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Research article

Improved motor-timing: effects of synchronized metronome training on golf shot accuracy

Marius Sommer ✉ and Louise Rönnqvist
Department of Psychology, Umeå University, Umeå, Sweden

Abstract
This study investigates the effect of synchronized metronome training (SMT) on motor timing and how this training might affect golf shot accuracy. Twenty-six experienced male golfers participated (mean age 27 years; mean golf handicap 12.6) in this study. Pre- and post-test investigations of golf shots made by three different clubs were conducted by use of a golf simulator. The golfers were randomized into two groups: a SMT group and a Control group. After the pre-test, the golfers in the SMT group completed a 4-week SMT program designed to improve their motor timing, the golfers in the Control group were merely training their golf-swings during the same time period. No differences between the two groups were found from the pre-test outcomes, either for motor timing scores or for golf shot accuracy. However, the post-test results after the 4-weeks SMT showed evident motor timing improvements. Additionally, significant improvements for golf shot accuracy were found for the SMT group and with less variability in their performance. No such improvements were found for the golfers in the Control group. As with previous studies that used a SMT program, this study's results provide further evidence that motor timing can be improved by SMT and that such timing improvement also improves golf accuracy.

Key words: Golf accuracy, motor timing, golf shot variability, metronome training.

Introduction

A successful golf stroke is obviously a very complex motor action, that requires precise coordination and control of numerous of muscles and sensors guided by the underlying timing centres in the brain. Timing includes observing, controlling, and differentiating the rhythm of a specific motor action depending on the situational demands (Martin, 1988). Moreover, timing is described to be an important factor in learning, development, and performance of any motor skills, and golf players and instructors (e.g., Pelz and Frank, 1999) have a long time believe that timing is a key attribute in performing the optimal golf shot. Thus, given the focus of importance of timing in the golf literature, and by golfers, it is surprising to find so few empirical-based studies investigating the timing properties of the golf swing and how timing training may affect the actual golf accuracy.

Several studies have drawn the conclusion that timing is critical in the generation of coordinated motor actions (Ivry, 1996; Mauk and Ruiz, 1992; Meegan et al., 2000; Medina et al., 2005) such as the golf swing. Motor planning requires a combination of attention, sensory integration, synchronisation, and timing (Baht and Sanes, 1998), and because movements involve changes in muscle length over time (Mauk and Buomonano, 2004), motor control and timing are inextricably related. When examining the commercial golf literature (e.g., GolfDigest and Golf Magazine) there are numerous testimonies regarding the importance of timing and as many definitions of what a well-timed golf shot involves. However, findings by Neal et al. (2008) suggest that there is no correlation between golfers' own classification of a well-timed shot and the temporal properties of their golf swing. Thus, this indicates that timing is a complex concept, not only in terms of definition, but also for the individual golfer to embrace and comprehend.

Libkuman et al. (2002) have reported that training by means of timing and rhythmicity leads to improvement in golf shot accuracy. For instance, they found that golfers after receiving just 10 hours of timing training over a 4-week period significantly improved their golf shot accuracy. These results indicate that training per se may not simply have to be golf-specific to affect and enhance our underlying control of the planned and ongoing sequential, integrated actions necessary to perform an optimal golf swing. In line with this view, Jagacinski et al. (1997) have reported evidence that the age-related decline found in golf performance may be explained by the differences found in the timing abilities between young and older adult golfers.

Using observations made of the neural basis and dynamics of rhythmic timing, researchers have noted that auditory rhythms rapidly entrain motor responses into stable steady synchronization states (Thaut, 2003). Accordingly, Meegan et al. (2000) found that training on a perceptual task, using enhanced representation of a particular temporal interval induced by auditory training significantly was transferred to a motor task. This implies that motor learning can occur even without any motor activity. Thus, one interpretation of these findings is that it may be possible to affect and/or improve the underlying, unconscious timing control of actions without any sport-specific training, a type of training that may improve motor output integrated in a sport performance.

Most complex movement skills involve synchrony between physical and cognitive activation and functioning. For instance, to optimize the outcomes of different sport activities (e.g., when playing football or performing a golf swing), dynamic processing and integration between attention/concentration, motor planning, sensory-motor coordination, timing, mental organization, and sequencing are required. Recent findings from synchronized metronome based intervention have reported bene-

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fits across many diverse domains of human performance as well as in rehabilitation of different clinical conditions. For instance, such improvements have been found for reading achievement and academic performance in school children (Taube, et al., 2007), and by means of improved attention, motor control, and behaviour regulation in children with ADHD (Shaffer, et al., 2001). Synchronized metronome training (SMT) and/or similar timing training methods may also benefit diverse sport performance (Libkuman et al., 2002; Zachopoulou et al., 2000). However, evidence-based studies of timing training effects on different sport performance are still very limited. Consequently, such documented observations are in great need of further scientific evaluations.

