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Training effects of Interactive Metronome® on golf performance and brain activity in professional woman golf players

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ABSTRACT

During putting in golf, the direction and velocity of the club head should be consistent across swings. In order to maintain consistency in swing timing, the cerebellum provides temporal information, motor timing, control of rhythm, and timing of movements. We utilized Interactive Metronome (IM), a brain training software program that combines the concepts of neurotechnology with the abilities of a computer, to improve an individual's rhythm and timing. We propose that IM would activate neural networks involved in decreasing variation in putt swing. Twenty professional female golfers (KLPGA) were randomly assigned to either an IM training group ($n = 10$, 35–40 min per session, twice a week for 6 weeks) or a control group ($n = 10$). The golf putting movements and brain activity were analyzed using Kinovea Software and resting state functional MRI, respectively. Consistency was measured as the standard deviation of mean swing speed (SSD) during three sections of the swing: backswing (AD-BS), backswing-impact (BS-IMP), and impact-finish (IMP-FIS). Our results show that the consistency of the IM group improved in the time between the back swing and impact in the 2 m putt and 5 m putt compared to the control group. Using functional MRI, after the training period, the IM group showed increased functional connectivity from the superior cerebellar vermis to the right medial frontal gyrus, left superior temporal gyrus, right middle occipital gyrus, right middle temporal gyrus, right cingulate gyrus, and right supramarginal gyrus (uncorrected $p < 0.001$, voxels > 40). These findings suggest that IM training in professional female golf players may improve consistency in putt timing. In addition, IM training may increase brain connectivity from the cerebellum to the frontal cortex, which plays an important role in motor control and timing.

1. Introduction

1.1. Golf swing and timing

Timing is important in sports such as golf, tennis, and badminton, which require hitting a ball with power and speed (Masaki, Sommer, Takasawa, & Yamazaki, 2012). For example, a golf swing requires integration of sensory inputs and motor coordination to optimize power and speed (Sommer & Rnnqvist, 2009). In previous studies, timing in the golf swing was analyzed based on rhythm and tempo (Jagacinski, Greenberg, & Liao, 1997). Rhythm is defined as speeding up or lowering the club head at a point, tempo represents the overall swing speed, and timing is analyzed as the speed and force pattern of each swing section (Jagacinski et al.,

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1997). Timing ranges from tens to hundreds of milliseconds (ms) in each section of the swing, comprising address posture, take back, back swing, down swing, impact, follow through, and finish. A golf putt consists of a few tens of milliseconds (ms) compared to a shot and involves rhythm and synchronicity, which are particularly important factors for success in putting (Hume, Keogh, & Reid, 2005; Pelz, 2000; Penner, 2002). According to many studies, putting performance involves timing, velocity, and sequential organization of each segment in the swing (Craig, Delay, Grealy, & Lee, 2000; Fairweather, Button, & Rae, 2002). Similarly, there have been numerous recent kinematic analyses that have investigated the relationship between motor strategy and putting performance (Craig et al., 2000; Grealy & Mathers, 2014; Masters, 1992).

However, empirically, elite golf players consider direction and force of the putter as critical factors of a successful swing (Grealy & Mathers, 2014; Hume et al., 2005; Pelz, 2000; Penner, 2002). Although putting ability is related to the adjustment of fine motor skills in coordinated movements, the effect of the relationship between improvement of motor timing and putting performance to improve fundamental fine motor skills during golf is unknown.

1.2. Neural basis of swing timing

During the golf swing, there are many chances to err based on individual timing. For example, one can use insufficient power from the lower body, and/or a golfer may improperly transfer power from the lower body to the upper body during the swing (Burden, Grimshaw, & Wallace, 1998; Neal & Wilson, 1985). Spatiotemporal patterns of movement are associated with timing sequences in each part of the segmented behavior (Buonomano & Laje, 2010), and these patterns require coordination between lower and upper body parts. The cerebellum plays an important role in attention, motor planning, calculation of timing, and emotional control during the golf swing (Sommer & Rnnqvist, 2009).

