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Effects of an Auditory Model on the Learning of Relative and Absolute Timing

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ABSTRACT. The effects of an auditory model on the learning of relative and absolute timing were examined. In 2 experiments, participants attempted to learn to produce a 1,000- or 1,600-ms sequence of 5 key presses with a specific relative-timing pattern. In each experiment, participants were, or were not, provided an auditory model that consisted of a series of tones that were temporally spaced according to the criterion relative-timing pattern. In Experiment 1, participants (n = 14) given the auditory template exhibited better relative- and absolute-timing performance than participants (n = 14) not given the auditory template. In Experiment 2, auditory and no-auditory template groups again were tested, but in that experiment each physical practice participant (n = 16) was paired during acquisition with an observer (n = 16). The observer was privy to all instructions as well as auditory and visual information that was provided the physical practice participant. The results replicated the results of Experiment 1: Relative-timing information was enhanced by the auditory template for both the physical and observation practice participants. Absolute timing was improved only when the auditory model was coupled with physical practice. Consistent with the proposal of D. M. Scully and K. M. Newell (1985), modeled timing information in physical and observational practice benefited the learning of the relative-timing features of the task, but physical practice was required to enhance absolute timing.

Key words: absolute timing, auditory model, motor learning, relative timing

One of the problems in almost any situation that requires the learning of a motor skill is how to provide the learner with an idea of the goal movement. Often, instructors attempt to furnish that information by providing learners with verbal descriptions and instructions or visual demonstrations of the movement. Although the effectiveness of verbal instructions regarding the coordination of the performer's body movements in motor skill learning has recently been questioned (e.g., Wulf, Höß, & Prinz, 1998; Wulf, Lauterbach, & Toole, 1999; Wulf & Weigelt, 1997), research on the effectiveness of observational learning, and modeling,[1] has yielded generally positive results (e.g., Blandin, Proteau, & Alain, 1994; Doody, Bird, & Ross, 1985; McCullagh & Caird, 1990; McCullagh, & Little, 1989; Newell, 1976; Shea, Wright, Wulf, & Whitacre, 2000; Shea, Wulf, & Whitacre, 1999), although in a few experiments null or even negative effects have been found (e.g., Lee, Wishart, Cunningham, & Carnahan, 1997).

There is a relatively large literature related to visual observation, but in few studies have the effects of an auditory model on skill learning been examined. Yet, there is some, partly anecdotal, evidence suggesting that that type of model might be comparatively powerful in facilitating the acquisition of movement sequences. For example, in the so-called Suzuki method, which has successfully been used to teach children how to play the violin (Suzuki, 1969), the students are repeatedly exposed to a recorded piece of music. During subsequent attempts by the students to reproduce the musical score, they are apparently able to use the memory representation developed through the repeated exposures as a template against which their own performance is compared, allowing them to make appropriate corrections on following attempts.

Research studies examining the effectiveness of providing the learner with augmented auditory information have also yielded some support for the view that the auditory type of model might be a useful means for enhancing the learning of motor skills. In a series of early studies, Newell

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(1976), Zelaznik, Shapiro, and Newell (1978); and Zelaznik and Spring (1976) examined the effects of auditory templates and auditory feedback on learning. For example, Zelaznik and his colleagues (Zelaznik et al., 1978; Zelaznik & Spring, 1976) showed that having participants listen to the sounds associated with the execution of rapid timing movements (linear position) produced by another participant can enhance their subsequent active attempts to produce the criterion movement. Similar findings have been obtained when the auditory consequences of movements are included with a visual demonstration (e.g., Doody et al., 1985; McCullagh & Little, 1989): The demonstration was more effective when the movement-associated sounds were presented along with the visual demonstration than when they were removed. More recently, Kohl and Shea (1995, Experiment 1) found that, compared with a no-sound condition, learners provided with the sound of the criterion movement before each trial can reduce movement variability (response bias was not affected).

Together those findings suggest that one might effectively use augmented auditory information to facilitate performance (and learning) by providing the learner with a reference of correctness. As of yet, however, no attempts have been made to determine exactly how auditory information functions to influence the movement representation. It is unclear, for example, whether the presentation of an auditory model can enhance the learning of the movement's relative-timing structure or the learning of its overall duration (parameterization), or both. With regard to visual demonstrations, Scully and Newell (1985), on the basis of research investigating the perception of biological motion, hypothesized that learners can effectively extract the relative pattern of motion from dynamic visual displays, whereas the precise scaling of the motion cannot easily be "picked-up" through observation. Furthermore, in terms of observation of human movement, they suggested that movement "demonstrations are primarily effective in transmitting information about the pattern of coordination to be produced rather than the scaling of effort within the action pattern" (p. 269). Some indirect support for that notion has come from recent visual observation studies in which the structure or pattern of the movement was enhanced via observation, but not the specific scaling characteristics (Blandin, Lhuisset, & Proteau, in press; Shea et al., 2000).

In the present study, we examined whether Scully and Newell's (1985) notion would also hold for auditory models; that is, whether or not an auditory model would facilitate relative-timing performance. In most of the current studies of the effects of an auditory model, investigators have used error measures that reflect only the absolute or scaling characteristics of the task, such as movement time (e.g., Lee et al., 1997) or movement time error (e.g., Kohl & Shea, 1995; Newell, 1976; Zelaznik et al., 1978; Zelaznik & Spring, 1976). In general, those experiments have demonstrated that auditory information enhances absolute-timing performance during acquisition and retention. It should be noted, however, that in those studies the relative-timing characteristics of the task were not of interest at the time and therefore were not measured.

In our first experiment, participants practiced a five-segment timing task; an auditory model that indicated the correct timing pattern was (sound condition) or was not presented (no-sound condition) before each trial. We asked whether training with an auditory model would facilitate performance in terms of relative or absolute timing, or both, and whether the effects, if any, would transfer to a situation in which no help was provided by an auditory model (i.e., affect learning) or to a new task-duration demand, or both. Furthermore, we wanted to determine to what extent the observation of another participant practicing the timing task with or without an auditory model would influence the participant's subsequent performance of that task (Experiment 2). Specifically, we asked whether, without physical practice, the presentation of an auditory model would differentially affect observers' learning of relative versus absolute timing.

