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# Training in Timing Improves Accuracy in Golf

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ABSTRACT. In this experiment, the authors investigated the influence of training in timing on performance accuracy in golf. During pre- and posttesting, 40 participants hit golf balls with 4 different clubs in a golf course simulator. The dependent measure was the distance in feet that the ball ended from the target. Between the pre- and posttest, participants in the experimental condition received 10 hr of timing training with an instrument that was designed to train participants to tap their hands and feet in synchrony with target sounds. The participants in the control condition read literature about how to improve their golf swing. The results indicated that the participants in the experimental condition significantly improved their accuracy relative to the participants in the control condition, who did not show any improvement. We concluded that training in timing leads to improvement in accuracy, and that our results have implications for training in golf as well as other complex motor activities.

Key words: golf swing, performance, timing

GOLFERS are constantly looking for ways to improve their performance. One of the ways in which they attempt to accomplish this is through the use of the modern or "high-tech" golf club. Although it is not clear whether performance is enhanced with the modern club, this quick-fix approach is popular, as evidenced by the millions of dollars spent annually on such clubs. The second way of trying to improve performance is through instruction. This approach is also popular, as witnessed by the numerous swing instructors (the so-called swing gurus), schools and academies, magazines, videos, and books devoted to improvement in golf. However, as with the modern golf club, it is not clear what impact instruction has on performance.

Golf aids, commonly used in conjunction with instruction, are another way in which golfers try to enhance performance (Wiren, 1995). There are numerous golf aids on the market. For example, a golfer who believes that he or she has a problem with wrist movement may use an aid (worn on the hand and wrist) that allows only for the appropriate movement. This approach is also popular (witness the common caricature of the golfer weighted down with a multitude of golf aids) but, like the other performance-enhancing approaches, there is little, if any, evidence to support the efficacy of this one.

In contrast to the applied approaches directed toward the improvement of golf performance, there is another approach, in which researchers are more concerned with understanding the nature of the golf swing (e.g., Cochran, 1992, 1995; Cochran & Stobbs, 1968; Hay, 1978; Jorgensen, 1994). This approach implies that understanding the golf swing will lead to its improvement and ultimately to lowered golf scores. Also for researchers, the golf swing, because of its complex nature, poses some interesting intellectual challenges.

Cochran and Stobbs (1968) attempted to simplify the complexity of this phenomenon by modeling the golf swing as a double pendulum system in which two levers rotate about a fixed pivot. The fixed point is between the golfer's shoulders, and it is fixed only in the sense that it does not change planes. The one lever is an upper lever and corresponds to the arms and shoulders swinging around the fixed point. The other lever is a lower lever and corresponds to the movement of the golf club. The two levers are hinged in the middle by the wrists and the hands. A fundamental assumption of this model is that, for the levers to work effectively, it is essential that the levers be timed. In other words, to transfer the maximum amount of energy to the club head at impact, the lower and upper levers must work in synchrony. Therefore, acquisition of this skill, particularly at the expert level (Ericsson, 1996; Ericsson & Lehmann, 1996), requires extensive and effortful practice, not only to learn the basic swing movements but also to time them. Furthermore, we assume that without any additional major changes in the basic movements of the golf swing (for example, changing the golfer's swing plane through training or instruction), the skill must continue to be "fine-tuned" or timed for the golfer to maintain the high level of reliability that is required for successful performance. In fact, a basic assumption made by many professional golfers is that the only practice that should occur immediately before a competitive event is fine-tuning, and that the major downfall in actual competition (with its inherent stresses and pressures) is the failure to maintain proper timing.

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It is important to emphasize that even though there is a scientific body of knowledge about the golf swing, there is little empirical literature concerning the timing properties of the golf swing. This is in direct contrast to the enormous importance that is attached to timing by instructors (e.g., Leadbetter, 1990, 1993) and golfers (e.g., Nicklaus, 1974; Watson, 1998). In fact, it would be a rare event to select any issue of any popular golf magazine (e.g., *Golf* and *Golf Digest*) and not find an article devoted to timing. In the present experiment, therefore, we examined this aspect of the golf swing. In particular, we asked whether extensive training in timing would improve performance accuracy. We chose accuracy over distance as the major dependent measure because even though distance is an important determinant of performance (Cochran & Stobbs, 1968), greens in regulation (an index of accuracy) accounts for more of the variance in golf scores than does any other single measure (Riccio, 1995).

There are at least three indications that training in timing might improve the golf swing performance. Jagacinski, Greenberg, and Liao (1997) found evidence that the age-related decline in golf performance may be explained by the differences in timing, rhythm, and tempo between young and older adults. The researchers referred to timing as those forces that are applied to the golf club during the swing. In contrast, tempo referred to the overall speed of the swing, and rhythm referred to the cycle of speeding up and down of the swing. In the Jagacinski et al. study, young and older adults were asked to swing an eight iron in order to hit a plastic ball that was placed on a rubber tee. The speed and force pattern of the club head was measured by a miniature accelerometer attached to the club head. Jagacinski et al. decomposed the swing by analyzing the force patterns into six phases: (a) beginning of the swing, (b) backswing, (c) downswing up to the maximum force, (d) downswing from the maximum force to impact, (e) impact to the resting level, and (f) the resting level to the maximum force during the follow-through. By measuring the duration of these phases, they were able to test the hypothesis that older adults swing the club too quickly or at too fast a tempo relative to younger adults. Their analyses partially supported the hypothesis: Older adults exhibited a shorter overall shot duration than did younger adults, even though the difference was only marginally significant. Rhythm, measured by the duration of each of the six phases, also showed age differences. The older adults, relative to the younger adults, exhibited shorter intervals during the beginning of the swing, from impact to resting, and from the resting level to the maximum force during the follow-through. Jagacinski et al. interpreted these results as indicating that for younger golfers, the club head reaches its peak maximal force just before impact, whereas for older golfers the club head reaches its peak maximal force earlier in the swing. The obvious implication is that getting the peak maximal force to occur just prior to impact for the older golfers should improve their performance. Interestingly, the amount of force was roughly the same for both groups. Thus, the findings of Jagacinski et al. indicate that timing is important in the golf swing and that age-related declines in golf performance may be due to this factor. On the basis of their results, these authors suggested that training in timing might improve one's golf swing. In particular, they suggested that slowing down the swing and maintaining this same tempo for all shots would be an effective strategy for improving performance.