Thus, the purpose of this study was two-folded; first, to investigate whether 4-weeks of timing and rhythmicity training by means of SMT improves motor timing and second; to investigate whether such effects of SMT influence golf shot accuracy of experienced golfers.

Methods

The preset inclusion criteria for this study were healthy male golfers between 20-40 years of age, and with a golf handicap (hcp) between 0-20. For all included golfers, the start off of this study (in January) was approximately 3 months after the end of the local golf season.

Participants

A total of twenty-six experienced male golfers participated in this study. Their age and handicap (hcp) ranged between 20 and 37.1 years (mean 27.7), and 4.4 to 19.8 hcp (mean 12.6) respectively. After completing the pre-test, the golfers were randomly assigned to either an SMT or a Control group. The two groups did not differ significantly on any background or golf pre-test variables except for years of golf experience ($t(24) = -2.877$, $p < 0.05$). (See Table 1 for background description).

Table 1. Participants' mean age, golf handicap and years of experience (± SD).

Group	N	Age (yrs)	Handicap	Experience
SMT	13	27.5 (4.6)	12.7 (5.0)	10.9 (4.8)
Control	13	27.7 (5.3)	12.3 (4.8)	7.3 (4.1)

Apparatus

Pre- and post-test golf precision measures were established in a P3ProSwing Golf Simulator located in a 5 m × 5 m × 3.5 m golf lab at Umeå University (Figure 1). The participants typically execute a full swing and hit a real golf ball that will travel approximately 3 m before hitting a screen. The screen displays the fairway, on which the ball is positioned, as well as the green and the hole with a pin and a flag. A visual ball path trajectory line of the golf ball's flight to the final position is instantly projected on the screen as the player makes his shot.

The ball is shot from a 22.9 cm x 35.6 cm sensing platform with 1.5 cm high artificial grass on top. The platform contains 65 optical sensors that capture information about the speed and direction of the club head at ball impact. The simulator estimates the distance and direction for each shot. According to the manufacturer (P3ProSwing, Sports Vision Technologies, California, USA), the simulator accurately monitors ball flight with 99% precision. Before this study, a number of golf shots performed in the P3ProSwing golf simulator were simultaneously measured by an Optoelectronic registration system (ProReflex, Qualisys Inc., Gothenburg, Sweden) by means of the club head velocity and angle at ball impact and compared with the P3ProSwing data. Outcomes from five different clubs (9-Iron, 4-Iron, Pitching Wedge, Driver and Putter) and in total 30 golf shots were analysed and compared. There was a high significant correlation between the two outcomes measures (overall $r = 0.97$). The mean velocity differences (km/h) between the two measurements were small, although consistently somewhat slower (both over repeated trials and clubs) for P3ProSwing (mean vel diff = -4.4, -4.2, -3.9, -7.4 and -0.4 km/h, respectively) in comparison to ProReflex outcomes. Similar correlations (overall $r = 0.82$) and differences were found for the club angle at ball impact (mean diff = 0.3, 0.23, 1.39, 0.89, 1.45 degree) for respective clubs between the two systems. Thus, we considered the outcome measures from the P3Pro simulator to be both valid and consistent.

Figure 1. Photo of the Golf simulator set-up.

For each golf shot, accuracy was measured using the distance (in meters) between the golf ball's final resting place and the pin (Absolute Error). Accuracy was also measured in terms of direction and distance accuracy as well as performance variability (Figure 2). In addition, the club head speed (tangential velocity) at ball impact was analysed. All scores were averaged over 20 trials for each club and each participant.

The Interactive Metronome (IM) ® system assessed all participants' (SMT and Control group) timing and rhythmic skills at pre- and post-test and as training intervention for the SMT group. The IM is a computer program for Windows based on the traditional music metronome that attempts to improve and maintain timing and rhythmicity. It is set up with standard stereo headphones and a set of contact-sensing triggers, including a hand glove and a flat plastic footpad. The participants are required to perform uni- and bilateral, rhythmic hand/arm and leg/foot movements in conjunction with a computer-generated reference beat, heard through headphones (Figure 3).

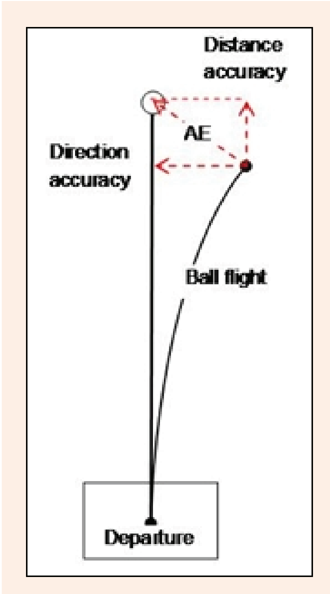

Figure 2. **Schematic illustration of Golf performance accuracy measuring, illustrating distance and direction accuracy and the absolute error (AE).**

The IM system generates scores on three dependent measures; namely the mean millisecond discrepancy between the participant's responses and the reference beat (timing skills), the variability average that is a measure of how close each hit is timed to the previous hit (rhythmic skills), and finally the highest number of times in-a-row that the participant is able to stay within ±15 ms of the reference beat (reflecting degree of stability in performance). A high timing score indicates a larger millisecond discrepancy between the metronome beat and the participant's movements, a score that indicates less accurate timing. Thus, lower timing scores signify better timing.