EXPERIMENT 1

Relatively simple linear-positioning timing tasks (e.g., Kohl & Shea, 1995; Newell, 1976; Zelaznik et al., 1978; Zelaznik & Spring, 1976) in which the structure of the movement is not defined have been used in previous studies of the effects of auditory information on motor learning. In the present study, however, we used a five-segment timing task that had specific timing requirements for each segment. That procedure allowed us to examine the effects of an auditory model on both relative- and absolute-timing performance. The learning effects of practice conditions with or without an auditory model were determined in a delayed retention test in which neither the auditory model nor augmented feedback was available.

In addition to providing or not providing an auditory model, we also manipulated the overall duration of the practice tasks. That is, although for two groups (with and without an auditory model) the overall duration was the same during practice and retention (i.e., 1,600 ms), two other groups had a shorter goal duration during practice (i.e., 1,000 ms). Thus, the latter group had to transfer to a novel absolute duration on the retention test. Our purpose in manipulating duration was to ensure that participants could maintain the learned relative-timing structure of the task when faced with new task-duration demands. In recent research (e.g., Lai & Shea, 1998; Lai, Shea, Wulf, & Wright, 2000; see also Langley & Zelaznik, 1984; Shapiro, 1977; Summers, 1975) with similar timing tasks, the ability of participants to maintain the relative-timing structure learned during practice as well on delayed retention tests (same parameter requirements) as on delayed parameter transfer tests (new parameter requirements) has repeatedly been demonstrated.

In some ways, Experiment 1 is reminiscent of the duration-modeling aspects of the work of Langley and Zelaznik

(1984), who evaluated transfer performance after participants practiced tasks with the same phasing but different durations. For example, in the present experiment we asked whether training on different-duration tasks, in which the relative-timing pattern was held constant, would influence relative- or absolute-timing performance, or both, on a retention and transfer test. More important, we asked whether the provision of an auditory model would change the pattern of results on one or both of the fundamental dimensions (i.e., relative or absolute) of the task. More specifically, it is of interest to determine if the groups performing the 1,000-ms task can maintain the relative-timing structure prescribed during practice when asked to slow down the movement during the 1,600-ms task retention and transfer tests and whether the benefits, if any, from an auditory model facilitate or hinder the participants' flexibility in adjusting to the new (unpracticed) task demands. In answering that question, the performance of the 1,600-ms groups became essentially that of a control group against which we could evaluate how effectively the participants in the 1,000-ms groups adapted to the new task-duration requirement. In the present experiment, however, the comparison between the sound and the no-sound conditions was the critical manipulation that enabled us to assess the impact of the auditory model.

The findings of Langley and Zelaznik (1984) as well as more recent experiments in which relative and absolute characteristics of the task have been analyzed (e.g., Lai et al, 2000; Whitacre & Shea, in press) suggested that participants should be effective in maintaining the relative-timing pattern when faced with a new task-duration requirement. Furthermore, on the basis of previous experiments in which auditory models were used, which have shown absolute-timing benefits from auditory models (e.g., Zelaznik et al., 1978; Zelaznik & Spring, 1976), and the proposal by Scully and Newell (1985), who suggested that relative (but not absolute) characteristics can be extracted via the presentation of a model, we hypothesized that both relative and absolute timing would be enhanced by an auditory model presented before each physical practice trial. At first glance, our hypothesis appears to be somewhat at odds with Scully and Newell's proposal. It should be remembered, however, that all participants in Experiment 1 physically practiced the task during acquisition, whereas Scully and Newell's proposal is concerned only with observation practice in the absence of physical practice, which, they hypothesized, would enhance the learning of relative timing.

The differential predictions for relative and absolute timing are particularly interesting with respect to a number of theoretical proposals in which movements are characterized along similar dimensions. That is, in a number of theoretical perspectives, movement is characterized along structural and metrical (Kelso, 1981; Newell, 1981), higher and lower order (e.g., Fowler & Turvey, 1978), essential and nonessential (Gelfand & Tsetlin, 1971; Kelso, Putnam, & Goodman, 1983; Langley & Zelaznik, 1984), and generalizable motor program (GMP) and parameter (Schmidt, 1975, 1985, 1988) dimensions. Those dimensions, at least with respect to the timing task used in the present experiments, can be selectively characterized by relative and absolute timing. For example, according to motor program theory (Schmidt, 1975; see Schmidt, 1985, 1988, and Schmidt & Lee, 1999, for reviews and overviews), a GMP is developed over practice and becomes the basis for generating responses within a movement class that share the same invariant features (e.g., sequencing, relative timing, and relative force). Specific movements are produced by the premovement assignment of parameters, such as absolute force or absolute time, via the recall schema. When the time parameter, for example, is varied, the invariant features specified by the GMP are thought to remain intact such that slower movements can be thought of as "stretched-out" (in time) copies of faster movements. Similarly, when the force parameter is manipulated, a movement sequence requiring minimal force can be thought of as a compressed (with respect to force) copy of a more forceful movement.

In the present experiments, the GMP (a hypothetical construct proposed in schema theory) can be characterized, as it has been in numerous experiments (e.g., Lai & Shea, 1998, 1999; Wulf, Lee, & Schmidt, 1994; Wulf, Schmidt, & Deubel, 1993), by relative timing. Relative-timing measures are sensitive to the participant's pattern of responding but not to the overall time required to complete the movement sequence. Alternatively, the timing parameter is characterized by absolute timing because that measure is sensitive to discrepancies between the time required to complete the total response and the goal time but not to the activation patterns that define the structure of the movement sequence. Evidence from experiments by Lai et al. (2000) has demonstrated that relative and absolute timing characterize independent (uncorrelated) dimensions of the movement.

Method

Participants

Twenty-eight university students volunteered to participate in the experiment. None of the participants had prior experience with the task or was informed about our purpose in the experiment. Each of the students was requested to read and sign an informed consent form before participating in the experiment.

Apparatus and Task

The apparatus consisted of a Pentium II computer with a 21-in. color monitor and a standard keyboard. In performing the task, participants were required to use only the *J* and *F* keys on the keyboard. We used the computer monitor to display the goal movement pattern and to provide feedback to the participant. A customized computer program controlled all the experimental procedures, provided feedback to the participants, and stored the data for further analysis. The participant's task was to alternately press the J key with the first finger of the left hand and the F key with the first finger of the right hand in order to produce the goal pattern displayed on the screen. The goal pattern consisted of six key presses. The goal relative times for Segments 1–5 were .188, .312, .125, .125, and .250 ms, respectively. For the longer duration task (1,600 ms), the goal times between consecutive key presses were 300, 500, 200, 200, and 400 ms; and for the shorter duration task (1,000 ms), the goal times between key presses were 188, 312, 125, 125, and 250 ms. That pattern is depicted in Figure 1 (top panels).