Specifically, the cerebellum contributes to the control of rhythm (Ivry, 1996) and timing of movements (Malapani, Dubois, Rancurel, & Gibbon, 1998), as well as optimization and coordination of sensory feedback for motor performance (Ito, 2000; Kawato, 1999). It is known that many types of skilled behaviors involving temporal mechanism require collaborative interaction between cognitive resource and cerebellar function (Ito, 2002). For example, Wright, Bishop, Jackson, and Abernethy (2010) documented that badminton racquet-shuttle contact activates the medial and lateral prefrontal cortex, which play a primarily cognitive role in everyday behavior. In another study, juggling training produced changes in the occipito-temporal cortex, which is associated with acquisition of motor skills (Driemeyer, Boyke, Gaser, Büchel, & May, 2008).

Putting performance is a skill that requires a player to minimize errors of physical body motion and club head movement, which affect velocity and direction. For instance, golfers must correctly judge situations, make decisions, and execute movements repeatedly using the flexor carpi ulnaris, flexor carpi radials, extensor carpi ulnaris, shoulders, and spine (Libkuman, Otani, & Steger, 2002). Research suggests that the complex skill also requires improvement in timing competencies (Ivry, 1996; Meegan, Aslin, & Jacobs, 2000; Medina, Carey, & Lisberger, 2005). Previous studies have focused on the improvement of motor behavior based on timing (Rammsayer & Brandler, 2007). For example, practicing a motor task using auditory stimuli improves synchrony between motor and cognitive activation, which results in improvement in a motor skill (Meegan et al., 2000). In addition, continued practice is required to maintain a motor skill (Christina, 2001). Lastly, motor learning patterns, specifically the timing of each segment and the sequence of the segments, promote optimal performance in competitive situations (Fairweather et al., 2002).

1.3. Interactive Metronome training

Interactive Metronome® (IM) is a rehabilitative and brain training neurotechnology that combines the concept of a musical metronome with a computer-based program that accurately measures and facilitates the improvement of an individual's rhythm and timing. IM training involves reducing the mean negative synchronization error during normal tracking of a regularly occurring auditory tone metronome beat. Participants receive feedback through a guidance system as they progress through interactive exercises. Although feedback is provided through both visual and auditory stimuli, the auditory feedback guidance system is the primary feedback method. The auditory feedback system provides tonal stimuli that indicate whether the participant responded prior to, at ("on target zone"), or past the regularly occurring auditory metronome beat. The accuracy of participant expectancy response to the metronome beat is provided in milliseconds, with different tones indicating far from, close to, or at the metronome beat.

The IM adaptive neuro-activity involves timing, rhythm, sequence, motor planning, and concentration, making it appealing for golfers (Libkuman et al., 2002; Sommer & Rnnqvist, 2009). IM research has also reported significant effects on ADHD, attention, motor control, language, reading, and math (McGrew, 2013; Shaffer et al., 2001; Taub, McGrew, & Keith, 2007, 2015). Several studies have also shown that IM can also benefit sports performance (Libkuman et al., 2002; Zachopoulou, Mantis, Serbezis, Teodosiou, & Papadimitriou, 2000) and golf specifically (Sommer, Hger, & Rnnqvist, 2014). IM employs motor control strategies that allow golfers to perform more coordinated movements, thereby improving accuracy and consistency. However, despite previous studies showing the importance of IM motor control, little research has yet been conducted on the effects of IM training on the fine tuning adjustments used during putting. To examine this issue directly, we proposed two specific aims. First, we wanted to determine if Interactive Metronome promoted improvement in motor timing and putting performance. Second, we used brain functional magnetic resonance imaging (fMRI) to measure the difference in brain connectivity between an IM training group and a control group. We hypothesize that the motor improvement of limb timing will promote a positive change in putting, and that there will be an increase in connectivity in the areas of the brain required for motor learning during IM learning compared to controls.

Table 1
Demographic data.

	IM group	Control group	Statistics (p value)
Age (years)	22.2 ± 1.1	25.9 ± 4.4	0.051
Height (cm)	166.6 ± 6.1	165.0 ± 4.6	0.395
Weight (kg)	56.3 ± 4.4	59.6 ± 8.0	0.363
BMI (kg/m^2)	20.2 ± 1.8	21.9 ± 2.4	0.070
Career (years)	6.2 ± 1.9	7.4 ± 1.8	0.261

Note: IM: Interactive metronome, BMI: body mass index.

