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Cognitive Processes Underlying Observational Learning of Motor Skills

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There is evidence indicating that an individual can learn a motor skill by observing a model practising it. In the present study we wanted to determine whether observation would permit one to learn the relative timing pattern required to perform a new motor skill. Also, we wanted to determine the joint effects of observation and of physical practice on the learning of that relative timing pattern. Finally, we were interested in finding whether there was an optimal type of model, advanced or beginner, which would lead better to observational learning. Data from two experiments indicated that observation of either a beginner or an advanced model resulted in modest learning of a constrained relative timing pattern. Observation also resulted in significant parameterization learning. However, a combination of observation followed by physical practice resulted in significant learning of the constrained relative timing pattern. These results suggest that observation engages one in cognitive processes similar to those occurring during physical practice.

It is generally agreed that the first determinant of motor learning is physical practice. However, physical practice is not always a suitable first step, nor is it always possible. This is the case, for example, when the task involves a certain degree of danger or when an injury requires that certain skills be relearned. In such instances, observation of a model performing the task may prove to be beneficial for learning or to reduce the amount of physical practice needed to reach proficiency (Newell, 1981; Schmidt, 1988; Scully & Newell, 1985). In fact, research indicates that observation facilitates learning of a large variety of tasks such as action pattern production (Carroll & Bandura, 1982), coincidence anticipation (Blandin, Proteau, & Alain, 1993; Weeks, 1992) and gross (Landers, 1975; Southard & Higgins, 1987) as well as fine motor skills (Martens, Burwitz, & Zuckerman, 1976; Pollock & Lee, 1992).

Sheffield (1961) and more recently Bandura (1977, 1986) proposed that observation of a model results in the observer developing what they called a "cognitive representation" of the task to be learned. The exact nature of this cognitive representation remains vague. However, Bandura proposed that observation might result in the development of a

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standard of reference for the task to be learned (named a "perceptual blueprint" by Sheffield, 1961) as well as mechanisms for the detection and correction of errors (Carroll & Bandura, 1990). These hypothesized mechanisms are not totally estranged from mechanisms thought to develop during physical practice and to be responsible for motor learning. In fact, it has been hypothesized that observational learning and learning through physical practice might be mediated by similar cognitive processes (Adams, 1986).

In this respect, according to motor program theory (Schmidt, 1975), movements are governed by a generalized motor program (GMP), which controls a whole class of actions (see Raibert, 1977; Shapiro, 1977; Shapiro, Zernicke, Gregor, & Diestel, 1981; Viviani & Laissard, 1996; but, see also Collier & Wright, 1995; Gentner, 1987, for a critique of this view). This GMP codes the sequencing of actions required to perform a task, as well as the relative timing and the relative force required to produce an action. Once a GMP has been chosen as appropriate to meet a specific goal, one must parameterize it or, in other words, determine the effector as well as the absolute timing and force value to be used. Increasing physical practice enables one to determine which GMP is more appropriate to reach a particular goal. In addition, one becomes better at parameterizing that GMP. Thus, from a cognitive point of view, and if observational learning is mediated by processes similar to those occurring during physical practice, observation of a model should enable one to learn a new GMP: the sequencing of actions, relative timing, and movement parameterization.[1]

Sheffield's and Bandura's accounts of observational learning have been criticized by Scully and Newell (1985) because the findings supporting the view that observation was beneficial for motor learning "did not directly support the theoretical position that information cues are symbolically coded and stored in memory for later retrieval to mediate overt responses" (p. 174). Rather, Scully and Newell proposed that the focus of observational learning theories should be on "what" is perceived rather than on "how" it is perceived. Reviewing the existent literature from this perspective, Scully and Newell proposed that the crucial information available during observation is the topological characteristics of the relative motion of the activity. They went further and proposed that this relative motion pattern, a coordination variable in the language of dynamic theories of movement control, is probably what is first learned by the observer. Then, with sufficient exposure to the task, one might learn how to parameterize this movement pattern, which represents a control variable.

Regardless of whether one favours a cognitive or a dynamic perspective of motor learning and control, it is clear that learning a new skill requires learning of the relative timing of the different components of that skill and also of its parameterization. There is some evidence in the literature suggesting that observation might enable one to learn the relative timing of a motor task. For example, Scully and Newell's (1985) proposition was based on the results from numerous studies showing that observers allowed to see the displacement over time of light spots located on the main articulations of a human participant were able to identify immediately whether he or she was walking, running,

[1] It is unclear whether relative force could also be learned through observation because in many instances this information might not be available (visible) to the observer.

or cycling (Johansson, 1973), whether the participant was male or female (Barclay, Cutting, & Kozlowski, 1978), or whether he or she was a friend or a stranger (Cutting & Kozlowski, 1977). Thus, it appears that all activities have a unique relative motion pattern recognizable by non naive observers. However, one must admit that recognizing a familiar relative motion pattern is very different from being able to perform successfully this pattern following observation.

More recently, Vogt (1995, Experiment 1) studied the effects of observation on the learning of cyclical movement sequences. Participants were asked to learn to reproduce a visually presented movement pattern by making a series of cyclical flexion–extension movements with their right forearm. Acquisition of the movement pattern was made either through 80 physical practice trials (with or without concurrent visual feedback) or through 80 observation trials. In either case, on each trial participants were first shown on a video screen the criterion pattern to be reproduced. This was achieved by displaying a vertical bar on a video screen, which moved rhythmically for 5 sec without leaving a trace. Then participants in the physical practice group tried to reproduce the criterion pattern while the lever position was illustrated on the video screen (condition with visual feedback), whereas participants of the observation group were asked to count backwards for 10 sec in steps of three, starting from an unpredictable two-digit number. Retention tests were performed after the 40th and the 80th acquisition trials and 24 hours later. These tests consisted of the participants being presented the criterion pattern once before being required to perform it for 8 trials without visual feedback. The results indicated that observation enabled the participants to learn the movement form as well as they did with physical practice. Moreover, the variability in the proportion of time required to complete a trial in relation to that of the criterion movement pattern was found to be the same after observation or physical practice. Finally, the consistency in relative timing—that is, the standard deviation of the proportion of the total time required to perform each segment of the pattern—was also identical for the two groups. Although these data underline that observation enables one to learn the general spatial characteristics of a new movement pattern as efficiently as does physical practice, it is not clear whether it enabled the participants to learn movement parameterization and relative timing. This is because becoming less variable with practice does not ensure that one performs exactly the criterion pattern; it only indicates that one performs more and more consistently one's own approximation of this pattern. The first goal of the present study was to determine whether movement parameterization and relative timing could be learned from observation.

A second goal was to determine whether observation of a beginner or of an advanced model would favour the development of a new relative timing. On the one hand, Sheffield (1961) proposed that observation permitted the observer to develop what he called a "perceptual blueprint" of the task to be learned. This led to the widely accepted utilization of a perfect model in observational learning studies. However, Adams (1986) proposed that it might be fruitful to watch a model who is also learning the task. By doing so, the observer learns which type of response leads to a poor performance and which type leads to a better performance. In short, the observer will be able to discriminate between successful and less successful movement patterns when knowledge of results (KR) based on the model's performance is provided to him or her. Data on this issue are surprisingly scant and inconsistent. Regardless of whether all observation trials are completed before physical practice (Landers & Landers, 1973; Martens et al., 1976; Weir & Leavitt, 1990), or are interspersed with physical practice, as long as KR on the model's performance is available (McCullagh & Caird, 1990; Pollock & Lee, 1992) there is no clear evidence favouring the utilization of a skilled or of a learning model as the best way to promote learning.