Figure 3. **Photo of the IM training set-up.**

Procedures

First, at the pre-test occasion the participants received an explanation of the experiment protocol and provided informed consent before testing, thus, in accordance with the ethical standards specified in the Helsinki Declaration. They received 500 SEK (70 USD) for taking part in the study. Additionally, to increase the ecological validity, they were competing for a 1000 SEK (140 USD) bonus prize, information every participant received at the first pre-test occasion. All participants used their own clubs.

At the time of the golf pre-test, the participants began by setting the distance from the ball (fairway) to the pin. It was emphasized that they should choose a distance from the pin that was, with some margin, within the reach of their shot with each club (4-Iron, 7-Iron and Pitching Wedge, respectively). They were informed that the same distances, with the same clubs, and under the same conditions would apply for the post-test. Before the pre-test measurement started, they could take up to five practice shots with each club to familiarize themselves to the new surface and the artificial environment. At the start of the measurement, the participants were instructed to aim for the pin and to proceed at their own pace. All golfers performed 20 test shots with each club (60 in total) in a counterbalanced randomized block design. The same procedure was used during post-test.

The purpose of the IM pre- and post-test test was to assess the participant's timing and rhythmic skills. The test is a standardized assessment developed by the instrument manufacturer, consisting of 14 different tasks, involving uni- and bi-manual hand and feet actions (Interactive Metronome, 2008). In addition, the optional Attend Over Time (AOT) test, which challenges the participant to clap both hands in synchrony with the reference beat for 10 consecutive minutes, were distributed as part of pre- and post-testing. The AOT test assesses the participants' ability to attend selectively to a stimulus without being burdened by internal thoughts or external distractions for extended periods. At the start of the test, the experimenter attached the handsensor to the participant's hand, and placed the headphones properly on the head. Before each of the tasks included in the test the participants were shown a video modelling the appropriate movements. The IM pre-and post-test took about 20 minutes to complete. The tempo of the metronome was set at 54 beats per minute (bpm) for all tasks during both tests.

Intervention

The SMT group received 12 training sessions of IM training, distributed on three 45-50 min sessions a week over a 4-week period after the post-test. The IM training was accomplished individually, and a certified IM provider was present for all sessions, monitoring the participants' activities, modelling proper actions and correcting any technical problems. During training sessions, the IM system instantaneously transposes the timing information into discriminative, temporally based guide sounds presented in the participant's headphones, continually indicating whether the participant was on target, early, or late. Guide sounds were not present during pre- and post-test. An early contact (i.e., a contact that precedes the beat) generates a low pitch tone in the user's left ear. A late contact (i.e., a contact that follows the beat) generates a higher pitch tone in the right ear. A contact that matches the beat within ±15 ms generates a higher pitched tone in the centre of the headphones and is simultaneously perceived in both ears. These instantaneous guide sounds enable the participant to correct deliberately their timing errors as they occur (for further details of the IM devise, see Libkuman et al., 2002; Taube et al., 2007). The participants would typically perform 4-10 successive tasks involving use of hands and feet in uni- and bi-lateral manners in synchrony with the metronome reference beat that was set at 54 bpm for all tasks during the first seven sessions. From session number eight several new tasks and reference beat tempos (45, 66, and 78 bmp) were introduced: clapping hands while standing on a balance-board, hitting wall-mounted sensors with hands crossing body midline, clapping hands behind back, and tapping footpad crossing body midline. At the completion of training, participants typically have engaged in approximately 27,000 motor repetitions. After each training session, the participants were shown their scores, meant to work as a motivating feedback for future performance enhancement. The purpose of the training was twofold: to improve the participants' motor timing and rhythmic skill and to improve their ability to attend selectively to a stimulus for extended periods.

Due to the off-golf-season, the participants in the Control group were allowed to maintain some aspect of golf activity by performing golf swings in a commercial swing training device (Explanar Trainer®). These golfers performed in total eight 20 minute sessions with the Explanar Trainer ® distributed on two sessions a week, during a four week period between pre- and post-test. The purpose of this training was twofold; first to keep the golfers motivated to participate in the study, second; to be able to control the amount of golf-activity amongst the participants in the control group. All golfers, independent of group belonging, agreed not to take part of any other golf activity during the period between the pre- and post-test.

