyon et al., 1997; Doyon et al., 1998; Grafton et al., 1995; Hazeltine et al., 1997; Honda et al., 1998; Maquet et al., 2000; Peigneux et al., 2000; Rauch et al., 1995) and functional magnetic resonance imaging (fMRI) (Rauch et al., 1997; Schendan, Searl, Melrose, & Stern, 2003; Willingham et al., 2002) studies have been carried out to find out which particular areas of the striatum and what other related brain areas are activated during sequence learning.

In 6 of the neuro-imaging studies cited above, experimenters set out to systematically compare brain activation associated with procedural (implicit) versus explicit sequence learning within the same experiment. Evidence from 4 studies (Grafton et al., 1995; Hazeltine et al., 1997; Honda et al., 1998; Rauch et al., 1995) strongly suggests that separate brain regions are responsible for implicit and explicit learning. Findings from these studies also suggest that implicit and explicit learning are mutually exclusive, because completely different brain regions are associated with implicit compared to explicit learning.

However, a behavioural study discussed in section 1.6 (Willingham & Goedert-Eschmann, 1999) indicates that implicit and explicit learning can occur in parallel which runs counter to the idea that they are mutually exclusive, and 2 more recent neuro-imaging studies (Schendan et al., 2003; Willingham et al., 2002) revealed a considerable overlap of the brain regions thought to be involved in implicit and explicit learning. A detailed description of each of the key imaging studies in which a comparison is made between implicit and explicit learning within studies will be given in sections 1.9.1 & 1.9.2. Sections 1.9.3 & 1.9.4 will focus on the remaining imaging experiments, in which experimenters claimed to investigate brain regions associated with either implicit or explicit learning in isolation, and under several different circumstances. It should be noted that in all of the experiments mentioned, experimenters employed a variety of different techniques including the adoption of
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different criteria to ascertain levels of awareness and using different training procedures. Therefore, given these methodological differences, it is often difficult to compare across studies.

1.9.1 Implicit and explicit learning within studies: single compared to dual task learning

As mentioned previously in section 1.3.1, it has been suggested that if the SRT task is undertaken under conditions of divided attention, it may be more likely that participants will learn the sequence unconsciously. To investigate whether or not this claim could be supported by imaging data, Grafton et al. (1995) used PET to examine regional cerebral blood flow changes (rCBF) in a group of participants who initially performed single task learning, where they were trained on a sequence of target locations as usual (explicit blocks). This stage was followed by a period of dual task sequence learning, where they were required to perform a secondary tone counting task in addition to the sequence learning task (implicit blocks). Furthermore, participants performed random blocks to enable comparison of brain activation during sequence and random blocks. Analysis of the behavioural data revealed an RT difference between random and sequence blocks which was significantly greater for the single task blocks (170 ms) compared to the dual task blocks (50 ms), hence the magnitude of learning decreased when a secondary task was included. This finding is in contrast to an earlier observation reported by Frensch et al. (1998) but is entirely consistent with findings from Shanks and Channon’s (2002) study.

By subtracting the areas which showed increases in (rCBF) during random blocks from regions that showed increases during either single or dual task learning, Grafton et al. calculated that different regions within the frontal and posterior cortex were associated with the dual (implicit) and single (explicit) task conditions respectively. The brain areas correlated with dual task learning were as follows: the left occipital cortex (BA18) and the junction of the parietal and occipital lobes bilaterally. Grafton et al. suggested that this reflected the visual nature of the task. Activations were also recorded in Areas 40 and 7, which Grafton et al. linked to spatial representation and
visually guided actions. Within the frontal regions, activations were recorded in the supplementary motor area and motor cortex in the left hemisphere. For single task learning, activations occurred in the following regions: the posterior cortex including inferior aspects of the parietal occipital lobe (BA 40/19) and temporal lobe of the right hemisphere (BA 21). In the frontal lobe, increases in rCBF were observed in BA 8 and inferior prefrontal cortex (BA 10 and 46), and the lateral premotor cortex (BA 6) (see Table 1.1 for all brain regions associated with an increase in rCBF in this study).

In a very similar PET study, Hazeltine et al. (1997) compared single with dual task sequence learning but in this instance, the location of the target did not vary, and participants responded by pressing appropriate keys on the basis of target colour. During dual task or implicit learning, activations were observed in the left hemisphere: in the parietal cortex, supplementary motor area and primary motor cortex. For the single task or explicit learning condition, activations were observed in the right hemisphere: in the occipital and temporal foci in the posterior cortex and the lateral prefrontal and premotor foci in the frontal cortex (see Table 1.1).

When the Grafton et al. and Hazeltine et al. studies are considered together, the brain regions responsible for dual and single task sequence learning do not appear to overlap. For example, it is suggested that dual task learning primarily engages the left hemisphere including a ‘dorsal pathway’ comprising the parietal, supplementary motor area and primary motor cortex. Conversely, single task learning primarily involves the right hemisphere including a ‘ventral pathway’ consisting of the occipital, temporal, prefrontal and lateral premotor cortex (Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003).

It is claimed that the apparent activation of dorsal and ventral pathways during dual and single task learning is strong evidence for the existence of 2 separate learning systems (Keele et al., 2003). First, the multidimensional system is dependent on the ventral pathway associated with single task learning. This system builds associations between different modalities and enhances contextual information, which facilitates the learning of complex sequences. Moreover, the multidimensional system is capable of both implicit and explicit learning, which can occur in parallel. Second,
the one-dimensional system is dependent on the dorsal pathway associated with dual-task learning, and it is suggested that this system keeps modalities separate, which means that the one-dimensional system is capable only of implicit learning. Hence Keele et al. (2003) suggest that when a dual task was introduced in the Grafton et al. and Hazeltine et al. studies, the multidimensional system was rendered incapacitated, requiring the one-dimensional system to engage in the task instead.

Although it has been suggested that dividing attention leads to the emergence of implicit learning (Reed & Johnson, 1994: Frensch et al., 1998). Grafton et al.'s (1995) behavioural data are inconsistent with that claim because the magnitude of sequence learning decreased (rather than increased) upon the introduction of a secondary task. Keele et al.'s (2003) theory amounts to a complex account of the pattern of neurophysiological and behavioural data reported by Grafton et al., Hazeltine et al. and others (e.g. Shanks and Channon). It provides one possible explanation of why the behavioural data in Grafton et al. and Shanks and Channon's studies revealed that dual task learning led to less learning overall: under single task learning conditions participants were capable of both implicit and explicit learning, whereas under dual task conditions they were only capable of implicit learning. Nevertheless, a simpler explanation of the observed pattern of results is also possible; perhaps the different brain regions supposedly engaged by the implicit or explicit nature of the task, are simply associated with different task difficulties and/or attentional states. Furthermore, it is possible that the introduction of a secondary task simply leads to a decrease in the amount of explicit learning that can be accomplished.

1.9.2 Implicit and explicit learning within studies: single task learning

Under single task conditions, Rauch et al. (1995) conducted a PET study to investigate which areas of the brain are activated during SRT task performance. In the first stage of the experiment (the implicit stage) 7 participants were trained for 2 sequence blocks and a random block and Rauch et al. argued that at this stage, any learning of the sequence should be implicit on the basis that the participants were not informed about the presence of a sequence. In the second stage, participants were
debriefed about the presence of a sequence and then asked to generate their sequence knowledge with 15 key presses. Next they performed a recognition test where they had to discriminate between 12 6-item test chunks (6 old, 6 new) and then, participants were repeatedly shown the entire sequence 3 times to ensure that they were aware of its content. In the third stage (the explicit stage) participants' brain activity was scanned while they performed 2 sequence blocks. Rauch et al. argued that at this stage, any sequence learning would be explicit because participants had been made aware of the presence of the sequence. Finally, participants were tested again for both recall and recognition of the sequence.

It was reported that the explicit blocks were performed faster than the implicit blocks, which were in turn performed faster than the random blocks. Interestingly, participants' discrimination performance was at chance for both recognition tests, and it is possible that they were entirely unaware of the sequence throughout the entire experiment. However, it is equally plausible that recognition performance was at chance because the small sample size led to low power to detect an effect if it was present in the population. This latter explanation seems the most likely given that participants were encouraged to develop explicit knowledge of the sequence during the second stage. Moreover, recall performance revealed a pattern of results that indicated participants did become aware of the sequence. Rauch et al. measured the number of items generated at chance by randomly generating 16,000 recall series. They compared the mean of this chance level with participants' recall performance at the second stage and found it was not different from chance. However, when participants' recall performance after the third stage was examined, it was found to be above chance.

Rauch et al. (1995) compared the areas activated during random blocks with areas activated during the implicit and explicit blocks. Most important, in the case of the implicit-random contrast (calculated by subtracting areas of brain activation associated with random block performance from implicit block areas of activation) suprathreshold activations were reported within the right ventral pre-motor cortex, right ventral caudate/nucleus accumbens, right thalamus, and bilateral visual association cortex (BA 19). The implicit-explicit contrast demonstrated significant activation only within right ventral pre-motor cortex. The explicit-random foci of
significant activation were within the bilateral cerebellar vermis, left fusiform cortex (BA 19), left inferior frontal cortex (BA 45), right thalamus, right middle temporal cortex (BA 39), right brain stem, primary visual cortex and peri-sylvian cortex. The explicit-implicit condition demonstrated significant activation within the bilateral primary visual cortex (BA 17) and left inferior parietal cortex (BA 39/40) (see Table 1.1).

In another brain imaging study, Honda et al. (1998) trained participants for 7 blocks of 100 trials in which the target appeared according to a 10-item sequence, and PET scans were conducted after each block. In addition, in an attempt to systematically measure the development of sequential awareness during training, participants were required to verbally report fragments of the sequence following each training block. On the basis of verbal report performance, the training blocks and corresponding brain scans were classified as implicit or explicit. It was reported that the following regions were associated with increased rCBF during explicit learning: the posterior parietal cortex, precuneus, bilateral premotor cortex, right dorsolateral prefrontal cortex, left thalamus and SMA, predominantly in the contralateral anterior portion. For implicit learning the contralateral SM1 was associated with a decrease in RT for sequence blocks (see Table 1.1).

1.9.2.1 Overlapping brain regions are responsible for implicit and explicit learning

The studies discussed so far indicate that the regions associated with implicit learning are entirely different from the regions associated with explicit learning. However, when considered together, the findings reported by Grafton et al., (1995), Hazeltine et al. (1997), Rauch et al., (1995) and Honda et al., (1998) paint an inconsistent picture of the neural systems which are supposedly involved in implicit and explicit learning; and this is perhaps the result of considerable methodological differences across studies.

Plainly, the view that learning is always accompanied by awareness is difficult to reconcile with data showing that distinct neural networks are activated under implicit and explicit learning conditions. However, this finding also supports the idea that
implicit and explicit learning are mutually exclusive because implicit and explicit learning appear to have no neural components in common. Yet behavioural evidence described in section 1.4 indicates that implicit and explicit learning can occur in parallel (Willingham & Goedert-Eschmann, 1999).

Moreover, Willingham et al. (2002) pointed out that the brain-imaging findings discussed so far are surprising because, at the very least, perceptual motor practice was common to both implicit and explicit conditions. Therefore, neural activation associated with perceptual motor practice should also be common to implicit and explicit conditions in all studies. Conversely, the evidence described suggests the occurrence of explicit learning actually inhibits the procedural learning system. In the studies where dual task learning has been compared with single task learning, the effect of a dual task on attentional demand is confounded with the learning process. Similarly, in studies where the development of implicit knowledge followed by explicit knowledge is investigated, this confounds order because the explicit stage always follows the implicit stage. Hence, the reported differences between implicit and explicit neural networks could simply be due to differential effects of confounding variables (Willingham et al., 2002).

To formally investigate whether the development of declarative knowledge inhibits procedural learning, Willingham et al. (2002) designed an experiment to look at brain activation when procedural and declarative knowledge were developed in alternation rather than sequentially. To eliminate the potentially confounding effect of test order, participants learned sequences at the same time under either implicit or explicit conditions. Ostensibly they were told that red circles denoted a repeating sequence (A) and that black circles denoted a random pattern of target locations. Before scanning, all participants were required to respond to targets that appeared in a sequence, which always determined the location of the red circles (A). This sequence was called the explicit overt condition because participants were aware of the presence of a repeating sequence. In addition, before scanning participants responded to black circles but unknown to them some of these appeared in a different sequence (B) and a proportion of the black targets appeared randomly. The second sequence was called the implicit condition because participants were not made aware of the presence of a repeating sequence for the black targets.
At test, the participants underwent a brain scan using fMRI. In the explicit overt condition the red circle sequence (A) was repeated again, and it was predicted that brain regions associated with explicit knowledge would be activated. In the implicit condition participants performed the black circle sequence (B) and it was predicted that brain regions associated with implicit learning would be associated. Finally, in the explicit covert condition, participants performed the sequence that had previously been denoted by red circles (A) but this time it was denoted by black circles. Therefore, because participants performed identical actions for the same sequence in the explicit overt and covert conditions it was possible to look at the effect of awareness to determine whether the presence or absence of awareness led to the recruitment or inhibition of the procedural system. In the implicit condition, participants performed at chance on a recognition test of sequence knowledge.

The areas activated in the implicit condition were as follows: the left inferior frontal gyrus (BA 46 and BA10), right putamen, and left inferior parietal cortex (BA 40). Moreover, all active regions in the implicit condition were also active in the explicit-covert condition. In addition, it was reported that regions active in the implicit and explicit covert conditions were also active in the explicit overt condition. Furthermore, other areas were associated with the explicit overt condition including the bilateral superior parietal cortex, bilateral cerebellar cortex, brain stem, bilateral middle frontal and inferior frontal gyri, cingulate gyrus, right caudate and bilateral premotor cortex (see Table 1.1).

Therefore, the very same neural systems (e.g., left prefrontal cortex, left inferior parietal cortex, right putamen) were activated in both conditions but some additional regions were activated in the explicit condition (e.g., premotor cortex). This seems entirely consistent with a unitary account of the contribution of awareness to learning, with the proviso of course that it is doubtful that participants in the implicit condition were genuinely unable to perform above-chance in the recognition test; indeed Willingham et al. did find a difference between ratings (on a 4-point scale) to old and new test sequences, albeit non-significant. Therefore, it is suggested that Willingham et al.'s implicit and explicit groups merely represented participants with weaker and stronger sequence knowledge.
Consistent with this view, Schendan et al. (2003) reported that there was considerable similarity between brain regions thought to be responsible for implicit and explicit sequence learning. In their experiment, participants performed alternating sequence and pseudo-random blocks under both implicit and explicit conditions. In the implicit condition, participants were not told about the presence of a sequence whereas for explicit runs they were informed about the presence of a sequence and told to try to memorize it. Various tests of awareness were administered after both implicit and explicit conditions and the experimenters reported that participants performed worse after the implicit than after the explicit condition.

Brain regions associated with the implicit condition were as follows: the bilateral medial temporal lobe, bilateral putamen, bilateral caudate, and right dorsolateral prefrontal cortex. For the explicit condition they were: bilateral medial temporal lobe, bilateral putamen, bilateral caudate, and bilateral dorsolateral prefrontal cortex. Notice that Schendan et al. (2003) reported medial temporal lobe activation during both implicit and explicit conditions which contrasts sharply with the view that the medial temporal lobe has a particularly important role in the development of awareness.
Table 1.1. Brain regions activated when implicit learning was compared with explicit task learning in the same experiment (regions were associated with an increase in activation unless otherwise specified).

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<thead>
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<th>Authors</th>
<th>Brain region</th>
<th>Implicit learning</th>
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<td>Related Changes</td>
<td>Related Changes</td>
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<tr>
<td>Grafton et al.</td>
<td>Frontal cortex</td>
<td>Left anterior (10)</td>
<td>Right dorsolateral (46)</td>
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<td></td>
<td>Supplementary motor area (6)</td>
<td>Right superior (6/8)</td>
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<td></td>
<td>Posterior cortex</td>
<td>Left parietal (40/7)</td>
<td>Right parietal/occipital (19/39)</td>
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<td></td>
<td>Left lingual gyrus (18)</td>
<td>Right parietal/occipital (19/39)</td>
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<td></td>
<td>Subcortical</td>
<td>Left putamen of basal ganglia</td>
<td>Right putamen and nucleus accumbens of basal ganglia</td>
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<td>Hazeltine et al.</td>
<td>Frontal cortex</td>
<td>Supplementary motor area (6)</td>
<td>Right lateral prefrontal (IFC 45)</td>
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<td>(1997) (PET)</td>
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<td>Left primary motor cortex</td>
<td>Right premotor</td>
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<td></td>
<td>Posterior cortex</td>
<td>Left parietal (40)</td>
<td>Right occipital (19)</td>
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<td>Right temporal (ITC) 20</td>
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<td>Rauch et al.</td>
<td>Frontal cortex</td>
<td>Right ventral pre-motor</td>
<td>Left inferior frontal cortex (45 Broca’s area)</td>
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<td>Right middle temporal cortex (39)</td>
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<td>Primary visual cortex</td>
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<td>Left inferior parietal cortex (39/40)</td>
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<td>Bilateral primary visual cortex (17)</td>
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<td>Honda et al.</td>
<td>Subcortical</td>
<td>Right ventral caudate/nucleus accumbens of basal ganglia</td>
<td>Right thalamus</td>
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<td>(1998) (PET)</td>
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<td>Right brain stem</td>
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<td>Frontal cortex</td>
<td>Bilateral cerebellar vermis</td>
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<td>Left supplementary motor area (1)</td>
<td>Decrease in rCBF</td>
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<td>Posterior cortex</td>
<td></td>
<td>Right superior temporal gyrus (42/22)</td>
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<td>Left fungiform gyrus (36)</td>
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<td>Left angular gyrus (39)</td>
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<td></td>
<td>Left inferior occipital gyrus (18/19)</td>
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<td>Willingham et al. (2002)</td>
<td>Frontal cortex</td>
<td>Left inferior/mid frontal gyrus (46)</td>
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<td>Left inferior mid frontal gyrus (10)</td>
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<td></td>
<td>Posterior cortex</td>
<td>Left inferior parietal (40)</td>
<td>Right posterior parietal (7/40)</td>
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<td>Left posterior parietal</td>
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<td>Subcortical</td>
<td>Right putamen</td>
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<td>Right globus pallidus</td>
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<td>Right cerebellum</td>
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<td>Left fusiform (19)</td>
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<td>Right fusiform (19)</td>
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<td></td>
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<td>Precuneus</td>
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<tr>
<td>Schendan, et al. (2003)</td>
<td>Frontal cortex</td>
<td>Right dorsolateral prefrontal cortex</td>
<td>Bilateral dorsolateral prefrontal</td>
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<td></td>
<td></td>
<td></td>
<td>cortex</td>
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<td></td>
<td>Posterior cortex</td>
<td>Bilateral caudate</td>
<td>Bilateral caudate</td>
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<td>Bilateral medial temporal lobe</td>
<td>Bilateral medial temporal lobe</td>
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<tr>
<td></td>
<td>Subcortical</td>
<td>Bilateral putamen</td>
<td>Bilateral putamen</td>
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</table>
1.9.3 Neural basis of implicit and explicit learning when studied in independence

1.9.3.1 Neural basis of implicit learning

Several experimenters have aimed to discover the brain areas associated with implicit learning without making any comparison to explicit learning within the study. In some experiments either awareness was assessed using an insensitive test or no test of awareness was employed at all (Berns et al., 1997; Doyon, Owen, Petrides, Sziklas, & Evans, 1996; Jenkins et al., 1994; Maquet et al., 2000) and when sensitive tests of awareness have been employed, it has not been established that experimental power was great enough to detect an effect (Peigneux et al., 2000; Rauch et al., 1997).

In a study by Berns et al. (1997) participants underwent a lengthy period of training for one sequence, then they were switched to another sequence and they were subsequently unable to report either the existence of a sequence or the switch to a new sequence (Berns et al., 1997). However, both the pattern of reaction times during training and brain imaging data (PET) indicated that participants were sensitive to the sequence change. When the sequence was switched, it was reported that rCBF significantly increased in the left premotor area, left anterior cingulate and right ventral striatum and nucleus accumbens, and it was suggested that the activation in the right ventral striatum was specifically related to the introduction of a novel sequence. Activity was also recorded in the right dorsolateral prefrontal cortex, which showed an rCBF increase during the onset of the first sequence and a decrease when the sequence was switched. It was suggested that this area was related to the maintenance of contextual information. Although the activations recorded do indeed appear to be closely associated with the pattern of reaction times, the claim that learning was implicit in this study is rather weak because the experimenters employed an insensitive test of awareness.

In another experiment conducted by Rauch et al. (1997), fMRI was used to investigate the brain areas involved during implicit learning. 10 male participants were trained for a series of alternating blocks comprising 72 trials each. The blocks
either consisted entirely of sequence trials, or of random trials (the only constraint being that no location was immediately repeated in the random blocks). Following training, participants were debriefed during which they were asked questions about the existence of a sequence. Then they were asked to recall the sequence by making a series of 15 key presses. Rauch et al. (1997) reported significant RT differences between the random and sequence blocks. However, participants were not able to explicitly recall the sequence as indexed by the debriefing task. In all participants, activations were evidenced in the right caudate and right inferior putamen. However, only 7/10 participants exhibited a significant RT advantage for sequence compared to random blocks and these participants all exhibited activation specifically in the putamen. Furthermore, this activation correlated with the level of RT improvement they showed. The remaining 3 participants exhibited activation in the caudate. Other brain regions that were involved outside the striatum included: the right anterior cingulate gyrus, left prefrontal cortex, left premotor cortex, left inferior parietal cortex, left visual cortex and left cerebellum. Again, it is unlikely that learning was genuinely implicit in this study because although the test of awareness employed was probably sensitive, such a small number of participants very likely led to low power in this study, which could lead to the observation of a null result on an awareness test. However, the experimenters did not present a power analysis to formally address this issue.

Another experiment was conducted in which participants learned a sequence of motor responses by the presentation of auditory feedback (Jenkins et al., 1994). In addition, PET was performed during both the learning of new sequences and practice of previously learned sequences. The parietal cortex and putamen were found to be activated under both circumstances, and the cerebellum was involved only in the practice of previously learned sequences. Consistent with this finding, a study by Doyon et al. (1996) suggested a specific involvement of the cerebellum and the striatum in an advanced stage of the learning process (see Table 1.2). Again, no convincing evidence was presented to suggest that learning was implicit in either of these investigations.
1.9.3.2 Neural basis of probabilistic implicit learning

Until now the discussion of the neural basis of sequence learning has focused on studies where deterministic sequence learning was employed. Are the same regions responsible for learning deterministic sequences also implicated in probabilistic sequence learning? Peigneux et al. (2000) conducted a PET study of probabilistic sequence learning. 14 participants were trained for 12 blocks of 410 trials on a sequence that was generated by a finite state grammar. In addition, there was a 15 % chance that any particular trial would be non-grammatical, allowing the experimenters to compare RTs for grammatical versus non-grammatical trials, as an indirect measure of sequence learning. Following scanning, participants performed a generation task in which they were given a stimulus and asked to predict the next stimulus for 1 block of 410 trials (the correct stimulus was given after each response regardless of its accuracy).

Peigneux et al. reported that RTs for grammatical trials were significantly faster than RTs for non-grammatical trials and participants’ performance on the generation task did not differ from chance, which was taken as evidence that learning was implicit. For participants who specifically showed an RT saving for grammatical trials, an increase in rCBF was observed in: the left caudate nucleus, the putamen and the middle (BA10) and inferior frontal gyri (BA 44, 45, 46 and 47). This finding confirms that the striatal region is involved in probabilistic sequence learning showing that the same areas are common to both deterministic and probabilistic sequence learning. However, the claim that learning was implicit in this study is again less convincing because the possibility that low power led to the observed poor performance on the awareness test cannot be ruled out.

1.9.3.3 Neural basis of implicit learning followed by sleep

Maquet et al. (2000) conducted a PET study to investigate whether or not the waking experience of sequence learning influences later regional brain activity during REM sleep in humans. In the first group, 7 participants were scanned both at rest and during training for 205 trials of a probabilistic sequence generated by a finite state grammar. In the second group, 6 participants were scanned during performance of the task and during subsequent REM sleep, and in the third group, 5 participants
were scanned both at rest and during REM sleep. Maquet et al. reported that some areas were more active in trained than in non-trained participants during REM sleep including: the bilateral cuneus and adjacent striate cortex, the left premotor cortex, the inferior part of the left thalamus and the mesencephalon. Moreover, some of these regions were both more active during REM sleep in the trained participants (group 2) compared to the non-trained participants (group 3) and activated by task performance during waking (group 1) including: the bilateral cuneus and adjacent striate cortex, left premotor cortex and mesencephalon. Therefore, when participants undergo sequence learning, the same brain regions involved are also activated during subsequent REM sleep, and this is interesting evidence that sleep plays a role during the storage of sequence knowledge. Nevertheless, a test of awareness was not conducted in this study so the claim that learning was implicit remains open to question.

1.9.3.4 Neural basis of explicit learning

In a recent experiment, Destrebecqz, et al. (2003) used PET to examine the brain regions underlying sequence learning. They trained participants on a sequence, followed by a modified free generation task in which participants were required to generate and withhold free generation responses upon request. It was observed that participants could both generate and withhold the expression of their sequence knowledge upon request, indicating that learning was explicit in this study (see section 1.10 for an explanation of the rationale behind this reasoning). The brain regions associated with explicit sequence learning were: the left anterior cingulate and mesial prefrontal cortex (BA 32/10) (see Table 1.2).

1.9.4 Summary of brain imaging section

The purpose of the research described in this section was to establish the neural networks responsible for implicit and explicit learning. Two different approaches have been taken, the first involves comparing implicit and explicit sequence learning in the same study and the second involves examining either implicit or explicit learning in isolation.
Several within-study comparisons of implicit and explicit learning indicted that when participants were classified as either aware or unaware different brain regions were recruited for sequence learning. However, these studies were problematic for 2 reasons: a) it is debateable that participants were genuinely unaware under so-called implicit conditions or according to performance on a variety of tests of awareness, and b) confounding variables were often present like test order and the effects of divided and undivided attention.

A recent study by Willingham et al. (2002) revealed that the same brain regions were recruited during implicit and explicit learning when they were examined simultaneously. Combined with the fact that participants were probably not unaware in the implicit condition of this study, the observation is entirely consistent with the view that there is no need for a distinction between implicit and explicit learning to be made.

Where experimenters have claimed to establish the neural basis of implicit learning, evidence presented for unawareness of the sequence is unconvincing. Nevertheless, all findings described in this section provide an analysis of the brain regions recruited during procedural learning. During sequence learning, both the putamen and pre-motor cortex (including the supplementary motor area) are activated. The pre-motor cortex projects to the putamen and together with the cerebellum these regions constitute a brain system that is purported to mediate motor functions (Alexander, Crutcher, & DeLong, 1990). This theory is also supported by the fact that individuals with striatal and cerebellar damage are impaired at sequence learning. Broadly speaking, the striatum relieves the cortex of its load in order for it to be freed up to perform other explicit tasks. Furthermore, Rauch et al. (1998) reported that the thalami were deactivated whereas the striatum was recruited in the early phase of learning. This led them to propose the existence of a thalamic gating mechanism mediated by the indirect striato-pallido-thalamic pathway.
Table 1.2. Brain regions activated when single task learning was investigated under a variety of different circumstances (regions were associated with an increase in activation).

<table>
<thead>
<tr>
<th>Authors</th>
<th>Brian region</th>
<th>Implicit learning</th>
<th>Related changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berns, Cohen and Mintun</td>
<td>Frontal cortex</td>
<td>Right dorsolateral prefrontal cortex</td>
<td>Left prefrontal cortex</td>
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<tr>
<td>(1997) (PET)</td>
<td>Posterior cortex</td>
<td>Left prefrontal cortex</td>
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<td></td>
<td></td>
<td>Left premotor area</td>
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<td></td>
<td></td>
<td>Left anterior cingulate</td>
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<td></td>
<td>Subcortical</td>
<td>Right ventral striatum</td>
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<td></td>
<td></td>
<td>Nucleus accumbens</td>
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<tr>
<td>Doyon, Owen, Petrides,</td>
<td>Frontal cortex</td>
<td>Lateral prefrontal cortex</td>
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<td>Sziklas, &amp; Evans (1996)</td>
<td>Posterior cortex</td>
<td>Parietal</td>
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<td>(PET)</td>
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<tr>
<td>Rauch, Walen et al. (1997)</td>
<td>Frontal cortex</td>
<td>Left prefrontal cortex</td>
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<tr>
<td>(MRI)</td>
<td>Posterior cortex</td>
<td>Left prefrontal cortex</td>
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<td></td>
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<td>Left premotor cortex</td>
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<td>Right anterior cingulate</td>
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<td></td>
<td>Subcortical</td>
<td>Left inferior parietal</td>
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<td>Left visual cortex</td>
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<td></td>
<td>Posterior cortex</td>
<td>Right caudate</td>
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<td></td>
<td></td>
<td>Right inferior putamen</td>
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<tr>
<td>Jenkins, Brooks, Nixon,</td>
<td>Posterior cortex</td>
<td>Parietal</td>
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<tr>
<td>Frackowiak &amp; Piaingham</td>
<td></td>
<td>Parietal</td>
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<tr>
<td>(1994) (PET)</td>
<td></td>
<td>Temporal lobe</td>
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<td></td>
<td>Subcortical</td>
<td>Cerebellum</td>
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<td></td>
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<td>Putamen</td>
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<tr>
<td>Perignex (2000) (PET) areas</td>
<td>Frontal cortex</td>
<td>Middle (BA10)</td>
<td>Inferior frontal gyrus (44)</td>
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<td>activated by SRT</td>
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<td>Inferior frontal gyrus (45)</td>
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<td>Putamen of basal ganglia</td>
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<td>Maquet (2000) (PET) areas</td>
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<td>Left premotor cortex</td>
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<td>activated by SRT task</td>
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<td>subsequent REM sleep</td>
<td>Posterior cortex</td>
<td>Striate cortex bilaterally</td>
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1.10 How ‘exclusive’ are objective measures?

1.10.1 Objective measures are contaminated by implicit knowledge

The argument for the existence of implicit learning has been described and it is fair to say that the opponents of this view are in a rather strong position. Clearly, when objective tasks are used to measure participants’ awareness their performance is almost always above chance (Cleeremans & McClelland, 1991; Jiménez et al., 1996; Perruchet & Amorim, 1992; Shanks & Johnstone, 1998, 1999; Willingham et al., 1993).

However, researchers who strongly believe in the existence of implicit learning have attempted to find an alternative means of interpreting these particular findings. Although participants’ performance on a forced-choice objective task may in part be based on explicit knowledge, it is also possible that performance could be contaminated by implicit knowledge. Therefore, above chance performance on such tests should not be taken as evidence that participants learned entirely explicitly.
Some researchers (Merikle, 1992; Merikle et al., 2001) have remarked on the necessity to employ so called 'exclusive' tasks to measure awareness, meaning that the possibility that performance is contaminated by implicit processes should be ruled out. By the same token, it has been pointed out that recognition performance following sequence learning may involve dual components. Specifically, performance may be based upon an explicit judgment made about whether or not items are actually old or new and upon some sort of unconscious perceptual and/or motor information (A. Cohen & Curran, 1992; Perruchet & Gallego, 1993; Shanks & Johnstone, 1999). Similarly, implicit processes may contaminate performance on a test like free generation too.

1.10.1.1 Evidence for dual components of recognition performance

A closer look at recognition performance suggests that in some cases there are at least 2 processes involved. Recall that in this test, participants must first execute each test sequence before giving a recognition judgment. In an experiment discussed previously by Shanks and Johnstone (1999) 1 group of participants performed a recognition test comprising old and new sequences of only 3 trials, whereas another group was tested with sequences composed of 6 trials. For the group tested with 6-item sequences, old chunks were not only more likely to be judged as 'old' but they were also executed significantly more quickly than new sequences. Therefore, it is possible to examine 2 processes concurrently during the recognition test; recognition ratings and an effect of fluency revealed by an RT difference between old and new chunks. The latter effect will henceforth be known as a priming effect. It could be argued that recognition judgements are not a pure reflection of awareness because they are in part based on such a priming effect rather than on actual old/new item discrimination. For instance, perhaps participants execute old sequences more rapidly via the unconscious retrieval of a motor program and then they infer that the sequence is old because it was executed rapidly.