EXPERIMENT 1

To reach our goals, we first determined the natural relative timing used by individuals who physically practised the experimental task (Collier & Wright, 1995). To that end, we conducted a pilot study in which participants physically practised the task illustrated in Figure 1. Specifically, they were asked to leave the starting base, hit in succession the first, second and third barrier, and to end their movement on target in a movement time of 900 msec. In addition to measuring the time required to complete the task (hereafter called movement time), we also recorded the time spent between the home base and the first target, the first and the second target, and so on. The data revealed a stable relative timing both within and across participants. On average, participants used a relative timing of 19%, 36,9%, 18.4%, and 25.6% to complete the first, second, third, and fourth segments of the experimental task, respectively (within-participant variability and between-participants variability fluctuated between 2% and 5%). Moreover, this pattern was noted very early in practice and was not modified with further practice.

The critical point for the present study is that a stable and predictable relative timing pattern was apparent right from the beginning of physical practice. The main question addressed in the present experiment is whether this pattern of relative timing, to which we will refer as "natural timing", can be changed by observation of a model who practises changing it to a different one.

Our first two goals concerned the effects of observation per se on the learning of movement parameterization and of relative timing. In an acquisition phase, participants of a first group (models) physically practised completing the movement pattern illustrated in Figure 1 in a movement time of 900 msec. For a second group, this acquisition phase consisted of observing a beginner model as he or she was practising the task. These groups—models and observers—were called the natural timing (NT) groups and served as controls. It was believed that in a no-KR retention test these participants would use the relative timing pattern noted in our pilot study. The remaining participants were also asked to complete the task in a movement time of 900 msec, but also to execute each of its four segments in 225 msec (i.e. a relative timing of 25%–25%–25%–25%). Again, for some participants the acquisition phase consisted in physical practice. For the remaining participants, acquisition consisted in observing either a novice model of the above group practising the task or an advanced model who was successful at producing the constrained timing pattern. These two groups were called the constrained timing–beginner (CT–B) observers and constrained timing–advanced (CT–A) observers, respectively. If observation enables one to learn a new relative timing pattern, the CT–B and CT–A observers should be able to produce in a no-KR retention test a timing pattern that would be closer to the constrained relative timing pattern than that of the Natural Timing group. Moreover, if observation of an advanced model enhanced learning of a specific task when

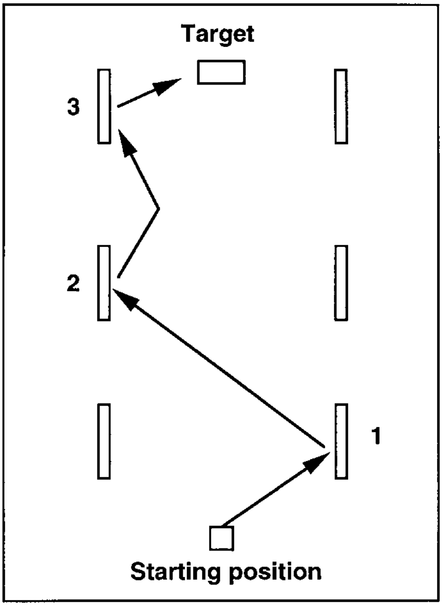

FIG. 1. View of the apparatus and of the movement pattern used in Experiment 1. Participants had to leave the starting base as they pleased and hit in succession the first, second, and third barrier, before ending their movement on the target in a movement time of 900 msec.

compared to observation of a beginner, the CT–A observers would outperform the CT–B observers in an immediate retention test following observation.

Finally, because it is doubtful that observation alone can lead to optimal learning of a spatio-temporal task, we sought to determine the joint effects of observation and physical practice on learning of a new relative timing pattern. To that effect, following the retention test alluded to above, all observers physically practised the task with KR available. Learning resulting from a combination of 50% observation followed by 50% of physical practice was evaluated in 10 min and in 24-hr retention tests with no KR.

Method

Participants

Fifty-five undergraduate students from the Department of Kinesiology of the University of Montreal participated in Experiment 1 in exchange for a course bonus. None of them had previous experience with the experimental task. An additional participant was a Masters student from the Faculty of Music of the University of Montreal, with 10 years of experience as a professional percussionist. It should be noted that the advanced model was chosen from a subset of seven participants coming from the same population (professional percussionists). He was chosen because he was the only one who could perform the constrained timing task while maintaining an overall movement time of approximately 900-msec. This underlines the great difficulty of the experimental task.

Apparatus

The apparatus was similar to that used by Shea and Morgan (1979) and is illustrated in Figure 1. It was composed of a wooden base and six wooden barriers (10×8 cm). Three barriers were equidistant from the central axis of the base. At the beginning of each trial, these barriers were placed perpendicular to the wooden base, which closed the circuit of a microswitch. On this central axis, close to the participant, was a microswitch, which served as the starting position; 46 cm further along the same axis was a metal plate where the movement terminated. The movement pattern used in the present study is also illustrated in Figure 1. The starting position, the target, and each of the barriers (microswitch) were connected to the computer via the I/O port of A–D converter (National Instruments). A millisecond timer was activated when the participant left the starting base; it recorded the time at which each barrier was knocked down (thus, releasing the microswitch) and stopped when the target was reached. Therefore the movement time—that is, the time elapsed from the starting point to the target, including the time required to knock down the three designated barriers—was known, as was the time needed to complete each segment of the task. The experimental movement pattern and its corresponding movement time and relative timing were illustrated on a poster located directly in front of the apparatus. This poster was present for all the experimental phases.

Experimental Groups and Procedure

Models. Twenty-three participants physically practised the task during an acquisition phase consisting of 60 trials. Each of these participants (called models) was filmed while performing the acquisition phase. The camera was located above the model's right shoulder to capture the visual information of the arm and of the targets and to keep the vision of the apparatus similar for the models and for the observers. For a first group of models (models NT; $n = 11$), the task was to produce the movement pattern in a movement time of 900 msec without any other requirements. For the other group (models CT–B; $n = 11$) and the percussionist (model CT–A; $n = 1$), the task was to perform the movement pattern in a movement time of 900 msec but with the additional requirement that each segment of the pattern be completed in 225 msec (or 25% of movement time). Following completion of each trial, verbal KR was provided to all participants concerning their movement time. In addition, the participants submitted to the constrained relative timing were also informed of the time required to complete each segment of the task. Following delivery of KR, the participant had to indicate whether his or her movement time was shorter or longer than 900 msec. Furthermore, participants of the CT–B and CT–A groups had to indicate how their performance differed from the constrained relative timing. This procedure was followed to ensure that participants paid attention to KR. The constrained relative timing pattern used in the present study has been chosen to make it easy for the participants to evaluate KR on each segment of the task (i.e. a unique reference for all four segments of the task). Trials for which participants hit a wrong barrier or missed the final target were repeated.

