Sequence learning by action and observation: Evidence for separate mechanisms

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In the Serial Reaction Time (SRT) task, participants respond to a set of stimuli the order of which is apparently random, but which consists of repeating sub-sequences. Participants can become sensitive to this regularity, as measured by an indirect test of reaction time, but can remain apparently unaware of the sequence, as measured by direct tests of prediction or recognition. Some researchers have claimed that this learning may take place by observation alone. We suggest that observational learning may be due to explicit acquired knowledge of the sequence, and is not mediated by the same processes which give rise to learning by action. In Expt 1, we show that it is very difficult to acquire explicit sequence knowledge under dual task conditions, even when participants are told that a regular sequence exists. In Expt 2, we use the same conditions to compare *actors*, who respond to the sequence during learning, and *observers*, who merely watch the stimuli. Furthermore, we manipulate the salience of the sequence, in order to encourage learning. There is no evidence of observational learning in these conditions, despite the usual effects of learning being demonstrated by *actors*. In Expt 3, we show that observational learning does occur, but only when observers have no secondary task and even then only reliably for a sequence which has been made salient by chunking subcomponents. We conclude that sequence learning by observation is mediated by explicit processes, and is eliminated under conditions which support learning by action, but make it difficult to acquire explicit knowledge.

The Serial Reaction Time (SRT) task is used widely in both the motor learning and implicit learning literature. Participants see a sequence of stimuli, for example an 'X' appearing at one of four different locations on a computer screen, and must respond to each stimulus, for example with a button press corresponding to the position of the 'X'. Participants are usually told that the stimuli will appear in random order; however the order is in fact manipulated by the experimenter, and consists of a short repeating sequence. After many trials, reaction times (RTs) typically decrease. The sequence is

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then disrupted, in that a novel stimulus order is introduced. Participants' acquired knowledge of the learning sequence is measured by their increased RT to the new sequence. This indirect measure of sequence learning is often contrasted, within the same experiment, to a direct measure of sequence knowledge, such as asking participants explicitly to predict items or recognize sub-sequences. It is quite common for participants to show evidence of learning on the indirect measure, while showing no evidence of learning on the direct measure.

This study was concerned primarily with conditions in which participants show learning on an indirect test but not on a direct test. Our aim was to establish whether this type of learning without awareness can occur by simple observation of stimuli, or whether it requires action on the part of the learner. However, before describing these experiments, we briefly review the accounts of sequence learning which are currently under debate. We should note that the effect generalizes over a number of surface forms. For example, the most common version of the task involves stimuli appearing at four different spatial locations on a computer screen, although Mayr (1996) has shown that a non-spatial, as well as a spatial, sequence can be learned. Goschke (1996) has also demonstrated this effect using different response criteria.

Cohen, Ivry, and Keele (1990) examined the type of sequence which could be learned. They used three different types of sequence: unique (each item in the sequence had a unique association with the next item), ambiguous (each item was followed by two different items at different positions in the sequence) and hybrid (contained both ambiguous and unique parts). They found that under single task conditions, participants learned all three types of sequence. However, under dual task conditions, only the unique and hybrid sequences were learned. They hypothesized that learning in the SRT task is underpinned by a non-attentional system which operates without awareness and forms associations between sequentially presented items, and an attentional system which requires awareness and forms hierarchical representations of the sequence structure. Although this result was confirmed by Curran and Keele (1993), Frensch, Buchner, and Lin (1994) found that even under dual-task conditions, ambiguous transitions within a hybrid sequence could be learned. Hsiao and Reber (1998) suggest several possibilities for why these differences exist; however, the existence of a separable attentional and non-attentional system remains under debate.

Recently, Goschke (1998) has proposed independent mechanisms for the learning of stimulus and response sequences. Previous debates in the literature have centred on whether SRT performance arises out of perceptual learning, or motor learning of required responses. Nattkemper and Prinz (1997) gave participants a task in which they were required to respond to eight different letters using four different response keys. The letters were paired according to which response key had to be used. The letters appeared sequentially although occasionally an item would appear which violated the sequence. Nattkemper and Prinz found that there were reaction time costs only when the irregular stimulus required a different response to that required by the regular stimulus. Ziessler (1994) also found that performance was degraded in a matrix scanning task when participants had to respond to a display using the same response as compared to conditions with a unique response for each stimulus. These results suggest that learning can be specific to a particular effector site.

Willingham, Nissen, and Bullemer (1989) attempted to separate knowledge of the stimulus presentation from knowledge of the responses by using coloured stimuli. The stimuli could appear in four different spatial locations but participants were required to respond to colour. Willingham *et al.* found a reduction in response latency only for a

random colour sequence and not a random spatial one, suggesting that learning is mediated primarily by motor systems. However, in a transfer task where responses were made to uncoloured stimuli in sequential locations, transfer was not shown when the location sequence gave the same pattern of responses as the earlier motor condition. This led Willingham *et al.* to conclude that learning is not solely motor nor solely perceptual in nature, but occurs at some information processing stage between perception and action. Recently, though, Willingham (1999) found robust transfer of knowledge in changing from digits to spatial cues. Willingham notes that this should change the stimulus response mappings but learning was unaffected. He suggests that participants may be learning a set of locations in egocentric space to which they should respond.

Other evidence for SRT learning being perceptual in nature comes from Howard, Mutter, and Howard (1992). They found that participants instructed only to watch a display demonstrated as much learning as those who had been responding manually during the training phase. Stadler (1989) trained participants on a sequence learning task then gave two transfer conditions. In one condition responses were the same as in the learning phase, and in the other, the target positions were the same. Stadler only found transfer when the target positions were the same as in the training task. Seger (1997) also reports observational learning of a 10-item sequence under both dual and single task conditions.

