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Sequence learning by action, observation and action observation

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The serial reaction time (SRT) task was used to compare learning of a complex sequence by action (participants responded to sequential stimuli), by observation (participants watched but did not respond to sequential stimuli), and by action-observation (participants watched an expert model responding to sequential stimuli). Each of these groups was compared with an untrained control group. Experiment 1 indicated that both observation and action-observation were sufficient to support learning of a 12-item second-order conditional (SOC) sequence. Experiment 2 confirmed these findings, and showed that, as indexed by reaction time (RT), the extent of learning by observation and by action-observation was comparable to that of action-based learning. Using a recognition test, Experiment 2 and 3 also provided evidence that, whereas learning by stimulus observation was explicit, learning by action-observation was implicit. These findings are consistent with a connection between motor systems and implicit learning, but do not support the hypothesis that overt action is necessary for implicit learning.

In principle, sequence knowledge may be acquired through action, observation or action-observation; by responding to sequential stimuli, by observing a stimulus sequence without responding, or by watching another person responding to a stimulus sequence. The present study uses the serial reaction time (SRT) task (Nissen & Bullemer, 1987) to investigate whether the same processes mediate sequence learning under these three sets of conditions.

The standard version of the SRT task examines action-based sequence learning. In each trial a stimulus appears at one of several locations on a computer screen, and the participant is required to press a key corresponding to that location as quickly as possible. The stimulus follows a predictable repeating sequence over many training cycles, and evidence of sequence knowledge is provided when a change in the sequence on test trials causes reaction time (RT) to increase. Many studies have reported that action-based learning in the SRT task may be implicit, i.e. not accompanied

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by conscious awareness of the sequence. For example, in a recognition test participants respond faster to fragments of the training sequence than to fragments of an alternative sequence, but do not rate the former as being more familiar than the latter (e.g. Exner, Koschack, & Irle, 2002; Kelly & Burton, 2001; Reber & Squire, 1998; Seger, 1997). However, it should be noted that such a dissociation between RT and ratings of familiarity on recognition tests may be explained by a single memory system, rather than separate implicit and explicit memory systems (e.g. Kinder & Shanks, 2001; Kinder & Shanks, 2003; Shanks & Perruchet, 2002).

In an observational version of the SRT task, participants watch stimulus presentation but do not respond during the training phase. Studies using this method have generally concluded that observational sequence learning is explicit; that it does not occur in the absence of conscious awareness (Berry, 1991; Kelly & Burton, 2001; Kelly, Burton, Riedel, & Lynch, 2003; Willingham, 1999). For example, Howard, Mutter, and Howard (1992) compared an observation group that simply watched stimulus presentation, with an action group that responded to target presentation, using SRT and free generation tasks. During a free generation task participants are asked to generate the training sequence in the absence of any cueing stimuli. Observers showed as much knowledge as those who had responded during training on the SRT test, and their knowledge was explicit as indicated by successful generation of the training sequence. Willingham (1999) replicated this result and found that an observational learning effect on RT was shown only by those participants with high levels of explicit knowledge.

These results prompted Kelly and colleagues to argue that action is necessary for implicit learning in the SRT task; whereas action-based learning can be implicit, learning through stimulus observation is necessarily explicit (Kelly & Burton, 2001; Kelly *et al.*, 2003). In support of this hypothesis they compared actors with observers of screen stimuli using an SRT task in which the salience of the sequence was varied (Kelly *et al.*, 2003; Experiment 3). Half of the participants in each group were shown the sequence as normal, and the other half were shown the sequence broken up into differently coloured triplets (salient condition). Both of the actor groups, but only the salient observer group, showed significant sequence learning on test, suggesting that action-based learning, but not observational learning, involved the acquisition of implicit knowledge.

The hypothesis that action is necessary for implicit learning is consistent with evidence that implicit learning relies on action-related neurological structures. For example, Pascual-Leone, Grafman, and Hallet (1994) found that motor fields evoked by transcranial magnetic stimulation (TMS) expanded during the time when participants were deemed to have little explicit knowledge, but decreased in size with increased explicit awareness during SRT learning. Similarly, Grafton, Hazeltine, and Ivry (1995) used positron emission tomography (PET) to show that activation of different brain regions is associated with differing amounts of sequence awareness on the SRT task. Specifically, sensorimotor and parietal cortex, supplementary motor areas and the putamen were implicated in implicit learning. With explicit learning, areas of activation were found to be prefrontal cortex, basal ganglia and parieto-occipital areas (see also Hazeltine, Grafton, & Ivry, 1997). Kelly *et al.*'s (2001, Kelly *et al.*, 2003) hypothesis that action is necessary for implicit learning is also consistent with a recent theory of motor skill learning (Hikosaka, Nakamura, Sakai, & Nakahara, 2002), which describes the properties of two parallel learning processes. The first of these acquires motor information that is not available to consciousness, i.e. it is implicit (see also Russeler & Rosler, 2000). The second mediates learning of spatial information that is explicitly represented. Thus, in this model, implicit learning is exclusively linked to motor learning, or in the terms of Kelly *et al.* 'learning by action'.

In comparison with action-based and observational learning, relatively few studies have examined learning by action-observation in the SRT task. However, recent work on action observation, rather than sequence learning, suggests that observing another person performing a movement initiates preparation of the same movement by the observer. The occurrence of this kind of motor priming raises the possibility that learning by action-observation in the SRT task will resemble action-based learning more closely than observational learning. Thus, if action-based learning can be implicit, one would expect it also to be possible for learning based on action-observation to occur without conscious awareness.

