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Motor learning by observation: Evidence from a serial reaction time task

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This study sought evidence of observational motor learning, a type of learning in which observation of the skilled performance of another person not only facilitates motor skill acquisition but does so by contributing to the formation of effector-specific motor representations. Previous research has indicated that observation of skilled performance engages cognitive processes similar to those occurring during action execution or physical practice, but has not demonstrated that these include processes involved in effector-specific representation. In two experiments, observer subjects watched the experimenter performing a serial reaction time (SRT) task with a six-item unique sequence before sequence knowledge was assessed by response time and/or free generation measures. The results suggest that: (1) subjects can acquire sequence information by watching another person performing the task (Experiments 1–2); (2) observation results in as much sequence learning as task practice when learning is measured by reaction times (RTs) and more than task practice when sequence learning is measured by free generation performance (Experiment 2, Part 1); and (3) sequence knowledge acquired by model observation can be encoded motorically—that is, in an effector-specific fashion (Experiment 2, Part 2).

Can observation of skilled performance result in effector-specific motor learning of the sequential structure of the observed skill? This question assumes that there are two routes through which observation of skilled performance can facilitate skill acquisition: (1) observational motor learning, in which knowledge gained by observation of a model's body movements is encoded in effector-specific motor representations; and (2) observational perceptual learning, in which the knowledge gained through observation is effector independent (Cohen, Ivry, & Keele, 1990). Thus, in the present context (cf., Blandin, Lhuisset, & Proteau, 1999), the term "observational motor learning" refers to a type of learning in which model observation not only facilitates motor skill acquisition but does so via the activation of effector-specific motor representations.

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The occurrence of observational motor learning would be consistent with theories suggesting that action planning and movement recognition are supported by a common representational system (e.g., Annett, 1995; Heilman, Rothi, & Valenstein, 1982; Jeannerod, 1994), and with recent evidence of "mirror" systems in monkey and human frontal cortex that are active during both performance and observation of reaching movements (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Iacoboni et al., 1999; Nishitani & Hari, 2000; Rizzolatti & Arbib, 1998; Rizzolatti et al., 1988). It would also be compatible with research on working memory showing that performance of configural body movements interferes selectively with encoding and rehearsal of sets of observed configural body movements (Smyth & Pendleton, 1989, 1990). These findings raise the possibility that there are conditions in which observation of body movements activates motor representations that guide performance of the same movements, and therefore that movement observation may substitute for movement execution in effector-specific motor learning. However, although there is ample evidence of observational perceptual learning, it remains unclear whether action observation can promote skill acquisition via motor learning.

Observational perceptual learning vs. observational motor learning

The clearest examples of observational perceptual learning are provided by studies in which subjects observe body-movement-correlated stimuli, but not body movements themselves. In a study of this kind (Vogt, 1995, Experiments 2 and 3), subjects were trained to move a lever using flexion–extension movements of the right forearm in a cyclical temporal pattern matching the vertical oscillation of a bar on a computer screen. On test, when the visual display was withdrawn, the relative timing of the movements of subjects who had merely observed the computer screen was as good as that of subjects who had practised the skill and superior to that of subjects who had imagined the criterion pattern during training. This effect was replicated when the criterion pattern was represented by Morse code-like pulses of the bar at a constant position on the screen, confirming that observers did not learn a pattern of eye movements, and suggesting instead that they encoded temporal information in an effector- and modality-nonspecific fashion (Ivry, 1993).

Research in which observers are exposed simultaneously to body movements and correlated object movements typically fails to disambiguate effects of body and object movement observation. For example, Whiting, Bijlard, and den Brinker (1987) allowed subjects simply to practise a complex cyclical action on a ski simulator, or to practise and to watch a video showing an expert model performing the action. After 5 days of training, the platform moved with greater fluency and consistency of tempo when operated by observers of the video model than by practice alone subjects. However, the video showed movements of the simulator platform as well as those of the model, and therefore it is not clear whether the subjects learned by observation about platform movement, body movement, or both.

The present study sought evidence of observational motor learning of sequence information, and therefore previous experiments in which subjects observed sequences of body movements are of particular interest. Carroll and Bandura (e.g., Carroll & Bandura, 1990) conducted a series of experiments of this kind, but each confounded observation of body movement and object movement, and failed to report whether subjects showed reliable evidence of sequence learning. Carroll and Bandura's subjects observed a model performing an invariant sequence of nine arm movements with a hand-held paddle. Both paddle orientation and the relative positions of the model's shoulder, elbow, and wrist were unique for each sequence component. The sequence was observed on several occasions, and subjects were asked to reproduce it on test trials interspersed with observation trials. Reproductive accuracy scores improved across test trials, but these scores did not distinguish arm and paddle positions, or free and serial recall measures. Therefore, it is not clear whether subjects learned about paddle and/or arm positions, and whether any sequence knowledge was acquired by observation.