2. Methods

2.1. Participants

The study group was composed of 20 female golfers from the Korean Ladies Professional Golf Association (KLPGA). The demographic characteristics are described in Table 1. The participants were randomly assigned to either an IM or a control group. Inclusion criteria were: 20–30 years old, injury free, and no pharmaceutical drug use. The IM group was asked to participate in IM training sessions for 35–40 min per session, twice a week for 6 weeks, while the control group was asked to increase golf training time (compared to regular training time) by 35–40 min per session, twice a week for 6 weeks. The purpose of this study and all experimental procedures were fully explained to the participants prior to their providing consent to participate. Approval for the research protocol was granted by the Institutional Review Board at Chung-Ang University in Korea.

2.2. Swing (putting) analysis

The primary dependent variable was swing speed of a putt, which was executed 2 m and 5 m from a hole (diameter 10.8 cm) with no slope. These distances were chosen by Pelz (Pelz, 2000), who suggested that 2-m putts are common when players achieve successful scores (i.e., par or birdie). In contrast, professional golfers have only a 10% success rate for 5-m putts.

Pre- and post-intervention video data were collected on a real green using a swing speed of 10 feet (this speed is similar to that used in elite competitions (United States Golf Association)), and participants completed five strokes. The video camera was placed in front of the golfer at pelvic height when the golfer was in address posture, the basic position for capturing a golf swing, and the putter head was recorded using video cameras sampling at 60 Hz. Video data were extracted and filtered by Kinovea Software (Charmant, 2014 Kinovea Version 0.8.24). Using built-in tools, we generated real-time traces of the putter head in each frame. We noted three specific positions of the club head and determined the club head timing sequence. The first capture, point zero, was marked after the putter head moved away from the ball and all motion stopped, including that of the putter head and the participants' elbow, shoulders, and hands; this marked the end of the backswing. The head then moved back toward the ball, and the second frame capture was marked when the club head made contact with the ball. The third capture (end of swing) was marked when all movement stopped, including that of the club head, elbow, shoulder, and hands; this marked the end of the swing.

2.3. IM training

The subjects who participated in this study performed 35–41 min sessions, twice a week for 6 weeks, for a total of 12 sessions (Table 2). The protocol consisted of a basic exercise program with the metronome set at 54 beats per minute (bpm) for all sessions. Each training session utilized the computer program, standard stereo headphones, a contact-sensing trigger, and a footpad. Participants listened to the beat through headphones and were asked to tap the footpad on each beat. The monitor then gave immediate feedback noting if the participant was late, on target (± 15 ms), or fast. The first session included a progressive long form assessment (LFA) with 14 movements to serve as a reference of participant ability in regard to responses and inter-response time—1: clapping both hands, 2: clapping the right hand, 3: clapping the left hand, 4: tapping the foot pad with both feet, 5: tapping the foot pad with the right toe, 6: tapping the foot pad with the left toe, 7: tapping the foot pad with both heels, 8: tapping the foot pad with the right heel, 9: tapping the foot pad with the left heel, 10: alternating tapping right toe/left hand, 11: alternating tapping left toe/right hand, 12: balancing on the right leg while tapping the left toe, 13: balancing on the left leg while tapping the right toe, and 14: guide sound with clapping both hands. Sessions two through four included features from each of the 14 movement patterns with emphasis on uni- and bi-lateral motion of the hands and feet. At the completion of training, participants typically had engaged in approximately 25,000 synchronized metronome repetitions. These synchronized movements are the physical and reading and math indication of one's expectancy of the onset of the metronome beat. The aim of the sessions was to perform the movements with the set beat (± 15 ms). In sessions five to 11, participants were asked to alternate between two movements, such as clapping the right hand and tapping the left foot. Thus, these sessions required coordination to perform sequential motor tasks. The experiment was conducted at the Sports Science Center of Chung-Ang University (Fig. 1).

Table 2
Interactive Metronome training program.

Exercise	Training session											
	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6	
	1	2	3	4	5	6	7	8	9	10	11	12
Both hands	180	378	216	1000	1000	1000		1500		2000		108
Right hand	180	324	324				500					108
Left hand	180	216	324	500			500					108
Both toes	180	216		500		1000		500		500		108
Right toe	180	324	378				250				250	108
Left toe	180	216	378				250				250	108
Both heels		216	216	250		500			500			108
Right heel								250			250	108
Left heel								250			250	108
Right hand/left toe cross					500		500		500		250	108
Left hand/Right toe cross					500		500		500		250	108
Right balance left toe touch					250		250		500			108
Left balance right toe touch					250		250		500			108
Total time (min)	35 min	39 min	39 min	40 min	41 min	41 min	41 min	41 min	41 min	41 Min	41 min	37 min
Total beats	1080	2016	2016	2250	2500	2500	2500	2500	2500	2500	2500	1404

Note: The IM program had 12 sessions. As the sessions progressed, the program increased the number repetition that requires high level of timing, rhythm, coordination, motor planning to improve all task.