Evidence of motor activation by action observation has come from both neurological and behavioural studies. The neurological work has revealed comparable patterns of activation in the SMA, premotor cortex, primary motor cortex, cerebellum, parietal cortex and inferior frontal gyrus during observation and execution of action (Aziz-Zadeh, Maeda, Zaidel, Mazziotta, & Iacoboni, 2002; Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Strafella & Paus, 2000). For example, using single-pulse TMS, Aziz-Zadeh *et al.* found that motor evoked potentials (MEPs) from the right hand were greater during right hand than left hand movement observation, and vice versa for MEPs recorded from the left hand, suggesting that movement observation can activate representations of movement stored in the primary motor cortex (Aziz-Zadeh *et al.*, 2002). In a behavioural study, Brass, Bekkering, and Prinz (2001) required participants either to lift or to lower their index finger as soon as they saw a stimulus hand perform either of the movements (lifting or lowering the index finger). Responding was faster when the stimulus movement and pre-instructed response movement were compatible than when they were incompatible, suggesting that finger movement observation automatically primed performance of the matching response (see also Brass, Bekkering, Wohlschlager, & Prinz, 2000; Craighero, Fadiga, Rizzolatti, & Umilta, 1998; Stürmer, Aschersleben, & Prinz, 2000).

To our knowledge, only two studies have used the SRT task to investigate sequence learning by action-observation, i.e. under conditions in which participants observe a model responding to sequential stimuli (Kelly & Burton, 2001, Experiment 1; Heyes & Foster, 2002). Kelly and Burton used a 12-item second-order conditional sequence (in which each item is predicted by the combination of the two preceding items), allowed participants to observe an inexperienced model, and found no evidence of learning by action-observation. In contrast, Heyes and Foster (2002) used a simple 6-item sequence (in which each item was uniquely predicted by the previous item), allowed participants to observe an expert model, and found that the extent of learning by action-observation was comparable to that of learning through direct action. Learning of long, complex sequences is more likely to be implicit than learning of short, simple sequences. Therefore, if these studies are taken to indicate that simple sequences can, and complex sequences cannot, be learned by action observation, then they are consistent with the hypothesis that learning by observation – including learning by action-observation – cannot be implicit. However, given that the two studies did not only differ with respect to sequence length, and that implicit learning by action-observation is predicted by recent evidence of motor priming, they do not provide a satisfactory test of this hypothesis.

The present study addressed three questions: (a) Can action-observation support learning of a 12-item second-order conditional (SOC) sequence? (b) If so, how does the extent of learning by action-observation compare with that of learning through action, and through stimulus observation? (c) Can learning by action-observation be implicit?

EXPERIMENT 1

Experiment 1 sought to determine whether a 12-item SOC sequence can be learned by action-observation using a four-location version of the SRT task. A group that observed screen stimuli, rather than action, was also included. The purpose of this group was to check that stimulus observation is insufficient to support learning of a complex, non-salient sequence (Kelly *et al.*, 2003). The performance of each of these observation groups was compared with that of an untrained control group. Thus, Experiment 1 sought to identify *any* effect of observation by comparing observers with participants who had no opportunity to learn the sequence.

To identify appropriate stimulus parameters, we varied factorially the amount of training given to participants. Half of each observation group was presented with 64 sequence cycles during training, while the remaining participants were presented with 96.

The experiment consisted of a familiarization phase in which all participants physically responded to one block of the SRT task with random stimulus presentation in order to gain task practice without being exposed to the training sequence. Training, which followed the familiarization phase, was completed according to group assignment. Group Stimulus Observation watched stimuli presented in the training sequence but did not respond. Group Action Observation watched an expert model complete the SRT task, and were instructed to pay equal attention to stimulus presentation and to the model's responses. Control participants completed anagrams for a similar period of time. In the test phase, all participants responded to stimuli in the SRT task. Stimulus presentation was governed by the training sequence in the first block of test trials, and by an alternative 12-item SOC sequence in the second. An RT increase at transfer to the new sequence was used as the index of learning. If this increase is greater in observers than in control participants, then observational learning has been demonstrated.

If action-based and observational learning are mediated by separate learning systems (Kelly *et al.*, 2003), and a difference between these systems is reflected in their capacity to support learning of a 12-item SOC sequence, then one would not expect any evidence of sequence learning in either of the observation groups. Operationally, one would expect the observation groups to show the same effects of changing from the training sequence to a new sequence, as the control group. If sequence learning is greater in the observation groups than in the control groups, then a common system for observational and practice-based learning is implied.

Method

Participants

Seventy-two students at UCL participated in the experiment, 24 in each of groups Stimulus Observation, Action Observation, and Control. Their mean age was 23 years, 37 were male, and each was paid a small honorarium for their participation. Twelve participants who made more than 10% errors during the random and test blocks were replaced.

Stimuli and apparatus

Stimulus presentation, RT measurement, and response recording were all implemented on IBM-compatible PCs with 43 cm colour monitors and standard QWERTY keyboards. Four boxes were presented in a horizontal row in the centre of the screen, drawn with black lines against a grey background. The boxes were 2.2 cm wide and 1.2 cm high, spaced 1 cm apart, and viewed at a distance of approximately 60 cm. A white asterisk (Arial font, size 36, subtending approximately 0.5° of visual angle) appeared in the centre of one of these boxes on each target location trial. Target locations are referred to as 1–4 from left to right. Participants were instructed to indicate locations 1–4 as quickly as possible by using the V, B, N, and M keys located across the bottom of the keyboard, respectively. They operated the V and B keys with the ring and index fingers of their left hand, and the N, and M keys with the index, and ring fingers of their right hand, respectively.