Ishikura and Inomata (1995) came closer to providing evidence of observational motor learning of sequence information in a study where subjects observed body movements in the absence of correlated object movements. They required subjects repeatedly to watch a model performing an invariant sequence of seven balletic poses, each consisting of a unique configuration of arm and leg positions, and then to attempt to reproduce the sequence. Blocks of seven observation trials were followed by three practice trials until the sequence was reproduced perfectly in each of three successive practice trials, and the number of practice trials required to reach this criterion was greater when the model was viewed from the front than when she was viewed from behind. These results imply that the observers acquired sequence information and, because body movements were not correlated with object movements, that they learned a sequence of body movements. However, the observers did not necessarily engage in observational motor learning. This kind of learning is more likely to arise when observation of body movement, rather than of object movement, is the critical input for learning, but processing of observed body movements does not necessarily involve motor activation or result in effector-specific encoding. The subjects in Ishikura and Inomata's experiment may, for example, have formed via observation a visual and/or verbal representation of the modelled movement sequence and may have used this to guide their performance on practice trials by comparing it with visual or verbal representations of their own actions. Evidence of transfer of learning across effectors would favour this kind of hypothesis over observational motor learning, but such evidence is difficult to obtain when, as in Ishikura and Inomata's experiment, the training sequence consists of gross body movements.

Observational learning in a serial reaction time task

The present experiments sought evidence of observational motor learning of sequential information using a serial reaction time (SRT) task (Nissen & Bullemer, 1987). Practice subjects in this procedure perform a tapping task in which one of a number of keys has to be pressed with a corresponding finger in response to a stimulus at a corresponding location on a computer screen. Stimulus locations occur in a continuously repeating sequence during blocks of training trials, then in a different sequence or random order for a block of test trials, and reaction time (RT) elevation between the final block of training and the test trials is used as an index of sequence learning. Several studies (e.g., Willingham, Nissen, & Bullemer, 1989) have found that subjects who show RT elevation do not provide evidence of sequence knowledge when they are instructed to recall the sequence by responding to each stimulus with the key corresponding to the next location in the sequence (the "generate test"), or to reproduce the sequence on the keyboard without cueing (the "free generation test"). Consequently, it has been suggested that the SRT test can be used to measure implicit learning. However, that is not why it was used in the present study, which is concerned with the distinction between perceptual and motor learning, rather than between implicit and explicit learning.

The SRT task was used here to test for observational motor learning because it can be readily adapted to assess the effector specificity of sequence learning, and because there is evidence that motor learning is involved when subjects practise (i.e., perform the task themselves) during training (Mayr, 1996; Willingham, 1999; Willingham et al., 1989). Willingham (1999, Experiment 3) added to the SRT task a transfer test in which the stimulus–response mapping was changed so that one group of subjects pushed the same sequence of keys but saw new stimuli (motor condition), whereas another group pushed a different sequence of keys but saw the same stimuli (perceptual condition). Transfer to the new mapping occurred only if the motor sequence was kept constant.

Kelly and Burton (2001) failed to find evidence of observational learning of any kind (perceptual or motoric) when they compared the SRT performance of practice subjects with that of observers, each of which had watched a practice subject during training on a 12-trial ambiguous sequence (423413214321, where each digit refers to one of four stimulus locations). In ambiguous sequences, each base item (e.g., stimulus location) is followed by more than one other base item, whereas in unique sequences, each base item uniquely predicts the next. Using "control tasks" that have features in common with SRT tasks, Berry (1991) reported observational learning when the training sequence was relatively simple or obvious, but not when it was more complex. This raises the possibility that evidence of observational learning could be obtained in the SRT task using a simpler sequence than that of Kelly and Burton.

In summary, there is evidence of observational learning of sequence information from a study in which subjects observed balletic poses (Ishikura & Inomata, 1995), and evidence that practice subjects engage in motor learning of sequence information in an SRT task (e.g., Willingham, 1999). However, it is not yet clear whether model observation can support sequence learning in an SRT task via either perceptual or motoric processes, and it has not been established whether observational motor learning, of sequence or other information, can occur under any conditions. The purpose of Experiment 1 was to find out whether subjects show any observational learning of sequence information in an SRT task with a simple, six-trial sequence. Experiment 2 went a step further and used additional stimulus and response transfer procedures to investigate whether observational learning of sequence information in this SRT task is effector specific—that is, whether it constitutes observational motor learning.