Fig. 1. Interactive Metronome training. The IM system measures the millisecond discrepancy between the participant's limb response and the reference bit (timing skill). In addition, the participant trains with a goal of ± 15 ms of the reference bit and hit in green (reflecting the degree of stability). In the feedback provided on the computer screen, a large number indicates a greater number of millisecond mismatches between the metronome beat and the participant's movement, which indicates inaccurate timing. The lower is the timing score, the better is the timing. Participants must constantly correct their sense of error to achieve the lowest possible score. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.4. Brain analysis

All magnetic resonance imaging (MRI) was performed using a 3.0 T scanner (Achievar, Philips, Eindhoven, The Netherlands). For 720 s in 230 volumes, resting state functional MRI (rs-fMRI) images were acquired with the following protocol: axial, echo-planar imaging (EPI) sequence, TR/TE = 300/40 ms, 40 slices, 64 × 64 matrix, 90° flip angle, 230-mm field of view (FOV), and 3-mm section thickness without a gap.

Functional connectivity analysis was performed as in our previous study (Kim, Han, Kim, & Han, 2015) Rs-fMRI assesses brain activity within regional and neural circuits in the absence of a task during scanning (Lui et al., 2010). Functional connectivity (FC) has frequently been used in rs-fMRI analysis (Lui et al., 2010). In the current research, FC was calculated using the blood-oxygenation level-dependent (BOLD) signal in all participants and represents the signal synchronicity of low-frequency fluctuation activity between different brain areas or within brain networks (Biswal et al., 2010; Lui et al., 2010). Brain function activity in FC analysis was assessed using REST software (seed regions approach). A *seed* is a region selected a priori to serve as a point from which to evaluate connectivity with other brain regions (Biswal et al., 2010). The cerebellum, in particular the superior cerebellar vermis, has a crucial role in timing processes (Spencer, Gouw, & Ivry, 2007). For assessing the association between timing and golf swing, we set the supra cerebellar vermis as the seed region (De Guio, Jacobson, Molteno, Jacobson, & Meintjes, 2012).

2.5. Statistical analysis

Demographic characteristics of age, BMI, years as a professional golfer, and career duration were compared between the IM group and the control participants using the Mann-Whitney *U* test. In a first-level analysis, a comparison was conducted between the IM group and the controls; FC maps of the supra cerebellar vermis (seed region) to other brain areas were compared using a two-sample *t*-test. The results were set to a threshold of $p < 0.001$ uncorrected for multiple comparisons with a cluster size of 40 voxels. In a second-level analysis, a repeated-measures ANOVA was applied to assess the differences in the changes of functional connectivity in response to length of IM training (weeks) between the IM training group and the control group. Statistical significance was determined at $p < 0.001$ uncorrected for multiple comparisons with a cluster size of 40 voxels.

3. Results

3.1. Swing analysis

In a full swing analysis of the 2 m putt, there was no significant difference in swing time standard deviation (SSD) between the IM group and the control group during the training period ($F = 1.45$, $p = 0.24$). However, the IM group showed decreased SSD at the 2BS-Imp section of the 2 m putt compared to the control group ($F = 5.27$, $p = 0.03$). In a full swing analysis of the 5 m putt, the IM group showed lower SSD compared to the control group ($F = 5.59$, $p = 0.02$). The IM group showed lower SSD in swing time in the 5AD-BS section of the 5 m putt compared to the control group ($F = 9.24$, $p < 0.01$) (Fig. 2).

3.2. Brain connectivity analysis

At baseline, there were no significant differences in brain functional connectivity between the IM group and the control group. After the training period, the IM group showed increased functional connectivity from the superior cerebellar vermis to the right medial frontal gyrus, left superior temporal gyrus, right middle occipital gyrus, right middle temporal gyrus, right cingulate gyrus, and right supramarginal gyrus (uncorrected $p < 0.001$, voxels > 40) (Table 3) (Fig. 3).