Each test block consisted of 96 target location trials. Half of the participants in each group were trained with blocks consisting of 96 trials, and the other half were trained with blocks of 144 trials. Incorrect responses were signalled by a tone. A trial ended when a participant pressed the correct key, at which time the target was erased. The next trial began 200 ms later. Response latencies were measured from the onset of the target to the completion of a correct response. The sequence of targets in training blocks was 2-4-2-1-3-4-1-2-3-1-4-3, a 12-item second-order conditional sequence. Each block of 96 or 144 trials included 8 or 12 repetitions of the whole training sequence, and began at a random point in that sequence.

Procedure

Participants were told that they were taking part in a choice RT task designed to measure their speed of response. For all participants, the experiment had three phases: (a) familiarization, (b) training, and (c) testing. The three groups received identical treatment in all phases except the training phase. During training, Group Action Observation (AO) watched the experimenter's fingers as she performed the SRT task, and also observed stimulus presentation, that is, the asterisk moving between the on-screen boxes. Group Stimulus Observation (SO) watched stimulus presentation only; the experimenter did not make responses. In order to approximately equate the inter-stimulus interval (ISI) between the two observation groups, the ISI was set at 500 ms for Group SO. This duration is made up of the standard length between a response and the next trial on test blocks (200 ms), plus the experimenter's target RT for training blocks given to Group AO (300 ms). Group Control (C) completed anagram problems for a comparable period of time.

Familiarization

In the familiarization phase, participants were asked to complete one block of 96 target location trials in which the order of target presentation was randomly determined.

Training

Group AO were instructed to watch the experimenter's fingers, and the movement of the stimulus on the screen, as she completed eight blocks of target location trials. The importance of paying equal attention to the screen and the experimenter's fingers was stressed to participants. Observers in Group AO were seated to the right, and just behind the experimenter, on a chair which had been raised to give them a slightly elevated view of her fingers on the keyboard. The screen was turned slightly towards the observers so that they could see the target stimuli to which the experimenter was responding. The experimenter provided a model of expert performance, with a mean RT over all experiments of 330 ms and an average error rate of less than 1%. Participants in Group SO were seated in front of the computer and were asked to watch the screen as the asterisk moved between stimulus locations. Asterisk presentation was governed by the same sequence as used for Group AO. Participants in Group C solved anagram problems for 9 minutes during training, which was the average time taken to complete training in the observation groups.

Testing

The test of sequence learning consisted of two blocks of target location trials, completed by all participants. In the first of these blocks, targets were presented in the training sequence, that is, 2-4-2-1-3-4-1-2-3-1-4-3. In the second block, they were presented in a new, 12-item SOC sequence: 2-4-1-3-2-1-4-2-3-4-3-1 (from Reed & Johnson, 1994).

Results and discussion

A mean RT for each participant in each block was calculated after exclusion of RTs greater than 1000 ms. Each analysis of RT data was accompanied by a parallel analysis of error data. The results of error analyses are reported only if they yielded significant effects or interactions. For all analyses, all significant effects are reported.

Initially, results were analysed including amount of training (64 or 96 sequence cycles), as a between-subjects factor. However, this factor did not interact significantly with any other factor, nor was it significant as a main effect in any analysis. Therefore, this variable was not included in the reported analyses. For all analyses, α was set at $p < .05$.

Data from the initial familiarization stage were analysed using univariate ANOVA with group (AO, SO, and C) as a between-subjects factor. The effect of group was not significant ($F < 1$), indicating that groups did not differ in their RT to random stimuli (Group AO: M = 453 SEM = 14, Group SO: M = 451 SEM = 15, Group C: M = 450, SEM = 13).

In order to assess sequence knowledge on test, RTs in the training and new sequence blocks were compared. An increase in RT upon transfer to the new sequence suggests that participants were able to use their sequence knowledge to anticipate stimulus location when the stimulus followed the training sequence, but not when it followed a new sequence. Furthermore, if it is found that the observation groups show a greater increase in RT than the untrained control group, one can assume that the sequence knowledge of the former groups is a result of observational learning during the training phase.

The mean RT increase for each group upon transfer to the new sequence is shown in Fig. 1. These data were analysed by computing a difference score for each participant by subtracting their RT on the sequence with which they were trained, from their RT on the new sequence block. These difference scores were then analysed using univariate ANOVA with group (AO, SO, and C) as a between-subjects factor. This analysis was supplemented by a Helmert contrast, comparing the control group to the two

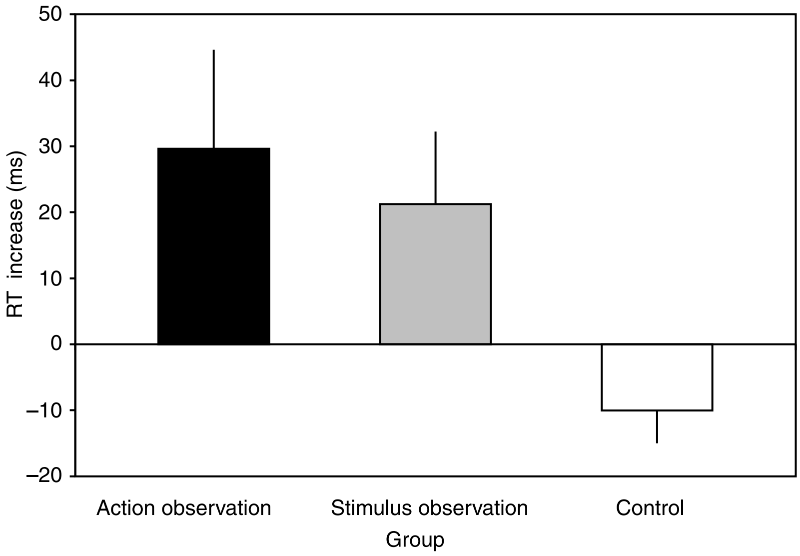

Figure 1. Mean RT increase upon transfer from the training to a new sequence for groups that: Observed screen stimuli and the model's responses (Action Observation), observed screen stimuli alone (Stimulus Observation), or completed anagram problems (Control), during training in Experiment 1.

observation groups, and then Group AO with Group SO. The main effect of Group was significant, $F(2, 69) = 3.7$, $p = .03$, as was the contrast between the control ($M = -10$ ms, $SEM = 5$) and observation groups ($p = .01$). Thus, the observation groups demonstrated a greater increase in RT upon transfer to the new sequence than the control group, and therefore demonstrate greater sequence knowledge. The contrast between Group AO ($M = 30$, $SEM = 15$) and Group SO ($M = 21$, $SEM = 11$) was not reliable, suggesting that the amount of sequence knowledge gained through observation of a model's response was not significantly different from that gained through the observation of inanimate stimuli.