EXPERIMENT 1

Experiment 1 sought evidence of observational learning in an SRT task using a six-trial unique sequence and, also in contrast with Kelly and Burton (2001) and Berry (1991), by comparing observers' performance with that of "non-exposed" subjects who completed an irrelevant task during observer training. This was thought to be the appropriate control because Experiment 1 was intended to establish whether *any* sequence information can be acquired by observation in the SRT task, not to compare the extent of learning via practice and observation. In a further attempt to increase the probability of finding an observational learning effect of some kind, sequence learning was measured by RT elevation for half of the subjects in

Experiment 1 and by a free generation test for the remainder. The free generation test was chosen because it was thought that, as an uncued procedure, it may be sensitive to response learning.

Method

Subjects

A total of 58 psychology students at University College London (34 females and 24 males) participated in the study. Their mean age was 25.4 years, all reported normal or corrected-to-normal vision, and they were paid a small honorarium for their participation.

Apparatus and materials

The experiment was run on a personal computer (Dell Optiplex 560/L), attached to a standard QWERTY keyboard. The target stimulus was a white rectangle, 3 mm wide × 1 mm high, that appeared on a black background in one of six boxes arranged in a row in the middle of a VGA colour monitor. Each box was outlined in white, measured 3 cm wide × 1.5 cm high, and was positioned at a distance of 1 cm from adjacent boxes. The target stimulus appeared in the centre of the box. The visual angle of the distance between two adjacent targets was 5.7°. Subjects used the x, c, v, b, n, and m keys for their responses, operating x, c, and v keys with the ring, middle, and index fingers of their left hand, respectively, and the b, n, and m keys with the index, middle, and ring fingers of their right hand, respectively. The keys corresponded spatially to the boxes on the screen such that, for example, a correct response to a target in the box on the extreme left consisted of pressing the × key. The target remained on the screen until a correct response was made, and the following target appeared 200 ms later. Correct and incorrect responses were recorded.

Two 6-item unique sequences were used: 125436 and 124653, where each digit refers to a box on the screen (1 indicating the box on the extreme left, 2 the second box from the left, and so on). Each block consisted of 100 trials, including 16 sequence repetitions, and began at a randomly selected point in the sequence.

Procedure

Subjects were tested individually in laboratory cubicles. They were seated approximately 50 mm from the screen and were instructed to respond as quickly as possible to the target stimuli by pressing the corresponding response keys. All subjects completed an initial block of trials with the training sequence to familiarize them with the task. Group OBSERVE ($n = 40$) were then seated beside the experimenter as she completed six blocks with the training sequence. Before these blocks began, the observers were told by the experimenter to "watch me carefully as I perform the task". The experimenter/ model's mean RT was approximately 300 ms with a 5% error rate. Group NON-EXP ($n = 18$) spent a comparable period of time (approximately 7 min) solving anagrams. At the end of this training phase, half of the subjects in group OBSERVE were given a response time test, and the other half were given a free generation test. The response time test consisted of two blocks of trials. In the first test block subjects responded to the training sequence, and in the second they responded to an alternative test sequence. 125436 was the training sequence, and 124653 was the test sequence for half of the subjects in each treatment group, whereas the other half received the reverse assignment. At the beginning of the free generation test subjects were told that the stimuli had appeared in a repeating sequence during the training phase and were asked to reproduce that sequence on the keyboard. Their key presses were echoed by the appearance of the corresponding stimulus on the screen, and they were required to make 96 key presses in total. Subjects in group NON-EXP were given both tests, with half receiving the response time test first. These subjects completed one block of trials with the training sequence after the response time test and before proceeding to the free generation test.

Results and discussion

Response times. Mean RTs in Block 1, prior to the training phase, were comparable in group OBSERVE (M = 555.0.1 SE = 20.1) and in group NON-EXP (M = 546.3, SE = 25.2) ($F < 1$). However, as shown in Figure 1, introduction of the alternative sequence in the second test block was associated with a greater RT elevation in observers than in non-exposed subjects. Three-way analysis of variance (ANOVA) examining the effects of group, (first vs. second test block), and training sequence (125436 vs.124653) yielded a main effect of block, $F(1, 34) = 122.75$, $p < .001$, and a reliable Group × Block interaction, $F(1, 34) = 9.09$, $p < .01$. Simple effects analysis confirmed that RT was greater in the second than the first test block for group OBSERVE, $F(1, 34) = 6.3$, $p < .05$, but not for group NON-EXP, $F(1, 34) = 1.85$.