Observers. Three groups of observers were differentiated by the type of model observed in the first acquisition phase. Each participant of a first group (observers NT; $n = 11$), was yoked to one model of the model NT group, whereas each participant of a second group (observers CT–B; $n = 11$) was yoked to one model of the CT–B group. They observed the 60 trials performed by their respective models. All participants of the last group (observers CT–A; $n = 11$), observed the 60 trials performed by the model percussionist. We used a yoking procedure for groups CT–B and NT rather than having all participants observe the same model, in order to ensure that the observers' performance could be attributed to observation per se rather than to some characteristics of a particular model.

All observers were informed as to the nature of the six experimental phases that they had to complete. The first phase was a pre-test made up of 20 physical practice trials for all participants without KR on either movement time or relative timing. The observers NT were instructed to produce the task in a movement time as close as possible to 900 msec without any mention of relative timing. The instructions informed the observers CT–B and CT–A of the requirements of the task for both movement time and relative timing.

In the second phase, after a rest of three minutes, participants observed on a 90-cm video screen, and under their respective conditions, 60 trials performed by a model. Participants were informed of the KR provided to the model that they observed (i.e. movement time, or movement time and relative timing when appropriate). The third experimental phase, performed after a three-minute rest, was a post-test made up of 20 physical practice trials without KR. It was followed by a second acquisition phase made up of 60 physical practice trials, each being followed with appropriate KR. Finally, two delayed retention tests, each made up of 20 trials without KR, were performed 10 min and 24 hr after the end of the second acquisition phase (i.e. physical practice).

As was the case for the models, when KR was provided the observers had to indicate whether their movement time (or the one observed) was shorter or longer than 900 msec. Furthermore, the participants of the CT–B and CT–A groups had to indicate how the preceding trial (observed or performed) differed from the constrained relative timing; for example, they had to indicate that the first segment of the task was completed too quickly whereas the second segment took too much time. This procedure was followed to ensure that the participants paid attention to KR.

Results

For each of the experimental phases, the data were regrouped into blocks of four trials each. Three dependent variables were computed. First, the absolute constant error ($|CE|$) and the variable error (VE) were computed on movement time (in msec). These measures indicate the accuracy and the consistency of the overall duration of the participants' responses, respectively. Finally, the time spent on each segment of the task was expressed as a percentage of movement time. We used these data to compute for each trial the participant's root mean square error ($RMSE$) in relation to the constrained relative timing.[2] The effects of observation per se were evaluated by contrasting these three dependent variables for the three groups of observers (CT–A, CT–B, and NT) in pre-test and in post-test. The effect of physical practice on acquisition of the task was determined by contrasting the performance obtained for the three groups of observers across the 15 blocks of acquisition. Finally, the effect of a combined schedule of observation and of physical practice on learning of the task was determined by contrasting the performance obtained for the three groups of observers across the two retention tests. The different analyses of variance were computed using the Greenhouse–Geisser corrections when the epsilon value was smaller than 1 (Greenhouse & Geisser, 1959; see also Winer, 1971). All significant effects are reported at $p < .05$ and post hoc comparisons of

[2] $RMSE$ = square root [(segment 1%–25%)^2 + (segment 2%–25%)^2 + (segment 3%–25%)^2 + (segment 4%–25%)^2]/4. Note that the relative timing pattern used in the pilot study would have led to a $RMSE$ of 7.44%.

the means were computed using the Newman–Keuls technique. Movement pattern errors occurred in less than 1% of the trials. No analysis was computed on these errors.

Preliminary Analysis: Models' Performance

Figure 2 (upper panel) shows that physical practice followed with KR enabled the models to complete their movement close to the required movement time. However, this was somewhat easier to achieve when there were no constraints regarding the relative timing to be used. This is supported by a significant Group × Blocks interaction for $|CE|$ ×, $F(14, 280) = 1.9$, indicating that the model NT group had a smaller error than the model CT–B group for the first eight blocks of trials, Fs $(1, 295) \geq 4.1$. Moreover, as illustrated in the lower panel of Figure 2, although both broups of models decreased their movement time variability as practice increased, $F(14, 280) = 5.9$, having to produce a constrained relative timing resulted in higher variability than having no such constraints to meet, $F(1, 20) = 7.5$. Concerning relative timing, the results revealed that physical practice followed with KR enabled the models (CT–B group) to perform closer to the constrained pattern than the models (NT group) who had no relative timing constraints (4.49% vs. 6.14%, respectively), $F(1, 14) = 7.46$. Complementary analyses indicated that the CT–B group differed significantly from the NT group only for the second segment of the task. The CT–B group spent less time on this segment of the task than did the NT group (30.6% vs. 33.4%, respectively), $F(1, 20) = 4.9$. No differences were noted for the remaining three segments of the task, all Fs$(1, 20) < 2$, $p > .05$.

Finally, it should be noted that the performance of the percussionist, for both the $|CE|$ and VE in movement time as well as for relative timing, was better than that of the beginner models. Concerning relative timing, this superior performance was especially true for segments 1 and 2. The relative timing of this participant was 24% (SD 3.1%), 26.4% (SD 2.3%), 27.5% (SD 1.5%), and 22.1% (SD 1%), for Segments 1, 2, 3, and 4, respectively, for a mean $RMSE$ of relative timing of 2.04%.

Observers' Relative Timing

Our first objective was to determine whether observation of a model, and/or a combination of observation and of physical practice, enables one to move away from the natural timing toward the constrained timing. Also, we wanted to assess whether the model's skill level had an effect on the observer's learning of the constrained timing.

As illustrated in Figure 3 (upper panel, pre/post-tests), all three groups of observers performed closer to the constrained relative timing in the post-test than in the pre-test, $F(1, 20) = 32.5$. Because the NT group behave in the same way as CT–A and CT–B groups ($F < 1$), it would seem that observation per se did not enable one to move away from the natural relative timing. This, however, does not indicate that observation is useless in this type of task. Rather, it appears that physical practice followed by KR is mandatory for what had been learned during observation to become manifest. Figure 3 (upper panel, acquisition) illustrates that, beginning with the first block of trials and lasting for the whole acquisition phase, observation of an advanced model permitted