Nevertheless, Shanks and Johnstone (1999) conducted a multiple regression analysis using their data from the 6-item group, and they demonstrated that recognition performance was predicted by both the actual status of the test chunk (old/new) and by priming. This means that independently of the effect of priming, recognition
performance is based upon an explicit discrimination of old/new items. Moreover, for the group tested with 3-item chunks no significant priming effect was observed yet participants were still capable of old/new item discrimination. So, under some circumstances (i.e. with 6-item test sequences) recognition performance was in part based on the influence of motor fluency. However, above and beyond this, participants did make recognition judgements based upon conscious information. Furthermore, even if fluency does influence recognition performance, it does not inevitably follow that the effect of fluency is unconscious.

Previous experiments involved the examination of learning and awareness at separate stages, because RT performance is typically measured during the training stage whereas awareness is measured during a subsequent test phase. This design is problematic because even when RT performance is observed in the absence of awareness, it is difficult to determine whether participants performed at chance on the awareness test because they were unaware of the sequence or because the intervening interval between performance and the test stage led to the decay of their memory of the sequence, before the awareness test was undertaken.

However, the examination of an influence of motor fluency on recognition performance is a significant development in the progress of research on implicit learning because it allows the experimenter to measure performance and awareness concurrently; if it was demonstrated that participants showed a priming effect while simultaneously being incapable of good recognition performance, then the possibility of an interfering interval between training and test is eliminated and therefore, this finding would constitute good evidence of implicit learning. Such a pattern of results has not been reported thus far.

Upon careful examination of the priming and the rating data from Shanks and Johnstone’s (1999) study, Shanks and Perruchet (2002) reported another very interesting analysis. Shanks and Johnstone originally reported a strong group level association between priming of 6-item test chunks and mean recognition ratings. Shanks and Perruchet conducted a finer grained analysis of these data and they examined specific RTs for old and new items when participants gave a particular recognition rating i.e. 1-6. If performance and awareness are closely related it was
hypothesized that there would be no difference between RTs for old and new sequences if they are given the same recognition rating.

However, Shanks and Perruchet's analysis yielded a striking dissociation. It was reported that old items were executed more quickly than new items at each recognition rating. Therefore, when participants gave a rating of 1 indicating they certainly did not recognise the sequence, they still performed old items much quicker than they performed new items. This pattern of results appears to reflect the workings of two separate systems because performance and awareness are dissociated.

Similarly, Shanks and Perruchet looked at specific recognition ratings when participants executed items at various speeds. Recognition ratings were plotted against actual quintiles of the speed taken to perform each item and it was shown that when subjects performed items rather slowly (i.e. the lowest quintile) old items were given higher recognition ratings than new items, and this pattern of results continued up to the highest quintile. Regardless, Shanks and Perruchet demonstrated that such a pattern of results does not necessarily reflect the workings of 2 separate implicit and explicit systems. Instead, they outlined a mathematical model of a unitary learning system that can produce an identical pattern of results. This model will be discussed in greater detail in Chapter 2.

1.10.2 Summary

It is plausible that performance on objective tests like recognition can be contaminated by implicit knowledge implying that above chance performance on such tests cannot be taken as evidence that learning is explicit in nature. Shanks and Johnstone (1999) developed a technique to measure learning and awareness concurrently during the recognition test phase, and they demonstrated that recognition performance of 6-item test chunks was in part dependent on an effect of motor fluency. However, it does not necessarily follow that the effect of fluency is implicit in nature, and in truth, it could just as easily be explicit. Moreover, Shanks and Johnstone (1999) showed that recognition ratings were predicted by the actual old/new status of test strings, independently of the influence of fluency.
Furthermore, when Shanks and Perruchet (2002) looked at the relationship between priming and recognition in more detail, they demonstrated an apparent dissociation between learning and awareness that could at face value be taken as reliable evidence for the existence of implicit knowledge. However, they also reported that a unitary model that takes into account the existence of random error in the data set could also replicate the pattern of results obtained.

1.11 Intentional control

Unsatisfied by the progress of research, some proponents of implicit learning suggested that rather than concentrating on overall performance on objective tests like recognition and free generation, perhaps a more interesting question is to ask whether participants have control over the expression of their knowledge. This idea originates in the implicit memory literature where researchers have developed the logic of opposition to explore whether certain components of retrieval are unconscious.

On this approach it is claimed that if knowledge is conscious then it should be under intentional control, meaning that a participant should be able to both generate and suppress the expression of knowledge whenever they are required to do so. However, if knowledge still influences a person’s behaviour, despite their intention to prevent it from doing so then such knowledge is believed to be unconscious. The process dissociation procedure was developed to measure the respective contributions of unconscious and conscious memory to performance on stem completion tasks (Jacoby, 1991; Jacoby, Toth, & Yonelinas, 1993; Jacoby, Woloshyn, & Kelley, 1989). In Jacoby et al.’s (1993) experiment, participants were instructed to study a list of words and at test they were required to complete word stems by including any words they could remember from the list (inclusion condition) or by excluding any words they could recollect from the studied list (exclusion condition). If participants were unable to exclude words from the studied list in the exclusion condition, then this performance was believed to reflect an automatic or unconscious response.
Recently, Destrebecqz and Cleeremans (2001) applied Jacoby’s process dissociation procedure to the SRT. They aimed to demonstrate that under certain circumstances, performance on the free generation task is based, at least in part, on implicit knowledge. In addition, they undertook to confirm that this knowledge is implicit by examining subsequent recognition performance. Destrebecqz and Cleeremans attempted to interfere with participants’ anticipatory responses by manipulating the response stimulus interval (RSI). This is the time interval between the participants’ response to a stimulus and the onset of the next stimulus. If participants are trained and tested in a no RSI condition, the response stimulus interval is 0 msec. In this instance, during training they must work rather quickly through the training blocks and perhaps do not have much time to develop conscious expectation of the items in the sequence. Hence, it was hypothesised that this condition should encourage people to learn the sequence implicitly. Similarly, if participants are trained in an RSI condition, in this case the response stimulus interval is 250 msec. During training, these participants must work through the training blocks slowly and therefore they have much more time available to experience the sequence consciously and to develop an expectation of sequence items. In this case, participants should learn the sequence explicitly. Participants were allocated to one of two conditions, either no RSI (0msec) or RSI (250 msec) and were trained for 12 blocks of 96 trials of a 12-item SOC sequence. The 13th training block consisted of 96 trials of another SOC sequence and the 14th and 15th blocks were each composed of 96 trials of the initial sequence again.

Immediately after the training phase, participants in both groups performed a free generation task under both ‘inclusion’ and ‘exclusion’ conditions. This was done under first, the inclusion condition, where they had to generate as much of the sequence as possible. Then, they performed the exclusion condition where they had to avoid producing the training sequence yet still produce key presses. Finally participants performed a recognition test. As usual they were asked to differentiate between 24 old and new test sequences, each composed of 3 trials.

Destrebecqz and Cleeremans reported that priming was demonstrated in both conditions because RTs decreased over blocks 1-12, and furthermore, increased on block 13, the transfer block. In both RSI and no RSI conditions participants in the
inclusion condition were capable of above chance generation of triplets from the sequence on which they were trained. This finding is merely a replication of previous ones (Perruchet & Amorim, 1992; Shanks & Johnstone, 1998, 1999). The crucial result was that participants in the RSI condition were capable of excluding triplets from the sequence on which they were trained, but were incapable of exclusion in the no RSI condition. In other words, they could not stop themselves generating the sequence, despite trying not to. With regards to recognition performance, the RSI group was clearly capable of differentiating between the old/new chunks because ratings were significantly lower for old chunks. However, the no RSI group performed at chance for both old and new chunks.

The results have some interesting implications; firstly, the no RSI group was incapable of withholding responses during a forced choice free generation task, suggesting that they had no control over the expression of this knowledge. Destrebecqz and Cleeremans (2001) argued that this demonstrates that forced choice free generation performance is dependent on implicit knowledge and is not an ‘exclusive’ test of awareness. Secondly, the unconscious knowledge the no RSI exclusion group demonstrated in the free generation task was not expressed in the recognition test as their performance here was at chance. Once more this supports the position that this knowledge was unconscious.

However, the design of Destrebecqz and Cleeremans’ experiment is problematic because participants performed both the free generation task, followed by the recognition test. This design led to the creation of an interfering retention interval, between the training stage and the recognition test phase. The retention interval could have caused interference to the memory representation and therefore produced an apparent dissociation between learning during the training phase and awareness in the recognition test. It would be interesting to ascertain whether or not Destrebecqz and Cleeremans’ findings are replicable when the interval between training and test is removed.
1.12 Is implicit learning impaired by the introduction of explicit knowledge?

Another body of evidence which at face value provides strong support for the implicit/explicit distinction comprises studies showing that participants given explicit instructions about the rules or regularities embedded in a learning task may learn less efficiently than ones not given such instructions. Such findings seem to imply that an efficient implicit learning mechanism may be detrimentally overridden by a conscious, explicit system. For example, Shea, Wulf, Whitacre, and Park (2001) required their participants to move the platform of a stabilometer in order to track a moving target. In each 75 sec trial, a 25 sec segment of target movement was repeated. Shea et al. found that participants instructed about the repeated segment performed worse than uninstructed ones.

Although such findings are intriguing, appealing to the implicit/explicit distinction is only one of several possible ways of accounting for them. A relatively simple alternative explanation is that the explicit instructions may have changed the focus of participants’ attention such that they attended to a source of information, which was not appropriate for good task performance (see Perruchet, Chambaron, & Ferrel-Chapus, 2003, for elaboration of this issue). Results such as those obtained by Shea et al. are compelling only if it can be established that the information provided to participants in the explicitly instructed group is precisely the information needed for successful (implicit) task performance. Otherwise, the results can simply be explained by appeal to interference between 2 conflicting sources of information in the explicit group (see Shanks, in press, for an overview of the evidence for implicit learning including other paradigms). If the history of research in implicit learning reveals nothing else, it has shown that correctly identifying the form of knowledge required for task performance can be exceptionally difficult (Shanks & St. John, 1994).
1.13 Subjective measures revisited

1.13.1 Guessing criterion

Another significant criticism of the use of objective tests to measure awareness is that they are not sensitive to participants' phenomenological experience (see Dienes, in press). If a participant is capable of above chance discrimination when they genuinely believed they were guessing it is not possible that they were aware of the knowledge upon which performance was based.

Several authors have suggested that knowledge should be defined as unconscious if participants who believe they are guessing, can perform above chance on an objective test (Cheesman & Merikle, 1984) also known as the 'guessing criterion' of awareness (Dienes et al., 1995).

For example, Dienes et al., (1995) used artificial grammar leaning to investigate whether or not learning can be implicit. In the training phase, participants studied test strings of letters, which unbeknownst to them were generated by an artificial grammar. At test, participants were presented with a series of new letter strings, half of which were generated by the same artificial grammar as the training strings, and half of which were random. Participants were asked to classify strings as being either 'grammatical' or 'ungrammatical' and after each item they were required to make a confidence rating about their performance ranging from 50 to 100 (where 50 was a complete guess and 100 was absolutely sure). When Dienes et al. isolated the proportion of responses that were rated as guesses (confidence = 50), it was reported that classification accuracy for those guess responses was above chance. Recall, Shanks and Johnstone, 1998, reported a similar finding using the serial reaction time task (see section 1.2).

Nevertheless, it has been pointed out that the guessing criteria could be influenced by response bias because under-confident participants may choose to rate all responses as a guess as a result of their lack of confidence in their performance, rather than their lack of awareness (Eriksen, 1960; Shanks & St John, 1994; Kunimoto et al., 2001).
1.13.2 Zero-correlation criterion

An alternative method of studying phenomenological awareness is to examine the correlation between confidence and accuracy, because, if they are conscious, when participants perform well on an objective test, their confidence should be great, and likewise when they perform poorly, their associated confidence level should be small. On the other hand, when knowledge is unconscious there should be no correlation between confidence and accuracy (also known as the 'zero correlation criterion' of awareness, Dienes et al., 1995).

For example, Dienes and Altman, (1997) looked at whether rule based artificial grammar learning can be implicit. In their experiment, participants were trained as usual on a set of letter strings generated by an artificial grammar, but were subsequently tested on letter strings composed of another vocabulary, but which were generated by the same underlying grammar. As before participants were required to make confidence ratings on a scale of 50-100 after each test string. Dienes and Altman reported that participants were capable of above chance discrimination of test items, but that there was no relationship between confidence and accuracy, and they concluded that knowledge was implicit according to subjective a criterion.

Tunney and Shanks, (in press) replicated both Dienes et al.'s (1995) and Dienes and Altman's experiments. First, they used an identical scale (50-100) to assess confidence ratings. Second, they used a slightly modified version of the accuracy scale devised by Kunimoto et al. (2001) whereby participants were required to make binary confidence ratings (high or low confidence in accuracy). When continuous confidence rating scales were employed Tunney and Shanks observed no correlation between accuracy and confidence, which simply replicates Dienes and Colleages initial findings. However, when a binary scale was employed a relationship between confidence and accuracy emerged. Tunney and Shanks concluded that binary measures of confidence ratings are more sensitive to phenomenal knowledge than continuous scales.
1.14 Overview of thesis

In Experiments 1-3, the claim that recognition performance is at chance when participants are trained on deterministic sequences with an RSI of 0 msec, will be tested (Destrebecqz & Cleeremans, 2001). It is hypothesised that the claim will not be upheld when recognition is performed immediately after the training phase, as opposed to following an interfering interval between training and test. Furthermore, in an attempt to foster the development of implicit knowledge, probabilistic sequence learning will also be investigated under 0 msec RSI conditions. A technique devised by Shanks and Johnstone (1999) will be employed to examine priming and recognition concurrently during the test phase, and this work will be developed by using another technique devised by Shanks and Perruchet (2002) to examine the precise relationship between priming and recognition.

Chapter 3 will examine the neuropsychological and psychopharmacological evidence for the view that implicit and explicit learning are distinct systems, depending on different brain regions. For example, Reber and Squire (1994, 1998) reported that MTL amnesics demonstrated preserved sequence learning in addition to chance level recognition performance. In Experiment 4, this claim will be tested, by investigating recognition performance following sequence learning in a group of drug-induced amnesic participants.

In Chapter 4, the thesis will turn to a further claim made by Destrebecqz and Cleeremans (2001, 2003) who observed that participants were unable to withhold the expression of sequence knowledge following deterministic sequence learning with an RSI of 0 msec. In addition to an attempt to replicate this finding (Experiments 5 and 6), a further attempt will be made to replicate it using probabilistic sequences (Experiment 5), and a much longer period of training than is usually employed (Experiment 7). The question of whether extensive training leads to the development of implicit knowledge will be further developed in Chapter 5 (Experiment 8) where participants were trained on a probabilistic sequence during a period of 4-5 days.
1.15 Conclusion

The present review examined findings from numerous studies of sequence learning to consider an important question; "Can people learn implicitly?" Clearly, participants can learn complex sequential information but can this knowledge be classified as unconscious? The crux of the argument lies in the fact that there are several definitions of awareness and hence several different ways of measuring it; therefore, an experimenter may choose the particular test that is likely to produce results in line with their particular agenda. For instance, some experimenters may consider it reasonable to argue that if knowledge of a sequence is unavailable for verbal report, then it is unconscious. However, it has been showed that verbal report is an insensitive measure of awareness, so any evidence for implicit learning based on verbal report performance remains unconvincing.

Other researchers have developed objective measures like the free generation and the recognition tests and have demonstrated that sequence learning is explicit on the basis that participants perform above chance on such tests. One key experiment by Reed and Johnson (1994) apparently produced a dissociation between performance and awareness. However, the results were not replicable (Shanks & Johnstone, 1998, 1999). The claim that amnesic individuals can learn implicitly has been examined briefly and it has been shown that these experiments suffer from the same concerns highlighted in the general literature. Damage to the MTL region leads to an impairment of the ability to perform well at recognition or verbal report tasks, and although it has been claimed that sequence learning can still proceed normally in these individuals that view is still open to question. Studies involving patients with damage to the basal ganglia combined with existing brain imaging studies indicate that the striatum, pre-frontal cortex, and cerebellum are all implicated in sequence learning. But the view that these areas are in turn responsible for unconscious learning is more controversial. Chapter 4 will consider whether drug-induced amnesticics provide any convincing evidence that sequence learning is implicit. Furthermore, the use of objective methods as an accurate method of measuring awareness is also subject to some criticism because it is plausible that unconscious processes may influence task performance. Shanks and Johnstone (1999) underlined...
that performance on the recognition test is influenced by motor fluency but it is not clear whether this effect is unconscious. The possibility that recognition is contaminated by implicit knowledge means that proponents of implicit learning can dismiss the data from both recognition and free generation tasks that indicate above chance performance at a group level. To make progress in this area it is necessary to look in much more detail at the relationship between priming and recognition, as described in section 1.10.2. Shanks and Perruchet devised some useful techniques to examine this relationship and the thesis aims to develop this area of work.

By the adoption of yet another criterion for the assessment of awareness the suggestion has been made that if knowledge is unavailable for intentional control it is unconscious. An experiment conducted by Destrebecqz and Cleeremans (2001) suggested that a) people are influenced by unconscious process in the free generation task and b) that under certain circumstances they can learn the sequence of key presses without being able to express this in the recognition test. These findings will be held up to scrutiny in Chapters 2, 3, 5 and 6.
2 Relationship Between Priming and Recognition in Deterministic and Probabilistic Sequence Learning

Exposure to a repeating sequence of target stimuli in a speeded localization task can support both priming of sequence-consistent responses and recognition of sequence components (Fendrich, Healy, & Bourne, 1991; Marsolek & Field, 1999; Perruchet & Amorim, 1992; Shanks & Johnstone, 1999; Shanks & Perruchet, 2002; Willingham et al., 1993). Priming is an example of implicit memory and is often argued to be independent of explicit memory, which supports recognition (N. J. Cohen & Eichenbaum, 1993; Gabrieli, 1998; Schacter & Buckner, 1998).

It has often been claimed that direct and indirect measures of sequence knowledge can be dissociated, and such dissociations have been taken to support the existence of an "implicit" learning process, that is independent of explicit learning. Since implicit sequence learning is proposed to be unrelated to and dissociable from consciously accessible knowledge, it is conjectured to be an unconscious process. The following 3 experiments are concerned with examining in detail whether such an unconscious learning mechanism needs to be postulated or whether sequence learning can be understood from the perspective of a unitary learning system.

As discussed in Chapter 1, prior examples of dissociations in sequence learning experiments between direct and indirect tests are rather equivocal. Key results appearing to demonstrate dissociations have not been replicated (see T. Curran, 1997b; Shanks & Johnstone, 1999) or have been criticized (Dienes & Berry, 1997; Perruchet & Amorim, 1992; Perruchet & Gallego, 1993; Perruchet, Gallego, & Savy, 1990; Shanks & Johnstone, 1998; Shanks & St. John, 1994) on a variety of methodological grounds. To take just one example, particularly pertinent to the present work, it is almost always the case that the direct and indirect measures are

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1 The 3 experiments in this chapter are reported in Shanks, Wilkinson, and Channon (2003).
taken at different times in distinct test phases and this creates several potential difficulties: for instance, if the direct test is administered some time after the indirect test they may be differentially affected by forgetting. Moreover, with distinct test phases participants may be inclined to adopt different response sets, response biases, strategies, levels of motivation and so on which may significantly affect the relative levels of performance obtained in the tests. The availability of a testing method that enables concurrent direct and indirect knowledge assessment would allow many methodological problems of this sort to be finessed. Here such a method was exploited, which was initially introduced by Shanks and Perruchet (2002).

Many of the key methodological issues at the heart of the debate over implicit learning can be illuminated by reference to the recent study by Destrebecqz and Cleeremans (2001) already reviewed in the Introduction. These authors trained participants on a choice sequential reaction time (SRT) task in which the target moved between 4 horizontally-arranged locations (designated 1-4) on the display according to a repeating 12-element second-order conditional (SOC: (Reed & Johnson, 1994) sequence such as 342312143241. The learning phase consisted of 15 blocks of 96 trials for a total of 1440 trials. For half the participants there was a response-stimulus interval (RSI) of 250 msec between the execution of one response and the appearance of the next target whereas for the remainder the RSI was 0 msec. RTs reduced somewhat across blocks 1-12 in both groups. Then on block 13 the sequence was changed to a different SOC sequence with the original sequence being reintroduced on blocks 14 and 15. Destrebecqz and Cleeremans found that RTs were significantly slower in the transfer block (block 13) and concluded that their participants had learned something about the sequence which permitted them to anticipate, perhaps unconsciously, where each successive target would appear and hence make fast, "primed," responses.

To ascertain whether this sequence knowledge was conscious or unconscious, Destrebecqz and Cleeremans presented two tests following block 15. First, they informed participants that there had been a repeating sequence and asked them to generate a sequence of key presses under both "inclusion" and "exclusion" conditions following the logic of opposition developed in the process dissociation procedure (Jacoby et al., 1993). In the inclusion test participants were to try to
reproduce the sequence they saw in training whereas in the exclusion test they were to avoid reproducing the training sequence or any of its parts. The key finding was that, at least for participants in the RSI = 0 msec group, the sequence generated under exclusion conditions contained more chunks from the training sequence than would be expected by chance. Therefore participants' sequence knowledge, Destrebecqz and Cleeremans argued, was unconscious in the sense that they could not exert voluntary control over it when explicitly required to exclude it in generating a sequence.

The second assessment of awareness comprised a recognition test and the results of this are particularly pertinent since recognition tests were also employed in Experiments 1-3. Participants were shown short sequences of 3 targets half of which came from the training sequence (e.g., 342, 423) and half of which were new (in fact they were not completely new since they came from the block 13 transfer sequence). Participants executed each sequence just as in the training stage and then made an old/new rating on a 6-point confidence scale. Recognition was above chance in the RSI group but not in the no RSI group. Willingham, Salidis, and Gabrieli (2002) have recently reported a similar result, though in their experiment chance-level recognition was observed with a 250 msec RSI.

If recognition is indeed a measure of conscious sequence knowledge then the results of Destrebecqz and Cleeremans' no RSI group seem to suggest, in line with the exclusion generation data, that participants' knowledge of the sequence was entirely implicit. Note however that the measure of conscious knowledge was obtained in a test conducted some period of time after the transfer test of implicit knowledge. Therefore to conclude that participants possessed implicit but not explicit knowledge requires assuming, amongst other things, that their state of knowledge had not altered (e.g., by interference or forgetting) during the lengthy interval prior to the recognition test in which they performed the inclusion and exclusion generation tests. Note also that Destrebecqz and Cleeremans tested recognition with 3-item sequences. Shanks and Johnstone (1999) and Shanks and Perruchet (2002) have shown that recognition is far superior with 6- than with 3-item sequences. If participants genuinely cannot recognize their training sequence then it should not matter how long the test sequences are. Therefore an interesting prediction arising from
Destrebecqz and Cleeremans' position is that recognition will continue to be at chance even when longer test sequences are used.

As an alternative to the proposition that implicit and explicit learning depend on distinct mechanisms, the contrasting possibility will be considered, that a single knowledge source underlies performance on recognition and priming tests. Later a simple formal model embodying this idea will be discussed. The model was initially introduced by Shanks and Perruchet (2002) and it predicts that under many conditions, including those employed by Destrebecqz and Cleeremans (2001), priming and recognition will be strongly related. Since their data appear to falsify this prediction, the present chapter begins with 3 experiments in which the objective was to replicate their results. Instead of finding priming combined with chance-level recognition under no RSI conditions, both above-chance priming and recognition will be reported in all of the experiments, as the model predicts, and this result was obtained under a fairly broad range of conditions (e.g., with both deterministic and probabilistic sequences). Finally, some more subtle item-based analyses of the data in Experiments 1-3 will be discussed, which reveal certain dissociations between priming and recognition. However it will be shown that these dissociations are also consistent with the single-system model.

2.1 Experiment 1

The first experiment is an attempt to reproduce Destrebecqz and Cleeremans' (2001) finding that recognition is at chance in a group trained with a 0 msec RSI. In addition, a group was included with an RSI of 250 msec and two improvements were incorporated which it was assumed would allow a more conservative test of the claim that recognition is at chance with a 0 msec RSI. First, the test phase was administered immediately after the final training block, and secondly the test sequences were increased to length 6. If participants do have some ability to discriminate old from new items in recognition, this latter change should give them more opportunity to manifest that ability. On the other hand, if they genuinely lack conscious knowledge of the training sequence, and if the recognition test is sensitive to conscious knowledge as Destrebecqz and Cleeremans assumed, then recognition should be just
as poor with 6- as with 3-item sequences.

2.1.1 Method

2.1.1.1 Participants

Thirty-six University College London (UCL) undergraduate students (14 male, 22 female) were recruited to take part in the study. Participants were all unfamiliar with the experimental task. They were assigned randomly to two groups (n = 18 per group) with RSIs of 0 and 250 msec and were paid according to their recognition performance as detailed below.

2.1.1.2 Apparatus

The experiment was fully automated. Stimulus presentation, RT measurement, and response recording were all implemented on IBM-compatible PCs with 33 cm colour monitors and standard QWERTY keyboards. Four boxes were arranged horizontally along the middle of the computer screen in white against a grey background. The boxes were 13 mm wide and 13 mm high. On each trial, a black X appeared in the centre of one of the boxes. The boxes will henceforth be referred to as locations 1-4 from left to right. Reaction times were measured using ExacTicks software in Visual Basic.

2.1.1.3 Materials

Two second order conditional sequences (SOC1 = 3-1-4-3-2-4-2-1-3-4-1-2, SOC2 = 4-3-1-2-4-1-3-2-1-4-2-3) were used in the target location task. These sequences are equated with respect to location frequency (each location occurs 3 times), first-order transition frequency (each location is preceded once by each of the other 3 locations), repetitions (no repetitions in either sequence), reversal (e.g., 2-4-2) frequency (one in each sequence), and rate of full coverage (see Reed & Johnson, 1994). The only difference between the sequences is in their second- and higher-order conditional structure.
2.1.1.4 Procedure

Training phase. The experiment comprised 12 training blocks during which participants were exposed to a four-choice SRT task. Each block consisted of 100 trials for a total of 1200 trials. On each trial, participants reacted to the location of the target as quickly as possible by pressing the corresponding key. Keys V, B, N, and M corresponded to locations 1-4, respectively. Participants were required to respond to locations 1 and 2 with the middle and index fingers, respectively, of their left hand and to locations 3 and 4 with the index and middle finger, respectively, of their right hand. Participants were told to respond to the target as fast and as accurately as possible.

Each block of target-location trials began at a random point in the sequence. A target location trial ended when a participant pressed the correct key, at which time the target was erased. Response latencies were measured from the onset of the target to the completion of a correct response and errors were recorded. The next target appeared after either a 0 msec (no RSI group) or 250 msec interval (RSI group). Erroneous responses were signalled to participants by means of a tone. For counterbalancing, about half the participants in each condition (9 in the RSI group and 10 in the no RSI group) trained on the SOCl sequence and the remainder on the SOC2 sequence.

Test phase. The test phase involved a recognition test for chunks from the training sequence. Before the test phase, participants were told that the Xs had followed a repeating sequence in the training stage and that they would now be presented with short sequences of 6 X movements some of which were part of the training sequence and some of which were not. They were requested to respond to each X as before and then judge whether the sequence was old or new and give a rating of how confident they were.

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2 The RSI was timed from the moment at which the response key was pressed down, rather than from the point at which it was released, using the Visual Basic KeyDown command. This eliminates the possibility of participant-controlled lengthening of the RSI by time-on-key. If RSI is timed relative to the release of the response key, the actual RSI can become up to 200 msec longer (Soetens, Boer, & Hueting, 1985). In many sequence learning studies which vary RSI (Willingham, Greenberg, & Thomas, 1997) the method section is vague on this point and the actual RSI cannot be precisely determined.
they were in their judgment. Participants were told that their ratings would be rewarded incrementally according to their performance: specifically, in addition to a UK £2 turn-up fee, they earned an extra UK 20 pence for each correct old/new decision. Ratings were made by first clicking on option buttons labelled "old" and "new" and then on buttons labelled "sure," "fairly sure," and "guess." For analysis purposes the responses were converted to a scale from 1 to 6, where 1 = sure new, 2 = fairly sure new, 3 = guess new, 4 = guess old, 5 = fairly sure old, and 6 = sure old. In previous research (Shanks & Perruchet, 2002) participants were asked to make a 1-step recognition rating rather than the 2-step ratings made here but the results appear to be very similar with both methods.

There were 24 test sequences in total, presented in a randomised order for each participant. Twelve of the sequences were constructed by starting at each serial location of SOC1 and 12 were constructed by starting at each serial location of SOC2. Therefore, the SOC1 test sequences were old for participants trained on SOC1 and new for those trained on SOC2 and vice versa for the SOC2 sequences. Two dependent variables were measured in the test stage: reaction times to the targets and recognition judgments.

2.1.2 Results

In all this and all other analyses in this thesis:

1) A significance criterion of $\alpha = 0.05$ is used, unless otherwise specified.

2) When repeated measures analyses are employed, univariate statistics are reported and sphericity assumptions were checked using Mauchly's test. Unless otherwise stated, the sphericity assumption was met, but, for any departure from sphericity, the reported statistics have been corrected using a Greenhouse-Geisser correction.

2.1.2.1 Training phase

Reaction times for participants trained with SOC1 and SOC2 were combined in the following analyses. In this and all subsequent training phase analyses, RTs to the first 2 targets of each block were excluded since their locations cannot be predicted. Also,
trials on which an error was made were not included in the calculation of mean RT. Figure 2.1 shows the mean reaction times obtained over the training phase, plotted separately for the two groups. RTs reduced somewhat across training and were much faster in the RSI group. An analysis of variance (ANOVA) with blocks [12 levels] as a within-subjects variable and RSI [250 vs. 0 msec, 2 levels] as a between-subjects variable revealed significant effects of block, $F(5.8, 196.8) = 6.81$, $MSE = 2033.3$, and of RSI, $F(1, 34) = 15.83$, $MSE = 61334.8$. The interaction failed to reach significance. It is clear that the RSI group were able to speed-up somewhat more than the no RSI group, consistent with the idea that with a 0 msec RSI it is impossible to prepare for the next target.

Error rates were generally low. They varied between 2% and 6% for each group across blocks, and the RSI manipulation made little difference to accuracy. An ANOVA showed that accuracy was not affected by RSI nor did RSI interact with block (both $F$s < 2.0, ps > .1). Errors did tend to increase across blocks, however, $F(6.8, 228.9) = 4.75$, $MSE = 8.1$.

![Figure 2.1](image-url)

**Figure 2.1.** Mean RT in milliseconds across blocks in Experiment 1. Error bars depict standard errors. The response-stimulus interval (RSI) was 0 msec in the no RSI group and 250 msec in the RSI group.
2.1.2.2 Test phase

Priming.

Figure 2.2 shows mean reaction times for old and new test sequences at each sequence position in each group. On targets 1 and 2, which could not be predicted, there was no evidence of an old/new RT difference but across targets 3-6, which were predictable, RTs were about 30 msec faster per target for old compared to new sequences, indicative of response priming. RTs were faster also in the RSI group.

An analysis of variance (ANOVA) with position [4 levels] and old/new [2 levels] as within-subjects variables, and RSI [2 levels] as a between-subjects variable revealed significant effects of old/new, $F(1,34) = 38.77, MSE = 1943.6$ and of RSI, $F(1, 34) = 9.11, MSE = 24937.0$. The main effect of position and all interactions failed to reach significance (all $Fs <3$).

