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THE EFFECT OF MOTOR IMAGERY WITH SPECIFIC IMPLEMENT IN EXPERT BADMINTON PLAYER

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Abstract—Motor skill can be improved with mental simulation. Implements are widely used in daily life and in various sports. However, it is unclear whether the utilization of implements enhances the effect of mental simulation. The present study was designed to investigate the different effects of motor imagery in athletes and novices when they handled a specific implement. We hypothesize that athletes have better motor imagery ability than novices when they hold a specific implement for the sport. This is manifested as higher motor cortical excitability in athletes than novices during motor imagery with the specific implement. Sixteen expert badminton players and 16 novices were compared when they held a specific implement such as a badminton racket and a non-specific implement such as a a plastic bar. Motor imagery ability was measured with a self-evaluation questionnaire. Transcranial magnetic stimulation was used to test the motor cortical excitability during motor imagery. Motor- evoked potentials (MEPs) in the first dorsal interosseous (FDI) and extensor carpi radialis muscles were recorded. Athletes reported better motor imagery than novices when they held a specific implement. Athletes exhibited more MEP facilitation than novices in the FDI muscle with the specific implement applied during motor imagery. The MEP facilitation is correlated with motor imagery ability in athletes. We conclude that the effects of motor imagery with a specific implement are enhanced in athletes compared to novices and the difference between two groups is caused by long-term physical training of athletes with the specific implement. © 2014 Published by Elsevier Ltd. on behalf of IBRO.

Key words: implement, motor-evoked potential, motor imagery, training, transcranial magnetic stimulation.

INTRODUCTION

Physical training improves motor skills in sports (Nakata et al., 2010). In particular, previous studies have demonstrated that long-term physical training with specific implements leads to functional and structural alterations in multiple brain areas in expert players of racket sports (Lees, 2003; Maravita and Iriki, 2004), such as soft tennis (Ohguni et al., 2009), badminton (Di et al., 2012), table tennis (Jafarzadehpur and Yarigholi, 2004) and tennis (Fourkas et al., 2008).

The effects of physical training may be enhanced with mental simulation both in athletes and novices (Driskell et al., 1994; Gregg et al., 2011). Motor imagery is the mental process of a motor task in the absence of movement and muscle activity (Hanakawa et al., 2003). The effects of motor imagery are modulated by the interactions between various physiological and psychological factors in a complex manner (Decety et al., 1989; Q5 Lafleur et al., 2002; Jackson et al., 2003; Bakker et al., 2008; Saimpont et al., 2012). It is widely accepted that motor imagery and real motor execution share similar neuronal elements at cortical and subcortical levels in the motor pathways (Grezes and Decety, 2001). If a transcranial magnetic stimulation (TMS) is delivered to the primary motor cortex during motor imagery, motor-evoked potential (MEP) in the target muscle is facilitated compared to that at rest condition (Fadiga et al., 1998; Hashimoto and Rothwell, 1999). The degree of MEP facilitation depends on the excitability of the motor pathway at the time of motor imagery. Using TMS, it has been reported that expert tennis players show increased corticospinal excitability during motor imagery of a tennis forehand but not during motor imagery of a table tennis forehand or the golf drive (Fourkas et al., 2008). This study suggests that the motor cortical network is altered by long-term training with specific implements. The results further support the notion that utilization of specific implements leads to functional or structural changes in the brain (Elbert et al., 1995; Draganski et al., 2004; May et al., 2007). However, it is not clear whether the application of a specific implement during the motor imagery enhances the effect of this mental process.

Badminton is a racket sport involving intermittent movements with high intensity in short periods. The high-level performance in handling the racket requires a

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Abbreviations: ANOVA, analysis of variance; ECR, extensor carpi radialis; EMG, electromyogram; FDI, first dorsal interosseous; MEP, motor-evoked potential; MIQ, movement imagery questionnaire; RMT, Q4 resting motor threshold; TMS, transcranial magnetic stimulation.

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fine combination of perception and action which is related to high cortical functions with activity in different brain regions (Lees, 2003; Maravita and Iriki, 2004). Therefore, expert badminton player provides a good model for investigating how the long-term utilization and application of a specific implement may affect the brain functions. In the present study, we investigated the effect of motor imagery with a specific implement (badminton racket) in athletes (expert badminton players) and novices. We hypothesize that the effects of motor imagery are enhanced in athletes compared to novices when they handle the specific implement. This can be tested by measuring the different motor outputs with different degrees of MEP facilitation during motor imagery in the two subject groups.

Long-term training with implements leads to better performance in athletes (Maravita and Iriki, 2004; Nakata et al., 2010). However, it is not known whether the performance of motor imagery with a specific implement is also affected by the long-term physical training. We tested the motor imagery ability with kinesthetic and visual items in athletes and novices (Hall and Martin, 1997). Our second hypothesis is that athletes will show better motor imagery ability than novices when they handle the implement. In addition, the better motor imagery ability will be correlated with larger MEP facilitation during motor imagery in athletes.

EXPERIMENTAL PROCEDURES

Subjects

Sixteen expert badminton players (athletes, eight women, mean age 20.0 ± 1.4 years) and 16 age- and gender-matched healthy subjects (novices, eight women, mean age 20.8 ± 1.9 years) participated in the study. All subjects were right-handed, confirmed using the Oldfield Handedness Inventory (Oldfield 1971). Expert badminton players were Chinese national first-class or second-class athletes who had experience in competition at national or international tournaments. The average training time for athletes was 14.1 ± 1.9 h per week for 11.1 ± 1.2 years. Novices were university students with no formal badminton training experience. All subjects provided written informed consent in accordance with the Declaration of Helsinki. The experimental protocol was approved by the Human Research Ethics committee of the Shanghai University of Sport.