Thus, the results of Experiment 1 demonstrated that observers are able to learn a 12-item SOC sequence. In addition, they suggested that the extent of learning did not vary between a group that observed the model's responses as well as the on-screen stimuli, and a group which observed the on-screen stimuli alone. Furthermore, the amount of training (64 vs. 96 sequence cycles) did not affect the amount of sequence knowledge shown on test. These results provide an initial demonstration of observational learning of a 12-item SOC sequence, and suggest that if observational and practice-based learning are mediated by different learning systems, the capacity to learn long, complex sequences does not differentiate the two systems. However, the hypothesized learning systems responsible for observational and practice-based learning may produce different amounts of sequence learning when long, complex sequences are to be learned. This possibility was tested in Experiment 2 by comparing the extent of sequence knowledge after action-based and observational training of a 12-item SOC sequence. In addition, the results of Experiment 1 do not provide information about whether the sequence learning shown by observers was explicit or implicit. Therefore, Experiment 2 sought to discover the relative contributions of implicit and explicit learning to the observational sequence learning shown in Experiment 1 and thus investigate Kelly *et al.*'s (2001, 2003) claim that observational learning cannot be implicit (as evidenced by the results of a recognition test).

EXPERIMENT 2

Experiment 1 indicated that a 12-item SOC sequence can be learned by observation. Experiment 2 had two aims; the first was to compare the amount of sequence knowledge gained through observation with that gained through action, and the second was to compare the performance of action- and observation- based learners on a recognition test. To these ends, groups trained by observing the onscreen stimuli only (Group SO), and the onscreen stimuli and an expert model's responses (Group AO), were compared with an action-based learning group (Group A) that responded to onscreen stimuli, and a control group.

Observers were compared with action-based learners in an attempt to explain the conflicting results obtained by Kelly and Burton (2001) and Heyes and Foster (2002). Kelly and Burton found significantly less learning of a 12-item SOC sequence when observers were compared with action-based learners. In contrast, Heyes and Foster (2002) found equivalent observational and action-based learning of a 6-item unique sequence. It is possible that the difference in structure and length between the sequences used in the studies may have resulted in differing amounts of observational learning. This hypothesis was indirectly tested in Experiment 2 by comparing observational and action-based learning of a 12-item SOC sequence. If observational and action-based learning was only equivalent due to the use of a short, simple sequence in Heyes and Foster (2002), one would not expect these groups to show equivalent learning in Experiment 2.

In addition to a test of sequence knowledge, a recognition test was included in order to establish participants' awareness of any sequence knowledge gained through training. If, as hypothesized by Kelly *et al.* (2001, 2003), action is necessary to learn implicitly, one would expect observers to learn explicitly. However, studies have suggested that observation of an action causes that action to be primed in the observer (e.g. Brass *et al.*, 2001; Buccino *et al.*, 2001; Strafella & Paus, 2000; Stürmer *et al.*, 2000). Thus, observation of a model's responses may lead to implicit learning through the activation of action representations. Observation of screen stimuli, however, would still be expected to rely on explicit knowledge. Thus, one would expect the performance of Group SO, and Group AO to differ on the recognition test.

Method

The method was exactly the same as that of Experiment 1, except as noted.

Participants

An additional 48 volunteers participated in Experiment 2. These were randomly allocated to four equal groups: Stimulus Observation (SO), Action Observation (AO), Action-based learning (A) and Control (C). The mean age of these participants was 23 years, 15 were male, and each was paid a small honorarium for their participation. Two participants who made more than 10% errors during the random and test blocks were replaced.

Procedure

In Experiment 1, the number of sequence cycles presented to participants during training (64 or 96) did not affect the magnitude of learning. Therefore, participants in Experiment 2 were trained with an intermediate number of sequence cycles, that is, 80. The training procedure for Group AO, Group SO, and Group C was the same as in Experiment 1. Group A were asked to respond to training blocks in the same manner as test blocks using the same keys and fingers. Participants in Group A were seated approximately 60 cm in front of the computer screen, so that their visual experience of the onscreen stimuli was the same as that of Group SO.

Recognition test

Following training and initial testing, participants were given a recognition test. Participants were told that they would be given sequences of six asterisk locations, presented in the usual stimulus array. They were to respond to these stimuli as they had during familiarization and initial testing, using keys V to M, operated by the index and middle fingers of each hand. After responding to the sequence of six stimulus presentations, they were asked to give a rating of how confident they were that the test sequence was the same as the sequence used during training. Ratings were made on a scale from 1 to 6, where 1 = *certain I have not seen the sequence before*, 2 = *fairly certain I have not seen the sequence before*, 3 = *guess I have not seen the sequence before*, 4 = *guess I have seen the sequence before*, 5 = *fairly certain I have seen the sequence before*, and 6 = *certain I have seen this sequence before*. Both ratings and trial-by-trial RTs were recorded. There were 12 test sequences in total, presented in random order. Six 'old' sequences were derived from the training sequence, and six 'new' sequences were derived from the sequence: 2-4-1-2-1-3-4-2-3-1-4-3. New test sequences were selected that did not occur in the training sequence.