Another indication that training in timing may improve the golf swing is based on studies that investigated the effects of transcranial stimulation on timing. These studies indicated that by stimulating the motor cortex, a voluntary motor act could be delayed without affecting the intention to act (Day, 1996). Day and colleagues (Day, Dressler, et al., 1989; Day, Rothwell, et al., 1989) administered transcranial stimulation in two ways. One was a short-duration, high-voltage electrical stimulus that passed through an electrode attached to the scalp; the other stimulus was a pulsed magnetic field delivered through a flat, circular coil held on the head. The stimulation was delivered 100 ms after the onset of a "go" signal. The results showed that both types of stimulation delayed the onset (approximately 50 ms) of the motor movement (i.e., wrist flex and wrist extension). Furthermore, the electromyographical pattern of agonist/antagonist muscle activation (i.e., contracting muscles that are resisted by other muscles) was similar between trials with or without the stimulation. The latter observation indicated that the stimulation did not affect the way in which their voluntary movement was produced. In contrast, stimulation to the peripheral nerve produced different results. When the median nerve at the elbow was stimulated, there was no delay in the onset of muscle activity. The stimulation suppressed only the first burst of agonist muscle activity. On the basis of these observations, Day and colleagues (Day, Dressler, et al., 1989; Day, Rothwell, et al. (1989) concluded that stimulation per se does not cause the delay. Day, Rothwell, et al. (1989) also asked whether the stimulation delays the onset of movement by delaying one's intention to act. To test this hypothesis, they instructed participants to flex both wrists while receiving stimulation to the motor cortex from only one side of the brain. The rationale for this treatment was that if the stimulation delays the participants' intention to act, then the unilateral stimulation would delay the activation of the muscles for both wrists. On the other hand, if the stimulation delays the movement by affecting an executive process that controls the nerve pathways, the unilateral stimulation would delay only the movement of the limb contralateral to the stimulation. The results showed that the delay of movement was greater for the contralateral limb than for the ipsolateral limb. They concluded that the cortical stimulation does not affect one's intention to act. Instead, stimulation delays movement by affecting the executive process that sends signals to the muscle.

Day (1996) interpreted these results to mean that transcranial stimulation inhibits the motor cortex to initiate the movement. However, this does not explain the result that the normal movement returned after the cortical inhibition was over. To explain this, Day proposed a hierarchical model of timing consisting of two partially independent components. One is a high-level process that prepares the movement and instructs the motor cortex to release the movement. The second is a subordinate level process that refines the precise timing of the movement. It is the second process that determines when the instructions to move relevant muscles would be sent. According to Day, the important property of this model is that "our limbs would not necessarily move when we tell them" (p. 233). For our purpose, this implies that practice may be needed to refine the coordination between one's intention to act and the precise timing of the act itself.

A more recent view of sensory and motor timing also proposes a common neural mechanism to represent temporal properties of perceived events and motor movements (Meegan, Aslin, & Jacobs, 2000). Research has suggested that the cerebellum may play an important role in representing sensory and motor timing (Ivry & Keele, 1989; Jueptner et al., 1995). In support of this view, Meegan et al. showed that motor timing could be improved by sensory timing training. In that study, participants were asked to use their right thumbs to press a button twice in succession with a prespecified interpress interval. The sensory training consisted of discriminating between a short and long interval between two tones. The researchers found that even though the sensory training did not involve motor movements, motor performance improved significantly after the training. On the basis of these results, Meegan et al. concluded that sensory timing training alters motor timing because a common neural mechanism is used to represent timing for the sensory and motor systems.

On the basis of the considerations mentioned in our literature review, we thought that it would be useful to examine the notion that extensive training in timing would improve performance in golf. The design of the present study was relatively simple. First, all participants were pretested, with accuracy as the measure of golf performance. Second, the participants were assigned to the experimental or control condition. The experimental-condition group received approximately 10 hr of training with a specialized metronome (Interactive Metronome®). The Interactive Metronome®, unlike other metronomes, uses auditory feedback to train an individual to match a variety of movements to a steady beat. The control-condition group read golf instruction literature. Third, after 5 weeks, both groups were posttested with the same procedure and measure that were used in the pretest. We hypothesized that training in timing would improve accuracy.