Data and statistical analysis

From the pre- and post-test outcome data of timing and rhythmic skills (IM tasks) for each golfer, we analyzed the task average (deviation from reference beat) and the variability average, which is the measure of how close each hit is timed to the previous hit (reflecting the degree of rhythmic skill). Additionally, the highest number of times in-a-row (IARs) that the golfer was able to stay within ±15 ms of the reference beat, and the attention over time (AOT) scores were analyzed to map any possible changes in attention skills. To further investigate possible pre- to post-test improvements from the IM tasks, statistical differences were analysed by performing a mixed ANOVA with group (Control, SMT) as between-subject factors and test (pre-, post-test) as within-subject factors, using repeated measurement on dependent measures. For analysing possible differences between groups, tests, and possible interactions regarding the pre- and post-test outcome data from the golf shots (made in the golf simulator), all accuracy records (Absolute Error, Distance and Direction Error, and Variability in performance) were further analysed by separate mixed ANOVAs with use of repeated measures. Additionally, as the participants set the distance from the ball (fairway) to the pin individually, we divided the golfers into two sub-groups; low (< 10.9) and high (> 10.9) hcp golfers (resulting in 6 high hcp- and 7 low hcp golfers in respective group) to analyse possible effects of golf handicap on self selected distance between ball and pin. *Scheffe's* post hoc test was used on all significant effects, and the pre set *alpha* level was 0.05.

Results

For Task Average, a 2 (group: SMT and Control) × 2 (test: pre- and post-test) ANOVA revealed no main effect for group; F (1, 24) = 3.1, p = 0.09. However, a significant effect of test; F (1, 24) = 37.2, p < 0.0001, as well as a significant interaction between group and test; F (1, 24) = 25.3, p < 0.0001, was found. The post-hoc comparisons showed that only the SMT group differed significantly (p < 0.001) between pre-and post-test scores (Figure 4).

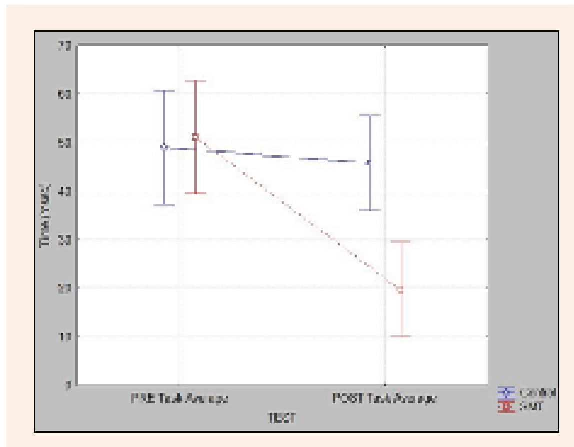

Figure 4. Timing deviation (task average) from reference beat as a function of group and test.

For Task Variability, the ANOVA revealed no main effect for group; F (1, 24) = 3.06, p = 0.09, however, a significant effect of test; F (1, 24) = 91.39, p < 0.0001, as well as a significant interaction between group and test; F (1, 24) = 29.85, p < 0.0001, was found. In agreement with the findings from Task Average, the post-hoc comparisons showed that only the SMT group differed significantly (p < 0.01) between pre-and post-test scores (Figure 5).

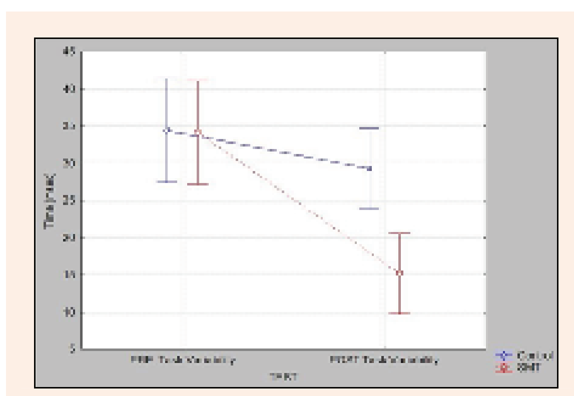

Figure 5. Task variability of timing (average) as a function of group and test.

For AOT, the ANOVA revealed a significant main effect of group; F (1, 24) = 6.54, p < 0.05, as well as of test; F (1, 24) = 13.1, p = 0.01. Additionally, a significant interaction between group and test; F (1, 24) = 35.60, p < 0.001, was found. The post-hoc comparisons showed that the SMT group significantly differed (p < 0.001) between pre-and post-test scores for AOT; in addition, a significant difference (p < 0.05) between the SMT and the Control group for the post-test scores was found (Figure 6).

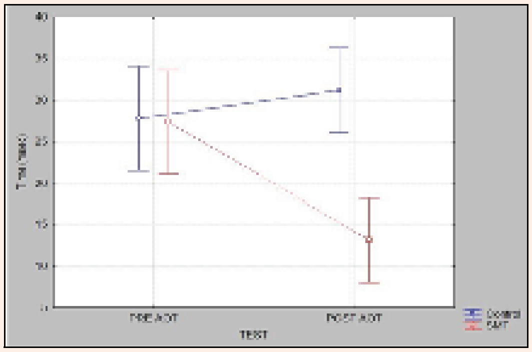

Figure 6. Timing deviation from the reference beat (AOT test), as a function of group and test.