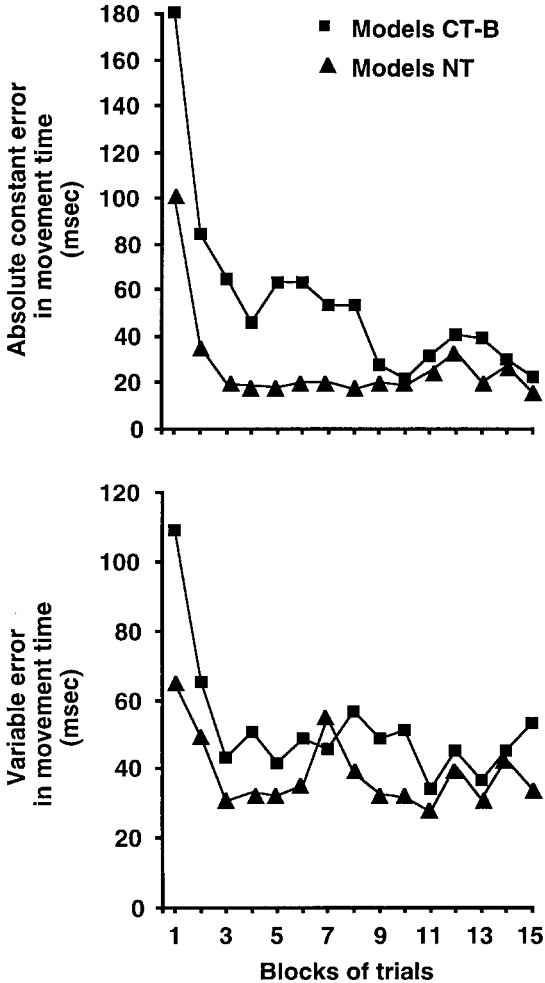

FIG. 2. Absolute constant error and variable error in movement time for the models constrained timing–beginner (models CT–B) and the models natural timing (models NT) as a function of the blocks of physical practice.

the CT–A group to perform closer to the constrained relative timing than did observation of either a beginner model (CT–B group) or a natural timing model (NT group), which did not significantly differ from each other, $F(2, 18) = 9.7$. This suggests that it is only observation of an advanced model combined with physical practice and KR that resulted in observers performing their movement closer to the constrained relative timing than participants with no such constraints. A similar conclusion emerges from the results of the retention tests, which indicated that it is only the observers of the advanced model who performed significantly closer to the constrained relative timing than participants of the NT group (see Figure 3, upper panel, 10–24-hr retention), $F(2, 30) = 4.85$. Note,

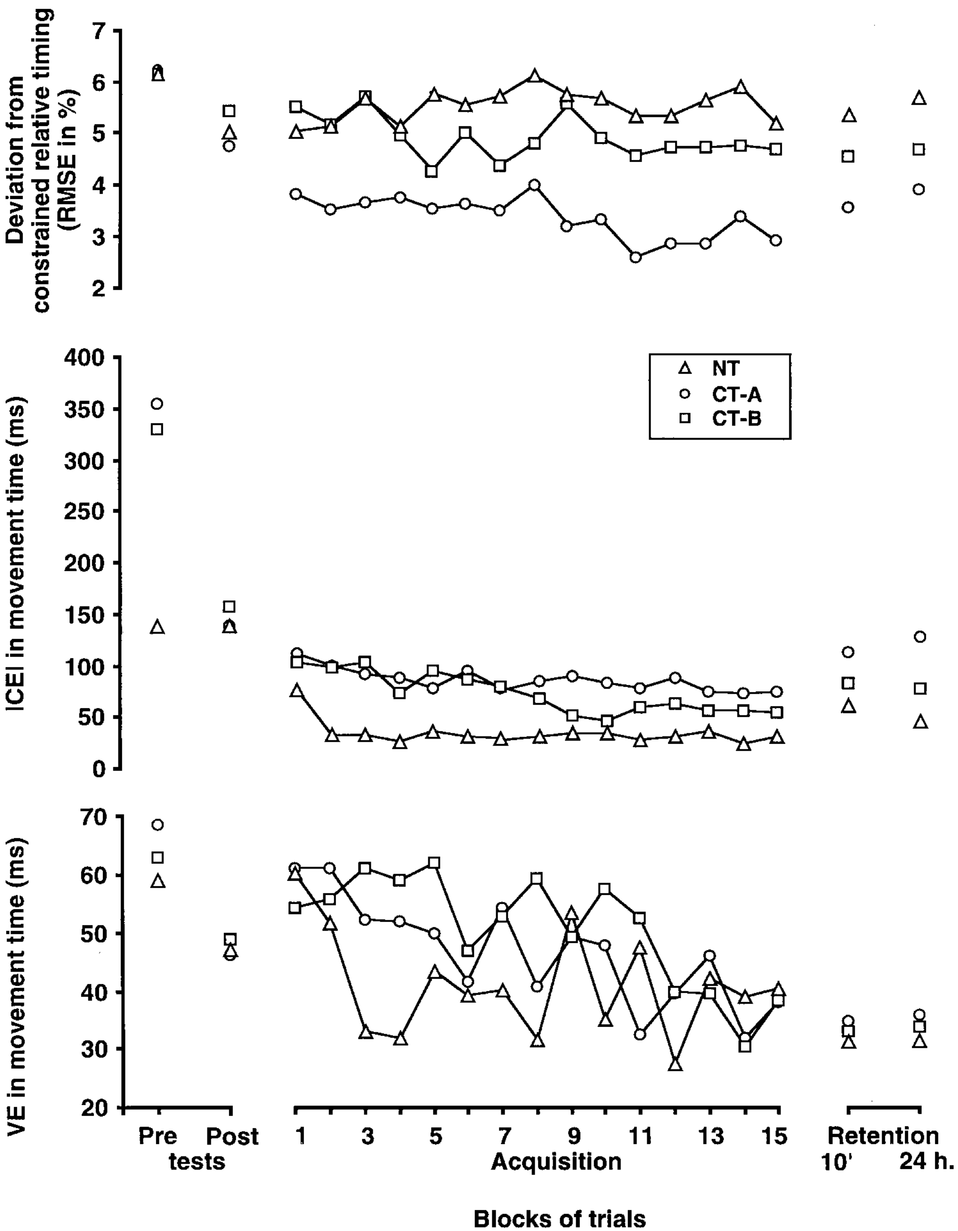

FIG. 3. Deviation from the relative constrained timing, absolute constant error in movement time, and variable error in movement time for the three groups of observers in each experimental phase. The observation phase took place between the pre-test and the post-test. Experiment 1.

however, that the CT–B group did not significantly differ from either the CT–A or the NT group.[3]

Complementary Analyses. To evaluate further the effects of observation on relative timing, we computed a series of complementary analyses. In the first analysis, we compared the performance in acquisition of the model CT–B group to that of the observers CT–A and CT–B groups. The only difference between the model CT–B group and the other two groups was that the models began the acquisition phase without any previous observation. The results of this comparison showed an overall significant different between the groups, $F(2, 30) = 5.7$. Newman–Keuls post hoc tests indicated that the observers CT–A performed closer to the constrained relative timing (*RMSE* of 3.37%) than did either the model CT–B group or the observer CT–B group (*RMSE* of 4.49% and 4.92%, respectively), which did not differ from each other. Thus, observation of an advanced model resulted in better performance than did a sole regimen of physical practice. In the second series of analyses we wanted to determine whether the relative timing pattern was learned as a whole or segment by segment. The results from these analyses (pre-test vs. post-test) indicated that observation per se of an advanced model enabled the participants to produce the first segment of the task closer to the constrained timing than did the NT and CT–B groups. $F(2, 30) = 3.5$. In addition, results of the retention tests indicated that for both Segments 1 and 2, participants of the CT–A group performed closer to the constrained value than did the participants of the CT–B group who did not differ from the NT group. This is supported by significant main effects of group, $Fs(2, 30) = 7.1$ and 5.3, respectively.