Errors. On average, group OBSERVE made 2.8 (SE = 0.92) errors in the first test block and 5.7 (SE = 1.3) in the second, whereas group NON-EXP made 1.5 (SE = 0.7) in the first test block and 3.72 (SE = 1.04) in the second. Three-way ANOVA yielded only a main effect of block, $F(1, 34) = 22.89$, $p < .001$, and simple effects analysis confirmed that introduction of the alternative sequence was associated with an increase in error rate in group OBSERVE, $F(1, 34) = 15.49$, $p < .001$, and in group NON-EXP, $F(1, 34) = 8.20$, $p < .01$.

Free generation. The free generation test was scored by counting the number of triplets (three successive key presses) that adhered to the training sequence. For example, if a subject executed 564321256 as part of their free recall performance, and they had 125436 as their training sequence, they would score 1 for this component because it contains only one triplet, 125, that appears in the training sequence. Excluding the possibilities of item repetition and reversal (Shanks & Johnstone, 1999), chance performance on this measure is 24.5.

On average, group OBSERVE generated 51.8 correct triplets (SE = 8.39), and group NON-EXP generated 29.3 (SE = 7.83). Two-way ANOVA indicated that the sequence counterbalancing variable had no effects and that observers performed marginally better on the free generation task than did the non-exposed subjects, $F(1, 37) = 3.58$, $p = .067$.

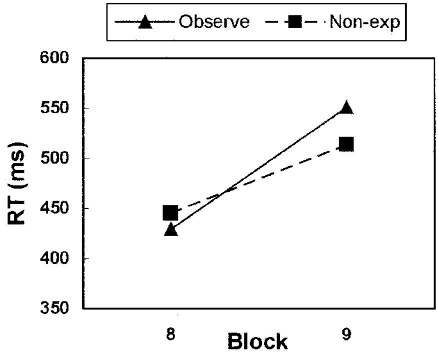

Figure 1. Mean response times for Block 8 (training sequence) and Block 9 (alternative sequence) in Experiment 1.

These results suggest that subjects acquired sequence information by observation of a model performing the SRT task with a six-item unique sequence. The RT measure provided relatively clear evidence of observational learning, but the effect was marginal on the free generation test. This pattern of results may have arisen from the use of one non-exposed control group that underwent both tests. The free generation performance of half of the non-exposed subjects (those who completed the RT test first) may have reflected information gained during the RT test. This feature of the design is unlikely to have affected the RT scores of non-exposed subjects because the free generation task does not involve performance feedback.

EXPERIMENT 2

Experiment 2 compared three groups: OBSERVE, NON-EXP, and PRACTICE. In the first part of the experiment, groups OBSERVE and NON-EXP received the same treatment as in Experiment 1 except that each subject performed the RT test followed by the free generation test, providing a less conservative estimate of observational learning on the latter measure. In Part 1 of Experiment 2, practice subjects performed the SRT task themselves throughout the training phase and were also given both the RT and the free generation test. The purpose of this part of the experiment was to replicate the effects of observation on response time and free generation performance found in Experiment 1, and to compare the extent of observational learning with that arising from direct experience of task practice.

In the second part of Experiment 2, after all three groups had completed the response time and free generation tests, subjects were given a stimulus transfer test and a response transfer test, each consisting of two blocks of trials. In the first block of the stimulus transfer test the stimulus array was changed such that the asterisks appeared in the training sequence but in boxes arranged on the screen vertically rather than horizontally. In the second block, the stimuli continued to appear in a vertical array but now in the alternative sequence rather than the training sequence. Similarly, in the first block of the response transfer test subjects were required to respond to the training sequence, displayed in the usual horizontal array, using their thumbs rather than their fingers, and in the second block they responded with their thumbs to the alternative sequence.

These tests are similar to those used by Stadler (1989) to investigate whether learning in a visual search task is primarily perceptual or motoric. To the extent that sequence information acquired during training is encoded motorically, one would expect response times to increase between the first and second blocks of the stimulus transfer test and not to increase between the first and second blocks of the response transfer test. Motorically encoded sequence information would be usable in the first block of the stimulus transfer test, when the stimulus locations but not the finger movements have changed, and therefore one would expect RT elevation in the second block when this information is invalidated by introduction of the alternative sequence. However, motorically encoded sequence information would be rendered useless in the first block of the response transfer test, when subjects are required to respond with their thumbs rather than their fingers, and therefore one would not expect (further) RT elevation on introduction of the alternative sequence in the second block.

Conversely, to the extent that the sequence information acquired during training is encoded perceptually, one would expect response times to increase between the first and second blocks of the response transfer test and not to increase between the first and second blocks of the stimulus transfer test. Perceptually encoded sequence knowledge would be invalidated by the change in stimulus locations introduced in the first block of the stimulus transfer test, but would remain applicable in the first block of the response transfer test when the motoric requirements, but not the stimulus array, change relative to training conditions.