For IAR, the ANOVA revealed a significant main effect of test; F (1, 24) = 34.14, p < 0.001, and group; F (1, 24) = 9.78, p < 0.001. Furthermore, a significant interaction between group and test; F (1, 24) = 19.81, p < 0.001, was found. The post-hoc comparisons revealed that the SMT group significantly differed (p < 0.001) between pre- and post-test scores for number of IARs, in addition, a significant difference (p < 0.01) between the SMT and the Control group for the post-test scores was found (Figure 7).

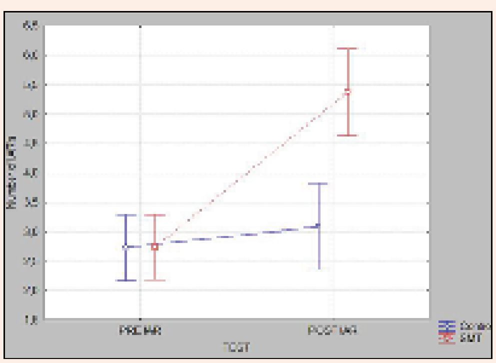

Figure 7. Highest number of time-in-a-row within ±15 ms of the reference beat (IAR's), as a function of group and test.

Golf accuracy

As each participant set their own distance from the ball (fairway) to the pin, based on their individual judgement on what was the reach of the shot with each club (4-Iron, 7- Iron and Pitching Wedge, respectively), a 2 (group: SMT and Control) x 2 (Handicap: High and Low) x 3 (Clubs) MANOVA, with group and handicap as between factors and clubs as a within factor and with repeated measures over the last factor, was initially conducted. Thus, to investigate the existence of possible group differences in relation to handicap level and the distance chosen between fairway and the pin. No main effect of group F (1, 22) = 0.52, p = 0.48, or handicap; F (1, 22) = 2.28, p = 0.15, was found. However, as expected a significant main effect of clubs; F (2, 44) = 615.5, p = < 0.001, was evident. Independently of group and handicap, the mean distance chosen for respective clubs was 175 m for the 4-Iron; 152 m for the 7-Iron; and 115 m for the Pitching Wedge. No significant Group x Handicap (p = 0.39); Group x Clubs (p = 0.48), or Group x Handicap x Clubs (p = 0.35), interactions were found.

Accuracy (Absolute Error): To control for possible training effects associated to repeated trials (golf shots) during the pre- and post-test sessions, data analysis was conducted by splitting respective test-sessions into two blocks. Each block (block 1: trial 1-30 and block 2: trial 31-60) includes the composite mean absolute error for 10 shots with each of the three clubs. The outcome illustrated by Figure 8 does not depict any learning effects of repeated golf trials, either for groups or tests. Thus, no overall training effects between the first 30 trials in comparison to the last 30 trials of golf shots for respective group or test were found (Figure 8).

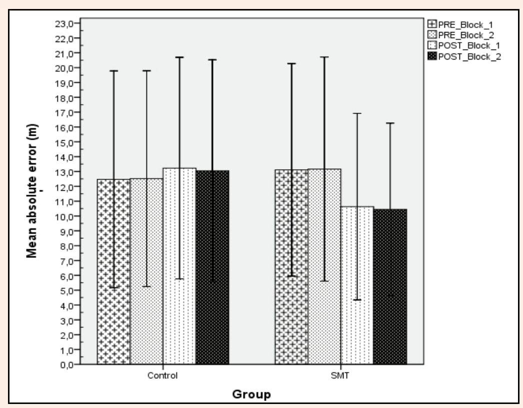

Figure 8. Absolute error as a function of groups, tests, and the two blocks (Block 1: trial 1-30; Block 2: trial 31-60).

A 2 (group: SMT and Control) × 2 (test: pre- and post-test) x 3 (club: 4-Iron, 7-Iron and Pitching Wedge) mixed-design ANOVA revealed no significant main effect of group; F (1, 24) = 0.99, p = 0.33. However, a main effect of test; F (1, 24) = 4.35, p < 0.05, as well as a main effect of clubs; F (2, 23) = 34.68, p < 0.0001, was found. The post-hoc test revealed that the absolute error by the Pitching Wedge (9.7 m) was found to be significantly shorter (p < 0.01) than the absolute error by the 7-Iron (13.2 m) and the 4-Iron (14.5 m), respectively. Furthermore, a significant Group × Test interaction was found; F (1, 24) = 12.03, p < 0.01 (Figure 9).

The post-hoc comparisons showed a significant (p < 0.01) difference between the pre- to post-test for the SMT group by means of an overall increasing accuracy (decreasing distance to the pin) at the post-test in comparison to the pre-rest. Such improvement was not found for the Control group. In addition, the improvement

Table 2. Pre- and Post-test mean accuracy (absolute error) in meters, as a function of group and club (± SD).