The more important consideration in the design of the study was the timing parameter. What value should be selected? Furthermore, should the value remain constant or should it vary across training? Because there are no known empirical studies that have tested for the effects of timing on golf, and little, if any, theoretical guidance, we had to set the timing parameter largely on the basis of experience and intuition. In agreement with the suggestion of Jagacinski et al. (1997), we fixed the value at a relatively slow pace of 54 beats per minute (bpm) for all of the motor tasks across all of the training sessions. We assumed performance problems associated with the timing of the golf swing were largely due to tempo, and that extensive training at the slow pace of 54 bpm would improve tempo. Finally, we did not ask participants to practice with a golf club because we assumed that movements are stored in the central nervous system as general motor programs (e.g., Schmidt, 1975), and therefore the training does not have to be task specific. A recent study by Meegan et al. (2000) also supports the assumption that training in timing does not require motor movements.

## Method

### *Participants*

We recruited participants via advertisements that were posted in local golf retail shops, at driving ranges, and in the pro shops of area country clubs. The advertisements stated that participants were needed for a golf training technology study and that the study was designed to evaluate the effectiveness of a golf skills training aid on golf shot accuracy. Participants were informed of the schedule and time requirements of the study. To qualify for participation, interested individuals had to be 25 years of age or older and had to possess at least a basic skill level in golf. The first 50 individuals who met these requirements were selected and randomly assigned to the 2 conditions with the restriction that each condition contained 25 participants. Of the 50 participants who started the study, 9 did not complete it. Further, 1 participant from the experimental group was randomly excluded to equalize the numbers of participants in the experimental and control conditions. The final sample therefore consisted of 6 women and 34 men who ranged in age between 25 and 61 years ($M = 37$, $SD = 11.57$). Unfortunately, the random assignment produced a significant age difference, $t(38) = 4.34$, $p < .001$, between the experimental ($M = 45$, $SD = 11.62$) and control groups ($M = 31$, $SD = 6.43$). (One participant in the control condition did not report her age.) To statistically control for this variable, we analyzed the data using age as a covariate. Participants were informed that, if they completed the study, they would receive a gift certificate for golf equipment or clothing and that they would be competing for two $100 bonus prizes. Finally, participants were informed as to the risks and benefits of participation before they signed informed consent.

### *Apparatus*

Pre- and posttest accuracy was measured using a Full Swing Golf Simulator™ located in an indoor 10 ft × 10 ft × 20 ft booth in a local retail golf shop. The indoor booth allowed for a controlled testing environment. As the name implies, the Full Swing Golf Simulator™ allows the golfer to execute a full swing and to hit a golf ball onto a screen that contains a picture of a golf hole including the tee box, fairway, and green with a pin and flag. The golfer can play a simulated round of golf at a number of famous golf courses. The simulator estimates the distance and direction for each shot and records the score for each hole. The simulator also provides for each shot a visual ball path trajectory line or a visual image of the flight of the golf ball from impact until the ball is stationary. Particularly important for the present study, the Full Swing Golf Simulator™ contains a duel-tracking system that cycles more than 2 million infra-red beams per second. As a consequence, the simulator is able to accurately monitor ball flight within 0.1 in. The measure of accuracy used in the present study for each golf shot was the distance in feet between the golf ball and the pin. Finally, the simulator requires that the approximate box-to-pin yardage be estimated and preset for each club. For example, a golfer hitting a nine iron would estimate and set his distance at 125 yards, a five iron at 170 yards, and so forth.

The Interactive Metronome® was used to train and analyze the golfer's ability to match a variety of movements to a steady beat. The Interactive Metronome® is a computer program for Windows 95/98 with peripherals, which include standard stereo headphones and a set of motion-sensing triggers. The trigger set plugs into the computer's serial port and includes a hand glove and a footpad. One trigger is attached to the participant's hand with a Velcro™ strap. When the participant claps or pats a hand, the attached trigger sends a signal to the program. A second trigger is contained in a floor pad on which the participant steps or taps. The computer program produces an auditory fixed reference beat. The beat can be set at any number of beats per minute. Participants are required to complete various hand and foot exercises in synchrony with the beat. The objective on the part of the participant is to move his or her limb at the same time as that set on the metronome. In other words, the participant attempts to pat or tap his or her hand or foot at the exact moment of the beat.

The program immediately analyzes the timing relationship between the participant's movements and the beat to the nearest millisecond. The tone of the beat (C6) is in monophonic and thus is spatially perceived as occurring in the center of the headphones. Movements include variations of clapping hands together, tapping the right or left hand on the side of the leg, tapping both toes or heels on the footpad, or tapping the right or left toe or heel on the footpad. The program produces different discriminative sounds that are based on the pitch and placement in the headphones. These reference pitches are tailored to guide the participant. The program transposes the timing information of each movement into one of the recognizable sounds. Each sound is a representation of when the movement occurred in relation to the beat. An early movement (i.e., a movement that precedes the beat) generates a low pitch tone in the user's left ear. A late movement (i.e., a movement that follows the beat) generates a higher pitch tone in the right ear. A movement that matches the beat within ±15 ms generates a higher pitched tone in the center of the headphones and is simultaneously perceived in both ears. A participant's timing score is the difference in milliseconds between the moment the beat sounds and the participant's tap.

All of the experimental-condition participants received their training in a room that contained five desktop computers arranged at the points of a pentagon. The computers, monitors, keyboards, and other materials were placed on tables, each with a chair. There were no partitions between the stations. The spacing and arrangement of the stations allowed the participants to stare ahead and not see anyone else working. The participants were also not likely to be disturbed by extraneous sounds because they were wearing headphones.

