REAL-TIME NON-INVASIVE MEASUREMENT OF IMPLICIT AND EXPLICIT KNOWLEDGE DURING A SERIAL REACHING TASK

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INTRODUCTION

Is it possible to learn without awareness, the structure or knowledge acquired, that is, without verbal mediation? The question has prompted much research recently. In 1987 Nissen and Bullemer introduced the Serial Reaction Time Task (SRT). In the SRT participants make a keypress response spatially related to an on screen stimulus appearing in one of 3-4 positions. In an experimental condition a particular sequence of trials is repeated 10 or more times in a block of trials. Participants are exposed to this repeating sequence during a training period but are not informed of the structure. However, in the control condition there is no sequential structure for the task. In most studies a dual task tone counting design is employed to reduce the onset and development of explicit learning.

Many studies (Cohen Ivry & Keele, 1990; Curran & Keele, 1993; Keele & Jennings, 1992; Reed & Johnson, 1994; Stadler, 1992; Willingham Nissen & Bullemer, 1989) have shown that relative to the control condition, response latencies on experimental trials are decreased. By using tests that encourage performance based on implicit knowledge it has been concluded that this facilitation is due to participants acquiring knowledge of the sequence structure. Post hoc tests for explicit knowledge of the sequence reveal that some participants have no awareness of the repeating structure, inviting the conclusion that these experimental subjects have learnt the sequential information implicitly.

The standard indirect test for implicit knowledge comprises a block of trials the same length as the training blocks but lacking the sequential structure. The block occurs unannounced immediately following the training blocks and a rebound in response time is considered evidence that the subjects have learnt sequence information. Due to the lack of explicit instructions and the performance based nature of this test it is tempting to attribute performance to implicit knowledge of sequence information, but explicit knowledge could produce a similar rebound. To support the theory that facilitation during training is due to implicit knowledge of sequence structure, a separate group of subjects trained in the same manner are tested for explicit awareness of the sequence structure.

A range of explicit knowledge measures have been employed in SRT task research. Initially a questionnaire was used but more recent studies employ a generate task or a recognition test technique to assess explicit knowledge. The common elements of these tests are that they occur after training, they are preceded by a partial debriefing, and they attempt to incorporate the task features of the training phase. These direct tests encourage performance based on conscious information available to verbal report.

Both indirect and direct tests have been criticized in recent literature (Cohen & Curran, 1993; Perruchet & Amorim, 1992; Shanks & St John, 1994) for failing to isolate the memory system they were designed to test. Earlier techniques of assessing explicit knowledge failed to meet the information and sensitivity criteria described by Shanks and St John (1994) and have been replaced by a new Generate Task and the Recognition Test developed by Perruchet and Amorim (1992).

The information criterion requires that direct tests examine the same information that enhances performance. In the SRT task this has been shown to be fragmental sequence knowledge (Perruchet & Amorim, 1992; Stadler, 1989). The sensitivity criterion necessitates that direct tests assess all available relevant conscious knowledge. While the new generate task and the recognition test meet these criterion as discussed by Shanks and St John (1994), standardized procedures for these have not been established. The new direct tests, while encouraging the use of explicit knowledge, have been criticized for not preventing implicit perceptual or motor fluency facilitating performance on the tests (Cohen & Curran, 1993), although their role is assumed to be minor (Perruchet & Amorim, 1992; Shanks & St John, 1994; Willingham et al., 1993).

The indirect Transfer Block does not separate subjects using implicit knowledge from those using explicit knowledge as both types of knowledge show a rebound when the repeating sequence is removed. This criticism is evidenced in the study by Cohen Ivry & Keele, (1990) where, during the supplementary experiment the group showing the greatest rebound during transfer was the group showing the most awareness on the later generation task. A further problem with the indirect test is that it does not assess "what" about the sequence structure is learned. Simple frequency information such as statistical probabilities or pairwise associations cause a similar rebound effect as more complex knowledge of sequence structure (Reed & Johnson, 1994; Shanks & St John, 1994; Stadler, 1989).

The major shortcomings of previous research are firstly that indirect and direct tests measure after the event "knowledge about" the sequence structure which may differ from the actual "knowledge used" in real time. Both tests can only be performed after the training period as they disrupt and alter performance, therefore the knowledge used during early trials can not be assessed and it may be different from that used after many trials. Perruchet and Amorim (1992) ran an abbreviated SRT and discovered explicit knowledge of the sequence before any RT decreases appeared.

Secondly, in the standard SRT design, each participant can perform only a direct test of explicit knowledge or an indirect test of implicit knowledge. This makes the assumption that individuals in the two groups compared, learn and perform the task the same way. In many studies (Cohen, Ivry & Keele, 1990; Perruchet & Amorim, 1992; Willingham, Nissen & Bullemer, 1989) direct explicit tests reveal that individuals express different levels of explicit knowledge, making the similarity assumption invalid. To resolve these issues a noninvasive real time measure of learning is required that is capable of distinguishing implicit from explicit learning in the same individual.

Previous studies which have compared the performance of subjects judged to have explicit knowledge of all or part of the sequence structure, to those judged to have no explicit knowledge, have found greater decrease in RT across trials among those demonstrating explicit knowledge (Curran & Keele, 1993; Perruchet & Amorim, 1992; Willingham, Greeley & Bardone, 1993; Willingham, Nissen & Bullemer, 1989). As RT improves in these examples there is a corresponding increase in the number of anticipatory responses. Such anticipations do not accompany decreases in RT where explicit knowledge is lacking (Willingham, Nissen & Bullemer, 1989). Anticipatory responses require that a response be initiated before stimulus onset and RTs reflect a response execution process in which there can be no involvement of stimulus detection or response choice processes (Willingham, Nissen & Bullemer, 1989). Anticipation represents an observable difference between performance when explicit information is available and that based on purely implicit knowledge. The experiments to be performed are designed to exploit this difference between implicit and explicit learning.

The traditional SRT task can not take advantage of this qualitative difference because the three components underlying the response are represented by a single dependent measure. To separate the processes the current research proposes a change from an arbitrary finger press keyboard response to an active stimulus target reaching task. On each trial participants reach from a homekey to extinguish a light which appears in one of four locations, and then return to the homekey in preparation for the next trial. This change will allow partitioning of the Total Response Time (TRT) into two dependent measures, firstly a Reaction Time (RT) recorded between stimulus onset and homekey release, and secondly a Movement Time (MT) measured after homekey release until target stimulus contact.

A varied interval between homekey depression and stimulus onset requires stimulus detection processing by all subjects and this is incorporated in the RT measure. In the original SRT task the time between response and stimulus onset was constant allowing timing anticipations for all subjects. In the present task the response choice process is also included mainly in the RT measure while the response execution process is largely measured by MT. Due to different response strategies by participants and the pilot nature of the apparatus it is difficult to describe the dependent measures as process pure. Ultimately the use of a hand movement tracker may be required.

Anticipation of sequence structure moves the response choice process forward in time. Consequently, it is predicted that subjects who have explicit access to sequential information will have a reduced response choice component after stimulus onset, and as a result, faster RTs. Therefore, faster RTs can be interpreted as indicating the presence and use of explicit knowledge during the training period. As noted, previous research suggests that anticipations, and hence fast response decisions, are not supported when learning is implicit. This raises the question as to what underlies the faster responses when learning is implicit. One possibility is that implicit learning facilitates the execution of motor movements. This possibility is supported by findings of neurophysical studies linking motor cortex activity to implicit learning. Specifically, the cortical output maps to the muscles involved in the task increase for subjects trained on a repeating sequence compared to control subjects. These increases in activity return to baseline when subjects achieve full explicit knowledge of the sequence (Pascual-Leone, Grafman & Hallet, 1994). The benefits in response times for sequence groups without explicit knowledge will be seen in MT, as the bulk of response execution processing is measured by MT.

Reed and Johnson (1994) established the need to equate repeating and control sequences for simple frequency information. The present experiments use repeating sequences comprised entirely of Second Order Conditionals (SOC) and a structured control condition derived from a pool of available SOC pairs with the constraint that each pair be used once in every 13 trials. A SOC sequence occurs when every trial position is determined by the previous two positions. There is debate whether such a sequence can be learnt within a dual task tone-counting environment (Shanks & St John, 1994; Cohen, Ivry & Keele, 1990). In the Reed & Johnson study learning of the SOC sequence with a concurrent tone counting task was achieved. Tone counting is alleged to disrupt organization of information (Stadler, 1995) while intervals between trials have been shown to facilitate organization (Frensch, Buchner & Lin, 1994). Since implicit learning is sought and the new reaching task has longer intervals between stimuli, the tone task was considered necessary to prevent widespread acquisition of explicit knowledge.

By changing to the new reaching task the action component is increased in duration and should allow greater motor learning effects for sequence conditions over control conditions. The SRT task measured times that were perhaps too fast and occluded the difference between implicit and explicit improvements that the current research investigates. The changes in RT and MT are noninvasive real time measures of learning. It is proposed that they are capable of distinguishing implicit (MT decreases) from explicit (RT decreases) learning.

SELECTION FOR ACTION THEORY

Action theory states that perceptual affordances are linked with motor action plans (Bootsma, 1989). The environment is packed with affordance information which is perceived directly (Gibson, 1979) but a system must exist by which only intended action plans are carried out. It is proposed that environmentally activated action plans compete and that the unintended plans are inhibited (La Heig, Kaptein, Kaliff, De Lange, 1995; Tipper, Lorte & Baylis, 1992). This pattern of activation and inhibition is produced by task characteristics and occurs without awareness (Van der Heijden, 1993).

It has been suggested that the difference between implicit learning and explicit learning is that tasks which are learnt implicitly produce fragmental instance learning while explicit learning produces abstract rules (Shanks & St John, 1994). The learning of fragments or instance learning could be supported by the build up of activation and inhibition of action plans that occurs without awareness. Action plan "weights" could develop that are not accessible to conscious awareness. These weights may take the form, given X and Y everything but W is inhibited by 50%. Such weighting would allow a faster response to W and perhaps an awareness that it is easier to respond to W, but not conscious access to the processes. This is different from abstract rule learning where the relationship between X, Y, and W is known explicitly and conscious predictions can be made.

In the reaching task one of four action plans must be performed on each trial, the remaining three action plans must be inhibited to allow successful completion of the intended action plan. Although only one light is illuminated on each trial the remaining unlit lights should provide distraction, by supporting competing action plans that require inhibition. Tipper, Lorte and Baylis, (1992) performed a study where a red light was always the target and a yellow light always the distractor. The rule is explicit and should be simple enough to learn. However, even after hundreds of trials the yellow light produced a competing action plan that acted as a distractor.

During the initial part of the reaching response in the present study there is no conflict between the four action plans. They all begin with releasing the home key, therefore no specific inhibition of them is needed and implicit learning is not expected to occur. Once the homekey is released the finger must be guided to a specific target, the action plan for this is already activated and intended but now the three distractor action plans need to be completely inhibited. Therefore, MT is hypothesized to include an action inhibition component and as the sequence of action plans is acquired implicitly, inhibition time is hypothesized to reduce. A reduction in inhibition time is measured by participants who receive the repeating sequence having a more rapidly reducing MT than subjects in an appropriate no sequence control condition.

Where knowledge of the sequence is explicit the inhibition component can be completed before the onset of the target light, in which case the task becomes one of illumination onset detection. MT improvements under explicit learning are expected as the inhibition component increasingly occurs prior to release of the homekey. Due to the intention to respond to a specific location the activation and inhibition is complete resulting in improved RT to predicted occurrences. However, where learning is explicit, RT costs are expected if the sequence is broken by an unscheduled light. RT is increased because an inhibited action plan has now to be executed.

Using traditional post hoc testing to establish conditions where learning has occurred with or without explicit knowledge the present experiments are designed to show that there are unique patterns of response associated with explicit and implicit knowledge. These patterns are noninvasive real time measures of learning that can be used to monitor the emergence of implicit and explicit knowledge. The first experiment to be reported provides the initial calibration of a new apparatus, and comparison of results with previous research.

EXPERIMENT 1

In this experiment participants were assigned to one of three conditions. Subjects in the first experimental condition trained on a repeating sequence, followed by an indirect transfer block to measure implicit learning of the sequence. The second experimental condition trained on the same repeating sequence but received the direct recognition test to measure explicit knowledge of the sequence. The third group served as a control and received structured trials that did not repeat during the training phase but displayed the same simple frequency information as the repeated sequences. Following training, control subjects performed the indirect measure of implicit learning to establish a baseline performance for this block.

Experiment 1 investigated whether subjects learned a repeating sequence during the serial reaching task over nine training blocks. Learning was assumed if response times improved over the nine blocks for subjects in the sequence condition relative to the speed increase for subjects in the structured control condition. Subjects receiving the direct recognition test were not predicted to produce significantly higher familiarity ratings of training sequence fragments than of new foil fragments. This result would indicate that subjects were unaware of the repeating sequence. The conclusion that learning of sequence information facilitates performance is also supported by a rebound during the transfer block for sequence trained experimental subjects and no observable rebound for the control group.

Having calibrated the equipment and demonstrated implicit learning of sequence information the specific patterns of RT and MT can be examined. It is predicted that when learning occurs without awareness, RT improvements will be minimal while MT decreases will be larger than evidenced by control subjects. Where RT decreases are observed it has been theorized that explicit knowledge of at least some of the sequence is influencing performance and correlating performance on the recognition test is expected.

METHOD

PARTICIPANTS

Participants were 21 volunteers, 16 female and 5 male aged between 16 and 50 years. All were members of rural South Canterbury communities approached by the researcher. They were assigned randomly to the three groups with the constraint that all conditions be represented by an equal number of subjects. Data from 3 of these subjects were removed from the analysis leaving each group with 6 data sets to be analyzed.

APPARATUS

An electronic board controlled by Turbo Pascal programming on a PC 486 DX2-80 computer was used. The board was a 20cm x 30cm rectangle that sloped upwards and away from the subject. It had a 7mm diameter round switch labeled "homekey", which was 2cm from the base of the board. The homekey was separated from each of four stimulus-targets by 12cm. The stimulus-targets were arranged in an arc and consisted of copper touch sensitive pads etched on an opaque perspex board over a red LED light display.

PROCEDURE

Subjects sat on a comfortable chair at a large desk that had a computer and the experimental board on it. The computer screen was not visible to subjects while seated in the chair. The desk was in a small quite room at the Aorangi academy, it contained only the desk, chair, and experimental apparatus.

Stimulus location, onset, timing (accuracy of 1 msec) and data collection were controlled by the computer. Subjects were informed that the experiment was designed to examine dual task abilities, and they were asked to perform a target-reaching and tone-counting task simultaneously. Participants read information sheets (Appendix A) that met with ethical approval before signing consent forms (Appendix B). All subjects performed both the target-reaching task and tone-counting task for 1 practice block of 25 trials and 9 training blocks of 96 trials each. These were either followed by a transfer block of 96 trials or a recognition test comprising 144 trials in which subjects decided whether 3-trial fragments had occurred during training or were completely novel. The entire experiment lasted about 50 min, after which subjects were debriefed and received $5 for their participation.