Procedure

Participants were randomly assigned to one of four groups that were either presented (sound) or not presented (no-sound) an auditory model during practice and practiced either a short-duration (1,000 ms) or a long-duration (1,600 ms) task. In the sound groups, six beeps were presented. The intervals between beeps, which corresponded to the goal movement pattern, were 300, 500, 200, 200, and 400 ms for the 1,600-ms task or 188, 312, 125, 125, and 250 ms for the 1,000-ms task. The duration of the beeps was 25 ms, and the intervals were timed from the initiation of one beep to the initiation of the subsequent beep. Similarly, segment times were determined from the initiation (switch closure) of one key press to the initiation of the subsequent key press.

Participants were informed that pressing the J key would cause the line to move left in an upward direction at a constant velocity, whereas pressing the F key would cause the line to change directions and to move to the right in an upward direction at a constant velocity. Participants were told that they could begin their response any time after the word "go" appeared at the bottom of the computer monitor. Approximately 3 s before the go signal appeared, the goal pattern was displayed on the monitor (see Figure 1, top panels) and the auditory model was presented (sound groups only). The goal pattern remained on the monitor during the

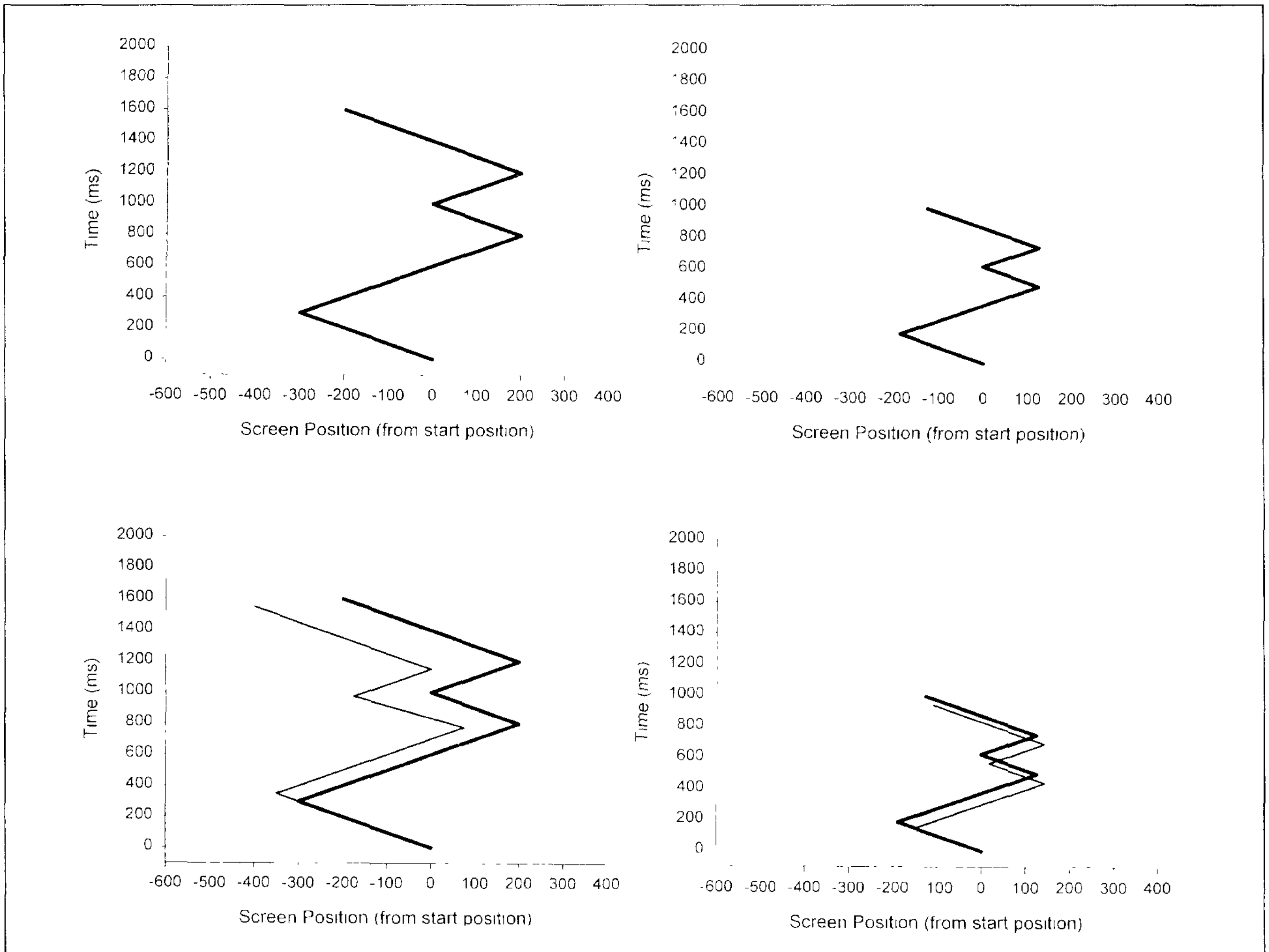

FIGURE 1. Examples of the computer screen before (**top panels**) and after completion of the response (**bottom panels**). The 1,600-ms task is depicted in the left panels, and the 1,000-ms task is illustrated in the right panels The darker line depicts the criterion response, and the lighter line represents the participant's response The x- and y-axes scales were not presented to participants during the experiment.

response and for 10 s after the completion of the response. Upon the completion of each acquisition response, the pattern produced by the participant was superimposed on the target pattern for 10 s. That feedback provided information concerning both relative- and absolute-timing errors (see Figure 1, bottom panels). Before the first trial, the experimenter explained the feedback that would be provided by using illustrations of the goal pattern with hypothetical feedback overlaid. Participants were told to attempt to match the pattern as closely as possible (both relative and absolute time).

All participants performed 90 practice trials, with 30-s rest periods between blocks of 15 trials. Approximately 24 hr later, participants performed a retention and transfer test consisting of 10 trials without the auditory model and without postresponse feedback. The retention and transfer tests for all groups consisted of the 1,600-ms task with the same relative-timing requirements as in acquisition.