*Procedure*

The participants were randomly assigned to the two conditions prior to the pretest. The pretest was completed for all participants on two consecutive Saturdays in the month of May. Each participant was scheduled for a 1-hr appointment on one of the Saturdays at his or her convenience. Participants were informed that the pretest would take about 1 hr and that they should bring their own golf clubs. They were also informed that the type of clothing and shoes worn during the pretest should be worn during the posttest. The participants played the same hole under the same conditions (Troon North Course, AZ, Hole #1) for all shots using the same balls, driving mats, and rubber tees. The pretest consisted of 15 shots each with their nine, seven, and five irons, and the driver for a total of 60 shots. There was a 1-min rest period between each set of 15 shots. The participants were permitted to go through their normal warm-up routine and take as many as 10 shots before beginning the pretest.

In the actual pretest, participants began by setting the distance from the tee box to the pin. The experimenters informed the participants that the selected distance for each club would also be used for the posttest and that they would be required to use the same club. The participants were then instructed to aim for the pin and to proceed at their own pace. The experimenter recorded each score (i.e., the distance in feet from the pin). Finally, all participants were informed that they were strictly prohibited from practicing with any of the clubs that were used during the pretest as well as receiving any instruction or lessons during the study.

The participants in the experimental-condition group ($n = 20$) received 10 hr of Interactive Metronome® training in 12 sessions of 50-min each. The sessions began the day after the completion of the pretest. They were scheduled throughout the day and early evening for the next 5 weeks. The schedule included weekdays and weekends. Participants scheduled the sessions at their convenience with the stipulation that they could not complete more than 1 training session per day, and that they needed to complete the entire training sequence by the end of the 5-week period. All of the experimental participants were trained in the same room that contained the five computer stations. An experimenter was present for all sessions. Up to 5 participants could be trained simultaneously with one experimenter monitoring their activities by sitting on a bar stool that was placed in the middle of the pentagon. Six experimenters (including the experimenter who collected the pre- and posttest data) were paid and trained in the use of the Interactive Metronome.® All of these experimenters had completed the actual training themselves. There was no attempt to balance experimenters with participants or training sessions. The experimenters simply signed up for scheduled times that were convenient for them and compatible with participant times. The primary duties of the experimenters were to greet the participants and ensure that they signed in and selected the correct daily training schedule. Experimenters also monitored and corrected, if necessary, any technical problems with the equipment, recorded data that were not recorded by the software program, and made sure that the participant scheduled his or her next training session before leaving. Finally, during the first session, experimenters modeled the use of the equipment and the proper technique for each of the prescribed motor movements that were later required of the participants.

Before each training session began, participants were required to sign in and select the appropriate training schedule for the day and to enter some demographic information (e.g., name, age, sex) into the computer. The experimenter attached the hand sensor to the participant's hand, and placed the headphones properly on the head. The experimenter stressed the importance of using controlled, smooth (nonballistic) motions in matching the movement to the steady reference beat. The experimenter also emphasized that participants should not aim, think about, adjust their motions, or listen to the guidance sounds, but rather focus their attention on the steady beat, and whenever they got off beat to refocus their attention on the beat. These instructions were also posted beside each computer station.

The beat of the metronome was set at 54 bpm for all 12 sessions. For each of the tasks within each of the 12 training sessions, concurrent, temporally based, guide sounds continually indicated that the participant was on target, early, or late. At the beginning of the first session and at the end of the last training session, participants were administered 30- to 60-s tests on each of the 13 movements that were used in the training sessions. Guidance sounds were not used during the testing, with the exception of one additional task (the 14th), which was a repeat of clapping both hands with the standard guide sounds. The test took about 10 min to complete. Two dependent measures were recorded for each task: One was the mean number of milliseconds across the 14 tasks the participant deviated from on-target performance, and the other was the highest number of times in-a-row (IARs) that the participant was able to stay within ±15 ms of the reference beat.

Before beginning the 10-min test, the experimenter placed the hand sensor on the participant's hand, and the foot sensor was placed on the floor. Then the experimenter modeled the appropriate movements. There were no exercises that paralleled the motions in the golf swing.

The first 4 tasks in the 10-min test involved the hands. In the 1st task (clapping hands), participants were instructed to make circles of about 10-in. in diameter with the hands coming together on the beat and to continue the circular path without stopping after the beat. The 2nd task was identical to the 1st with the exception that the early, late, and on-target guidance sounds were presented. The guidance sounds were presented only for the 2nd task in the 10-min test. The 3rd

**TABLE 1**
**Training Schedule**

| Task | Session 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Clapping hands | 180 (1) | 385 (1) | 500 (1) | 1000 (1) | 1000 (3) |
| Preferred hand | 180 (2) | 385 (2) | 500 (2) | | |
| Nonpreferred hand | 180 (3) | 385 (3) | | 500 (3) | |
| Both toes | 180 (4) | 385 (4) | 500 (3) | 500 (2) | |
| Preferred toe | 180 (5) | 385 (5) | | | |
| Nonpreferred toe | 180 (6) | 385 (6) | | | |
| Both heels | | 385 (7) | | | |
| Preferred heel | | | | | |
| Nonpreferred heel[a] | | | | | |
| Preferred hand and nonpreferred toe | | | 250 (4) | | 500 (1) |
| Nonpreferred hand and preferred toe | | | 250 (5) | | 500 (2) |
| Choice | | | 500[b] (6) | 250[b] (4) | |
| Free style | | | | | 500[c] (3) |
| Total beats | 1080 | 2695 | 2500 | 2250 | 2500 |