	Club							
	PW		7 Iron		4 Iron		Overall	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
SMT	10.1 (3.6)	7.7 (1.7) *	14.4 (3.8)	11.4 (1.8) †	15.0 (4.4)	12.5 (2.8)	13.1 (3.1)	10.5 (1.5) *
Control	9.0 (2.9)	10.0 (3.0)	13.6 (3.6)	13.6 (4.5)	14.9 (3.8)	16.0 (4.7)	12.5 (2.9)	13.1 (3.3)

* and † denote p < 0.05 and p < 0.01 respectively compared with pre.

showed by the SMT group by means of a decreasing distance to the pin was found to be consistent over all clubs (Table 2). No other significant interactions were found.

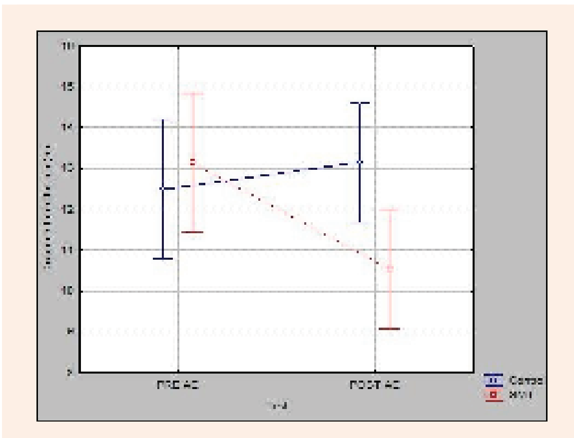

Figure 9. The overall distance from the pin (AE) as a function of group and test.

As the number of years of experience differed between the two groups, a mixed-design ANCOVA was further conducted (on AE) using experience (number of years) as a covariate. The ANCOVA revealed no main effects of group; $F(1, 23) = 0.54$, $p = 0.47$, or test; $F(1, 23) = 0.056$, $p = 0.81$. However, the Group x Test interaction was still found to be significant; $F(1, 23) = 8.29$, $p < 0.01$. Thus, this finding confirmed the result from the previous analysis. Consequently, golf experience does not explain the outcome differences between the SMT- and Control group found at the post-test.

Accuracy in distance and direction: In terms of Distance, a 2 (group: SMT and Control) × 2 (test: pre- and post-test) ANOVA revealed no significant main effect of group; $F(1, 24) = 0.003$, $p = 0.96$. However, a main effect of test; $F(1, 24) = 4.96$, $p < 0.05$, but no Group × Test interaction; $F(1, 24) = 2.65$, $p = 0.11$, was found. The post-hoc comparisons revealed that the improvement between pre- and post-test was only evident ($p < 0.05$) for the SMT group (Table 3).

For the Direction measure, the ANOVA revealed no significant main effects of group; $F(1, 24) = 1.23$, $p = 0.28$, or test; $F(1, 24) = 0.96$, $p = 0.34$. However, a significant Group × Test interaction was evident; $F(1, 24) = 6.35$, $p < 0.05$. In agreement with the outcome from the distance, the post-hoc comparisons revealed that the direction improvement between pre-post-tests was only evident ($p < 0.05$) for the SMT group (Table 3).

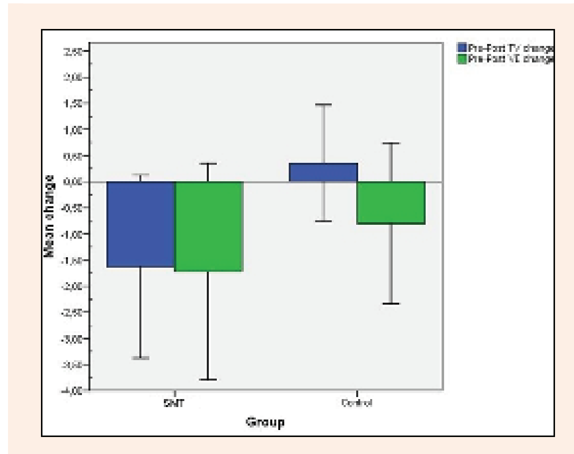

Figure 10. Mean Variable Error (VE) and Target Variability (TV) change from pre- to post-test, as a function of group (positive numbers denotes a decline in performance).