A priming score was obtained by taking average RTs for new test sequences and subtracting the corresponding RTs for old sequences (excluding positions 1 and 2). Priming was significant in both the no RSI group, $M = 39$ msec, $SE = 7.6$, $t(17) = 5.18$, $p =.00$ and the RSI group, $M = 25$ msec, $SE = 7.1$, $t(17)= 3.57$, $p = .00$ and did not differ between the groups, $t(34) = 1.36$, $p = .069$ (one-tailed). A Bonferroni correction was applied to this analysis, hence an $\alpha = 0.017$ was used.
Figure 2.2. Mean reaction time to targets 1-6 in old and new test sequences in Experiment 1. Targets 3-6 are predictable from the preceding targets whereas targets 1-2 are not predictable. Error bars depict standard errors. RSI = response-stimulus interval.

Recognition. Mean recognition ratings for old and new sequences for both groups are shown on the left of Figure 2.3 (recall that higher ratings correspond to greater confidence that the sequence is old). It is clear that participants in both the RSI and no RSI groups were able to differentiate between old and new sequences. These observations were confirmed by an ANOVA with old/new [2 levels] as a within-subjects variable and RSI [2 levels] as a between-subjects variable. This revealed a significant old/new effect, $F(1, 34) = 27.82, MSE = .3$. The main effect of RSI was not significant, $F(1,34) = 1.31, p = .26, MSE = .2$, and the Old/New x RSI interaction also failed to reach significance, $F(1,34) = .01, p = .93, MSE = .3$. 
2.1.3 Discussion

Priming was demonstrated in this study and this indicates that sequence information was indeed learned. However, participants were also quite good at recognizing whether a 6-target test sequence was old or new and no hint of any dissociation between priming and recognition was obtained. Even in the no RSI group participants’ recognition performance was reliable. As Figure 2.3 clearly shows, there was no significant difference between the two RSI groups.

2.2 Experiment 2

The results of the first experiment failed to support Destrebecqz and Cleeremans’ (2001) claim that sequence knowledge under RSI=0 msec conditions can be inaccessible on a recognition test. However, their experiment was not truly replicated in one important respect because 6- rather than 3-item test sequences were used. It is entirely possible that with shorter 3-item test sequences recognition is not detectable. It is even possible that with such short sequences priming occurs in the absence of...
recognition. Therefore, the RSI=0 msec conditions of Experiment 1 were repeated in the present experiment but 3-item test sequences were employed instead. In addition, the same sequences Destrebecqz and Cleeremans used were adopted and the training phase was modified to match theirs: there were now 15 training blocks with block 13 being a transfer block.

2.2.1 Method

2.2.1.1 Participants
Sixteen participants (6 male, 10 female) were recruited to take part in the study. They were all unfamiliar with the experimental task and were assigned randomly to two counterbalancing groups (trained on either SOC3 or SOC4) with the constraint that each group was represented by an equal number of participants. As in Experiment 1 participants were paid according to their recognition performance.

2.2.1.2 Materials
The second order conditional sequences used by Destrebecqz and Cleeremans (SOC3 = 2-4-1-3-4-2-3-1-2-1-4-3, SOC4 = 1-2-4-3-1-4-2-1-3-2-3-4) were used.

2.2.1.3 Procedure
Training phase. Participants were trained for 15 training blocks of 100 trials. During the 13th block participants were transferred to the alternate sequence with the training sequence being reintroduced on blocks 14 and 15. All participants were trained in a no RSI condition where the response-stimulus interval was set at 0 msec.

Test phase. The recognition test was identical to that in Experiment 1, the only differences being that the test sequences were composed of 3 items rather than 6 and that they were derived from sequences SOC3 and SOC4.
2.2.2 Results

2.2.2.1 Training phase

Reaction times of the two counterbalancing sub-groups were again combined for analysis. Figure 2.4 shows the average RTs obtained over the training phase. It is clear that response latencies decreased overall during training and increased dramatically on block 13, the transfer block, indicating that participants had learned the sequence. RTs fell on blocks 14 and 15 to their previous level. An ANOVA with blocks [15 levels] as a within-subjects variable revealed a significant main effect, \( F(3.9,58.9) = 7.09, \text{MSE} = 3554.8 \). To look specifically at the transfer effect, a difference score was computed based on the RT on block 13 minus the average RT on blocks 12 and 14. This difference score had a mean of 71 msec (\( SE = 8 \)) which is reliably above zero, \( t(15) = 8.31 \). Error rates were generally low (they varied between 3% and 5% across blocks), except on the transfer block where they increased to 7%, again indicative of sequence learning.

![Figure 2.4. Mean RT in milliseconds across blocks in Experiment 2. Block 13 is the transfer block. Error bars depict standard errors.](image-url)
2.2.2.2 Test phase

*Priming.* Mean reaction times for old and new test sequences at each position are shown in Figure 2.5.

A priming score was obtained as before by taking the difference in mean RTs for new versus old test items, in this case including only position 3. A one-sample t-test showed that the resulting priming effect ($M = 28$ msec, $SE = 14$) was statistically significant (one-tailed), $t(15) = 2.01$. Twelve out of sixteen participants showed a priming effect in the expected direction with the remainder showing an effect in the opposite direction.

![Figure 2.5](image)

*Figure 2.5.* Mean reaction time to targets 1-3 in old and new test sequences in Experiment 2. Target 3 is predictable from the preceding targets whereas targets 1-2 are not predictable. Error bars depict standard errors.

*Recognition.* Figure 2.3 shows mean recognition ratings for old and new sequences. It is clear that participants were able to differentiate between the sequences. The old/new difference was significant, $t(15) = 3.04$. Twelve out of sixteen participants showed a recognition effect in the expected direction with the remainder showing an...
effect in the opposite direction.

2.2.3 Discussion

Participants in this experiment showed an excellent ability to discriminate between old and new 3-element test sequences in recognition, seriously questioning Destrebecqz and Cleeremans' (2001) claim that sequence knowledge under RSI=0 msec conditions is inaccessible on a recognition test. Moreover, unlike Destrebecqz and Cleeremans, reliable priming was observed in the test phase. Thus the present experiment reveals both priming and recognition in the test stage whereas Destrebecqz and Cleeremans' experiment revealed neither. Therefore it is suggested that this difference is due to a weakness in their experimental design. The requirement Destrebecqz and Cleeremans placed on their participants to perform both an inclusion and an exclusion generation test during the lengthy interval between their training and recognition test phases provided ample opportunity for forgetting of the training sequence. Whatever the merits of this speculation, the important point is that our results clearly show that knowledge acquired under RSI=0 msec conditions can be accessed in recognition under more appropriate testing conditions.

2.3 Experiment 3

The no RSI condition failed to yield any clear evidence of implicit knowledge in Experiments 1 and 2. One possible reason for this is that deterministic sequences

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3 Because their participants showed an increase in RTs on the transfer block in the training stage, Destrebecqz and Cleeremans took their results as evidence for a dissociation between implicit sequence knowledge (i.e., response priming in the training stage) and recognition. However, in the test stage of their experiment, participants did not show priming: RTs to old and new sequences were reported as being similar. Given that the experiments reported here and elsewhere (Shanks & Johnstone, 1999; Shanks & Perruchet, 2002) indicate that priming in a recognition test is quite easy to detect, and given that a measure of priming taken concurrently with recognition ratings is to be preferred over one taken in a separate stage, it seems that Destrebecqz and Cleeremans' data are in truth entirely compatible with the claim that priming and recognition are not dissociable at the group level: they observed neither priming nor recognition in their test stage whereas both were observed here.
such as the ones used in those experiments may encourage explicit rather than implicit learning (e.g., Cleeremans & Jiménez, 1998). Under single-task conditions the repeating nature of second-order conditional sequences is not difficult to detect. Therefore one could plausibly argue that such sequences are not ideal for studying implicit learning. Introducing noise into a sequence may render that sequence much harder to consciously detect and allow implicit learning to take centre stage. In the present experiment, therefore, Experiment 1 was replicated but with a probabilistic rather than deterministic sequence.

In a deterministic SOC sequence the probability of a target on trial n appearing at a given location is 1.0 if its locations on trials n-1 and n-2 are known. For example, in sequence SOC1 the target necessarily appears at location 4 following 3-1. In the present experiment a sequence generation method for SOC sequences was adopted. This method was developed by Schvaneveldt and Gomez (1998) and it arranges for the corresponding probability to be less than 1.0. Specifically, in the sequences used in the present experiment the probability was .85. Thus at any point in the training phase the location of the next target could only be predicted with probability .85. Despite this, the second-order statistical properties of the sequence are maintained.

Using probabilistic rather than fixed sequences adds a degree of noise to the sequence, hopefully minimizing the likelihood that the sequence will be learned explicitly. Another advantage is that an on-line measure of sequence knowledge becomes available in the comparison during training between RTs to probable and improbable targets. Schvaneveldt and Gomez showed that these RTs begin to diverge within only about 300 trials. In the present experiment the foremost question is whether learning of a noisy sequence is sufficient to support priming in the test stage and whether this priming is dissociable from recognition. Furthermore one could speculate that the RSI manipulation is effective with such sequences: given Destrebecqz and Cleeremans' (2001) results, priming without recognition might be especially anticipated under conditions of RSI = 0 msec.
2.3.1 Method

2.3.1.1 Participants

One hundred 1st year UCL undergraduate students (26 male, 74 female) took part in the experiment as part of a research methods class. They were all unfamiliar with the experimental task and were assigned randomly to two RSI groups ($n = 45$ and 55 in the RSI and no RSI groups, respectively).

2.3.1.2 Materials

The second order conditional sequences (SOC1 and SOC2) described in Experiment 1 were again used here. For approximately half the participants in each RSI group SOC1 was the training sequence and for the remainder it was SOC2. During the training phase the location of the target was specified by the assigned training sequence with probability .85 and by the alternate sequence with probability .15. The probabilistic sequences were implemented by using the 2 most recent events to select the next event. With probability .85, the next target would be the event in the training sequence specified by the last 2 locations and with probability .15 it would be the event in the alternate sequence specified by the last 2 locations.

For example, if SOC1 was the training sequence for a given participant then the transition 4-1 was followed by a target at location 2 (following the specified sequence of SOC1) with a probability of .85 and it was followed by a target at location 3 (following the specified sequence of SOC2) with a probability of .15. This algorithm was applied on each trial and determined the location of the current target simply on the basis of the 2 preceding targets. Each block of trials was started at a random point in the assigned training sequence. It is important to note that this method of generating sequences exposes participants to sub-sequences of both the training and the alternate sequence and this might be expected to reduce both priming and recognition. With the deterministic sequences used in Experiment 1, new sequences in the test stage were genuinely new both as entire 6-element sequences and in terms of the triplets that composed them. In the present experiment, in contrast, new test sequences were composed of triplets that the participant had very likely seen in the context of improbable targets in the study phase. For example, for a
participant allocated SOC1 as his/her training sequence, the test item 4-3-1-2-4-1 from SOC2 is nominally a new item. However, the triplets that it is composed of would be familiar: on approximately 15% of occasions during the training phase in which the target moved from location 4 to location 3, it would then have appeared in location 1. It is also possible (p ≈ .6) that a participant would have seen at least one entire "new" test item at some point during the training phase. Hence the terms "old" and "new" should be read as relative.

2.3.1.3 Procedure

Participants were trained for 12 blocks of 100 trials prior to the recognition test, which used nonprobabilistic, 6-item test sequences extracted from SOC1 and SOC2 exactly as in Experiment 1. The only difference between the recognition tests in Experiments 1 and 3 was that the participants in the present study were not rewarded incrementally for their recognition performance. Instead, to maintain motivation, they were informed that the participants with the 5 best overall recognition scores would be given a UK £15 book token.

2.3.2 Results

2.3.2.1 Training phase

Reaction times for participants trained with SOC1 and SOC2 as their probable sequence were combined in the following analyses. Figure 2.6 shows the mean RTs obtained over the training phase, plotted separately for the two RSI groups and for each type of target, probable or improbable. Probable targets elicited faster RTs than improbable ones in both groups, indicative of sequence learning. Consistent with Schvaneveldt and Gomez’ results, a probable/improbable difference emerged by block 3 (300 trials). The difference widened across blocks, mainly as a result of an increase in RT on improbable trials. Note that this is not an artefact of a higher likelihood of errors on improbable trials (see below), as trials on which errors were made were not included in the RT calculations. As in Experiment 1 response latencies were longer in the no RSI than the RSI group.

To analyse these data, an ANOVA was performed with probability [probable vs.
improbable, 2 levels] and block [12 levels] as within-subjects variables and RSI [250 msec vs. 0 msec, 2 levels] as a between-subjects variable. This analysis revealed significant main effects of probability, $F(1,98) = 131.81$, $MSE = 2294.0$, block, $F(7,688.1) = 4.87$, $MSE = 3285.6$, and RSI, $F(1,98) = 31.80$, $MSE = 106014.3$. The probability x block interaction was also significant, $F(8.9,876.7) = 4.05$, $MSE = 1099.7$, indicating a greater probability effect later in practice than earlier. The probability x RSI interaction did not reach significance, $F(1,98) = 2.24$, $p = .14$, $MSE = 2294.0$. Therefore training under RSI and no RSI conditions lead to comparable learning of probabilistic sequences as reflected by response latencies. Other interactions failed to reach significance: block x RSI, $F(7,688.1) = 1.61$, $p = .13$, $MSE = 3285.6$, and probability x block x RSI, $F(8.9,876.7) = 1.40$, $p = .18$, $MSE = 1099.7$.

Error rates varied between 2% and 11% across groups and blocks. Participants made more errors for improbable targets, presumably reflecting their expectations of the probable sequence, and errors increased across blocks. An ANOVA revealed significant effects of probability, $F(1,98) = 86.93$, $MSE = 64.7$, and block, $F(8.9,872.4) = 10.53$, $MSE = 36.6$. The interaction between block x probability was significant $F(9.1,901.2) = 3.08$, $MSE = 33.3$. However, accuracy was not affected by RSI nor did RSI interact with block or probability (all $Fs < 2.0$, $ps > .1$).
Figure 2.6. Mean RT in milliseconds across blocks in Experiment 3. Probable targets (85% of all targets) were consistent with the generating sequence whereas improbable ones (15% of all targets) were not. Error bars depict standard errors. RSI = response-stimulus interval.

2.3.2.2 Test phase

Priming. Figure 2.7 shows mean reaction times for old and new test sequences at each sequence position in each group. Apart from a reduction in the magnitude of priming to about 10 msec, the results are very similar to those in Experiment 1: RTs for old and new sequences began to diverge at the first predictable target, position 3.

An analysis of variance (ANOVA) with position [4 levels] and old/new [2 levels] as within-subjects variables, and RSI [2 levels] as a between-subjects variable revealed significant effects of position, $F(3,294) = 10.00$, $MSE = 806.5$, old/new, $F(1,98) = 15.5$, $MSE = 1911.1$ and of RSI, $F(1,98) = 19.18$, $MSE = 23838.2$. All interactions failed to reach significance (all Fs < 2).

A priming score was obtained as before by taking average RTs across targets 3-6 for new test sequences and subtracting average RTs for old sequences. Priming was significant in both the no RSI group, $M = 12$, $SE = 4.1$, $t(54) = 2.85$, $p = .006$ and the
RSI group, $M = 13, SE = 4.7, t(44) = 2.73, p = .009$ and did not differ between the groups, $t(98) = .20, p > .5$. A Bonferroni correction was applied to this analysis, hence an $\alpha = 0.017$ was used.

**Figure 2.7.** Mean reaction time to targets 1-6 in old and new test sequences in Experiment 3. Targets 3-6 are predictable from the preceding targets whereas targets 1-2 are not predictable. Error bars depict standard errors. RSI = response-stimulus interval.

Recognition. Figure 2.3 shows mean recognition ratings for both groups and for both types of sequences. It is clear that participants in both the RSI and no RSI conditions were able to differentiate between old and new sequences despite having been trained on noisy sequences. These observations were confirmed by an ANOVA with RSI [2 levels] as a between-subjects variable and old/new [2 levels] as a within-subjects variable. This revealed a significant old/new effect, $F(1,98) = 26.15, MSE = .2$. The main effect of RSI, $F(1,98) = 1.42, p = .24, MSE = .4$, and the old/new x RSI interaction, $F(1,98) = 1.45, p = .23, MSE = .2$, were not significant.

The results of the present experiment are quite consistent with those of Experiments 1 and 2 but generalize those results to probabilistic sequence learning. Participants
showed priming at test but were also able to discriminate between old and new sequences in recognition. The RSI manipulation had no qualitative impact on responding.

**Magnitude of priming as recognition approaches chance.** The findings presented in Experiments 1-3, indicate that priming and recognition cannot be dissociated at the group level under circumstances similar to those employed by Destrebecqz and Cleeremans (2001) and when a novel methodology was employed which was specifically designed to elicit implicit learning. Clearly this is strong evidence that priming and recognition are closely associated.

However, Shanks et al. (2003) conducted a finer grained analysis of the data reported in Experiment 3 to investigate whether or not positive evidence of priming could be detected when recognition performance was at chance. For example, it was highlighted that although recognition performance was far from perfect in Experiment 3, participants received quite extensive training and most were capable of distinguishing old from new sequences: of the 100 participants, 64 gave a higher mean rating for old than new sequences and only 26 rated them the other way round (there were 10 participants whose mean ratings were tied). Therefore, Shanks et al. asked whether there was any tendency for priming to remain significantly above chance as recognition approaches and reaches chance. The data from Experiment 3 were ideal for answering this question because of the large sample size and the fact that probabilistic sequences ensure that recognition is closer to chance than with the deterministic sequences used in Experiments 1 and 2.

Shanks et al. (2003) combined data from Experiment 3 across the RSI and no RSI groups as this factor had no effect on either priming or recognition in the test stage. For each participant, they computed a priming score as in Experiments 1-3 and compared this with a recognition score calculated as the difference between the mean rating for old and new sequences. When the magnitude of priming was plotted across 3 terciles of the recognition scores it was observed that unsurprisingly, priming tended to increase with recognition. Furthermore when data from participants whose recognition was close to zero was combined with data from those whose overall recognition was below chance the magnitude of priming detected was not significant.
Shanks et al. observed that the fact that priming was significant overall is due almost entirely to the fact that participants with the highest recognition scores also showed substantial priming.

Even though priming was not reliable when recognition was close to chance, Shanks et al.'s analysis did reveal an intercept a few milliseconds above zero when recognition was zero. This is not evidence, however, of a small but real residual priming effect. The model described briefly below and in more detail by Shanks and Perruchet (2002) and Shanks et al. (2003), which assumes a common process underlying priming and recognition, similarly predicts a non-zero intercept, for reasons elaborated shortly.

In sum, the finer grained analyses conducted by Shanks et al. (2003) suggest that priming and recognition do not dissociate as the latter approaches chance. Although their comparison was based on natural variations in recognition across individuals rather than on an experimental manipulation, the results are similar to those obtained by Perruchet, Bigand, and Benoit-Gonin (1997) in a set of studies that systematically reduced the length of training to reduce recognition to chance. As with Shanks et al.'s results, Perruchet et al. found no evidence of response priming in the absence of recognition.

### 2.4 Distinguishing single-process and dual-process accounts

At this point a summary of the findings and their theoretical interpretation may be useful. Both priming and recognition have been demonstrated at the group level in Experiments 1-3 and further analysis by Shanks et al. (2003) failed to obtain any dissociation between these measures. One conclusion, therefore, is that the group-level dissociation reported by Destrebecqz and Cleeremans (2001) is not robust. The results of Experiments 1-3 are consistent with a model, such as the one discussed below in which priming and recognition are assumed to derive from a unitary learning system (Kinder & Shanks, 2001; Nosofsky & Zaki, 1999; Nosofsky & Zaki, 1998; Shanks & Perruchet, 2002).
However the results are also consistent with, or at least not inconsistent with, a dual-process account. Such an account, which assumes distinct implicit and explicit processes, can appeal to the notion that recognition measures may be "contaminated" by unconscious influences. Instead of providing an index of explicit knowledge, it is possible that the recognition test is functionally just another implicit test. On this account, participants' ability to perform old/new recognition is based in part or whole on priming, such that old sequences tend to be executed faster than new ones, with participants unconsciously attributing speed or fluency of execution to old/new status.

There is good evidence in support of the idea that purportedly-explicit tests may be contaminated in this way. Consider the above-chance free generation often observed in SRT task studies (e.g., Perruchet & Amorim, 1992; Shanks & Johnstone, 1999) where participants are able to generate the SOC sequences on which they were trained. Although this might be taken as evidence that participants' sequence knowledge was entirely conscious, another possibility is that it was unconscious but that free generation was controlled at least to some extent by unconscious influences. In fact, of course, this is precisely the point Destrebecqz and Cleeremans' (2001) made: their participants tended to generate the sequence on which they had been trained despite instructions to avoid doing so. In practical terms participants might find their eyes or fingers being drawn entirely unconsciously from one screen location to the next via learned motor programs (i.e., by precisely the same process that leads to response priming), and might in consequence perform well above chance in a generation test.

In the present section various additional analyses of the data of Experiment 3 conducted by Shanks et al. (2003) are discussed which indeed revealed evidence of contamination and also evidence of dissociation between priming and recognition. In the next section, however, a single-system model is discussed which does an excellent job of simulating the data, including the dissociations reported below.

How might it be determined whether performance in the recognition tests employed in Experiments 1-3 was contaminated in this way? A fairly straightforward approach is to ask whether recognition ratings are affected by speed of execution
independently of true old/new status. Such a relationship was found in a study on data entry by Fendrich, Healy, and Bourne (1991). The contamination account assumes that speed (i.e., fluency) of execution is at least in part the basis for recognition judgments and hence such an independent influence should be expected. The recognition test data from Experiment 3 were re-analysed by Shanks et al. (2003) in such a way as to reveal this influence of fluency. They plotted the mean recognition ratings for old and new sequences in each RSI group as a function of RT quintile. To obtain these data they first calculated the mean RT across targets 3-6 for each test item. For each condition they then calculated the quintiles of these mean RT data and the accompanying recognition rating at each quintile.

Shanks et al. reported several interesting findings. First, old items tended to receive higher ratings than new ones, consistent with the overall recognition analysis. Even when executed with the same fluency, an old sequence tended to be rated higher than a new one, indicating that the recognition test is at least in part a genuine measure of recollective ability. Secondly, the RSI manipulation had little effect other than to shift the points such that RTs tended to be longer in the no RSI group conditions. Thirdly, and most interestingly, recognition ratings tended to be influenced by speed of execution independently of whether the items are old or new. Put another way, a new item and an old item received about the same recognition rating if the new item was executed about 200 msec faster to compensate for its being new. Plainly, this item-based way of analysing the data revealed a dissociation between priming and recognition in that RTs influence recognition ratings independently of old/new status.

These effects were statistically reliable. Multiple regression analysis for each group with recognition ratings as the dependent variable revealed significant influences of both old/new status and execution speed ($p < .05$ in each case).

Furthermore, Shanks et al. took the same data but analysed it in a different way (Shanks & Perruchet, 2002, performed a similar analysis on their data). This time they computed the mean RTs for old and new sequences in each RSI group as a function of recognition quintile calculated in an analogous manner to that described above. This way of depicting the data revealed a particularly striking dissociation: speed of execution was influenced by old/new status, independently of recognition
2. Priming and Recognition

rating. Therefore it was reported that old items were executed about 10 msec faster than new items even when they received the same recognition rating. This appeared to be a strong dissociation between priming and recognition as a difference that is not reflected on an explicit measure is reflected in an implicit one.

These effects were again statistically reliable. Multiple regression analysis for each group with mean RT as the dependent variable revealed significant influences of both old/new status and recognition rating ($p < .05$ in each case).

These results reported by Shanks et al. provide support for the claim that the recognition tests used in Experiments 1-3 were "contaminated" by implicit knowledge. Therefore Shanks et al.'s data are consistent with an account which proposes a distinction between implicit and explicit knowledge and which assumes that any given test can be influenced by some combination of both processes. Moreover, these item-level dissociations seem to challenge a single-system account. However, it must be stressed that the independent influence of speed of execution on recognition ratings cannot both be explained by implicit influences and be used to justify the existence of such influences. Put another way, the results are consistent with the contamination account but do not provide any independent support for the implicit/explicit distinction. If it turns out that the data presented by Shanks et al. (2003) can be explained without appeal to this distinction, then parsimony would suggest that the distinction is not providing any additional explanatory power. With the aid of a formal model, Shanks et al. showed that the apparent evidence for contamination was in fact little more than a statistical artefact and they showed that all of the key data presented by them (including the findings of Experiments 1-3) are consistent with a single-system account.

2.5 A model of priming and recognition

A unitary model of priming and recognition was introduced by Shanks and Perruchet (2002), and further employed by Shanks et al. (2003). The model, which is conceptually very similar to standard signal detection theory models for recognition judgments and their latencies (Pike, 1973; Ratcliff & Murdock, 1976; Stretch &
Priming and Recognition

Wixted (1998), starts with the simple assumption that new and old test items are associated with a memory strength variable which they called familiarity \( f \). Greater degrees of familiarity lead to higher recognition judgments and faster RTs, and familiarity can be thought of as some composite but unidimensional function of the perceptual familiarity of the stimulus sequence and the motor fluency of the executed response sequence. In the model \( f \) is a normally distributed random variable with mean .4 and standard deviation .4 for new items and with mean .6 and standard deviation .4 for old items. Thus the mean familiarity of old items, \( f_{\text{old}} \), is slightly higher (by .2) than the mean for new items, \( f_{\text{new}} \). For each participant a single value of familiarity was independently sampled for new and old items from these distributions. Next, they assumed that RT is a decreasing function of \( f \) but with the addition of some random error:

\[
RT = b + 100(1 - f) + 500e_r
\]  

(1)

Where \( e_r \) is normally distributed random error with mean .5 and standard deviation .2. The parameter \( b \) was set to a value of 80 msec for the RSI group and 120 msec for the no RSI group. The numbers in the equation were chosen simply to ensure that RTs are generated between approximately the right limits and that they are appropriately faster in the RSI group.

Recognition judgments \( (J) \) are also based on familiarity, but include another (independent) source of error:

\[
J = 2f + e_j + 1
\]  

(2)

Where \( e_j \) is again normally distributed random error with mean 1.5 and standard deviation 1.5. \( J \) is rounded to the nearest integer value and trimmed at 1 and 6, yielding recognition ratings between a maximum of 6 when the familiarity of the test item is equal to or greater than 1 and a minimum of 1 when familiarity is equal to or less than 0.

Shanks et al. (2003) evaluated the ability of this simple model to capture the main features of the data obtained in Experiment 3. They concentrated on this experiment as the sample size was large. Its application to Experiments 1 and 2 is
straightforward but yields little additional information. In their analyses they were concerned to simulate five aspects of the test data: (1) overall mean RTs to old and new targets in the RSI and no RSI groups; (2) mean recognition ratings to old and new sequences in the RSI and no RSI groups; (3) the independent influences of speed of execution and old/new status on recognition ratings; (4) faster RTs for old than new sequences which are not discriminated in recognition; and (5) an above-chance priming intercept when recognition is at chance.

Because RTs and recognition judgments depend on the same variable (f) in the model, it predicts that priming and recognition will in general be associated. Thus for the RSI group old items will evoke an average RT of 370 msec compared to 390 for new items (Eqn. 1), while at the same time old items will elicit a higher recognition rating (3.7, Eqn. 2) than new items (3.3). For the no RSI group old items will evoke an average RT of 410 msec compared to 430 for new items (Eqn. 1), with identical recognition ratings to those in the RSI group. These figures are fair approximations to the observed means (Figs. 2.3 and 2.7). The model would be falsified by group-level evidence that old items are executed faster on average than new ones but not better recognized. However, no such evidence was obtained in any of the 3 experiments reported here. On the contrary, the predicted association between priming and recognition was manifest in each study.

Despite the intuition that the item-level dissociations described in the previous section must be indicative of separable memory influences on priming and recognition, the unitary model reproduced all of the major trends in the data. Most important, the model yielded recognition ratings that were influenced by speed of execution independently of old/new status as well as faster RTs for old than new sequences that were not discriminated in recognition.

The reason the model captured the dissociation lies in the independent sources of error in the processes that translate underlying memory strength into priming and recognition measures. More specifically, for old and new sequences to be rated equally in recognition a larger value of $e_j$ is required in Eqn. 2 for the new compared to the old items, on average, to offset the larger average value of $f_{old}$ compared to $f_{new}$. However, when these same $f$ values are used to determine RTs in Eqn. 1 they
will be combined with independently-generated values of \( e_r \). Since the latter are uncorrelated with the \( e_j \) values incorporated in the recognition judgments, on average they will not differ for old and new items. Hence, as \( f_{\text{old}} \) is on average greater than \( f_{\text{new}} \), \( RT_{\text{old}} \) will be lower than \( RT_{\text{new}} \), as observed empirically in the participants' behaviour.

Lastly, the model predicted an above-zero intercept when priming was calculated across different levels of recognition. When error was incorporated into the output processes, the model produced a good fit to the observed data. Significantly, the predicted priming intercept when recognition is at chance was considerably above zero. Despite the intuition that such a result

2.6 Discussion

The results of Experiments 1-3 go beyond those previously reported in several ways. A design was used in which measures of priming and recognition were obtained concurrently rather than in separate test stages and this avoids the possibility that they are differentially affected by factors such as forgetting. Destrebecqz and Cleeremans' (2001) design was improved upon by reducing the interval they imposed between the end of training and the test stage. With this change, quite good levels of old/new recognition discrimination were found and no evidence was seen of priming combined with chance-level recognition in group-level analyses of the data. Additionally, the findings were extrapolated to a probabilistic version of the task. In a condition (Experiment 3) in which predictable and unpredictable targets appeared in the proportions \( .85/.15 \), respectively, sequence learning emerged but the probabilistic nature of the materials did not prevent old/new recognition.

The results of Experiments 1-3 (significant priming and recognition in each experiment) thus reveal association rather than dissociation and are consistent with a single-process model described by Shanks and Perruchet (2002) and Shanks et al. (2003). The model is also consistent with more fine-grained analyses of the test data.
in Experiment 3 conducted by Shanks et al. (2003). These analyses appeared to reveal, first, independent influences on recognition ratings from two sources, fluency of execution and old/new status. This independence is a purely statistical phenomenon, which can be understood in terms of a single-mechanism model provided that independent sources of error in the priming and recognition measures are allowed. Secondly, Shanks et al.’s analyses revealed that old and new items that are not discriminated in recognition are nonetheless executed with different latencies. Again, though, there is an explanation of this phenomenon, which does not require a dual-process theory. Thirdly, the data revealed that priming diminishes to near zero when recognition is at chance, a pattern that is once again predicted by the model.

The model described by Shanks and Perruchet (2002) and Shanks et al. (2003) predicts association between priming and recognition at the group level and is therefore contradicted by data suggesting that certain special populations display dissociations between priming and recognition in sequence learning. In truth this claim is not especially strong (see Chapter 3 for a detailed discussion).

Also relevant are data from brain imaging studies of implicit and explicit learning. Plainly, the single-system approach developed here would be challenged by data showing that different neural networks are activated under implicit and explicit learning conditions. In fact this does not seem to be the case. As discussed previously, Willingham, Salidis, and Gabrieli (2002) have reported a functional magnetic resonance imaging study in which an implicit condition was defined as one in which recognition was at chance and an explicit condition as one with above-chance recognition. Willingham et al. found that the very same neural systems (e.g., left prefrontal cortex, left inferior parietal cortex, right putamen) were activated in both conditions but that some additional regions were activated in the explicit condition (e.g., premotor cortex). This seems entirely consistent with a single-system account, with the proviso of course that it is doubtful that participants in the implicit condition were genuinely unable to perform above-chance recognition; indeed Willingham et al. did find a difference between ratings (on a 4-point scale) to old and new test sequences of comparable magnitude to those depicted in Figure 2.3, albeit non-significant. Therefore it is suggested that Willingham et al.’s implicit and explicit groups merely represented participants with weaker and stronger sequence
knowledge.