An explicit and an implicit system?

One possible reason for the discrepancies between these many studies is that different results reflect differential learning by implicit and explicit mechanisms. There is substantial experimental and neurological evidence that learning with and without awareness in the SRT task are not identical processes. Since the task was first described (Nissen and Bullemer, 1987), many studies have reported learning on the indirect RT measure in the absence of learning being demonstrated on direct measures, such as verbal awareness, prediction or recognition tasks. However, some experimental reports describe participants who do become aware of the sequence. Willingham *et al.* (1989) found that participants aware of the sequence showed stronger behavioural evidence of learning than those unaware of the sequence, a difference of up to 100 ms.

Some direct measures of learning have been criticized as not being sufficiently sensitive (e.g. Shanks & St John, 1994), and hence it is possible that participants who show no evidence of awareness on direct tests nevertheless are aware of some characteristics of the sequence. However, neuropsychological evidence points to a dissociation in learning systems when participants are classified as aware or unaware. Eimer, Goschke, Schlaghecken, and Sturmer (1996) found differential ERP patterns for those who were aware of the sequence and those unaware on direct tests. Pascual-Leone, Grafman, and Hallet (1994) used Transcranial Magnetic Stimulation during SRT learning and found that motor fields expanded during the time when participants were deemed to have little explicit knowledge but decreased in size with increased practice and associated explicit awareness. They interpret this as showing the possible role for motor cortex in implicit learning with the decrease in field size reflecting development of explicit knowledge and takeover by other brain mechanisms. Both the methodology and interpretation of this study have been criticized by Stadler (1994), who suggests that the expansion of the motor cortex field might better represent explicit learning and the return to baseline being more indicative of

automatization. In a single/dual task paradigm, Grafton, Hazeltine, and Ivry (1995) found differential patterns of awareness for two groups, one of whom performed the SRT task under dual task conditions and the other under single task. In addition, Positron Emission Tomography (PET) showed that different brain regions were associated with the different patterns of awareness. Specifically, sensorimotor and parietal cortex, supplementary motor areas and the putamen were implicated with implicit learning. With explicit learning, areas of activation were found to be pre-frontal cortex, basal ganglia and parieto-occipital areas. Hazeltine, Grafton, and Ivry (1997) found similar results using a non-spatial sequence.

All these sources of evidence suggest that learning during the SRT task is fundamentally different, according to whether participants are aware of the sequence or not. This makes it rather difficult to compare some SRT studies in the literature. For example, both Cohen *et al*. (1990) and Keele, Jennings, Jones, Caulton, and Cohen (1995) used sequences which were only five items long. The use of such short sequences raises the possibility that the pattern may have been quite salient to participants. Ziessler (1994) used only a verbal awareness test which is now considered unsuitable for eliciting explicit knowledge (e.g. Shanks & St John, 1994).

Acting versus observing

The SRT literature contains apparently contradictory results on the possibility of implicit learning through mere observation. Studies by Howard *et al*. (1992) and Seger (1997) have provided evidence of learning on indirect (RT) tests for participants who observe stimuli during a learning stage rather than respond to them. In contrast, Willingham (1999) and Kelly and Burton (2001) provide evidence that observer participants cannot learn sequences. The awareness data from the studies by Howard *et al*. (1992), showing learning by both actors and observers, reveals that observers showed significantly higher levels of awareness than actors. It is possible that the way in which observers learn the sequences is in fact different from the way in which actors learn it, and specifically it may be that observers are learning the sequence explicitly. In fact, when attempting to replicate these results, Willingham (1999) found that only observers classed as 'high awareness' participants showed evidence of observational learning. More experimental evidence is required to resolve this debate as the study by Willingham was correlational, in that the awareness was identified after the direct tasks and not manipulated experimentally. Additionally, as Willingham and Kelly and Burton's position requires that a null hypothesis be accepted, it is important to demonstrate replication of the null effect across a variety of situations. These examples suggest that the apparently contradictory SRT literature might be resolved by consideration of the awareness of participants in particular experiments.

In the present study, we examined learning by observation under conditions which are designed to eliminate most, if not all, explicit learning. In Expt 1 we demonstrated a sequence learning task in which it is very difficult to develop explicit awareness. In Expt 2 we went on to use this task to examine observational learning. Specifically, we tested whether learning by observation is possible in conditions which make explicit knowledge very difficult to acquire.

The sequences used in all our experiments were long (12 items in length) and required second order knowledge (i.e. an item can only be uniquely predicted by the preceding two items). In addition, participants were required to carry out a secondary task, accurate tone counting, during the learning phase of the experiments. This type of

dual task learning has been shown to result in less explicit knowledge than single task learning (Goschke, 1998; Seger, 1997). It was anticipated that such a combination of sequence structure and learning conditions would make it unlikely that explicit awareness would develop. Experiment 1 examined this assumption by assessing the amount of explicit awareness using a recognition task. However, given criticisms that such tasks may not access all explicit knowledge or may be contaminated by implicit knowledge, half of the participants were given incidental learning instructions as normal and half were told that there was a repeating sequence and encouraged to discover it. The inclusion of this latter group was intended to maximize the possibility of awareness developing.

EXPERIMENT 1

Method

Participants
A total of 60 participants were recruited from the student population of the University of Glasgow. All were naïve to the experimental aims of the study and all received a small payment in return for their participation. All participants had normal or corrected-to-normal vision.