Behavioral measures for motor imagery

Behavioral measures and TMS measures were performed on two separate days at least two weeks apart in a random order. For the behavioral measures, we measured the time course of motor imagery in athletes and novices. First, subject performed the motor task physically. The motor task was a badminton serving task. A short period of training was performed before recording. A brief instruction with basic rules of badminton was provided for novices. The motor task was performed 20 times. An acoustic cue was given as the start signal for serving. The time at the delivery of cue was defined as time 0. The time course 1 s before the cue to the time when the shuttlecock landed on the floor was video-recorded (Fig. 1A). For the motor imagery task, the subjects were seated comfortably in a chair and wore an eye mask. The present study was designed to investigate the different effects of motor imagery with different implements (specific vs. non-specific) in athletes and novices. To this end, the effects of motor imagery with a badminton racket (specific implement) were compared to that with a plastic bar (non-specific implement) in the two subject groups (Fig. 1B). A commercial plastic bar was used for a non-specific implement because it had a similar weight and shape as the badminton racket. We assumed that

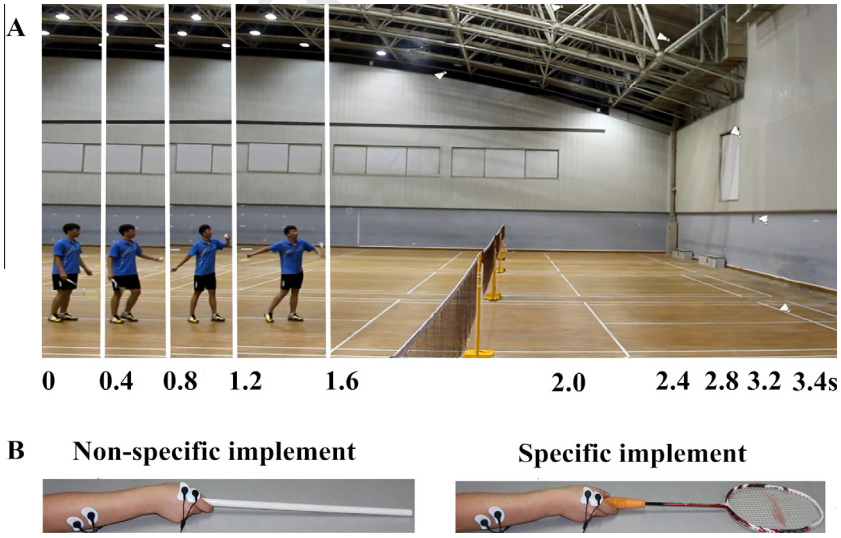

Fig. 1. Motor task and experimental setup. (A) Badminton serving performed by a representative expert player. The time course of the badminton serving was recorded. For the motor imagery task, subject was instructed to perform the task in the same way mentally. (B) Motor imagery was performed when the subject held a non-specific implement such as plastic bar (left) or when they held a specific implement such as badminton racket (right).

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athletes can distinguish the racket from the plastic bar with different hand-friendliness between two implements while novices cannot. For motor imagery, subjects were instructed to perform the badminton serving task mentally in the situation that they were standing in front of the net and facing their opponents' half of court. Motor imagery of performing their own serving task with a first-person perspective was likely being used by most subjects with such instruction. At the end of the motor imagery when the shuttlecock struck the floor in the mental process the subject pressed a button. The duration of motor imagery was calculated. Two blocks of motor imagery with specific and non-specific implements were performed on a same experimental day. Each block consisted of 20 trials. The order for two blocks of motor imagery with different implements was randomized. However, the block for real execution of the task was always performed before the blocks for motor imagery.

To assess motor imagery ability in each subject, the process of motor imagery was measured with self-evaluation using the revised version of movement imagery questionnaire (MIQ) (Hall and Martin, 1997; Fourkas et al., 2008). We first tested the hand-friendliness with different implements in two subject groups. A 5-point Likert-type scale with a score of 5corresponding to the best friendliness was used. We further tested motor imagery with different implements with detailed items for kinesthetic and visual properties. The measures included 4kinesthetic and 4visual items using a 7-point scale with a score of 7 corresponding to the highest clarity or intensity during the imagery. Four kinesthetic items were difficulty of imagery, sequence of muscle contraction, muscle tension and hitting force during imagery. Four visual items were difficulty of imagery, clarity of serving action, clarity of shuttlecock flying path and clarity of shuttlecock landing in opponent's court during imagery. The average scores of 4 items for kinesthetic and visual properties were calculated.

The strategy used by the subject during motor imagery is important for this mental process. Our subjects were instructed and supposed to perform motor imagery with a first-person perspective. In a subgroup of 9 athletes and 9 novices, we tested whether the subjects used the first-person perspective during motor imagery with a self-evaluation questionnaire. The test consisted of three introspective questions in a 5-point scale. The first question asked the subject directly whether the first-person perspective was used under different experiment conditions with specific and non-specific implements. A score of 5to this question corresponds to the strongest agreement to the first-person perspective during motor imagery while a score of 1 corresponds to the strongest agreement to the third-person perspective. If the subject indicated that a first-person perspective (scored beyond 3; 3 corresponding to neutral position) was used in motor imagery, we asked two more questions. The following two questions asked the subject whether the motor imagery was easily controlled (second question) and whether it was clear (third question) with the first-person perspective. A 5-point scale with 5corresponding to the highest easiness or clearness was used.

Neurophysiological measures with transcranial magnetic stimulation

Surface electromyogram (EMG) was recorded from the right first dorsal interosseous (FDI) and extensor carpi radialis (ECR) muscles with 9-mm diameter Ag-AgCl surface electrodes. The active electrode was placed over the muscle belly. The reference electrode was placed over the metacarpophalangeal joint of the index finger for FDI muscle and was 2 cm away from the active electrode for the ECR muscle. FDI and ECR muscles were selected for recording because they are representative hand and forearm muscles and they play important roles in the badminton serving (preliminary discussion with national badminton coaches). The signal was amplified (1000 times), band-pass filtered (2 Hz–2.5 kHz, Micromed, Matrix 1005, Italy), digitized at Q6 10 kHz by an analog-to-digital interface (Micromed, MT2502A, Italy) and stored in a computer for off-line analysis.