3.3. Correlation between SSD and brain connectivity

In all golfers, the change in functional connectivity from the superior cerebellar vermis to the right medial frontal gyrus was negatively correlated with change in SSD during the 5AD-BS section of the golf swing ($r = -0.63$, $p < 0.01$) (Fig. 4). There were no significant correlations between the changes in functional connectivity from the superior cerebellar vermis to other brain regions and the changes in SSD during other swing sections.

4. Discussion

To our knowledge, this is the first study implementing IM to investigate the correlations between brain connectivity and putting performance as measured by swing time standard deviation in professional golf players. Our results show that the IM group experienced a reduction in variability of timing between back swing and ball impact in a 2-m putt compared to the control group. In addition, over the course of the study, variability of timing in the duration of the swing for a 5-m putt was reduced in the IM group and worsened in the control group.

4.1. Swing analysis

One of our goals in the experiment was to enhance temporal processing by utilizing IM and to see if this change resulted in a difference in putting performance in the IM group versus controls. After 6 weeks, the IM group showed a significant reduction in the variability of timing from the back swing to impact for a 2 m putt, address- back swing and duration for 5 m putt. These results show that the 2 m putt was significantly affected only in the backswing-downswing section, although there was a relative decrease in all sections compared to before the IM training. Particularly, since a 2 m putt involves adjustment of very fine-tuned movement, it is highly likely that the change in this section contributed to alterations in the other sections. Similarly, in the 5 m putt, both the variation of timing in the AD-BS section and the variation of timing in the overall swing were significantly affected, which means that the actual out swing timing was optimized and putt swing was consistent before the IM training. According to Jagacinski et al. (1997), the times per segment are independent in a golf swing; however, since the motions of the segments are connected like a chain, the time variation between segments can be proportional to the time variation in other segments (Jagacinski et al., 1997). However, we deduce that swing length is a reason why the sectional variation of the 2 m putt did not have a statistical effect on overall swing time. The smaller is the swing length, the greater is the proportion of time allotted to each section. Considering that the swing length