Stadler (1989) suggests that variation in the magnitude of RT elevation between training and the first test block of each transfer test can also be used to infer whether learning is motoric or perceptual, but this measure is impure. Any such increases may be due to the changes in stimulus–response mapping that accompany both the transition from a horizontal to a vertical stimulus array, and the transition from finger to thumb responding. The latter transition may also result in RT elevation by increasing travel time.

Method

Subject

A total of 35 undergraduate students at University College London (18 females and 17 males) participated in the study. Their mean age was 20 years, all reported normal or corrected-to-normal vision, and they were paid a small honorarium for their participation.

Materials and procedure

The materials and procedure were the same as those of Experiment 1 except in the following respects.

The response time and free generation performance of groups OBSERVE ($n = 13$) and NON-EXP ($n = 11$) were compared with those of group PRACTICE ($n = 11$). In the training phase, practice subjects performed six blocks of the SRT task themselves, whereas the observers watched a model performing six blocks of the task, and the non-exposed subjects solved anagrams. After the response time test and before the free generation test, each subject performed one block of trials, Block 10, with the training sequence.

A second, transfer, phase was added to the experiment, in which each subject completed a stimulus transfer task and a response transfer task. Half of the subjects were given the stimulus transfer test first and the response transfer test second, whereas the other half received the reverse assignment. On each trial in the stimulus transfer test subjects responded, using the same keys and fingers as those during the first part of the experiment, to an asterisk that appeared in one of six boxes arranged in a central, vertical column on the computer screen. Representing the top box as 1 and the bottom box as 6, the stimuli appeared in the training sequence in the first block of the stimulus transfer test and in the alternative sequence in the second block. In the response transfer test subjects responded using the same keys and to stimuli appearing in the same visual array as those during the first part of the experiment, but they were instructed to use their thumbs rather than their fingers. The left thumb operated the x, c, and v keys, and the right thumb was used to depress the b, n, and m keys. Stimuli appeared in the training sequence in the first block and in the alternative sequence in the second block of the response transfer test.

Results and discussion

Due to computer error, all of the data from three subjects (two in group NON-EXP and one in group OBSERVE) and Block 1 data from two additional subjects (one in each of groups NON-EXP and OBSERVE) were not recorded. Therefore, analysis of the pretraining block data was based on 30 cases, and all other analyses on 32 cases (PRACTICE, $n = 11$; NON-EXPOSED, $n = 9$; OBSERVE, $n = 12$).

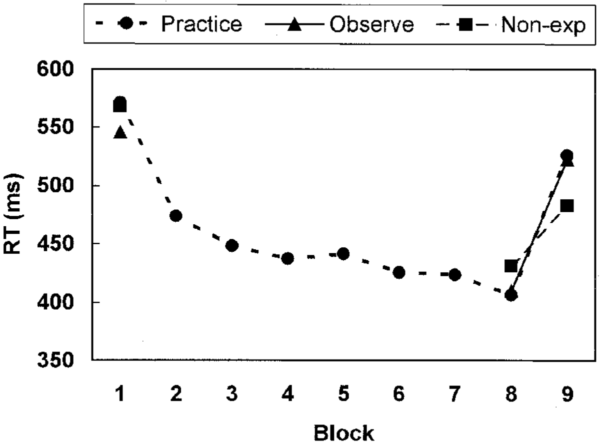

Figure 2. Mean response times for Blocks 1–8 (training sequence) and Block 9 (alternative sequence) in Experiment 2.

Part 1: The standard SRT and free generation tests

Response times. Mean RTs for the standard SRT test are shown in Figure 2. In Block 1, the pretraining block, RT did not vary across groups or with the identity of the training sequence (*F*s < 1). Introduction of the alternative sequence in Block 9 (the second test block) resulted in an increase in RT relative to Block 8 (the first test block) in groups PRACTICE and OBSERVE but not in group NON-EXP. Three-way ANOVA indicated only a main effect of test block, $F(1, 26) = 40.5$, $p < .001$, and simple effects analysis confirmed that whereas responding during the second test block was slower in group PRACTICE, $F(1, 26) = 24.9$, $p < .001$, and group OBSERVE, $F(1, 26) = 24.3$, $p < .001$, group NON-EXP responded at a comparable speed to the training sequence and to the alternative sequence, $F(1, 26) = 3.84$.