TMS was applied to the left primary motor cortex with a figure-of-eight shaped coil (outside diameter of each loop was 9.5 cm) connected to a Magstim 200 stimulator (Magstim, Whitland, Dyfed, UK). The handle of the coil pointed backward at 30–45° from the mid-sagittal line. The induced current in the brain was in the posterior–anterior direction, approximately perpendicular to the central sulcus (Kaneko et al., 1996; Di Lazzaro et al., 2001). The optimal location where TMS with slight superthreshold intensity produced the largest MEP in FDI muscle was marked with a pen as the motor hot spot. This location was also the optimal location for ECR muscle in most subjects. Resting motor threshold (RMT) was defined as the lowest TMS intensity that evoked MEP of more than 50 μV in FDI muscle in at least five out of ten consecutive trials when the muscle was completely relaxed. We used TMS intensity of 120% RMT and produced MEP of 0.5–1 mV in FDI muscle at rest condition in both athletes and novices.

The different effects of motor imagery in two subject groups were compared under different experimental conditions (specific and non-specific implements). The subject was instructed to perform the motor imagery after the acoustic cue. This was compared to a resting state during which the subject held the implement and maintained the muscle relaxation. TMS was delivered during the motor imagery or at rest. For motor imagery, TMS was delivered at the middle of badminton serving during the motor imagery. The timing was adjusted individually according to the video-recorded real-time course in each subject because the time was different across all subjects. In addition, the time course was also slightly different for motor imagery and real motor execution (see results and Fig. 2). We obtained feedback from the subjects during the experiment. If the subject reported that TMS was applied before the serving began or after the shuttlecock passed the net in the motor imagery, the recording was discarded from the

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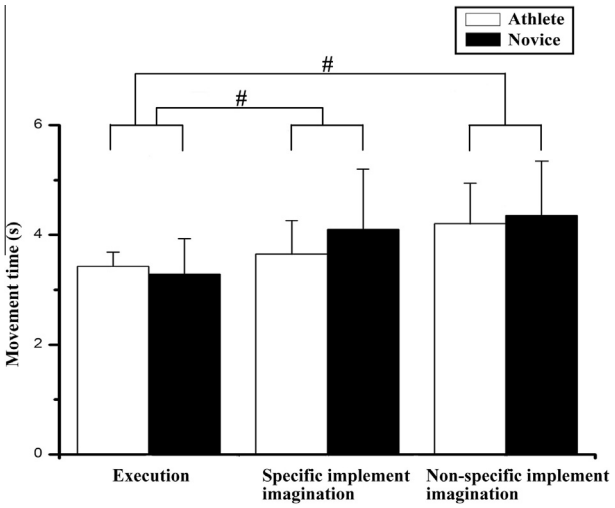

Fig. 2. Duration for performing the motor task under various experimental conditions in athletes and novices. Group analysis with data obtained from 16 athletes (white columns) and 16 novices (black columns). The ordinate shows the duration for performing the motor task under various experimental conditions. Three experimental conditions were compared: real execution of the motor task, motor imagery with specific and non-specific implements. $^{\#}p < 0.05$, post-hoc paired *t*-test comparing execution of real motor task to motor imagery.

final data analysis. For most subjects, TMS was delivered at about 1.5 s after the acoustic cue. We set an inter-trial interval of 10 s to avoid fatigue for the motor imagery task. For the rest condition, subjects were instructed to keep relaxed both physically and mentally. TMS was delivered in a random inter-trial interval of 12–15 s. Therefore, the interval between TMS pulses for motor imagery (inter-trial interval of 10 s + motor imagery task of about 4 s) and rest condition was similar. The experiment for TMS measures consists of four blocks (specific and non-specific implements × motor imagery and at rest). Twenty trials for each block were recorded in a random order.

We further tested whether the different effects of motor imagery between athletes and novices with different implements (see results) were simply due to the existence of implements but not due to the type of implements during motor imagery. A subgroup of 9 athletes and 9 novices participated in this control experiment. Motor imagery without implements (no implement) was compared to same motor imagery with specific and non-specific implements. TMS was delivered in the same way as the main experiment. Six blocks (specific implement, non-specific implement and no implement × motor imagery and at rest) with twenty trials in each block were recorded in a random order.

Data and statistical analysis

Values are reported as mean ± standard deviation. Background EMG 50 ms before the TMS delivery was rectified and integrated. MEP amplitude was measured peak-to-peak. In addition, we also calculated the MEP ratio between MEP amplitude during motor imagery and that at rest for different experimental conditions.

The MIQ scores in athletes and novices were compared using a non-parametric Mann–Whitney *U* test. A two-way repeated measures analysis of variance (ANOVA) with group as the between-subject factor and implement as the within-subject factor was used to test the difference in the duration for performing the motor task and MEPs under different experimental conditions. Unpaired (between-subject comparisons) and paired (within-subject comparisons) *t*-test with Bonferroni correction for multiple comparisons was used for post hoc analysis if ANOVA showed significant interaction. Further analysis with non-parametric Spearman rank correlation was performed to explore the relationship between MEP ratio (motor imagery/at rest) and MIQ scores. In addition, we performed an analysis for detecting outliers before the correlation test. Subject either with MEP ratio or MIQ score located outside of mean ± 2 standard deviation (corresponding to $p < 0.05$) was defined as an outlier and was excluded from the final correlation analysis. The threshold for significance was set at $p < 0.05$.