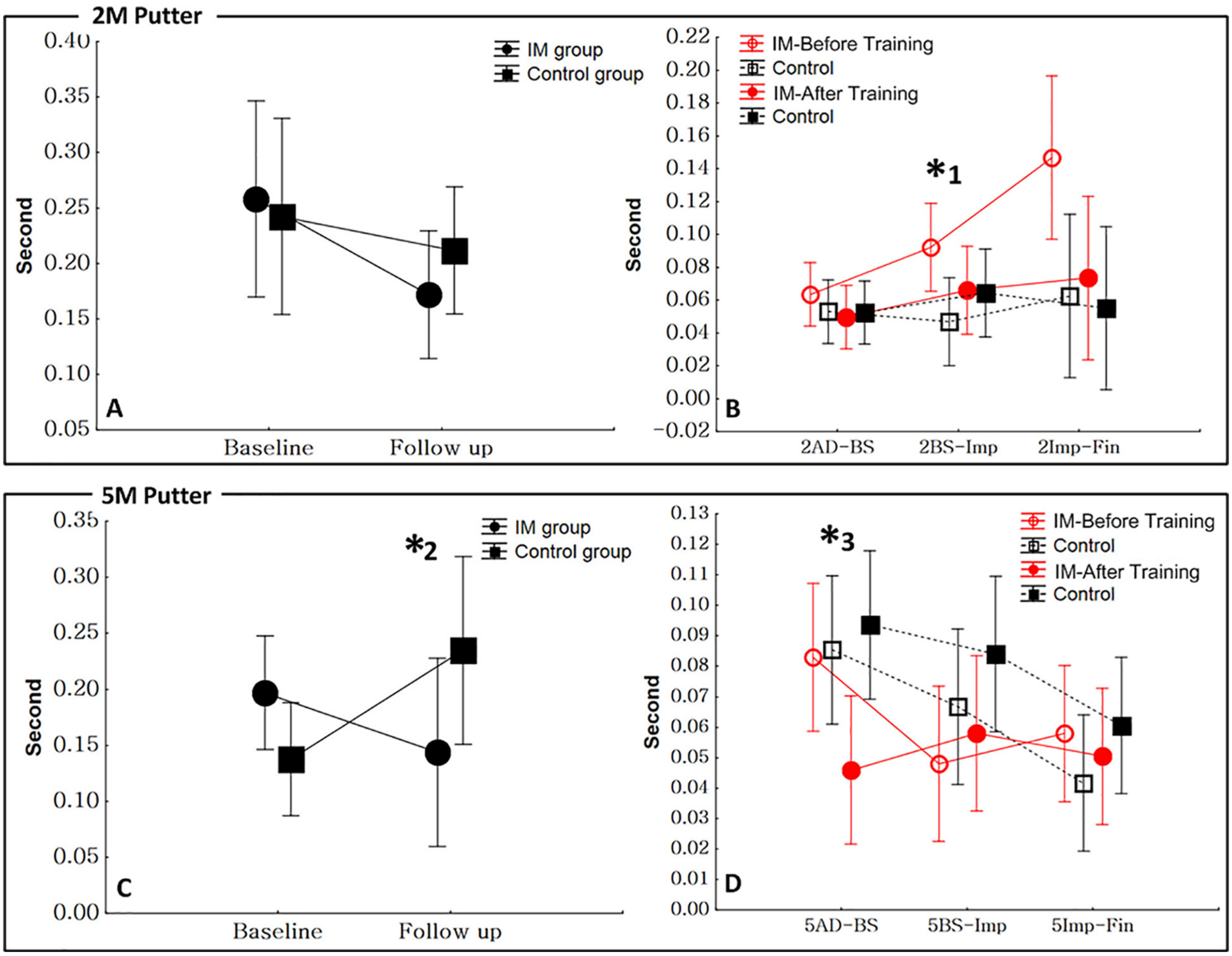

Fig. 2. The differences in standard deviations in swing times between the IM training group and the control group. A: The standard deviation of the full swing time for the 2-m putt, repeated-measures ANOVA, F = 1.45, p = 0.24. B: The standard deviation of the 3 sections (AD-BD: address to back swing, BS-Imp: back swing to impact, Imp-Fin: impact to finish) time for the 2 m putt, *1: repeated-measures ANOVA, the standard deviation of the swing duration of the BS-Imp section before training and after training between the IM training group and the control group, F = 5.27, p = 0.032, C: The standard deviation of the full swing time for the 5 m putt, *2: repeated measure ANOVA, F = 5.59, p = 0.02. D: The standard deviation of the duration of the 3 sections for the 5 m putt, *3: repeated-measures ANOVA, F = 9.24, p = 0.007.

Table 3
Brain Connectivity.

Talairach code			Voxels	p	Regions
x	y	z			
12	42	33	58	< 0.001	1. Right Medial Frontal Gyrus, BA 9
−54	−57	27	74	< 0.001	2. Left Superior Temporal Gyrus, BA 39
33	−93	3	110	< 0.001	3. Right Middle Occipital Gyrus, BA 18
69	−27	−9	77	< 0.001	4. Right Middle Temporal Gyrus, BA 21
15	21	45	102	< 0.001	5. Right Cingulate Gyrus, BA 32
63	−51	36	91	< 0.001	6. Right Supramarginal Gyrus, BA 40

Note: Comparison of brain connectivity from the cerebellum to other brain regions between IM and the control group (IM group > control group).

and total time are short in a 2 m putt, the reduction of the backswing-impact section is interpreted as the club head accelerating to the ball quickly. This finding suggests that very fine-tuning is positively impacted by IM training, while the control group showed no statistically significant changes. Therefore, it would be more effective for a golfer to optimize the timing of each section than to adjust the tempo of the swing, namely, the overall swing speed consistency. However, training for fine-tune optimization, such as in a golf swing, must also be focused on cognitive involvement during the motor sequence (Fairweather et al., 2002).

The golfers in the IM group reduced timing error to within approximately 15 ms on either side of the beat. During six weeks of