Observers' Movement Time (|CE| and VE)

Following observation, all groups of observers completed the task closer to the 900-msec goal, and they were also more consistent in doing so (see Figure 3, middle and lower panels, pre/post tests, respectively) than in pre-test, $F(1, 30) = 10.5$ and 10.8, respectively. No differences attributable to the type of model observed were noted $Fs(1, 20) < 2$, $p > .05$.[4] Further improvements on both the $|CE|$ and the *VE* in movement time were also noted when participants were allowed to practise physically the task with KR (see Figure 3, middle and lower panels, acquisition, respectively), $Fs(14, 420) = 2.98$ and 3.4, respectively. The improvement on $|CE|$, however, was significantly less pronounced when it was required to perform the constrained relative timing. This was supported by a significant group effect, $F(2, 30) = 5.3$, indicating that the $|CE|$ of movement time

[3] It is worth noting that the mean data reported in this section were an accurate representation of the performance of most participants. For instance, 9 or 10 participants of each group reduced their relative timing error going from pre-test to post-test. However, a further reduction in relative timing following physical practice was noted in the two retention tests for 9 participants of the CT–A group, and 8 participants of the CT–B group, but for only 1 participant of the NT group.

[4] The large difference noted in pre-test for the CT–A and CT–B groups in comparison to the NT group did not reach significance because of the huge between-participant variability noted in pre-test. This variability was to be expected because participants did not receive KR in that experimental phase and, accordingly, performed the task in what he or she felt was 900 msec.

of the CT–A and CT–B groups (85.8 msec and 72.9 msec) were larger than that of the NT group (34.5 msec). Finally, in retention, the observers of an advanced model had more difficulty in completing the task in a movement time of 900 msec than did both the observers of beginner participants and those of a free timing model. As illustrated in Figure 3 (middle panel, retention tests), the CT–A group (120.7 msec) had a larger $|CE|$) than the CT–B (80.5 msec) and NT groups (54.2 msec), $F(2, 30) = 3.7$. However, variability in movement time was similar across groups (see Figure 3, lower panel, retention tests), $F(2, 30) < 1$.

Discussion

In the present experiment we wanted to determine whether a new relative timing could be learned through observation of a model who was physically practising a spatio-temporal task. Also, because of opposing views in the literature (Adams, 1986; Sheffield, 1961) we wanted to determine the effect of the model's skill level on observational learning.

The results of the present experiment indicated that, when the movement to be performed is evaluated as a whole, observation per se did not allow the observers to move significantly away from the natural relative timing in favour of the constrained relative timing. Nonetheless, a step was made in that direction for the observers of an advanced model who were able to perform the first segment of the task closer to the constrained timing than participants in the CT–B and NT groups. Moreover, following observation of an advanced model, it appears that only a few trials of physical practice with KR were sufficient to improve performance of the constrained relative timing. Because this improvement was maintained in the retention tests, it can be concluded that a combination of observation of an advanced model and of physical practice results in significant learning.

For the observers of the CT–B group, no significant improvement toward the production of the constrained relative timing was noted following observation of a beginner model, or a combination of observation of a beginner model and of physical practice. This last result is somewhat surprising because physical practice followed by KR had permitted the models of the CT–B group to improve their performance of the constrained relative timing with practice. Nevertheless, it suggests that observation of a beginner model prior to physical practice did not facilitate acquisition of the constrained relative timing over what can be developed during physical practice. However, because the group effect (CT–B vs. NT) was significant for the models and was not for the observers, it is difficult to assess whether physical practice alone did allow participants to acquire a new relative timing. We address this question further in Experiment 2.

Concerning movement time, the data revealed that observation enabled participants to learn the movement time in which to complete their movement. This is contrary to Scully and Newell's (1985) proposition that relative timing is learned prior to parameterization and also to Schmidt's (1975) motor schema theory for which learning of the GMP implicitly has to take place prior to that of movement parameterization. Rather, it seems that both movement attributes could be learned at the same time. In fact, considering the significant benefit of observation per se on this aspect of the task, it might even be that one first learns to fit movement within the appropriate time frame and then proceeds to make adjustments to relative timing. In that regard, the results of the complementary analyses indicated that participants improved their performance mainly on the first two segments of the task.

Although we have shown that observation of an advanced model promotes learning of a new relative timing pattern over and above that occurring through physical practice alone, it is not clear whether this pattern could be used as effectively with a different movement time. In other words, is the newly developed relative timing generalizable to a new movement time? We sought to answer this question in Experiment 2.

EXPERIMENT 2

Regardless of whether one is favouring a cognitive or a dynamic approach to movement learning and control, both points of view argue that one should be able to rescale a relative timing pattern to a different movement time. Thus, a strong test of the results reported in Experiment 1 would be to show that the newly acquired movement pattern could be rescaled to a movement time different from that used during practice (physical practice and observation). The goal of Experiment 2 was to determine whether rescaling of the constrained timing pattern would be possible following observation alone or a combination of observation and physical practice. In addition, because Collier and Wright (1995) recently showed that rescaling might only be possible for a simple (or more natural) relative timing pattern we also sought to determine whether a better rescaling would be noted for the natural timing pattern than for the constrained timing pattern.

Method

Participants

Forty-eight undergraduate students from the Department of Kinesiology of the University of Montreal participated in this experiment in exchange for a course bonus. None of these participants had participated in Experiment 1, and they were all unaware of the goals of the present study.

Task, Apparatus, and Procedures

The experimental task, the apparatus, and the general procedures were, with a few exceptions, similar to those detailed in Experiment 1. As in Experiment 1, there were six experimental phases: pre-test, observation of a model, post-test, physical practice, 10-min retention/transfer test, and 24-hr retention/transfer tests.

Participants were randomly assigned to three different conditions of observation. In all cases, the models attempted to complete the movement pattern illustrated in Figure 1 in a movement time of 900 msec. For the participants of a first group (CT–A), the observation phase consisted of watching the same videotaped performance of an advanced model as that used in Experiment 1. During this phase, participants of a second group (CT–B) watched the videotaped performance of a beginner model as he or she physically practised the experimental task. Again, these films were those used in Experiment 1. Two observers were randomly assigned to one of eight randomly picked models used in Experiment 1. It should be remembered that the models used in both the CT–A and the CT–B conditions, in addition to completing the movement pattern in 900 msec, had to execute each segment of the task in 225 msec. Finally, participants of a third group (NT) observed a model practising the experimental task under the NT instructions. The films used were the same as in Experiment 1. Also, as for the CT–B group, two of the observers were randomly assigned to one of eight models used in Experiment 1. Following each trial, the observers received KR on the pertinent aspects of the models' performance (movement time for the NT group, and both movement time and relative timing for the CT–A and CT–B groups).

For each of the pre-test, post-test, and the two retention/transfer tests, participants were asked to perform the experimental task for 20 trials under their respective set of instructions (see later). For 10 of these trials, participants were asked to perform the task in a movement time of 900 msec, whereas they were asked to perform it in a movement time of 1200 msec for the remaining 10 trials. The order of presentation of these two movement times was counterbalanced across participants and experimental phases. Participants did not receive KR on their performance in any of these experimental phases.

