

The effectiveness of repetitive practice on the neuromuscular pathways in elite badminton athletes

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1 Introduction

To be an elite badminton athlete requires many years of constant training and refinement of specific skills. Although widely acknowledged at the “fastest” racket sport (in terms of the speed of the shuttle hit as compared to speed of the ball in other racket sports), it is the fine touch skills (particularly around the net) that differentiate badminton to other racket sports. Elite athletes will dedicate daily practice refining net skills which include “tumbling and spinning” the shuttle.

By the nature of their training, badminton players have developed strong neuromuscular patterning through repetition. However, no study has shown the underlying neurophysiological mechanisms, such as motor cortex excitability and representation that contribute to highly skilled movement.

Transcranial Magnetic Stimulation (TMS) is a tool commonly used in clinical neurology. TMS is non-invasive and causes no pain (Barker et al., 1985). More recently, TMS has become widely used as a research tool investigating many areas of human neuromuscular physiology including the effects of motor control and skill acquisition. However, to date, studies have been limited to simple, short term learning tasks such as five-fingered tapping tasks (see a review by Hallett, 2000).

It was the aim of this study to use TMS to measure the neuromuscular excitability and motor representation of a hand muscle used extensively in badminton in a group of highly skilled elite badminton athletes.

2 Methods

2.1 Participants

The investigation focussed on three groups. The elite group consisted of five athletes (4 male, 1 female; 22 - 28 years of age). All athletes participated in regular international standard competition and, apart from one, played right handed. On-court training averaged 16 hours per week (total average training of 22 hours per week), which included match play, drill-practice and technical skill training. All athletes had suspended their training program for two weeks prior to testing. Five social-competition level subjects (3 male, 2 female; 22 - 50 years of age, all right handed) who play regularly (up to 3 times per week) but who did not actually train their skills, and 10 normal right handed subjects (5 male, 5 female; 23-40 years of age) who did not participate in any form of racket sport served as controls. All

subjects gave written informed consent, and the study had the approval of the human rights committee of the University of Western Australia.

2.2 Materials

TMS was delivered using a Magstim 200 stimulator (Whitland, Dyfed UK) with a 5cm diameter figure-eight coil.

A snugly fitting cap (Figures 1a and b), with pre-marked sites at 1cm spacing was placed over the subject's head and positioned with reference to the nasion-inion (NIL) and inter-aural lines (IAL).

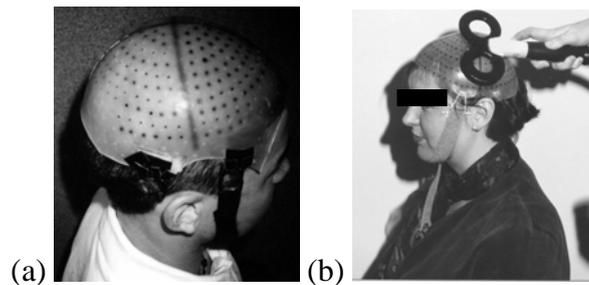


Figure 1. (a) Fitted cap for identification of sites for mapping, and (b) Antero-posterior orientation of coil held during studies.

Skilled badminton strokes (such as precise net shots) require racket manoeuvres involving muscles of the hand. Electromyographic (EMG) activity was recorded from surface electrodes (4mm, Grass-Telefactor, USA) placed over the motor point and the insertion of the first dorsal interosseous (FDI) muscle of the hand. EMG signals were amplified (x1000) and digitised at 200 Hz for 500 ms following each stimulus.

2.3 Procedure

Prior to testing subjects answered a written questionnaire on handedness, and training schedule including training time on court and off-court.

Subjects in each group were tested individually in the laboratory, and sat relaxed in a comfortable chair during the testing session. Testing consisted of concentrating on one half of the scalp, being the subject's non-dominant hemisphere, then after a short rest period, the other half of the scalp (subject's dominant hemisphere).

With the coil held tangential to the skull in an antero-posterior orientation, (Figure 1b), sites near the estimated centre of the hand area (4 - 7 cm lateral to the vertex) were first explored to determine neuromuscular excitability, that is, the site at which the largest motor evoked potential (MEP) could be obtained. This site was defined as the centre site. At centre site, input/output curves were measured by increasing stimulus intensity in 5% steps from a level below the subject's motor threshold until the MEP amplitude became saturated. Motor threshold was defined as the intensity at which a MEP could be obtained with at least two from a series of four stimuli. Following input/output curve measurement, stimulus intensity was set at 20% of stimulator output above motor threshold for mapping each hemisphere.