Errors. Mirroring the response time effects, error rate increased between the first and second test blocks in group PRACTICE, Block 8, $M = 1.36$, $SE = 0.73$; Block 9, $M = 4.55$, $SE = 1.45$; $F(1, 21) = 29.2$, $p < 001$; and group OBSERVE, Block 8, $M = 1.92$, $SE = 0.92$; Block 9, $M = 4.25$, $SE = 1.37$; $F(1, 21) = 5.56$, $p < .05$; but not in group NON-EXP, Block 8, $M = 0.78$, $SE = 0.43$; Block 9, $M = 1.33$, $SE = 0.41$; $F(1, 21) = 3.25$.

Free generation. Figure 3 shows the mean number of correct triplets generated by each group. Two-way ANOVA (Group × Sequence) indicated only a main effect of group, $F(2, 26) = 7.11$, $p = .003$, and Tukey HSD post hoc tests showed that group OBSERVE generated more correct triplets than did group NON-EXP ($p = .002$), and that group PRACTICE did not differ from either of the other two groups.

Confirming the results of Experiment 1, the contrasts between observers and non-exposed subjects in the first part of Experiment 2 indicate that observation of a model performing the SRT task supports learning as measured by response time, error rate, and free generation measures. Furthermore, the comparisons between observers and practice subjects suggest that, on RT and error rate measures, observation results in as much learning as task performance.

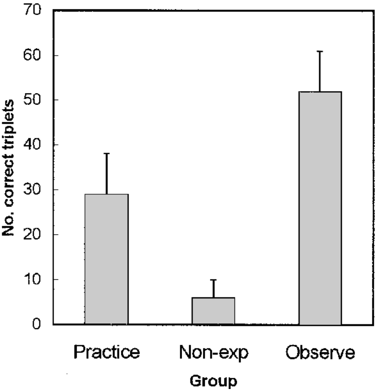

Figure 3. Mean number of triplets correctly reproduced in the free generation test in Experiment 2. Bars represent standard error of the mean.

Part 2. Transfer tests

Stimulus transfer test. The left panel of Figure 4 shows the RT data from the stimulus transfer task. RTs in the first test block (new stimulus array, training sequence) were compared with: (1) RTs in Block 10 (old stimulus array, training sequence), to assess the effects of alteration of the array only; and (2) RTs in the second test block (new stimulus array, alternative sequence), to assess the consequences of changing the sequence in addition to the array.

Four-way ANOVA (Block × Group × Sequence × Transfer Test Order) revealed a main effect of block, $F(1, 21) = 67.0, p = .001$, and no other reliable effects or interactions. Simple effects analysis showed that responding was slower in the first test block than in Block 10 in groups NON-EXP, $F(1, 21) = 5.71, p < .05$, and OBSERVE, $F(1, 21) = 7.48, p < .01$, but not in group PRACTICE ($F < 1$). RT elevation across this first transition could have been due to

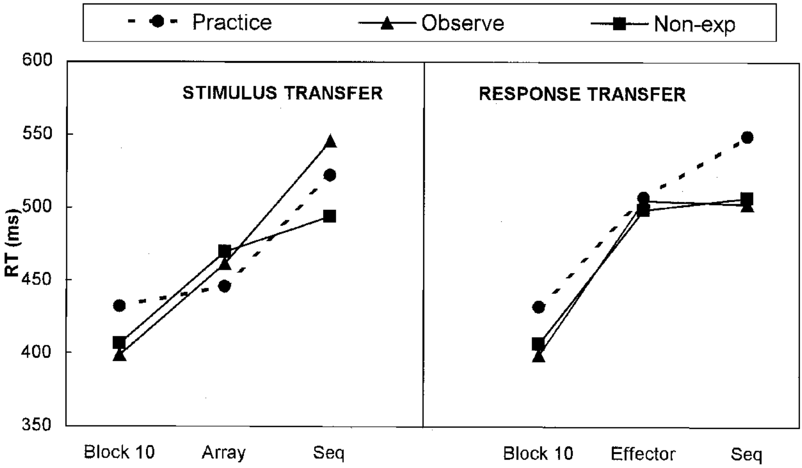

Figure 4. Mean response times in the stimulus transfer test (left panel) and response transfer test (right panel) in Experiment 2. Response times in Block 10, the last training block before the transfer tests, are shown in each panel.

change in stimulus–response mappings, and therefore comparisons at the second transition, between the first and the second test blocks, are of greater interest. Simple effects analysis of the second transition showed RT elevation in group PRACTICE, $F(1, 21) = 10.11, p < .01$, and group OBSERVE, $F(1, 21) = 13.45, p < .001$, but not in group NON-EXP ($F < 1$).