SERIAL REACTION TIME TASK

For each block of target reaching task trials, subjects were presented with a stimulus-target of a red LED illuminated below the perspex touch sensitive switch. This target was 1cm round and located 12 cm from the homekey. The four targets were separated by 5cm and arranged in an arc centered on the homekey. The target locations were referred to as positions 1 through to 4 from left to right. Participants were instructed to reach to the target from the homekey as quickly as possible. They turned the lamps off by touching the touch sensitive pads located directly over an illuminated lamp, using either the index or middle finger of the left or right hand. The elected finger was used throughout the entire experiment.

Each block of target-reaching trials began at a random point in the repeating sequence and followed the sequence for the remainder of the block. A target reaching trial began when the subject depressed the homekey, stimulus-target onset required the homekey to remain depressed and onset occurred after a varying delay 450-700 msec. Delays in the 500-600 msec range occurred twice as often as the other delay lengths. The response latency to release the homekey after stimulus-target onset was recorded as Reaction Time (RT). A trial was completed by touching any one of the four touch sensitive pads and the type of response was recorded as well as the Movement Time (MT) from releasing the homekey to touching the pad. The sum of these times was recorded as Total Response Time (TRT). Subjects were informed of their mean RT and mean MT at the end of each 96 trial block. This motivated subjects to respond as quickly as possible, and if possible, faster than previously.

SEQUENCE INFORMATION

The structured non-repeating sequence and the repeating sequence were based on Reed and Johnson (1994) who stress the importance of maintaining the same simple frequency information in the control and experimental groups. The repeating sequence for the experimental group was 121342314324. This 12-item sequence is comprised completely of second order conditionals (SOC). That is, two positions are required to predict the third. The 12 sequential positions repeat 8 times to create each 96 trial block for the sequence condition. The structured control sequence was created from a pool of SOC pairs that were linked together to create 9 non-repeating blocks of 96 trials. Each pair occurred once in every 13 trials and in total each pair appeared the same number of times in the non-repeating and repeating sequence conditions.

The need for the indirect test to incorporate the same simple frequency information as the training phase was also established by Reed and Johnson (1994). The indirect sequence 1, 2, 3, 4, 1, 3, 2, 1, 4, 2, 4, 3, used by Reed and Johnson (1994) and repeated 8 times constituted the transfer block employed in the present experiment.

To avoid the criticism that results may be confined to a particular set of movements the spatial location of the sequence positions was randomly assigned for each subject. For example, a participant may receive and respond to sequence position 1 in the actual physical location 3 on the apparatus. In this way the sequential information was constant across participants while the particular sequence of physical movements varied between them.

STRUCTURED INTERVIEW

Immediately following the training period subjects in the sequence direct test condition were asked a set of structured interview questions. These questions initially focusing on general task attributes became more focused on the sequence, finally subjects were informed of the existence of the sequence and it's length before completing the recognition test. The questions were based on those used by Reed and Johnson (1994), but altered in accord with subjects understanding as demonstrated by their answers or questions. The questions were 1) Can you describe anything about the task that made it easier, (what about the light touching part)? 2) Were there any regularities (patterns) you noticed, with the light touching part? 3) Can you describe the pattern? Question 3 was asked if considered appropriate. Subjects were then informed that there was a 12 item repeating pattern to the light task and asked if they could describe verbally or spatially this sequence or part of it.

RECOGNITION TASK

Perruchet and Amorim (1992) introduced a recognition test for explicit knowledge to SRT research. This test examined awareness of fragments by having subjects provide familiarity scores for sequence and foil fragments. It has been described as a more sensitive and appropriate direct test of explicit learning than previous techniques. Reed and Johnson (1994) used this technique presenting twelve three item sequence fragments and twelve novel fragments twice each. Each fragment was rated according to familiarity by subjects using a four-item scale that ranged from definitely familiar (1) to definitely not familiar (4). This version of the recognition test is employed in the current experiments.

TONE COUNTING TASK

For each block of the serial reaching task subjects performed a tone counting task. A 60 msec computer-generated tone was emitted immediately following a stimulus-target response. Each tone was either low (450Hz) or high (1250Hz), and subjects were instructed to keep track mentally of the number of high tones emitted during each block. Subjects were asked to provide their count and were given feedback concerning their accuracy. They were encouraged to try harder if accuracy was in error by more than 8%.

RESULTS

To establish that implicit learning had occurred with the new apparatus and the new task, the results are treated in a similar manner to previous studies. Of primary interest are the changes in TRT over blocks and the difference between control and experimental groups in this measure. The change between training block 9 and transfer block 10, and the results of the recognition test are crucial for establishing the new reaching task as producing implicit learning of sequence information.

COUNTING ERRORS

Since all subjects appeared to be making a genuine effort to master both tasks, no participants were excluded because tone counting errors exceeded 10%. Only one subject in the repeating sequence conditions (11.7%) and one in the structured control condition (11%) produced errors exceeding 10%. When the TRT, MT and RT of participants with counting errors exceeding 10% were compared to others in the assigned group they were similar. Tone counting errors were treated by a mixed Group x Block Anova, which revealed no significant main or interaction effects.

REACHING ERRORS

It was exceptionally rare (<.001%) for subjects to touch an incorrect target. Experimenter observation of subject hand movements revealed that it was quite common to begin reaching for the wrong target, but a hand tracker would be needed to record this. This effect could be due to expectation once a fragment of the sequence was known explicitly, subjects commented that there hand wanted to go to a different target than the one lit.

The apparatus was sensitive to sweaty or dirty contacts. If moisture or dirt was left on a switch the apparatus recorded that the finger was still on the target. This meant that as soon as the homekey was released the target extinguished and MT was recorded as a physically impossible time of less than 50msec. These trials were flagged by programming and easily removed from the data and for most subjects occurred on less than 2% of the experimental trials. When a light extinguished before target contact subjects continued the already initiated reach and reported feeling that they felt they had to "keep up" with the lights. This problem with the apparatus could be reduced by increasing the distance between the copper wires that comprise the touch sensitive pads. Two subjects had ongoing problems and constantly left moisture or dirt on the apparatus, despite hand washing and drying. These subjects received payment but their data were not analyzed.

ANTICIPATION ERRORS

A variable interval between homekey depression and stimulus onset required that subjects detect the stimuli before lifting their fingers. If the homekey was released before a lamp was lit the trial fell through, the LED did not illuminate, and the homekey needed to be depressed again before the trial continued. If a trial fell through it continued with a reduced delay of 150-350 msec. Such anticipations were common during the practice block but once participants became aware that the interval was irregular and that their finger must remain on the homekey for the LED to illuminate, anticipations were rare. There were fewer than 1% of trials with RTs of less than 100 msec, except for a single participant who had RTs of less than 100 msec on 53% of trials. This participant persisted with a rolling motion of depressing the homekey that programming recorded as instantaneous release of the key, even though a target reach had not yet been initiated by the subject. The participant attributed this to a habit acquired from experience on video game machines. This participant was paid but data generated were not included in the analysis.

TESTS OF EXPLICIT KNOWLEDGE

Since the main focus of the present research is to show that patterns of RT and MT under explicit learning are distinguishable from those where learning is implicit, it is necessary to establish where there is and is not awareness of the knowledge underlying enhanced performance. Subjects in the sequence direct test condition performed a recognition test following the ninth training block. There was a partial debriefing that initially questioned participants' awareness of the sequence and then informed them that there had been a repeating sequence and that they would be required to rate fragments as to their familiarity on the basis of the previous training period.

Two of the subjects mentioned the presence of a sequence but they could not recall any part of the sequence, except in general terms such as it moved left to right alternating, which in fact it did not. The results of the recognition test for each subject were collapsed into 4 mean scores, one for "old" to be recognized fragments and one for "new" to be rejected fragments, for each of the 2 blocks. When the familiarity ratings for "new" and "old" fragments were compared using a repeated measures blocks x origin of fragments Anova, no evidence for explicit learning was found, origin of fragments effect $F(1,5) = .001$, $p<.95$, supporting the hypothesis that any learning occurred implicitly rather than explicitly. The means for both the old to be recognized (2.44) and the new to be rejected (2.45) fragments are at the higher, maybe unfamiliar (3) end of the rating scale, suggesting a general lack of confidence by subjects in their recognition.

In accord with Reed and Johnson (1994) two identical blocks of the recognition test were performed and they were analyzed separately to establish if the first revealed awareness while the second did not. The blocks x origin of fragments interaction effect was not significant, $F(1,5) = .52$, $p <.5$, the old fragments in the first block had a mean rating of 2.36 and in the second 2.49 while the new fragments in block one were rated 2.53 and in the second 2.42. These results indicate that the second block is redundant as both blocks produce similar results, blocks effect $F(1,5) = .12$, $p>.7$.

Further investigation of the 12 repeating sequence fragments reveals that 31% of fragments rated definitely familiar (1), during the first block of the recognition test were also rated definitely familiar in block 2. These fragments are considered accurately recognized. It may be argued that compared to the ratings for the new to be rejected fragments there is no significant difference in the pattern of responding, as evidenced by the fact that 31% of foil fragments are incorrectly recognized in both blocks. However there is a fundamental difference between correctly recognized repeated sequence fragments and incorrectly recognized foil fragments, being that repeated sequence fragments have associated response times.

The analysis undertaken suggests that what is explicitly known is less than what is not known and that what is known is not significant. The effect of explicit knowledge on response times can not be judged by comparing old and new fragments. It is obvious that most parts of the repeating sequence are not explicitly known and the foil fragments being only 3 items long are often mistakenly recognized and represent "guessing" by subjects. The few "old" fragments that are correctly recognized could reveal explicit knowledge of some parts of the sequence for each subject even if participants guessed, they guessed correctly, but that this slight fragmentary explicit knowledge is overcast by the larger lack of explicit knowledge of the repeating sequence for each subject. With only 31% of fragments considered recognized continued analysis will lack statistical power.

TREATMENT OF RESPONSE TIME DATA

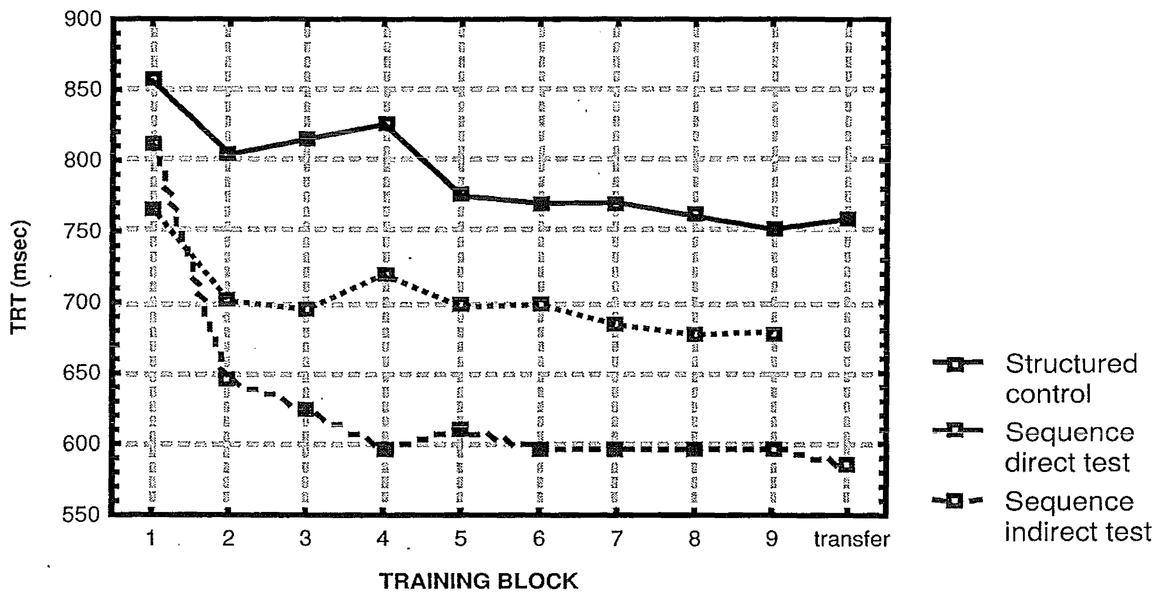
Due to the natural skew in reaction time measures the median Response Time for each block by each subject was calculated and used as the measure of central tendency. The mean of the individual subject medians was then calculated for each block of trials. This manipulation was carried out separately for each of the three dependent measures, Total Response Time (TRT), Movement Time (MT) and Reaction Time (RT).

TOTAL RESPONSE TIME

REAL-TIME MEASURE OF LEARNING

To establish that the participants learnt the SOC sequence implicitly during the reaching task, TRT times were compared with previous SRT results. Visual inspection of Figure 1 suggests greater improvement in response speed for the repeated sequence groups compared to the control group. This improvement is evident from block one and is most apparent in the earlier blocks. Rapid decrease in Response Time during the first block has been reported previously for repeated sequences (Cohen, Ivry & Keele, 1990). Perruchet and Amorim (1992) indicate that subjects learn a sequence rapidly and do not need the long training periods most experiments employ.

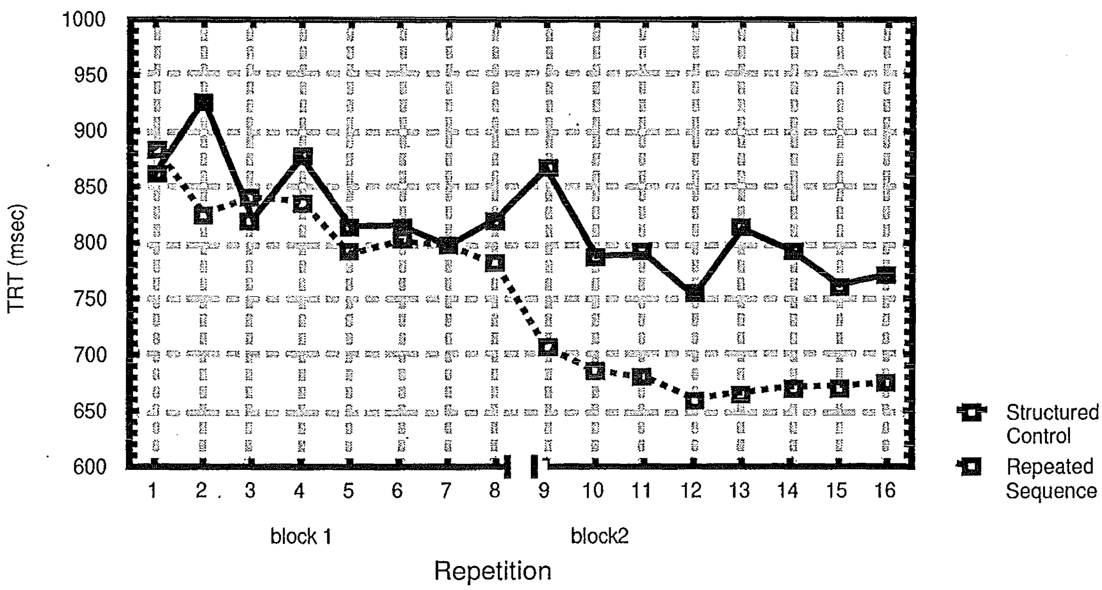
Figure 1 Mean TRT as a function of training/transfer block



The data from the nine training blocks were treated by a mixed Groups x Training blocks Anova. While the decrease in TRT across blocks was significant, $F(8,120) = 5.07$, p<.001, the rate of decrease did not differ between groups, F(16,120) = .83, p>.65. The main effect for group was not significant F(2,15) = 2.93, p=.084. These results support the conclusion that TRT improved for all groups with training, but the difference between repeating sequence learning and learning of non-repeating sequence simple frequency information, while visible in Figure 1, does not achieve statistical significance.