For motor representation mapping, four stimuli were delivered at the first site, and then at increasingly anterior, and then posterior sites (2 cm steps) until a MEP could no longer be elicited. This pattern was repeated for lateral and then medial sites (1cm steps) until all map borders had been determined. Stimuli were a minimum of 5 s apart and subjects rested briefly between stimulation at each site.

MEP latency (from stimulus to onset of MEP), amplitude (peak-to-peak) and silent period (SP) duration (from MEP onset to return of uninterrupted EMG activity) were measured off-line for the four stimuli at the first site (Figure 2). A complete map of MEP amplitude vs. scalp position was generated by calculating mean peak-to-peak MEP amplitude at each stimulus site and interpolating these values between stimulus sites. The peak of the maps was determined from the position of the greatest value. This position was expressed in millimetres from the vertex and from the IAL (Figure 3). For a detailed description of the cortical mapping protocol, see Thickbroom et al. (1999).

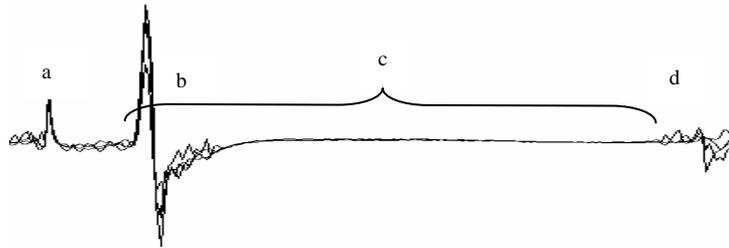


Figure 2 – An example of Motor Evoked Potential. MEP latency is measured from stimulus onset (a) to deflection defining the MEP (b). The silent period (SP) follows the MEP (c, highlighted with bracket) until return of EMG (d). This example shows an overlay of 20 MEPs illustrating the reliability of TMS and the MEP.

Neuromuscular and mapping parameters from subjects in the elite and social groups were compared to normal range at a significance level of $p < 0.05$. Data is expressed as mean \pm standard deviation.

3 Results

3.1 Control Subjects

Control subjects' showed small, but non-significant differences in motor threshold between dominant and non-dominant sides, being equal to or less than 5% for all control subjects.

MEP parameters also showed no differences. MEP latency for the dominant and non-dominant sides was 21.3 ± 2.2 ms and 21.4 ± 2.1 ms respectively. MEP amplitude between dominant and non-dominant sides was 6.0 ± 4.9 mV and 5.8 ± 3.4 mV respectively. SP duration was also similar on both dominant and non-dominant sides (175 ± 35 ms and 182 ± 42 ms respectively).

Figure 3 shows a typical symmetrical map that was observed in subjects in both control and social player groups. Medio-lateral interside difference (dominant/non-dominant map centre calculation) from the vertex was less than 3 mm and antero-posterior difference from the IAL was less than 7 mm (please see Figure 5 for all subjects).

3.2 Social Players

Interhemispheric results in motor threshold, MEP latency, MEP amplitude and SP duration were non-significant for all social players.

There were no significant interside differences in the centre of the maps between the playing and non-playing sides (Figure 3) with less than 3 mm difference in medio-lateral and less than 7 mm difference in antero-posterior maps (Figure 5).

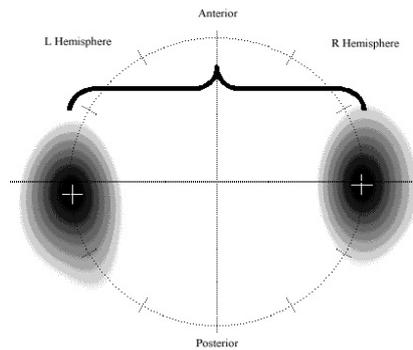


Figure 3. MEP map viewed from superior aspect illustrating symmetrical medio-lateral map positioning typical of control and social players. Vertex divides left/right hemisphere; the IAL divides anterior/posterior positioning. White cross represents the peak value of the maps.

3.3 Elite Athletes

MEP latency was similar on both sides in the athlete group (mean 20.6 ms for the non-playing side, 21.2 ms for the playing side).