One might conjecture that the dependency observed between priming and recognition hinges on an aspect of the experimental procedure, namely that recognition judgments were always elicited after sequence execution. Perhaps if participants were required to make recognition judgments about a sequence of target movements prior to executing that sequence they would be more likely to be independent of priming? Some previous research on a data entry task by Fendrich, Healy, and Bourne (1991) demonstrates that sequence execution can indeed increase recognition accuracy, but also that the recognition/priming relationship was not affected by whether recognition preceded or followed sequence execution. The fact that recognition is worse prior to than following sequence execution seems unsurprising if one assumes (see Fendrich et al.) that repeating a motoric procedure can act as a retrieval cue for memory. The important point about obtaining recognition judgments after sequence execution is that this ensures that recognition and priming measures are compared under identical retrieval conditions: motor execution is surely implicated in priming so one has to allow recognition the opportunity to be similarly cued. Fendrich et al.'s finding that recognition judgments exceeded chance even when they were made prior to sequence execution suggests that a similar result might be obtained with the SRT task. Plainly this would be an interesting issue to explore in future work.

Finally, although the present results question Destrebecqz and Cleeremans' (2001) claim that priming and recognition can be dissociated at the group level, they do not in any way challenge the results of Destrebecqz and Cleeremans' generation tests. Recall that participants in their study were unable to avoid generating parts of the training sequence under explicit instructions ("exclusion") to do so. This claim will be the focus of Chapters 4 and 5.

### 2.7 Related work on learning/memory systems

The present work is part of a much broader body of work seeking to determine whether multiple learning/memory systems are needed to understand human
performance. Proposed distinctions, which are in many respects overlapping, include the implicit/explicit, procedural/declarative (Squire, 1994), and recollection/familiarity (Jacoby et al., 1993) distinctions. The SRT task and data-analytic methods employed here represent only one of a large number of methods under current exploration: others include the process-dissociation (Jacoby, 1991) and remember/know procedures (Rajaram, 1993; Yonelinas, 2001), the analysis of receiver operating characteristics (ROCs: Yonelinas, 2001), and the comparison of task performance on matched direct and indirect tests (e.g., Knowlton, Ramus, & Squire, 1992; Knowlton & Squire, 1993), each of which comes with its own analytical techniques.

Although there is much evidence in support of multiple learning systems, the findings reported here are consistent with those of others who have sought to account for memory phenomena using formal models, which assume only a single learning/memory mechanism. For instance, data from the process-dissociation procedure have been reinterpreted from a single-system perspective (Ratcliff, McKoon, & Van Zandt, 1995; Yu & Bellezza, 2000), as have data from experiments using the remember/know procedure (Xu & Bellezza, 2001) and from comparisons of task performance on matched direct and indirect tests (Kinder & Shanks, 2001; Nosofsky & Zaki, 1998; Zaki & Nosofsky, 2001). Whatever the outcome of this important debate, the use of formal models such as that described by Shanks and Perruchet (2002) and Shanks et al. (2003) to explore the underlying structure of data obtained in learning experiments is invaluable.
3 Differential Effects of Diazepam in Probabilistic Sequence Learning

In Experiments 1-3, Destrebecqz and Cleeremans' (2001) claim that recognition performance is at chance when an RSI of 0 msec is employed, was not replicated. Instead the existence of priming was never observed in the absence of above chance recognition performance, thus priming was closely associated with recognition when both deterministic and probabilistic sequences were adopted. Given this failure to observe any evidence of implicit learning in normal populations, are there any alternative circumstances under which such evidence can be observed? It is possible to look at the performance of populations with damage to particular brain regions that may be involved in implicit learning. For instance if one group of individuals with damage to a specific brain region is found to be impaired on tasks thought to be supported by explicit memory while their performance on implicit tasks remains unaltered then this is evidence for dissociated implicit and explicit memory systems that depend on different brain areas (Tulving, 1985). Individuals with medial temporal lobe amnesia and Alzheimer’s disease are reported to provide such evidence. Other populations have been shown to be impaired at sequence learning, e.g., patients with Parkinson’s disease or Huntington’s disease, leading to the belief that areas damaged by these disorders play an important role in sequence learning. In addition to neuropsychological evidence, it has been argued that the memory deficits resulting from Alzheimer’s disease and medial temporal lobe amnesia can be modelled by the administration of cholinergic drugs and benzodiazepines to normal populations.

The present chapter will begin with a review of the evidence for implicit learning from neuropsychological and psychopharmacological studies. It will be suggested that the extensive neuropsychological literature on implicit sequence learning is problematic due to a) low statistical power in most cases, b) the heterogeneous nature of the samples c) the same methodological issues described in Chapter 1, that have plagued the non-clinical literature on implicit sequence learning. However it will be demonstrated that the problems of low power and heterogeneous samples can be
avoided by the adoption of psychopharmacological techniques, which allow the experimenter to control extraneous variables more carefully. In Experiment 4, a psychopharmacological approach is taken to examine whether evidence of implicit learning would be observed when normal participants were given different doses of a drug (diazepam), believed to be a suitable model of medial temporal lobe amnesia.

### 3.1 Neuropsychological studies

#### 3.1.1 Evidence for implicit learning in amnesia

Amnesia is either caused by circumscribed damage to the hippocampus and related medial temporal lobe region or pathological degenerative diseases of the brain like encephalitis, which leads to damage in the medial temporal lobe or Korsakoff’s syndrome which leads to damage in the diencephalons. Such individuals have difficulty with explicit tasks like word list recall, but it is reported that they can perform well on procedural tasks (N. J. Cohen & Squire, 1980; Corkin, 1968; Milner, 1962). Furthermore, it has been established that when they undertake sequence learning, amnesics show an RT difference during training combined with an inability to describe or convey what they have learned (Nissen & Bullemer, 1987; Nissen, Willingham, & Hartman, 1989; P. J. Reber & Squire, 1994; 1998). According to a multiple systems view the medial temporal lobe and related area is specifically responsible for explicit learning whereas implicit memory resides in another brain region.

For instance Nissen and Bullemer (1987) trained 6 Korsakoff’s individuals and 6 controls under single task conditions on 4 blocks of 100 trials of a sequence followed by 4 blocks of 100 random trials. In both groups, RTs for the sequence blocks were lower than for the random block. Following block 8, participants were asked whether they had noticed a repeating sequence and all of the control participants but none of the Korsakoff’s individuals remarked on this change. In addition, Korsakoff amnesic individuals showed normal retention of the sequence even after 1 week had elapsed since training (Nissen et al., 1989). In Nissen et al.’s study, 7 Korsakoff’s individuals, 7 healthy elderly controls and 8 alcoholic participants were trained on 4...
blocks of a 10-item sequence followed by a random block. A week later, the same procedure was carried out and participants were asked to report how much of the sequence they knew. It was reported that 5/7 healthy elderly and 6/8 alcoholics said they noticed a pattern but none of the amnesics did. The amnesics showed improved RT speed up over the first 4 blocks with a sharp increase on block 5 and this speed up was replicated again in the second week.

These studies have shown a single dissociation between learning and awareness and experimenters have suggested that this is evidence for two separate systems because amnesic individuals are impaired at explicit learning. It is argued that if amnesics can show improvement on RT measures in the SRT task in the absence of awareness then implicit and explicit memory must be separate systems, dependent on distinct brain regions. However in a large proportion of the existing sequence learning studies conducted with such amnesic individuals, the experimenters looked at a comparison between RTs for 10-item sequence blocks with RTs for a random block, as evidence that participants had learned the sequence (Nissen & Bullemer, 1987; Nissen et al., 1989; P. J. Reber & Squire, 1994; 1998). This technique will henceforth be known as Nissen and Bullemer’s (1987) training method. As mentioned in Chapter 1 this method has been criticised because participants may show an improvement in RT on sequence blocks on the basis of simple event probabilities rather than complex sequence information (Shanks et al., 1994). To avoid this problem some sequence learning experimenters compare RTs for several blocks on one SOC sequence, with RTs on one block of a different SOC (Reed & Johnson, 1994).

Another problem is that some of the studies did not employ sensitive measures of awareness (Shanks & St. John, 1994). For example, Nissen and Bullemer (1987) and Nissen et al. (1989) used verbal report to ascertain awareness of sequence knowledge. As discussed in Chapter 1 recognition is a more sensitive measure of awareness and non-clinical samples have been shown to perform above chance on this test.

Nonetheless, in some studies involving amnesic individuals, researchers have attempted to address some of these methodological issues. For example in an
experiment conducted by Reber and Squire (1994) it was reported that 8 MTL amnesics were able to learn SOC sequences as indexed by an improvement in RTs during training blocks. Further, their subsequent recognition performance was at chance and following the recognition test, the experimenters showed that a preserved RT improvement for sequence blocks compared to a random block, remained comparable to controls. Therefore the amnesics' poor recognition performance could not be explained simply on the basis that they forgot the sequence before the recognition test phase.

Another study conducted by Reber and Squire (1998) revealed a double dissociation between performance and awareness. It was hypothesised that if control participants were told to observe and memorise a sequence during training they should develop intact explicit knowledge and yet be incapable of expressing this in an implicit task. In their experiment, 5 amnesics practised as normal on the SRT task and were then given a verbal report task, followed by a recognition task and finally an implicit learning task (transfer from a sequence block to a pseudo-random block). Similarly, both old and young matched controls were asked to observe the SRT task sequence and instructed to memorise it, then they were given a verbal report and a recognition task followed by an implicit learning task (transfer test). The amnesic group performed well on the implicit task and at chance on the recognition task and the controls performed well on the recognition task and poorly on the implicit task.

Taken together Reber and Squire's (1994, 1998) evidence supports two conclusions, firstly, that implicit and explicit systems are separate because both single and double dissociations were observed between performance and awareness as indexed by a recognition test. It is proposed that the systems work in parallel and behaviour results from them working together but they involve two different types of information. Secondly, the view that the systems depend on distinct brain regions is supported. It is proposed that explicit memory is dependent on medial temporal lobe and related structures damaged by amnesia. Furthermore, it is believed that the brain system supporting implicit memory is located in an area of the brain that remains intact in amnesics and which allows them to perform well on procedural tasks. It is suggested that the cortico-striatal system is of importance for implicit learning because individuals with lesions to this area are impaired at sequence learning.
3. Evidence against implicit learning in amnesia

Although impaired sequence recognition has been well-documented empirically (P. J. Reber & Squire, 1994; 1998), the accompanying theory that response priming remains normal in amnesic individuals is rather more controversial. For example, in Nissen and Bullemer's original study (1987) the Korsakoff individuals learned the sequence less well than controls. However, Nissen et al. (1989) found no significant difference between amnesic and controls groups in the degree to which RTs increased on the introduction of a block of trials with a transfer sequence, apparently supporting the claim that implicit knowledge remains intact in amnesic individuals. As mentioned previously, these findings are not particularly convincing given that the experimenters employed training and transfer sequences that were not equated for the frequencies of individual targets.

The 3 studies employing such sequences with memory-impaired groups have been much less convincing in demonstrating intact response priming in amnesia. In Reber and Squire's (1998) studies the RT difference that accompanied the introduction of the transfer sequence, was numerically much larger (50 msec) in the controls than in the amnesic participants (25 msec), although not significantly so. Moreover, upon careful examination MTL amnesics show deficits in sequence learning that indicate that priming is not normal in these individuals. To demonstrate this, Curran (1997b) compared learning of complex SOC sequences and simpler first order conditional (FOC) sequences by controls and amnesic participants. In this experiment, FOC sequences like $FOC_1 = 1-2-1-4-2-3-4-3-1-4-2-3$, were used which are probabilistically predictive because each element (e.g.) 1 is followed by one element, e.g. 4, 67% of the time and another, e.g. 2, 33% of the time, but is never followed by the third element, e.g. 3. Therefore, simple pair wise information is sufficient to learn FOC sequences and it was predicted by Curran (1997) that amnesics would be able to learn FOC sequences as well as controls.

In contrast for SOC sequences like (1-2-1-4-2-3-4-1-3-2-4-3), each element is equally likely to be followed by any other, and pairwise information is not sufficient
for learning. Therefore it is necessary to acquire second order associations to learn SOC sequences. Curran pointed out that even if overall RTs differed between random and SOC blocks, as was the case in Reber and Squire’s (1994) experiment, it is still possible that participants learned isolated pairs within the sequence. Therefore if by chance learned pairs occurred more often in the sequence trials than random trials, RTs would be faster on sequence trials.

Curran trained participants on 9 blocks of either a FOC or SOC sequence in which structured and random trials alternated as follows; RSSRSSRSSR. Therefore, it was possible to control for learning of pairwise associations during training by comparing RTs for each pairwise transition between random and structured conditions. Although RT learning effects were comparable overall during training, the finer grained analysis in which learning of pairwise associations was controlled showed that amnesics can acquire pairwise associative information of FOC sequences but are impaired at learning higher-order associations between multiple locations required to learn the SOC sequences. This raises the possibility that consequences of damage to the medial temporal lobe are not confined to tasks like recognition but include impairment of RT priming too. In accordance with this view, it has been demonstrated by fMRI brain imaging that medial temporal lobe structures are active during the acquisition of sequence knowledge (training stage) and in participants who are both aware and unaware of the presence of a sequence during training (Schendan et al., 2003) (see Chapter 1 for a description of the neural structures involved).

Additionally, it has been reported that amnesic patients with damage to the hippocampus showed normal perceptual skill learning but were impaired on contextual learning in a visual search paradigm (Chun & Phelps, 1999). It was suggested that the medial temporal lobe system is important for learning contextual information, which requires the binding of multiple cues. Chun and Phelps propose that the key feature of hippocampus dependent tasks is that they are context dependent rather than that they are accessible to awareness and this view is in accordance with the evidence described above.
3. Effects of Diazepam on Sequence Learning

3.1.3 Summary

The question of whether or not amnesic patients can learn implicitly has been addressed by looking at their performance on the SRT. In early experiments unreliable methods were used to determine both the presence of learning, and to ascertain awareness of sequence knowledge. In 2 studies it has been shown that amnesics’ recognition performance is at chance (P. J. Reber & Squire, 1994; 1998) and it has been claimed that priming remained intact. This finding supports the need for a distinction between implicit and explicit learning. However, this position has been challenged by the finding that implicit sequence learning and hence response priming may not be normal in amnesia (T. Curran, 1997b). It may be more likely that priming and recognition both depend on a single underlying explicit system. Plainly, more research is needed to resolve this issue.

3.1.4 Alzheimer’s disease

Like amnesic individuals, patients with Alzheimer’s disease have been shown to have preserved sequence learning capabilities (Grafman et al., 1990; Knopman, 1991a; Knopman & Nissen, 1987) leading to the speculation that procedural learning is mediated by brain regions left intact by Alzheimer’s disease. In contrast, Ferraro, Balota and Connor (1993) reported that patients who had been diagnosed with mild Alzheimer’s disease were impaired at sequence learning, raising the possibility that Alzheimer’s disease does damage the areas of the brain involved in sequence learning. Why is there a disparity amongst these findings? Ferraro et al. proposed that the extent of brain damage in earlier studies was in truth relatively small and not yet severe enough to even be considered ‘mild’ Alzheimer’s, or to reveal impaired sequence learning. This explanation is plausible because Alzheimer’s disease is known to cause widespread brain damage, which is not confined to a particular region so it would be surprising if procedural leaning was not impaired in these patients.
3.1.5 Degeneration of the basal ganglia and sequence learning

3.1.5.1 Huntington’s disease

It is proposed that skill learning is dependent on the integrity of the basal ganglia (Squire, 1992). This claim is supported by findings that have suggested that sequence learning is altered in individuals with basal ganglionic deficits like Huntington’s disease (Knopman & Nissen, 1991; Willingham & Koroshetz, 1993). In a study conducted by Knopman and Nissen (1991) the experimenters compared 13 Huntington’s individuals with 12 normal individuals and the participants were trained on 4 blocks of a 10-item deterministic sequence, followed by a random block in which the target did not appear consecutively on two separate trials: (i.e., Nissen and Bullemer’s, 1987 training method). Participants performed the generate task after the 5th block of trials and here they were shown a series of sequence trials and asked to generate the next response. It was reported that Huntington’s individuals performed at chance on the generate task, so they were compared with a subgroup of the control participants who performed at chance. The Huntington’s individuals showed impaired procedural learning in comparison to the control group and it was concluded that this could not be attributed to impaired explicit knowledge, because this factor had been eliminated. It was claimed that the striatum is involved in implicit learning because it is damaged in Huntington’s disease. Hence, it is likely that the striatum is involved in procedural learning but as with the studies on MTL amnesic and Alzheimer’s disease patients, the position that this learning is implicit needs to be examined more closely by employing more recent techniques presently employed by implicit learning researchers.

3.1.5.2 Parkinson's disease

An extensive body of research exists to investigate the performance of Parkinson’s patients on the SRT task. Although findings have not been entirely consistent it can be broadly concluded that sequence learning is not normal in Parkinson’s patients with damage to the basal ganglia including the striatal region of the brain, leading to a loss of dopamine activation in this region. As with other neuropsychological evidence most SRT task studies with Parkinson’s patients have employed Nissen and
Bullemers (1987) training method (Ferraro et al., 1993; Pascual-Leone et al., 1993; Smith, Siegert, & McDowall, 2001; Sommer, Grafman, Clark, & Hallett, 1999). Some experimenters have dispensed with the use of random blocks and have chosen instead to examine the change in RTs across sequence blocks as a measure of learning. This method is problematic because it fails to distinguish between sequence learning and non-specific learning which may produce additional acceleration of RTs (Doyon et al., 1997; Doyon et al., 1998).

Studies show that sequence learning is attenuated in individuals with Parkinson’s disease using the standard SRT task (Brown et al., 2003; Doyon et al., 1997; Doyon et al., 1998; Ferraro et al., 1993; Pascual-Leone et al., 1993; Sommer et al., 1999) and verbal versions of the SRT task (Westwater et al., 1998). This latter finding supports the claim that the impairment in sequence learning is not simply due to motor deficits caused by Parkinson’s disease. On the other hand, Smith et al. (2001) failed to replicate an impairment of sequence knowledge on a verbal version of the SRT. Moreover, it has been claimed by others that Parkinson’s patients are impaired at learning stimulus-motor response sequences but are unimpaired at learning sequences of spatial locations (Helmuth, Mayr, & Daum, 2000). It is plausible that Parkinson’s patients are impaired at producing a speeded response due to poor motor abilities rather than impaired sequential learning per se.

In most of the studies mentioned in which Parkinson’s patients were involved experimenters set out to systematically measure awareness of sequence knowledge (Brown et al., 2003; Doyon et al., 1997; Doyon et al., 1998; Helmuth et al., 2000; Pascual-Leone et al., 1993; Smith et al., 2001; Sommer et al., 1999; Westwater et al., 1998). However, on some occasions a test of awareness was not conducted (Ferraro et al., 1993).

Some experimenter employed verbal report to assess awareness claiming that participants were unaware of sequence knowledge on that basis (Brown et al., 2003; Helmuth et al., 2000; Smith et al., 2001). Others used various versions of generate tasks to measure sequence knowledge and the overall findings suggest that Parkinson’s patients were able to express sequence knowledge explicitly (Doyon et al., 1997; Doyon et al., 1998; Helmuth et al., 2000; Pascual-Leone et al., 1993;
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Sommer et al., 1999) because performance on the generate test was above chance.

One of the most convincing demonstrations of impaired sequence learning in Parkinson’s patients was conducted by Jackson et al. (1995). Eleven Parkinson’s patients and 10 controls were all trained on a pseudo-random SOC sequence for 6 blocks and then switched to another pseudo-random sequence on the 7th block. Finally, they performed a generate task to measure awareness. The introduction of the transfer block produced significant slowing for the controls but not the Parkinson’s individuals, which is clear evidence of a deficit in sequence learning for patients with basal ganglia dysfunction. For the generate task, chance performance was estimated from data obtained from participants who were trained on a different pseudo-random sequence and tested for their knowledge of the sequence employed for the Parkinson’s group. Inspection of generate task performance reveals that there was no between groups difference in generate task performance overall. It was reported that 5/10 of the controls, and only 1/11 Parkinson’s participants performed more than 1 standard deviation above chance on the generate task, suggesting a numerical difference in the amount of explicit knowledge expressed by the 2 groups. These findings support the notion that procedural learning requires integrity of the basal ganglia. However the generate task findings do not support the idea that sequence learning is implicit, because controls who learned the sequence were subsequently able to perform above chance on the generate task.

3.1.5.3 Specific role of the putamen in sequence learning

Existing literature concerning sequence learning in Parkinson’s disease is conflicting because studies reveal attenuation rather than abolition of learning, which occurs in some, but not all patients (Brown et al., 2003). One explanation is that robust procedural learning processes exist which can function even in the presence of degenerative brain damage caused by Parkinson’s disease. However, it is equally likely that normal functioning is only partially disrupted because the extent of brain degeneration and neuronal compensation is heterogeneous within studies, and therefore the extent of dopamine activation in the basal ganglia may vary greatly across studies, and it is possible that dopamine activation is not lost completely in some individuals.
In a recent neurosurgical treatment for Parkinson's disease, a lesion of the posteroventral segment of the globus pallidus (GPi) is conducted (pallidotomy) leading to elimination of the disordered output from the putamen to the cortical motor areas including the supplementary motor area. The result of this surgery is that the striatal output of the brain is completely eliminated. Brown et al. (2003) were able to compare sequence learning in patients both before and after surgery to examine more specifically the role of the striatum in sequence learning.

Two groups of Parkinson's patients were recruited (pre and post pallidotomy operation) and they were trained for 10 blocks of 80 trials of a 10-item sequence including 1 pseudo random block. Brown et al. reported that the post operative patients showed no evidence of sequence learning compared to controls whatsoever, whereas the pre operative patients demonstrated attenuated sequence learning. This finding is supported by functional brain imaging evidence collected by Rauch et al. (1997, see Chapter 1 section 6.4) who reported that normal participants exhibited activation in the putamen specifically during sequence learning and moreover this activation correlated with the level of RT improvement they showed. This evidence supports the view that the striatum and more specifically the putamen plays a fundamental role in motor sequence learning.

In Brown et al.'s study, a structured verbal report test was employed to assess awareness and it was observed that all but 2 Parkinson's patients reported no awareness of the sequence, and therefore it was suggested that learning occurred implicitly in the pre operative group. To test this and other claims made by researchers who have hypothesised that implicit learning in particular, is attenuated by Parkinson's disease, it would be interesting to examine the level of sequence knowledge awareness in Parkinson's individuals using a more sensitive test like recognition. In addition, Brown et al. (2003) employed Nissen and Bullemer's (1987) training method to investigate sequence learning in their patients. Their study could be replicated using more up-to-date methods to establish whether sequence learning is indeed eliminated by a lesion of the G Pi.

The basal ganglia and the medial temporal lobes are not the only important brain areas implicated in sequence learning (see Chapter 1, section 6 for a review of the
neuro-imaging evidence of the neuronal architecture of sequence learning). In addition, sequence learning can be impaired in individuals with lesions of the cerebellum (Doyon et al., 1997; Doyon et al., 1998; Gomez-Beldarrain, Garcia-Monoco, Rubio, & Pascual-Leone, 1998; Molianri et al., 1997; Pascual-Leone et al., 1993) and supplementary motor area (Ackermann, Daum, Schugens, & Grodd, 1996). However, these findings do not indicate whether sequence learning is implicit - they merely demonstrate the importance of particular brain regions for successful sequence learning.

3.1.6 Problems with neuropsychological studies

There are fundamental difficulties with the use of behavioural evidence from clinical populations as evidence for the existence of implicit learning. Firstly, sample sizes are often very small leading to low statistical power. This is particularly problematic when evidence for implicit learning depends on the demonstration of a null result like chance level performance on an awareness test. For instance, recall that in Reber and Squire’s studies of sequence learning by amnesic individuals (where recognition performance was reported to be at chance), the number of amnesics tested in each experiment was small. In the 1994 study in which 8 amnesics were tested, the power to detect a small effect was 0.10, a medium effect was 0.24 and a large effect was 0.45. Similarly in the 1998 study, in which 5 amnesic individuals were studied, the power to detect a small effect was 0.09, a medium effect was 0.17 and a large effect was 0.31. Therefore, for both studies the possibility that recognition was at chance because of low statistical power rather than genuine implicit knowledge is difficult to rule out.

Secondly, it is extremely difficult to control the extent of brain damage in neuropsychological experiments so brain damage is often heterogeneous and the extent of neuronal compensation within participants is often uncertain. Therefore, if tests of performance and awareness are conducted at separate times and differ according to difficulty, it is possible that preserved performance on an indirect test may simply be due to the existence of a residual explicit system remaining unimpaired by the presence of brain degeneration. As discussed in the present
3, Effects of Diazepam on Sequence Learning

chapter this can lead to problems for studies involving amnesics because it is not certain whether preserved performance on an indirect test is truly implicit, and it is a problem for studies involving Parkinson's and Huntington's disease because the specific role of the brain regions that are disrupted by these disorders is not clear.

3.2 Psychopharmacological studies of sequence learning

How can these dilemmas be resolved? Psychopharmacology offers one solution. It is possible to administer particular drugs to non-clinical samples thereby inducing an artificial brain state similar to that found in clinical populations. Therefore the role in memory of neurotransmitters and brain areas can be examined by looking at the effects of drugs known to have a particular effect on that neurotransmitter in certain brain regions. According to dissociation logic if a particular drug impairs performance on one task while leaving performance on another intact then this is support for a multiple systems theory. An advantage that psychopharmacological methods have over neuropsychological ones is that the experimenter can employ large sample sizes relatively easily. Moreover, the experimenter can exert control over variables like drug dose to control the extent of a drug's effect.

For example, it is known that acetylcholine (Ach) is depleted in the brains of individuals with Alzheimer's disease. One cholinergic drug called scopolamine (hyosine), which blocks the action of ACh in the brain, has been administered to normal participants to model Alzheimer's disease. It is then possible to compare the memory impairment induced by the drug, with that induced by Alzheimer's disease. Another group of drugs found to have amnesic effects are the benzodiazepines: diazepam, alprazolam, triazolam and lorazepam. Benzodiazepines act on specific benzodiazepine receptors to facilitate the transmission of gamma-aminobutyric acid (GABA), which is the major inhibitory neurotransmitter in the brain. Benzodiazepine receptors are found in greatest concentrations in the cerebral cortex and limbic system (including the hippocampus and the amygdala) (H.V. Curran, 1999).

It has been demonstrated that cholinergics and benzodiazepines impair episodic memory while semantic memory remains respectively intact (H. V. Curran, 1999).
However, it has been reported that benzodiazepines and scopolamine do not impair procedural learning. To date, a small number of SRT task experiments have been conducted in which the effect of benzodiazepines and scopolamine were investigated.

In one study (Nissen et al., 1986), scopolamine (0.43 mg) was administered subcutaneously to 12 participants while 12 controls were given saline solution as a placebo. To test procedural learning, 45 min after administration, participants performed 4 (10-item) sequence blocks followed by 1 random block and 3 sequence blocks. Finally, to test explicit knowledge of the sequence they performed the 'generate task' for two blocks of 100 trials. This involved responding to a stimulus and indicating which target comes next. During training, the scopolamine and saline groups responded similarly, i.e. RTs increased on block 5 and the difference between blocks 4 and 5 was equivalent. However, in the generate task, the saline group (83.4% correct) were significantly more accurate than the scopolamine group (69.6% correct). Although Nissen et al. interpreted the difference found in generate task performance between the two groups as evidence that the scopolamine group learned implicitly, in truth, both the saline and scopolamine groups performed above chance on the generate task, which is sufficient evidence that in both groups learning was explicit.

Similarly Bishop, Curran, and Lader (1996) looked at the effects of scopolamine (0.3 mg and 0.6 mg) and lorazepam (1mg and 2mg) on the SRT task of Nissen et al. (1987). Participants completed 7 40 trial blocks of the SRT; blocks 1, 2 and 7 were random and the other blocks followed a 5 item deterministic sequence. Learning was comparable in the placebo and drug groups indicating that neither drug affected procedural learning under these circumstances. In this experiment a test of awareness was not employed.

Nissen et al.'s findings (1986) support the hypothesis that central cholinergic blockage caused by scopolamine affects declarative memory, presumably as a result of a disruption to the cholinergic projection system to the neocortex and hippocampus. However both studies reveal that the administration of either scopolamine or lorazepam does not affect procedural memory suggesting that it
depends on a separate memory system that was unaffected by either central cholinergic blockage or the activation of GABA which both lead to inhibition of activation in the hippocampus.

In contrast, Knopman (1991b) looked at the effects of scopolamine (0.43) and lorazepam (2.5 mg) on either a motor or a verbal version of the SRT. In both versions participants were trained on 3 blocks containing a 10-item repeating sequence, followed by a random block and the fifth block was a sequence block. Following training participants performed a motor or a verbal version of the generate task to assess awareness. In a verbal version, but not the motor version of the SRT task, the participants who received scopolamine or higher dose (2.5 mg) lorazepam showed impairment of sequence specific learning but participants who received the placebo revealed no such impairment. It was reported that the scopolamine and lorazepam groups performed above chance on both the motor and verbal versions of the generate task. These findings indicate that sequence learning is impaired by scopolamine and lorazepam when knowledge is acquired verbally.

Again Nissen and Bullemer's (1987) training method was adopted in these experiments which is problematic for reasons already discussed. Furthermore, the scopolamine and lorazepam groups performed above chance on the generate task in Nissen et al.'s (1986) and in Knopman's (1991b) experiment, indicating that the procedural knowledge acquired in these studies was explicit.

A recent study (Volkerts et al., 1999), was conducted to investigate effects of more centrally acting drugs known to act upon a general state of alertness on procedural learning in the SRT. The experimenters employed phentermine (thought to increase arousal) and pentobarbital (thought to decrease arousal) in a signal detection task in which the participants were exposed to both easy and difficult sequences of varying lengths, under both fast and slow conditions. In this experiment participants were required to first respond to each target and then to predict the following sequence item for a training block, which constituted 24 sequence repetitions. The experimenters demonstrated that the amount of sequence learning varied according to both the difficulty and pacing of the task. Phentermine enhanced the acquisition of sequence knowledge, when both difficult and easy sequences were presented
slowly. In contrast, sequence learning was impaired by pentobarbitol for difficult sequences that were presented slowly. This indicates that phentermine and pentobarbital have a differential effect on the acquisition of procedural memory, and these findings are consistent with the view that sequence learning is impaired under conditions of divided attention (Shanks & Channon, 2002). However, because no specific tests of awareness were employed, the findings of this study do not contribute to an understanding of whether procedural learning can be implicit.

3.3 Present study

It is clear that with a few exceptions in the neuropsychological literature, most neuropsychological and all psychopharmacological investigations of sequence learning conducted thus far have employed Nissen and Bullemer’s (1987) training method to establish a learning effect. This method has been criticised, leading to the development of more reliable methods like the use of SOC sequences during the training stage.

In addition, there has been no research to date examining the effect of pharmacological manipulations on probabilistic sequence learning. Further, measures of awareness have been used that have also been criticised in the implicit learning literature (verbal report measures), leading to the development of more sensitive measures of awareness (see Chapters 1 and 2 for a discussion). Therefore, in the present study, diazepam (a benzodiazepine) was used to induce a state of amnesia in normal participants. In addition, identical methods were employed as in Chapter 2 (Experiment 1, RSI group) to examine probabilistic sequence learning and to examine whether administration of a drug like diazepam leads to evidence for implicit learning. As in Chapter 2 a concurrent test of priming and recognition will be adopted to examine the relationship between priming and recognition. If knowledge can be acquired implicitly by diazepam-induced amnesics, it is hypothesised that they will learn the sequence, as indexed by priming, and this will be accompanied by chance level recognition performance. If on the other hand, all knowledge acquisition is conscious, it is hypothesised that if amnesic participants can learn the sequence, they will also be able to recognise it or in other words,
priming will always be accompanied by recognition.

3.4 Experiment 4

Different doses of diazepam were administered to participants who were subsequently trained on a probabilistic sequence of a target detection task. Immediately after training, they underwent a recognition test, which involved discrimination of 6 item test sequences. The recognition test phase allowed concurrent examination of priming and recognition following training on the sequence. In addition to sequence learning, prose recall tests were conducted, to assess the effect of diazepam on declarative memory. To assess the effects of the drug on various mood states, analogue self-rating scales were administered throughout the experiment.