Error rate did not vary across the second transition in group NON-EXP, Block 8, $M = 2.44$, $SE = 1.61$; Block 9, $M = 3.89$, $SE = 1.15$; $F < 1$; or in group OBSERVE, Block 8, $M = 4.42$, $SE = 1.43$; Block 9, $M = 5.17$, $SE = 0.98$; $F < 1$; but group PRACTICE made more errors in the second test block than in the first, Block 8, $M = 3$, $SE = 1.61$ Block 9, $M = 7.27$, SE = 3.33 $F(1, 21) = 7.54, p < .01$.

These results of the stimulus transfer test imply that, in spite of alteration in the stimulus array, the observers and practice subjects were able to make use during the first test block of sequence knowledge acquired during training. This suggests, in turn, that some or all of the sequence information acquired during training through practice and through observation was encoded motorically rather than perceptually.

Response transfer test. RT data from the response transfer test, shown in the right panel of Figure 4, were analysed in the same way as those from the stimulus transfer test. In this case, four-way ANOVA indicated not only a main effect of block, $F(1, 21) = 51.8, p < .001$, but also a Block × Order interaction, $F(1, 21) = 6.35, p < .05$, reflecting slower responding during test blocks when the response transfer test preceded the stimulus transfer test. No other effects or interactions were reliable, including the Group × Block × Order interaction, and therefore the data from subjects who completed the response transfer test first and second were pooled for simple effects analysis. This analysis indicated significant RT elevation at the first transition, between Block 10 and the first test block, in all three groups, PRACTICE, $F(1, 21) = 9.48, p < .01$; NON-EXP, $F(1, 21) = 11.67, p < 01$. OBSERVE, $F(1, 21) = 20.66, p < .001$, and no reliable difference at the second transition, between the first and second test blocks, in any of the three groups, PRACTICE, $F(1, 21) = 2.95, p = .10$; NON-EXP and OBSERVE, $F\text{s} < 1$.

Error rate did not vary at the second transition in the response transfer test in group NON-EXP, Block 8, $M = 5.1$, $SE = 1.7$; Block 9, $M = 5.2$, $SE = 1.3$; $F < 1$, or in group OBSERVE, Block 8, $M = 8$, $SE = 2.8$; Block 9, $M = 11.3$, $SE = 3.6$, $F < 1$. However, group PRACTICE made more errors in the second test block than in the first, Block 8, $M = 6.4$, $SE = 2.5$; Block 9, $M = 14.5$, $SE = 3.5$; $F(1, 21) = 11.61, p < .01$.

The combined results of the stimulus transfer test and the response transfer test imply that: (1) non-exposed subjects did not acquire any sequence knowledge during the training and test phases of the standard SRT task; (2) subjects who performed the task themselves acquired sequence information that was represented motorically and perceptually; and (3) observers acquired sequence information that was encoded motorically—that is, that they engaged in observational motor learning.

The transfer tests provided no evidence of sequence learning in non-exposed subjects because their RTs increased when the stimulus array and response mode were changed, but not between the first and second test blocks when a sequence change was superimposed on these alterations. RT elevation during the first block in each transfer test could be due solely to the requirement to use new stimulus–response mappings and need not reflect interference with the use of sequence information.

Evidence that practice subjects encoded sequence information motorically came from increases in their RT and error rates between the first and second blocks of the stimulus transfer test. If their sequence knowledge was coded purely perceptually, it would have been invalidated by the change in stimulus array introduced in the first test block, and therefore a further sequence change should not have affected performance. However, there was also some evidence of perceptual coding in practice subjects. They showed a substantial, although not significant, increase in RT between the first and second blocks of the response transfer test, and their error rate increased with introduction of the alternative sequence in the response transfer task, implying that the alteration in response mode, from fingers to thumbs, had not completely invalidated their sequence knowledge.

There was evidence of motoric but not perceptual coding in observers; their RTs increased between the first and second blocks of the stimulus transfer test, but not between the first and second blocks of the response transfer test. This pattern of results suggests that changing response mode from fingers to thumbs invalidated the observers' sequence knowledge, whereas changing stimulus presentation from a horizontal to a vertical array did not.

GENERAL DISCUSSION

The results of the current experiments suggest that in a six-item, unique sequence SRT task: (1) Subjects can acquire sequence information by watching another person performing the task (Experiments 1-2); (2) observation results in as much sequence learning as task practice, when learning is measured by RT elevation, but observation may result in more explicit learning (Experiment 2, Part 1); (3) task practice gives rise to sequence knowledge that is partly perceptual and partly motoric; (4) sequence knowledge acquired by model observation can be encoded motorically—that is, in an effector- specific fashion (Experiment 3, Part 2). Thus, in the terminology used in the Introduction, Experiment 2 provides a demonstration of observational motor learning.