The experimental phase consisting of physical practice followed the pre-test and was, for each group of participants, similar to that used in Experiment 1. Briefly, participants of the NT group only had to complete the constrained movement pattern in a movement time of 900 msec. In addition to this requirement, participants of the CT–A and of the CT–B groups attempted to complete each of the four segments of the task in 225 msec (i.e. 25% of movement time). KR on movement time, and when appropriate on the time required to complete each segment of the task, was provided following each trial of acquisition.

Results

The dependent variables and the different analyses were similar to those described in Experiment 1. However, for the pre-test, the post-test, and the two retention tests, the target movement time (i.e. 900 msec or 1200 msec) was added to the design as a within-participant variable. As in Experiment 1, movement pattern errors occurred for less than 1% of the trials; no analysis was computed on these errors. Finally, a last series of analyses was computed to determine whether rescaling was significantly better for the natural timing pattern than for the constrained timing pattern as suggested by Collier and Wright (1995). Again, all significant effects are reported at $p < .05$, and post hoc comparisons of means were computed using Newman–Keuls tests.

Observers' Relative Timing

As illustrated in Figure 4 (upper panel, pre/post-tests), all three groups of observers, $F < 1$, performed closer to the constrained relative timing in the post-test than in the pre-test, $F(1, 45) = 11.8$. Further, this is true for both the observed movement time (i.e. 900 msec) and the new movement time (i.e. 1200 msec). However, as in Experiment 1, because the NT group behaved in the same way as the CT–A and CT–B groups, it is unclear whether observation alone enabled one to move away from the natural relative timing. However, physical practice with KR enabled the observers of the CT–A and CT–B groups to perform closer to the constrained relative timing than participants of the NT group, $F(2, 45) = 11.8$. This aspect of the results had also been noted in Experiment 1, although only for the observers of an advanced model. Thus, it appears that a few trials of physical practice followed with KR is sufficient for what had

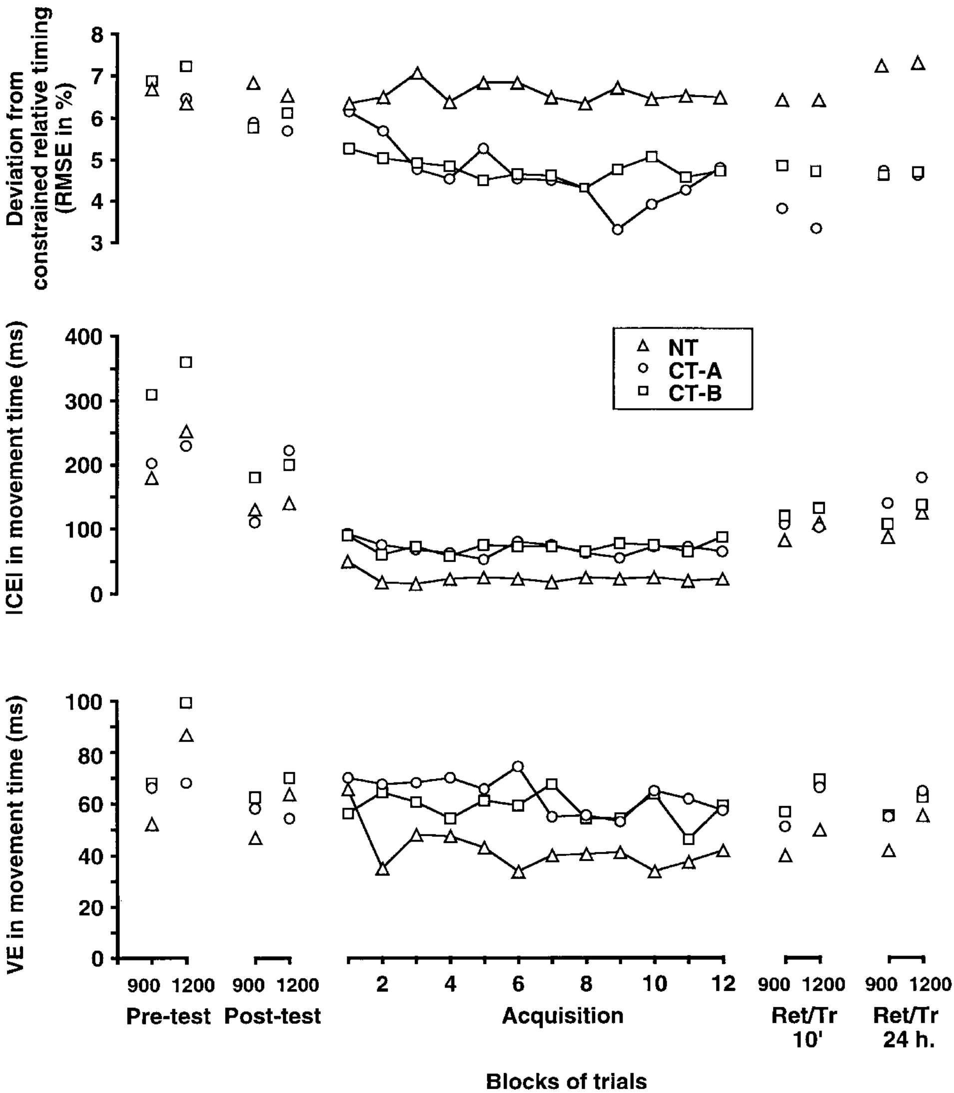

FIG. 4. Deviation from the relative constrained timing, absolute constant error in movement time, and variable error in movement time for the three groups of observers in each experimental phase (Ret = retention, Tr = transfer). The observation phase took place between the pre-test and the post-test. Experiment 2.

been learned during observation to become manifest (see Figure 4, upper panel, acquisition). This conclusion is further warranted by the results of the retention/transfer tests, which indicated that both the observers of an advanced model and those of beginner models performed significantly closer to the constrained relative timing than did participants of the NT group (Figure 4, upper panel, retention/transfer tests), $F(2, 45) = 17.8$. This last conclusion applies both for the observed/practised movement time (900 msec) and the new movement time (1200 msec) because no differences have been noted between these two movement times, $F(1, 45) = 1.55$, $p > .20$. Finally, for NT and CT–A groups, a larger deviation from the constrained relative timing was noted for the 24-hr than for the 10-min retention tests, $F(2, 45) = 4.1$.[5]

Complementary Analyses. In these analyses we wanted to determine, as in Experiment 1, whether the relative timing pattern had been learned as a whole or segment by segment. The results from these analyses revealed modest effects of observation per se on the learning of segments of the task. For the CT–A group, trends ($.98 > p > .05$) in this direction have been noted for the first two segments of the task, whereas participants in the CT–B group performed the second and the third segments of the task closer to the constrained relative timing than did participants in the NT group, Fs$(2, 45) = 4.19$ and 3.34, respectively. A mixed schedule of observation and of physical practice revealed that the CT–A and CT–B groups performed closer to the constrained relative timing than did the NT group for Segments 1, 2, and 4 of the task, Fs$(2, 45) = 5.78$, 8.7, and 6.7, respectively. Finally, participants were at least as effective at performing each segment of the task for the 1200-msec movement time as they were for the 900-msec movement time.