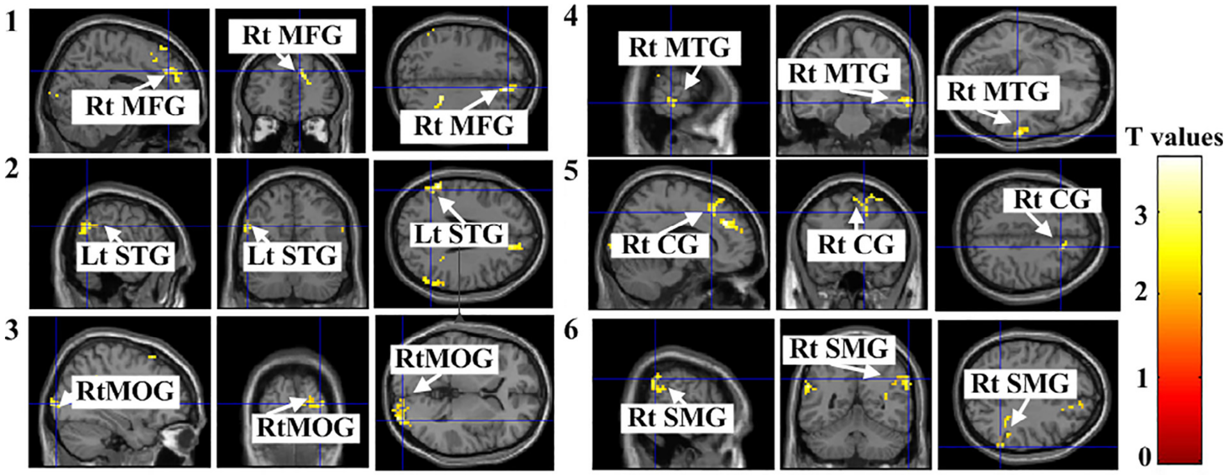

Fig. 3. Comparison of brain connectivity from the cerebellum to other brain regions between IM and control groups. Rt MFG: Right Medial Frontal Gyrus, Lt STG: Left Superior Temporal Gyrus, Rt MOG: Right Middle Occipital Gyrus, Rt MTG: Right Middle Temporal Gyrus, Rt CG: Right Cingulate Gyrus, Rt SMG: Right Supramarginal Gyrus; red bar: less functional connectivity from cerebellum to areas, white bar: more functional connectivity from cerebellum to areas (See Table 2). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

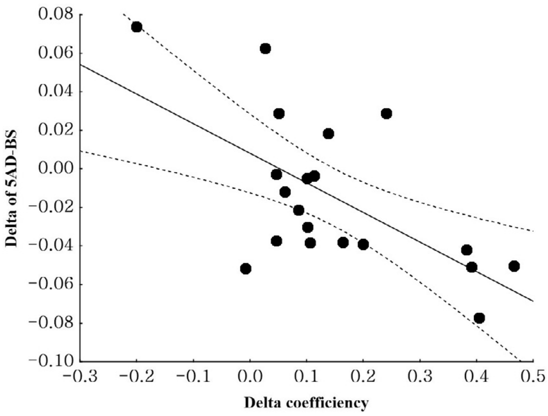

Fig. 4. Correlations between the change in standard deviation of the duration of a swing section of the 5 m address to back swing and the change in brain connectivity from the cerebellar vermis to the median frontal cortex.

training, participants were able to optimize coincident timing based on three components. First, the subjects were given the task of auditory stimulation using a metronome. In this task, subjects responded over a continuous interval to match the precise timing of the beat. Second, visual and auditory feedback is presented to train the individuals to move within a 'target zone.' Third, the feedback presented with every beat increases synchronization of movement. If an incorrect movement had been performed, the subject was asked to find the correct timing that appeared message middle in the screen. Participants typically engaged in approximately 25,000 synchronized metronome repetitions of synchronized movements based on the physical and cognitive functions of one's expectancy of the onset of the metronome beat. The various movements incorporated into the training included clapping hand-to-hand with a sensor on one palm, tapping the palm sensor lightly on the thigh, and tapping floor sensors with either the toe or the heel.

On the basis of the considerations mentioned, participant comparison was made with regard to improvements of motor timing. Similar to our results, previous studies showed that motor timing learning through IM resulted in reduced head speed variability in golf shots (Sommer, & Rnnqvist, 2009). According to Myskja (2005), cognitive connectivity of time and space enables more rhythmic and coordinated movements, resulting in stabilized coordination of the limb through IM training, thereby positively reducing the golf swing speed.

Based on the results of previous studies, our results show that the change in putting performance through IM learning is very meaningful when compared with the control group. The golf players in the IM group continued their training to perceive even fine-tune in the auditory sense of the golf swing and at the same time corrected sensory signal errors in the hands and feet through visual feedback. This allowed the golfers to focus on timing errors in movement and to reduce the error range for the duration of the training. This reduction of error range can be interpreted as a balanced change of limb timing. On the other hand, the golfers in the control group were not able to correct individual timing errors through simple putting practice.