3.4.1 Method

3.4.1.1 Participants

Forty-eight healthy volunteers (24 male, 24 female) were recruited to take part in the study. They were aged between 19 and 51 (mean age = 24). Males ranged in weight from 55 to 100 kg (mean weight = 74.00 kg) and females from 49 to 76kg (mean weight = 59.59 kg). The males ranged in height from 160 to 188 (mean height = 178.42 cm) and females from 155 to 183 cm (mean height = 166.17 cm). Participants were instructed to abstain from alcohol for at least 24 hours prior to the commencement of the study. If taking part in the morning they were asked to have, at most, a light, low-fat breakfast. If taking part in the afternoon, they were asked to have, at most, a light, low-fat lunch. It was established that participants were not taking any medication at the time of test and were unfamiliar with the experimental task. Participants were paid a turn up fee of £12 plus an extra amount calculated according to their recognition performance as detailed below. The experiment was approved by the ethics committee of University College London.
3.4.1.2 Experimental design and drugs

A double blind, independent group design was used in which 24 male and 24 female volunteers were randomly assigned to 3 groups, each with 8 female and 8 male participants: a placebo group, a diazepam 7.5 mg (low dose) group and a diazepam 15mg (high dose) group. Matched capsules containing 7.5mg, 15mg diazepam, or lactose placebo were given orally. To investigate the cognitive effect of diazepam on sequence learning during its peak plasma concentration a delay of 40 minutes followed administration of the capsules before the main test session commenced.

3.4.1.3 Tasks

A series of memory and cognition tasks was administered to each participant individually and participants repeatedly rated their subjective mood on visual analogue scales. They were given prose recall tasks (immediate and delayed) to assess the effects of diazepam on explicit memory. Participants performed the sequence learning task to assess the effects of diazepam on procedural learning (see Table 3.1 for experimental testing schedule).
Table 3.1. Experimental testing schedule employed in Experiment 4.

<table>
<thead>
<tr>
<th>Test</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mood rating 1, of factors 1, 2 and 3.</td>
<td>1 - 2 min</td>
</tr>
<tr>
<td>Prose 1 (either A or B) immediate recall.</td>
<td>2 No min</td>
</tr>
<tr>
<td>Oral administration of either 7.5mg, 15mg or a placebo.</td>
<td>6 min</td>
</tr>
<tr>
<td>Prose 2 (either A or B) immediate recall.</td>
<td>46-50 min</td>
</tr>
<tr>
<td>Mood rating 2, of factors 1, 2 and 3.</td>
<td>50-52 min</td>
</tr>
<tr>
<td>Sequence Learning task.</td>
<td>52- 82 min</td>
</tr>
<tr>
<td>Delayed recall of prose 1, then delayed recall of prose 2.</td>
<td>82- 88 min</td>
</tr>
<tr>
<td>Mood rating 3, of factors 1, 2 and 3.</td>
<td>88 - 90 min</td>
</tr>
</tbody>
</table>

3.4.1.4 Sequence learning task

Apparatus. This was the same as the apparatus used in Experiments 1-3.

Materials. Two second order conditional sequences (SOC1 = 3-1-4-3-2-4-2-1-3-4-1-2, SOC2 = 4-3-1-2-4-1-3-2-1-4-2-3) were used in the target location task. These were the same as in Experiments 1 and 3. The second order conditional sequences were transformed into probabilistic sequences as in Experiment 3.

Procedure. Training phase. The experiment consisted of 12 training blocks during which participants were exposed to a four-choice SRT task. Each block consisted of
100 trials for a total of 1200 trials. The procedure was identical to Experiment 1 (RSI group). For counterbalancing, half the participants in each condition trained on the SOC1 sequence and the remainder on the SOC2 sequence. Thus 8 males and 8 females in each group were trained on SOC1 (n = 4), and SOC2 (n = 4) respectively. One participant in the low dose group, trained on SOC2 was excluded from the SRT task analysis on the basis that her reaction times were found to be exceptionally slow (3 standard deviations above the mean). Hence for the low dose group n = 15 (8 males and 7 females).

**Test phase.** The test phase involved a recognition test for the target location task and was identical to the recognition test employed in Experiment 1 (RSI group). Twelve of the sequences were constructed by starting at each serial location of SOC1, and twelve were constructed by starting at each serial location of SOC2. Thus, the SOC1 test sequences were old for the subgroups trained on SOC1 and new for the subgroups trained on SOC2 and vice versa for the SOC2 sequences. Two dependent variables were measured in the test stage: reaction times for the target location task and participants’ recognition ratings of the sequences.

Following training, and before commencing the recognition test, participants were instructed that their recognition test performance would be rewarded incrementally depending on how well they did. The intention of this payoff schedule was to maximize participant motivation in the recognition test. They were instructed that, in addition to a £12 turn up fee, for every correct response they would receive an extra 20p. Therefore the maximum payoff participants could receive was £12 + 24 x 20p = £14.80 and the minimum they could receive was £12.

### 3.4.1.5 Prose recall

**Immediate recall.** The Rivermead Behavioural Memory Test (Wilson, Cockburn, & Baddeley, 1985) was employed to assess prose recall. Participants were presented with a neutral story 60-65 words long and consisting of 21 idea units. Immediately they were asked to write down as much of the story as they could remember. This was done for 2 different stories, A and B at 2 time points (see Table 3.1). The order of presentation of the stories was counterbalanced across design with half the
participants receiving story A first, and half the participants receiving story B first.

**Delayed recall.** Participants were required to write down as much as possible of the first story they heard (either A or B) followed by the second story they heard (either A or B). Scoring of the immediate and delayed recall was standard.

### 3.4.1.6 Mood ratings

Participants completed a 16 item visual analogue mood rating scale (Bond & Lader, 1974). This consisted of visual analogue scales each representing opposite extremes of mood. On each scale, a line was drawn between one mood state and its opposite and participants had to state where they fell on the continuum at that present time by placing a vertical mark on the line. Mood rating scales were scored by measuring (in mm) the distance between the beginning of the line and the vertical mark and participants completed the same 30 mood ratings on 3 separate occasions (see experimental protocol). Principal components analysis yielded an arousal factor (Mood Factor 1), contentedness factor (Mood Factor 2) and an anxiety factor (Mood Factor 3).

### 3.4.2 Results

#### 3.4.2.1 Sequence learning task

**Training phase.** Reaction times for participants trained on either SOC1 or SOC2 were combined in the following analyses. In this analysis, RTs to the first 2 targets of each block were excluded since their locations cannot be predicted. Also, trials on which an error was made were not included in the calculation of mean RT. Figure 3.1 shows the mean reaction times obtained over the training phase plotted separately for the 3 dose conditions and for each type of target location, probable or improbable. In all 3 conditions the probable strings were executed faster than the improbable strings. An ANOVA was performed on RTs with probability (probable vs. improbable, 2 levels) and block (12 levels) as within participants variables and dose (placebo, low, high, 3 levels) as a between participants variable. This analysis revealed a significant main effect of probability, \( F(1, 44) = 40.97, MSE = 2518.6, \) which indicates that in all 3 conditions, probable strings were executed faster than...
improbable strings.

Main effects of block, $F(2.5,110.4) = 1.34, MSE = 25661.2$, and dose, $F(2,44) = 1.24, MSE = 257621.4$, both failed to reach significance suggesting that RTs did not decrease significantly across all training blocks, and that there was no overall RT difference between each dose condition. Interactions between block and dose, $F(5,110.4) = .83, MSE = 25661.2$, probability and dose, $F(2,44) = 2.07, MSE = 2518.6$, block and probability, $F(3.5,155.7) = 2.13, MSE = 5614.2$, and block x probability x dose, $F(7,155.7) = .72, MSE = 5614.2$, all failed to reach significance, indicating that sequence learning during the training phase did not differ across drug groups in this experiment. The lines are flat because errors were excluded from this analysis, as in Experiments 1-3.

Inspection of Figure 3.1 reveals that differentiation between probable and improbable targets emerged during block 3 in all 3 groups and in the placebo group it remained consistent across blocks 3-12. In the low and high dose groups differentiation is consistent across blocks 3-12, except blocks 8 and 10 in the low dose group and block 10 in the high dose group for which mean RTs for probable trials are numerically slower than mean RTs for improbable trials. To further investigate whether there was any differential effect of the drug on the magnitude of overall learning during the training phase, a composite measure of learning across blocks 1-12 was calculated by obtaining a difference score (probable N improbable trials) for each participant, and taking the mean difference score across blocks 1-12. The mean difference scores were -21.12 (placebo), -10.83 (low) and -25.48 (high) dose groups, therefore, the low dose group learned numerically less overall than the other groups, although this difference was not statistically significant.

Errors. The error rates varied between 0.02 - 0.06 (placebo), 0.02 N 0.04 (low dose), 0.02 N 0.05 (high dose) for probable targets and 0.03 N 0.13 (placebo), 0.07 - 0.08 (low dose), 0.04 N 0.09 (high dose) for improbable targets.
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Figure 3.1. Mean RT in milliseconds across training blocks in Experiment 4. Probable targets were consistent with the generating sequence whereas improbable ones were not. Error bars represent standard errors.

**Test phase. Priming.** Figure 3.2 shows mean reaction times for old and new test sequences at each sequence position for each dose group. An ANOVA was performed on RTs with position [6 levels] and old/new [2 levels] as within participant variables and dose [3 levels] as a between participants variable. This analysis revealed a significant main effect of position, $F(1.1,2.2) = 75.61$, $MSE = 152579.6$, reflecting the fact that overall RTs changed across test item positions. The main effect of dose was significant, $F(2,44) = 5.51$, $MSE = 116981.6$, showing that overall RTs are different in each drug group. The interaction between position x dose, $F(2.2,48.3) = 4.77$, $MSE = 152579.6$, was significant, and from the figure, it is clear that the main effect of dose depends on position. For example the main effect of dose is apparent at positions 1 & 2, but is less evident across positions 3-6. Participants were unable to predict the first two items of the test sequences, therefore, diazepam led to slower RTs on these first two unpredictable trials. The main effect of old/new and all other interactions failed to reach significance.
Figure 3.2. Mean reaction time to targets 1-6 in old and new test sequences in Experiment 4. Targets 3-6 are predictable from the preceding targets whereas targets 1-2 are not predictable. Error bars depict standard errors.

Closer inspection of old/new RTs across positions 3-6 reveals that in the placebo group, old targets were executed faster than new targets but this difference was not present in the high dose group. However, in the low dose group an old/new difference was not present at positions 3 and 4 but emerged at positions 5 and 6. To investigate this pattern further an ANOVA was conducted on RTs with position [2 levels, positions 3 and 4 combined and 5 and 6 combined] and old/new [2 levels] as within participant variables and dose [3 levels] as a between participants variable. Again, the analysis revealed significant effects of position, $F(1,44) = 29.24$, $MSE = 682.0$ and old/new, $F(1,44) = 4.96$, $MSE = 2035.8$. Moreover, there was a significant interaction between position x old/new x dose, $F(2,44) = 3.28$, $MSE = 554.8$, reflecting the pattern of results described above. The main effect of dose and all other interactions were non-significant.

To examine the apparent differential effect of diazepam on contextual cueing a RT difference score was calculated for each participant in the following way, where numbers 1-6 denote positions on the test item:

- $(1+2)/2$ new $- (1+2)/2$ old
- $(3+4)/2$ new $- (3+4)/2$ old
(5+6)/2 new N(5+6)/2 old

Because an old/new difference in RT was not expected at positions 1 and 2 (recall, it is not possible to predict the first 2 items of a SOC sequence) only the data for positions 3-6 are plotted in Figure 3.3. If difference scores are significantly different from zero then this would indicate priming. Therefore, one sample t-tests were conducted to compare these scores to zero. For all groups the positions 1 and 2 difference score failed to reach significance, (placebo) $t(15) = 0.51$, (low) $t(14) = 0.48$, (high), $t(15) = -0.63$, which confirms that there was no old/new RT difference present at positions 1 and 2.

However, the positions 3 and 4 difference score was significantly different from 0 in the placebo group, $t(15) = 4.24$, but not in the low, $t(14) = 1.22$, or high, $t(15) = -0.40$ groups. This finding illustrates that both low and high doses of diazepam disrupted priming at positions 3 and 4. Moreover, the positions 5 and 6 difference score was significantly different from 0 for the placebo, $t(15) = 2.18$, and low, $t(14) = 2.57$, groups, but not for the high dose group, $t(15) = 0.09$. Clearly, only the high dose of diazepam disrupted priming at positions 5 and 6.

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1 The analysis is reported without a Bonferroni correction for multiple tests. If an $\alpha = .0006$ of is used, the 3 and 4 difference score remains significant ($p=.0005$, one-tailed). However the 5 and 6 difference scores are not significantly different from zero in both the placebo, $p = .045$ and low dose group, $p = .022$. 

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Figure 3.3. Mean difference scores (old-new) for targets ((1+2), (3+4), (5+6)) / 2, for test sequences in Experiment 4. Error bars depict standard errors.

Recognition. Figure 3.4 shows mean recognition ratings for both conditions and for both types of sequences (recall that low ratings correspond to judgements of novelty and are expected for new sequences). It is clear that participants in all drug conditions were able to differentiate between old and new strings. These observations were confirmed by an ANOVA performed on recognition ratings with dose [3 levels] as a between participants variable and old/new [2 levels] as a within participants variable. This revealed a significant effect of old/new, $F(1,44) = 15.61$, $MSE = .1$. However the main effect of dose and the old/new x dose interaction failed to reach significance (all $F$s < 1).

It could be argued that the drug-induced amnesics might alter their criterion for discriminating between old and new items. For example they may be more likely to call old items old than the placebo group. To investigate this further, both $d'$ and $c$ were calculated for each group. Mean $d'$ for each group were as follows; Placebo = 0.25, Low dose = 0.22 and High dose = 0.26. There was no significant difference between $d'$ or $c$ across groups (all $F$'s < 1).
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3.4.2.2 Prose recall

Figure 3.5 shows mean prose recall for each drug group in either the immediate or delayed conditions and either for pre or post drug administration. A prose recall difference score was calculated for immediate and delayed recall respectively by subtracting prose recall post drug administration from prose recall pre administration. An ANOVA was performed on this difference score with type [immediate and delayed, 2 levels] as within participants variables and dose [3 levels] as a between participants variable. The main effect of dose, $F(1,45) = 5.86, MSE = 12.9$, and the interaction between type and dose, $F(2,45) = 3.45, MSE = 2.5$, reached significance. The main effect of type was non-significant ($F < 1$).
Figure 3.5. Mean prose recall for each group in Experiment 4. Participants were tested twice (immediately and delayed) at 2 separate times (pre and post drug administration) for 2 different stories (A or B).

One sample t-tests were conducted to compare these scores to zero. For the placebo group both the immediate and delayed difference scores were not different from zero, indicating that neither immediate nor delayed recall was impaired by the dose. For the low dose group, the immediate scores were not different from zero, but the delayed score almost was $t(15) = 2.12, p = .02$ (one-tailed), indicating that delayed recall was impaired by the dose in this group. For the high dose group both immediate $t(16) = 3.46$, and delayed $t(16) = 4.21$, recall scores were different from zero, indicating that both immediate and delayed recall was impaired by the dose in this group. A Bonferroni correction was applied to this analysis, hence an $\alpha = .008$ was used.

3.4.2.3 Mood ratings

Mood Factor 1 (alert vs. drowsy). Figure 3.6 shows mean scores for mood factor 1, which represents a shift in mood from alert to drowsy, i.e. the higher the score the more sedated participants were. Clearly, participants in the high and low dose groups became progressively more sedated, and for those in the placebo group there appears to be no apparent change in self rating of sedation. These observations were
confirmed by an ANOVA performed on factor 1 scores with time [times 1, 2 and 3, 3 levels] as a within participants variable and dose [3 levels] and sex [2 levels] as between participants variables. This revealed significant main effects of time, $F(1.5,61.4) = 42.99, MSE = 144.7$, and dose, $F(2,42) = 6.80, MSE = 510.8$, and a significant time x dose interaction, $F(2.9,61.4) = 5.51, MSE = 144.7$, reflecting that fact that the effect of time depends on dose: in the high and low dose groups participants became more sedated over time, but in the placebo group the rating of sedation did not change. The effect of dose depends on time: at time 1 there is no apparent difference between the groups, whereas at times 2 and 3 the placebo group is lower than the low dose group, which is lower than the high dose group. The main effect of sex and other interactions failed to reach significance.

**Mood Factor 2 (contented-discontented).** Figure 3.6 shows mean scores for mood factor 2, representing a shift in mood from contented to discontented, i.e. the higher the score the more discontented participants were. There appears to be little difference between drug groups on self-ratings of contentedness and little change over time in these ratings. These observations were confirmed by an ANOVA performed on factor 2 scores with time [times 1, 2 and 3, 3 levels] as a within participants variable and dose [3 levels] and sex as between participants variables. All main effects and interactions failed to reach significance.

**Mood Factor 3 (calm-anxious).** Figure 3.6 shows mean scores for mood factor 3, representing a shift in mood from calm to anxious, i.e. the higher the score the more anxious participants were. Participants in all groups became calmer during the experiment. This was confirmed by an ANOVA performed on factor 3 scores with time [time 1, time 2 and time 3, 3 levels] as a within participants variable and dose [3 levels] as between participants variables. Main effects of time, $F(1.7,72.9) = 25.55, MSE = 104.9$, and the time x dose interaction, $F(3.5,72.9) = .423, MSE = 104.9$, were significant. The effect of dose depends on time: at time 1 there is no effect of dose, at times 2 and 3 the high dose group was calmer than the placebo and low dose groups, and at time 3 the low and high dose groups were calmer than the placebo group. Other main effects and interactions failed to reach significance.
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Figure 3.6. Mean mood factor score for each group in Experiment 4. Participants gave self ratings of mood at 3 separate times: Pre drug administration (Time 1), 40 minutes post drug administration (Time 2) and 88 minutes post drug administration (Time 3). On the Y axis alertness represents a shift in mood from alert to sedated, anxiousness represents a shift from calm to anxious, and contentedness represents a shift from contented to discontented.

3.4.3 Discussion

The present findings indicate that different doses of diazepam led to an impairment of declarative memory because immediate prose recall was significantly impaired by a high dose of the drug, whereas delayed recall was significantly impaired by both low and high doses of the drug. This confirms that diazepam induced a temporary state of amnesia in participants. These memory-impaired individuals were nevertheless capable of successful sequence learning. For example, during the stage at which sequence information was encoded i.e. the training phase, performance of the high and low dose groups did not differ from the performance of a non-memory impaired group (placebo). All 3 groups showed a similar pattern of learning at this stage: probable trials elicited both shorter RTs and numerically less anticipatory
errors than improbable trials during the training stage. This pattern of results reveals that participants in all groups learned the complex sequence of targets to which they were exposed. During the training phase, there was no significant difference in the magnitude of sequence leaning across the experimental groups. These findings are consistent with previous research using MTL amnesics and drug induced amnesics in which sequence learning was found to remain intact during the training stage (Bishop et al., 1996; Knopman, 1991b; Nissen et al., 1986; P. J. Reber & Squire, 1994; 1998).

Was this preserved procedural learning implicit? Awareness of sequence knowledge was investigated by looking at participants’ subsequent recognition performance following the training phase. The placebo group was capable of above chance recognition performance revealed by significantly higher ratings for old test strings than new strings, indicating that participants were able to discriminate between the test items. This finding supports the conclusion that probabilistic sequence learning is conscious in non-memory impaired individuals, replicating the findings obtained in Chapter 2. Furthermore, the memory-impaired participants’ recognition performance was comparable to the placebo group. Both the low and high dose groups performed above chance at recognition suggesting that the drug induced amnesic participants were capable of learning the sequence explicitly, despite temporary memory impairment caused by administration of the drug.

Performance and awareness were found to be closely related even when declarative memory was severely impaired. However, in addition to the measure of priming during the encoding stage of sequence learning (training phase), the expression of motor priming during the retrieval stage was examined (test phase) by comparing participants’ response latencies to old strings versus new strings in the recognition test phase. Interestingly, a differential effect of the experimental manipulation on the amount of motor fluency expressed was observed. In the placebo group old strings (locations 3-6) were performed significantly faster than new strings replicating previous findings in Experiment 1. However, the low dose group showed no significant old/new priming effect at locations 3 and 4 of the test strings, but the fluency effect emerged at locations 5 and 6. Lastly, the high dose group did not demonstrate a significant fluency effect at all, reflected by the fact that RTs were comparable for old and new strings across positions 3-6.
Different doses of diazepam had a differential effect on the expression of procedural knowledge, rather than on recognition ratings as would be predicted by a multiple systems account of memory. This effect on procedural learning was quite specific being confined to the test phase whereas performance during the training phase remained comparable to the placebo group. In the high and low dose groups, diazepam decreased the effectiveness of contextual information when participants performed the test strings. Hence, the placebo group showed retrieval priming for the entire test items, the low dose group showed priming for the last half of the test strings and the high dose group did not show priming at all. It is clear that increasing doses of diazepam impaired participants' ability to use sequence chunks as cues for successful motor fluency performance. The finding is in agreement with the idea that contextual cueing rather than explicit learning is affected in amnesia (Chun & Phelps, 1999).

This novel finding supports the view that contextual cueing and recognition ratings depend on different brain regions and it is possible that contextual cueing depends on a brain region or regions that are affected by the administration of diazepam (MTL structures). Nevertheless, the presence of priming was not observed in the absence of recognition, therefore it can be concluded that the procedural learning observed in this experiment was explicit.

An alternative possibility is that performance on the recognition test is not process pure, meaning that in addition to explicit knowledge of the sequence participants were guided by some kind of unconscious motor program towards making their recognition judgements. On that view, both implicit and explicit processes are capable of contributing to overall recognition performance, and the contribution of motor fluency to overall performance is thought to be such an implicit process. Therefore, it could simply be argued that recognition performance was above chance in the drug-induced amnesic groups because their performance was based on implicit processes rather than genuine explicit knowledge.

However, if implicit processes did contaminate overall recognition performance, it follows that the drug-induced amnesics should have revealed more of an implicit effect during their recognition performance than the placebo group. However, in
contrast, during the recognition test, an effect of motor fluency was not observed in the high dose group’s performance. It is not clear what aspect of performance during the recognition test stage (other than motor fluency) could have been based on an implicit process (see Chapters 4 and 5 for a discussion of this issue).
4 Intentional Control and Implicit Sequence Learning

In Chapters 2 and 3, sequential awareness was assessed by performance on a recognition test. Clearly, participants performed above chance on this test when several different manipulations were employed designed specifically to elicit implicit learning. In Chapter 4 a different test of awareness will be examined, the free generation task. In this test participants are told to generate 100 key presses and to include in their responses as much information as they can remember from the trained sequence. As discussed briefly in Chapter 1, if performance were at chance then this would be excellent evidence that participants have learned implicitly and lack conscious sequence knowledge. However, it has been repeatedly demonstrated that participants perform above chance on free generation tasks suggesting that sequence learning is, at least to some degree, explicit (Perruchet & Amorim, 1992; Shanks & Johnstone, 1998, 1999).

Several proponents of implicit learning have pointed out the importance of determining whether putative tests of awareness are 'process-pure.' Is it possible that performance on a supposedly explicit test might be contaminated by implicit knowledge? For example, a participant engaged in a free generation task may be reliant upon an unconscious motor program to perform the task and hence could perform above chance on the basis of implicit knowledge rather than by using conscious knowledge alone. This possibility is a problem for proponents of the single-system view of learning because it implies that free generation and other tests of awareness may not be 'exclusive.' One way to ascertain the purity of free generation performance is to ask whether or not the expression of knowledge underlying it is under intentional control. This idea originates in the implicit memory literature where researchers have developed the logic of opposition to determine whether certain components of retrieval are contaminated by automatic knowledge.

1 The 3 experiments in this chapter are reported in Wilkinson and Shanks (in press).
On this view, it is claimed that if knowledge is conscious then it should be capable of coming under intentional control, so a participant should be able to suppress this knowledge if they are instructed to do so. On the other hand if knowledge still influences the person’s behaviour despite their intention to prevent it from doing so, then this knowledge must be unconscious (Jacoby et al., 1989). Jacoby (1991) developed the process dissociation procedure to measure the respective contributions of unconscious and conscious memory to performance on stem completion tasks (Jacoby et al., 1993). In a prototypical experiment using this method, participants study a list of words and at test are required to complete word stems by including any words they can remember from the list (inclusion condition) or by excluding any words they can recollect from the studied list (exclusion condition). If they are unable to exclude words from the studied list in the exclusion condition then this is assumed to reflect an automatic or unconscious influence.

In Chapter 2 both the training phase and recognition test phase of an experiment conducted by Destrebecqz and Cleeremans (2001) were discussed in detail. The focus of the present chapter is on the free generation task phase that was employed immediately after the training phase to assess awareness. Recall that participants were trained on 15 blocks of a sequence under either RSI (RSI = 250 msec) or no RSI (RSI = 0 msec) conditions. Significantly, during the test phase Destrebecqz and Cleeremans applied Jacoby’s process dissociation procedure to the SRT. They aimed to demonstrate that, under certain circumstances, participants could not avoid freely generating the training sequence despite instructions to do so.

As already discussed with reference to recognition performance, the intuition behind the RSI manipulation was that with a non-zero RSI participants have time to consciously anticipate the next target location. With a 0 msec RSI, however, no such conscious anticipation is possible. Destrebecqz and Cleeremans speculated that this would especially foster implicit learning.

Participants in the RSI and no RSI groups performed free generation tasks under both ‘inclusion’ and ‘exclusion’ conditions. They were told to generate a total of 96 key presses (note, therefore, that this is a forced choice test). This was done first under inclusion instructions, which required them to generate as much of the sequence as
possible. Then, participants generated under exclusion instructions where they had to produce a sequence of key presses that did not overlap with the training sequence. In both RSI and no RSI groups, participants in the inclusion condition were capable of above-chance generation of the sequence on which they were trained. This finding is merely a replication of previous results (Perruchet & Amorim, 1992; Shanks & Johnstone, 1998, 1999). The two fundamental findings were the following: (1) although participants in the RSI group were capable of excluding the training sequence, participants in the no RSI group were not. In other words, these latter participants could not stop themselves generating the sequence, despite trying to. Specifically, they were as likely to generate the training sequence under exclusion as under inclusion instructions. (2) Under exclusion instructions, these participants tended to generate the training sequence more than would be expected in comparison to an appropriate baseline level. Therefore chunks of the training sequence intruded into the sequences generated by participants despite their intention to prevent this from happening. Some other attempts to apply this framework to sequence learning have also been reported (Buchner, Steffens, Erdfelder, & Rothkegel, 1997; Buchner, Steffens, & Rothkegel, 1998; Destrebecqz & Cleeremans, 2003; Goschke, 1997; 1998). For instance, studies by Buchner et al. (1997, 1998) used the process dissociation procedure to try to isolate the separate influences of fluency and recollection in sequence learning.

Destrebecqz and Cleeremans’ (2001) findings have important implications for the implicit/explicit debate. The results from participants in the no RSI group suggest that they had no control over the expression of their sequence knowledge. Destrebecqz and Cleeremans argued that this demonstrates not only the existence of implicit knowledge (characterized as knowledge outside intentional control) but also that forced choice free generation performance is at least in part dependent on implicit knowledge and, hence, that generation is not an ‘exclusive’ or ‘pure’ test of awareness. If performance on a free generation task can be influenced by unconscious knowledge then this calls into question the strength of evidence supporting the single-system theory, which interprets above-chance performance on objective tests like free generation as evidence that learning was explicit. Indeed it is plausible that unconscious processes could also influence performance on other so-
called tests of explicit knowledge, such as recognition.

There are some reasons to be cautious about these results, however. First, the idea that implicit learning creates a knowledge base that cannot come under intentional control constitutes a theoretical claim that has received very little support even in the domain of such prototypically automatic skills as word reading. Although the common characterization of word reading as exemplified in Stroop interference is that it occurs automatically, ballistically, and independently of the reader's intentions, recent research has instead suggested that word reading can in fact be controlled (Besner, Stolz, & Boutilier, 1997; McCann, Remington, & Van Selst, 2000; Tzelgov, Henik, & Berger, 1992). A clear illustration of this comes from the finding (Tzelgov et al., 1992) that the magnitude of Stroop interference diminishes as the proportion of colour words in the experiment is increased. This effect has been taken to suggest that participants' expectation that the word will name a colour causes them intentionally to suppress the influence of the word. Such an effect would not be possible if word reading were outside intentional control.

Secondly, with regard to the specific procedures used by Destrebecqz and Cleeremans, certain other potential problems should be noted. In Chapter 2, another important result which Destrebecqz and Cleeremans obtained, was not replicated. After their participants had performed the inclusion and exclusion tests they were given a recognition test, and in the critical no RSI group, recognition was at chance, consistent with the idea that sequence learning was implicit. Several attempts to replicate this finding failed. Recognition in Experiments 1-3 was always above chance. This failure of replication places a question mark over the generation results.

Moreover, participants in Destrebecqz and Cleeremans' experiment underwent both the inclusion and the exclusion tests, and always in that order, and this design potentially confounds task (inclusion/exclusion) with several other possible factors such as changes in alertness or motivation. In Experiment 5 a between-participants design was therefore adopted with participants assigned to either an inclusion or an exclusion group.
4.1 Experiment 5

Experiment 5 is an attempt to replicate Destrebecqz and Cleeremans’ (2001) findings that free generation performance is above chance under exclusion conditions in a group trained on a deterministic sequence with a 0 msec RSI and that there is no inclusion/exclusion difference in such a group.

As discussed in Chapter 2, deterministic sequences may encourage explicit rather than implicit learning. Therefore, in a second group, a probabilistic rather than deterministic sequence was used. The aim of the manipulation is to investigate the free generation performance of participants trained on a probabilistic sequence under inclusion and exclusion conditions with a 0 msec RSI. In both groups a between-participants design was employed and participants performed the free generation task under either inclusion or exclusion instructions.

Regardless of whether participants are trained on a deterministic or probabilistic sequence, the critical predictions are that \( I = E > B \) if knowledge is wholly implicit (i.e., outside intentional control) and \( I > B > E \) if knowledge is wholly explicit, where \( I \) and \( E \) refer to measures of the extent to which sequences generated under inclusion and exclusion conditions overlap with the training sequence, and \( B \) refers to an appropriate baseline level of generation. Put differently, positive evidence of implicit knowledge would come from either the null effect \( I = E \) or from the finding that \( E > B \).

4.1.1 Method

4.1.1.1 Participants

Eighty-five University College London (UCL) undergraduate students (18 male, 67 female) were recruited to take part in the study. Participants were all unfamiliar with the experimental task. They were assigned randomly to four groups (deterministic/inclusion, \( n = 21 \); deterministic/exclusion, \( n = 23 \); probabilistic/inclusion, \( n = 18 \); probabilistic/exclusion, \( n = 23 \)). Participants were told that the 6 people performing most accurately in the test would be rewarded with
a £15 book token.

Data from 1 participant, who was trained on SOC4 in the probabilistic/exclusion group, were excluded because she did not follow the instructions for the generation test and adopted the response strategy '2-3-2-3.' for the entire 100 trials of the test phase. This strategy ensures that by chance alone a very large number of own triplets (see below) would be generated as SOC4 contains the triplet 3-2-3.

4.1.1.2 Apparatus

This was the same as the apparatus used in Experiments 1-4.

4.1.1.3 Materials

**Deterministic Sequences.** Two second order conditional sequences (SOC3 = 2-4-1-3-4-2-3-1-2-1-4-3, SOC4 = 1-2-4-3-1-4-2-1-3-2-3-4) were used in the target location task. The same sequences were used in Experiment 2.

**Probabilistic Sequences.** The second order conditional sequences were transformed into probabilistic sequences using the same technique employed in Experiments 3 and 4.

4.1.1.4 Procedure

**Training phase.** The experiment comprised 12 training blocks during which participants were exposed to a four-choice SRT task. Each block consisted of 100 trials for a total of 1200 trials. The procedure was identical to Experiment 1 (no RSI group). For counterbalancing, about half the participants in each condition were trained on the SOC3 sequence and half on the SOC4 sequence (deterministic/inclusion: SOC3 n = 11, SOC4 n = 10; deterministic/exclusion: SOC3 n = 15; SOC4 n = 8; probabilistic/inclusion: SOC3 n = 9, SOC4 n = 9; probabilistic/exclusion: SOC3 n = 11, SOC4 n = 11).