Comparisons of motor thresholds between dominant and non-dominant hemispheres were similar to controls and social players in 3 of the 5 subjects (subjects 1, 2, and 5). However, for two subjects, the motor threshold was 10% lower in the hemisphere controlling the playing side compared to the non-playing side ($p < 0.05$).

MEP amplitude was higher on the playing side for all subjects in the athlete group (mean playing amplitude 10.5mV vs. mean non-playing amplitude 5.7 mV; $p < 0.05$). SP duration was similar on each side (168 ± 31 ms vs. 162 ± 38 ms).

MEP maps on the athletes' non-playing side ranged from 45 mm to 58 mm (mean 54 mm) from the vertex and from 13 mm anterior to 3 mm posterior to the IAL (mean 6 mm anterior). Map centre on the athlete's playing side ranged from 39 mm to 59 mm lateral (mean 52 mm) to the vertex and from 17 mm anterior to 5 mm posterior to the IAL (mean 5 mm anterior). Maps on the athletes playing side were displaced 7 to 16 mm medially in 3 subjects (Figure 4a), and 6 mm to 12 mm laterally in 2 subjects (Figure 4b) with respect to the maps on the non-playing side. No significant differences were found in the antero-posterior position of the maps on the two sides.

There was no association between MEP changes, or degree of map shift and the overall time the athlete had been playing badminton.

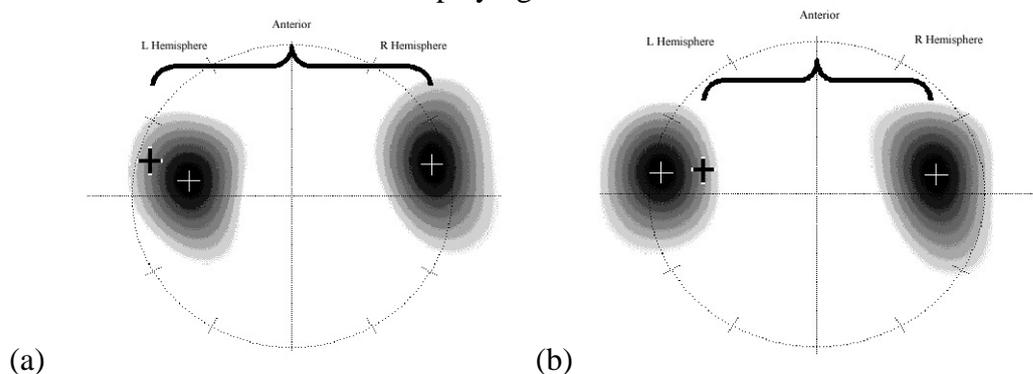


Figure 4. Typical examples in two elite athletes showing medial (a) and lateral (b) shifts in MEP maps. Black cross represents where a symmetrical map would place.

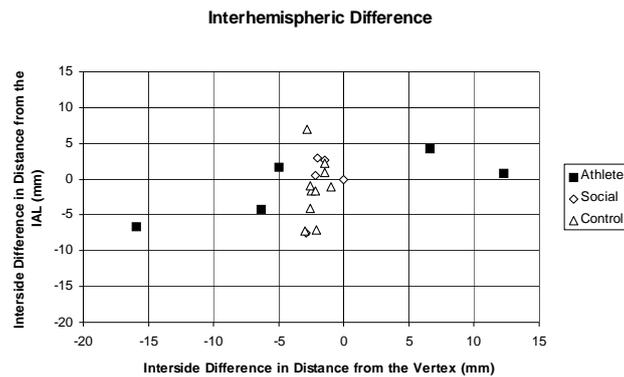


Figure 5. Inter-side difference in map position in the mediolateral and anteroposterior axis for all subjects in all groups. Social players and control subjects had a high degree of inter-hemispheric symmetry in the mediolateral axis (0 – 3 mm interside difference). Athlete maps had similar anteroposterior dispersion to the other groups, but a significantly larger mediolateral difference ($p < 0.05$).