In contrast with the present study, Kelly and Burton (2001) failed to find evidence that sequence information could be acquired by observing a model performing the SRT task. This contrast is likely to be due to the use of a more complex sequence, a 12-item ambiguous sequence, in the previous study. It is possible that, with the amount of observation experience given by Kelly and Burton and in the present study, subjects can acquire sequence information when each sequence component uniquely predicts the next, but not when each base item may be followed by two or more other base items. This would be consistent with Berry's (1991) report that, in a control task, model observation supports learning of a salient, but not of a non-salient, rule.

The finding, in Part 1 of Experiment 2, that sequence change was associated with equivalent RT elevation in observers and practice subjects is superficially similar to the report by Howard, Mutter, and Howard (1992) of equivalent learning by observers and practice subjects of a 10-item, ambiguous sequence in an SRT task. However, the present findings do not merely replicate those of Howard et al. (and the latter do not contradict Kelly & Burton's, 2001, results) because the observers in Howard et al.'s study passively watched stimulus presentation but did not see a model responding in the SRT task. Furthermore, the results of the second part of Experiment 2 are inconsistent with Howard et al.'s conclusion that practice-based implicit learning in the SRT task is purely perceptual. The free generation performance of practice subjects in Experiment 2 was at roughly chance level and no better than that of non-exposed controls. This implies that their RT performance was based on implicit learning, and the finding that their RTs increased between the first and second blocks of the stimulus transfer test suggests that, at least in part, practice subjects' sequence knowledge was encoded motorically.

In suggesting that practice-based implicit learning of sequence information is not exclusively perceptual, the results of Experiment 2 are consistent with those of several previous studies of learning based on SRT performance (Mayr, 1996; Willingham, 1999; Willingham et al., 1989). For example, using a stimulus–response mapping transfer task, Willingham (1999) found evidence of motor learning in practice subjects, but only when their free generation test performance was poor. Interpreting the free generation test as a measure of explicit learning, Willingham concluded that practice-based sequence learning in the SRT task is partially motoric, but only when it is implicit. Corroborating this conclusion, the practice subjects in Experiment 2 showed signs of motor learning in the stimulus and response transfer tasks, whereas their free generation performance was no better than that of non-exposed controls.

In conflict with Willingham's conclusion, the observers in Experiment 2 both provided evidence of motor learning *and* performed well on the free generation task. If one assumes that the free generation test measures explicit learning, the present results therefore suggest that practice subjects learn implicitly whereas observers learn explicitly, and, focusing on the observers' performance, that sequence learning in the SRT task can be both explicit and motoric. However, as an uncued procedure, the free generation test may index motor learning, instead of in addition to explicit learning. In this case or, it may be that observers' free generation performance was superior to that of practice subjects because this test was more sensitive to motor learning in observers. If practice subjects typically look at the screen during training whereas observers look at the model's hands, then the transition from training to the free generation test (an uncued procedure in which many subjects look at their hands) would involve less context change for observers than for practice subjects. More speculatively, the free generation task may be less sensitive to motor learning in practice subjects because perceptual sequence knowledge impairs free generation performance by eroding confidence (Anastasopoulou & Harvey, 1999).

Alternatively, when the SRT task is based on a six-item unique sequence (rather than a 12-item ambiguous sequence, used by Willingham, 1999), the free generation task may be equally sensitive to motor learning in practice subjects and observers. In this case, the practice subjects' relatively poor free generation performance would indicate that, relative to observers, they formed a weaker motor representation of the sequence, or a representation that was more dependent on perceptual coding. The latter interpretation is consistent with the finding that the practice subjects in Experiment 2, but not the observers, provided some evidence of perceptual learning in the form of an increase in error rate between the first and second blocks of the response transfer task.

Three features of the present procedure made it a conservative test of observational learning: (1) use of the training sequence in Block 1; (2) the occurrence of the 1–2 transition in both training and alternative sequences; and (3) the provision of a further block of training trials, Block 10, between the response time and free generation tests. Thus, if Block 1 involved a random sequence and therefore did not provide an opportunity for practice-based learning in all groups, if the test sequences did not have a salient transition in common, and if the free generation test were not preceded, in all groups, by practice with the training sequence, more pronounced group differences may have been obtained.

In conclusion, the experiments reported here contribute to a growing body of behavioural and neuroscientific evidence that action observation engages similar cognitive processes to those occurring during physical practice (e.g., Blandin et al., 1999; Fadiga et al., 1995; Jeannerod, 1994; Rizzolatti & Arbib, 1998). Going beyond previous studies, they provide evidence of observational motor learning; effector-specific representation of sequence information arising from observation of a model's body movements.

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