*Note.* Value in each cell indicates the prescribed total number of beats that were to be completed. Value in parentheses indicates the order in which the task was presented. [a]The use of the nonpreferred heel occurred only in the both heels and free style tasks. [b]Participant could choose any task that had been previously performed. [c]Participant was required to start with clapping hands, move to preferred hand, then preferred toe, nonpreferred toe, and end with both toes, all within 500 beats. [d]Participant was required to complete three sequences: Sequence 1, 4 beats clapping hands alternating with 4 beats preferred hand for 250 beats; Sequence 2, 4 beats clapping hands alternating with 4 beats both toes for 250 beats; and Sequence 3, 2 beats clapping hands alternating with 2 beats both toes for 500 beats. [e]Participant was required to alternate between 8 beats clapping both hands and 8 beats both toes. [f]Participant could switch between any of the tasks with the restriction to limit switching to every 100 beats.

and 4th tasks involved using either the preferred or nonpreferred hand and required that the participant, using the same circular motion, tap his or her hand on his or her leg on beat. The next 3 tasks involved the toes. In the 5th task, participants were instructed to face the floor trigger with both toes about 2 to 3 in. away from the trigger. They were instructed to start by lifting one foot and tapping that toe on the trigger with the beat and to return that foot to the previous position between beats, then tap the other toe on the next beat, and so forth. Tasks 6 and 7 involved the same movement but with only the preferred or nonpreferred toe, respectively. The next 3 tasks involved the heels. In the 8th task, participants were instructed to face away from the floor trigger with both heels about 2 to 3 in. away from the trigger and to start by lifting one foot and tapping that heel on the trigger on the beat, and return that foot to the previous position between beats, and then tap the other heel on the next beat, and so forth. Tasks 9 and 10 involved

| Session | | | | | | | |
|---|---|---|---|---|---|---|---|
| 6 | 7 | 8 | 9 | 10 | 11 | 12 | Σ |
| 1000 (1) | | 1500 (1) | | 2000 (1) | | | 7565 |
| | 1000 (1) | | | | | | 2065 |
| | | 500 (2) | | | | | 1565 |
| 1000 (3) | | | | 500 (2) | | | 3065 |
| | 500 (2) | | | | 250 (2) | | 1315 |
| | | | | | 250 (3) | | 815 |
| 500 (2) | | | | | | | 885 |
| | | 500 (3) | | | | | 500 |
| | | | | | | | 000 |
| | | | 1000 (1) | | | | 1750 |
| | | | 1000 (2) | | | | 1750 |
| | | | | | | | 750 |
| | 1000[d] (3) | | 500[e] (3) | | 2000[f] (1) | 2000[f] (1) | 6000 |
| 2500 | 2500 | 2500 | 2500 | 2500 | 2500 | 2000 | |

the same movement but with only the preferred or nonpreferred heel, respectively. The next 2 tasks involved combinations of movements. In Task 11, the preferred hand and nonpreferred toe were combined. Participants were instructed to face the floor trigger, tap their preferred hand against their leg on one beat, then tap the toe of the opposite (nonpreferred) foot on the floor trigger on the next beat and then to continue to alternate. In Task 12, the nonpreferred hand and preferred toe were combined with the same movements outlined in Task 11. In the final 2 tasks, balancing was added. In Task 13, participants were required to balance on their preferred leg while tapping the toe of their other foot on the floor trigger on each beat, and in Task 14, they had to switch to the nonpreferred leg.

After the completion of the 10-min test, the training sessions began. The purpose of the training was to increase the timing accuracy. Table 1 provides the training schedule. The development of this training schedule was based on three assumptions. First, we incorporated variability in the tasks that were required because we thought it would be more likely to generalize or transfer to another motor activity (Schmidt, 1988), in this case the golf swing. In other words, participants would become more sensitive to the timing properties necessary to execute this motor response. Second, although the total number of beats was relatively consistent across sessions (the number of beats required for testing are not included in Table 1), we increased the number of beats per task and decreased the number of tasks across sessions, assuming that this type of extended training on

**TABLE 2**
**Mean IAR and Deviation From the Target in ms as a Function of Task and Test, Pretest and Posttest**

| | IAR | | Target deviation | |
|---|---|---|---|---|
| Task | Pre | Post | Pre | Post |
| 1. Both hands | | | | |
| *M* | 3.40* | 5.85* | 48.86* | 21.17* |
| *SD* | 2.30 | 2.68 | 19.32 | 6.86 |
| 2. Both hands with sounds | | | | |
| *M* | 2.70* | 6.30* | 71.54* | 19.85* |
| *SD* | 1.81 | 1.94 | 43.70 | 6.30 |
| 3. Preferred hand | | | | |
| *M* | 2.75* | 4.50* | 42.12* | 25.19* |
| *SD* | 1.83 | 2.59 | 17.00 | 13.02 |
| 4. Nonpreferred hand | | | | |
| *M* | 2.50* | 4.00* | 41.67* | 22.65* |
| *SD* | 1.67 | 2.34 | 19.45 | 7.57 |
| 5. Both toes | | | | |
| *M* | 1.90* | 3.60* | 68.99* | 26.40* |
| *SD* | 1.25 | 1.47 | 48.26 | 10.67 |
| 6. Preferred toe | | | | |
| *M* | 2.05* | 3.70* | 53.24* | 27.38* |
| *SD* | 1.19 | 2.68 | 24.89 | 9.82 |
| 7. Nonpreferred toe | | | | |
| *M* | 2.00* | 3.90* | 58.32* | 27.08* |
| *SD* | 1.26 | 2.05 | 32.67 | 10.25 |
| 8. Both heels | | | | |
| *M* | 1.65* | 2.90* | 71.43* | 32.17* |
| *SD* | 1.09 | 1.83 | 36.02 | 16.66 |