**Test Phase.** The test phase involved a free generation task for the training sequence. After the training blocks, participants were informed that the targets had followed a repeating sequence and that they would have to do a slightly different task now. Four
4. Sequence Knowledge and Intentional Control

Blank boxes appeared on the screen and participants were required to generate a sequence by pressing corresponding keys on the keyboard (the same box-to-key mapping was used as in training). Targets appeared when participants made their key press and remained on the screen until they made their next response. All participants were required to produce 100 targets. Participants in the inclusion groups were required to include in their responses as much sequence knowledge as they could recall. Conversely, in the exclusion groups, participants were required to generate 100 key presses but to exclude from their response any segments of the sequence they could remember (see Appendix for the exact instructions).

4.1.2 Results

4.1.2.1 Training phase

Reaction times for participants trained on SOC3 and SOC4 were combined in the following analyses and the training data are also collapsed across the inclusion and exclusion groups, which were treated identically in this stage. Figure 4.1 shows the mean reaction times obtained over the training phase plotted separately for the deterministic groups and for probable and improbable trials within the probabilistic groups. RTs shortened over training and were numerically lower for deterministic than probabilistic (i.e., probable and improbable) trials.

**Deterministic groups.** An analysis of variance (ANOVA) on RTs in the deterministic groups with blocks [12 levels] as a within-subjects variable revealed a significant effect of block, $F(6.2, 266.4) = 13.12, MSE = 1592.2$, which reflects the significant RT variation as a function of block. Inspection of figure 4.1 indicates that RTs decreased during the training phase.

**Probabilistic groups.** Probable targets elicited faster RTs than improbable ones, indicative of sequence learning. Consistent with results reported in Experiments 1-4, a probable/improbable difference emerged by block 3. The difference widened across blocks, mainly as a result of an increase in RT on improbable trials. As in previous experiments this is not an artefact of a higher likelihood of errors on improbable trials (see below), as trials on which errors were made were not included in the RT.
calculations. To analyse these data, an ANOVA was performed with probability [probable vs. improbable, 2 levels] and block [12 levels] as within-subjects variables. This analysis revealed a significant main effect of probability, $F(1,39) = 39.67$, $MSE = 2283.7$. The main effect of block also reached significance, $F(5.1, 197.9) = 4.62$, $MSE = 4050.2$, and the probability x block interaction was significant, $F(7.8,303) = 2.71$, $MSE = 1014.8$, indicating a greater probability effect later in practice than earlier on. The shapes of the learning curves in Figure 4.1 are consistent with those observed in Experiments 1-3.

**Errors.** Error proportions varied between .03 and .10 across blocks. Participants made more errors for improbable targets ($M = .08$) than for probable targets ($M = .05$) and this presumably reflects the fact that they were able to develop expectations about the location of probable targets which caused anticipations and hence errors when the target appeared in an unanticipated location.

![Figure 4.1](image-url)  
*Figure 4.1. Mean RT in milliseconds across training blocks in Experiment 5. Data from both groups of participants (inclusion or exclusion), trained on either the deterministic or probabilistic sequence, were combined. The probabilistic data were broken down into probable targets, which were consistent with the generating sequence and improbable ones, which were not. Error bars represent standard errors.*
4.1.2.2 Test phase

Participants created sequences of 100 key presses based on what they had learned about their training sequence. The data were coded from each participant as 98 consecutive response triplets and the number of triplets was computed that were consistent or inconsistent with the training sequence. Therefore, if a participant trained on SOC3 (2-4-1-3-4-2-3-1-2-1-4-3) generated the sequence 3-4-2-1 at some point during the free generation task, then this would be coded as the triplets 3-4-2 and 4-2-1, the first of which is 'own' (i.e., is part of SOC3), and the second of which is 'other' (i.e., is part of SOC4: 1-2-4-3-1-4-2-1-3-2-3-4). Triplets that were from neither SOC3 nor SOC4 were disregarded. This method of analysing the data is the same as that employed by Destrebecqz and Cleeremans (2001).

The first analysis compared the number of own triplets generated under inclusion and exclusion instructions in the deterministic and probabilistic groups. These data are shown in Figure 4.2. The total number of own triplets was combined for participants trained on SOC3 and SOC4. For participants trained on both deterministic and probabilistic sequences the number of own triplets was greater in the inclusion than in the exclusion test (that is, I > E). This observation was confirmed by a two-way ANOVA on the number of own triplets with instructions [inclusion vs. exclusion: 2 levels] as a between-subjects variable and sequence [deterministic vs. probabilistic: 2 levels] as a between-subjects variable. Most important, this revealed a significant instructions effect, $F(1,80) = 23.63$, $MSE = 117.3$, indicating that overall the number of own triplets was significantly greater in the inclusion groups than in the exclusion groups. The main effect of sequence did not reach significance, $F(1,80) = .04$, $MSE = 117.3$. The instructions x sequence interaction also did not reach significance, $F(1,80) = 3.44$, $MSE = 117.3$, $p = .07$, although the pattern of results indicates that the effect of instructions was numerically greater in the deterministic than in the probabilistic group.

Independent-samples t-tests showed that the number of own triplets generated was significantly greater in the deterministic/inclusion than in the deterministic/exclusion group, $t(42) = 4.38$, and was significantly greater in the probabilistic/inclusion than in the probabilistic/exclusion group, $t(38) = 2.42$, $p = .015$ (one-tailed).
Bonferroni correction was applied to this analysis, hence $\alpha = .025$ was employed.

The above analysis is simply concerned with the relative difference between the number of own triplets generated by inclusion and exclusion participants. Although it can be concluded that more own triplets were generated in the inclusion than the exclusion condition for both types of sequence, suggesting that participants had some level of control over the expression of their knowledge, it is also important to determine whether the number of own triplets in the exclusion condition was above or below an appropriate baseline (chance) level of performance. For the second analysis, a comparison was made between the number of own (correct) triplets generated and the number of other (incorrect) triplets generated. The number of other triplets should reflect an acceptable baseline level of triplet generation because the alternative sequence is structurally identical to the training sequence; the difference between these sequences is simply that one was trained and the other untrained.

Figure 4.2 shows the number of own versus other triplets generated in each group. For the inclusion tests and for both deterministic and probabilistic groups, it is clear that the number of own triplets was greater than the number of other triplets generated (that is, $I > B$). However, in the exclusion test, the number of own and other triplets was about the same for both groups ($E = B$). To analyse these data, an ANOVA was performed with instructions and sequence as between-subjects variables and type of triplets generated [own vs. other: 2 levels] as a within-subjects variable. This analysis revealed a significant main effect of instructions, $F(1,80) = 9.29$, $MSE = 68.843$, indicating that overall more triplets were generated in the inclusion than in the exclusion groups. The main effect of type also reached significance, $F(1,81) = 21.41$, $MSE = 70.6$, reflecting the fact that overall more triplets were generated from the own than from the other sequence. The type x instructions interaction was significant, $F(1,80) = 15.98$, $MSE = 151.4$, revealing that the own/other contrast was greater under inclusion than exclusion instructions. The type x instructions x sequence interaction also reached significance, $F(1,80) = 4.09$, $MSE = 151.4$, indicating that the type x instructions interaction described above was moderated by whether the sequence was deterministic or probabilistic: looking at Figure 4.2 it is clear that the type x instructions interaction is more pronounced in the
deterministic condition.

Paired-samples t-tests were conducted to compare the number of own and other triplets generated in each group. These contrasts reached significance in the deterministic/inclusion, $t(20) = 4.63$, and in the probabilistic/inclusion groups, $t(17) = 3.12$. Under these inclusion instructions participants were quite capable of demonstrating above-baseline sequence knowledge. However, the comparison between own and other failed to reach significance in either the deterministic/exclusion, $t(22) = -0.51$, or probabilistic/exclusion groups, $t(21) = 1.38$, indicating that there is no difference in exclusion between the number of own triplets generated and an appropriate baseline level. This result is consistent with the notion that participants were able to withhold their responses during the exclusion task. A Bonferroni correction was applied to this analysis, hence $\alpha = .013$ was employed.

The finding that $E = B$ contrasts with data reported by Destrebecqz and Cleeremans (2001, 2003) where they showed that $E > B$ under no RSI conditions in 2 experiments. To shed some light on this discrepancy, a power analysis was conducted to investigate whether the null result reported here, $E = B$, can simply be explained by inadequate statistical power to detect a true difference. First, a weighted mean measure of the population effect size was obtained by conducting a meta-analysis on their 2 reported $E > B$ effect sizes. These were $r = 0.484$ in Destrebecqz and Cleeremans (2001) and $r = 0.455$ in Destrebecqz and Cleeremans (2003). Therefore the weighted mean effect size was $r = 0.464$ and this will be used in all subsequent analyses of power in Experiments 5-8 (see Field, in press, for an explanation of the $r$ measure of effect size). Note that the weighted mean effect size was calculated using Field’s (2001) SPSS syntax for meta-analysis.

The power analysis revealed that for the own/other comparison under exclusion instructions in the present experiment, power was .78 ($n = 23$) and .76 ($n = 22$) for the deterministic and probabilistic groups, respectively. Cohen (1988) has recommended a criterion of .80 as an acceptable level of power, and these values fall only slightly short of this criterion. As such, the conclusion that $E = B$ is not simply a failure to detect an effect that exists in the population.
It might be objected that the failure to observe own > other difference in the probabilistic/exclusion group is attributable to the other baseline level being artificially inflated with probabilistic sequences as a result of the fact that participants received exposure to the other sequence on improbable trials in the training stage. Hence the own/other difference would be greater if a more appropriate baseline were adopted. It is not at all clear what such an alternative baseline would be that would control for sequence structure, but in any case Figure 4.2 shows that the other score is no higher in the probabilistic/exclusion group than in the deterministic/exclusion group who received no exposure to the other triplets in the training stage. If anything, the score is lower in the probabilistic/exclusion group.

Figure 4.2. Mean number of SOC triplets generated by participants trained on either the deterministic or probabilistic sequences and tested under inclusion or exclusion conditions in Experiment 5. Own refers to the number of SOC triplets generated from the training sequence, other to the number of triplets from the alternate, untrained, sequence. Error bars depict standard errors.

Breakdown of sequence components. Inspection of Figure 4.2 reveals that the group trained on the probabilistic sequence generated numerically more of their own than of the other sequence despite instructions (exclusion) not to do so. Although the effect is not statistically significant overall, it is certainly feasible that some
component triplets of the SOC sequences were more likely to be generated than others in the exclusion condition. For example, perhaps the SOC3 reversal triplet 1-2-1 is particularly salient and hence participants can prevent themselves from generating it when instructed to do so. On the other hand, the SOC4 triplet 2-1-3 has little salience, and it is entirely possible that participants may find it more difficult to withhold the production of such a triplet. To determine whether participants found some triplets harder to withhold than others, the sequences were broken down into their triplets and these were classified into groups on the basis of various abstract characteristics such as the presence of a reversal (e.g., 1-2-1), the sequence of hands needed to execute the triplet (e.g., right-left-left), and continuous (e.g., 2-3-4) and non-continuous (e.g., 1-3-4) runs (see Table 4.1 for a complete breakdown of each sequence).

The mean numbers of own and other triplets generated were compared for each type of triplet. From Table 4.2 it is clear that in the deterministic/inclusion group, for each type of triplets own is numerically greater than other and this finding suggests that participants were able to generate most parts of the sequence well above the baseline level. For triplets classified as types Right-Left-Left, Left-Right-Left, Right-Left-Right, and for non-continuous runs, own was not significantly greater than other. In the deterministic/exclusion condition for all triplet types own was not significantly greater than other, and this demonstrates that participants were able to withhold all sequence information upon request.

From Table 4.3 it is clear that in the probabilistic/inclusion group, own was significantly greater than other for triplets classified as Right-Right-Left and Left-Right-Left, but this comparison did not reach significance for the majority of triplet types indicating that participants found it quite difficult to generate sequence

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2 The means reported in Tables 4.2 and 4.3 have been divided by the possible number of triplets of each type. For instance, Table 4.1 shows that SOC3 contains only one L-L-R triplet whereas SOC4 contains two. Hence when a generated sequence is matched against SOC4 it is twice as likely by chance to contain an L-L-R component compared to when it is matched against SOC3. For this reason, the total numbers of triplets of each type must be divided by the possible number of that type.
information in this condition. However own was numerically higher than other in most instances, accounting for the reliable own/other difference found in the main analysis. In the case of Left-Right-Right and continuous and non-continuous triplets, other was numerically greater than own, suggesting that this group found these particular triplets difficult to learn.

In the probabilistic/exclusion group and for most triplet types, own and other were not significantly different indicating that most sequence information was withheld in this group. More interestingly, in the case of continuous triplets, own was significantly greater than other implying that participants could not withhold this particular chunk during the exclusion task. Table 4.1 shows that the continuous triplet in SOC3 was 4-3-2 and in the case of SOC4 it was 2-3-4. It is possible, therefore, that participants learned these triplets implicitly and produced them unconsciously (i.e., contrary to intentions) in the exclusion test. However, ten comparisons were conducted on the data from each group and the reported p values were computed without correction for multiple tests. With a Bonferroni correction yielding an $\alpha$ value of $0.05/10=0.005$, the comparison between own and other does not reach significance for the probabilistic/exclusion continuous triplets; hence it may be a chance finding. In addition, note that the corresponding comparison between own and other in the deterministic/exclusion group for continuous triplets did not reach significance.
Table 4.1. Breakdown of SOC3 and SOC4 sequences into their abstract constituents.

<table>
<thead>
<tr>
<th>Group</th>
<th>SOC3</th>
<th>SOC4</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-R-L</td>
<td>3-4-2</td>
<td>3-4-1</td>
</tr>
<tr>
<td></td>
<td>4-3-2</td>
<td>4-3-1</td>
</tr>
<tr>
<td>L-L-R</td>
<td>2-1-4</td>
<td>1-2-4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-1-3</td>
</tr>
<tr>
<td>L-R-R</td>
<td>1-4-3</td>
<td>2-3-4</td>
</tr>
<tr>
<td></td>
<td>1-3-4</td>
<td>2-4-3</td>
</tr>
<tr>
<td>R-L-L</td>
<td>3-1-2</td>
<td>4-1-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-2-1</td>
</tr>
<tr>
<td>L-R-L</td>
<td>2-3-1</td>
<td>1-4-2</td>
</tr>
<tr>
<td></td>
<td>2-4-1</td>
<td>1-3-2</td>
</tr>
<tr>
<td>R-L-R</td>
<td>4-2-3</td>
<td>3-1-4</td>
</tr>
<tr>
<td></td>
<td>3-2-4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4-1-3</td>
<td></td>
</tr>
<tr>
<td>Reversal</td>
<td>1-2-1</td>
<td>3-2-3</td>
</tr>
<tr>
<td>Continuous</td>
<td>4-3-2</td>
<td>2-3-4</td>
</tr>
<tr>
<td>Non-Continuous</td>
<td>1-3-4</td>
<td>1-2-4</td>
</tr>
<tr>
<td>1 Hand</td>
<td>1-2-1</td>
<td></td>
</tr>
</tbody>
</table>

Note: The triplets were classified into groups according to the sequence of hands used to execute the triplet (L = Left, R = Right), the presence of a reversal, a continuous run, or a non-continuous run, and whether only one hand was used to execute the triplet. Note that a given triplet can be classified in more than one way.
Table 4.2. Mean (SE) number of own and other triplets of each type generated by participants trained on the deterministic sequence and under either inclusion or exclusion instructions in Experiment 5.

<table>
<thead>
<tr>
<th>Triplet Group</th>
<th>Deterministic</th>
<th>Inclusion</th>
<th></th>
<th></th>
<th></th>
<th>Exclusion</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Own</td>
<td>SE</td>
<td>Other</td>
<td>SE</td>
<td>t</td>
<td>Own</td>
<td>SE</td>
<td>Other</td>
</tr>
<tr>
<td>R-R-L</td>
<td>4.26</td>
<td>0.58</td>
<td>1.71</td>
<td>0.37</td>
<td>3.3 *</td>
<td>2.61</td>
<td>0.40</td>
<td>2.71</td>
</tr>
<tr>
<td>L-L-R</td>
<td>4.07</td>
<td>0.88</td>
<td>1.29</td>
<td>0.36</td>
<td>2.8 *</td>
<td>2.28</td>
<td>0.37</td>
<td>1.98</td>
</tr>
<tr>
<td>L-R-R</td>
<td>3.81</td>
<td>0.56</td>
<td>2.07</td>
<td>0.34</td>
<td>2.5 *</td>
<td>1.96</td>
<td>0.29</td>
<td>3.37</td>
</tr>
<tr>
<td>R-L-L</td>
<td>2.24</td>
<td>0.57</td>
<td>1.45</td>
<td>0.25</td>
<td>1.3</td>
<td>1.72</td>
<td>0.38</td>
<td>2.11</td>
</tr>
<tr>
<td>L-R-L</td>
<td>4.31</td>
<td>0.63</td>
<td>4.07</td>
<td>0.64</td>
<td>0.7</td>
<td>3.83</td>
<td>0.56</td>
<td>4.11</td>
</tr>
<tr>
<td>R-L-R</td>
<td>5.10</td>
<td>0.90</td>
<td>3.60</td>
<td>0.62</td>
<td>2.0</td>
<td>4.13</td>
<td>0.71</td>
<td>3.06</td>
</tr>
<tr>
<td>Reversal</td>
<td>4.19</td>
<td>1.08</td>
<td>1.29</td>
<td>0.57</td>
<td>2.3 *</td>
<td>1.30</td>
<td>0.39</td>
<td>2.30</td>
</tr>
<tr>
<td>Continuous</td>
<td>7.00</td>
<td>1.13</td>
<td>2.81</td>
<td>0.72</td>
<td>2.8 *</td>
<td>4.22</td>
<td>0.81</td>
<td>5.26</td>
</tr>
<tr>
<td>Non Cont.</td>
<td>2.14</td>
<td>0.54</td>
<td>1.00</td>
<td>0.30</td>
<td>2.0</td>
<td>1.35</td>
<td>0.35</td>
<td>1.61</td>
</tr>
<tr>
<td>1 Hand</td>
<td>2.73</td>
<td>1.10</td>
<td>0.00</td>
<td>0.00</td>
<td>2.4 *</td>
<td>1.00</td>
<td>0.35</td>
<td>0.75</td>
</tr>
</tbody>
</table>
4. Sequence Knowledge and Intentional Control

**Table 4.3.** Mean (SE) number of own and other triplets of each type generated by participants trained on the probabilistic sequence and under either inclusion or exclusion instructions in Experiment 5.

<table>
<thead>
<tr>
<th>Triplet Group</th>
<th>Inclusion</th>
<th>Probabilistic</th>
<th>Exclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Own</td>
<td>SE</td>
<td>Other</td>
</tr>
<tr>
<td>R-R-L</td>
<td>3.81</td>
<td>0.60</td>
<td>2.31</td>
</tr>
<tr>
<td>L-L-R</td>
<td>2.36</td>
<td>0.88</td>
<td>1.58</td>
</tr>
<tr>
<td>L-R-R</td>
<td>2.47</td>
<td>0.40</td>
<td>3.61</td>
</tr>
<tr>
<td>R-L-L</td>
<td>2.53</td>
<td>0.77</td>
<td>1.17</td>
</tr>
<tr>
<td>L-R-L</td>
<td>4.61</td>
<td>0.45</td>
<td>3.72</td>
</tr>
<tr>
<td>R-L-R</td>
<td>5.17</td>
<td>1.09</td>
<td>2.87</td>
</tr>
<tr>
<td>Reversal</td>
<td>4.28</td>
<td>1.01</td>
<td>2.06</td>
</tr>
<tr>
<td>Continuous</td>
<td>4.17</td>
<td>0.61</td>
<td>5.50</td>
</tr>
<tr>
<td>Non Cont.</td>
<td>1.00</td>
<td>0.42</td>
<td>1.72</td>
</tr>
<tr>
<td>1 Hand</td>
<td>3.22</td>
<td>1.61</td>
<td>0.44</td>
</tr>
</tbody>
</table>

*Note:* Paired samples *t*-tests (2-tailed) were conducted to compare *own* with *other* in each case, apart from the 1 handed triplet comparisons, for which independent samples tests (2-tailed) were conducted because the one handed triplet only occurred in one of the sequences. The reported *p* values were computed without a Bonferroni correction for multiple tests. An asterisk indicates *p* < .05.

**4.1.3 Discussion**

For the deterministic group RTs decreased during the training phase and following training there was a significant difference between the number of *own* triplets generated in the inclusion compared to the exclusion condition (*I* > *E*), indicating that participants not only learned the sequence of target locations, but were also capable of avoiding generating the sequence upon request. In addition, it was found that the number of triplets generated in exclusion did not exceed the baseline level (*E* = *B*). Hence, contrary to the findings of Destrebecqz and Cleeremans (2001) nothing
in the data from participants trained on deterministic sequences demands an explanation in terms of implicit knowledge.

For the probabilistic group RTs were faster for probable than improbable target locations and this confirms that participants learned the sequence. Again they generated significantly more of their own sequence triplets under inclusion than exclusion instructions (I > E). Furthermore, they showed no appreciable tendency to generate their own sequence more than the other sequence under exclusion instructions (E = B).

4.2 Experiment 6

The results of Experiment 5 failed to support Destrebecqz and Cleeremans’ (2001) claim that sequence knowledge under RSI=0 msec conditions can be inaccessible on a free generation task. However their experiment was not replicated exactly because a transfer block was not included during the training phase. It could be argued that the participants were somehow unable to develop implicit learning in the absence of a transfer block. Moreover, recall that participants in Destrebecqz and Cleeremans’ study were trained on 15 blocks including 1 transfer block and 14 sequence blocks (rather than 12 blocks as in Experiment 5) and hence it could be speculated that slightly more extensive training may lead to the development of implicit knowledge.

As a consequence of these differences between Experiment 5 and Destrebecqz and Cleeremans’ original study the aim of the present study was two-fold. Firstly, included within the experiment was an exact replication of their original experiment: one group of participants (inclusion/exclusion group) was trained for 15 blocks, including a transfer block, and with a deterministic sequence. Following training they were given two free generation tasks, one under inclusion conditions followed by another under exclusion conditions (within-participants design). Secondly, a between-groups manipulation was included under identical training and test conditions as Destrebecqz and Cleeremans. Therefore a further group of participants (exclusion group) was trained for 15 blocks (including a transfer block) and at test they were required to do free generation under exclusion conditions. The first
group's inclusion data and the second group's exclusion data will be used for a between-groups comparison.

4.2.1 Method

4.2.1.1 Participants

Thirty-four UCL undergraduate students (22 female, 12 male) were recruited to take part in the study. Participants were all unfamiliar with the experimental task. They were assigned randomly to two groups (inclusion/exclusion group, \( n = 18 \) and exclusion group, \( n = 16 \)) with an RSI of 0 msec. Participants were paid a turn-up fee of £5 and in addition they were rewarded according to their free generation performance: as in Experiment 5 they were told that the 6 people performing most accurately in the test would each receive a £15 book token.

Data from 4 participants, 2 in each group, were excluded because they did not follow the instructions that preceded the generation test and chose to adopt the single response strategy '1-2-3-4' for the entire 100 trials of a test phase. This strategy ensures that by chance alone a participant trained on SOC4, which includes the triplet 2-3-4, would generate a very large number of own triplets, whereas one trained on SOC3 would produce an own score of zero.\(^3\) Hence, the final sample included 16 participants in the inclusion/exclusion group and 14 in the exclusion group.

4.2.1.2 Procedure

Training phase. The procedure was identical to that of Experiment 5 (deterministic group) except in this study participants in both groups were trained on 15 blocks of 100 trials instead of 12. In addition, during the 13th block, participants were transferred to a different sequence with the training sequence being reintroduced on blocks 14 and 15. Participants trained on SOC3 were exposed to SOC4 on the transfer block and vice versa for participants trained on SOC4.

\(^3\) Note that no participants in Experiment 6 produced the run '2-3-2-3' throughout the test phase which was produced by a participant in Experiment 5. Likewise, no participants in Experiment 5 generated
For counterbalancing, about half the participants in each condition were trained on the SOC3 sequence and half were trained on the SOC4 sequence (inclusion/exclusion: SOC3 \( n = 8 \), SOC4 \( n = 8 \); exclusion: SOC3 \( n = 8 \), SOC4 \( n = 6 \)).

**Test phase.** The test phases involved free generation tasks of 100 target locations. Participants in the inclusion/exclusion group were required to freely generate 100 key presses under inclusion instructions, then to generate 100 further key presses under exclusion instructions. Participants in the exclusion group were required to freely generate 100 target locations under exclusion instructions only (see Appendix for exact instructions).

### 4.2.2 Results

#### 4.2.2.1 Training phase

Reaction times for participants trained with SOC3 and SOC4 are combined in the following analyses and the data are also combined across the 2 groups, which were treated identically during training. Figure 4.3 shows the mean reaction times obtained over the training phase. RTs reduced across blocks 1-12 and increased dramatically on block 13, and then returned to lower levels on blocks 14 and 15. An analysis of variance (ANOVA) on RTs with blocks [15 levels] as a within-subjects variable revealed a significant effect of block, \( F(6.1, 175.5) = 23.36, MSE = 2189.7 \). To look specifically at the transfer effect, a difference score was computed based on the RT on block 13 minus the average RT on blocks 12 and 14. The difference score had a mean of 97 msec (\( SE = 8.0 \)) which is reliably above zero, \( t(29) = 12.13 \).

**Errors.** Error proportions were generally low. They varied between .02 and .04 for blocks 1-15 excluding the transfer block where the mean error rate was .07.

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*the run '1-2-3-4' throughout the test.*
4.2.2.2 Test phase

Figure 4.4 shows the number of own and other SOC triplets generated in each group and condition. To summarise, the number of own triplets generated was greater in the inclusion condition than in the exclusion conditions (I > E). In both groups, the number of own triplets under exclusion instructions was no different from the number of other triplets (E = B).

Inclusion/Exclusion Group. An ANOVA was conducted with own/other [2 levels] and instructions [inclusion/exclusion: 2 levels] as within-participants variables. This revealed a significant instructions effect, $F(1, 15) = 11.23$, $MSE = 46.3$, indicating that overall the number of triplets generated was greater in the inclusion than in the exclusion test. The main effect of own/other did not reach significance, $F(1, 15) = 1.25$, $MSE = 331.0$, and the instructions x own/other interaction also failed to reach significance, $F(1, 15) = 2.47$, $MSE = 320.3$.

A paired-samples t-test revealed that the number of own triplets generated in the
inclusion test was significantly greater than the number generated in the exclusion test, \( t(15) = 3.12 \), replicating the effect of instructions (I > E) observed in Experiment 5. The number of own triplets generated in the inclusion group was almost significantly greater than the number of other triplets generated, \( t(15) = 1.85, p = 0.04 \) (one-tailed). Lastly, there was no reliable difference between the numbers of own and other triplets generated in the exclusion test, \( t(15) = 0.31 \). A Bonferroni correction was applied to these t-test analyses, hence \( \alpha = 0.017 \) was employed.

**Exclusion group.** A paired-samples t-test found that the numbers of own and other triplets generated did not differ, \( t(13) = 0.44 \).

**Between-participants comparison.** Next, the exclusion test data of the two groups was analysed. Figure 4.4 suggests that two groups performed very similarly in their exclusion tests and this was confirmed by an ANOVA with group and own/other as the factors. Neither effect nor their interaction was significant, \( F < 1 \) in each case. Note therefore that the possible confounding caused by the fact that Destrebecqz and Cleeremans gave all participants the inclusion and exclusion tests in the same order in their experiment does not seem to be a major source of concern. Test performance was similar in participants who undertook an exclusion test immediately after training and in ones who first performed an inclusion test. The failure to obtain any own/other difference under exclusion confirms the findings of Experiment 5 (i.e., E = B).

Because exclusion performance did not appear to differ across groups, data was combined from the two exclusion tests.\(^4\) A further analysis revealed that the number

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\(^4\) The combined exclusion data contains observations from the Inclusion/Exclusion group as well as data from the Exclusion group (people who did not do the Inclusion task). So when Inclusion and Exclusion performance were compared, data was used from both the same participants, and also from different participants. But all data were treated as if from different participants. Statistically speaking, this gives a conservative test of the difference between Inclusion and Exclusion (see Field, in press, for an explanation of why between subjects comparisons are less sensitive than repeated measures comparisons).
of *own* triplets generated by participants in the inclusion/exclusion group during their inclusion test ($M = 45.7$) was significantly greater than the number of *own* triplets generated by the combined groups in their exclusion tests ($M = 32.1$), $t(44) = 3.38$. Also, the number of *other* triplets generated in inclusion ($M = 33.6$) was not significantly different from the number generated in exclusion ($M = 33.9$), $t(44) = 0.18$. These results therefore replicate those obtained in Experiment 5. A Bonferroni correction was applied to these t-test analyses, hence $\alpha = .025$ was employed.

As in Experiment 5, a power analysis was conducted on the combined data from the 2 exclusion tests in the present experiment. This analysis revealed that for the *own/other* comparison, power was .87 ($n = 30$), which is greater than Cohen's (1988) recommended criterion of .80. Therefore there was a high probability of detecting an effect if it exists in the population, bolstering our conclusion that $E = B$.

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*Figure 4.4.* Mean number of SOC triplets generated by the inclusion/exclusion and exclusion groups in Experiment 6. *Own* refers to the number of SOC triplets generated from the training sequence, *other* to the number of triplets from the alternate, untrained, sequence. Error bars depict standard errors.
Breakdown of sequence components. Again it is important to determine whether participants found certain kinds of triplets harder to withhold than others. Data from the inclusion and exclusion tests were analysed separately with exclusion data combined from the two groups. Like Experiment 5, the sequences were broken down into triplets to be classified according to the features listed in Table 4.1, and t-tests were used to compare the mean number of own and other triplets generated for each group of triplets (see Table 4.4).

In the inclusion test own is numerically higher than other for nearly all types of triplets, but this comparison reached significance only in the case of reversal and 1-handed triplets. Clearly these were easier to learn than other triplets in these particular sequences. In the exclusion test, own was not significantly greater than other for any triplet type, suggesting that participants were able to withhold all sequence information upon request. This finding is a replication of the observations in the deterministic exclusion condition in Experiment 5.
Table 4.4. Mean number of own and other triplets of each type generated by participants tested under either inclusion or exclusion instructions in Experiment 6.

<table>
<thead>
<tr>
<th>Triplet Group</th>
<th>Inclusion</th>
<th></th>
<th></th>
<th></th>
<th>Exclusion</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Own</td>
<td>SE</td>
<td>Other</td>
<td>t</td>
<td>Own</td>
<td>SE</td>
<td>Other</td>
<td>t</td>
</tr>
<tr>
<td>R-R-L</td>
<td>3.31</td>
<td>0.49</td>
<td>2.66</td>
<td>0.56</td>
<td>0.7</td>
<td>2.45</td>
<td>0.29</td>
<td>3.10</td>
</tr>
<tr>
<td>L-L-R</td>
<td>2.56</td>
<td>0.79</td>
<td>1.06</td>
<td>0.34</td>
<td>1.7</td>
<td>1.83</td>
<td>0.50</td>
<td>2.43</td>
</tr>
<tr>
<td>L-R-R</td>
<td>3.50</td>
<td>0.47</td>
<td>2.38</td>
<td>0.56</td>
<td>1.3</td>
<td>2.82</td>
<td>0.40</td>
<td>2.72</td>
</tr>
<tr>
<td>R-L-L</td>
<td>2.06</td>
<td>0.65</td>
<td>1.56</td>
<td>0.40</td>
<td>0.6</td>
<td>2.23</td>
<td>0.38</td>
<td>1.63</td>
</tr>
<tr>
<td>L-R-L</td>
<td>4.72</td>
<td>0.66</td>
<td>4.06</td>
<td>0.73</td>
<td>1.0</td>
<td>3.75</td>
<td>0.54</td>
<td>3.57</td>
</tr>
<tr>
<td>R-L-R</td>
<td>4.04</td>
<td>0.78</td>
<td>4.54</td>
<td>0.90</td>
<td>-0.6</td>
<td>3.03</td>
<td>0.50</td>
<td>3.68</td>
</tr>
<tr>
<td>Reversal</td>
<td>7.44</td>
<td>1.47</td>
<td>1.00</td>
<td>0.43</td>
<td>4.0*</td>
<td>1.07</td>
<td>0.25</td>
<td>2.53</td>
</tr>
<tr>
<td>Continuous</td>
<td>5.63</td>
<td>0.82</td>
<td>3.50</td>
<td>1.04</td>
<td>1.5</td>
<td>4.33</td>
<td>0.72</td>
<td>4.40</td>
</tr>
<tr>
<td>Non Cont.</td>
<td>1.38</td>
<td>0.41</td>
<td>1.06</td>
<td>0.34</td>
<td>0.6</td>
<td>1.40</td>
<td>0.38</td>
<td>1.43</td>
</tr>
<tr>
<td>1 Hand</td>
<td>5.88</td>
<td>2.17</td>
<td>0.13</td>
<td>0.13</td>
<td>2.7*</td>
<td>1.50</td>
<td>0.35</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Note: The reported p values were computed without a Bonferroni correction for multiple tests. An asterisk indicates the own/other comparisons that reached significance, p < .05.