Variability in accuracy: As variability is a major challenge for the golfer, Total Variability (TV) and Variable Error (VE) were analysed. TV (root-mean-square error) is a measure of the participant's total spread about the target, representing an overall measure of how successful the subject was in achieving the target. VE denotes the variability of the participant's deviation from his own mean, representing the variability or inconsistency in the golf shots. A 2 (group: SMT and Control) × 2 (test: pre- and post-test) mixed design ANOVA on the TV measure revealed no main effect of group; $F(1, 24) = 0.461$, $p = 0.50$, but a main effect of test; $F(1, 24) = 4.92$, $p < 0.05$, was found. Furthermore, a Group × Test interaction was evident; $F(1, 24) = 11.75$, $p < 0.01$. The post-hoc comparisons revealed that the SMT group significantly differed ($p < 0.01$) between pre-and post-test scores for TV by means of an overall decreasing variability at the post-test in comparison to the pre-test. Such improvement was not found for the Control group (Figure 10). For the VE measure, the ANOVA revealed no main effect of group; $F(1, 24) = 0.002$, $p = 0.96$, but a main effect of test; $F(1, 24) = 12.43$, $p < 0.01$, was found. In agreement with the outcome from TV, the post-hoc comparisons

Table 3. Pre- and Post-test mean overall distance from the pin (in meters) as s function of distance, direction and group (± SD).

	Overall distance		Overall direction	
	Pre	Post	Pre	Post
SMT	6.23 (1.85)	5.18 (1.03)	10.25 (2.90)	8.65 (1.68)
Control	5.81 (1.71)	5.67 (2.04)	10.08 (2.53)	10.79 (2.87)

showed a significant ($p < 0.05$) difference between the pre- to post-test for the SMT group only, by means of an overall decreasing variability at the post-test in comparison to the pre-rest. However, no Group × Test interaction was found: $F(1, 24) = 1.67$, $p = 0.21$ (Figure 10).

Individual golf accuracy improvement: In the SMT group, ten of 13 participants (76.9%) improved their golf accuracy from pre- to post-test (mean absolute error improvement = 3.57 m). In comparison, only 4 of 13 (30.8%) participants in the Control group showed improvement from pre- to post-test (mean improvement = 1.14 m). When investigating the proportion of golfers improving from pre- to post-test as a function of group, a χ^2-test showed a significant difference in the proportion of successful golfers within the SMT and the Control group (χ^2 (Yate's Control for Continuity) = 3.87, df = 1, $p < 0.05$).

Club head speed variability: As consistency is a crucial factor in golfing, we conducted a paired samples t-test on the composite score of all clubs to analyze any possible pre- to post-test changes in club head speed variability. This test indicated a significant ($t(38) = 3.83$, $p < 0.001$) decrease in club head speed variability from pre- to post-test for the SMT group (mean diff. = -1.83, SD= 2.98 $km \cdot h^{-1}$). No significant change ($t(38) = 1.07$, $p = 0.13$) was evident for the Control group (mean diff. = -0.72, SD= 2.29 $km \cdot h^{-1}$).

Discussion

Timing and rhythmicity training programs have been used in a variety of rehabilitation settings with documented success. Based on that success, the concept of timing training has also gained popularity in applied fitness settings to enhance sport performance. However, few studies have looked at the efficacy of timing training and its effect on sport performance. The present study was designed to determine the efficacy of Synchronized Metronome Training (SMT) on motor timing and to determine its possible effect of improved motor timing on golf shot accuracy using a pre-test/post-test design in groups of experienced male golfers.

As with Libkuman et al., (2002), this study provides further evidence that improved timing and rhythmicity has positive effects on the outcomes of golf performance, investigated by means of accuracy. First, as with previous SMT studies including various groups of populations, it was found that SMT produced significant improvements in the timing and rhythmicity for the experienced golfers investigated in this study as measured repeatedly by the IM measurement system. As expected, the golfers in the SMT group, when compared to the golfers in the Control group, demonstrated significant improvements in measured timing and rhythmicity scores, from pre- to post-test. Second, and more importantly, the analysis made of the golf accuracy revealed significant overall improvements as well as decreasing variability for the golfers in the SMT group from pre- to post-test, outcomes not found for the golfers in the Control group.

One explanation in line with Libkuman et al., (2002) is that SMT increased accuracy because the temporal properties of the golf swing were improved. As the metronome-based training is primed to enhance motor timing, this may seem like a plausible explanation. However, also other explanations have to be considered on the subject of the link between improved motor timing and its positive effect on the golf shot accuracy. Some current, related findings might bring further insight to such relationship.