*(table continues)*

a single task would lead to an increase in the ability to maintain focus on the task as well as when executing the golf swing. Third, because of the positive relationship between the amount of practice and skilled performance (Ericsson, 1996; Schmidt, 1988), we assumed that by providing 10 hr of training (a total of 28,025 beats plus the beats during testing), the training in timing would be more likely to transfer to the golf swing. Finally, because of the repetitive nature of the training, participants in the experimental group were provided with motivating instructions beginning with the 3rd session and ending with the 11th session. These instructions urged them to decrease their millisecond average and increase their IARs. Furthermore, participants were informed that their millisecond averages and IARs would be ranked and posted and that the top two performing individuals would receive a $100 gift certificate for golf equipment or clothing.

TABLE 2 (Continued)

| Task | IAR Pre | IAR Post | Target deviation Pre | Target deviation Post |
|---|---|---|---|---|
| 9. Preferred heal | | | | |
| *M* | 1.60* | 2.85* | 96.74* | 36.08* |
| *SD* | 1.43 | 1.50 | 99.04 | 15.62 |
| 10. Nonpreferred heel | | | | |
| *M* | 1.55 | 2.30 | 76.07* | 38.37* |
| *SD* | 1.32 | 1.49 | 49.77 | 18.52 |
| 11. Preferred hand and nonpreferred toe | | | | |
| *M* | 1.15* | 2.15* | 97.75* | 42.14* |
| *SD* | 0.75 | 0.93 | 41.76 | 16.24 |
| 12. Nonpreferred hand and nonpreferred toe | | | | |
| *M* | 1.15* | 2.50* | 100.10* | 34.69* |
| *SD* | 0.88 | 1.28 | 57.17 | 11.04 |
| 13. Balance with preferred foot and tap with nonpreferred toe | | | | |
| *M* | 1.65 | 2.75 | 70.63* | 33.08* |
| *SD* | 1.27 | 2.00 | 38.60 | 14.89 |
| 14. Balance with nonpreferred foot and tap with preferred toe | | | | |
| *M* | 1.55* | 3.15* | 61.64* | 25.15* |
| *SD* | 0.94 | 1.53 | 28.19 | 6.77 |

*Note.* IAR = number of items in-a-row.
$^{*}p < .05$.

In contrast to the participants in the experimental group, the participants in the control group received a letter indicating that the attached 12 pages of golf tips were to be read at least once a day before the posttest. The golf tips were taken from popular golf magazines and books and were authored by prominent professional golfers and instructors. The participants were also informed that after completing the posttest they would receive a golf certificate. The control participants were not contacted again until they were scheduled for the posttest.

## Results

Unless otherwise specified, the significance level was set at .05 for all of the analyses. We first determined whether the participants in the experimental group made a significant improvement in timing. Table 2 shows how participants performed on the tasks in the 10-min test before and after the training. As mentioned earlier, IARs and the milliseconds from the target were used to index the participants' timing. The table indicates that for both measures, participants performed better on the posttest than on the pretest (see Table 2). A 2 (test: pretest and posttest) × 14 (task: 14 different tasks on the 10-min test completed) repeated-measures analysis of variance (ANOVA) on the IAR scores indicated that the effects of test, $F(1, 19) = 145.61$, $MSE = 2.56$, task, $F(13, 247) = 12.46$, $MSE = 2.80$, and the Test × Task interaction, $F(13, 247) = 2.40$, $MSE = 2.08$, were significant. The interaction simply indicated that the amount of improvement differed across tasks. A priori $t$ tests performed on each task indicated that all tasks except for 2, tapping with the nonpreferred heel and tapping with the nonpreferred toe while balancing on the preferred foot, showed significant improvement from pre- to posttest. However, improvement was marginally significant for these 2 tasks ($p < .10$). Similar results were obtained with the deviation from the target measure. A 2 (test: pretest and posttest) × 14 (task: 14 different tasks on the 10-min test) repeated-measures ANOVA revealed that the effects of test, $F(1, 19) = 53.16$, $MSE = 4031.07$, task, $F(13, 247) = 9.48$, $MSE = 661.68$, and the Test × Task interaction, $F(13, 247) = 3.27$, $MSE = 675.39$, were significant. A priori $t$ tests showed that all 14 tasks showed significant improvement from pre- to posttest. In summary, both measures indicated that the metronome training improved participants' timing.