RESULTS

Behavioral measures

The duration of badminton serving was similar for athletes and novices ($F_{1,60} = 0.40$, $p = 0.530$) although the main effect for experimental condition (real execution, motor imagery with specific and non-specific implements) was significant ($F_{2,60} = 15.50$, $p < 0.001$) (Fig. 2). The interaction between main effects of group and experimental condition was not significant ($F_{2,60} = 1.58$, $p = 0.214$). Further post hoc test revealed that the time for real motor task execution was shorter than that for motor imagery with both specific and non-specific implements ($p < 0.05$ for both comparisons) while the time course of motor imagery was not different between two types of implements.

Motor imagery ability was assessed with MIQ scores (Table 1). Athletes reported better hand-friendliness than novices with specific implements ($Z = 4.13$, $p < 0.001$). This resulted in better performance of motor imagery with kinesthetic items in athletes than that in novices ($Z = 4.35$, $p < 0.001$). However, the performance with visual items was not different between two subject groups ($Z = 0.21$, $p = 0.832$). On the other hand, there was no difference for hand-friendliness ($Z = 0.46$, $p = 0.643$), motor imagery either with kinesthetic items ($Z = 0.54$, $p = 0.588$) or visual items ($Z = 0.23$, $p = 0.819$) between athletes and novices when they held the non-specific implement.

In addition, we used an introspective questionnaire to test whether our subjects performed motor imagery with first-person perspective. The results (Table 1) showed that both athletes and novices confirmed by themselves that first-person perspective was used during motor imagery for both experimental conditions with specific and non-specific implements. This was supported by easy control and high clearness during motor imagery in both groups.

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Table 1. Behavioral measures under various experimental conditions in athletes and novices

	Non-specific implement		Specific implement	
	Athlete	Novice	Athlete	Novice
Movement imagery questionnaire (N = 16)				
Hand-friendliness	1.9 ± 0.8	1.9 ± 0.7	4.0 ± 1.0	2.1 ± 0.7***
Kinesthetic items	4.0 ± 0.7	3.9 ± 0.6	5.7 ± 0.8	4.1 ± 0.7***
Visual items	5.1 ± 0.8	5.2 ± 0.6	5.2 ± 0.4	5.3 ± 0.5
First-person perspective (N = 9)				
Perspective	4.7 ± 0.7	4.7 ± 0.5	4.7 ± 0.4	4.6 ± 0.5
Control	3.9 ± 1.3	3.8 ± 1.1	4.0 ± 1.1	3.9 ± 1.3
Clearness	3.7 ± 1.3	3.7 ± 1.1	3.8 ± 1.1	3.6 ± 1.3

Test for movement imagery questionnaire was performed in all subjects (N = 16 for both athletes and novices). Test for first-person perspective during motor imagery was performed in a subgroup of subjects (N = 9 for both athletes and novices).
Hand-friendliness is scored by a 5-point scale with 5 representing the best friendliness with an implement and 1 representing the worst friendliness with the implement.
Values for kinesthetic and visual items are the average scores of 4 items in each category. Each item is scored by a 7-point scale with 7 representing the best performance (intensity felt or clarity seen by the subject) and 1 representing the worst performance.
Test for first-person perspective is scored by a 5-point scale with 5 representing the strongest agreement to the first-person perspective. Further items test the easiness and clearness of imagery with this first-person perspective using the 5-point scale with 5 representing the highest easiness and clearness.
*** $p < 0.001$, non-parametric Mann–Whitney U test, comparing athlete to novice.

Neurophysiological measures

No background EMG was found in either FDI or ECR muscle under any experimental condition in either subject group. RMT was similar in two subject groups (athlete, 43.6 ± 3.5%; novice, 44.3 ± 3.0% stimulator output; $t_{30} = 0.55$, $p = 0.464$).

We first analyzed MEP in the FDI muscle. At rest condition, TMS with 120% RMT stimulus intensity produced MEP with similar amplitude in both athletes and novices when they held a specific implement or a non-specific implement (Fig. 3A and Table 2). There was no significant effect of group ($F_{1,30} = 0.19$, $p = 0.668$), implement ($F_{1,30} = 0.27$, $p = 0.608$) or their interaction ($F_{1,30} = 1.31$, $p = 0.261$) at rest condition. However, significant effects for group ($F_{1,30} = 19.27$, $p < 0.001$), implement ($F_{1,30} = 14.21$, $p = 0.001$) and their interaction ($F_{1,30} = 11.59$, $p = 0.002$) were found during motor imagery. Post hoc tests showed that athletes had more MEP facilitation than novices when they performed motor imagery with a specific implement ($p < 0.001$) but not with a non-specific implement ($p = 0.917$). In addition, comparison in each subject group showed that MEP was larger with a specific implement than that with a non-specific implement in athletes ($p < 0.001$) but not in novices ($p = 0.747$). Further analysis using MEP ratio between two experimental conditions (motor imagery/at rest) confirmed the difference between two groups in holding a specific implement (Fig. 3B). ANOVA found significant effects for group ($F_{1,30} = 6.165$, $p = 0.019$), implement ($F_{1,30} = 7.05$, $p = 0.013$) and their interaction ($F_{1,30} = 9.34$, $p = 0.005$). Post hoc tests showed that the MEP ratio was larger in athletes than novices with a specific implement ($p < 0.001$) but not with a non-specific implement ($p = 0.335$). In addition, MEP ratio with a specific implement was larger than that with a non-specific implement in athletes ($p < 0.001$) but not in novices ($p = 0.683$).