4.3 Experiment 7

One limitation with the methodology of Experiments 5 and 6 arises from the fact that the testing procedure collected 100 free generation responses in the inclusion and exclusion conditions. As previously mentioned, this creates the possibility for participants to adopt various perseverative response strategies. For example, a participant could generate the sequence 1-2-3-4 repeatedly throughout the test phase and because this run contains the triplet 2-3-4 (which appears in SOC4) that person would achieve a maximal own score of 98 if trained on SOC4 or a maximal other score if trained on SOC3. Numerous such strategies are possible. It is probably especially tempting for participants to perseverate following exclusion instructions, because it is obvious that the SOC sequences do not contain runs like 1-2-3-4.
Therefore, when required to exclude the trained sequence, a participant may be tempted to repeatedly generate 1-2-3-4 or some other such run as a feasible exclusion strategy. In contrast, the temptation to perseverate is presumably not as strong after inclusion instructions because the task is to reproduce the training sequence and it is evident that the SOC sequences do not contain runs.

A participant who adopts such a strategy may be making a genuine effort to include or exclude the sequence seen in training. However, another possibility is that the production of such simple runs represents a convenient way for an unmotivated participant to finish the experiment as quickly as possible. In Experiments 5 and 6 an attempt was made to avoid this problem by excluding participants who adopted perseverative response strategies for the entirety of the test phase (see footnotes 1 and 2). Nevertheless, it is possible that the remaining participants may also have generated sporadic chunks like 1-2-3-4 on a proportion of generation trials. It is probably impossible to ascertain when the appearance of such runs in the exclusion data reflects genuine effort.

Given this limitation of the procedure in Experiments 5 and 6 it is possible that the measures of own and other triplets that were computed might be contaminated by what is effectively noise in the data set attributable to perseverative response strategies. Furthermore, because this possibility seems more likely for the exclusion test than for the inclusion test, this would increase the chance that own and other scores would approach comparable levels under exclusion, as was observed in Experiments 5 and 6. Hence the reported failure to obtain an own/other difference under exclusion instructions may have arisen because a small effect was masked by this unwanted variance.

An improvement that can be made to the procedure to ameliorate this problem is the adoption of a trial-by-trial testing method in which participants observe a short sequence of targets from the training sequence and then produce a single generation response. This will allow a more specific examination of participants’ sequence knowledge and their capacity for intentional control, and avoid the potential contaminating effect of perseverative response strategies.
Finally, regardless of the reported failures thus far to replicate Destrebecqz and Cleeremans' findings, it is possible that knowledge might become implicit given a more extensive period of training than has previously been used, because this might allow participants the opportunity to develop more 'automatic' knowledge of the sequence. It could be argued that sequence knowledge is acquired explicitly, and gradually becomes more and more implicit depending on the amount of exposure to the sequence that participants receive (see Cleeremans & Jiménez (2002), for a discussion of this issue). Earlier inclusion/exclusion experiments have employed a relatively short training period (12-15 blocks of 100 trials), and hence the present study aims to examine performance after a longer period of training.

4.3.1 Method

4.3.1.1 Participants

Twenty-four Washington University undergraduate students (3 male, 21 female) were recruited to take part in the study. Participants were all unfamiliar with the experimental task, and they were assigned randomly to four equal sized groups. Participants were told that in addition to a turn-up fee of $10 dollars or a course credit depending on their preference, they would also be rewarded according to their free generation performance as detailed below.

4.3.1.2 Procedure

Training phase. The experiment comprised either 15 or 45 training blocks using the same procedure as for the probabilistic groups of Experiment 5. The training blocks were administered during a single session and the final block was followed by the test phase. Each block consisted of 100 trials for a total of either 1500 or 4500 trials, and the RSI was again set at 0 msec. For counterbalancing purposes half the participants in each condition were trained on the SOC3 sequence and half on the SOC4 sequence.

Test phase. The test phase involved two trial-by-trial sequence generation tests. Participants were informed that the targets had followed a repeating sequence in the training phase and that they would have to do a slightly different task in the test.
Participants were instructed that on each test trial they would first observe and respond to a 5-target sequence, and then they would be required to produce a single continuation response. In each test, they were presented with 12 5-target sequences in a randomised order, each consisting of a sequence of 5 targets taken from the training sequence (either SOC3 or SOC4). Hence there were 12 different 5-target test sequences for each training sequence comprising all the possible 5-target runs starting at each location in each training sequence. Note that although participants were trained on probabilistic sequences, the test sequences always comprised probable transitions.

In the inclusion test, participants were required to respond to test sequences as before and then to predict the final target of the sequence by generating the next item in the training sequence (see Appendix for exact instructions). They were cued to generate the next target of the test sequence by means of a green question mark that appeared in each box immediately after responding to the final target. Participants were told that in addition to their turn-up fee, they would receive an extra 25 cents for each correct test sequence, and in this case a correct inclusion response constituted generating the probable next item of the training sequence.

In the exclusion test, participants were required to complete the same 5-target sequences and they were told to respond to each target and then to generate a continuation response at the end of the sequence. In this case, they were told that the target they should generate must be different from the next item of the training sequence (see Appendix for exact instructions). Participants were cued to generate their response by means of a red question mark that appeared in each box immediately after completion of the final trial of the test sequence. Again participants were told that they would receive an extra 25 cents for each correct response, and in this case a correct response constituted any response that was not the probable next item of the training sequence. Half the participants performed the inclusion test prior to the exclusion test and the remainder did the reverse.
4.3.2 Results

4.3.2.1 Training phase

Reaction times for participants trained on SOC3 and SOC4 were combined in the following analyses. Figure 4.5 shows mean reaction times averaged across 5 blocks of trials for both the 15 and 45 block groups. In both groups, probable targets elicited faster RTs than improbable ones, indicative of sequence learning. For the 15 block group an ANOVA on RTs with probability and block as within-subjects variables revealed a significant main effect of probability, $F(1,11) = 20.57, \text{MSE} = 1354.4$, and a significant probability x block interaction, $F(14,154) = 1.93, \text{MSE} = 634.0$. The main effect of block was not significant, $F(14,154) = 1.33, \text{MSE} = 3065.1$. For the 45 block group a comparable ANOVA revealed a significant main effect of probability, $F(1,11) = 17.74, \text{MSE} = 20818.5$, and of block, $F(44,484) = 3.04, \text{MSE} = 4629.5$, and a significant probability x block interaction, $F(44,484) = 1.80, \text{MSE} = 1915.9$.

Errors. Error proportions were low overall. Participants in both the 15 and 45 block groups made more anticipatory errors for improbable targets than probable ones and the difference widened across blocks, as a result of an increase in errors for improbable trials. In the 15 block group the proportions varied between 0.01 and 0.03 for probable trials and between 0.01 and 0.07 for improbable trials. In the 45 block group they varied between 0.02 and 0.05 for probable trials, and between 0.03 and 0.15 for improbable trials.
Figure 4.5. Mean RT in milliseconds across 15 and 45 training blocks in Experiment 7, which employed probabilistic sequences. Data are averaged across sets of 5 blocks. Error bars depict standard errors.

4.3.2.2 Test phase

Participants completed 12 sequences each comprising 5 targets and were either asked to generate the next item in the sequence (inclusion) or a target that was different from the next item in the sequence (exclusion). The first analysis compared the number of test sequences that were completed by generation of the next correct location in the trained sequence (i.e., *own* responses) given under inclusion and exclusion instructions. These data are shown in Figure 4.6 collapsed across test order. The number of *own* completions was greater in the inclusion than in the exclusion test (that is, I > E). This observation was confirmed by an ANOVA on the number of *own* completions with instructions as a within-subjects variable and block [15 vs. 45] as a between-subjects variable. The main effect of instructions was significant, $F(1,22) = 19.42, MSE = 3.0$, indicating that overall the number of *own* completions was significantly greater under inclusion than exclusion instructions. The main effect of block, $F(1,22) = 0.12, MSE = 4.2$, and the interaction between
instructions x block, $F(1,22) = 1.56, MSE = 3.0$, were not significant, indicating that the number of blocks on which participants were trained had no effect on the number of own completions generated during the test phase. Paired-samples $t$-tests showed that the number of own completions was significantly greater under inclusion than exclusion instructions for the 15 block group, $t(11) = 4.62, p < .001$, and approached significance for the 45 block group, $t(11) = 2.0, p = .04$ (one-tailed). A Bonferroni correction was applied to these $t$-test analyses, hence $\alpha = .025$ was employed.

The second analysis looked at the number of sequence chunks completed with a triplet from the untrained or other sequence and these data are also shown in Figure 4.6. For the inclusion tests and for both 15 block and 45 block groups, it is clear that the number of own completions was greater than the number of other completions generated (that is, $I > B$). However, in the exclusion test, the number of own and other completions was about the same for both groups ($E = B$). Because the main effect of block and all interactions involving this factor failed to reach significance, data were combined for the 15 and 45 block groups and an ANOVA was conducted on type of completions [own vs. other] and instructions [inclusion vs. exclusion] as within-subjects variables. This analysis revealed a significant main effect of instructions, $F(1,23) = 11.69, MSE = 3.0$, and a significant interaction between instructions and type, $F(1,23) = 7.56, MSE = 3.2$. This reflects the fact that the own/other difference was greater under inclusion than exclusion instructions. The main effect of type failed to reach significance, $F(1,23) = 1.2, MSE = 5.0$.

Paired-samples $t$-tests showed that the number of own completions was significantly greater than the number of other completions under inclusion instructions for the combined groups, $t(23) = 2.49, p = 0.02$, and that the own/other comparison under exclusion instructions was not significant for the combined exclusion conditions, $t(23) = 0.88, p = 0.39$. A Bonferroni correction was applied to these $t$-test analyses, hence $\alpha = .025$ was employed.

As in Experiments 5 and 6, a power analysis was conducted on the combined exclusion data from the 2 exclusion conditions. This revealed that for the exclusion own/other comparison, power was .80 ($n = 24$). Hence the power to detect an effect if it exists in the population was acceptable (J. Cohen, 1988), lending further support.
to the conclusion that $E = B$.

**Figure 4.6.** Mean number of test chunks completed with either the final item of a triplet from the trained sequence (*own*) or the untrained sequence (*other*) in Experiment 7. Completions were calculated out of a possible 12 that could have been achieved by the inclusion and exclusion groups. Error bars depict standard errors.

### 4.3.3 Discussion

For both the 15 and 45 block groups RTs were faster for probable than improbable target locations confirming that participants learned the training sequence. When the novel trial-by-trial test procedure was employed both groups completed significantly more of their *own* sequence triplets under inclusion than exclusion instructions ($I > E$). Both groups were able to exclude their responses under exclusion instructions to the baseline level ($E > B$) as *own* was not significantly different from *other*.
4.4 Discussion

The present research offers little support for the claim that sequence learning can yield a knowledge base that is outside intentional control as suggested by the findings of a previous study conducted by Destrebecqz and Cleeremans (2001). They demonstrated that when participants were trained under an RSI of 0 msec, a dissociation was obtained between sequence learning and subsequent awareness. Participants in their study were able to learn the sequence as indexed by an RT speedup for sequence blocks compared to a pseudo-random block during the training phase. Furthermore, they were able to express their sequence knowledge in a free generation task. The crucial finding that they were subsequently unable to withhold their sequence knowledge when instructed to do so led Destrebecqz and Cleeremans to propose that participants did not have control over their sequence knowledge and to conclude that the knowledge these participants had acquired was, in this sense at least, 'implicit'.

In addition to the deterministic sequence used by Destrebecqz and Cleeremans, in Experiment 5 one group of participants was trained on a probabilistic sequence. Following training on 12 blocks of trials, participants who were trained on either a deterministic or a probabilistic sequence and then tested in the inclusion condition were able to express sequence knowledge upon request (that is, $I > B$). Moreover, another group of participants who were also trained on either of the sequences, and subsequently tested under exclusion instructions, were able to withhold the expression of sequence information ($E = B$). In this notation $I$ and $E$ refer to measures of the extent to which sequences generated under inclusion and exclusion conditions overlap with the training sequence, that is to say own scores; $B$ refers to a baseline level of generation, namely other scores.

Experiment 6 was a more exact replication of Destrebecqz and Cleeremans' study, and participants were trained on a deterministic sequence for 15 blocks of 100 trials with the 13th block as a transfer block. Following training, participants performed a
free generation task under either exclusion followed by inclusion conditions (as in Destrebecqz and Cleeremans' experiment) or they performed only the exclusion test. Again participants demonstrated reliable learning of the sequence as indexed by an RT speedup for the sequence blocks compared to the transfer block. Crucially, participants in the inclusion/exclusion group were able to both generate and withhold sequence knowledge at test, and this represents a direct failure to replicate the findings reported by Destrebecqz and Cleeremans. Furthermore, as was the case in Experiment 5, participants in the exclusion group were also able to withhold sequence knowledge when instructed to do so.

A finer-grained analysis of the free generation data was conducted to examine whether participants found knowledge of some parts of the 12-item SOC sequences easier to control than others. The sequences were broken down into their component parts according to various characteristics of SOC triplets. These analyses revealed very little evidence of sequence components being generated with greater probability in exclusion than baseline.

Why do the results of Experiments 5 -7 differ so much from those of Destrebecqz and Cleeremans (2001)? The finding that inclusion scores are higher than exclusion scores is a simple failure to replicate their null result. It is conceivable that Destrebecqz and Cleeremans did not have sufficient power in their experiment to detect the effect I > E that was repeatedly observed in Experiments 5-7. To test this possibility, a power analysis was conducted using Destrebecqz and Cleeremans' (2001) data. Firstly, effect sizes were calculated of the inclusion own vs. exclusion own comparisons in Experiments 5-7 where a total of 6 effects with I > E were reported. Then a meta-analysis of these data was conducted to obtain a weighted mean estimate of the population effect size (r = 0.51). Finally, the analysis revealed that Destrebecqz and Cleeremans' (2001) study had power of .60 (n= 12) in their no RSI group, which indicates that they only had a moderate likelihood of detecting the effect observed in Experiments 5 -7.

Moreover, it is worth noting that another study reported very recently by Destrebecqz and Cleeremans (2003), using a similar procedure to that adopted in the original study and in the present Experiment 6, did obtain a small medium effect of I > E (r
Destrebecqz and Cleeremans took this, however, as confirming their original position as the effect was not conventionally significant. It was, however, very close to being significant ($p < .06$, two-tailed) and hence adds to our confidence that there is a true $I > E$ effect under these conditions.

What about our failure to observe $E > B$? At present it is only possible to speculate but one suggestion is that performance on the free generation task is prone to contamination by the adoption of perseverative response strategies. Indeed, it seems likely that under exclusion instructions the temptation to adopt response strategies is stronger than it is under inclusion instructions, and it is plausible that this could add noise to the own and other scores and hence yield comparable inclusion and exclusion data. Perhaps Destrebecqz and Cleeremans’ participants were less prone to adopt such strategies.

In Experiment 7 a novel trial-by-trial method of measuring sequence knowledge under inclusion or exclusion instructions was introduced, that was devised to overcome the contamination problem. Furthermore, the possibility was examined that sequence knowledge may become implicit following a longer period of training, and therefore participants were trained on a probabilistic sequence for 15 or 45 blocks, and again under no RSI conditions. The findings were very similar to those in Experiments 5 and 6, i.e., participants were able to both express ($I > B$) and withhold ($I > E$) sequence knowledge upon request and exclusion performance was not significantly different from baseline ($E = B$).

In Experiments 5-7 power analyses were reported of the $E = B$ result in which high levels of power to detect a true difference were demonstrated (Experiment 5: 0.76 and 0.78; Experiment 6: 0.80; Experiment 7: 0.87). This means that the probability of incorrectly accepting the null hypothesis in all of these comparisons is extremely low ($p = 0.0014$); therefore the present findings cannot easily be dismissed by the argument that there was not enough power to detect a true $E > B$ effect.

The results have been described as indicating that participants can withhold sequence knowledge under exclusion conditions and this is certainly true by comparison with their inclusion performance. That is to say, $I > E$ in all of the relevant comparisons.
tested in these experiments. But in a more subtle sense the data suggest that intentional control under exclusion instructions is somewhat limited: in none of these comparisons was it found that own was reliably lower than other. If sequence knowledge is fully explicit then participants should have a lower own than other score as they should be able to restrain themselves from executing own triplets. As noted earlier, positive evidence of implicit knowledge would come from either the null effect I = E or from the finding that E > B and neither of these was observed. However, it could be argued that for any given participant, some knowledge was explicit and some implicit. For implicit knowledge, it is predicted that E > B whereas for explicit knowledge it is predicted that B > E. If these are combined they might cancel out to yield the observed effect E = B. Hence it is conceded that none of the present results categorically rule out the possibility that implicit knowledge was acquired in these experiments and contributed to performance.

One response to this, however, is to point out that the triplet-by-triplet analyses presented in Tables 4.2 and 4.4 provide little evidence (other than in the case of the continuous type in Experiment 5) that knowledge of some triplets was explicit (i.e., own < other) and that of other triplets was implicit (i.e., own > other) under exclusion conditions. Rather it appears that own and other were roughly similar for all categories of triplets. Perhaps instead it is the case that knowledge of each particular triplet or sequence component is partly explicit and partly implicit? This is a harder possibility to reject. It certainly would account for the overall finding that own and other scores did not differ under exclusion instructions. However it must be borne in mind that the present data provide no positive evidence of an implicit contribution and it is plainly more parsimonious, all other things being equal, to account for the data in terms of a unitary form of learning than in terms of multiple forms. It is possible that one reason for the asymmetry between performance in inclusion and exclusion conditions is that exclusion is inherently more difficult than inclusion: participants find it easier to recall a sequence component and generate it than they do to recall a sequence component, construct an alternative component, and generate that. Exclusion seems by its very nature to require more memory monitoring than inclusion.

The baseline level measured in Experiments 5 and 7 was the extent to which
participants generated the 'other' sequence during the test phase. Of course, participants in Experiments 5 and 7 actually saw the other sequence during training 15% of the time, and they were exposed to their own sequence 85% of the time. In other words, it was demonstrated in Experiments 5 and 7 that participants, who were exposed to one sequence 85% of the time, were then able to exclude it to the same extent that they could exclude a sequence to which they were exposed only 15% of the time. Similarly, in Experiment 6 participants actually saw the other sequence during the transfer block (which comprised 6.7% of the training phase), and they were able to withhold sequence knowledge of their own sequence to the same extent they could withhold knowledge about the other sequence.

The present findings are consistent with research on other supposedly "automatic" skills such as word reading, which suggests that some degree of control is invariably possible (Besner et al., 1997; McCann et al., 2000; Tzelgov et al., 1992). The findings are also consistent with a unitary model of sequence learning in which the implicit/explicit distinction is given up (Kinder & Shanks, 2001; 2003; Shanks & Perruchet, 2002). As has been argued in Chapters 1 and 2 and elsewhere (Shanks et al., 2003), this distinction does not appear necessary to understand performance in so-called 'implicit' learning tasks. The present results showed that participants were capable of learning at least some sequence information from exposure to a 12-element sequence when it was presented in either a deterministic or in a probabilistic context and, moreover, exerted intentional control of this knowledge. It is therefore suggested that the knowledge acquired during sequence learning is available for intentional control and is, in this sense, explicit.

The application of the process dissociation procedure to sequence learning rests upon the assumption that implicit knowledge is outside of intentional control and explicit knowledge is under intentional control. However, one might be able to exert control over automatic or implicit sequence knowledge. Alternatively, simply because knowledge is outside intentional control it doesn't necessarily follow that such knowledge is automatic or implicit. These possibilities are conceded here, but to follow through these points would involve conceding that the process dissociation technique is not adequate for identifying automatic/implicit processes. This is the conclusion suggested here.
5 Extended Practice and the Development of Implicit Sequence Knowledge.

Up to this point in the thesis, it is fair to say that convincing evidence of implicit learning has not been reported. Nevertheless, it could be argued by a proponent of implicit learning that the failure of attempts to elicit implicit learning can be given a methodological explanation (circumstances were insufficient to induce implicit learning) rather than a theoretical one (all learning is conscious).

In Chapter 4, Experiments 5-7, an attempt was made to separate the 'automatic' or implicit contributions to performance on so called explicit tasks (free generation and the trial-by-trial generation test). In addition to several manipulations designed to foster implicit learning (no RSI manipulation, probabilistic sequences), the number of training blocks was varied (12 N 45) to examine whether extensive periods of training would lead to the development of automatic sequence knowledge, characterised as being outside of intentional control. The present chapter will begin with a discussion of two variables already explored to some extent in Experiments 5-7: length of training phase and tests of awareness, to establish whether further manipulation could lead to better evidence of implicit learning. In Experiment 8 these ideas will be tested empirically.

5.1.1 Length of the training phase in Experiments 5-7, and the development of routine or automatic knowledge

In Experiments 5-7 the training phase consisted of 12-45 blocks of 100 trials administered during a single session, and following the most extensive training phase (45 blocks) participants were able to both produce and withhold sequence knowledge upon request. This finding does suggest that sequential knowledge acquired over an extensive period during a single session is accessible to awareness. However, if implicit learning is possible, it is feasible that knowledge might become implicit
given an even more extensive period of training than was used in Experiment 7, because this might only allow participants the opportunity to develop a more ‘automatic’ knowledge of the sequence.

In the field of attention, a distinction has been proposed between ‘non-routine’ and ‘routine’ knowledge. For example it is suggested that non-routine knowledge is stored in a general purpose centrally acting system (supervisory attentional system or S.A.S.). But when actions are performed on a routine basis, they develop into action patterns or schemas that are qualitatively different from non-routine knowledge and are transferred to and stored in a non-centrally acting system. Moreover, it is believed that these action schemata can be triggered by appropriate environmental cues. The S.A.S. is thought to modulate the action of the routine system so schemata can be actively inhibited or activated according to environmental demands (Norman & Shallice, 1986).

The S.A.S. model can be applied to the process of sequence learning. For example, if participants are exposed to long enough periods of training they may develop routine patterns of responding that are qualitatively different from the expression of sequence knowledge when it is initially acquired. For instance, if participants are trained over a period of days rather than during a single session it is plausible that sequence knowledge may become routine or automatic in the same sense that skills like typing or driving become automatic over a long period of time and practice.

It is feasible that one qualitative difference between non-routine and automatic knowledge is with respect to its accessibility to awareness, and therefore perhaps non-routine knowledge is explicit whereas automatic knowledge is implicit. In Experiment 8 this hypothesis will be tested by examining the development of sequence learning over a period of several days, and assessing awareness following such an extensive period of exposure to a sequence.

It should be mentioned that Cleeremans and Jiménez (2002) argue that the development of automaticity alone is not necessarily sufficient to produce implicit learning. In addition, they suggest that the memory trace must also be sufficiently weak for unconscious learning to take place. To address this matter, both
probabilistic sequences and an RSI of 0 msec will be employed in Experiment 8 to specifically foster an environment where implicit learning can emerge.

5.1.2 Tests of awareness employed in Experiments 5-7

Two tests of awareness were exploited in Experiments 5-7: the free generation task and the trial-by-trial generation test, and both tests were conducted under inclusion and exclusion instructions. When probabilistic sequences were employed and the free generation task was administered as a test of awareness (Experiment 5), a hint of an effect in favour of implicit learning was reported (recall that exclusion was numerically greater than baseline, although this was non-significant). However, certain methodological problems were identified with the free generation task introducing the possibility that the observed implicit learning effect was an artefact (see Chapter 4 for a discussion of these issues). To solve the problem, a trial-by-trial test was devised, and when this method was employed, no implicit learning effect was seen, even when extensive training was adopted.

Regardless of the potential methodological problems identified with the free generation task in Chapter 4, it could be argued that this test is more sensitive to implicit knowledge than the trial-by-trial test because it requires participants to initiate and generate a response pattern with no constraints other than the instructions to ‘include’ or ‘exclude’ information. Hence responses are self-paced, which perhaps allows participants to achieve a more ‘natural’ pattern of movement in their fingers that might bring forth the expression of implicit or routine knowledge, by triggering a response schema. By the same token, the more constrained nature of the trial-by-trial test may not enable participants to develop such a natural response rhythm. Therefore if implicit learning does exist it is feasible that it is not possible to detect its presence using the trial-by-trial test.

Given the existing methodological problems with using either the free generation or the trial-by-trial generation test to measure awareness, it is necessary to employ both tests in the present experiment. If longer periods of training lead to the development of implicit learning, it is hypothesised that it will be detected by at least one of these tests.
5.2 Experiment 8

To test the hypothesis that lengthy periods of training lead to the development of automatic implicit sequence knowledge, participants performed the sequence learning task for 75 blocks of 100 trials during 5 sessions over a period of 4-5 days. As in previous studies, a probabilistic sequence and an RSI of 0 msec were employed to foster implicit learning. To examine awareness of routine sequential knowledge, immediately following training, participants underwent either a free generation task or a trial-by-trial generation test under both inclusion and exclusion instructions.

5.2.1 Method

5.2.1.1 Participants

Thirty participants (15 male, 15 female) from the University of London were recruited to take part in the study. Participants were all unfamiliar with the experimental task. They were assigned randomly to 4 groups (inclusion-exclusion/free generation, \( n = 7 \); exclusion-inclusion/free generation, \( n = 7 \), inclusion-exclusion/trial-by-trial, \( n = 8 \), exclusion-inclusion/trial by trial, \( n = 8 \)). In addition to a turn up fee of £15, participants in the free generation groups were told that the 6 people performing most accurately in the test would be rewarded with a £15 book token, as in Experiments 5 and 6, and those in the trial-by-trial groups were told they would be rewarded according to their performance (as in Experiment 7). Note that participants in the trial-by-trial group were given 25p per correct response during the test phase, instead of 25 cents as in Experiment 7.

Data from 1 participant, who was trained on SOC3 in the inclusion-exclusion/trial-by-trial group, were excluded from the following test phase analysis because he indicated to the experimenter that he did not correctly follow the instructions for the trial-by-trial generation test. However, this participant’s data from the training phase were included in the training phase analysis because it was not affected by the test phase instructions.
5.2.1.2 Apparatus

The apparatus was the same as in Experiments 1-6.

5.2.1.3 Materials

**Probabilistic sequences.** Two second order conditional sequences (SOC3 = 2-4-1-3-4-2-3-1-2-1-4-3, SOC4 = 1-2-4-3-1-4-2-1-3-2-3-4) were used in the target location task. These were the same sequences that were employed in Experiments 2, 4, 5, 6 and 7 and they were transformed into probabilistic sequences as in Experiments 4, 5 and 7.

5.2.1.4 Procedure

**Training phase.** The experiment comprised 75 training blocks during which participants were exposed to a four-choice SRT task as in Experiments 1-7. The blocks were presented during 5 separate sessions of 15 blocks each and the sessions were completed over a period of 4-5 days with the final session of blocks being immediately followed by the test phase. Each block consisted of 100 trials for a total of 7500 trials and the RSI was 0 msec. For counterbalancing, about half the participants in each group were trained on the SOC3 sequence and half on the SOC4 sequence (inclusion-exclusion/free generation: SOC3 \( n = 3 \), SOC4 \( n = 4 \); exclusion-inclusion/free generation: SOC3 \( n = 4 \), SOC4 \( n = 3 \), inclusion-exclusion/trial-by-trial: SOC3 \( n = 4 \), SOC4 \( n = 4 \); exclusion-inclusion/trial-by-trial: SOC3 \( n = 4 \), SOC4 \( n = 4 \)).

**Test phase, free generation group.** The test phase involved free generation tasks of 100 target locations. Participants in the inclusion/exclusion group were required to freely generate 100 key presses under inclusion instructions, then to generate 100 further key presses under exclusion instructions. Participants in the exclusion group were required to freely generate 100 target locations under exclusion instructions, then to generate 100 further key presses under inclusion instructions (see Appendix for exact instructions).

**Trial-by-trial test group.** The test phase involved trial-by-trial generation tests, which were completed under inclusion and exclusion instructions. This was identical
to the test phase in Experiment 7 (see Appendix for exact instructions).

5.2.2 Results

5.2.2.1 Training phase

Reaction times for participants trained on SOC3 and SOC4, tested in the free generation and trial-by-trial groups, and tested in the orders inclusion-exclusion and exclusion-inclusion, were combined in the following analyses because these groups were all treated identically in this stage. Figure 5.1 shows the mean reaction times for each session of 5 blocks obtained over the training phase, plotted separately for probable and improbable trials. Probable targets elicited faster RTs than improbable ones, indicative of sequence learning. An ANOVA was performed with probability [probable vs. improbable, 2 levels] and set of blocks [15 levels] as within-subjects variables. This analysis revealed a significant main effect of probability, $F(1,29) = 197.79, MSE = 3052.6$. The main effect of block also reached significance, $F(14,406) = 44.6, MSE = 1852.4$ and the probability x block interaction was significant, $F(14, 406) = 30.09, MSE = 210.5$, indicating a greater probability effect later in practice than earlier on. Clearly, extensive training on a probabilistic SOC sequence led to very fast RTs on probable targets, while RTs for improbable targets remained relatively slow, consistent with the view that sequence knowledge becomes automatic over a period of days. Note that every 3 points on the learning curve represents a single session of 15 blocks, and within each session the difference between probable and improbable trials increases.
5. Does Extended Practice Lead to Implicit Learning?

![Figure 5.1. Mean RT (msec) across 75 training blocks in Experiment 8. Probable targets were consistent with the generating sequence whereas improbable ones were not. Error bars represent standard errors.](image)

**Errors.** Participants made more anticipatory errors for improbable targets than probable ones, and the difference widened across blocks as a result of an increase in errors for improbable trials. Error rates varied between 0.02 and 0.03 for probable trials and 0.08 and 0.15 for improbable trials.

**5.2.2.2 Test phase**

**Free generation group.** Participants generated 100 key presses under inclusion and exclusion instructions and the data were coded as in Experiments 5 and 6 to obtain own and other scores for each participant. To minimize the extent of contamination in free generation performance, all data were screened according to the same criteria as in Experiments 5-7. However, no participants were excluded from the analysis on the basis of perseverative response patterns. The number of own and other triplets generated under inclusion and exclusion instructions are shown in Figure 5.2; note the total number of own and other triplets was combined for participants in the inclusion-exclusion and exclusion-inclusion groups, and for participants trained on SOC3 and SOC4.
For inclusion and exclusion tests, the number of *own* triplets was numerically greater than the number of *other* triplets generated and this pattern of results is depicted in Figure 5.2. To analyse these data, an ANOVA was performed with type of triplets generated [own vs. other: 2 levels] and instructions [inclusion vs. exclusion: 2 levels] as within-subjects variables. This analysis revealed a significant main effect of *own/other*, $F(1,13) = 6.52$, $MSE = 110.6$, reflecting the fact that overall more triplets were generated from the *own* than from the *other* sequence. The main effect of instructions and the interaction between instructions and *own/other* failed to reach significance (all $Fs < 3$). The lack of interaction shows that the difference between *own/other* triplets under inclusion instructions was not significantly greater than the difference between *own/other* triplets under exclusion instructions.