Next, we analyzed the accuracy scores. We measured accuracy by the distance in feet between the pin and the ball's final resting place. The scores were averaged over 15 trials for each club for each participant. Table 3 displays the mean accuracy as a function of club, treatment group, and test (pre and post). As Table 3 indicates, the overall performance of the experimental group was better than that of the control group. Also, the accuracy differed between clubs. Figure 1 further shows the mean improvement that occurred between pre- and posttest as a function of club and treatment group. As shown, performance improved for the experimental condition for all clubs. In contrast, little or no improvement occurred for the control condition. These observations were confirmed by a 2 (group: experimental and control) × 4 (club: nine iron, seven iron, five iron, and driver) × 2 (test: pre- and posttest) mixed-design ANOVA. The results revealed that the main effect of club, $F(3, 114) = 106.14$, $MSE = 2323.48$, and the Group × Test interaction, $F(1, 114) = 4.42$, $MSE = 2598.87$, were significant. The main effect of group, $F(1, 39) = 3.10$, $MSE = 17308.23$, and test, $F(1, 114) = 3.13$, $MSE = 2598.87$, approached significance ($p < .10$). A priori independent $t$ tests indicated that the treatment groups did not differ from each other on the pretest, $t(39) < 1$. However, on the posttest, the experimental group was significantly more accurate than the control group, $t(38) = 2.97$. Furthermore, paired-sample $t$ tests indicated that there was a significant increase in accuracy between the pre- and posttest for the experimental group, $t(19) = 2.69$. No improvement occurred in the control group, $t(19) < 1$.

Because there was a significant difference in age between the experimental and control groups, we conducted another analysis on accuracy using age as a covariate. We also used the mean estimated distance across four clubs as a covari-

TABLE 3
**Pretest and Posttest Mean Accuracy in Feet as a Function of Group, Club, and Testing**

| Group | Club | | | | | | | | Overall | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 9 Iron | | 7 Iron | | 5 Iron | | Driver | | | |
| | Pre | Post | Pre | Post | Pre | Post | Pre | Post | Pre | Post |
| Experimental | | | | | | | | | | |
| *M* | 66.32 | 57.00 | 76.95 | 58.31 | 114.45 | 82.14 | 186.86 | 158.87 | 111.15 | 89.08 |
| *SD* | 39.78 | 24.49 | 55.21 | 22.29 | 80.60 | 35.64 | 113.02 | 96.60 | 66.99 | 39.63 |
| Control | | | | | | | | | | |
| *M* | 78.64 | 78.20 | 88.01 | 93.45 | 122.28 | 126.75 | 212.26 | 210.43 | 125.32 | 127.21 |
| *SD* | 44.81 | 32.97 | 43.88 | 38.77 | 62.86 | 66.61 | 70.52 | 66.20 | 48.77 | 41.59 |

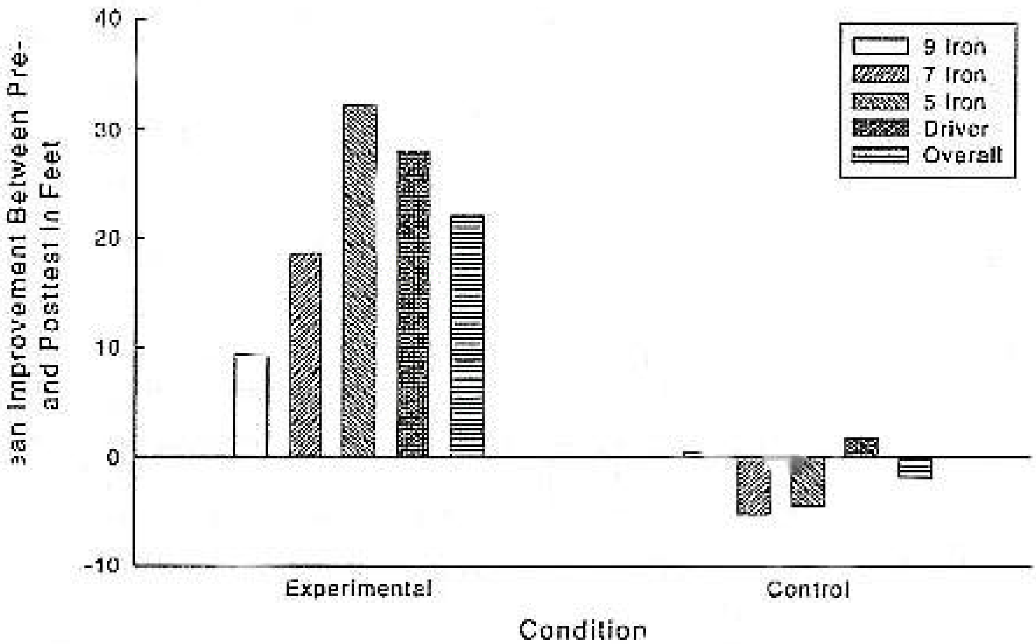


**FIGURE 1. Mean improvement as a function of club and treatment group.**

ate. As mentioned earlier, each participant determined at the pretest how far he or she would be able to hit the ball with each club. We expected the estimated distance to reflect each participant's expertise with playing golf. By using this variable as a covariate, we attempted to equate the level of expertise between the experimental and control groups. A 2 (group: experimental and control) × 4 (club: nine iron, seven iron, five iron, and driver) × 2 (test: pre- and posttest) mixed-design analysis of covariance (ANCOVA) indicated that the effects of club, $F(3, 105) = 6.35$, $MSE = 2318.47$, test, $F(1, 35) = 5.07$, $MSE = 2462.79$, and the Group × Test interaction, $F(1, 105) = 4.72$, $MSE = 2462.79$, were significant. Further analyses indicated that these results were similar to the previous accuracy analysis.