Materials
The stimuli were presented to the participants on a Power Macintosh using the 'Superlab' experimental package. Participants made their responses using a standard computer keyboard.

Design and procedure
There were two stages to the experiment. In the sequence learning phase, participants were exposed to a repeating sequence which was eventually disrupted, as in the normal SRT. In the second, unexpected, phase of the experiment, participants were given a recognition task, which served as the direct test of learning.

Part 1: Sequence learning
Participants were positioned in front of the computer, their eyes at a distance of 50 cm from the computer screen. Four boxes, arranged in a row, appeared in the middle of the screen. The boxes were 3.5 cm × 3.5 cm in size and placed at an equal distance of 3.5 cm from one another. A black asterisk, 2 cm in diameter, could appear in any of the four boxes. The response-stimulus interval was 250 ms. Participants were informed that the experiment would examine the effect of tone counting on reaction times made to stimuli appearing at uncertain locations. They were told that an asterisk would appear at random locations in one of the four boxes. Their task was to press a key corresponding to the location of the asterisk. Response keys were v, b, n and m on the keyboard mapping spatially onto the responses A, B, C and D, respectively (where A stands for the left-most box, B for inner-left etc.). Participants were instructed to use the middle and index fingers of each hand for responding with each finger remaining in light contact with each key throughout the entire experiment. Before starting the experiment, participants were shown examples of the stimulus-response mapping. They were

informed that there would be 10 blocks of trials in total with an opportunity to rest between each.

Participants were told that each time they made a response they would hear a tone. This tone would either be high-pitched or low-pitched, and examples were provided. The hi/lo order of the tones was generated once, at random, but this same sequence was held constant for all participants in order to equate task demands. They were told to count the number of high tones, and were asked to report the total at the end of each block.

Participants were assigned randomly to one of four experimental groups. Two of the four groups were not told about the presence of a sequential pattern in the asterisk locations. These were termed the 'incidental learning groups'. The remaining participants were informed about the presence of the sequential pattern of the asterisk locations. They were told that they would find it helpful if they discovered the underlying sequence, but that they should not slow down in order to do so. These were termed the 'intentional learning groups'. Two different sequences were used in this experiment, and half the participants in each group (intentional and incidental) learned each. Both sequences were 12 items long and were constructed to meet the specifications of a Second Order Conditional (SOC) sequence (meaning that each position in the sequence can be identified uniquely by the preceding two positions) detailed in Reed and Johnson (1994).

In sequence one (SOC1), the asterisk appeared in the spatial order of BDBACDABCADC (see above for spatial mapping). In sequence 2 (SOC2), the asterisk appeared in the order of BDACBADBCDCA. According to Reed and Johnson, these two sequences should be matched for:

(1)   location frequency (the frequency with which each target location is represented within the sequence);
(2)   transition frequency (the frequency with which each possible location transition occurs);
(3)   reversal frequency (the frequency with which back-and-forth movements occur);
(4)   rate of full coverage (the average number of targets encountered so that each possible location has been occupied at least once); and
(5)   rate of complete transition usage (the average number of targets encountered so that each possible transition has occurred at least once).

Blocks 1–8 consisted of either SOC1 or SOC2 and Block 9 introduced a novel sequence, the sequence from the counterbalanced group, to participants. Stimulus presentation in Block 10 reverted back to the learning sequence for each group. Participants were not made aware of these changes. These sequences were repeated without pause for eight cycles per learning block and each asterisk appeared until a response was made.

After each block of trials, participants were asked how many high tones they had counted in that particular block. Participants with a higher than 10% error rate on any block were replaced.

Part 2: Direct measure of awareness
After completing the 10 blocks of trials satisfactorily, participants were informed that a further task would follow. Those in the incidental learning groups were advised that the asterisk had not appeared at random, but that it had appeared according to a certain sequence. This sequence was repeated throughout each block, except Block 9.

Participants in the explicit groups were reminded of the existence of the sequential nature of the asterisk position. Both groups were informed that the tones had appeared at random and were simply there to make identification of the sequence difficult.

Participants were then informed that their knowledge of the sequence would be tested. To do this, they were required to respond to six-item chunks of the sequence as fast as possible by responding to the asterisk as before. They were reminded that they had to be as fast and as accurate as they could, and a cash incentive was offered to the two participants who had the highest accuracy and speed. There were no tones presented during this phase of the experiment. There were 24 chunks in total with 12 of these taken from the learning sequence and the other 12 from the test sequence (Block 9).

After responding to each chunk, participants were asked to rate whether the chunk they had just seen was new to them or whether it formed part of the sequence they had been responding to throughout the learning phase. There was no time constraint for this decision. They were then fully debriefed.