Dependent Variables and Data Analysis

The dependent variables of interest were relative- and absolute-timing error. Relative-timing error (*AE* prop) was used as a measure of the proficiency of the GMP because that measure is sensitive to discrepancies between the participant's pattern of key presses and the goal pattern but not to the overall time required to complete the sequence. Relative timing (*AE* prop) was computed as the sum of the absolute differences between the goal proportions and the actual proportions for each segment. That measure provides an estimate of the accuracy of relative-timing performance. In equation form,

$$AE\text{ prop} = |R_1 - .1875| + |R_2 - .3125| + |R_3 - .1250| + |R_4 - .1250| + |R_5 - .25|,$$

where R_n = (the actual movement time of segment$_n$/total movement time). Thus, $R_1 - R_5$ are the proportions of total movement time used in Segments 1–5, respectively. For absolute-timing performance, we used E (total error) to characterize timing parameter errors because E can be thought of as a measure of overall accuracy in responding that considers both response biases and response variability with respect to the total movement time. E is considered a measure of parameter error because it is sensitive to discrepancies between the time required to complete the total response and the goal movement time but not to the pattern of key presses. Thus, absolute-timing error (termed absolute timing [E]) was computed as

$$E = (CE^2 + VE^2)^{1/2},$$

where constant error (CE) is a measure of response bias and is computed as the average of the signed errors (goal movement time minus actual movement time). Variable error (VE) is a measure of response variability and is computed as the standard deviation of the signed errors.

For the practice phase, relative-timing errors and absolute-timing errors were analyzed in separate 2 (auditory information: sound vs. no sound) × 2 (task duration: 1,000 vs. 1,600 ms) × 6 (block) analyses of variance (ANOVAs) with repeated measures on block. The retention data were analyzed in separate 2 (auditory information: sound vs. no sound) × 2 (task duration: 1,000 vs. 1,600 ms) ANOVAs.

Results

Practice

Relative Timing

The sound groups demonstrated clearly smaller relative-timing errors than the no-sound groups throughout practice (see Figure 2).[2] The analysis indicated a main effect of both auditory information, $F(1, 24) = 22.15$, $p < .01$, and block, $F(5, 120) = 14.88$, $p < .01$. Duncan's new multiple range test on block indicated that relative-timing errors were higher in Block 1 than in all other blocks, and the errors were smaller for Blocks 4–6 than for Block 2. The main effect of task duration and all two-way interactions were not significant. However, the Auditory Information × Task Duration × Block interaction was significant, $F(5, 120) = 2.59$, $p < .05$. Simple main effects analyses indicated that the sound groups decreased relative-timing error very quickly (by Block 1 or 2, or both), with performance leveling off thereafter, whereas the no-sound groups demonstrated a more gradual but steady decrease across acquisition.

Absolute Timing

The sound groups also produced smaller absolute-timing errors than the no-sound groups (see Figure 3). The analysis indicated main effects of auditory information, $F(1, 24) =$

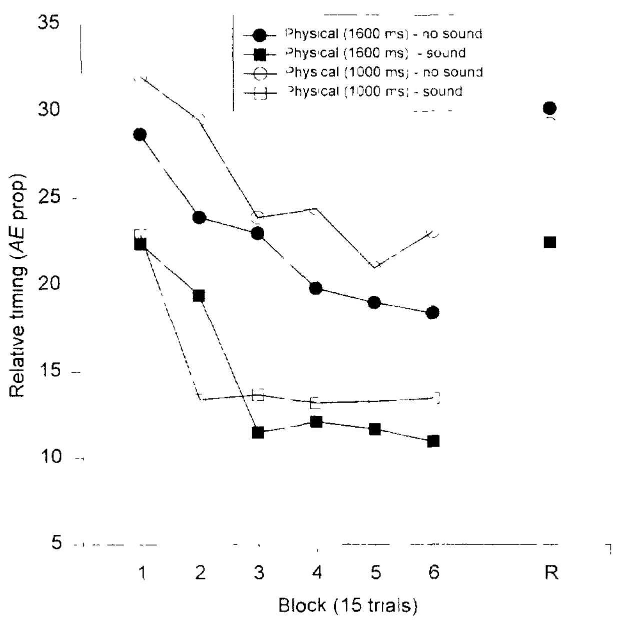

FIGURE 2. Relative-timing errors (*AE* prop) for groups across acquisition and retention (R) in Experiment 1.

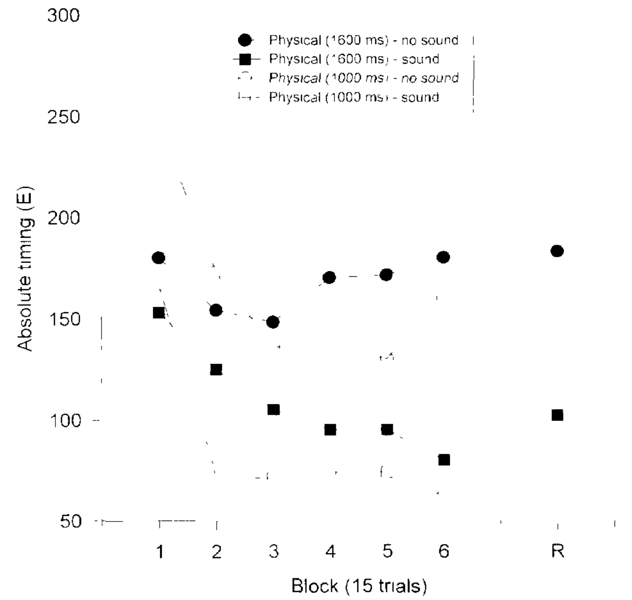

FIGURE 3. Absolute-timing errors (E) for groups across acquisition and retention (R) in Experiment 1.

26.87, $p < .01$, and block, $F(5, 120) = 6.79$, $p < .01$. Duncan's new multiple range test on block indicated that absolute-timing errors were higher in Block 1 than in all other blocks.

The main effect of task duration was not significant, $F(1, 24) = 1.90$, $p > .05$, but the Task Duration × Block interaction was significant, $F(5, 120) = 2.40$, $p < .05$. Simple main effects analysis indicated that absolute-timing errors were larger in the 1,000-ms task than in the 1,600-ms task on Block 1 but were smaller than those in the 1,600-ms task on Blocks 5 and 6. All other interactions failed significance.