Different results were found in the ECR muscle (Fig. 3C, D and Table 2). No significant main effect of group (at rest, $F_{1,30} = 0.04$, $p = 0.853$; motor imagery, $F_{1,30} = 0.02$, $p = 0.885$), implement (at rest, $F_{1,30} = 0.31$, $p = 0.584$; motor imagery, $F_{1,30} = 0.35$, $p = 0.558$) or their interaction (at rest, $F_{1,30} = 0.01$, $p = 0.994$; motor imagery, $F_{1,30} = 0.06$, $p = 0.809$) was found in MEP amplitude either at rest condition or during motor imagery. Analysis of MEP ratio between two experimental conditions showed similar results with no significant group ($F_{1,30} = 0.23$, $p = 0.638$), implement ($F_{1,30} = 0.03$, $p = 0.864$) effect and their interaction ($F_{1,30} = 0.01$, $p = 0.999$).

We further tested if motor imagery without implements was different from that with implements (specific and non-specific) in a subgroup (Fig. 4). ANOVA explored significant main effects of group ($F_{1,16} = 6.31$, $p = 0.023$), implement ($F_{2,32} = 27.48$, $p < 0.001$), and significant effect of their interaction ($F_{2,32} = 9.27$, $p < 0.001$) for the MEP ratio. Post hoc test confirmed the results from the main experiment that athletes had more MEP facilitation than novices when they performed motor imagery with a specific implement ($p = 0.002$) but not with a non-specific implement ($p = 0.959$). Importantly, additional MEP facilitation was also found in athletes compared to novice under the no-implement condition ($p = 0.043$). We also compared different experimental conditions in two subject groups. In athletes, MEP ratio with specific implements was larger than those with non-specific implements and without implements ($p < 0.001$ for both comparisons). No difference was found between MEP ratios with a non-specific implement and without an implement. On the other hand, MEP ratios both with a non-specific implement ($p = 0.045$) and with a specific implement ($p = 0.025$) was larger than that without an implement in novices. No difference was found between MEP ratios with specific and non-specific implements.

Correlation between behavioral and neurophysiological measures

Because both MIQ score (behavioral measure) and MEP ratio in the FDI muscle (motor imagery/rest) showed

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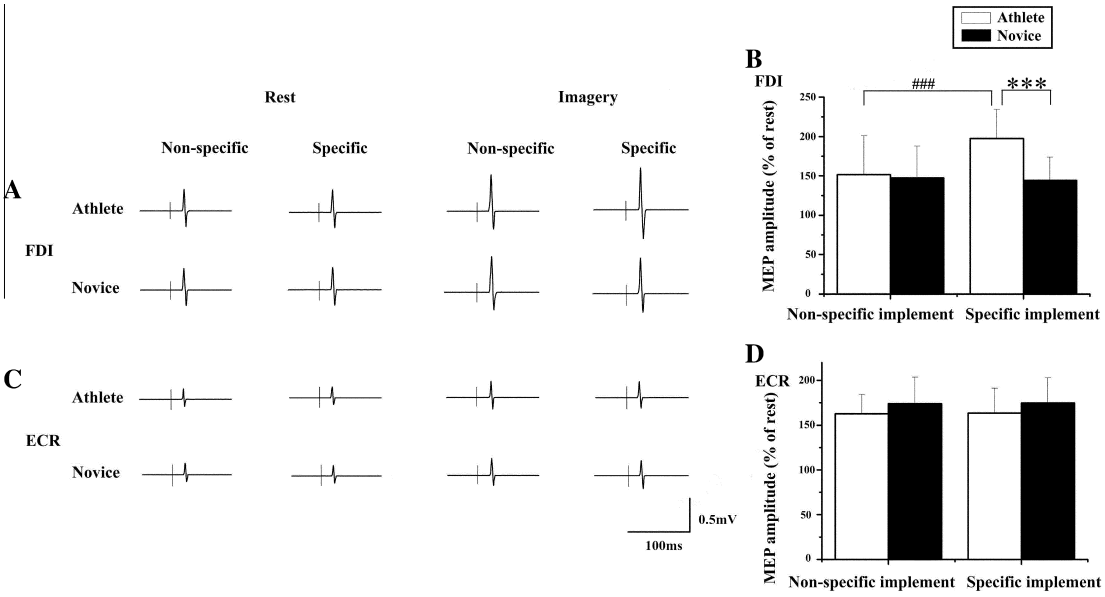

Fig. 3. Example of MEP recordings and MEP ratios under various experimental conditions in athletes and novices. (A) Recordings in first dorsal interosseous (FDI) muscle. (C) Recordings in extensor carpi radialis (ECR) muscle. Left panel shows recordings at rest. Right panel shows recordings during motor imagery. (B) and (D) Group analysis for MEP ratio in 16 athletes (white columns) and 16 novices (black columns). (B) Results in FDI muscle. (D) Results in ECR muscle. The ordinate shows MEP ratio expressed as a percentage value of the MEP amplitude during motor imagery to that at rest. $^{***}p < 0.001$, post hoc unpaired *t*-test, comparing athlete to novice. $^{\#\#\#}p < 0.001$, post hoc paired *t*-test, comparing specific to non-specific implements.

Table 2. MEP amplitudes (mV) under various experimental conditions in athletes and novices

	Rest		Motor imagery	
	Athlete	Novice	Athlete	Novice
FDI muscle				
Specific implement	0.69 ± 0.11	0.73 ± 0.14	1.33 ± 0.17	1.02 ± 0.14***
Non-specific implement	0.70 ± 0.14	0.71 ± 0.15	1.01 ± 0.18	1.00 ± 0.17
ECR muscle				
Specific implement	0.32 ± 0.07	0.32 ± 0.08	0.50 ± 0.09	0.51 ± 0.04
Non-specific implement	0.32 ± 0.06	0.32 ± 0.08	0.51 ± 0.05	0.50 ± 0.05

ECR, extensor carpi radialis; FDI, first dorsal interosseous.
*** $p < 0.001$, post hoc unpaired *t*-test, comparing athlete to novice.