Paired samples t-tests were conducted to compare *own* with *other* in the 2 conditions. Inclusion/own was significantly greater than inclusion/other, $t(13) = 3.49$, $SEM = 2.64$, demonstrating that participants were able to generate sequence knowledge upon request, or $I > B$. However, exclusion/own was not significantly different from exclusion/other, $t(13) = 1.43$, $SEM = 3.60$, $p = 0.085$ (1-tailed), indicating that participants were also able to withhold the expression of knowledge when required to do so, or $E = B$. A Bonferroni correction was applied to these t-test analyses, hence $\alpha = .025$ was employed.

On the other hand, the latter effect was marginally significant, and the numerical pattern shown in Figure 5.2 is actually $E > B$. Moreover, inspection of the data revealed that 10 out of 14 participants showed the $E > B$ effect numerically, which together with the lack of interaction in the previous analysis could be interpreted as evidence for the existence of implicit learning.
Inclusion Exclusion

Figure 5.2. Mean number of SOC triplets generated by participants trained on the probabilistic sequence and tested under free generation inclusion and exclusion conditions in Experiment 8. *Own* refers to the number of SOC triplets generated from the training sequence, *other* to the number of triplets from the alternate, untrained, sequence. Error bars depict standard errors.

**Breakdown of sequence components.** As mentioned previously, it is possible that participants found particular triplets in the sequence more difficult to withhold than others, and to determine whether this was true, the sequences were broken down into their triplets, and then classified into groups on the basis of various abstract characteristics (see Chapter 4: Experiments 5 and 6; and see Table 4.1 for a description of abstract characteristics that were employed to classify SOC3 and SOC4 triplets).

As in Experiments 5 and 6, where SOC3 and SOC4 were also employed, the mean number of *own* and *other* triplets generated for each ‘type’ of triplet was computed and these data are presented in Table 5.1. In the inclusion condition, *own* was significantly greater than *other* for triplets classified as Right-Right-Left and Reversals, but this comparison did not reach significance for the majority of triplet types indicating that participants found it quite difficult to generate all sequence information in this condition. However *own* was numerically higher than *other* in
most instances, accounting for the reliable *own*/other difference found in the main analysis. In the case of Left-Left-Right, Left-Right-Right and Non-Continuous triplets, other was numerically greater than own, suggesting that this group found these particular triplets difficult to learn and express.

In the exclusion group and for most triplet types, own and other were not significantly different indicating that most sequence information was withheld in this group. More interestingly, in the case of Right-Left-Right triplets own was significantly greater than other implying that participants could not withhold these particular chunks during the exclusion task. Table 4.1 reveals that the Right-Left-Right triplets in SOC3 were 4-2-3 and 3-2-4 and in the case of SOC4 it was 3-1-4. It is possible, therefore, that participants learned these particular triplets implicitly and produced them unconsciously (i.e., contrary to intention) in the exclusion test.\(^1\)

**Trial-by-trial group.** As in Experiment 7, participants completed 12 chunks of 5 target locations, and were either asked to generate the next item in the sequence (inclusion) or a different item in the sequence (exclusion). The analysis compared the number of own and other responses given under inclusion and exclusion instructions, so data were collapsed across test order, and treated as a single group. These data are shown in Figure 5.2. Note the test data were also combined for participants trained on SOC3 and SOC4. The number of own responses was greater in the inclusion than in the exclusion test (that is, I > E). Furthermore, the number of own responses was greater than the number of other responses in the inclusion condition but not in the exclusion condition. These observations were confirmed by an ANOVA on the

\(^1\) In the exclusion condition, the sums of the mean number of triplets of each type are: 27.2 (exclusion own) and 28.3 (exclusion other). Therefore, at first glance the overall numerical effect (E > B) shown in Figure 5.2 does not appear to be reflected in Table 5.1. However, as shown in Table 4.1 the mean numbers of Continuous triplets generated (4-3-2 in SOC4 and 3-2-1 in SOC5) were also included when calculating the mean numbers of R-R-L and L-R-R triplets, so the number of Continuous triplets was in truth counted several times in Table 5.1. In Table 5.1, the pattern of results shown in the Continuous triplet type row in the exclusion condition runs counter to the trend shown in Figure 5.2, providing an explanation of why the own/other column means in Table 5.1 also appear inconsistent with the trend in Figure 5.2.
number of responses with instructions [inclusion vs. exclusion: 2 levels] and type
[own vs. other: 2 levels] as within-subjects variables. This analysis revealed a
significant main effect of own/other, $F(1,14) = 4.65, MSE = 3.9, p = 0.049$, reflecting
the fact that overall more responses were generated from the own than from the other
sequence. The main effect of instructions was significant, $F(1,14) = 13.11, MSE = 3.1$, indicating that overall more responses were generated in the inclusion than in the
exclusion groups. Lastly, the instructions x own/other interaction was significant,
$F(1,14) = 6.08, MSE = 5.1$, indicating that there were significantly more own than
other responses generated in the inclusion condition but this was not the case in the
exclusion condition for which own and other were comparable. Paired samples t-
tests were conducted to compare own with other in the 2 conditions. Inclusion/own
was significantly greater than inclusion/other, $t(14) = 2.62, SEM = 1.0, p = 0.02$.
Exclusion/own was not significantly different from exclusion/other, $t(14) = 0.65,
SEM = 0.5, p = 0.53$. A Bonferroni correction was applied to these t-test analyses,
therefore $\alpha = .025$ was employed.

Table 5.1. Mean number of own and other triplets of each type generated by
participants tested under both inclusion and exclusion instructions in Experiment 8.
Note that the Inclusion-Exclusion and Exclusion-Inclusion groups were combined.

<table>
<thead>
<tr>
<th>Triplet Group</th>
<th>Inclusion</th>
<th></th>
<th>Exclusion</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Own</td>
<td>$SE$</td>
<td>Other</td>
<td>$SE$</td>
<td>$t$</td>
</tr>
<tr>
<td>R-R-L</td>
<td>3.79</td>
<td>0.79</td>
<td>1.29</td>
<td>0.26</td>
<td>*2.8</td>
</tr>
<tr>
<td>L-L-R</td>
<td>2.43</td>
<td>0.60</td>
<td>2.61</td>
<td>0.73</td>
<td>-0.2</td>
</tr>
<tr>
<td>L-R-L</td>
<td>2.14</td>
<td>0.58</td>
<td>1.71</td>
<td>0.43</td>
<td>0.7</td>
</tr>
<tr>
<td>R-L-L</td>
<td>4.61</td>
<td>0.49</td>
<td>3.50</td>
<td>0.55</td>
<td>2.1</td>
</tr>
<tr>
<td>R-L-R</td>
<td>4.83</td>
<td>0.83</td>
<td>3.60</td>
<td>0.84</td>
<td>1.1</td>
</tr>
<tr>
<td>Reversal</td>
<td>4.57</td>
<td>0.92</td>
<td>2.07</td>
<td>0.61</td>
<td>*2.4</td>
</tr>
<tr>
<td>Continuous</td>
<td>6.29</td>
<td>1.45</td>
<td>2.79</td>
<td>0.84</td>
<td>1.9</td>
</tr>
<tr>
<td>Non Cont.</td>
<td>0.43</td>
<td>0.17</td>
<td>1.43</td>
<td>0.57</td>
<td>-1.6</td>
</tr>
<tr>
<td>1 Hand</td>
<td>2.86</td>
<td>1.35</td>
<td>0.86</td>
<td>0.55</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Note: The reported $p$ values were computed without a Bonferroni correction for
multiple tests. An asterisk indicates the comparisons that reached significance. In all
cases a p value of .05 was used.

Because this failure to obtain $E > B$ is a null result, a power analysis was conducted as in Experiments 5-7 (see Experiment 5, section 4.1.2.2 for a description of the method used to obtain a weighted mean measure of the population effect size). This analysis revealed that the power to detect an effect if it is present in the population was .6. Cohen (1988) recommends .8 as an acceptable level of power, so there is a probability of .4 that a true effect was not detected.

![Figure 5.3](image)

*Figure 5.3.* Mean number of *own* and *other* completions out of a possible 12 achieved by the inclusion and exclusion trial-by-trial groups in Experiment 8. Error bars depict standard errors.

5.2.3 Discussion

During the lengthy training phase RTs were found be significantly faster for probable compared to improbable target locations confirming that participants learned the sequence. In one group, a free generation task was employed under inclusion and exclusion conditions to assess awareness. Firstly, under inclusion instructions the free generation group generated more of their *own* sequence triplets than *other*
sequence triplets (I > B) suggesting that they were capable of expressing sequence knowledge when required to do so. This observation confirmed that sequence knowledge was accessible during the test phase and is consistent with findings reported in Experiments 5 and 6.

Secondly, the free generation group were able to withhold sequence knowledge when required to do so, because statistically E = B. But the pattern of results suggests that numerically, they generated more of their own sequence than the other sequence under exclusion instructions (E > B) and although non-significant, this finding perhaps deserves replication in a future study. Moreover, it was demonstrated that triplets classified as Right-Left-Right were reliably more difficult to withhold upon request than others, and it is possible that the nature of the responses required to perform these triplets leads participants to learn them implicitly.

In a second group, a trial-by-trial generation test was employed under inclusion and exclusion conditions to assess awareness. Firstly, under inclusion instructions participants completed significantly more of their own sequence triplets than other sequence triplets (I > B) suggesting that they were capable of expressing sequence knowledge when required to do so. This finding confirmed that sequence knowledge was accessible during the test phase and is consistent with findings reported in Experiment 7. Secondly, the trial-by-trial group completed significantly more of their own sequence triplets under inclusion than under exclusion instructions, suggesting they had control over the expression of their sequence knowledge (I > E). Thirdly, they completed the same number of their own sequence triplets as other sequence triplets under exclusion instructions (E = B) suggesting that in this group, knowledge was explicit in nature.

The present findings are entirely consistent with Experiments 5 -7, because they indicate no strong evidence for the existence of implicit learning when both free generation and trial-by-trial tests were employed to measure awareness, even when training was conducted over a period of days. Nevertheless there are 2 opposing ways in which the findings can be interpreted, both of which will be outlined below.

According to an implicit learning interpretation, the circumstances employed in the
present study, including the lengthy amount of training, use of probabilistic sequences and 0 msec RSI manipulation encouraged participants to learn implicitly. This view is supported by the finding (albeit non-significant) that the free generation group were incapable of withholding generation of their sequence knowledge upon request. Therefore, the pattern of results supports the hypothesis that routine knowledge can be implicit in nature. Moreover, it is possible that the trial-by-trial procedure employed was not maximally sensitive to implicit knowledge because it did not allow participants to develop a natural rhythm of responding, providing a methodological explanation for why no significant evidence of implicit learning was observed in the trial-by-trial group, or in Experiment 7 (where 45 blocks were employed, followed by a trial-by-trial test of awareness). In addition, when a power analysis was conducted, experimental power was found to be .6 in the trial-by-trial study, which is below Cohen's (1988) suggested value of .8 for an acceptable level of power. Therefore, for the trial-by-trial group there was a .4 probability of not detecting a result if it was present in the population.

An alternative view is that the weak evidence in favour of implicit learning observed in the free generation group can be explained by methodological differences between the free generation and trial-by-trial procedures, rather than by recourse to any theoretical account in favour of separable implicit and explicit systems. For instance, it is plausible that the incentive offered to complete the test phase (the possibility to win a book token) was perhaps not sufficient to motivate the free generation group to perform as well as they might. It could be argued that this group may have been even less motivated than the groups tested in Experiments 5 and 6 because participants were required to attend 6 sessions over a period of days in Experiment 8. In contrast, the financial incentive offered to the trial-by-trial group (payment according to performance) may have been sufficient incentive to engage them in the task at hand (see Chapter 4 for a discussion of why low motivation may lead to a pattern of results that could be used in support of the existence of implicit learning).

Given that the trial-by-trial test does not enable participants to develop a natural pattern of responding, further work might involve a novel trial-by-trial procedure using more extensive chunks of the sequence (e.g. 12 item chunks) before participants complete the chunk under inclusion or exclusion instructions. Such a
procedure could again be employed following a lengthy period of training and under the same conditions exploited here (including payment according to performance).

To investigate the contribution of fluency to performance on the trial-by-trial generation test, the test phase could comprise strings from the own sequence mixed with test strings from the other sequence. This would enable the experimenter to examine concurrently a) whether own strings are performed more quickly than other strings (priming) and b) completion of old and new test items under inclusion/exclusion instructions. The effect of fluency might be greater when an implicit effect is observed compared to when an explicit effect is obtained.

Further, it would be interesting to examine the RSI manipulation in more detail when long periods of training are employed over a few days. It has been suggested that learning is implicit with an RSI is 0 msec but is explicit when it is set at 250 msec (Destrebecqz & Cleeremans, 2001). Perhaps when participants are trained for 75 blocks with an RSI of 250 msec they will learn sequences explicitly. It is feasible that automatic knowledge can be either implicit or explicit depending on the circumstances under which the knowledge is acquired (Cleeremans & Jiménez, 2002). For the same reason, future research could examine extensive learning of probabilistic, compared to deterministic sequences.
6 Theoretical Interpretations of Key Findings

How does the work in this thesis make a theoretical contribution to the current understanding of the relationship between learning and awareness? Clearly, the findings differ in many respects from previous published research and there may be simple procedural explanations for this. For instance, it is possible that subtle methodological differences between the present and previous research, like increasing participant motivation, statistical power, and other methodological changes, led to the observed differences between the results. Such procedural differences have already been explored in respective discussion sections of Chapters 1-5 so will not be repeated here. Instead, the present discussion will begin by summarising the key findings in this thesis, and then section 6.2 will turn to existing theories concerning the role of awareness in learning. Broadly speaking, all theories are consistent with one of the following 2 statements: a) Human learning can occur independently of consciousness. b) All human learning is conscious. The purpose of the present work is to examine the possibility that learning can occur unconsciously by using 3 different methods of estimating awareness that involve measuring 1) performance on objective tests like recognition and free generation tests, 2) the contribution of motor fluency to recognition performance and 3) the availability of sequence knowledge to intentional control. It will be argued that the key findings provide remarkably little evidence that learning can occur unconsciously. Nevertheless, in Experiments 5 and 8 the pattern of results could be interpreted as weak evidence of an implicit learning effect.

6.1 Key findings

The key findings can be summarised as follows:

1) Exposure to a repeating sequence of target stimuli in a speeded localization task can support both priming of sequence-consistent responses and recognition of sequence components. In 3 experiments (Experiments 1-3) with both deterministic
and probabilistic sequences and using a 0 msec response stimulus interval, a procedure was used in which measures of priming and recognition were taken concurrently, and it was asked whether these measures can be dissociated. In all of these experiments both measures were above chance at the group level and no evidence of dissociation was obtained. This represents a failure to replicate an effect obtained by Destrebecqz and Cleeremans (2001) who reported that recognition performance was at chance when participants performed a deterministic sequence learning task under no RSI conditions. The group-level results are compatible with a formal model introduced by Shanks et al. (2003) in which priming and recognition are both based on a single common memory variable.

2) Administration of different doses of diazepam prior to exposure to a repeating sequence has no effect on the encoding of sequence knowledge, or on the ability of that knowledge to support recognition ratings of sequence components (Experiment 4). However, different doses of the drug did cause differential interference to the observed contribution of motor fluency to recognition performance. Reber and Squire (1994, 1998) claimed that amnesic individuals reveal a dissociation between performance and awareness due to damage to the medial temporal lobe region of the brain, the putative locus of explicit learning. In Experiment 4 this claim was tested by inducing a temporary state of amnesia, then requiring participants to learn probabilistic sequences. In all groups (placebo, low, high), sequence learning remained intact during the training stage and recognition performance was above chance at the group level. This represents a failure to replicate the claim that amnesia leads to chance level recognition performance. The contribution of motor fluency to recognition performance was observed in the placebo group, but in the high dose group it was not observed at all. Further, only a partial effect of this sort was observed in the low dose group. This is consistent with the finding that amnesia leads to an impairment of the ability to use context as a cue to performance (Chun & Phelps, 1999).

3) The expression of sequence knowledge can be both produced and withheld upon request. Experiments 5-7 were devised to test Destrebecqz and Cleeremans' (2001, 2003) claim that under certain circumstances the expression of sequence knowledge cannot be brought under intentional control. In Experiment 5 participants were
trained on either a deterministic or a probabilistic sequence and then performed a free
generation test under either 'inclusion' or 'exclusion' instructions. Participants were
found to be capable of both expressing (inclusion) and avoiding expressing
(exclusion) sequence knowledge. These results were confirmed in Experiment 6 with
a more exact replication of Destrebecqz and Cleeremans' methodology. In
Experiment 7, after a longer period of training, participants performed a trial-by-trial
generation test under both inclusion and exclusion conditions. All the findings are
consistent with the proposal that information acquired during sequence learning is
under intentional control and therefore is explicit in nature. This represents a failure
to replicate Destrebecqz and Cleeremans' findings.

4) When participants were exposed to a repeating sequence of targets over 4-5 days
(Experiment 8), participants were capable of bringing the expression of their
acquired knowledge under intentional control, as indexed by free generation and
trial-by-trial generation performance under inclusion and exclusion instructions.

6.2 Theories concerning the role of awareness in learning

6.2.1 Human learning can occur independently of consciousness

One major problem for experimenters in search of evidence for unconscious learning
in humans is how to measure the contribution of 'consciousness' to performance, and
because there is little agreement over the definition of consciousness this has proven
to be an exceptionally difficult task. However, several different behavioural
measures have been used to estimate participants' awareness. To begin with,
experimenters have attempted to measure phenomenological experience. For
example, a subjective measure like the ability to verbalise knowledge upon which
performance is based, is one means by which participants' awareness can be
estimated. It has been demonstrated that participants cannot invariably verbalise
knowledge they had acquired about procedural tasks. However, as discussed in
Chapter 1, verbal report has been criticised on the basis that it may be an insensitive
test of awareness. Therefore, this particular index was not employed in this thesis
and will not be discussed further.
A more sensitive method of estimating phenomenological experience is to look at performance on objective tests of awareness like the recognition test and the generation task. It has been reported that participants performed at chance at recognition while demonstrating knowledge of a task, under a variety of different circumstances (P.J. Reber & Squire; 1994, 1998; Destrebecqz and Cleeremans, 2001). Objective tests have been repeatedly employed in the present thesis to examine whether such reports can be replicated. In the present thesis, performance on objective tests was always above chance at the group level. However, simply demonstrating that performance is above chance on objective tests of awareness is not conclusive evidence that learning occurred explicitly, because the possibility that learning was contaminated by implicit processes cannot be ruled out.

Another method of investigating the existence of unconscious learning is to examine performance under conditions of divided attention. It has been reported that implicit learning can proceed normally under conditions of divided attention whereas explicit learning is impaired by resource demanding tasks (Frensch et al., 1998). However, Shanks and Channon (2002) and Shanks, Rowland, and Ranger (2004) have presented strong evidence against this view, demonstrating that implicit learning is impaired under conditions of divided attention. Therefore, the idea that implicit learning emerges under conditions of divided attention has not been further explored in this thesis.

An alternative way of presenting the relationship between implicit and explicit learning is the view that performance on so called explicit tasks like recognition and generation tasks can be contaminated by implicit processes (Destrebecqz & Cleeremans, 2001, 2003; Jacoby 1991; Jacoby et al., 1993). This thesis is concerned with the question of whether or not objective tests of awareness can be contaminated by implicit processes. For example it is possible to examine the contribution of motor fluency to recognition performance, which could be conceived as an implicit component of that performance. Finally, it is also possible to examine 'controllability' meaning the extent to which participants are capable of controlling the expression of their knowledge. Destrebecqz and Cleeremans (2001, 2003) reported that the knowledge expressed in a generation task was outside of intentional control and this is strong evidence in favour of the existence of an implicit
contribution to generation task performance.

6.2.1.1 Do implicit and explicit learning depend on distinct brain regions?

In addition to the question of whether learning can occur independently of awareness, some researchers argue that implicit and explicit learning are associated with distinct areas of the brain e.g. (Ashby & Ell, 2002; Manns, Clark, & Squire, 2002; P. J. Reber & Squire, 1994, 1998; Willingham, Salidis, & Gabrieli, 2002). Conversely, others argue that conscious and non-conscious aspects of recognition performance are dependent on the same brain region. For example, Stark and Squire (2003) recently reported that patients with hippocampal damage were impaired at both recollection and familiarity-based recognition. Furthermore, Keele et al. (2003) have proposed a complex model of the relationship between distinct implicit/explicit learning systems and their underlying brain regions; they propose the existence of a left dorsal pathway capable of both explicit and implicit learning, in addition to a right ventral pathway that is capable only of implicit learning (see section 1.9.1). These claims are of course controversial but they lend weight to the theory that learning can occur independently of awareness.

6.2.2 All human leaning is conscious.

The idea that implicit learning can occur in humans can be contrasted with the view that all human learning is explicit e.g., (Dulany, 1997; Kinder & Shanks, 2001; Lovibond & Shanks, 2002; Perruchet & Vinter, 2002; Shanks & Perruchet, 2002; Shanks & St. John, 1994; Shanks et al., 2003). It is proposed that discrimination performance, procedural learning, and free generation performance, are all conscious processes and the idea that there is any unconscious contribution to learning is entirely rejected. Performance on different tasks may engage different brain regions but the idea that specific areas of the brain are dedicated to separate unconscious and conscious learning systems is not accepted. Plainly, the results of the experiments reported here are more supportive of this viewpoint than of the notion that learning can be dissociated form awareness.
6.3 How do key findings relate to existing theories about the role of awareness in learning?

6.3.1.1 Priming and recognition

Taken together, the pattern of results obtained in Experiments 1-3 is entirely consistent with the theory that all learning is conscious; evidence of sequence learning was accompanied by above chance recognition performance at the group level and this was true when priming and recognition were measured both separately and concurrently. Furthermore, when implicit learning was specifically promoted (0 msec RSI, probabilistic sequences) positive evidence of implicit learning was not obtained.

In Experiment 4, when participants were given diazepam to induce a temporary period of amnesia, they were found to be capable of sequence learning (indexed by improved RTs during the training phase) and this was accompanied by above-chance performance on the recognition test. This observation represents a failure to replicate Reber and Squire's (1994; 1998) data with an analogue sample of temporary amnesics, and is compatible with the view that all learning is conscious.

However, in Experiments 1-4 concurrent examination of priming and recognition ratings revealed that above-chance fluency and recognition were both observed. It is plausible that the latter effect is implicit; hence, the data are also entirely consistent with the view that learning can be unconscious. In truth, it is not possible to distinguish between these 2 alternative explanations for the recognition data, but Experiments 1-4 did not produce any convincing evidence that implicit processes can exist independently of explicit processes. For example, the observation that priming can exist in the absence of above chance recognition would constitute such a demonstration. Given that no positive evidence in favour of implicit learning was obtained in Experiments 1-4, the view that learning was entirely conscious is the most parsimonious explanation of the pattern of results.

6.3.1.2 Generation tests

In Experiments 5-8, both the free generation and the trial-by-trial generation tasks
were employed to assess the role of awareness in learning. Participants’ performance was assessed following instructions to generate as much knowledge as possible during these tasks (inclusion). Furthermore, to discover whether or not participants were capable of withholding the expression of their sequence knowledge, both tasks were conducted under exclusion instructions. The findings obtained in Experiments 5-8 revealed that inclusion performance was greater than exclusion performance and baseline, indicating that participants did learn the sequence because they were able to generate it upon request. Moreover, exclusion performance was comparable to baseline demonstrating that participants had control over the expression of their acquired knowledge. These findings strongly support the position that all learning is conscious. As a caveat, 2 Experiments demonstrated a non-significant pattern of results that could be interpreted as weak evidence in evidence in favour of implicit learning (free generation groups in Experiments 5 & 8). Although these findings can be given methodological explanations that do not require recourse to a separate implicit learning system, they do perhaps deserve future replication.

6.4 Conclusions

In Experiments 1-4, discrimination performance was above chance and this finding is in contrast to other studies where chance level recognition performance was reported (Destrebecqz & Cleeremans 2001; P.J. Reber & Squire 1994, 1998). In addition recognition performance was contaminated by the effect of motor fluency. However, it is impossible to say whether this latter effect is implicit because it was never apparent in isolation from explicit performance. The most parsimonious explanation of the data in Experiments 1-4 is that all learning was explicit. In Experiments 5-8, participants were able to exert control over their free generation and trial-by-trial generation performance, indicating that there was no implicit contribution to test performance. Again these findings constituted a failure to replicate an observation reported by Destrebecqz & Cleeremans (2001, 2003). Taken together, the preponderance of findings in this thesis support the theory that all human learning is explicit in nature.
References


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Appendix

Instructions used in Experiments 5 N 8

Experiment 5, inclusion condition: "During the reaction time trials, you may have noticed that the X appeared in a regular repeating sequence. (Don't worry if you didn't notice this, the sequence was designed to be very difficult to detect). Now in the final stage of the experiment we will see how much (if anything) you have learned about the sequence.

You will have to do a slightly different task in this final block of trials. Your reaction times will no longer be measured. Instead of responding to the position of the X, what we would like you to do is to press the keys 100 times, attempting to freely generate the sequence that you saw in the reaction time phase. Each time you press a key, the X will appear in the appropriate box. It will remain on the screen until you press a further key. Don't worry if your memory of the sequence is poor; just try to generate the sequence as well as you can. For example, if you think the X often went from the V box to the B box to the N box to the M box, then you should press V-B-N-M. If this is the only part of the sequence you can recall, then you should generate this sequence repeatedly for 100 trials. Please avoid pressing the same key on successive occasions. The computer will tell you when you have made 100 key presses.

To encourage you to do your best in this test, the 6 people performing most accurately in this test will each receive a £15 book token. The better you are at generating the sequence you saw, the more chance you have of winning, so try to be as accurate as possible."
**Experiment 5, exclusion condition:** Identical to inclusion condition, except the text in bold was replaced by the text below.

Your reaction times will no longer be measured. Instead of responding to the position of the X, what we would like you to do is to press the keys 100 times, attempting to freely generate a sequence that is as different as possible to the one you saw in the reaction time phase. If you can remember particular parts of the sequence, then you should AVOID generating them. Each time you press a key, the cross will appear in the appropriate box. It will remain on the screen until you press a further key. Don't worry if your memory of the sequence is poor, just try as best you can to avoid generating the sequence. For example, if you think the X often went from the V box to the B box to the N box to the M box, then you should AVOID pressing V-B-N-M and press different sequences instead. If this is the only part of the sequence you can recall, then you should generate a sequence for 100 trials without ever pressing V-B-N-M.

To encourage you to do your best in this test, the 6 people performing most accurately in this test will each receive a £15 book token. The better you are at avoiding generating the sequence you saw, the more chance you have of winning, so try to be as accurate as possible."

**Experiment 6, inclusion/exclusion group: inclusion instructions:** Identical to Experiment 5 inclusion, except participants were not told this was the final stage of the experiment.

**Experiment 6, inclusion/exclusion: exclusion instructions:** In the final stage of the experiment we will use a different method to see how much (if anything) you have learned about the sequence.

As in the last block you must press the keys 100 times, but this time attempting to freely generate a sequence that is as different as possible to the one you saw in the reaction time phase. If you can remember particular parts of the sequence, then you should AVOID generating them. Each time you press a key, the cross will appear in the appropriate box. It will remain on the screen until you press a further key. Don't worry if your memory of the sequence is poor, just try as best you can to avoid
generating the sequence. For example, if you think the X often went from the V box to the B box to the N box to the M box, then you should AVOID pressing V-B-N-M and press different sequences instead. If this is the only part of the sequence you can recall, then you should generate a sequence for 100 trials without ever pressing V-B-N-M. Please avoid pressing the same key on successive occasions. The computer will tell you when you have made 100 key presses.

To encourage you to do your best in this test, your performance will be taken into account in deciding which participants are given the £15 book tokens. The better you are at avoiding generating the sequence you saw, the more chance you have of winning, so try to be as accurate as possible."

**Experiment 6, exclusion group: exclusion instructions:** Identical to Experiment 5 exclusion.

**Experiment 7, inclusion/exclusion group: inclusion instructions:** This is the end of the first part of the experiment.

During the reaction time trials, you may have noticed that the X appeared in a regular repeating sequence. (Don't worry if you didn't notice this, the sequence was designed to be very difficult to detect). Now in the final stage of the experiment we will see how much (if anything) you have learned about the sequence.

You will have to do a slightly different task in this final block of trials. You will be presented with short sequences of X movements, all of which were part of the training sequence, and the test sequences will consist of 5 X locations. You should respond to the Xs just as before, pressing the buttons as fast as possible.

After each test sequence a green question mark will appear in each box, and instead of responding to the position of the X, what we would like you to do is to use it as a cue to recall the sequence you saw in the reaction time phase, and to press a key attempting to generate the next location of the sequence. Moreover, you should try as hard as possible to avoid repeating the final location of the test sequence, as there were no repetitions in the sequence you saw.

When you press a key, the question marks will disappear and the next sequence
will begin after a few seconds. Don't worry if your memory of the sequence is poor; just try to generate the next location in the sequence as well as you can. There will be 12 test sequences in total. Try to do as well as you can in this test. For each test sequence for which you correctly generate the next location, you will receive an additional 25 cents, so try to be as accurate as possible."

*Experiment 7, inclusion/exclusion group: exclusion instructions:* "This is the final stage of the experiment.

As in the second stage of the experiment, you will be presented with short sequences of X movements, all of which were part of the training sequence. Again, the test sequences will consist of 5 X locations. You should respond to the Xs just as before, pressing the buttons as fast as possible.

After each test sequence a red question mark will appear in each box and instead of responding to the position of the X, what we would like you to do is to use it as a cue to recall the sequence you saw in the reaction time phase and to press a key but this time attempting to generate a location that is different from the next location of the sequence. When you press a key, the question marks will disappear and the next sequence will begin after a few seconds. Don't worry if your memory of the sequence is poor; just try to AVOID generating the next location in the sequence as well as you can. Moreover, you should try as hard as possible to avoid repeating the final location of the test sequence, even though there were no repetitions in the sequence you saw.

There will be 12 test sequences in total. Try to do as well as you can in this test. For each test sequence for which you correctly avoid generating the next location, you will receive an additional 25 cents, so try to be as accurate as possible."

*Experiment 7, exclusion/inclusion group: exclusion instructions:* Identical to Experiment 7 inclusion, except the text in bold was replaced by the bold text in Experiment 7 exclusion.

*Experiment 7, exclusion/inclusion group: inclusion instructions:* Identical to
Experiment 7 exclusion, except the text in bold was replaced by the bold text in Experiment 7 inclusion.

**Experiment 8, free generation inclusion/exclusion group: inclusion instructions:**
Identical to Experiment 6, inclusion/exclusion group: inclusion instructions.

**Experiment 8, free generation inclusion/exclusion group: exclusion instructions:**
Identical to Experiment 6, inclusion/exclusion group: exclusion instructions.

**Experiment 8, free generation exclusion/inclusion group: exclusion instructions:**
Identical to Experiment 5, exclusion except that participants were not told it was the final stage of the experiment.

**Experiment 8, free generation exclusion/inclusion group: inclusion instructions:**
Identical Experiment 5, inclusion (bold text).

**Experiment 8, trial-by-trial inclusion/exclusion group: inclusion instructions:**
Identical to Experiment 7, inclusion/exclusion group: inclusion instructions.

**Experiment 8, trial-by-trial inclusion/exclusion group: exclusion instructions:**
Identical to Experiment 7, inclusion/exclusion group: exclusion instructions.

**Experiment 8, trial-by-trial exclusion/inclusion group: exclusion instructions:**
Identical to Experiment 7, exclusion/inclusion group: exclusion instructions.

**Experiment 8, trial-by-trial exclusion/inclusion group: inclusion instructions:**
Identical to Experiment 7, exclusion/inclusion group: inclusion instructions.