Retention

Relative Timing

The sound groups ($M = 23.6$, $SE = 0.54$)[3] demonstrated clearly smaller relative-timing errors than the no-sound groups ($M = 30.6$, $SE = 2.12$) in retention. The main effect of auditory information was significant, $F(1, 25) = 9.17$, $p < .01$. Thus, the benefits of the auditory template seen during practice generalized to a situation without the auditory model and without augmented feedback (see Figure 2, right). The main effect of task duration, $F(1, 25) < 1$, and the Auditory Information × Task duration interaction, $F(1, 25) < 1$, were not significant.

Absolute Timing

The sound groups ($M = 151.7$, $SE = 25.0$) also demonstrated smaller absolute-timing errors than the no-sound groups ($M = 215.4$, $SE = 19.9$) during retention, $F(1, 25) = 4.47$, $p < .05$. Just as with relative timing, absolute timing was enhanced through practice with the auditory model and the benefit endured even when the auditory model was withdrawn (see Figure 3, right). The main effect of task duration was also significant, $F(1, 25) = 5.04$, $p < .05$. The groups that practiced the 1,600-ms task ($M = 149.6$, $SE = 19.9$) and were tested on the 1,600-ms task produced moderately smaller absolute-timing errors in retention than the groups that practiced the 1,000-ms task ($M = 217.3$, $SE = 24.0$) and were tested on the 1,600-ms task. The Auditory Information × Task Duration interaction, $F(1, 25) < 1$, was not significant.

Discussion

Our purpose in Experiment 1 was to determine the extent to which the presentation of an auditory model, which consisted of a sequence of tones indicating the goal temporal structure of the response, enhanced relative and absolute timing. On the basis of the extant literature, we hypothesized that both relative and absolute timing would be enhanced by the auditory model presented before each physical practice trial.

The results of Experiment 1 showed that one can enhance the performance and learning of a five-segment timing pattern by providing learners with an auditory template of the segment movement times before each trial Most interesting, the benefits of the auditory information were not only seen in practice when the auditory model was present, but they transferred to the retention test, in which no auditory template was available. Thus, the augmented auditory information actually enhanced the learning of this task as compared with the learning produced in the absence of auditory information. In fact, participants did not seem to develop the type of dependence on that information that has been shown for concurrent feedback and physical guidance (e.g., Vander Linden, Cauraugh, & Greene, 1993; Winstein, Pohl, & Lewthwaite, 1994); rather, participants appeared to be able to effectively use the information to enhance their relative- and absolute-timing representations of the task.

Consistent with our initial hypothesis, the results demonstrated that the auditory template, coupled with physical practice, had beneficial effects on the learning of the relative-timing structure as well as on the absolute timing, or parameterization, of the movement. It is also interesting to note that the groups that practiced the 1,000-ms task were able to maintain the relative-timing structure in retention and transfer as well as the groups that practiced the relative-timing structure distributed across the 1,600-ms-duration task. Consistent with the literature (e.g., Lai & Shea, 1998, 1999; Shapiro, 1975; Summers, 1977), participants were capable of slowing down the movement while maintaining the relative-timing pattern when faced with a change in task-duration demands. That sort of flexibility in changing task duration without disrupting the underlying integrity of the relative-timing structure is key element of theoretical perspectives such as schema theory (Schmidt, 1975, 1985). In schema theory, the features prescribed by the motor program are thought to be generalizable (i.e., invariant) across changes in the parameters. The question remains whether a performer must execute the movement (and subsequent feedback) in order to learn its relative- and absolute-timing characteristics, or whether one could acquire those characteristics through experience with the auditory model alone. We designed Experiment 2 to answer that question.

EXPERIMENT 2

Our purpose in Experiment 2 was to examine whether the learning advantages of providing an auditory model observed in Experiment 1 would also be seen if the learner does not actively perform the movement but, rather, is provided the auditory model and associated feedback from another learner performing the task. In Experiment 1, the auditory model was coupled with physical practice, and we were unable to determine whether the interaction of those two factors was responsible for the beneficial effects or whether the benefits could be accrued without physical practice. It is possible, for example, that the benefits observed for relative timing could be achieved though experience with the auditory model in the absence of physical practice. On the other hand, one may have to couple the auditory model with physical practice in order to realize the absolute-timing benefits.

That notion would be consistent with the proposal of Scully and Newell (1985), who suggested that relative-timing patterns can be acquired via observation but that one needs physical practice in order to translate model information into appropriate scaling characteristics. That position is also consistent with previous research that has demonstrated that auditory information coupled with physical practice often produces benefits in absolute timing (e.g., Doody et al., 1985; McCullagh & Little, 1989). Furthermore, the finding of that type of differential effects arising from physical and observational practice is consistent with the proposal by Shea and colleagues (e.g., Shea et al., 2000; Shea et al., 1999) that physical and observational practice each offers unique information and perspective to the learner, resulting in unique contributions to learning.

Method

Participants

Thirty-two undergraduate students from Texas A&M University participated in this experiment. They had no prior experience with the task and were not informed about our purpose in the experiment. Each student signed an informed consent form before participating.

Apparatus and Task

The apparatus and task were identical to those used in Experiment 1.

Procedure

Participants were randomly assigned to one of four groups that were either presented (sound) or not presented (no-sound) an auditory model before each practice trial and either physically (physical) practiced the task or was permitted to only observe (observation). That resulted in four groups in a 2 (practice condition: physical vs. observation) × 2 (auditory information: sound vs. no sound) design. However, all participants practiced in physical–observation pairs. That is, while one member of the pair physically performed the task (physical practice groups), the other member observed (observation practice groups) the production of the response as well as the computer-produced feedback provided the physical practice participant. In addition, different groups of physical practice and observational practice participants were or were not provided with the auditory model before each trial.

Observation participants were permitted to observe the instruction provided the physical practice participant and were privy to any questions and answers that were asked by the physical practice participants during the instruction period. Observers were not permitted to ask questions or to provide comments, however. We stressed that the goal was to match both the pattern and the overall time (i.e., match the goal displayed on the monitor). Participants were informed that both physical and observational participants would be asked to physically perform the task without the auditory model and knowledge of results (KR) on the retention test. The practice phase consisted of 90 trials, with 30-s breaks between blocks of 15 trials. One day later, all participants performed a retention test consisting of 15 trials without the auditory template and without feedback.