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significant differences between athletes and novices only when a specific implement was used, we analyzed the correlation between these two measures with a specific implement. Data from all subjects showed that the MEP ratio correlated with MIQ scores for kinesthetic items (Rho = 0.759, $Z = 3.48$, $p < 0.001$) but did not correlate with MIQ scores for visual items (Rho = 0.025, $Z < 0.01$, $p = 0.930$). We further separated the correlation analysis between MIQ score and MEP ratio for different subject groups. The analysis showed that MIQ score with kinesthetic items was significantly correlated with the MEP ratio in athletes (Rho = 0.597, $Z = 2.41$, $p = 0.016$, Fig. 5A) but not in novices (Rho = 0.355, $Z = 1.30$, $p = 0.194$, Fig. 5B). One outlier was detected for the correlation analysis between the MEP ratio and MIQ score with visual items in athletes. The correlation between two measures was not significant even if the outlier was excluded from the analysis (Rho = 0.313, $Z = 1.13$, $p = 0.257$, Fig. 5C). There was also no significant correlation between the MEP ratio and MIQ scores with visual items in novices (Rho = 0.250, $Z = 0.89$, $p = 0.371$, Fig. 5D).

DISCUSSION

We examined how the application of a specific implement during motor imagery affects this mental process. The novel findings were that the degree of MEP facilitation during motor imagery with a specific implement was larger in athletes than that in novices. Motor imagery ability in athletes was better than that in novices with the specific implement. The degree of MEP facilitation correlated with the motor imagery ability in athletes but not in novices when the specific implement was used.

Motor imagery ability

Motor imagery is a subset of mental practice process which can be applied for various sports (Gerardin et al., 2000; Wei and Luo, 2010; Dey et al., 2012) and therapy

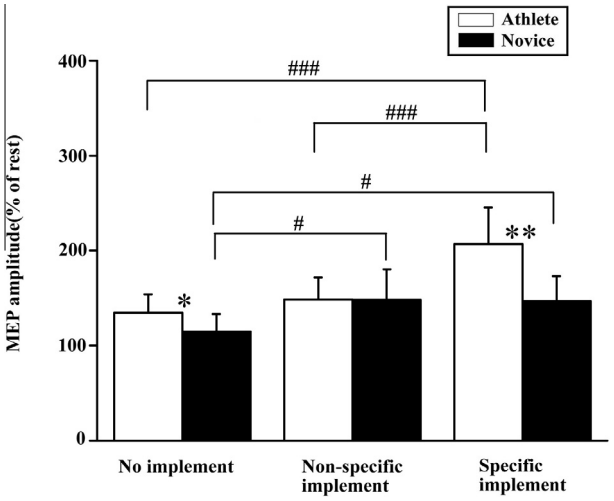

Fig. 4. MEP ratio under various experimental conditions in athletes and novices. Group analysis for MEP ratio in 9 athletes (white columns) and 9 novices (black columns). The ordinate shows MEP ratio expressed as a percentage value of the MEP amplitude during motor imagery to that at rest. $^{*}p < 0.05$, $^{**}p < 0.01$, post hoc unpaired *t*-test, comparing athlete to novice. $^{\#}p < 0.05$, $^{\#\#\#}p < 0.001$, post hoc paired *t*-test, comparing specific implement to non-specific implement or no implement.

(Page et al., 2007; Malouin et al., 2010; Grangeon et al., 2012) in combination with physical training. We found that the time consumed for motor imagery with both specific and non-specific implements was longer than the time consumed for the real motor task execution in both subject groups, suggesting that the time courses and underlying neural elements for motor imagery and real motor execution may not be completely same although they share similar components in the motor pathways (Fadiga et al., 1998; Hashimoto and Rothwell, 1999; Grezes and Decety, 2001). In addition, there was no difference in the time course between athletes and novices for either motor execution or motor imagery. Therefore, it is likely that similar neural elements are recruited in athletes and novices for both performing the motor task physically and mentally. The MIQ test used in the present study is a reliable measure to evaluate the ability of mental rehearsal of motor skills in both subject groups (Hall and Martin, 1997). Athletes reported motor imagery with better hand-friendliness with specific implements compared to novices. This led to better performance with kinesthetic items in athletes. The results suggest that with the same information by holding the implement, athletes simulate the motor task more accurately and successfully