The difference between sequence trained groups and the structured control groups during the early blocks requires further investigation. The reaching task is a slower task than the SRT, perhaps encouraging early differences that are occluded by the blocks grouping of data. To further examine early changes each repetition of the repeated sequence and each corresponding 12 trials of the structured control during block 1 were examined. In this analysis the two repeating sequence groups are treated as a single group, the results are presented in Figure 2. The observable movement of the conditions towards each other during the first 8 repetitions prompted a similar investigation of the data from block 2, represented as repetitions 9-16.

Figure 2 Mean TRT as a function of repetition



A mixed group x repetition Anova indicates that during the later repetitions the repeating sequence group decrease in TRT faster than the structured control group, F(15,225) = 1.71, p< .05, this is not mediated by a groups effect F(1,15) = .65, p=.43, and both conditions decrease in TRT during the 16 repetitions $F(15,225) = 6.68$, $p<.001$. These results suggest that the groups end the first block performing at similar TRT speeds but during the second block there is advantage to subjects training on the repeating sequence over subjects receiving similar simple frequency information in the non-repeating structured control.

INDIRECT TESTS OF LEARNING

After completing 9 training blocks the repeated sequence indirect test and the structured control groups completed a repeated sequence transfer block. It was expected that the repeated sequence indirect group would display longer TRTs to the transfer block. The TRTs of those transferring from the structured control series should show similar TRTs in the transfer block and the last block of training. It can be seen in Figure 1 that there is no rebound in TRT for either group, in fact there is a decrease in TRT. This lack of rebound during the transfer task for the repeated sequence group is surprising and in conflict with previous research (Reed & Johnson, 1994).

As the sequence indirect test group results were unexpected a further analysis was undertaken. During the transfer block a new SOC sequence was introduced and this sequence repeated 8 times to produce the 96 trial block. Changing the sequence may promote explicit awareness of the previously present sequence and facilitate learning of the new sequence, resulting in quicker responses than those observed during the training blocks. This learning during the block would mask the expected rebound. This explanation is similar to the phenomena where a repetitive background noise is only explicitly noticed if it suddenly changes, when it changes and is noticed the new sound receives attention and can be explicitly described easily.

An alternative explanation is that the physical configuration of motor responses a particular subject makes during the transfer task may permit faster responses than the original training sequence. This is an unlikely proposal with physical positions randomly assigned to subjects. To test these explanations only the first 20 trials of each block were compared. If learning of the new repeating sequence facilitated TRT then the first 20 trials should not be influenced and should show a rebound. If more favorable physical positions are the cause of the facilitation effect then this should be apparent from the beginning of the block.

Figure 3 Mean TRT for first 20 trials of each block

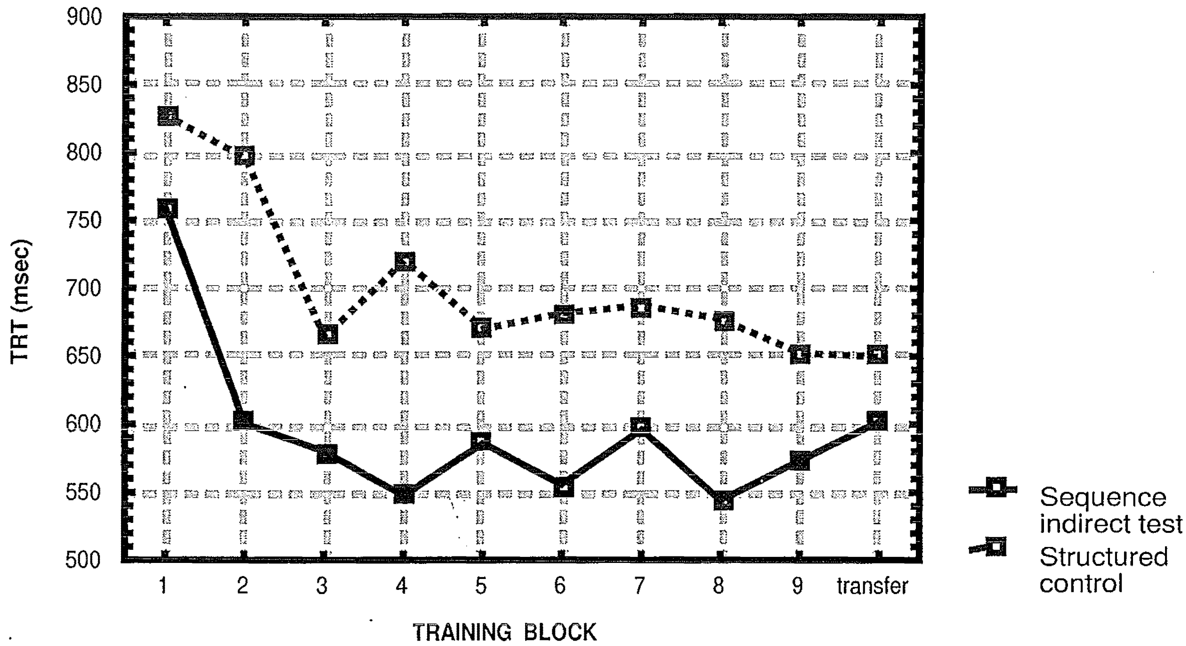
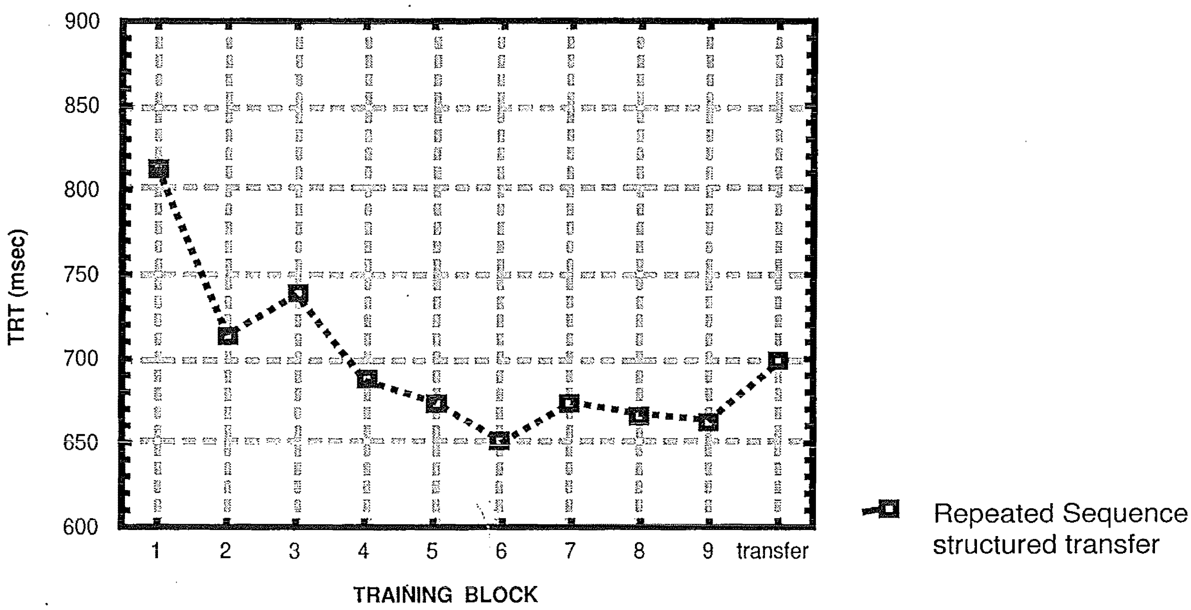


Figure 3 suggests there is a significant rebound for the sequence group, $t(5) = -3.45$, $p<.05$, between blocks 9 and 10, and a continuation of the learning trend for the control group $t(5) = .25$, $p>.1$. The rebound (29 msec) in the present study is smaller than that reported by Reed and Johnson (81 msec). Fewer training blocks were completed in the present study. In their experiment subjects completed 4 practice blocks and 17 training blocks of 96 repeating trials before the administration of the transfer block. In the present research the initial practice block does not contain the repeating sequence and each subject trained for only 9 blocks of 96 trials.

To further test the hypothesis that the repeating transfer task masked the rebound effect five participants completed a new variant of the experiment. Nine training blocks of the repeating sequence were completed followed by a transfer task with a non-repeating structured sequence of 96 trials. This transfer sequence was derived from the available SOC pool in the same way as the structured control condition in the original experiment and contained the same simple frequency information as the repeating sequence. The results for this additional condition are presented in Figure 4, there is a significant rebound of 34 msec, t(4) = -3.27, p<.05.

Figure 4 Mean TRT as a function of Block



Results from this structured transfer condition will be included in the following analysis of MT and RT as the appropriate repeated sequence indirect test group. Results from the condition using a repeated transfer sequence will be presented but not included in the statistical analysis because of the suspected explicit learning component. TRT measures provide clear evidence that learning of repeated sequence information occurs on the present task because TRTs decrease is greater during block 2 than the structured control group response time decrease. That this learning is implicit is supported by the results of real-time analysis and both direct and indirect tests.

The direct test provides evidence that explicit knowledge of repeating sequence information is not forthcoming and the rebound observed during the indirect test suggests that sequence information facilitates performance of the task. The significant interaction effect between groups receiving the repeated sequence and the structured non-repeating control during a repetition analysis suggest that repeating sequence information provides an advantage over similar simple frequency information in a non-repeating sequence.

These results support the conclusion that the new reaching task is examining the same processes as those that underlie the traditional SRT task. In particular the results replicate the recent experimentation using the SRT by Reed and Johnson (1994), albeit, after far fewer training blocks. The potentially contaminating effects of physical movements, anticipation, incorrect responses, and differential error rates are controlled for in the design. Therefore, the visible advantage for sequence groups appears to be a genuine effect and not the product of nuisance variables. It is now possible to examine MT and RT to establish if there is a pattern of responding distinguishing implicit learning.

MOVEMENT TIME

REAL-TIME MEASURE

The mean MT's for the 10 blocks are presented in Figure 5. The pattern is similar to that observed for TRT in Figure 1. The repeated sequence groups have a faster rate of decrease especially during early blocks. The main effect of block was significant $F(8,112) = 4.62$, $p<.001$, but the groups main effect, $F(2,14) = 1.94$, $p>.15$, and the groups x blocks interaction effect, $F(16,112) = .47$, $p>.95$, were not significant. Again all groups show an improvement across blocks that may be attributed at least to simple frequency information learning..

The analysis of repetitions for the first 2 blocks, comparing the structured control to a group that combines the data from the two repeated sequence groups, produced a significant repetitions effect $F(15,225) = 1.26$, $p<.001$ but the interaction effect was not significant $F(15,225) = 1.50$, $p=.11$. MT in Figure 6 shows a similar pattern to TRT in

Figure 2, the structured control condition reducing during early repetitions to the same level as the repeated sequence combined group. The real-time learning measure does not indicate learning for the repeated sequence conditions beyond learning of similar simple frequency information received during the structured control condition.

Figure 5 Mean MT as a function of training/transfer block

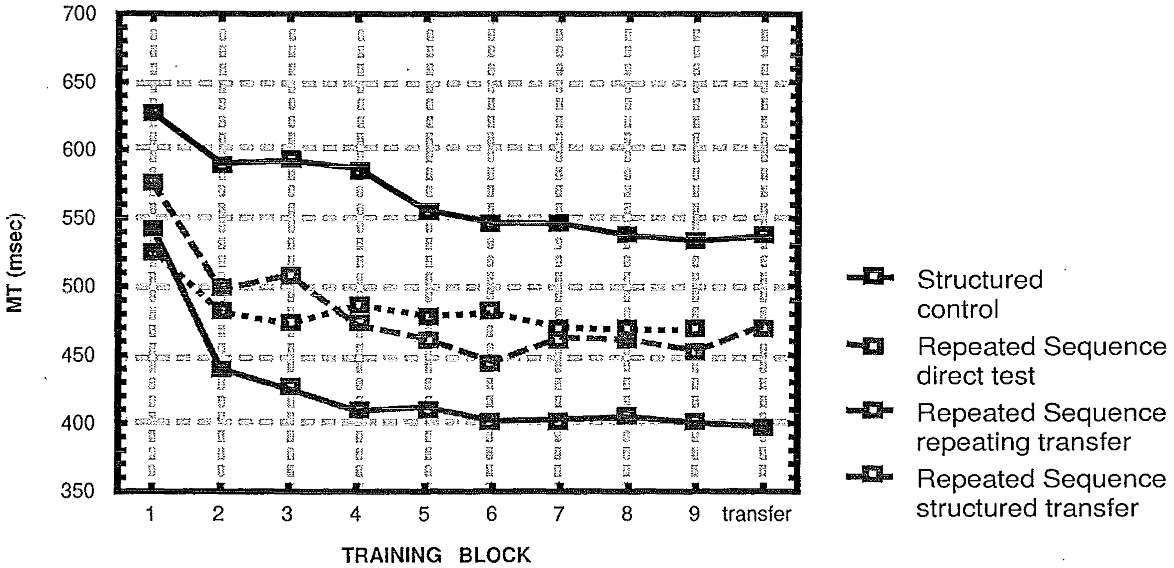
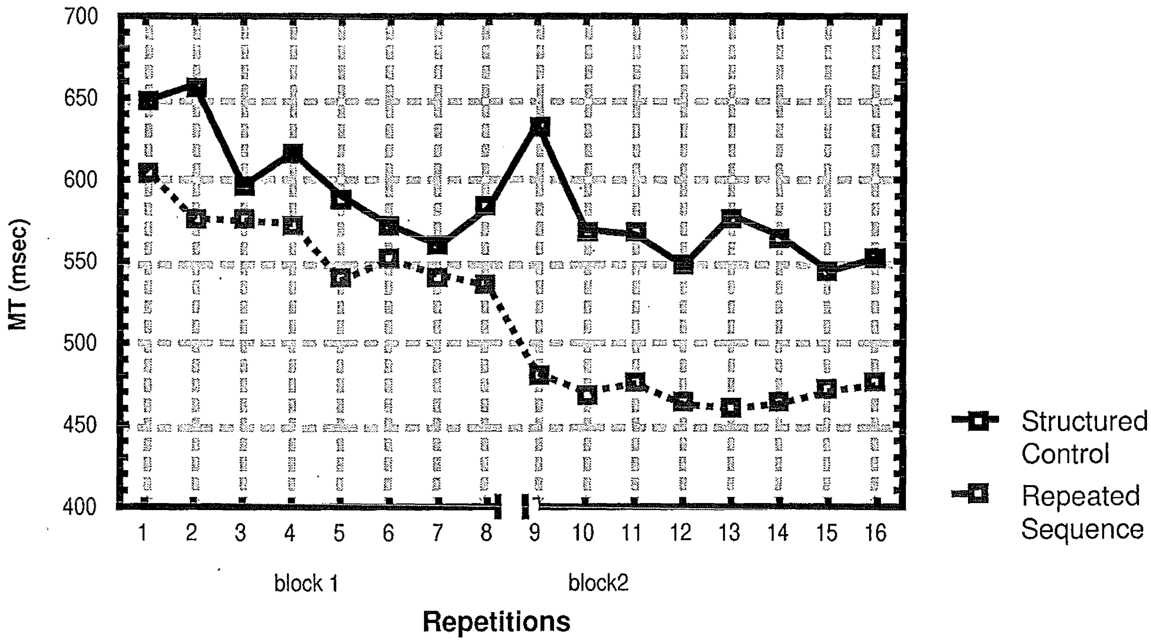


Figure 6 Mean MT as a function of repetition



INDIRECT TEST

The repeating sequence, non-repeating transfer group shows an 18 msec rebound during the indirect test, this fails to reach significance, $t(4) = -1.76$, $p = .16$. The structured control group also shows a slight rebound in MT during the indirect transfer block, while the discarded repeating transfer block for the repeated sequence trained group shows a decrease in MT for the indirect test, these effects are not significant. When the first 20 trials of the structured control and repeated sequence, repeating transfer block groups are analyzed in a similar investigation to TRT indirect test section, there is a rebound for both groups. The rebound for the structured control group is 18 msec while the repeating sequence group is 3 msec these are not significant effects. The indirect measure does not reveal repeated sequence learning, there is no advantage for repeated sequence learning over simple frequency learning of non-repeating sequence information, in MT.