Observers' Movement Time (|CE| and VE)

Figure 4 (middle panel, pre/post-tests) illustrates that all groups of observers reduced their error in movement time ($|CE|$) from pre-test to post-test (255.9 msec vs. 161.8 msec, respectively), $F(1, 45) = 7.4$, without differences attributable to the type of model observed $F(2, 45) = 1.72$, $p > .05$. In addition, movement time became less variable from pre-test to post-test, $F(1, 45) = 11.03$, again regardless fo the type of model observed (see Figure 4, lower panel, pre/post-tests). Finally, participants had a lower $|CE|$ and VE for the 900-msec movement time than for the 1200-msec movement time, Fs$(1, 45) = 9.4$ and 9.7, for $|CE|$ and VE, respectively. However, when expressed as a proportion of movement time, these differences were less than 1% and did not reach significance. This last point suggests that processes underlying the $|CE|$ and VE of parameterization did not differ as a function of movement time.

As illustrated in Figure 4 (middle panel, acquisition), physical practice with KR resulted in a further decrease of $|CE|$ in movement time, $F(11, 495) = 2.1$. This practice permitted the NT group to outperform both the CT–A and the CT–B groups, which did not differ from each other, $F(2, 24) = 11.2$. Movement time was also found to be less variable for the NT group than for the CT–A and CT–B groups, which did not differ from each other, $F(2, 45) = 6.36$. These differences noted in acquisition appear to have

[5] As in Experiment 1, the mean data reported in this section were an accurate representation of the participants' individual data. A reduction in relative timing $RMSE$ was noted in the retention tests (i.e. movement time of 900 msec) in comparison to the post-test for 13 participants of the CT–A group and 10 participants of the CT–B group, but only 5 participants for the NT group. Similar results were obtained for the transfer tests. Specifically, going from the 1200 msec post-test to the transfer tests resulted in a further decrease in relative timing for 13 participants of the CT–A group and 11 participants of the CT–B group, but only 8 of the 16 participants of the NT group.

been only "performance" effect and did not affect learning of the task. Specifically, the type of observation did not result in any differences in movement time during the 10 min and 24 hr tests. As illustrated in Figure 4 (middle and lower panels, 10-min and 24-hr, respectively), ANOVAs revealed only that the $|CE|$ and VE in movement time were larger for the 1200 msec than for the 900 msec movement time, Fs$(1, 45) = 4.27$ and 17.7, respectively. When expressed as a percentage of movement time these differences (less than 1%) did not reach significance again, suggesting that processes underlying the $|CE|$ and VE of parameterization did not differ as a function of movement time.

Rescaling of a Natural and of a Constrained Relative Timing Pattern

To determine whether it is easier to rescale a relative timing pattern that is "natural" than one that is not, as is the case with the constrained timing used in the present study, we evaluated whether rescaling a movement pattern from 900 msec to 1200 msec was performed more accurately by the NT group than by the CT–A and CT–B groups. For each participant, we determined in each experimental phase the relative timing pattern used for the 900-msec movement time or, in other words, the proportion of movement time spent on each of the four segments of the task. Then we computed a $RMSE$ of relative timing for the 1200 msec condition using as a reference the relative timing pattern shown for the 900 msec movement time. The data were submitted to a 3 groups (NT, CT–A, CT–B) $\times$ 4 experimental phases (pre-test, post-test, retention 10 min, retention 24 hr) $\times$ 2 blocks ANOVA using repeated measurements on the last two factors.

The ANOVA revealed a significant interaction between the experimental groups and the experimental phases, $F(6,135) = 3.45$. As illustrated in Figure 5, all three groups performed similarly in pre-test. This was expected because no experimental treatment had yet occurred. However, with a combination of observation and physical practice the relative timing pattern used with the 1200-msec movement time by the participants of the NT and CT–B groups became more closely related to that used with the 900-msec movement time, whereas the contrary was noted for the CT–A group. These trends culminated in a significant effect only for the 24-hr retention test. It was found that participants of the NT and of the CT–B groups used a relative timing for the 1200 msec movement time that was closer to that used for the 900 msec movement time than that of participants of the CT–A group.

Discussion

The first goal of Experiment 2 was to determine whether observation or a mixed schedule of observation and physical practice results in learning of only the spatio-temporal pattern that is observed, or whether observation enables one to rescale the relative timing pattern developed with a specific movement time to a different movement time. Also, we wanted to determine whether rescaling would be easier when a natural pattern was used rather than a constrained pattern. Second, we wanted to confirm our previous conclusion that observation of an advanced model should be favoured over that of a beginner model.

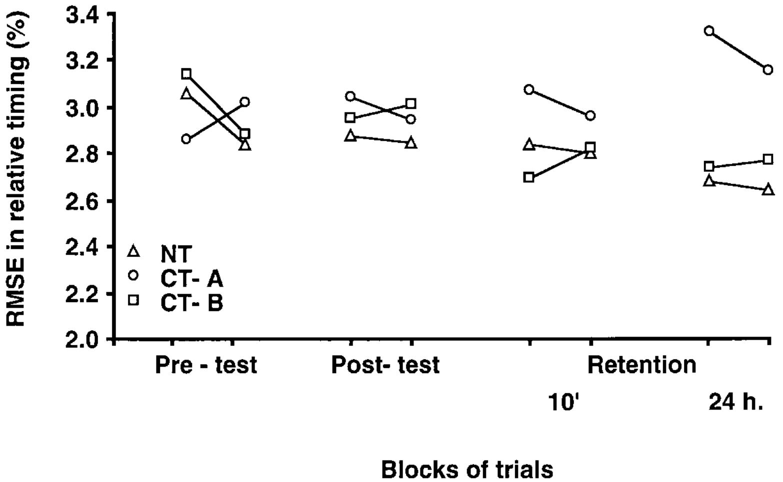

FIG. 5. Accuracy of rescaling from a movement time of 900-msec to a movement time of 1200-msec for the three groups of observers in each experimental phase.

Concerning the effects of observation per se, results of the post-test indicated that it resulted in significant learning of movement parameterization, particularly on some segments of the task. However, no significant learning was noted when relative timing was evaluated on the global task (i.e. all four segments of the task considered simultaneously). As in Experiment 1, the full potential of observation for relative timing learning was revealed after the observers had had an opportunity to practise physically the constrained movement pattern with KR (it should be remembered that both observation and physical practice used a fixed movement time of 900 msec). Specifically, results of the delayed retention and transfer tests showed significant improvements towards production of the constrained movement pattern following a combination of observation and of physical practice. It is also worth noting that this improvement on relative timing was not made at the expense of poorer movement parameterization. This is supported by the fact that movement parameteriztion was similar for the CT–A/CT–B observers who had to use a constrained relative timing and the NT observers who did not have this particular constraint.

The most important finding of Experiment 2 is that participants were able to rescale the relative timing pattern that they had observed and physically practised to a different movement time. This suggests that they had indeed learned the relative timing of the task. We come back to this point in the General Discussion.