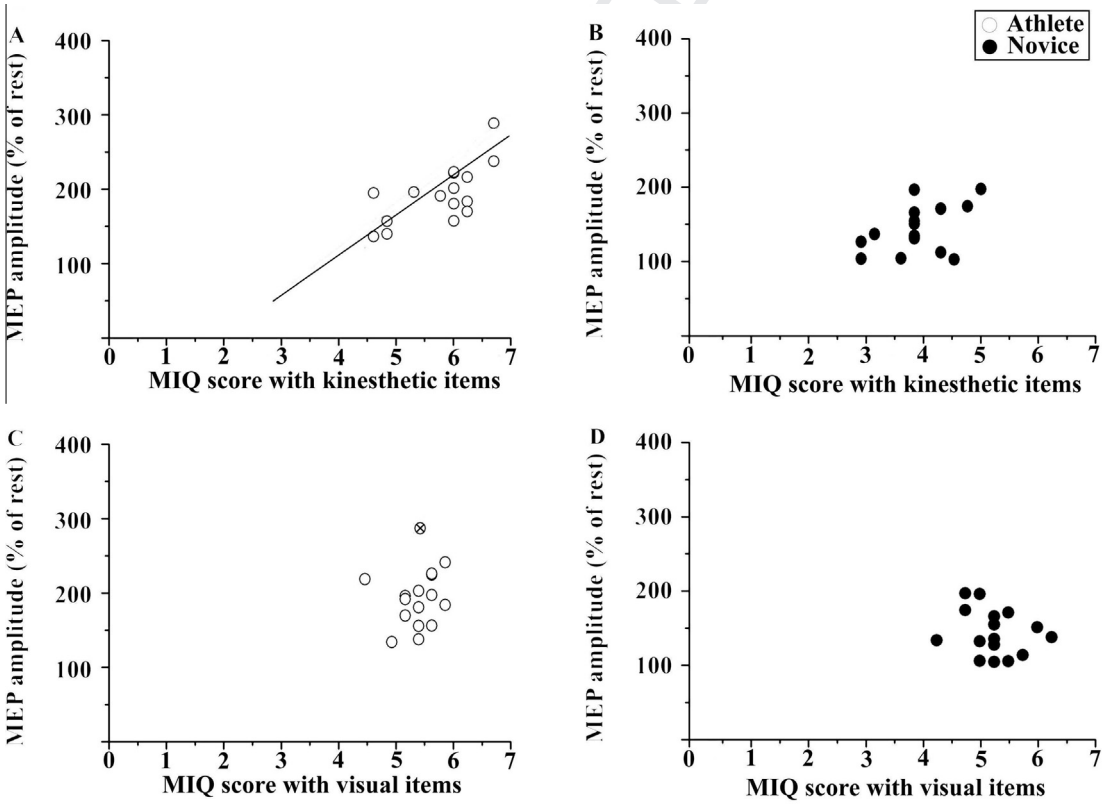

Fig. 5. Relationship between behavioral and neurophysiological measures. The ordinate shows neurophysiological measure with MEP ratio expressed as a percentage value of the MEP amplitude during motor imagery to that at rest. The abscissa shows behavioral measures of motor imagery questionnaire (MIQ) scores with kinesthetic items (A and B) and those with visual items (C and D). Left panels (A and C) show data in athletes and right panels (B and D) show data in novices. Note that an outlier (marked with "×") was detected in (C) and was excluded from the analysis. Solid line in (A) indicates that MEP ratio is correlated with MIQ score with kinesthetic items in athletes, $p < 0.05$.

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than novices in the mental process. The results may further indicate that athletes have the ability to gather essential information for the mental process of the motor task with the long-term training in the sport. In this regard, our previous study reported similar results in basketball players that athletes showed better anticipation behavior than novices in observation of a basketball free throw task (Wu et al., 2013). In addition, no difference between athletes and novices was found for the visual items of the motor imagery. The results might be explained by the fact that relatively less visual information was available in the present study which eliminated the difference in motor imagery with visual items between the two groups.

Motor cortical excitability during motor imagery

We found MEP was facilitated during motor imagery with both specific and non-specific implements in both athletes and novices. The result is consistent with previous studies and supports the notion that motor imagery increases the motor cortical excitability (Fadiga et al., 1998; Hashimoto and Rothwell, 1999; Jeannerod and Frak, 1999). More importantly, athletes showed larger MEP facilitation in the target FDI muscle than novices only when they held the specific implement. This was confirmed with the direct comparison of MEP amplitudes and indirect comparison of MEP ratios (motor imagery/at rest; representing the degree of MEP facilitation) between two subject groups. With the experience and knowledge gained from long-term training in the sport, it is likely that athletes are able to perceive the essential information when they hold the specific implement for the sport. Therefore, a reliable process of motor imagery may be initiated with essential information for the task. Alternatively, the essential information from the implement may be used to convert fluent motor command to the primary motor cortex during motor imagery and this leads to increased MEP facilitation in athletes. On the other hand, novices do not have knowledge about handling the specific implement in the sport or they even cannot distinguish the specific implement from a non-specific implement. This was manifested as less MEP facilitation during motor imagery compared to athletes. Similarly, it is also impossible for athletes to gather useful information for the sport to initiate the reliable motor imagery when they handle a non-specific implement. Therefore, no additional MEP facilitation was found for a non-specific implement, either in novices or athletes. In addition, for the comparisons in each subject group we found increased MEP facilitation during motor imagery with a specific implement compared to that with a non-specific implement in athletes but not in novices. It may be argued that the additional MEP facilitation in athletes is simply caused by the course of motor imagery itself but not necessarily requires the application of a specific implement during the motor imagery. We performed the control experiment to address this question. The results showed that motor imagery without implements led to a larger degree of MEP facilitation in athletes than in novices, consistent with previous study in tennis players (Fourkas et al., 2008). Importantly, within-subject comparison showed that additional MEP facilitation during motor imagery was pronounced in athletes with specific implements compared to that with no implements and non-specific implement conditions (Fig. 4). The results strongly support the notion that the application of a specific implement during motor imagery enhances the effect of this mental process in athletes. Skilled performance (e.g., racket sports) involves sensorimotor tasks, requiring a close coupling of actions with sensory inputs (Lees, 2003). If our subjects (likely only athletes, with long-term training in the sport) considered the racket as an extension of their body parts (Fourkas et al., 2008), such a sensory encoding process would be facilitated with essential inputs from the specific implement during motor imagery. Alternatively, it could be inferred that long-term training develops a pre-set motor program in athletes. A specific implement may have priming effects on this pre-set program when it is initiated. On the other hand, a non-specific implement cannot facilitate or even inhibit this program with no additional MEP facilitation during imagery. Interestingly, novices showed increased MEP facilitation during motor imagery with both specific and non-specific implements compared to that with no implements. The result is consistent with the idea that novices are not able to distinguish specific implements from non-specific implements while sensory inputs with either implement may slightly enhance the sensory encoding process in novices.