We also correlated age with IAR and millisecond deviation scores to rule out further that age was a factor in producing improvement. We computed a correlation between age and improvement that occurred in IAR and millisecond deviation scores between pre- and posttest (pre–post) on each task. None of the correlations except one was significantly different from zero. The only significant correlation occurred with the millisecond deviation score on the task that required tapping with the nonpreferred toe, $r = .55$. The positive correlation indicated that improvement was greater for older adults relative to younger adults. However, no other correlations reached significance, indicating that age was an unlikely source of improvement in overall timing. In summary, the results of this study indicate that the training in timing improved accuracy relative to a control group, which did not show any improvement.

## Discussion

The results of the present experiment suggest that training in timing improves accuracy in golf. Furthermore, the improvement in performance was consistent across golf clubs. Why does training in timing on an activity that does not mimic the golf swing enhance accuracy in this activity? There are several possibilities.

One obvious answer is that the training improved the golf swing by fine-tuning the timing properties (i.e., tempo and rhythm) of the golf swing. As mentioned in the introduction, the golfing community has attached considerable importance to the notion that timing is an essential property in a successful golf swing. Unfortunately, in the present study, we can only speculate about which timing properties were changed because these properties were not measured. However, we specifically suggest that the training in timing leads to changes in tempo. In support of this notion, Jagacinski et al. (1997) demonstrated that older individuals have faster tempos than younger individuals. These authors also reported that the maximal force of the club head occurs earlier with an older adult than with a younger adult. Note that the mean age of our experimental participants ($M = 44$) falls somewhat in between the age range (mean ages were not provided) of older participants (60 to 69) and the younger participants (19 to 25) in the study of Jagacinski et al. Thus, it is possible that training improved the tempo of the golfers in our study.

The second possibility is that the training made the coordination between participant's intention and voluntary movement more precise. On the basis of the model of Day (1996), intention to act and voluntary movement are organized in a hierarchical fashion. As Day indicated, the important implication of this model is that our limbs may not move when we intend to move them. It is possible that even without external interference (e.g., transcranial stimulation), the coordination between the motor planning component and the timing component is not perfect. Therefore, fine-tuning between these components may be necessary to produce motor movements that require precise timing. Similarly, it is conceivable that sensory training using the Interactive Metronome® may have modified the temporal representation used for both sensory and motor systems. In support of this hypothesis, our results are consistent with the results of Meegan et al. (2000), which indicate that motor movements are not necessary to improve the temporal properties of the motor movements.

The third possibility is that the improvement was simply an artifact of demand characteristics. Participants in the control group were not asked to come to the laboratory to engage in activities that could possibly improve their golf swing. It is difficult to rule out this possibility without further investigations in which other groups would be tested using other motor exercises. However, we are inclined to believe that the improvement in accuracy had something to do with timing. It is a commonly reported experience that improvement in golf, as in any highly skilled behavior, requires extensive and effortful practice with feedback

(Ericsson, 1996). We therefore doubt that the transient nature of demand characteristics can account for our results. Furthermore, it is important to note that although participants in the control group were provided with golf tips, these participants failed to show any improvement.

In the present study, we provided extensive training by varying the total number of beats across a variety of tasks while maintaining the same number of beats per minute. In future studies, it would be interesting and important to examine the effectiveness of various schedules that include different tasks, durations, and beats per minute. These studies could provide data concerning the most optimal relationship between timing and golf performance. Within this context, it would also be important to include other measures of golf performance, for example, distance in driving and accuracy in putting. Furthermore, future studies should examine the relationship between timing and golf performance by directly measuring some of the temporal properties of the golf swing itself, something that was not done in the present study. Even more ideally, at an individual differences level, it may be possible to determine the number of beats per minute that is most effective in producing the tempo that leads to the most effective performance. In other words, effective performance may depend on temporal properties that are unique to each individual, and the training may need to be tailored to each individual.

Future studies could also take advantage of the golf simulator to separate the distance and direction of the shots. It is possible that training in timing would improve both. Furthermore, the golf simulator is capable of simulating both fairway and green shots. Perhaps timing is more important for one type of shot than it is for the other. Also, in our study, participants were told to ignore feedback (i.e., the guidance sounds) when they were trained with the Interactive Metronome.® It would be interesting to examine whether focusing on feedback would influence the effectiveness of the training.[1]

Finally, the present results provide some interesting implications for other motor activities. If training in timing improves performance by fine-tuning the timing components of a motor movement, then this type of training may be used to improve performance in other activities that require precise timing. Thus, it would be interesting to examine whether Interactive Metronome® training would improve movements in other sports (e.g., basketball, baseball, and tennis) as well as in other endeavors such as flying and typing.

In summary, the results of the present experiment indicated that training in timing improved accuracy in golf. Future research will be necessary for further delineation of the phenomenon and for development of a theory that can explain how the property of timing influences this complex motor activity. However, it is important to note that this is the first experimental demonstration of the effec-

[1]We thank an anonymous reviewer for suggesting the future studies mentioned in this paragraph.

tiveness of training in timing on a complex motor activity, and that now there is evidence to indicate that training in timing may improve one's performance in golf. We envision that an instrument such as the Interactive Metronome® could be used not only for overall training in timing but also for fine-tuning one's swing before and during competition. Finally, we agree with Cochran and Stobbs (1968) that the terminology and concepts describing the temporal properties of the golf swing are elusive even though there is nothing more obvious than the gracefulness of a well-timed golf swing.

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