Results and discussion

Data from the familiarization stage were analysed as in Experiment 1, using univariate ANOVA with group (AO, SO, A, and C) as a between-subjects factor. The effect of group was not significant ($F < 1$), indicating that groups did not differ in response time to random stimuli (Group AO: $M = 418$, $SEM = 17$; Group SO: $M = 465$, $SEM = 22$; Group A: $M = 430$, $SEM = 20$; Group C: $M = 440$, $SEM = 21$).

As in Experiment 1, sequence knowledge was calculated using a difference score that reflects any difference in response speed to the training and new sequences. These data (shown in Fig. 2) were entered into a univariate ANOVA with group (AO, SO, A, and C) as a between-subjects factor. The effect of group was significant, $F(3, 44) = 4.4$, $p < .01$. A Helmert contrast compared control ($M = 0$, $SEM = 10$) with experimental (AO [$M = 55$, $SEM = 24$), SO [$M = 81$, $SEM = 17$], and A [M = 103, $SEM = 29$]) groups in the first instance, then practice with observation groups, and finally the two observation groups. This analysis revealed a significant difference between the control and experimental groups ($p < .01$), no significant difference between the practice and observation groups, and no significant difference between the two observation groups.

Results from the initial test indicate that groups AO, SO, and A learned more of the sequence than the control group. In addition, the amount of learning shown by the observation groups was not significantly different in magnitude to that of the group which physically responded during training. No difference was found, as indexed by

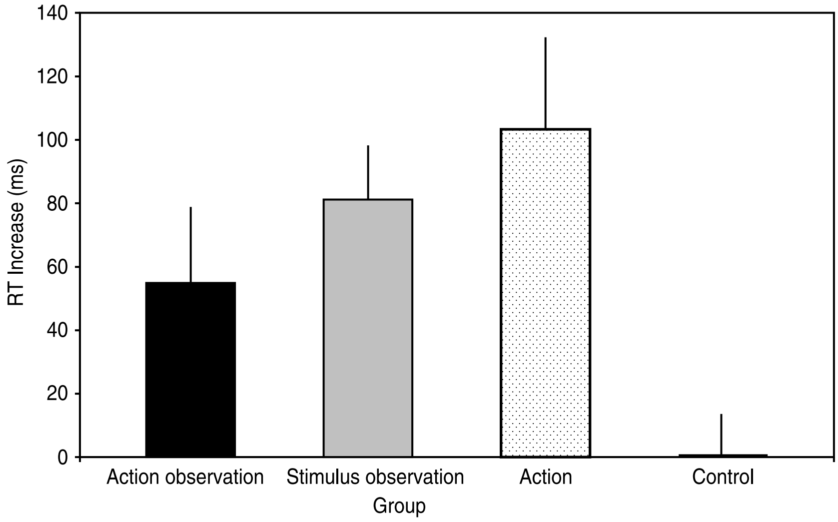

Figure 2. Mean RT increase upon transfer from the training to a new sequence for groups that: Observed screen stimuli and the model's responses (Action Observation), observed screen stimuli alone (Stimulus Observation), responded to stimuli (Action), or completed anagram problems (Control), during training in Experiment 2.

the amount of learning shown on the initial test, between observation of screen stimuli alone, and screen stimuli and the responses of the model.

Table 1 shows mean RT and rating data from both training and new test sequences presented in the recognition test. Separate analyses were performed on the RT and rating data to identify sequence knowledge shown by any group on each measure. Analysis of the RT data was completed using ANOVA with sequence (training, new) as a within-subjects factor, and group (AO, SO, A and C) as a between-subjects factor. The analysis revealed a significant main effect of sequence, $F(1, 44) = 34.4$, $p < .01$, but not of group, $F(3, 44) < 1$. The interaction between sequence and group was not reliable, $F(3, 44) < 1$. Simple effects analysis (warranted by Howell, 1996, p. 415) revealed that there was a significant difference in RT to training and new sequences for Groups AO, $F(1, 44) = 16.9$, $p < .01$, SO, $F(1, 44) = 9.8$, $p < .01$, and A, $F(1, 44) = 7.9$, $p < .01$. The difference in RT between training and new sequences for the control group was not reliable, $F(1, 44) = 2.9$, $p = .10$.

Table 1. Mean ($\pm$ standard error) RT and recognition ratings given to training and new sequences by groups that had observed screen stimuli (Stimulus Observation), observed screen stimuli and model's responses (Action Observation), responded to stimuli (Action), or completed anagrams (Control) during training in Experiment 2

Group	Mean RT Training (*SEM*)	Mean RT New (*SEM*)	Mean Rating Training (*SEM*)	Mean Rating New (*SEM*)
Stimulus observation	444 (20.2)	490 (26.7)	4.58 (0.19)	3.33 (0.31)
Action observation	443 (11.1)	504 (10.9)	3.86 (0.18)	3.46 (0.35)
Action	428 (11.9)	470 (16.0)	4.31 (0.24)	3.67 (0.21)
Control	441 (16.0)	466 (13.4)	4.04 (0.19)	3.74 (0.16)

The same ANOVA applied to the rating data revealed a significant main effect of sequence, $F(1, 44) = 19.0$, $p < .01$, but neither the main effect of group ($F < 1$), nor the sequence by group interaction, $F(3, 44) = 2.0$, $p = .13$, was reliable. Simple effects analysis demonstrated that training sequences were rated as significantly more familiar than new sequences by groups, SO, $F(1, 44) = 17.6$, $p < .01$, and A, $F(1, 44) = 4.6$, $p = .04$, but not by groups AO and C, $F(1, 44) = 1.8$, $p = .18$, and $F(1, 44) = 1.0$, $p = .31$, respectively.