Badminton is a non contact racket sport with rapid movements in changing directions. This requires a wide range of muscles cooperating in a fine combination (Lees, 2003). Surprisingly, additional MEP facilitation during motor imagery with specific implements in athletes was only found in the FDI muscle (an intrinsic hand muscle) but not in the ECR muscle (a forearm muscle). This was different from the result of a previous study in expert tennis players that both hand and forearm muscles showed more MEP facilitation during imagery of the tennis forehand compared to imagery of other sports (Fourkas et al., 2008). Each racket sport poses a unique challenge in combination of speed, power and agility, requiring unique cortical strategy for perception and action in motor control. The different results obtained from the present study and Fourkas et al. (2008)'s study may reflect the different cortical strategies used in badminton and tennis. It is likely that relatively skillful control within intrinsic hand muscles is required in badminton while relatively powerful control in tennis may spread the increased excitability into the muscles in the whole arm. Motor imagery involving high level performance in the absence of muscle activity may further enlarge this difference in the motor pathway (Schmidt and Wrisberg, 2003; Miller et al., 2010; Baeck et al., 2012). However, we cannot exclude the possibility that athletes with higher level of skill (e.g., Olympic medalists) have better control in forearm muscles which may lead to additional MEP facilitation during motor imagery compared to novices or athletes tested in the present study (national first or second class). Such higher level of motor control has been reported in pianists. In addition to different patterns of finger movements, pianists and novices show different patterns of forearm and shoulder movements during keystroke tasks (Furuya and Kinoshita, 2008). It should also be noted that the functional

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role of the primary motor cortex in motor learning is complex. It was reported that even in novices, the size of motor cortical activation map increased after 5-days training of a five-finger sequencing task on the piano (Pascual-Leone et al., 1995). In addition, a 2-week training course of a simple thumb-tapping task with the dominant hand produced MEP facilitation with TMS delivered to the dominant motor cortex. Similarly, the training course with the non-dominant hand produced MEP facilitation in the non-dominant motor cortex. On the other hand, this training course with the non-dominant hand also produced an initial increase followed by a later decrease in cortical excitability in the dominant motor cortex (Koeneke et al., 2006). Furthermore, there is increasing evidence showing that the sport-related motor learning process may also involve changes in motor cortical areas outside the primary motor cortex. Study using functional magnetic resonance imaging in middle-aged novices has reported decreased hemodynamic signal strength in non-primary motor areas after 40 h of golf practice when the subjects performed motor imagery of the golf swing task (Bezzola et al., 2012).

Relationship between neuropsychological and neurophysiological factors in motor imagery

Another important finding in the present study was that increased MEP facilitation during motor imagery with specific implements correlated with the MIQ score with kinesthetic items in athletes. MIQ test is a neuropsychological measure which subjectively evaluates the fluency and accomplishment of motor imagery (Hall and Martin, 1997). MEP amplitude is a neurophysiological measure which reflects the excitability of the motor pathway at the time of TMS (Hallett, 2007). During motor imagery, the memory of the motor task is internally recalled. The positive correlation between two measures with a specific implement suggests that better self-evaluation of the internal process is also related to a larger increase in motor cortical output indexed by the neurophysiological measure in athletes. This likely indicates that the accomplishment of a fluent process of motor imagery requires the integration of internal process and external inputs at certain regions in the cortical network (Olsson and Nyberg, 2010). Our previous study with functional magnetic resonance imaging performed during anticipation of a motor task in athletes explored increased activity in inferior frontal gyrus and inferior parietal lobule where mirror neuron systems may be involved (Wu et al., 2013). MEP ratio did not correlate with MIQ score with visual items. This was consistent with the result that motor imagery with visual items was not different between two subject groups. We instructed our subjects to perform motor imagery of their own badminton serving (with the position standing in front of the net and facing the opponent's half of court). Therefore, our subjects likely took internal and first-person perspective during motor imagery. In addition, a questionnaire with self-evaluation from a subgroup of subjects also showed evidence that they took first-person rather than third-person perspective during the motor imagery in the present study. Psychologically, more kinesthetic property rather than visual property may be involved during the course of imagery with this first-person perspective. However, potential contamination of visual items caused by external and third-person perspective should also be taken into consideration in the present study and this could lead to activation of completely different cortical regions during the course of imagery (Jeannerod and Frak, 1999; Fourkas et al., 2006). Particularly, it was impossible to control the exact timing of TMS delivery in the present study because the time course of motor imagery might slightly vary across trials. The variation of timing for TMS delivery increased the possibility that complex strategy with mixed imagery of kinesthetic and visual properties might contribute to the different degrees of MEP facilitation in athletes and novices. In addition, since the whole time course from the beginning of serving to the landing of shuttlecock was evaluated, the mixed strategies with different perspectives might further affect the result of MIQ test. The investigation for the important role of visual items in motor imagery requires different a study design with essential visual information to be provided (Grush, 2004).

CONCLUSION

Using a TMS paradigm, Fourkas et al. (2008) demonstrated that long-term utilization of a specific implement causes functional changes in the brain, leading to increased MEP facilitation in imagining the task in the sport. Using the psychological and physiological measures, the present study further examined the effect of application of a specific implement during this mental process of motor imagery. The results that increased MEP facilitation during motor imagery only with the application of specific implements in athletes may be helpful to develop new training methods in athletes with mental practice (Peluso et al., 2005; Reiser et al., 2011) and may even be helpful to develop new therapies for patients with neurological disorders (Page et al., 2007; Ietswaart et al., 2011). Motor imagery requires integration of internal memory and external inputs in the cortical network (Olsson and Nyberg, 2010). Since the implement (badminton racket in the present study) is an indispensable part for the sports (Lees, 2003), it may be inferred that specific implement applies important medium for the internal and external components to be integrated at certain cortical areas during motor imagery. In athletes, long-term physical training with specific implement in the sport leads to functional reorganization in motor related cortical network (Elbert et al., 1995; Bütefisch et al., 2000; Draganski et al., 2004; May et al., 2007; Bütefisch et al., 2004; Williams et al., 2012). This may provide a functional and structural foundation for athletes to adapt the implement as a medium in the cortical process. We conclude that the effects of motor imagery with a specific implement are enhanced in athletes compared to novices and the difference between the two groups is caused by long-term physical training of athletes with the specific implement.

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