REACTION TIME

REAL-TIME TEST

A mixed group x block analysis of mean RTs produced a different pattern of results from those of the MT and TRT analyses. Figure 7 shows that the dispersion between the three groups is much less and that there is no clear difference in pattern between the two sequence groups and the structured control group. The slope is much flatter than in Figures 1 and 5. An Anova testing these results indicates that, unlike MT and TRT, there is no blocks effect for the 9 training blocks, $F(8,112) = .89$, $p > .50$. There was no groups effect, $F(2,14) = 1.17$, $p > .30$, or interaction effect, $F(16,112) = .41$, $p > .95$. These results suggest that neither simple frequency information nor implicit knowledge of sequence structure benefit RT.

The analysis of the individual repetitions during the first two blocks reveals a decrease in RT across repetitions (see Figure 8). RT for both the repeated sequence and structured control groups decreases over the 16 repetitions $F(15,225) = 9.36$, $p < .001$. The reduction in RT between block 1 and 2 is seen in Figure 7, but does not continue consistently past block 2. The interaction groups x repetitions effect is not significant, both groups showing similar decreases in RT over repetitions. Also the groups effect is not significant. These results indicate that initial benefits in RT are not attributable to either implicit or explicit knowledge of repeated sequence information, since they apply equally to structured control and repeated sequences.

Figure 7 Mean RT as a function of training/transfer block

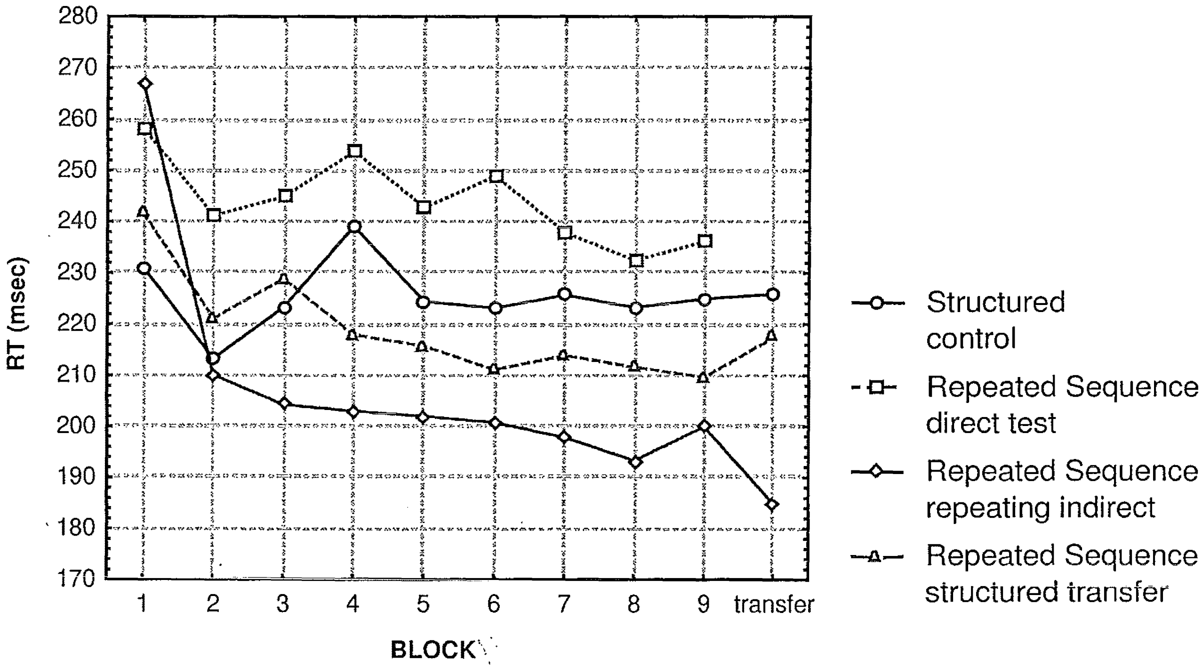
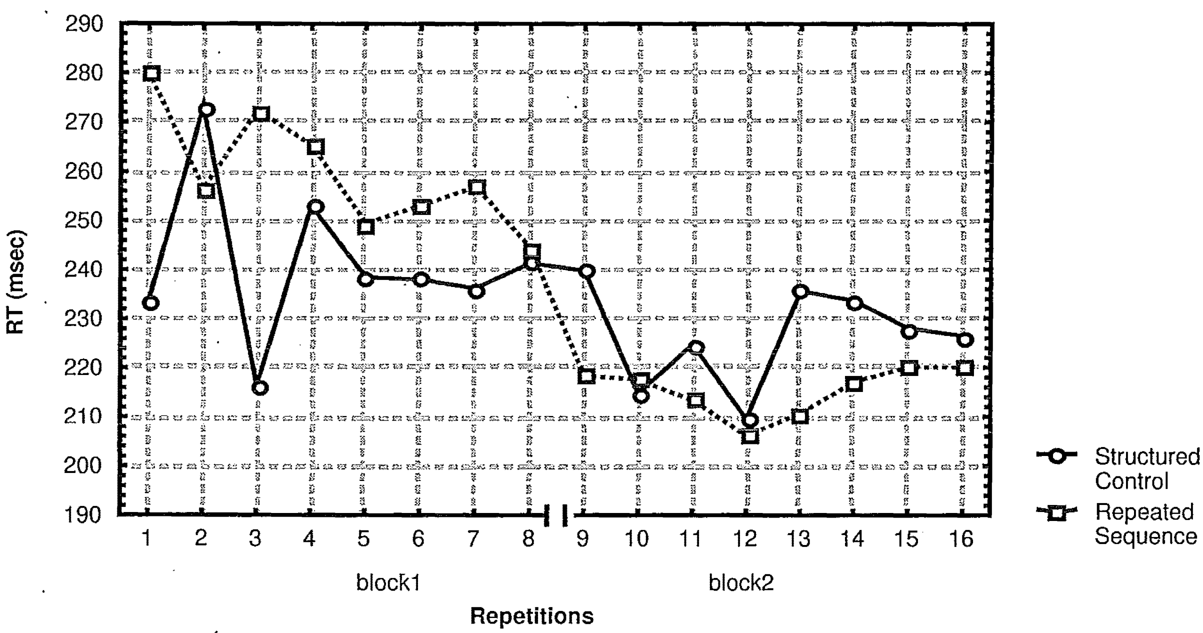


Figure 8 Mean RT as a function of repetition



INDIRECT TEST

Visual examination of Figure 7 shows that there is a 10ms rebound for subjects in the repeated sequence, non-repeating transfer block. This effect is not significant $t(4) = -1.86$, $p > .13$, although only one subject failed to show a rebound between the ninth and tenth blocks. The structured control condition did not show facilitation or rebound in RT during the indirect test. Further examination of Figure 7 shows a decrease in RT for the repeated sequence, repeating transfer block (15ms) this decrease is also not significant.

These results suggest that the training period and type of indirect test have different effects. These are interpreted differently to fit traditional theories of learning. If training involves a repeating sequence and the indirect test is a repeating transfer block facilitation possibly linked with explicit knowledge occurs, if the training sequence is structured but non-repeating and the implicit test is a repeating transfer block there is no noticeable effect on RT showing no explicit learning during training. If the training is repeated sequence and a non-repeating transfer block comprises the indirect test a rebound supposedly associated with implicit learning is observed.

A different perspective is to consider the possibility that RT is sensitive to explicit knowledge only, and to appreciate that neither of the two repeating sequence groups completing the indirect test was tested for explicit knowledge. The lack of explicit knowledge in the indirect transfer groups is inferred from the results of different subjects who were given the recognition test directly after the training blocks. The explicit knowledge that may have developed during the training period manifests itself during the indirect test as a rebound when there is a non-repeating transfer block and as facilitation when the transfer block is a repeating sequence.

It was hypothesized earlier that explicit knowledge would cause decreasing RT when an expected event occurred and a rebound when an event other than the predicted one occurred. During non-repeating transfer trials prediction of the target location is most likely to be incorrect and a rebound will be observed. Where the transfer block contains a repeating sequence prediction will be incorrect, causing a rebound on the first few repetitions of the sequence, but subjects quickly adapt to the new rules when these rules are sought, and produce facilitation.

To further explore the hypothesis that indirect test performance is influenced by explicit knowledge the training period of these two indirect test repeating sequence groups was examined. An analysis of the 9 training blocks revealed a significant blocks effect, $F(8,72) = 4.71$, $p.<.001$ for RT. By contrast the repeating sequence direct test and the structured control groups, which it can be claimed have no significant explicit knowledge, do not have a significant blocks effect, $F(8,80) = .60$, $p>.75$.

DISCUSSION

The aim of Experiment 1 was to establish the serial reaching task as an appropriate tool for investigating implicit learning. Traditionally to reach this conclusion three criteria for repeating sequence groups are set out: Improved total response times over the structured control group, a rebound in TRT during an indirect transfer block, and non significant rating scores for sequence over foil fragments during the direct recognition test. These criteria are discussed and it is concluded that the reaching task is an appropriate tool for studying implicit learning.

Participants trained with a repeating sequence showed an advantage over those in the structured control group, in TRT from the end of the first block. A fine grain analysis of individual repetitions reveals this early interaction effect. The significant training blocks effect in TRT indicates that the task provides opportunity for improvements in TRT as participants become comfortable with the apparatus and learn the simple frequency information in the structured control and repeated sequences.

One surprise was the lack of a significant rebound on transfer in the indirect condition. One explanation is that subjects noticed the change in the repeating sequence and explicitly learnt the new repeating sequence in the transfer block. Several factors support this conclusion. Firstly, for the repeating sequence group instead of a rebound, there is a sudden decrease in RT. Decreasing RT has been attributed to explicit knowledge, suggesting that the repeating transfer sequence has given participants access to explicit knowledge that facilitates their performance. Second, when only the first 20 trials are analyzed there is a significant rebound for the repeating sequence group which is absent for the structured control group suggesting that information later in the block masks an early rebound.

Further contributing evidence to this argument is the significant rebound observed in TRT when the indirect test was altered to a transfer block that retains the simple frequency information of the training period but repetition of a sequence is absent. As a rebound is observed for repeating sequence trained subjects during the non-repeating transfer block something other than simple frequency learning must contribute to repeating sequence subjects faster TRT performances during training. It is hypothesized that implicit knowledge of the repeating sequence improves response times during training and removing the repeating sequence causes the rebound.

Participants completing the direct tests after training did not show significant explicit knowledge of the training sequence. Performance on the structured interview for subjects from the repeated sequence conditions revealed two subjects having some explicit knowledge that a sequence existed but no specific knowledge of that sequence, and the recognition test showed that as a group, explicit knowledge was not significant. These results suggest that whatever provided the benefits in TRT during training to the repeated sequence direct test group was not accessible by explicit knowledge at the end of the training.

The three criteria for implicit learning are met and so the conclusion that the serial reaching task is an experimental tool capable of inducing traditionally measured implicit learning is accepted.

There are two possible interpretations of the MT and RT data. The first is to accept that implicit learning has occurred and that RT measures some of the implicit knowledge gained by subjects and the distinction between MT and RT is a false one that provides little explanatory power over the TRT analysis already discussed. The second alternative that does gain some support from Experiment 1, is that RT is sensitive to explicit knowledge and that without incorporating the benefits of explicit knowledge, sequence learning is confined to simple frequency learning measured by MT in the current experiment. Although neither of these two hypotheses can be conclusively accepted, the dissociation hypothesis is presented with supporting evidence.

Examination of MT as a separate component reveals that it is similar to TRT in visible patterns for the experimental groups. Repeated sequence groups display decreased MT compared to the structured control condition from the end of the first block. These benefits are not supported during the repetition analysis where the interaction effect is not significant. The indirect test also fails to produce a significant rebound in MT for either the 20 trial analysis of the original transfer block or the additional non-repeating transfer block condition. Together these results indicate that MT does not suggest an advantage to subject training on a repeating sequence trained over those receiving the structured control series.

The two analyzed repeated sequence groups, direct test and indirect test nonrepeating transfer group, appear identical in their training blocks MT data. The indirect repeated transfer condition is also very similar supporting the observation that explicit learning, if present in the indirect conditions, is not producing any significant difference in MT from the direct condition which has no significant explicit knowledge. MT appears to be accessible to task feature learning and simple frequency information provides decreases in this measure as evidenced by the significant training blocks effect. Learning simple frequency information should be considered implicit by traditional standards as the current direct tests are not sensitive to this information (Reed & Johnson, 1994; Shanks & St. John, 1994) and because Reed and Johnson (1994) have shown that it causes a rebound in response time if removed during a transfer block. Experiment 1 has produced evidence that implicit learning of at least simple frequency information is decreasing the MT measure.

During Experiment 1 the two groups with no significant explicit knowledge, repeated sequence direct test and the structured control showed only minimal improvements in RT that failed to reach significance. There appears to be an initial settling in period for all groups over the first two blocks of the task followed by minor fluctuations up and down. This observation is supported by the absence of a significant blocks effect but a significant repetitions effect for the first two blocks. The groups that received the repeating sequence and the indirect test show a slight but significant decrease across the training blocks for RT suggesting that these groups are different from the two groups that are known to have little explicit knowledge. Although not conclusive this is taken as support for the argument that implicit learning does not give access to RT improvements while explicit learning does. Further support for this is that when the transfer block repeats and potentially allows further explicit learning there is a decrease in RT while the non-repeating transfer with no opportunity for explicit knowledge to facilitate performance produces a rebound as large as that in MT.

In summary Experiment 1 established that implicit learning as judged by traditional SRT techniques occurs during nine training blocks of the reaching task. Experiment 1 supports the hypothesis that implicit learning is accompanied by MT decreases in the absence of RT changes, while explicit knowledge impacts on RT and not MT. The results of Experiment 1 indicate that for the reaching task to be a useful tool there is a need to produce explicit knowledge and to present the response pattern when explicit knowledge is used. Further the need to examine each repetition of the sequence was established and the need for a longer practice period to remove across the board improvements during the first block.