Thus, in the recognition test Groups SO and A showed sequence knowledge as indexed by RT and ratings of familiarity. Group AO exhibited sequence knowledge on the RT measure but not on the rating measure, whilst the control group did not show any sequence knowledge on either the RT or rating measures. Using the criteria of Kelly and colleagues (2001, 2003), this pattern of data suggests that Groups SO and A learned explicitly, but that Group AO learned implicitly.

Experiment 2 replicated and extended the results of Experiment 1 in several important respects. First, the observational learning of a 12-item SOC sequence shown by Groups AO and SO in Experiment 1 was also shown in Experiment 2. Second, the extent of this learning was found to be comparable in magnitude to a group of participants who physically practiced the task during the training period. These findings suggest that the hypothesized separate learning mechanisms that mediate action-based and observational learning cannot be distinguished by their ability to support learning of lengthy sequences with complex structures.

Third, the results of the recognition test did not support Kelly and colleagues' (2001, 2003) suggestion that observational learning cannot be implicit; as the AO group showed implicit sequence knowledge on the recognition test. The explicit learning demonstrated by the A group is not a refutation of Kelly *et al.*'s hypothesis, however, as they acknowledged that action does not necessarily result in implicit learning. The results of the recognition test supported the modification of Kelly *et al.*'s hypothesis presented earlier: that observation of action can support implicit learning, but that observation of inanimate stimuli may not. It was suggested that a sequence of responses could be learned implicitly due to the reliance of implicit learning on action, and the ability of human movement observation to produce motor activation. This hypothesis was tested further in Experiment 3.

EXPERIMENT 3

The results of Experiment 2 suggested that observational sequence learning by a group of participants who observed stimulus presentation only was explicit in nature. In contrast, the sequence knowledge gained through observation of stimuli and the responses of an expert model was implicit. There are at least two potential reasons for this contrast: observation of a model's actions and observation of screen stimuli may lead to different types of learning (qualitative explanation), or to different amounts of learning of a single type (quantitative explanation).

The former explanation assumes that learning a sequence of observed body movements is qualitatively different to learning a sequence of screen stimuli. Evidence consistent with this assumption includes studies reporting activation of cortical and periphery motor neurons in response to observation of biological, but not inanimate, movement stimuli (e.g. Aziz-Zadeh *et al.*, 2002; Manthey, Schubotz, & von Cramon, 2003; Stevens, Fonlupt, Shiffrar, & Decety, 2000). These data suggest that observation of a model's responses in addition to stimulus presentation may result in different cortical processing compared with observation of inanimate stimuli alone.

The second explanation is that observation of a model's response and screen stimuli may result in less sequence knowledge than observation of screen stimuli alone. This may be due to observation of the model's response distracting attention from observation of the screen stimuli. Such an explanation assumes a model of learning in which increasing training results in implicit knowledge becoming explicit, and therefore, that the reduced sequence knowledge available in Group AO means that their knowledge may not develop from an implicit to an explicit state (Frensch & Runger, 2003; Remillard & Clark, 2001; Seger, 1997). This explanation assumes that observation of the model's response does not contribute to sequence knowledge.

To distinguish between the qualitative and quantitative possibilities, Experiment 3 presented participants with stimuli in which hand movements were the sole source of information (Group Action Observation Only – AOO). Participants observed the model's responses but were prevented from viewing the stimuli to which the model was responding. If the difference in recognition test results between groups SO and AO was due to Group AO dividing their attention between two sources of sequence information, then one would expect Group AOO to show similar recognition results to Group SO (i.e. to demonstrate sequence knowledge on both the RT and rating measures of the recognition test). Removing the requirement to attend to two different sources of information would result in greater sequence knowledge, thus increasing the chances of the knowledge becoming explicit (Frensch & Runger, 2003; Remillard & Clark, 2001; Seger, 1997). In contrast, if Group AO demonstrated implicit knowledge on the recognition test due to action observation, then one might expect Group AOO to show similar recognition test results to Group AO (i.e. to demonstrate sequence knowledge on the RT, but not the rating measure of the recognition test).

Method

Participants

An additional 24 volunteers participated in Experiment 3. These were randomly allocated to two equal groups: Action Observation Only (AOO) and Control (C). Their mean age was 27 years, 15 were male, and each was paid a small honorarium for their participation. Three participants who made more than 10% errors during the random and test blocks were replaced.

Procedure

The procedure of Experiment 3 was exactly the same as Experiment 2 except as noted. The treatment of Group AOO during training was the same as that of Group AO in Experiment 2, except that the computer screen presenting stimuli to the expert model was rotated approximately 60 degrees away from the participants. This meant that participants could not see stimuli being presented. They were asked to pay attention to the model's hands as she completed the training blocks.

Results and discussion

Data from the familiarization stage were analysed using univariate ANOVA with group (AOO and C) as a between-subjects factor. The effect of group was not significant, $F(1, 22) = 1.4$, $p = .25$, indicating comparable RT to random stimuli between Group AOO ($M = 517$, $SEM = 19$) and Group C ($M = 485$, $SEM = 19$).