Dependent Variables and Data Analysis

The dependent variables were calculated in the same manner as in Experiment 1. For the practice phase, relative-timing errors and absolute-timing errors were analyzed in separate 2 (auditory information: sound vs. no sound) × 6 (block) ANOVAs with repeated measures on the last factor. The retention data were analyzed in 2 (auditory information: sound vs. no sound) × 2 (practice: physical vs. observational) ANOVAs.

Results

Practice

Relative Timing

Both physical practice groups generally reduced their relative-timing errors across practice blocks; the physical–sound group was more accurate than the physical–no-sound group by the end of the first block of practice[4] (see Figure 4). The main effect of auditory information did not reach significance, $F(1, 14) = 1.98$, $p > .05$. However, the block main effect, $F(5, 70) = 7.16$, $p < .01$, and the interaction of auditory information and block, $F(5, 70) = 2.58$, $p < .05$, were significant. Simple main effects analysis indicated that the physical–sound group was more accurate on Block 1 and Blocks 4–6 than the physical–no-sound group.

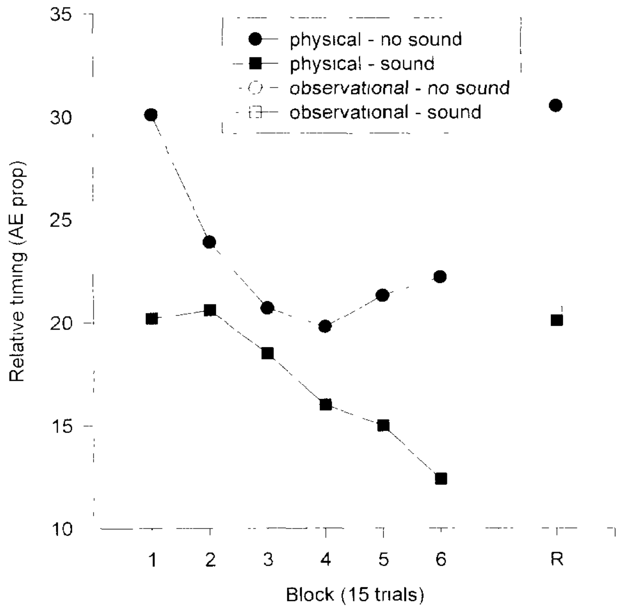

FIGURE 4. Relative-timing errors (*AE* prop) for groups across acquisition and retention (R) in Experiment 2.

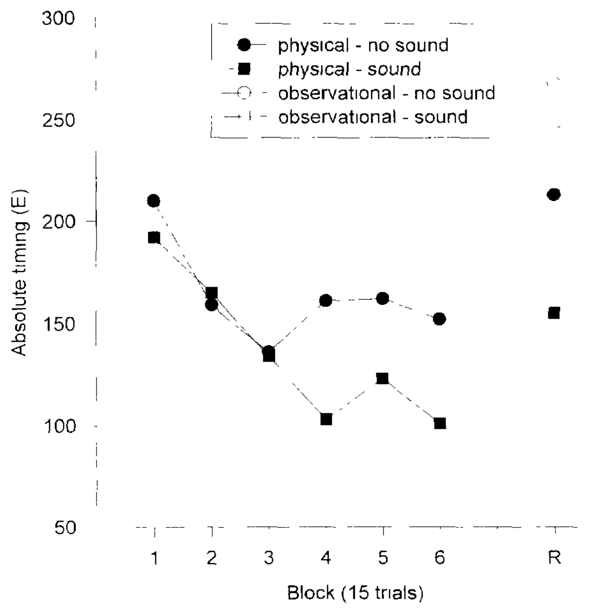

FIGURE 5. Absolute-timing errors (*E*) for groups across acquisition and retention (R) in Experiment 2.

Absolute Timing

Both physical practice groups reduced their absolute-timing errors across practice (see Figure 5), with the sound group appearing to perform somewhat better than the no-sound group by the end of practice. Yet the main effect of auditory information did not reach significance, $F(1, 14) < 1$. The main effect of block, $F(5, 70) = 5.26$, $p < .01$, was significant. Duncan's new multiple range test indicated that absolute-timing errors were higher on Block 1 than on all subsequent blocks of practice. Although the physical–sound group appeared to be more accurate toward the end of practice than the physical no-sound group, the interaction of auditory information and block, $F(5, 70) = 1.13$, $p > .05$, was not significant.

Retention

Relative Timing

On the retention test, the physical and observational practice participants who were presented auditory templates during practice (physical–sound and observational–sound) showed similar performances, and those groups produced the relative-timing pattern more effectively than the groups without the augmented auditory information (physical–no sound, observational–no sound; see Figure 4, right). The main effect of auditory information was significant, $F(1, 28) = 9.25$, $p < .01$. The practice main effect, $F(1, 28) < 1$, and the Auditory Information × Practice interaction, $F(1, 28) < 1$, were not significant.

Absolute Timing

Both physical practice groups (physical–sound and physical–no sound) were more accurate with regard to the overall movement duration in retention than the observational practice groups (observational–sound and observational–no sound; see Figure 5, right). Even though auditory information appeared to marginally enhance absolute-timing learning, especially for the physical practice group, the main effect of auditory information, $F(1, 28) = 1.17$, $p > .05$, was not significant. The main effect of practice, $F(1, 28) = 5.93$, $p < .05$, was significant, confirming that physical practice was generally more effective for parameterization learning than was observational practice. The Auditory Information × Practice interaction, $F(1, 28) = 1.41$, $p > .05$, was not significant, but orthogonal contrasts indicated a difference between the physical and observational practice groups provided the sound model. The contrast for the no-sound groups was not significant.

Discussion

The results of Experiment 2 were interesting in several regards. First, in line with the findings of Experiment 1, the auditory information provided during practice enhanced the learning of both relative timing and absolute timing. However, that improvement occurred only if the learner was provided the opportunity to physically practice the task after the presentation of the auditory model. In terms of comparisons between the respective physical and observational practice groups, a quite different pattern of results emerged for relative and absolute timing. That is, the absolute-timing benefits derived from the auditory model required an interaction with physical practice, whereas the relative-timing benefits of did not. When the auditory model was provided, relative timing was learned equally well under physical and observational practice conditions.