Experiment 2 was designed to investigate response times for participants using implicit and explicit knowledge and to show the different response patterns for these. Only four blocks were considered necessary to induce explicit knowledge and to look at early differences between the groups apparent in Experiment 1. As implicit learning has been described in detail during Experiment 1 it is not the main focus of Experiment 2, and there is no transfer block for any condition because a direct test cannot be applied subsequent to an indirect test and no evaluation of explicit knowledge for the training period of these subjects can be undertaken. The indirect test appears to be sensitive to all information rather than selectively implicit knowledge and this inability to discriminate decreases its usefulness.

EXPERIMENT TWO

In this experiment subjects were assigned to one of four conditions. Participants in the first experimental condition trained on a repeating sequence while performing the tone counting task, the second experimental condition had no tone counting task during training with the repeating sequence. The repeated sequence training period was followed by a direct recognition test to determine awareness of the training sequence. The two control conditions received a structured non-repeating sequence during training blocks with no subsequent recognition test, the dual task control group was required to count tones. Training periods during this experiment were reduced to four blocks of 96 trials while the practice block of non-repeating SOC sequences was increased to a full 96 trial block.

Experiment 2 investigated whether explicit knowledge of the repeating sequence can be induced during the reaching task over 4 blocks. Interview and a shortened version of the recognition test used in Experiment 1 were used to establish whether knowledge of the sequence was explicit. Reaction Time changes were expected to accompany explicit knowledge and to be absent for subjects who did not recognize the repeating sequence fragments. Experiment 1 established that the reaching task is an appropriate tool for investigating implicit learning. The aim of Experiment 2 is to establish that a qualitative difference between explicit and implicit learning exists and that this can be used to experimentally separate subjects using the different strategies when performing the reaching task.

Removing the tone counting task is predicted to facilitate explicit knowledge of the sequence. The no-count repeated sequence is expected to demonstrate faster RT across training blocks than the tone-count repeated sequence group. The difference between control subjects counting tones and control subjects not counting tones is hypothesized to be minimal on all response time measures as there is little opportunity for explicit learning. Participants exposed to the repeated sequence and demonstrating explicit knowledge of the sequence during the recognition test will show a greater rate of decrease in RT across training blocks than control subjects and of those displaying no explicit knowledge of the sequence. To demonstrate implicit learning beyond simple frequency information the MT's, but not the RTs of participants presented with the repeating sequence and displaying no explicit knowledge will decrease at a greater rate across training blocks than those of structured control subjects.

METHOD

PARTICIPANTS

Participants were 22 volunteers, 12 female and 10 males aged between 16 and 45 years, all are members of rural Mid-Canterbury communities and were recruited through sporting connections by the researcher. They were assigned randomly to the four groups with the constraint that all conditions be represented by five participants after any data exclusions.

APPARATUS

The electronic board employed in Experiment 1 was used. Due to prolonged usage, the homekey was replaced, the new switch had the same diameter but was raised 7mm off the board, reducing upward slope from the starting position to the stimulus-targets.

PROCEDURE

Stimulus location, onset, timing and data collection were controlled by the computer. Subjects were informed that the experiment was designed to examine how simple tasks were learnt and were asked to maintain accuracy. Half the subjects performed both the target-reaching task and the tone counting task while the other half performed the target-reaching task alone. The experiment consisted of 1 practice block of 96 trials and 4 training blocks of 96 trials. These were either followed by a 5th unrecorded training block for the control conditions or a recognition test comprising 72 trials in which sequence subjects rated old and new 3-trial fragments for familiarity. The entire experiment lasted about 30 min, after which subjects were debriefed and received $5 for their participation.

REACHING AND TONE COUNTING TASKS

The reaching task was identical to Experiment 1 the control sequences were again structured by selecting non-repeating strings from the available SOC pool with the constraint that each SOC pair occurred equal times in each block and occurred once within every 12 trials. The repeating sequence employed in Experiment 1 was used for both sequence groups. The spatial location of the sequence positions was again randomly assigned. All subjects heard tones after touching the target and the same frequencies were used for the tones as in Experiment 1. Participants not required to count tones were told to ignore the tones, that they were a distraction produced by the apparatus to signal the end of a trial. Those subjects required to count tones were encouraged to keep error rates below 8%.

STRUCTURED INTERVIEW AND RECOGNITION TEST

The structured interview used the same basic questions as Experiment 1, with embellishments where it was considered necessary. Since it was demonstrated in Experiment 1 that the two blocks of the recognition test gave identical results only one block comprising the twelve possible three item fragments and twelve foil fragments was used in Experiment 2. The rating scale remained: the fragment was definitely familiar, 1; maybe familiar, 2; maybe unfamiliar, 3; definitely unfamiliar, 4. The recognition test occurred after the structured interview and the relationship between the training period and ratings was explained.

RESULTS

The results of the direct recognition test are important in establishing whether experimental groups demonstrate explicit knowledge. In this experiment the primary interest is in the response pattern of subjects who demonstrate explicit knowledge of the structure of the repeated sequence. It is anticipated that explicit knowledge will be associated with a reduced RT component compared to other groups, while the MT measure will remain similar to other sequence trained participants. It is expected that subjects who do not demonstrate explicit knowledge will elicit a pattern of decreasing MT's, but not RTs compared to structured control subjects.

Implicit learning of repeating sequence information is investigated by real-time analysis. This process is similar to Experiment 1 with the exception that a complete repetition analysis of the 4 blocks is undertaken. It is expected that increased practice will have removed the overall improvements during the first block and reveal a real interaction effect between repeating sequence trained and structured control trained subjects. A benefit for repeated sequence groups is predicted in TRT and MT. If this effect is absent it must be concluded that implicit learning does not produce benefits beyond simple frequency learning.

COUNTING ERRORS

Only half of the subjects counted tones. Two of them had one block where the error rate exceeded 10%, they were 10.9% and 14.6%. Both these subjects were in the structured control group and produced response time data that were similar to the remainder of their group. The data were retained and included in subsequent analyses.

REACHING ERRORS

Subjective reports indicate that it was common for subjects to begin reaching for an incorrect target and correct this during the reach. Experimenter observation supports this, but to gain further information hand tracking equipment is required. There were no instances of an incorrect reach being completed in this experiment. The problem of moisture and dirt on the apparatus persisted with some subjects having ongoing difficulty. Again the data for two subjects who had ongoing misreading of movement times were removed from further analysis. The remaining 20 subjects had fewer than 1% of trials affected by the problem.

ANTICIPATION ERRORS

The design of the experiment requires movement follow stimulus onset. Evidence that the task is effective in reducing anticipation is the overall lack of fast RTs. In Experiment 2 less than 2% of responses in the repeating condition and fewer than 4% of responses in the control condition had trials with RTs faster than 100 msec. Tone counting appeared to have little effect on the incidence of anticipations. Eighteen RTs of less than 100 msec were observed in the tone counting conditions and 16 in the tone absent conditions. This is predicted because RTs faster than 100 msec suggest stimulus onset predictions rather than sequence knowledge, which would allow prediction of stimulus locations.

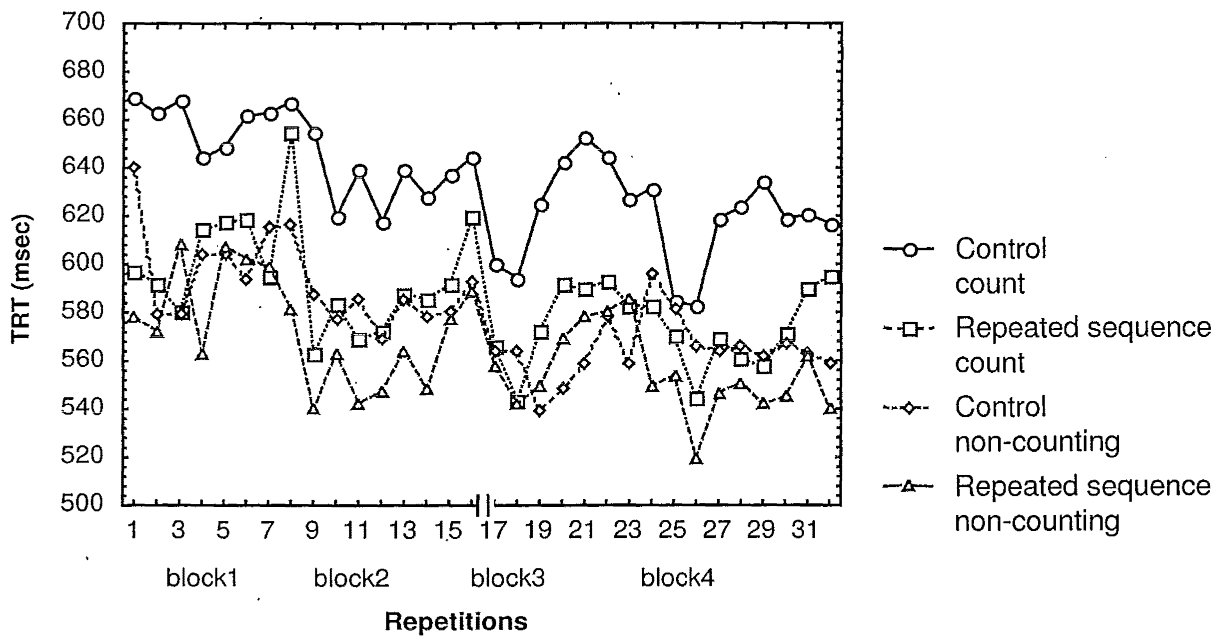
TREATMENT OF RESPONSE TIME DATA

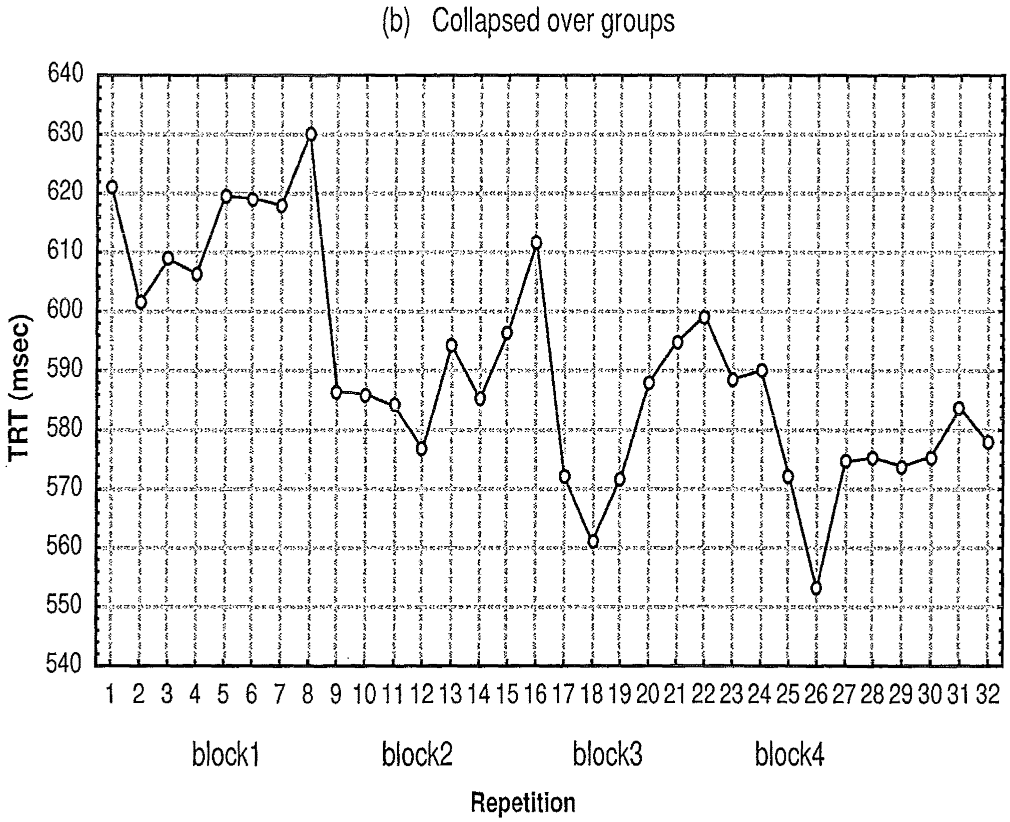
The median response time for each 12 trial repetition by each subject was calculated. The mean of individual subject medians was then calculated for each repetition of 12 trials. This manipulation was carried out separately for each of the dependent measures, Movement Time (MT) and Reaction Time (RT).

TOTAL RESPONSE TIME

Traditional SRT standards would expect that if implicit learning has occurred the rate of decrease in TRT across blocks will be greater for repeated sequence than for structured control sequence conditions. The results for each repetition in the four blocks are presented in Figure 9. A four way analysis of variance comprising between subject variables of stimulus (repeated sequence vs. structured control), and counting (tones counted vs not counted), and the within subject factors of repetition (8) and block (4) was performed. The blocks effect $F(3,48) = 8.42$, $p<.001$, and the repetitions effect were significant $F(7,112) = 3.77$, $p<.01$. No other main effects or any of the interaction effects had F-ratios values approaching significance. In all conditions, and within each block, TRTs progressively increase, from the first to the last repetition in the block. Despite this, the TRTs decrease in all conditions across blocks.