Concerning the type of model, beginner or advanced, which favours learning, the results of Experiment 2 show some similarities with those of Experiment 1 but also some differences. In the retention/transfer tests, consistent with the results of Experiment 1, observation of an advanced model followed by brief exposure to physical practice resulted in significant learning of the constrained relative timing. However, observation of a beginner model also favoured significant learning of the constrained relative timing, whereas only a trend in that direction (not significant) had been noted in Experiment 1.

This discrepancy between the two experiments might have been caused by the fact that we had more participants in Experiment 2 and, thus, a more powerful design. This interpretation is supported by the fact that the results of Experiments 1 and 2 are qualitatively very similar (see Figures 3 and 4). Alternatively, this discrepancy might reveal that some competition takes place between parameterization and relative timing learning. This proposition is supported by the fact that in the first experiment, participants in the CT–B group showed better parameterization learning than did participants in the CT–A group, whereas the reverse was true for relative timing learning. In Experiment 2, no difference was found between the two groups of observers for movement parameterization and also no difference for relative timing. Thus, it might be that participants in the CT–B groups in the two experiments put emphasis on different aspects of the task.

Finally, the results of the present study are equivocal concerning Collier and Wright's (1995) proposition that only natural relative timing patterns could be rescaled. Contrary to Collier and Wright's data, the results of the present study indicated that participants of the CT–B group were as effective at rescaling a constrained relative timing pattern as participants in the NT group were at rescaling a natural relative timing pattern. However, this was not the case for the CT–A group. This "split-decision" makes it impossible to reach any firm conclusion concerning this point. In addition, the fact that the CT–A group was able to learn the constrained relative timing in both Experiments 1 and 2 but, yet, had some difficulty at rescaling it remains to be explained.

GENERAL DISCUSSION

Although there is no doubt that physical practice is mandatory to learn new physical skills, there is a wealth of data suggesting that observation prior to physical practice might facilitate motor learning (Blandin et al., 1993; Blandin, Proteau, & Alain, 1994; Carroll & Bandura, 1982; Newell, 1981; Pollock & Lee, 1992; Schmidt, 1988; Scully & Newell, 1985). Starting with this suggestion, the first goal of the present article was to determine whether observation would enable one to learn a new relative timing and also how to parameterize it. Furthermore, we evaluated the effect of a schedule of practice made up of observation followed by physical practice on relative timing and parameterization learning. Secondly, we wanted to determine whether relative timing and parameterization learning would be favoured by a beginner or an advanced model.

The results of the two experiments are straightforward. First, observation favours learning of movement parameterization. Furthermore, this occurs with both beginner and advanced models. Thus, an advanced model favours observational learning (Sheffield, 1961), but observation of a beginner model is also efficient for motor skill learning as long as the observer is informed of the model's performance (McCullagh & Caird, 1990; Pollock & Lee, 1992).

The fact that parameterization learning was evident after observation whereas only modest evidence had been found for relative timing might appear somewhat surprising in the light of both Scully and Newell's (1985) proposition that the reverse should be true and Schmidt's (1975) motor schema theory, which implicitly made the same assumption. As proposed earlier, it might be that Scully and Newell's and Schmidt's point of view applies only when one does not have to fit movement within a very specific time frame. Also, the learning of relative timing might precede that of movement parameterization only when a natural timing pattern has to be learned. As discussed previously, when asked to perform the movement pattern used in the present study, participants typically produced a very similar relative timing pattern, both within and across individuals. In such instances, it appears very likely that the characteristics of the task (distance of each segment of the task, barrier/target size) dictated relative timing and also that consistent relative timing would be shown earlier than precise and consistent parameterization. However that may be, the data of the present study indicate that one can learn movement parameterization prior to relative timing when the movement pattern of interest is different from the pattern that would normally occur considering the characteristics of the task.

Following observation, only a few trials of physical practice followed with KR were sufficient for the observers to show significant improvements in producing the constrained relative timing and to maintain it in the two delayed retention/transfer tests. Our results add to those reported by Vogt (1995) in that we have shown that observation and physical practice with KR does not only permit one to become less variable while attempting to reproduce a specific relative timing pattern but also permits one to produce a motor response that better approximates the constrained pattern. The fact that only a few trials of physical practice with KR were required for participants to show larger improvements in performing the constrained pattern than those shown following observation suggests that observation resulted in some latent learning, which could be operationalized more effectively through physical practice with KR. Similar results and conclusions have recently been reported by Deakin and Proteau (1998), who used a task having minimal physical requirements (key pressing to move a cursor through a maze). These data suggest that observation enables one to determine the key features of the task. Depending on the difficulty of the task, observation enables one to approximate, more or less appropriately, how to reproduce these features. However, the fine tuning of one such feature, especially if it is complex (relative timing would appear to be more complex than movement parameterization), can be done only through physical practice with KR. This suggests that, as well as showing someone what to do, observation might enable one to react quickly and appropriately to KR. Thus, observation might reduce initial errors if the task is not too demanding, but more importantly, it appears to help one understand better these errors and determine/calibrate the appropriate corrections. In an applied setting, this aspect of the results suggests that observation could be more efficient if interspersed with physical practice.

Finally, the results of the second experiment indicated that the relative timing pattern that has been learned through a combination of observation and physical practice is rescalable to a different movement time than that used during practice. Moreover, this rescalability was as good for the CT–B group as that noted for the natural relative timing pattern. This was not the case for the CT–A group, however. As discussed previously, this aspect of the results is puzzling especially in the light of results reported by Collier and Wright (1995) who had shown that rescalability was only possible for natural relative timing. Future work should try to reconcile these diverging data.

Although indirectly, the results of the present study and of previous work showing that independent variables affecting learning through physical practice affect observational learning in a similar way (number of trials observed, Blandin & Proteau, 1998; schedule of practice, Blandin et al., 1994; Lee & Wright, 1990; Wright, Li, & Coady, 1997; and, the sensory information available during practice, e.g. Doody, Bird, & Ross, 1985; McCullagh & Little, 1989; Ross, Bird, Doody, & Zoeller, 1985; Zelaznik & Spring, 1976), suggest that both types of practice engage the participant in similar cognitive processes.[6] However, surprisingly enough, theories of learning based on physical practice (e.g. Adams, 1971; Schmidt, 1975, 1988) and on observation (Bandura, 1977, 1986; Sheffield, 1961) appear to have evolved in a vacuum with very few interactions. Although we have shown that movement parameterization might be learned prior to relative timing, which is problematic for Schmidt's (1975) motor schema theory, we believe that this theory is, in general terms, appropriate to explain motor learning. From a conceptual point of view, as indicated by Schmidt (1988), one of the most serious criticisms of the motor schema is that its "entire structure is vague in terms of how the program is formed in the first place, how the rules about parameters and sensory consequences are developed and used, how the individual makes the first response before any schema can exist . . ." (p. 489). The results of the present study suggest that a possible answer to some of these criticisms is that the framework of these processes might first be developed though observation.

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[6] This does not mean, however, that all cognitive processes involved during physical practice are also taking place during observation or that observation does not engage participants in some unique processes not taking place during physical practice. We thank David L. Wright for this suggestion.

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