The auditory model was beneficial for relative-timing learning regardless of whether the participant physically practiced the task or only experienced the observational practice condition. In fact, there was no difference in relative timing on the retention test between the physical-sound and the observational-sound groups or between the physical-no-sound and the observational-no-sound conditions, although the former two groups performed significantly better than the latter two. That finding suggests that physical practice per se played only a minor role in the learning of the relative timing of the task. Participants (observational) who received only the normal auditory consequences of the response (sounds resulting from the key presses) and the associated external feedback (on the computer monitor) learned the task as well as participants provided 90 physical practice trials. In addition, those practice conditions (physical and observational) equally benefited from the auditory model. Those findings extend the proposal of Scully and Newell (1985) to auditory models in which the relative characteristics of the movement structure are thought to be effectively extracted from observation. Clearly, with respect to relative timing, the participants in the present observation conditions performed as well as their physical practice counterparts.

On the other hand, physical practice more directly enhanced the learning of the correct parameterization (i.e., absolute timing), and that effect was enhanced when physical practice was paired with the auditory template. However, the auditory model did not enhance parameter learning for the observational practice group. Thus, with respect to absolute timing, physical practice was necessary for the benefits of the auditory model to emerge. It appears that whereas the auditory model does convey meaningful information pertaining to the absolute timing of the response, the usefulness of the information can be extracted only when it is provided in conjunction with physical practice (see Deakin & Proteau, 2000, for a discussion of the latent effects of observation).

GENERAL DISCUSSION

Our main purpose in Experiment 1 was to determine whether training with an auditory model would facilitate performance or learning, or both, in terms of relative and absolute timing, and whether the effects, if any, would transfer to a situation in which no help from the auditory model was provided (i.e., affect learning). The results of the physical practice groups in Experiments 1 and 2 indicated that the auditory model did enhance both relative- and absolute-timing performance during acquisition, and that the benefit transferred to a retention and transfer test in which the auditory model was not provided. Our purpose in Experiment 2 was to determine to what extent the observation of another participant practicing the timing task with or without an auditory model would influence the observers' subsequent performance (i.e., learning). The results indicated that physical and observational practice participants were, in terms of relative timing, equally effective in using the auditory model to enhance the learning of the relative-timing pattern. In terms of absolute timing, however, the full benefits of the auditory model could not be effectively extracted through observation alone but, rather, required an interaction between the auditory model and physical practice. Those findings are interesting for several theoretical and practical reasons, which are discussed in more detail next.

Modeling of Auditory Information

The finding that the auditory model was used equally effectively by physical and observational practice groups to enhance relative-timing learning but that absolute-timing benefits were seen only in the physical practice condition is particularly interesting It suggests that there is something important in the planning, execution, or sensory consequences (or in a combination of some of those processes) associated with generating a response that is important to absolute-timing learning but not necessarily for relative-timing learning. In terms of absolute-timing learning, that finding is consistent with Schmidt's (1975, 1988) notion of a recall schema. The recall schema, which is believed to be responsible for generating the specific parameter instances that scale the relative (termed the GMP) characteristics of the movement, is proposed to be developed on the basis of the relationship between previous parameters assigned to the motor program and the resultant movement outcome. In Experiment 2, the observers were privy to the movement outcome, but because they did not actually generate the movements they did not have direct access to the parameters that were specified Thus, according to the schema account, because observers do not have access to the all the essential information necessary to generate an accurate parameter rule, they would not be expected to achieve the same rates of parameter learning as the physical practice groups.

The present data, at least with respect to absolute timing, are also consistent with the proposal of Deakin and Proteau (2000) whereby observational and modeling effects remain latent until participants incorporate the information conveyed through observation into the action plan. They proposed that the process of activating the latent information gained via observation requires at least a minimal amount of physical practice. The fact that absolute timing was incremented only when coupled with physical practice is also consistent with the findings of earlier studies in which auditory information, which was presented in conjunction with physical practice, was beneficial in terms of the absolute timing (Newell, 1976; Zelaznik et al., 1978; Zelaznik & Spring, 1976). On the other hand, the finding that the relative timing was learned equally well through physical and observational practice was especially surprising. That finding suggests that the processing and execution activities involved in actually producing a response are not necessary for the development of stable relative-timing patterns, at least for relatively simple motor tasks such as those used in the present experiment. The development of novel relative-timing patterns for simple sequential motor tasks may involve either or both the reconfiguration and modification of existing motor programs or motor program modules that were developed for different but similar motor sequences. It is reasonable to assume that all but very young participants bring to an experiment a repertoire of motor programs and modules that can easily be adjusted to meet new task demands. What is surprising is that that process can effectively occur without actual physical practice. In that context, it should be noted that Scully and Newell (1985) proposed, on the basis of perceptual studies of biological motion and review of observation research, that detailed relative features, but not the absolute characteristics of visual displays, can be extracted via observation. Apparently, that also applies to auditory presentations.

In addition, it is interesting that participants did not appear to develop, at least to the extent seen with concurrent feedback, for example, a dependency on the auditory model. When the auditory model was presented before each acquisition trial for the sound groups, acquisition performance was nearly immediately enhanced, indicating a strong guidance effect of the information. Yet, the benefit of the auditory model carried over to the retention test, in which the model was removed. When concurrent knowledge of results (e.g., Schmidt & Wulf, 1997; Vander Linden et al., 1993), physical guidance (e.g., Winstein et al., 1994), and to a lesser extent terminal knowledge of results (e.g., Winstein & Schmidt, 1990) are presented after each trial, benefits are almost immediately realized in acquisition while the information is present. In retention, however, when the information or guidance is withdrawn, the beneficial effects disappear, suggesting a dependence on the information. That result clearly was not found for the auditory model; the benefits were seen in acquisition, where the model was presented before each trial, and in retention, where the model was not available (also see Park, Shea, & Wright, 2000). In the case of concurrent KR and physical guidance, the presentation of the information not only results in a dependence on the information but also appears to interfere with other important processing activities. Clearly, it will be important for theoretical and practical reasons to determine those variables that enhance performance without interfering with other processing that is important to learning and to avoid practice conditions that only temporarily enhance performance. More important, at least from a theoretical perspective, it is critical to understand why those conditions or information ultimately result in positive or negative effects. It is interesting to note that the auditory model in the present experiments was presented before each response rather than during the response, as is the case with concurrent feedback or physical guidance. The temporal change in the presentation of the guidance may reduce the likelihood that other important processing is sacrificed and, thus, reduce the participant's dependence on the information.