Figure 9 Mean TRT as a function of repetition
(a) All groups



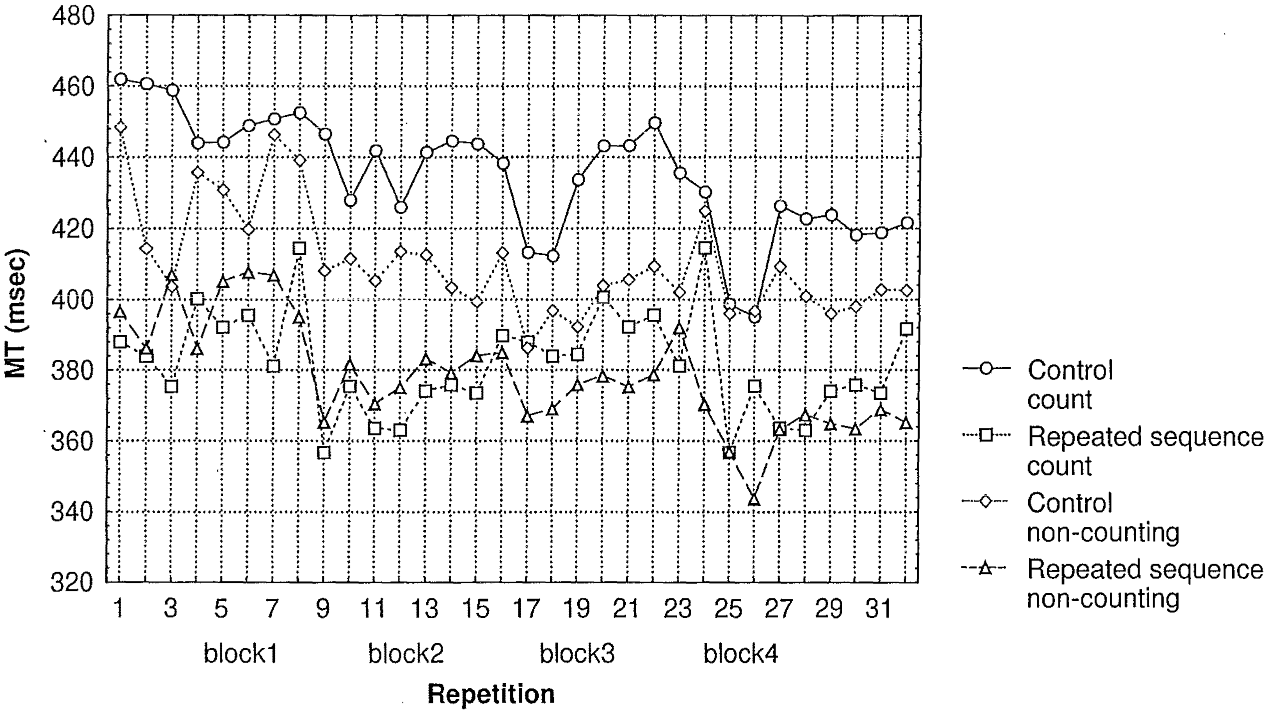


<u>MOVEMENT TIME</u>

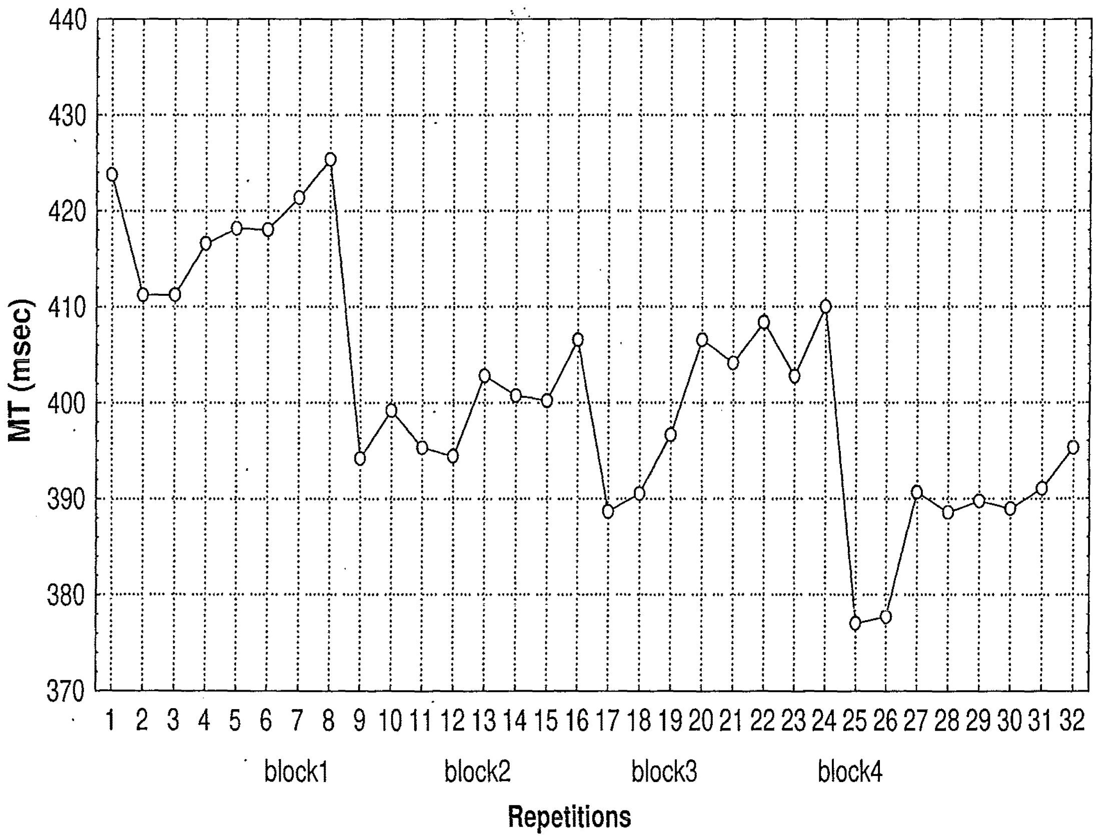
It is predicted that the rate of decrease in MT, will be greater across blocks for repeated sequence than for structured control sequence conditions. The data from the four training blocks were treated by the same analysis of variance as TRT data. Visual inspection of Figure 10 suggests participants exposed to repeated sequences during training have decreased MT compared to participants in the structured control training conditions. However the stimulus x blocks interaction effect does not reach significance $F(3,48) = .89$, $p>.45$. The main effects for blocks $F(3,48) = 12.58$, $p>.001$ and repetitions $F(7,112) = 2.81$, $p<.01$ are significant. The stimulus x counting x repetitions effect approaches significance $F(7,112) = 1.99$, $p=.062$ with structured control groups showing less increase over repetitions than repeated sequence groups especially the tone counting structured control. The remaining main and interaction comparisons did not reveal significant effects.

Figure 10 Mean MT as a function of repetition

(a) All groups



(b) Collapsed over groups

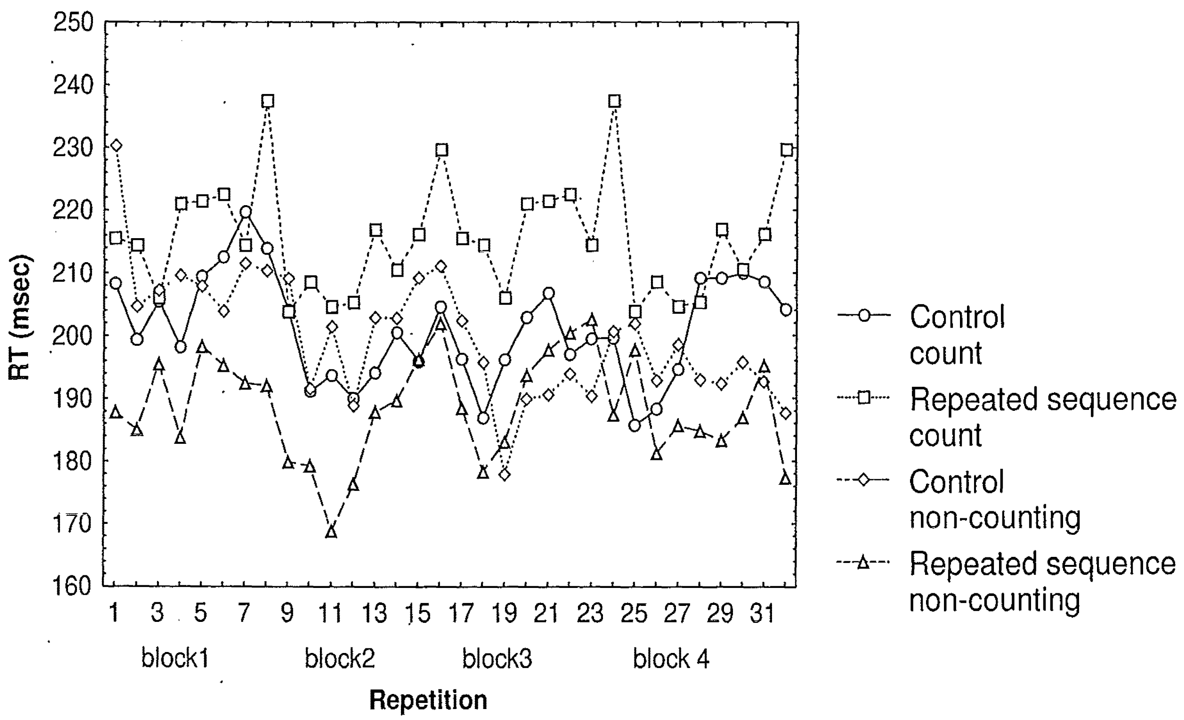


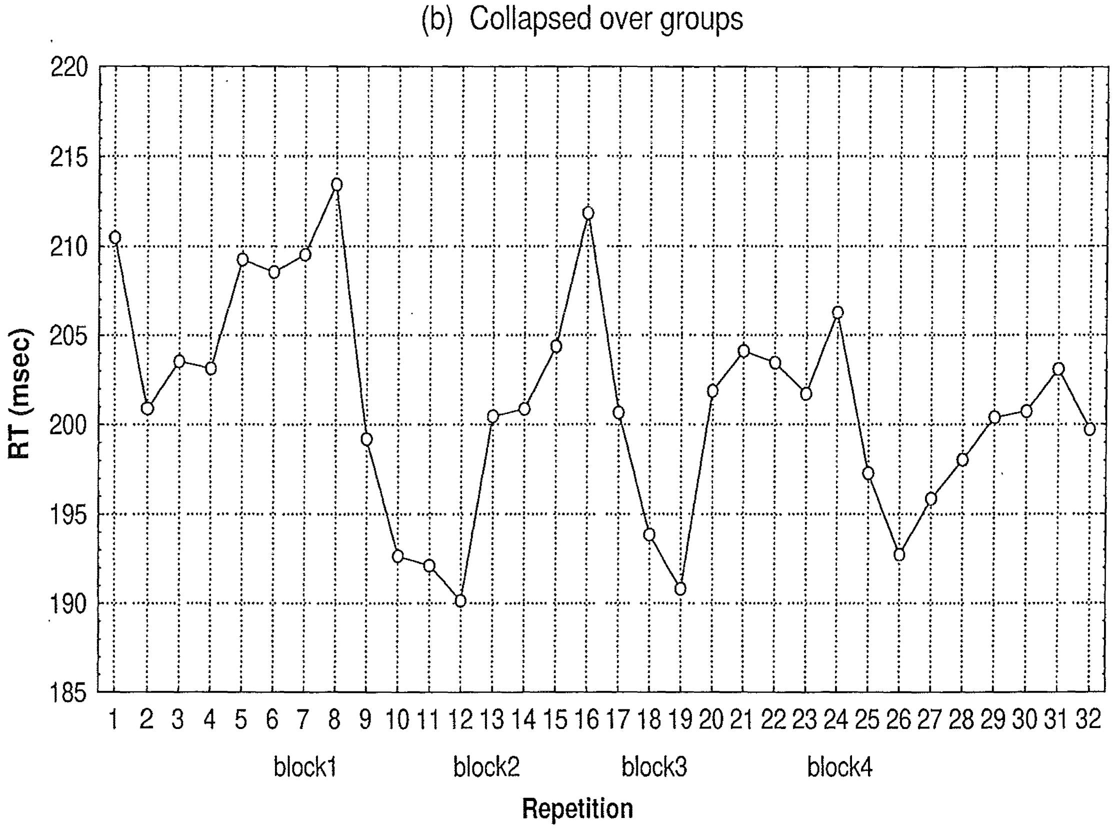
REACTION TIME

Similar to the pattern of results in Experiment 1, RT has no main block effect $F(3,48) = 2.11$, $p>.1$. The no-counting repeated sequence group was expected to improve in RT across blocks while the other three conditions were not. Neither the stimulus x count x blocks interaction $F(3,48) = .33$, $p>.8$ nor the stimulus x count x repetition interaction $F(7,112) = 1.05$, $p>.35$ were significant. There was again a significant repetitions main effect $F(7,112) = 3.815$, $p<.001$. A large decrease in RT between the first and second repetitions within a block is followed by a steady increase over the remaining 6 repetitions. This pattern is apparent for all conditions over the 4 blocks in Figure 11.

Figure 11 Mean RT as a function of repetition

(a) All groups





REAL TIME ANALYSIS

The real time analysis of TRT, MT and RT do not display the predicted interactions. Neither TRT nor MT reveals an advantage for repeated sequence groups over structured control groups. The expected advantage to subjects in the single task conditions is not apparent in RT, the proposed indicator of explicit knowledge. Being in a repeated sequence group afforded no advantage over either of the structured control conditions in any measure. Performing a single task produced slight advantages in MT for the structured control group but had no significant benefits.

The observed differences during repetitions for all measures and over blocks for TRT and MT appear to be genuine effects and not the product of nuisance variables. Potentially contaminating effects of physical movements, timing anticipations, incorrect response, and differential error rates are controlled for in the design. All four experimental groups improve in MT and TRT during the 4 blocks, suggesting that any task features learnt decrease the MT component selectively. The increase in repetitions for all measures suggest the task is prone to fatigue and that the larger practice period is effective. The decrease between the 1st and 2nd repetitions recorded in RT is may be due to the repeated sequence beginning in a random location for each block. The breaks between blocks produce the observed decreases across blocks, rather than any decreased increase in the repetitions effect as the interaction is not significant.

STRUCTURED INTERVIEW

The interview administered to all sequence condition subjects started with general task questions that lead to specific sequence questions and finally subjects were informed of the repeating sequence and it's length. If subjects mentioned a repeating sequence before being informed of its presence they were considered to have explicit awareness. If at any time during the interview they produced accurately any part of the sequence they were classified as being "more aware".

In the tone counting sequence group two subjects of the five were considered to demonstrate explicit awareness, no subjects produced any part of the sequence except in a general verbal description. For example, "it went around the board" when prompted to touch the specific lights an incorrect sequence fragment was produced. The remaining three subjects did not mention the sequence and expressed doubt when informed of it's existence.

In the no-counting sequence group two subjects produced short accurate fragments. The first was 4 items long and the second was 3 correct consecutive positions.

These subjects were considered "more aware". Of the remaining three no-count group members two had to be informed that there had been a repeating sequence while one mentioned the sequence and was considered to have explicit awareness of the sequence.

The results of the interview for the repeated sequence conditions were: 2 participants more aware, 3 aware and 5 less aware.

RECOGNITION TEST

Subjects classified by interview as having explicit awareness or "more aware" reported finding the recognition task difficult. This information was volunteered by the subjects who suggested that 3-item fragments were too short.

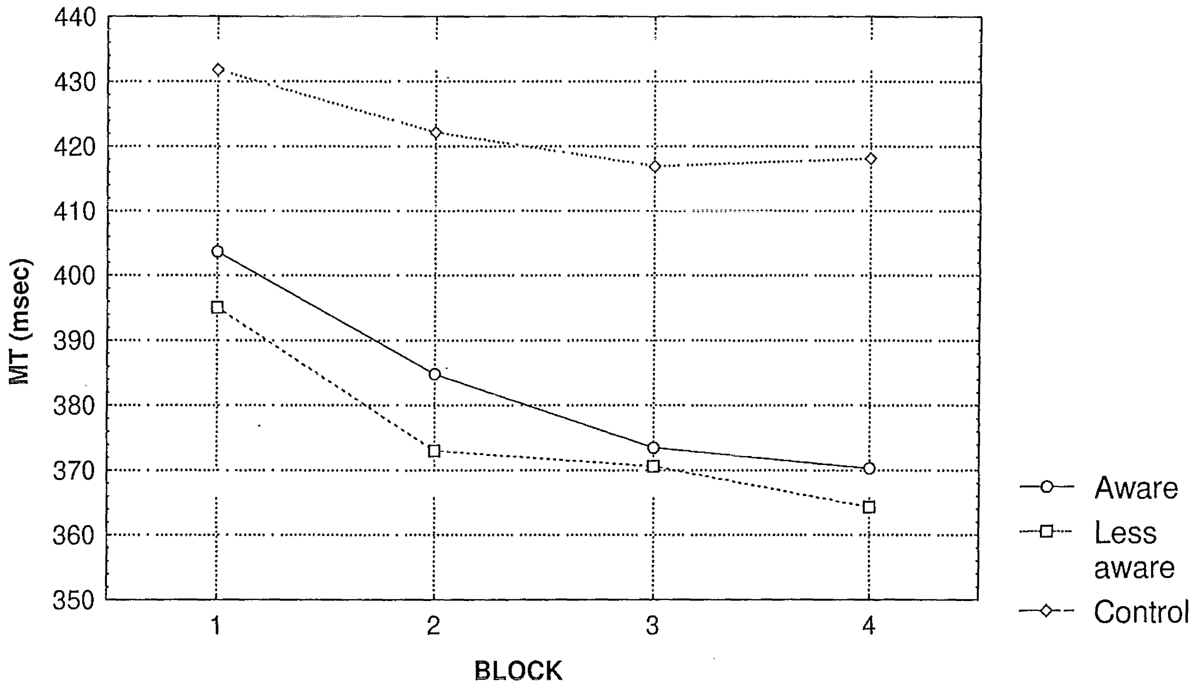
Data for each subject who completed the recognition test were collapsed to give a mean rating for "old" fragments and a separate mean rating for "new" fragments. These individual subject means were included in a mixed counting x recognition Anova. The mean recognition scores for subjects in the tone count repeated sequence group was 2.05 for the old, to be recognized fragments and 1.9 for the new to be rejected fragments. The no-count repeated sequence group had a mean rating for new fragments of 2.35 while the old fragments had a mean rating of 2.33. The interaction effect investigating the advantage to the no-count group in the recognition test was not significant $F(1,8) = .461$, $p>.5$. There were no significant main effects in this analysis.