Results

Figure 1 shows means of participants' median RTs for each block. All four groups show general decreasing RT with practice. All groups show increased RTs in Blocks 4 and 7, in opposition to the overall trend. The explanation for these two anomalous points is straightforward as these two blocks contained the largest numbers of high tones to be counted (59 in Block 4 and 55 in Block 7, as compared to an average of 45.6 [$SD = 3.9$] across the other eight blocks). The problem of differential difficulty of the secondary task does not arise for the three test blocks (8, 9 and 10) as the number of high tones to be counted was equal in all three.
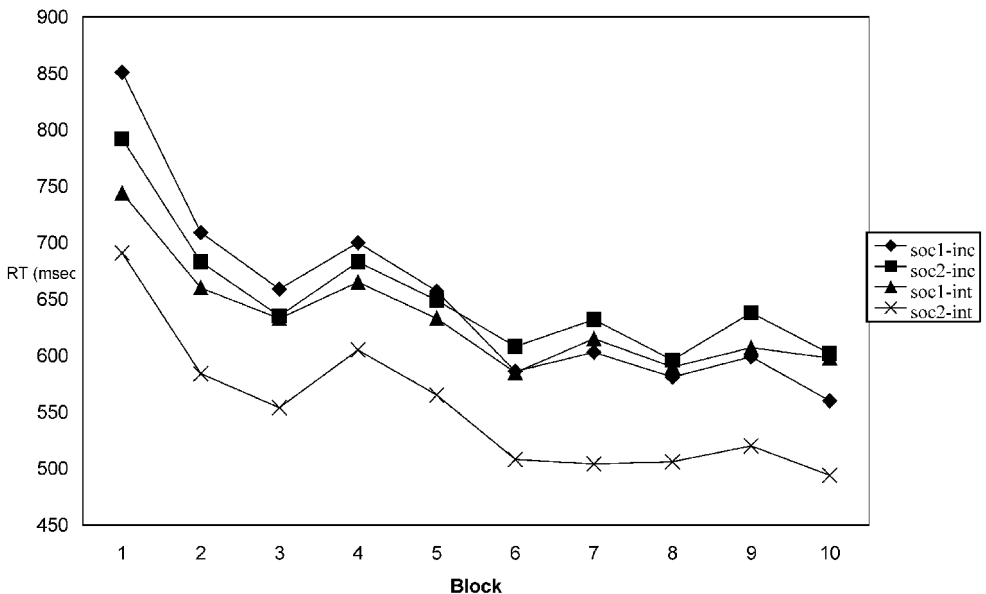

Figure 1. Reaction times for action and observation groups under incidental and intentional learning instructions. Note: inc = incidental learning instructions; int = intentional learning instructions.

Examination of the three test blocks shows that all groups displayed increased RTs when a new sequence was encountered (Block 9) and a subsequent decrease when responding to the familiar sequence again (Block 10). For statistical analyses, the average RTs for Blocks 8 and 10 are compared to Block 9. Analyses comparing Blocks 8 and 9, and Blocks 9 and 10, are not substantially different, and so for the sake of brevity, only the single analysis is reported.

A 2 (instruction: incidental vs. intentional)×2 (sequence: SOC1 vs. SOC2)×2 (learning: Blocks 8 and 10 vs. Block 9) mixed design ANOVA was conducted on RTs. There was a significant interaction between sequence and instruction, $F(1,56) = 4.63$, $p < .05$, MSe $= 26420$. This was caused by the 'SOC2—intentional' group simply having quicker RTs than the other groups. The threeway interaction was not significant, however, $F(1,56) < 1$, MSe $= 771$, but the main effect of learning was significant, $F(1,56) = 21.0$, $p < .05$, MSe $= 771$. To summarize, all four groups showed significant amounts of learning as measured by a decrement in RT to Block 9 compared to Blocks 8 and 10 and the amount of RT decrement was statistically equivalent for all four groups. Increasing the power of the analysis by collapsing across sequence type demonstrates the same result. A 2 (instruction: incidental vs. intentional)×2 (learning: Blocks 8 and 10 vs. Block 9) mixed design ANOVA shows a significant effect of learning, $F(1,58) = 21.7$, $p < .05$, MSe $= 748$, and a non-significant effect of instruction $F(1,58) = 2.50$, MSe $= 27981$, and a non-significant interaction, $F(1,58) = 2.13$, $p > .10$, MSe $= 748$.

Table 1. dprime values (*SDs*) for recognition awareness test

Sequence	SOC1	SOC2
Incidental	.029 (0.51)	.26* (0.46)
Intentional	− .15 (0.57)	.38 (0.78)

*$p < .05$.

Table 1 shows the results of the recognition awareness test converted into a dprime measure to remove response bias (see MacMillan and Creelman, 1991, for a full description of signal detection measures). These figures were analysed using a one-sample t test and a dprime value of 0 indicates chance performance. As can be seen, only one of the groups (SOC2—incidental learning) demonstrated any sort of awareness on the recognition test.

Discussion

In the experiments which follow, we examined whether learning a sequence by observation alone can occur via implicit means. However, first it had to be established that learning is unlikely to occur by explicit means. Awareness tasks have received criticism (e.g. Shanks & St John, 1994) in matters of sensitivity and validity; therefore this study employed two methods to study awareness. In addition to the standard post-experimental tests of awareness, this experiment also included conditions in which participants were told about the presence of a sequence prior to learning. Data from both the post-experiment tests and from the comparison of incidental and intentional groups suggest that the second order conditional sequences used are extremely difficult

to learn explicitly under dual task conditions. Learning under incidental and intentional learning conditions was statistically equivalent, suggesting that conscious strategy use is extremely limited in these conditions. It is interesting to note the direction of the results, however. The mean RT difference for the incidental groups is 31 msec compared to 16 for the intentional groups. With additional power it may be that intentional instructions have a detrimental effect on learning (for a discussion of such effects in implicit learning, see Reber, 1993).