Dissociation of GMP and Parameter Learning

The finding that the effects of physical and observational practice on relative- and absolute-timing measures of learning differ depending on whether an auditory model is or is not provided is important from a motor program theory (e.g., Schmidt, 1975, 1985, 1988) perspective, because the recall schema (characterized by absolute timing), which has been proposed to provide the rule or rules that specify the parameters, and the GMP (characterized by relative timing), which is proposed to specify the relative and sequential structure of the movement, are thought to be governed by independent memory states. Indeed, Wulf et al. (1993) have argued that the independence or dissociation of the GMP and parameter memory constructs is a critical feature of programming theory. The present data showing that relative-timing learning is enhanced by an auditory model equally well through physical and observation practice but that benefits arising from the model in terms of parameter learning require physical practice add to the growing number of examples of that dissociation (see Shea, Lai, Wright, Immink, & Black, 2001, in this issue, for additional discussion). For example, the results of recent research have indicated that relative- and absolute-timing learning are differentially affected by constant and variable practice (e.g., Lai & Shea, 1998, 1999; Whitacre & Shea, 2000), the manner in which parameter variability is scheduled (e.g., Lai et al., 2000; Sekiya, Magill, & Anderson, 1996; Sekiya, Magill, Sidaway, & Anderson, 1994; Wulf, 1992; Wulf & Lee, 1993), the type and scheduling of KR (e.g., Lai & Shea, 1999; Wulf et al., 1994; Wulf et al., 1993), and the difficulty of the relative-timing pattern (e.g., Whitacre & Shea, 2000; Wright & Shea, in press). The notion of a dissociation of independent dimensions of a motor task is also consistent with Shea and his colleagues' (Shea et al., 2000; Shea et al., 1999) recent proposal that physical and observational practice offer unique contributions to learning such that incorporating both into the training regime results in learning benefits that cannot be accrued from each independently. Furthermore, a few practice conditions (e.g., constant practice, reduced frequency KR, and bandwidth KR) that have been shown to enhance relative-timing learning have resulted in neutral or even negative results with respect to parameter learning. Likewise, the alternative conditions (e.g., random variable practice, 100% KR frequency, and quantitative KR) have been shown to facilitate the learning of absolute timing but to be detrimental to the learning of relative timing. For example, Lai and Shea (1998) found that, as compared with variable (i.e., random) practice, constant practice conditions are conducive to relative-timing learning. On the other hand, variable practice resulted in enhanced parameter learning, especially under parameter transfer conditions. That type of finding led Lai et al. (2000) to manipulate the conditions participants experienced early and late in practice (see also Roth, 1988). They found that providing constant practice, which is thought to enhance the learning of relative timing, early in practice and variable practice, which is thought to enhance the learning of absolute timing, later in practice resulted in relative and absolute learning that exceeded either single practice conditions throughout practice (i.e., all constant or all variable practice) or the reverse practice combination (i.e., variable practice early and constant practice late in practice). In terms of the present experiments, that finding suggests that benefits accrued from the auditory model might arise relatively early in practice, a time when the development of the relative-timing structure is most crucial, but should be coupled with physical practice later in learning so that the learner will receive the full benefit of the auditory model in terms of parameterization. Of course, that conclusion awaits further research.

Training Effectiveness and Efficiency

The present results indicate that auditory modeling can be important in terms of both learning and training effectiveness and efficiency (see Shea et al., 1999, for a discussion). More specifically, the auditory model used in the present experiments enhanced learning effectiveness without sacrificing training efficiency. Effectiveness is indicated, for example, by lower error scores, faster performance, better movement patterns, better transfer to novel task variations, and resistance to forgetting on the delayed tests. Training efficiency is assessed when one considers the time, money, potential for injury, and other personal and experimental resources that one must expend in order to conduct or supplement the training sessions. In optimal training situations, protocols should be both effective and efficient. Similarly, potential increases in learning effectiveness, in most situations, must be weighed in terms of the cost (efficiency). That is, we must be concerned with creating training protocols that maximize learning while minimizing cost. In the present experiments, the presentation of the auditory model enhanced learning effectiveness without incurring significant additional cost (e.g., time and effort); thus, efficiency was only minimally sacrificed so that a significant learning benefit could be obtained. The use of such a model may be especially important for tasks where the potential for injury is high, the cost of additional training is prohibitive, or there are physical limitations restricting additional physical practice.

In addition, in many applied learning environments auditory models like that used in the present experiments could be realistically used without incurring substantial additional costs. It would be possible, for example to simply play a recorded sequence of tones over a loudspeaker or headset that would provide a template for a golf or tennis swing, the tempo for the approach in high jumping, the rhythm associated with traversing the gates in slalom skiing, or the steps associated with running the hurdles in track. In fact, that is done routinely in music and dance, where the performer uses a metronome or the "hard" beat of the music to mark the beginnings and endings of movement segments. Presumably, that type of information is capable of providing relative-timing information that is easily incorporated into the movement plan.

NOTES

1. Although the terms *observation* and *modeling* are often used interchangeably, observation is sometimes distinguished from modeling on the basis of the format by which information is presented to the learner. The term observation is often used, at least with respect to the learning of motor skills, when a learner is provided the opportunity to view the performance of another individual. The term modeling is used when a display (or model) selectively depicts (visually or auditorially, or both) some aspect of task performance In the latter case, the model may be a computerized visual presentation of either or both the spatial and temporal movement patterns or an auditory sequence that presents a specific temporal pattern (e.g , Kohl & Shea, 1995; Lee et al., 1997).

2. In a supplementary analysis of the first five trials, we failed to detect main effects or interactions of auditory information or task duration for relative or absolute time. The absence of such effects or interactions suggests that the differences between conditions observed by the end of Block 1 were not the result of the assignment of participants to groups but rather were the rapid impact of the treatments

3. *M* = mean, and *SE* = standard error of the mean.

4. In a supplementary analysis of the first five trials, we failed to detect a main effect of auditory information for either relative or absolute time. That finding suggests that the differences between conditions observed by the end of Block 1 were not a result of the assignment of participants to groups but, rather, were the rapid impact of the treatments.

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