The results of the recognition test were compared to the results of the structured interview to assess the similarity of the two direct explicit knowledge tests. The recognition test individual means were divided on the basis of interview into 3 groups: more aware, aware and less aware. The mean old and new recognition ratings were then examined for these groups. The results are presented in Table 1. A larger discrimination in ratings of familiarity between old and new for the more aware group is apparent and the interaction effect $F(2,7) = 5.632$, $p=.035$ is significant. Therefore the two direct tests are measuring similar effects. The mean ratings for old and new fragments separated into interview classifications are presented in Table 1. The difference in mean rating for old fragments was not significantly less than for new fragments in a more aware and aware combined group, $F(1,4) = .97$, $p>.35$.

INTERVIEW GROUP	RECOGNITION TEST RESULTS	
	OLD	NEW
More Aware	2.13	2.58
Aware	2.25	2.19
Less Aware	2.18	1.9

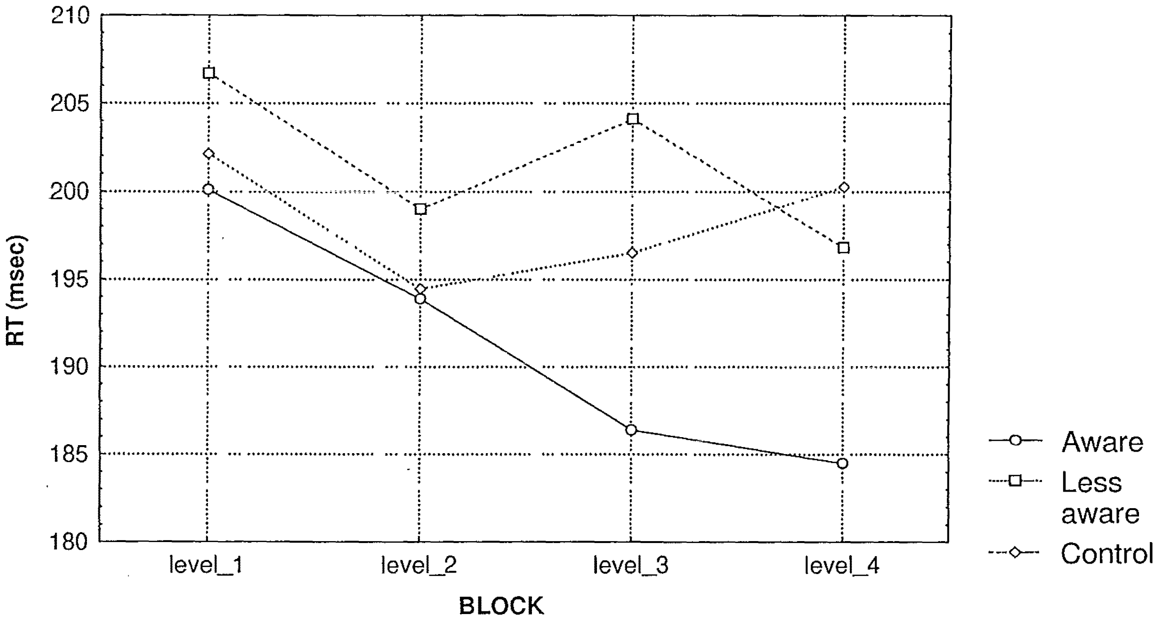
To further investigate the effects of explicit knowledge on response times, MT and RT scores for individuals were separated into 3 groups in accord with interview results. These three new groups: aware, less aware and control were treated by a mixed groups x blocks Anova. The aware group contained the 2 more aware subjects to increase this group to 5 members, the control group consisted of both tone counting and non-counting subjects as no significant difference has been observed between these two groups. The analysis of individual subject medians for each of the 4 training blocks produced no statistically significant group or interaction effects.

Figure 12 Mean MT for aware, less aware and control groups as a function of training block



The results are presented in Figures 12 and 13, the aware group appears to have decreasing RTs while the control and less aware groups do not. The aware and less aware groups appear to have more rapidly decreasing MT than the control group. These visible effects require further investigation. Only the aware group has a significant blocks effect in RT, $F(3,12) = 9.24$, $p<.01$, this is a large blocks effect and when an aware vs control interaction is investigated it approaches significance $F(3,39) = 2.62$, $p=.064$. For MT only the combined control group does not have a significant blocks effect $F(3,27) = .63$, $p>.6$, when the aware vs control analysis is run the interaction effect is not significant $F(3,39) = .46$, $p>.7$.

Figure 13 Mean RT for aware, less aware, and control groups as a function of training block



It would appear that direct test results do predict subject's RT improvements on the reaching task to a slight degree, but direct test results are not predictive of MT changes. The amount of explicit knowledge measured during the recognition test is not large and even the aware group of subjects do not reveal a significant difference between old and new fragments. It was not expected that the real-time analysis of RT would reveal explicit knowledge beyond direct tests.

FRAGMENT ANALYSIS

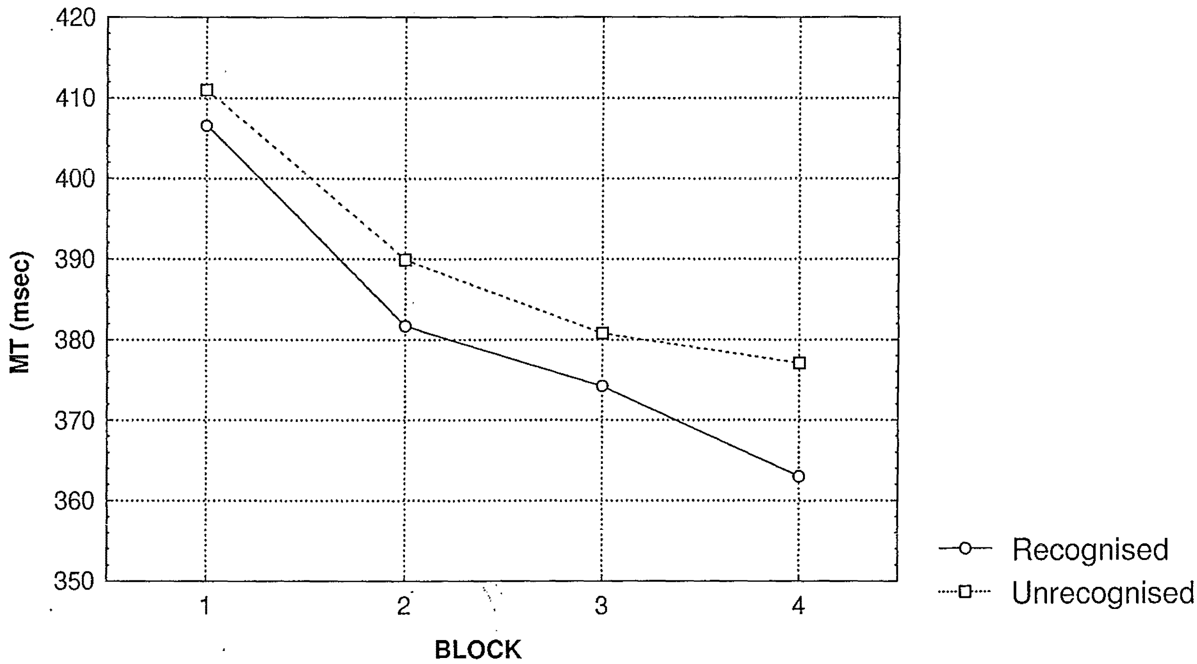
When the recognition test was introduced by Perruchet and Amorim (1992), an analysis that compared the rating on each fragment to the Response Times for that fragment was performed. A correlation was found with response times for recognized fragments being faster than those for fragments not recognized. One aim of this experiment is to characterize the pattern of response times when explicit knowledge is present. To achieve this aim the MT's and RTs for the fragments each subject correctly recognized were analyzed separately from those that were not recognized.

Each three item fragment was unique but the twelve old to be recognized fragments overlapped with the four adjacent fragments to completely cover the 12 item repeating sequence. For the hypothetical sequence string 1, 2, 3, 4, 3, three 3-item fragments would be created for the recognition test: 1, 2, 3; 2, 3, 4; and 3, 4, 3. The fragment 2, 3, 4, is overlapped by the adjacent fragments. A conservative estimate of explicit knowledge was used, where a fragment was only considered correctly recognized if one of the adjacent overlapping fragments was also recognized. The no-count sequence group correctly recognized on average 5.4 adjacent and overlapping fragments while the count sequence group correctly recognized 4.8 adjacent fragments on average.

The recognized fragments of the repeating sequence were separated from the unrecognized repeating sequence parts for each subject. The RT and MT data were analyzed along these dimensions to provide median recognized and unrecognized scores for each subject for each block of the training period. The first position in each recognized fragment of the sequence was classified as unrecognized because the position before which was "unrecognized" had no predictive power, and was considered to incur no RT benefits for the first position in each fragment.

Both MT and RT were investigated for an advantage for recognized fragments. Fifty six percent of all response times were included in the recognized category. The results are presented in Figures 14 and 15. Visual inspection of Figure 14 suggests little advantage for recognized fragments over those not recognized in the MT measure, while in Figure 15, the advantage to recognized fragments is easily observed, with RT decreasing across blocks. The implication is that only fragments that support explicit knowledge provide a decrease in RT, while MT decreases are observed for all fragments.

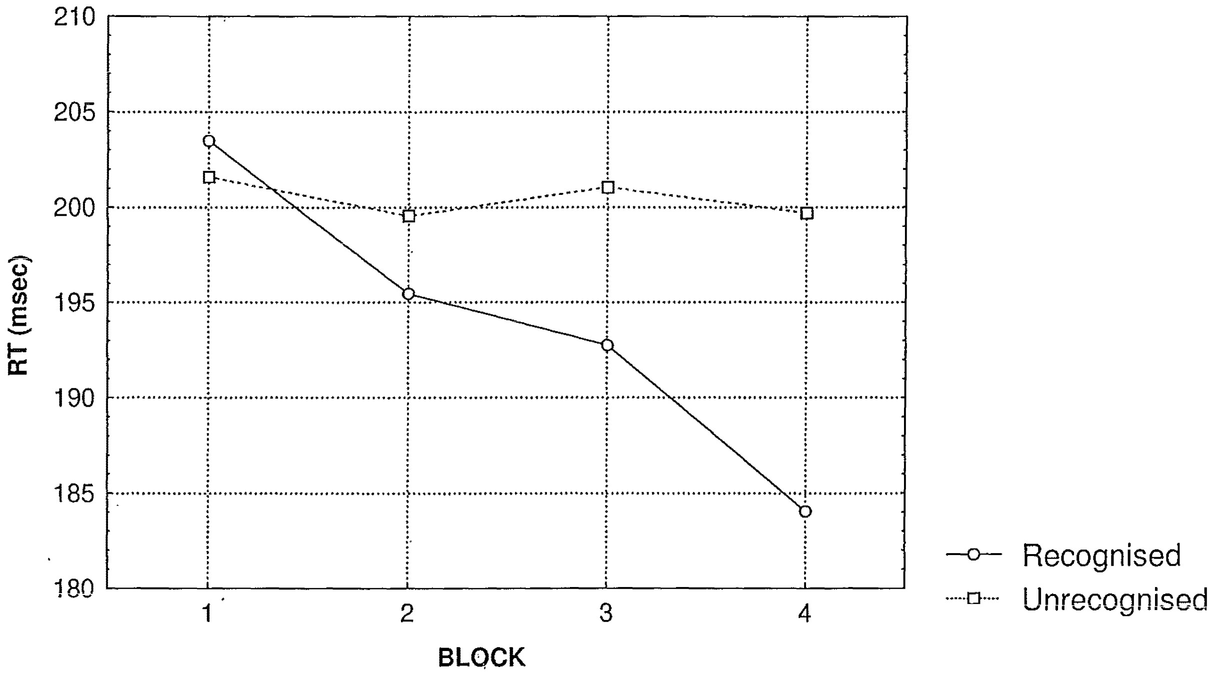
Figure 14 Mean MT for recognised and unrecognised fragments as a function of training block



The data were treated by a fragments x blocks repeated measures Anova, MT's decreased significantly over blocks, $F(3,27) = 7.07$, $p=.01$. There was no over all difference in MT's to recognized and not recognized fragments, $F(1,9) = 1.96$, $p>.15$, and fragments x blocks effect was likewise not significant, $F(3,27) = 1.11$, $p>.35$. This supports an overall improvement in MT unaffected by explicit knowledge.

When RTs were analyzed the blocks effect was found not to be significant but RTs to recognized fragments were made faster than to non recognized fragments, $F(1,9) = 6.83$, $p=.028$, and also the fragment x blocks interaction effect was significant $F(3,27) = 7.80$, $p<.001$. Further analysis shows that while there is no significant blocks effect for unrecognized fragments, recognized fragments produce RTs that decrease significantly across blocks F(3,27) = 4.69, p=.01. A concomitant of explicit knowledge is a decrease in RT across blocks.

Figure 15 Mean RT for recognised and unrecognised fragments as a function of training block



DISCUSSION

Experiment 2 created the opportunity for contrasting implicit and explicit learning response patterns. Real-time analysis of TRT and MT failed to support implicit learning of repeated sequence information. The longer practice period removed any early interaction effects, the length of the practice appears to be appropriate with no reduction in TRT or MT during the first block. The repetition analysis suggests that the reaching task induces fatigue and that benefits occur during inter-block intervals. This interval was not monitored and its length was determined by the participants, who initiated the next block of trials at will.

Removing the tone counting task did not reveal significantly greater explicit knowledge as measured by the direct tests and real-time analysis of RT. The single task condition had a slight advantage in MT for the structured control condition suggesting that the interference of the second task has a greater impact in the organization of structured frequency information than for explicit knowledge of exact repeated sequence locations. Stadler (1995) found that tone counting interfered with the organization of sequence information during implicit learning. The present results support that the impact of tone counting on implicit learning is greater than on explicit learning.