Thus, our interpretation is that the IM group experienced enhanced perceptual-motor variability of coordination between left and right hands and feet, allowing them to perform the motor sequence faster with the same or greater based on fine-tuning during the IM training. Moreover, the relationship between improvement of motor timing and golf performance emphasizes that modifying error of synchrony between physical and cognitive functions is necessary for golf performance.

4.2. The correlation between putting time and brain connectivity

In this initial study, we thought it was important to determine the changes in brain connectivity that occurred when acquisition of motor timing based on neural mechanisms that were repeated over time. Our results showed that the IM group experienced increased functional connectivity from the superior cerebellar vermis to the right medial frontal gyrus, left superior temporal gyrus, right middle occipital gyrus, right middle temporal gyrus, right cingulate gyrus, and right supramarginal gyrus compared to controls. Similar to our results, a previous study of IM and brain efficacy showed that IM contributed to internal neuronal processing and cognitive efficiency based on the neural network (Gorman, 2003). Our study showed that changes in motor timing, coordination, and rhythm, which are manifested by the effects of IM learning through fMRI, changed the connectivity between brain regions activated during the involved behavior. Specifically, we identified brain activation within the cerebellum-pontocerebral tract (left cerebellum connectivity to occipital lobe, temporal lobe, parietal lobe, and both frontal lobes) in the IM group. It has been proposed that these neural circuits play important roles in the human memory system (Bechara, Damasio, Tranel, & Anderson, 1998), awareness of sensory information (Kingsley, 2000), behavioral rhythm (Stewart & Leung, 2003), and movement coordination. Furthermore, the cerebellum is important for motor control, coordination of movement, maintenance of muscle tone, and fine motor movement (Abraham & Loeb, 1985; Grafton, Hazeltine, & Ivry, 1995; Mauk & Buonomano, 2004; Swinnen & Wenderoth, 2004). Moreover, the pathway of the superior cerebellar vermis of the cerebellum is thought to be involved in timing processes in response to the frontal lobe (Spencer et al., 2007; Ito, 2002). This is supported by our previous study finding that professional golfers who show consistent swing speed also showed increased brain connectivity between the cerebellum, parietal lobe, and frontal lobe (Kim et al., 2015). Our present research shows that IM training promotes greater brain connectivity in professional golfers compared to control training.

In addition, our study noted a correlation between brain connectivity and 5AD-BS for all tested golfers. The control group training focused on putting stroke consistency, and it is likely that improvements in the fine-tuning of motor timing through putting practice alone increased the correlation of brain connectivity. Furthermore, when comparing the 2 m and 5 m putt address-backswing sections of the two groups, there was similar standard deviation between the two groups during the 2 m putt, but a difference in the standard deviation data during the 5 m putt. This is likely due to the different swing length from the address to the backswing for every player at 5 m, while the variability of timing was reduced in the post-measurement. Specifically, the club head showed greater velocity during the 5 m putt to ensure that the ball reached the target. Therefore, it is possible that the golfers had previously optimized the backswing-impact section, where the peak speed is achieved. According to Grealy and Mathers (2014), elite golfers tend to maintain greater consistency in long putts than short putts. Therefore, as the length of the swing increases, optimization of all the swing segments will be necessary to maintain consistency. Considering that all of the subjects participating in this study were professional golf players, it is possible that address-backswing change is more strongly correlated with brain connectivity than the already optimized backswing-impact section.

On the other hand, it is important to note that the IM group showed greater inter-region connectivity than the control group, despite the correlation of putting stroke training in the control group with brain connectivity. In particular, the changes in the temporal region, which were different between the two groups, may have been generated by correcting the timing errors between the extremes through visual and auditory feedback performed during IM training.

Although the golfers in the two groups participated in this study to maintain swing timing over a long period of time, the difference in connectivity between the brain regions suggests that synchronization between cognitive and motor learning was more effective.

4.3. Limitations

There were several limitations to our study. First, we had a small sample size (N = 20); a larger sample size may have revealed a correlation between swing time and brain activity. Second, the IM protocol that we used involved the same application and time period as in several previous studies. However, in future studies, it would be important to examine a protocol using different numbers of beats and durations of tasks at different levels of golf expertise.

5. Conclusions

This study showed that motor timing practice through the use of Interactive Metronome (IM) can optimize the variability of swing timing and brain connectivity in golfers. This suggests that optimization of motor timing can promote improved motor learning and putting performance in professional golfers

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