For example, Meegan et al., (2000) found that training on a perceptual task can significantly be transferred to a motor task; that is, that motor learning can occur even without any motor training. This is in line with Prinz's (1990) claim that training of precise timing in motor performance is linked to the corresponding training and improvement of auditory temporal resolution. From a generalized motor program (GMP) perspective, it is compelling to search for answers in the impulse-timing hypothesis. This hypothesis explains how the motor program provides pulses of motor neuron activity to the muscles to be activated. In principal, it is hypothesized that the GMP controls bursts of force spread over time, defining the time of onset and offset of the relevant muscles involved in the actual movement (Schmidt and Lee, 2005). In concurrence with this notion, Thier et al., (2002) have found that for saccadic eye movements, involving agonist muscles to initiate and antagonist muscles to decelerate movement, the activity of cerebellar purkinje cells precisely encodes the onset and offset of a saccade. Much research has investigated the timing features/properties of the human being in relation to coordinated motor responses, and many have suggested that enhanced motor timing skills are due to fine-tuning of the precision in the neuronal activity, a higher frequency of neural oscillation (e.g., Rammsayer and Brandler, 2006), or via an increase in the *clock speed* of the master internal clock (Taube et al., 2007). The IM is thought to work by augmenting internal processing speed within the neuroaxis and increasing "cognitive efficiency" in the information-processing bottleneck (Gorman, 2003). In line with this notion Diamond (2003) suggests that SMT may increase the efficiency and organization of the central nervous system circuitry, making the brain's signal processing become more efficient and more consistent. Myskja (2005) states that when movements become more rhythmically stable along the time-axis this rhythmic coordination will generate a more optimal movement in space, as time and space are connected. As a result, movements will become more effective and advantageous; this may explain the golfer's outcome improvements found as a result of SMT. The decreased club head speed variability found at the post-test for the SMT group can also be understood in according to Myskja (2005). Thus, indicates a more stable and synchronized intra- and inter-limb coordination throughout the golf swing.

An alternative explanation is that SMT does improve the golfer's ability to concentrate and stay focused. There are two results pointing towards changes in the participant's attention and focus. First, the SMT significantly increased the mean number of IARs (hits in a row within ± 15ms of the reference beat) the participants could achieve. We interpret this as an improvement of the participant's ability to attend to the task at hand. Secondly, the significant decrease in the deviation from the reference beat during the AOT test (10 consecutive minutes of matching the reference beat) strengthens the notion that SMT improves the participant's ability to attend selectively to a stimulus without interruption by internal thoughts or external distractions for extended periods. Similarly, Diamond (2003) suggests that the use of guide sounds in SMT may help "choice discrimination" and thus increase the ability to exclude irrelevant information. The SMT is a demanding task over time and requires a high level of concentration to ensure improvements of the timing performance. Our interpretation is that SMT facilitates directed attention. In addition, the online motor correction based on feedback may contribute to optimization of timing and organized actions. Thus, SMT seems to affect the person's abilities to inhibit irrelevant stimuli and distracters.

Limitations and future research

It is not clear from the findings from the SMT whether number of repetitions, length of training sessions, alternative timing exercises, and a different reference beat tempo (longer/shorter) might affect the results differently. Furthermore, there is also a need for further investigations of what type of sensory feedback (by means of the instantaneous provided feedback – auditory and/or visual - that enables the participant to deliberately correct their timing errors as they occur) may optimize and/or affect the outcome of IM training. In addition, the possible long-term effects of SMT are unknown and in need of evaluation.

Thus, future research will be necessary to further delineate the phenomenon and to develop a theory that can explain how the property of timing influences the complex motor activity in golf performance. Thus, we plan subsequent investigations of the kinematics properties and dynamics of the golf swing performance and how timing training by means of SMT may affect the kinematics. However, such investigation was beyond the scope of the present study.

Conclusion

The present study showed a significant effect of SMT by means of improvements in motor timing and synchronizations. Additionally, significantly improved scores on selected golf shot accuracy variables and with clearly decreased variability after just 4-weeks of training were evident. As the present study shows, sensory motor control and golf shot accuracy outcomes were positively affected by SMT. This suggests that enhanced and optimal golf shot accuracy does require precise, timed, and synchronized sensory motor control.

The finding that improvements of golf shot accuracy are positively affected by improved motor timing and that such improvement occurs after just a 4-weeks intervention without any sport specific training has interesting implications for other sports as well. For example, other athletes could benefit from such a complementary training method. Additionally, the SMT method may also be useful during periods of limited and/or impaired sensory motor functions.

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Key points

- This study investigates the effect of synchronized metronome training (SMT) on motor timing and how this training might affect golf shot accuracy.
- A randomized control group design was used.
- The 4 week SMT intervention showed significant improvements in motor timing, golf shot accuracy, and lead to less variability.
- We conclude that this study's results provide further evidence that motor timing can be improved by SMT training and that such timing improvement also improves golf accuracy.

AUTHORS BIOGRAPHY

Marius SOMMER
Employment
PhD student, Department of Psychology, Umeå University, Sweden
Degree
Bachelor Sc.
Research interests
Effects of task specific vs. non-task specific training methods in sports. Laterality, timing and co-ordination, training and transfer, kinematics.
E-mail: marius.sommer@psy.umu.se

Louise RÖNNQVIST
Employment
Professor, Department of Psychology, Umeå University, Sweden
Degrees
PhD Psychology
Research interests
Sensory-motor development and deviation, laterality, brain plasticity, training and transfer, kinematics.
E-mail: louise.ronnqvist@psy.umu.se

✉ **Marius Sommer**
Department of Psychology, Umeå University, SE-901 87 Umeå, Sweden