The results of the awareness task support the suggestion that explicit knowledge is difficult to acquire by showing chance performance for both instruction groups and sequence groups. Only close examination of the data shows that there is a any explicit awareness in the SOC2—incidental group. The effect is small, and it seemed strange that it should occur for the incidental group and not the intentional group. This group did display the highest RT difference between test blocks (33 ms), although the next largest was SOC1—incidental with 29 ms. It may be that there is a small effect of explicit knowledge but this is not reliable, being found only in one out of four experimental groups. There is a possibility that performance on the awareness task is an under-estimate of explicit knowledge as, even though a participant may recognize a particular three-item chunk, they may not recognize the whole six-item chunk in which it is embedded. However, in Expt 1 and the following two experiments, it is the pattern of awareness data across the groups that is more interesting than the absolute demarcation between implicit and explicit processes.

EXPERIMENT 2

Experiment 1 established that it is difficult to acquire explicit sequence knowledge in the experimental setting described. To test whether observational learning can occur without explicit awareness, we examined observation in the same experimental setting. Results reported by Willingham (1999) suggest that there should be no observational learning when explicit awareness is eliminated. However, the position adopted by Howard *et al*. (1992) predicts that observers can learn a sequence in just the same way as participants responding to stimuli in the SRT. We propose that the difference between experiments reported by these authors is that observer participants in the Howard *et al*. studies have explicit sequence knowledge.

In this experiment, half the participants responded to stimuli as in the usual SRT (actors), and half the participants simply watched these stimuli appear (observers). In addition, we introduced a new manipulation, the salience of the sequence. For half the participants in this experiment, the 12-item sequence was presented in four different colours, such that the first three items shared a colour, which then changed for the next three, and so on. As the sequence repeated, this should have made its structure highly salient, because the three-item same-colour chunks are identical on each repetition. We predicted that this manipulation would be sufficient to induce explicit awareness of the sequence in all participants, and that both actor and observer participants would show evidence of learning.

Method

Subjects

A sample of 48 participants was recruited from the student population of the University of Glasgow. All were naïve to the experimental aims of the study and all

received a small payment in return for their participation. All had normal or corrected-to-normal vision.

Design and procedure

This experiment had a 2×2 (actors vs. observers; non-salient vs. salient sequence) between-subjects design. Participants were assigned randomly to one of four conditions, 12 per condition.

The spatial sequence used for all these conditions was the same as SOC2 in Expt 1 (mapping spatially on BDACBADBCDCA). The two sequences used in Expt 1 showed equivalent RT learning, and so for simplicity a single sequence was used here. A novel sequence was again introduced in Block 9, and this was SOC1 from Expt 1. None of the participants was told about the sequential nature of the stimuli. The number of trials, cycles and blocks remained the same as in Expt 1.

All participants were required to engage in concurrent tone counting and report the number of high tones at the end of each block. Once again, participants with error rates of greater than 10% on any block were replaced. This experiment had the same two-part structure as Expt 1.

Part 1: Sequence learning

The two actor groups were given exactly the same instructions as the incidental learning groups in Expt 1. Participants in the two observer groups were instructed to watch the asterisk rather than respond to it. Participants in these groups were told that their task was to keep watching the asterisk carefully while performing the tone counting task. All participants were told that there would be 10 blocks of trials in total and that they would have a chance to rest between each.

Stimuli presented to the two non-salient sequence groups were identical to those in Expt 1. A black asterisk would appear at one of the four locations until participants made a response. Stimuli for the two salient sequence groups followed the same pattern, but for the first three items of the sequence the asterisk appeared in blue, for the next three it appeared in green, the following three appeared in red, and the final three appeared in purple. No mention of the colour of stimuli was made in the instructions to participants.

Since observers did not respond to the asterisk, display times had to be set. In this experiment, observers were run after their equivalent actor groups, and presentation times for each of the stimuli were calculated on the basis of the performance of the actor groups. Presentation times for the salient observer group were calculated on the basis of the salient actor group, and presentation times for the non-salient observers were calculated on the basis of the non-salient actors. In both cases, presentation times for the asterisk were calculated by taking the mean RTs for each block (1–7) for each action participant and then calculating the mean RTs across participants.

Following the completion of the first seven blocks, observers were asked to begin responding to stimuli in the same way as actors. Participants received the same instructions prior to commencing Block 8 as the actor groups had on starting Part 1. Again, responses were required to be as fast and accurate as possible.

Part 2: Direct measure of awareness

After completing the 10 blocks of trials satisfactorily, all participants were informed that a further task would follow. The same instructions were given to participants as in
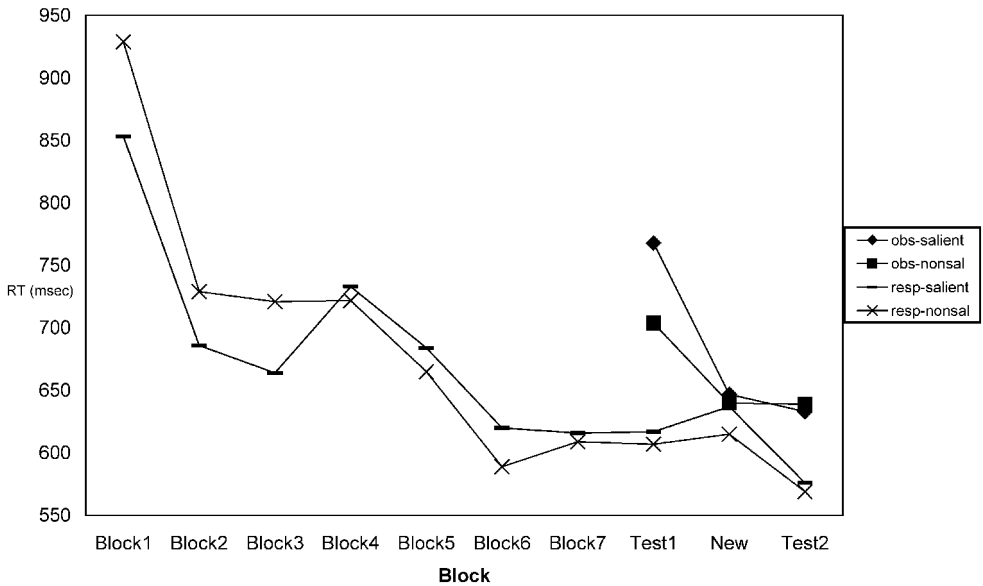
Figure 2. Reaction times for salient and non-salient action and observation groups with dual task.