A further reason that the difference between the single and dual task conditions is minimal is that Stadler found that pauses caused nearly as much disruption to implicit learning in a single task design as tone counting in a dual task design. Although the pauses in the present design are not great there is a variable stimulus-target onset time which may act in a similar disrupting manner. The variable onset is important for removing timing anticipations, the pauses it causes are only 300 msec compared to Stadler's 1600 msec pauses. However, equally it could be argued that by using pauses the timing anticipation of subjects is reduced and using the SRT task any timing anticipation is recorded as implicit learning. Rather than the pauses disrupting implicit learning of sequence information they have disrupted participants initiation of movement in accord with the information that they are learning.

The direct tests of explicit knowledge were shown to measure similar information. Neither test detected significant amounts of explicit knowledge for the repeated sequence trained groups. RT was shown to be sensitive to the same information that produced direct test performance. The real-time analysis of explicit knowledge could be considered the more sensitive measure because the "aware" group of subjects produced RTs with a significant training blocks effect while the recognition test still recorded the explicit knowledge of this group as not significant.

Traditional and modal approach in implicit learning is a treatment groups analysis: dual task vs no dual task, even dividing subjects into more aware, aware, less aware. but in a learning context like this awareness is not all-or-none of the sequence, it is fragmentary and perhaps even fickle and unstable. People acquire fragments, hesitantly at first. Crude global analyses are insufficient and likely to give confusing and conflicting results. Following the example of Perruchet and Amorim, very fine grain repetition by repetition and fragment by fragment analyses are required. When this was done, consistent results were found.

A fine grain analysis of recognition test results and corresponding real-time RT data reveal that the RT measure alone is sensitive to fragmentary predictive explicit knowledge. The RTs of sequence fragments that received the definitely recognized rating, decreased in RT during the four training blocks. This reduction is probably related to the build up of predictive power by the fragments. It is interesting that the benefits of explicit knowledge are apparent by the second block, the observed decrease is very small and unlikely to be detected in changes in TRT where the small RT component is likely to be masked by the variability in the much larger MTs. The decrease in MT during training is much larger and not attributable to specific predictive explicit knowledge. This improvement must rely on a qualitatively different learning that doesn't differentiate a repeating sequence from a structured control sequence with the same simple frequency information, and is additive with the explicit RT benefits.

GENERAL DISCUSSION

The current research investigated the suitability of employing non-invasive real-time measures of implicit and explicit learning in the new serial reaching task. The serial reaching task was demonstrated to be capable of producing results similar to previous SRT studies on traditional direct and indirect tasks. The present findings should be considered applicable to previous SRT research and during this discussion the results of SRT studies are compared to those of the serial reaching task.

Performance on the SRT task is supported by three distinct processes: stimulus detection, response choice and response execution. It was proposed that the differential impact of explicit and implicit knowledge on these processes be exploited to experimentally differentiate between task performance based on explicit knowledge and implicit knowledge. The primary difference was the temporal occurrence of the response choice process, the hypothesis being that explicit knowledge permits the response choice to be made prior to stimulus onset. The stimulus detection process was considered unnecessary when predictive knowledge combines with timing anticipation, this feature could occlude the desired response choice changes. To ensure all subjects, regardless of predictive knowledge performed the stimulus detection process the stimulus onset interval was randomly varied 450-700 msec.

The response choice process was proposed to be assessed independently of the response execution process by recording subject's reaction time from stimulus onset to movement initiation. The RT would include any response choice processing as well as a standard stimulus detection process. As explicit knowledge of the repeating sequence emerged the response choice process would show corresponding temporal forward displacement and the RT measure would decrease.

The response execution process was recorded by a separate movement time, from homekey release until target contact. The decreases in MT indicate learning of task characteristics that do not allow prediction of the next targets location, while theoretically these measures can not be considered entirely process pure the experimental evidence suggests that they are reasonably so.

It was consistently demonstrated during Experiments 1 and 2 that the groups known to be without explicit predictive knowledge did not reduce in RT across blocks. Performance in these conditions can not be attributed to processing the response choice before stimulus onset and any decreases must be related to response execution improvements only. It is therefore concluded that response execution is not measured by RT and response execution learning does not decrease the RT measure.

Support that RT measures the temporal displacement of the response choice process was established during Experiment 2. The reduction in RT during training blocks by a group of subjects classified as being "aware" compared to other repeated sequence trained and structured control subjects indicates that explicit knowledge produces RT decreases and further that the MT changes of this group were statistically similar to less aware, and control subjects. A fine grain analysis establishes the validity of this point, when recognized fragment response times are separated from the response times of fragments not recognized, an identical pattern is observed. Only recognized fragments reduce in RT while the MTs of both recognized and unrecognized fragments reduce equally in MT.

The "aware" condition and recognized fragments have predictive power and the response choice can be made prior to stimulus onset decreasing the RT measure alone. MT advantages for these predictively empowered groupings are not observed, indicating the temporal placement of response choice has no impact on the response execution process in the reaching task. Therefore it is concluded that the dissociation of response choice processes from response execution processes is achieved by the RT/MT dichotomy.

By removing timing anticipation of stimulus onset the advantage for repeated sequence trials accompanied by explicit knowledge is reduced. Explicit knowledge of some repeated sequence fragments was demonstrated to incur RT benefits by the second block of training during Experiment 2. The longer inter-trial interval in the reaching task may have facilitated this onset, however the evidence suggests that the advantage afforded by this fragmentary predictive knowledge could have contributed to the real-time interaction effect observed by Reed and Johnson (1994) and their resulting conclusion that repeating sequence learning provides an advantage over structured control conditions.

The present study provides little evidence that training on a repeating sequence provides implicit learning beyond that of a control condition, which contains similar frequency information. A longer practice period in Experiment 2 removed any real-time interaction effects in TRT observed in Experiment 1. Real-time investigation of the MT measure provided no evidence for learning beyond the structured control for any repeating sequence group in either Experiment 1 or 2.

The indirect transfer task was shown to be sensitive to explicit knowledge and when this was removed from the analysis, the MT rebound alone was not significant. A repeating transfer block was shown to be an inappropriate indirect test because the possibility of explicit learning of the new repeating sequence. Although the RT rebound may be due to some response execution processing being recorded in this measure the previously presented evidence does not support this. Both indirect test groups showed decreasing RTs over training blocks. This has been shown experimentally to occur when explicit knowledge is present. The observed rebound in RT is most likely due to explicit incorrect response choice processing, although this is not conclusively established.

The direct recognition test was shown to measure explicit knowledge that produced RT benefits while still recording this knowledge as not significant when an analysis comparable to that Reed and Johnson is used. As explicit knowledge is a build up of fragmental information this sort of analysis does not do justice to the sensitivity of the test. It was shown in Experiment 2, that significant RT improvements are associated with recognition test performance that does not achieve statistical significance. It was proven during the fine grain fragment analysis that it is not because RT is a more sensitive measure only that the recognition test performance must be examined with an appropriate analysis.

The conceptualization of implicit learning as a build up of weightings for the four different motor action plans does not suggest that an advantage for repeated sequence trained groups over suitably controlled non-repeating similar frequency groups, would be observed. Instead a difference between conditions with differing frequency information is predicted. Stadler (1992) performed a study that supports this description of implicit knowledge, although different terminology was used, in the study, Stadler found the greater the statistical structure in non-repeating conditions the greater the decrease in response time and described an aggregate representation similar to the action plan argument.

In Reed and Johnson (1994) Experiment 1 a rebound is observed when a non-repeating structured condition, similar to the present control conditions, transferred to a random sequence. This suggests that the non-repeating frequency information affords learning. In the present study a rebound in MT is observed when the repeating sequence group transfers to a non-repeating structured block, while this rebound does not reach significance it does suggest that the MT measure alone will record this non-predictive frequency learning. It also suggests that not all the frequency information of the repeating sequence is contained in the non-repeating control, which is true, and more complex frequency information such as third order conditionals are not controlled.

The improvements in MT across training blocks although not significantly different for repeated sequence and structured control groups, are significant in both experiments. This learning effect is large and while it may contain task characteristics unrelated to training sequences it is indicated that it is measuring learning that is qualitatively different from that measured by direct tests. The present research does not support that this learning is inaccessible to explicit knowledge. It is apparent however that the MT learning is not differentially influenced by predictive explicit knowledge such as measured by the recognition test. If the knowledge that underlies these MT decreases is explicit, it is qualitatively different from that producing RT decreases.

Predictive explicit knowledge measured by the interview, recognition test and RT decreases requires the presence of a repeating sequence, at least in the present experiment. The knowledge that supports MT decreases during training and rebound effects on transfer does not rely on a repeating sequence, a structured non-repeating sequence provides the opportunity for this type of learning to occur.

The reaching task has been shown to be a useful research tool for implicit learning studies as it circumvents the major short comings of previous SRT, studies by providing measures of actual "knowledge used" instead of post hoc "knowledge of". It is also possible to explore each participant's performance for evidence of "implicit" and "explicit" knowledge. The RT-MT distinction appears to be a noninvasive real time measure of learning that distinguishes predictive explicit learning from other learning in the same individual.

The new reaching task also removes incorrect responses, although mid-flight corrections need to be examined. By removing incorrect responses, action plan weights and therefore implicit learning should build correctly. The task also virtually eliminates anticipation errors. These result when timing anticipation and response anticipation combine, the variable onset is detected by participants during practice, requiring that they not remove their finger from the "homekey" until a stimulus is detected. Further benefit for the reaching task is that tone counting is not indicated in reducing explicit knowledge and therefore tone counting errors need not be a problem. Again the variable timing onset can decrease the impact of explicit knowledge, without the need for the secondary task (Stadler, 1995)

During Experiment 2 repetition effects were observed for all measures. These effects appear to be related to fatigue. In MT a constant but gradual increase is observed during each training block, while RT increases are less constant. This suggests that learning has the greatest impact immediately following the inter-block intervals and that these should be monitored carefully and perhaps the length of each block reduced, to achieve maximum learning effects.

The reaching task introduces some problems inherent in the design used. The first is the mentioned problem with moisture on the touch sensitive contacts, this could be avoided by replacing them with traditional switches or by using an intermediary object, such as a block, which acts as the non-sweating contact. Subjects move the block from the "home-plate" to a "target-plate". Another problem is the longer varying interval between trials is not monitored and there is no incentive to return as fast as possible to the homekey. Even the onset delay may correlate with the emergence of explicit knowledge. Although further investigation of such variables is indicated, the accomplishments of the present research stand. The means of distinguishing predictive explicit learning from response execution improvements, which are possibly implicit, has been established.

REFERENCES

Bootsma, R. J. (1989). Accuracy of perceptual processors subserving different perception-action systems. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 41, 489-500.

Cohen, A., & Curren, T. (1993). On tasks, knowledge, correlation, and dissociations: Comment on Perruchet and Amorim (1992). *Journal of Experimental Psychology: Learning Memory and Cognition*, 19, 1431-1437.

Cohen, A., Ivry, R., & Keele, S. (1990). Attention and Structure in sequence learning. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 16, 17-30.

Curran, T., & Keele, S. W. (1993). Attention and structure in sequence learning. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 19, 189-202.

Frensch, P., Buchner, A., & Lin, J. (1994). Implicit learning of unique and ambiguous serial transitions in the presence and absence of a distracter task. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 20, 567-584.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

La Heig, W., Kaptein, N.A., Kaliff, A. C., & de Lange, L. (1995). *Reducing color-color interference by optimizing selection for action.* Psychological Research, 57, 119-130.

Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology,* 19, 1-32.

Pascual-Leone, A., Grafman, J., & Hallett, M. (1994). Modulation of cortical output maps during development of implicit and explicit knowledge. *Science,* 263, 1287-1288.

Perruchet, P., & Gallego, J. (1993). Association Between Conscious Knowledge and Performance in Normal Subjects: Reply to Cohen and Curran (1993) and Willingham, Greeley, and Bardone (1993). *Journal of Experimental Psychology: Learning, Memory and Cognition,* 19, 1438-1444.

Perruchet, P., & Amorim, M. (1992). Conscious knowledge and changes in performance in sequence learning: Evidence against dissociation. *Journal of Experimental Psychology: Learning, Memory and Cognition,* 18, 785-800.

Reed, J., & Johnson, P. (1994). Assessing implicit learning with indirect tests: Determining what is learned about sequence structure. *Journal of Experimental Psychology: Learning, Memory and Cognition,* 20, 585-594.

Shanks, D. R., & St John, M. F. (1994). Characteristics of dissociable human learning systems. *Behavioral and Brain Sciences,* 17, 367- 447.

Stadler, M. (1989). On learning complex procedural knowledge. *Journal of Experimental Psychology: Learning, Memory and Cognition,* 15, 1061-1069.

Stadler, M. (1992). Statistical structure and Implicit Serial Learning. *Journal of Experimental Psychology: Learning, Memory and Cognition,* 18, 318-327.

Stadler, M. (1995). Role of attention in implicit learning. *Journal of Experimental Psychology: Learning, Memory and Cognition,* 21, 674-685.

Tipper, P., Lorte, C., & Baylis, G. (1992). Selective reaching: Evidence for action-centered attention. *Journal of Experimental Psychology: Human Perception and Performance,* 18, 819- 905.

Van der Heijden, A. H. (1993). The role of position in object selection in vision. *Psychological Research,* 56, 44-58.

Willingham, D., Greeley, T., & Bardone, A. (1993). Dissociation in a serial response time task using a recognition measure: Comment on Perruchet and Amorim (1992). *Journal of Experimental Psychology: Learning, Memory and Cognition,* 15, 1047-1060.

Willingham, D. B., Nissen, M. J., & Bullemer, P. (1989). On the development of procedural knowledge. *Journal of Experimental Psychology: Learning, Memory and Cognition,* 15, 1047- 1060.

Appendix A

University of Canterbury
Department of Psychology

Information

You are invited to participate as a subject in the research project entitled "Serial Reaction Time."

The aim of this project is to measure the time taken to turn off lights occurring in an extended sequence.

In this experiment lights on a small panel come on one after the other, each light has a touch sensitive pad above it. Your task is to turn the light off as quickly as you can, by touching the associated pad. The time it takes you to turn the light off is measured and recorded. After you turn one light off and press the home key another light will come on. You will also hear high and low tones as you work at turning the lights off. You are required to count the number of high tones while ignoring the low tones.

The lights come on 96 times in a block, after you have completed 9 of these blocks you will either be asked a few short questions about the task or you will perform another block of 96 trials. You will be required in total for about thirty minutes, this time includes an initial practice period. Participation in this research conveys no risk to you.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: the identity of participants will not be made public. To ensure anonymity and confidentiality the consent form that you sign will be kept in a locked drawer in the experimenters office. Your name will never be linked with the data produced as you will be assigned a random subject number.

The project is being carried out by Tania Leadley, who can be contacted at the University on ext.7179 or at home (03) 3027957. She will be pleased to discuss any concerns you may have about participation in the project.

The project has been reviewed and approved by the University of Canterbury Human Ethics Committee.

Appendix B

Consent Form

Serial Reaction Time

I have read and understood the description on the above-named project. On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved. I understand also that I may at any time withdraw from the project, including withdrawal of any information I have provided.

Signed.. Date...............................