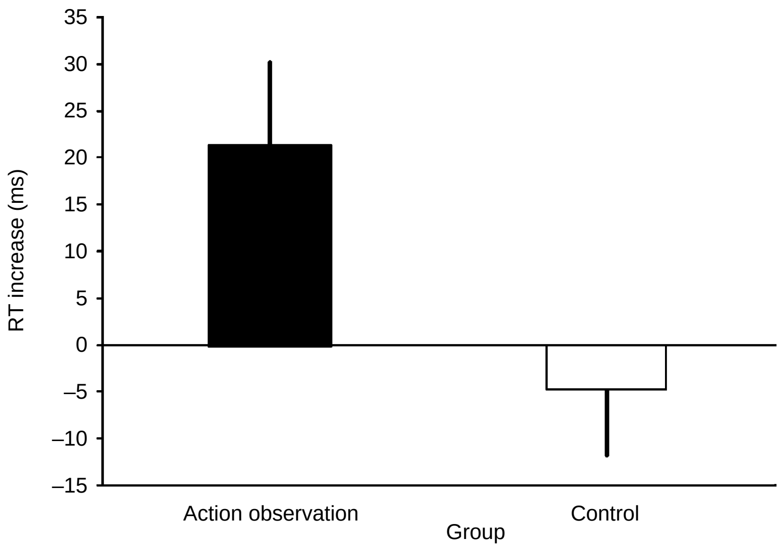

Figure 3. Mean RT increase upon transfer from the training to a new sequence for groups that observed the model's responses (Action Observation Only), or completed anagram problems (Control), during training in Experiment 3.

The mean RT increase for each group upon transfer to the new sequence is shown in Fig. 3. Difference scores derived from RTs to the training and new sequenced blocks were entered into a univariate ANOVA with Group as a between-subjects factor. The difference between Group AOO ($M = 22$, $SEM = 9$) and C ($M = -5$, $SEM = 7$) was significant, $F(1, 22) = 5.2$, $p = .03$.

Data from the recognition test are shown in Table 2. Analysis of the RT data from the recognition test revealed significant main effects of sequence, $F(1, 22) = 20.4$, $p < .01$, and group, $F(1, 22) = 14.4$, $p < .01$. The interaction between sequence and group was also significant, $F(1, 22) = 9.4$, $p < .01$. Simple effects analysis indicated that in Group AOO, RTs to new sequences were significantly longer than RTs to training sequences, and that for Group C, RTs to new and training sequences did not differ.

Table 2. Mean (± standard error) RT and recognition ratings given to training and new sequences by groups that had observed a model's fingers as he responded to the training sequence (Action Observation Only) or had completed anagram problems (Control) during training in Experiment 3

Group	Mean RT Training (*SEM*)	Mean RT New (*SEM*)	Mean Rating Training (*SEM*)	Mean Rating New (*SEM*)
Group AOO	513 (26.4)	571 (33.6)	3.86 (0.18)	3.46 (0.35)
Control	411 (15.4)	422 (15.1)	3.86 (0.21)	3.67 (0.12)

The same analyses applied to the recognition rating data did not show any significant effects in either the initial ANOVA, Sequence $F(1, 22) = 2.7$, $p = .12$, Group, Sequence × Group Fs < 1, or subsequent simple effects analysis, Group AOO $F(1, 22) = 2.4$, $p = .13$, Group C $F < 1$.

Thus, Experiment 3 demonstrated that observers of a model's response can learn a 12-item SOC sequence and that their sequence knowledge may have been implicit (i.e. sequence knowledge was demonstrated on the RT but not the rating measure during the recognition test). These results, in combination with the results of Experiment 2, suggest that observation of action may lead to learning that is qualitatively different from that gained through observation of inanimate stimuli. Furthermore, these results suggest that observation of a movement sequence may support implicit learning.

GENERAL DISCUSSION

The critical question addressed by these experiments is whether action-based and observational learning are mediated by separate learning systems. Kelly *et al.* (2001, 2003) suggest that features of the learning systems mean that practice-based and observational learning can be differentiated on their ability to support learning of long sequences with a complex structure, and, perhaps more importantly, on their level of awareness. Experiment 1 demonstrated that both observers of stimuli, and observers of stimuli plus the responses of an expert model, could learn a 12-item SOC sequence in an SRT task. Experiment 2 replicated and extended this result by confirming that a 12-item SOC sequence can be learned by observation, and that the amount of sequence knowledge shown by observers was not significantly different from that shown by participants who physically respond to stimuli during training. The results of the recognition test indicated that sequence knowledge gained by the SO and A groups was explicit, but knowledge gained by the AO group was implicit. Experiment 3 showed that observers of a model's response without screen stimuli were able to learn a 12-item SOC sequence. In addition, results of the recognition test suggested that participants were unaware of sequence knowledge they had gained through observational training.

The finding that a 12-item SOC sequence can be learned through observation of a model's responses to that sequence, and that the magnitude of such learning is not significantly different from action-based learning, conflicts with the results of Kelly and Burton (2001; Experiment 1). Kelly and Burton found no evidence that observation of a model's responses in the SRT task produced comparable learning to action-based training. However, the present findings support those of Seger (1997) and Heyes and Foster (2002) who found equivalent learning by observation of a model's response and physical practice using 10- and 6-item sequences, respectively. Our finding of explicit learning by observers of screen stimuli replicates the findings of a number of previous studies on observation learning in the SRT task (Berry, 1991; Kelly & Burton, 2001; Kelly *et al.*, 2003; Willingham, 1999).

Possible reasons for the contrast between the results of Kelly and Burton (2001; Experiment 1) and those obtained in these experiments may lie in the expertise of the model. In Kelly and Burton's experiment, observers watched a novice responder, while the present experiments used an expert model. Presumably the novice participant would have made more errors and produced less fluid movements than an expert model. Response errors would mean that the sequence is disrupted and thus would become probabilistic; instead of the stimuli appearing according to the sequence 100% of the time, the probability of a sequential response would be lower. Research that has investigated the effect of training on probabilistic sequences has suggested that learning proceeds at a slower rate with small amounts of sequence uncertainty, and does not occur at all with increased rates of uncertainty (Schvaneveldt & Gomez, 1998).