Expt 1. In the same way, 24 sequential test chunks were presented in randomized order across participants. Half of these chunks were new (taken from SOC1) and half were old (taken from SOC2, the learning sequence here). As in Expt 1, participants were required to respond to each item as fast as possible, and then say whether they thought the chunk was old or new. For the salient groups, the items in this phase were presented in the same colours as in the learning phase, in that the salient chunking was retained.

Results and discussion

Means of participant medians for each block are displayed in Figure 2. As observers had no practice responding to items prior to Block 8, the initial block is slow. Therefore, for this experiment we compare RTs at Blocks 9 and 10.

A 2 (response: action vs. observation)$\times$2 (salience: salient vs. non-salient)$\times$2 (learning: Block 9 vs. Block 10) ANOVA was conducted on the RT data. The three-way interaction was not significant, $F(1,44) < 1$. All other comparisons also produced $F < 1$ except the main effect of learning, $F(1,44) = 16.45$, and a response$\times$learning interaction, $F(1,44) = 8.87$, MSe $= 1350$. Simple main effects show that both the salient and non-salient versions of the sequence were learned by the action group, $F(1,44) = 16.5$ and 9.4, respectively, but that no learning was found for either of the observation groups, $F(1,44) < 1$ for both groups.

As salience was not found to be a factor affecting learning of the sequence, a further analysis was undertaken which collapsed across salience to increase statistical power. A 2 (learning: Block 9 vs. Block 10)$\times$2 (response: action vs. observation) mixed design ANOVA showed a significant effect of learning, $F(1,46) = 16.9$, $p < .05$, MSe $= 1316$, and a significant interaction, $F(1,46) = 9.1$, $p < .05$, MSe $= 1316$. Simple main effects demonstrated significant learning by the action group, $F(1,46) = 26.6$, $p < .05$, MSe $= 1316$, but no significant learning by the observation group, $F(1,46) < 1$, MSe $= 1316$.

We had predicted that observational learning of the salient sequence would occur, as the differing colours would enable participants to break down the sequence into small chunks which could be learned quite easily. There is no evidence of this at all in the indirect test. Similarly, the awareness data (dprime values shown in Table 2) provide no evidence of explicit knowledge of the salient sequence.

Table 2. dprime values (*SDs*) for recognition awareness test

Sequence	Salient	Non-salient
Action	.34 (0.60)	.08 (0.38)
Observation	− .07 (0.42)	.05 (0.50)

*$p < .05$.

Experiment 2 suggests that an observation group watching a non-salient sequence could not learn the contingencies which define that sequence. In contrast, action groups responding to either the salient or the non-salient versions demonstrated clear learning. Although the salient observation group was expected to learn the sequence, no evidence for this could be found. This is surprising given that intuitively, breaking down the sequence into four triplets of differing colour should have resulted in very obvious learning. The fact that this did not happen suggests a very interesting finding of how disruptive a concurrent task actually is. Numerous possibilities exist for the actual mechanism by which disruption of learning occurs. Frensch *et al.* (1994) argued that tone counting limits the amount of time that consecutive stimuli can be held in short-term memory, Stadler (1995) argues that tone counting disrupts the organization of the sequence and Schmidtke and Heuer (1997) suggest that disruption of learning is caused by interference in integrating the two tasks to be performed. Whatever the mechanism, the tone-counting task interfered with explicit learning of the sequence even in a highly salient condition. One possibility for why no learning was found in either observation condition may be that participants simply devote more attention to the secondary task when the primary task is observation rather than action. Analysis of tone counting accuracy of the four groups does not support this hypothesis. Numerically, there was little difference in errors with the mean number of tone-counting errors per block being 3.4 ($SD = 2.0$) for the non-salient action group, 4.1 (2.1) for the salient action group, 2.2 (1.1) for the non-salient observation group and 3.3 (1.5) for the salient observation group. Despite error rates being low, the data did not break assumptions of normality (Kolmogorov–Smirnov tests for all four groups gave $p > .10$) and a 2 (action vs. observation) × 2 (salient vs. non-salient) ANOVA did not reach significance on either main effect or the interaction—action vs. observation: $F(1,44) = 3.96$, $p = .053$, MSe = 2.96, salient vs. nonsalient; $F(1,44) = 3.44$, $p = .07$, MSe = 2.96; interaction: $F(1,44) = 1.07$, $p > .01$, MSe = 2.96.

Another possible reason may be that explicit awareness does not mediate observational learning as we suggest, and for some other reason we have failed to find learning in the observation conditions. Learning in the salient observer condition would rule this out, and therefore in Expt 3 we attempt to show a discrepancy between the non-salient observer condition and the other three groups. In order to facilitate learning, Expt 3 does not employ a secondary task.