Kelly *et al.*'s (2001, 2003) hypothesis that action-based and observational learning are mediated by different learning systems rested on two dissociations. The first referred to a differential ability of action- and observation- based learning to support learning of long sequences with a complex structure such as the 12-item SOC sequences used in the present experiments. This study found no evidence of such a difference between observation and action-based learning; in contrast, sequence knowledge due to observation- and action- based learning was not significantly different in Experiment 2.

The second claim was that action-based, but not observational learning can occur without awareness, that is, implicitly. Experiments supporting this claim have demonstrated the reliance of observational learning on explicit knowledge (Berry, 1991; Howard *et al.*, 1992; Kelly *et al.*, 2003; Willingham, 1999). Results of the SO group in the present experiments support this view. This group learned the sequence by observation and showed awareness of their knowledge on the recognition test. However, results of the group that observed screen stimuli and a model's responses (AO; Experiment 2), and the group which observed the model's responses only (AOO; Experiment 3) indicate that participants in these groups may have learned implicitly. These groups both learned through observation but did not reliably rate training sequences as more familiar than new sequences.

The hypothesized difference in awareness between the OS group and the groups that observed a model's response is striking, because all were exposed to the same amount of training on the same sequence. Two possible reasons for the different levels of awareness after observing responses and stimuli were proposed. The first was that observation of a model's response produces a different kind of learning and one of the features of this type of learning is that it can be implicit. The second suggests that learning goes through a transition from being implicit to explicit with increasing sequence experience. Observation of a model's response as well as screen stimuli may lead to distracted attention and reduce the amount of sequence experience compared with screen stimuli alone.

Results of Experiment 3 implied that the differences in recognition test results between groups AO and SO were not simply due to Group AO having to divide their attention between two sources of information. Observed responses were the sole source of sequence information in Experiment 3, and yet results suggest observers may still have learned the sequence implicitly. However, the results of Experiment 3 do not rule out an explanation based on decreased sequence knowledge. They show that viewing the model's fingers is not merely a source of distraction; that observed finger movements are instead a source of sequence knowledge. However, it is still possible that observing finger movements provides less sequence information than observing screen stimuli, and therefore, that the groups that observed finger movements failed to provide evidence of explicit knowledge because they had less information of the same kind as that of the OS group.

The finding that the SO and AO groups showed no difference in the magnitude of sequence knowledge upon initial testing in Experiments 1 and 2 argues against an explanation based on the amount of sequence knowledge. This finding suggests that sequence knowledge was equal between the groups. Although it is possible that the rating measure on the recognition test detected a difference in sequence knowledge which the RT measure did not, this is unlikely due to the categorical 6-point nature of the rating scale compared with the continuous RT measure. An explanation resting on differential amounts of sequence knowledge between the groups would still run counter to Kelly *et al.*'s (2001, 2003) claim that implicit observational learning cannot occur, as observational learning would have to be implicit in the early stages of training.

The alternative explanation, that observation of a model's response produces a different type of learning, has support from preceding experiments and can be incorporated into Kelly *et al.*'s hypothesis about the necessity of action for implicit learning. Evidence suggesting motor activation in response to action observation has been provided by neurological (e.g. Aziz-Zadeh *et al.*, 2002; Buccino *et al.*, 2001; Hari *et al.*, 1998) and behavioural (e.g. Brass *et al.*, 2001; Heyes & Foster, 2002; Stürmer *et al.*, 2000) experiments. The results of these experiments suggest that observers of responses may encode their sequence knowledge as action representations, as if they had responded during training. Observers who learn only screen stimuli have no opportunity to engage in this kind of learning (as they neither respond, nor observe responses during training), and thus are unlikely to encode their sequence knowledge as action representations.

The present study has operationalized implicit learning using the recognition test performance; we have classified learning as implicit when faster responding to the training sequence than to the alternative sequence was not accompanied by higher ratings of familiarity for the training sequence. Recent work using connectionist modelling suggests that such dissociations between performance on the RT and rating measures of the recognition test can be explained on the assumption that there is a single memory system, rather than distinct implicit and explicit memory systems (e.g. Kinder & Shanks, 2001; Kinder & Shanks, 2003; Shanks & Perruchet, 2002). However, even if one does not accept that a dissociation between RT and rating measures on the recognition test reflects implicit learning, the different patterns obtained on the recognition test between a group who observe a sequence of inanimate stimuli and a group that also observes the responses of a model are of interest.

If the argument is accepted that observers of a model's response learned implicitly as they formed action representations of the sequence, then Kelly and colleagues' (2001, 2003) claim that implicit observational learning is not possible must be modified. Implicit observational learning was ruled out due to a belief that action was necessary in order to learn implicitly. The results of this study suggest that action representations may be necessary to learn implicitly, but that these can be gained from observation of movements. Thus, in combination with the results of Kelly and Burton (2001), the present results suggest that implicit observational learning of a movement sequence may be possible, but implicit observational learning of a sequence of static, inanimate stimuli is not. Thus, observational learning of inanimate stimuli may be mediated by a different learning system to action-based learning, but observation of action may prompt the same learning system that occurs when the observed actions are performed.

In summary, Experiments 1–3 tested Kelly and colleagues' (2001, 2003) claim that observational and action-based learning are mediated by separate learning systems. In order to test this claim the amount and nature of any sequence knowledge gained through observation in an SRT task was measured. Results revealed that all observation groups could learn the sequence, and that the magnitude of observational learning was not significantly different from that of action-based learning. Tests of awareness revealed that participants who responded to stimuli during training and those who observed screen stimuli were aware of the sequence knowledge they had gained. In contrast, those participants who had observed either responses alone, or responses and screen stimuli, were unaware of their sequence knowledge, that is, they had learned implicitly. Such a pattern of results supports a distinction between action-based learning and observational learning of inanimate stimuli, but suggests that observation of actions may engage the same learning process as physical practice of the observed actions.

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