EXPERIMENT 3

Method

Participants
In all, 48 participants were recruited from the student population of the University of Glasgow. All were naïve to the experimental aims of the study and all received a small payment in return for their participation. All had normal or corrected-to-normal vision.

Design and procedure
This experiment was an exact replication of Expt 2, with the single exception that all sequence learning and testing was run without a secondary task, in that no tones were presented.

Results and discussion

Figure 3 shows the means of participant-median RTs per block. As with previous studies, action groups steadily improved through blocks. In contrast to Expt 2, the observation groups did not seem to suffer from extremely slow RTs in Block 8. This suggests that the apparent simplicity of key to stimulus mapping was made difficult by a concurrent tone-counting task in Expt 2.

Initially, the analysis was conducted comparing the average RTs of Blocks 8 and 10 against Block 9. A 2 (response: action vs. observation)×2 (salience: salient vs. non-salient)×2 (learning: Block 9 vs. average of Blocks 8 and 10) was conducted on the RT data. The threeway interaction was significant, $F(1,44) = 12.4$, $p < .05$, MSe $= 419$, as was the response×learning interaction, $F(1,44) = 9.60$, $p < .05$, MSe $= 419$, and also a main effect of learning, $F(1,44) = 87.8$, $p < .05$, MSe $= 419$, was found to be significant. In order to explore the threeway interaction further, separate two-way ANOVAs
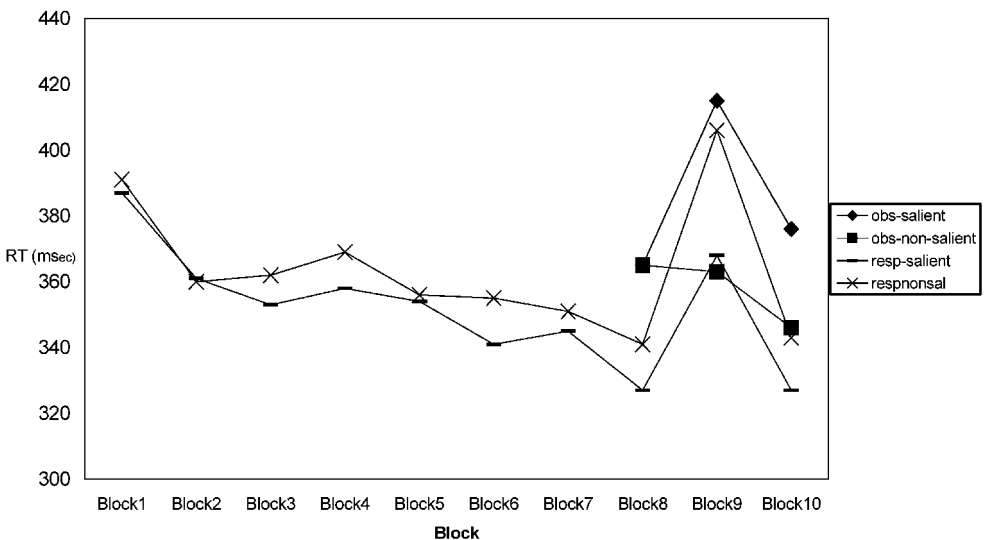

Figure 3. Reaction times for salient and non-salient action and observation groups with single task.

were conducted for actors and observers. For the action group there was a main effect of learning, $F(1,22) = 115.2$, $p < .05$, MSe = 283, and a significant interaction, $F(1,22) = 5.47$, $p < .05$, MSe = 283. Simple main effects show that learning was found for both the salient and non-salient action groups, $F(1,22) = 33.9$, $F(1,22) = 86.8$, $p < .05$, MSe = 283, respectively. For the observer groups, there was a main effect of learning, $F(1,22) = 14.8$, $p < .05$, MSe = 555, and a significant interaction, $F(1,22) = 7.1$, $p < .05$, MSe = 555. Simple main effects show that learning was found for the salient observer group, $F(1,22) = 20.9$, $p < .05$, MSe = 555, but not for the non-salient group, $F(1,22) < 1$.

A more conservative approach might exclude the data from Block 8, as RTs may have been underestimated for the observation group who may have required practice with the keypress mappings. Hence, a 2 (response: action vs. observation) × 2 (salience: salient vs. non-salient) × 2 (learning: Block 9 vs. Block 10) ANOVA was conducted on the RT data for Blocks 9 and 10 only. The three-way interaction approached significance, $F(1,44) = 3.32$, $p = .075$, MSe = 857, as did the learning × response interaction, $F(1,44) = 3.72$, $p = .06$, MSe = 857. The learning × salience interaction was not significant, $F < 1$. The main effect of learning was significant, $F(1,44) = 44.5$, $p < .05$, MSe = 857.

Table 3. dprime values (SDs) for recognition awareness test

Sequence	Salient	Non-salient
Action	.08 (0.50)	.10 (0.38)
Observation	1.06* (1.12)	.27 (0.75)

* $p < .05$.

Awareness data was again converted into dprime to remove possible response bias. In this experiment some participants in the salient observation condition achieved maximum performance on recognizing old items in the awareness task. As this would lead to a dprime measure of infinity, a correction procedure suggested by Snodgrass and Corwin (1988) was used to calculate hits and false alarms for this experiment. dprime values shown in Table 3 indicate that only the salient observation group demonstrated awareness of the sequence. This seems to suggest that the exclusion of the tone-counting task did not have any great effect on awareness of the non-salient sequence.

From these data it is clear that observational learning of a non-salient sequence is very much weaker than learning of a salient sequence—even to the point of being non-existent. The analysis suggests that learning via action can occur whether or not direct tests of awareness show evidence for explicit knowledge of the sequence; however, observational learning only occurs when there is concomitant evidence of explicit awareness. The more conservative analysis suggests that learning by an observation group can take place, even for a non-salient sequence; however, even in this analysis the response × learning interaction approached significance. This analysis also assumed that no motoric learning of the sequence took place during Blocks 8 and 10, so even with a conservative analysis we can suggest that implicit observational learning is very weak.

GENERAL DISCUSSION

In Expt 1, we demonstrated that intentional rule-search instructions convey no advantage over incidental learning instructions in a dual-task SRT. Experiment 1 demonstrates that under these conditions and assuming that incidentally instructed participants are indeed learning incidentally, it is extremely difficult to use explicit strategies in order to learn. This allows more confidence in interpreting the data from Expt 2, which was conducted under the same conditions. In Expt 2, no evidence can be found for observational learning under conditions which do allow learning by action. This was true even under conditions where the salience of the sequence was manipulated by chunking subcomponents together. In Expt 3, the effects of this salience manipulation was examined under single task conditions and was found to be extremely beneficial to observational learning.

In two experiments, learning by action was demonstrated under both salient and non-salient conditions. Robust learning by observation was only found for a salient sequence when there were no dual task demands. In summary, these results do not support the notion of implicit learning by observation. These data are consistent with Willingham's (1999) analysis, and suggest that previous results to the contrary (Howard *et al*., 1992) may have arisen because some participants gained explicit awareness of the sequence.

The suggestion that previous studies showing implicit observational learning may be confounded by explicit awareness may also apply to data reported by Seger (1997). This study used multiple awareness tasks and showed no explicit knowledge, despite observational learning. However, instructions in awareness tasks asked participants to rely on their intuition rather than conscious knowledge of the sequence. As shown by Perruchet and Amorim (1992), instructions to participants can have a great effect on the knowledge that they recall. It may be that in not emphasizing the recall of conscious knowledge, Seger's results are an underestimation of conscious knowledge of the sequence. Another possible reason for the difference in results may be the difference in sequence structure. The three studies, which have failed to find implicit observational learning (this study; Kelly and Burton, 2001; Willingham, 1999), all used 12-item sequences with at least lag 2 associations, whereas Seger (1997) used a 10-item hybrid sequence. It is possible that there are differences in the type of association that can be learned implicitly via observation.

The results presented here lend support to the argument that implicit learning in the SRT task is predominantly due to learning within motor systems (e.g. Nattkemper and Prinz, 1997; Ziessler, 1994). However, the results of Cohen *et al*. (1990) and Keele *et al*. (1995), showing substantial transfer between effectors and between manual and vocal responses, suggest that this may not be the whole story. Willingham (1999) suggests that participants are learning a sequence of spatial responses. However, Kelly and Burton (2001) report robust learning of a non-spatial sequence where learning was by vocal response and test was by keypress. As there were no spatial locations to respond to at study, it suggests that participants can learn something other than just response location.

A role for action?

Kelly and Burton (2001) have suggested that making a response to the stimulus is the major determinant of what can and cannot be learned implicitly in the SRT task. This suggestion follows on from work by Berry (1991), who found a dichotomy between

action and observation in a complex systems task. Berry found that participants who merely observed the system did not seem to learn when the governing rule was non-salient. Only those who responded to the system demonstrated any learning on an indirect measure. If the system was governed by a salient rule, then both groups could learn to control the system.

As Berry (1991) notes, however, it is difficult to control for the effect of attention when comparing learning by action and by observation. It may be that observers simply do not pay sufficient attention to the display in order for learning to occur. In contrast, responding to the display forces sustained attention to be deployed and therefore may result in learning where observation does not. Kelly and Burton (2001) present evidence which suggests that attention *per se* may be necessary but is not sufficient for learning to occur. They found learning in a non-spatial SRT task when training required a vocal response (for the actors) and test required a manual keypress (for both actors and observers). In order to ensure that observers were attending to the display (coloured circles appearing in the centre of the screen), they were given a cover story which suggested that they were taking part in a 'mood induction by colour' experiment. This gave participants an incentive to watch the display carefully (and in an experimental debrief, all reported having done so). The observation group who were watching the training set under this pretence displayed no learning of the sequence. Although it still cannot be claimed that participants in both groups gave equal attention to the display, it does suggest that simple non-attention is not the reason why observers fail to learn.

Neumann (1990) makes a distinction between perception with action and perception alone. He suggests that perception with action is evolutionarily primitive, requires subcortical structures and does not require consciousness. Perception alone, however, is proposed to be a much newer mechanism, requiring cortical structures and consciousness. This dichotomy is reminiscent of Reber's (1993) suggestion of implicit and explicit processes. Neumann suggests that the end-goal of perception with action is to perform the action, whereas the end-goal for perception alone is to update a mental representation. This implies that observation alone requires consciousness to form a mental representation of the stimulus. Hence, this theory would not predict the formation of sequential associations by observation alone unless they were formed with the aid of consciousness. Jiminez and Mendez (1999) make a similar suggestion in what they term 'the attention hypothesis'. They suggest that although implicit learning should be classified as an automatic process, one need not 'assume that it should associate every perceptual input impinging on the system in a completely non-selective way. Rather, this perspective would claim that attending to a predictor, *and even requiring a response to it*, could be necessary to maintain its representation activated long enough to enable it to become associated with the next event'. Both these theoretical positions are consistent with our suggestion that responses are necessary for implicit sequence learning.

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