4 Discussion

Results showing no differences between social players and control subjects suggest that reorganisation in the athletes may be influenced by structured, effective motor practice. These results concur with the studies of Grafton et al. (1992) and Plautz et al. (1995) who demonstrated neuromuscular changes associated with dexterous motor skill compared with elementary motor use. Plautz et al. (1995) demonstrated reorganisation in the representation of digit and wrist muscles in the monkey following structured motor training compared to simple motor use, similarly, Grafton et al. (1992), demonstrated neuro-anatomical differences between motor learning and general motor execution. Although skilful in their own right, social players do not undertake skilled practice sessions as the athlete group, further supporting the contribution of repetitive motor training in neuromuscular alteration and motor representation.

The changes found in 4 of the 5 elite athletes, suggest changes in the neuromuscular excitability to the playing hand. A change in motor threshold may arise from a shift in the balance between inhibitory and excitatory inputs to cortical or spinal motoneurons. A change in MEP amplitude in the absence of a change in motor threshold could arise from an increase in the number of descending volleys generated by the cortical stimulus, or from an increase in the number of cells activated. Mechanisms that have been suggested to explain such changes include the establishment of new motoneuron connections, and/or alterations in the effectiveness of previously existing motoneuron connections (Kaas, 1991; Pascual-Leone et al., 1994).

The variances of asymmetry found in all of the maps in the elite athletes suggest that there has been a functional reorganisation in the cortical hemisphere controlling the playing side in the athlete group. Such reorganisations may be a consequence of a change in the pattern of sensory inputs to the motor cortex, such as grip and stroke technique changes, or a reflection of task-related changes in the functional organisation of the primary motor cortex itself. Evidence of sensory influence on reorganisation in primary sensory cortex has been demonstrated on the playing side of highly trained musicians (Elbert et al., 1995), and it has been suggested that enhanced afferent input from increased use of a body part can produce reorganisation in the motor cortex (Kaas, 1991). Changes within primary motor cortex may be a result of repetitious motor training of complex skills from an early age and for long periods of

time. Although, no correlation was found between the degree of map shift and the age at onset and duration of formal training, or success of the athlete; the presence of map shifts in all of the athletes suggests that there has been modulation of the motor representation as a result of reinforced, continuous, skill training.

The range in the magnitude and direction of the map shifts maybe due to individual changes in the excitability of sub-sets of motor neurones within the cortical representation of the target muscle. Monkey studies (Schieber and Hibbard, 1993) have shown that the neuromuscular projection to individual hand muscles utilise a population of neurones dispersed throughout the motor cortex rather than a clearly defined segregated population, and that the pattern of modulation seems to be movement and task influenced. Again, the direction and magnitude in map shifts could not be correlated to playing history or success of the athlete.

5 Conclusion

This study aimed to investigate the effect of repetitive training on neuromuscular excitability and representation in the motor cortex.

It is clear that further study should investigate elite athletes from other racket sports. Moreover, study into elite athlete's who have retired would provide further insight into neuromuscular and brain plasticity, particularly when retired champions are still capable of producing excellent technique many years after ceasing formal training.

6 References

- Barker, A. T., Jalinous, R. and Freeston, I. L. (1985). Non-invasive magnetic stimulation of the human motor cortex. **Lancet**, 2, 1106-1107.
- Elbert, T., Pantev, C., Wienbruch, C., Rockstroh, B., and Taub, E. (1995). Increased cortical representation of the fingers of the left hand in string players. **Science**, 270, 305-307.
- Grafton, S. T., Mazziotta, J. C., Presty, S., Friston, K. J., Frackowiak, R. S. J. and Phelps, M. E. (1992). Functional anatomy of human procedural learning determined with regional cerebral blood flow and PET. **Journal of Neuroscience**, 12, 2542-2548.
- Hallett, M. (2000). Transcranial magnetic stimulation and the human brain. **Nature**, 406, 147-150.
- Kaas, J. H. (1991) Plasticity of sensory and motor maps in adult mammals. **Annual Review of Neuroscience**, 14, 137-167.
- Pascual-Leone, A., Grafman, J. and Hallett, M. (1994). Modulation of cortical motor output maps during development of implicit and explicit knowledge. **Science**, 263, 1287-1289.
- Plautz, E. J., Milliken, G. W. and Nudo, R. J. (1995). Differential effects of skill acquisition and motor use on the reorganisation of motor representations in area 4 of adult squirrel monkeys. **Society of Neuroscience**, San Diego, CA.
- Schieber, M. H. and Hibbard, L. S. (1993). How somatotopic is the motor cortex hand area? **Science**, 261, 489-491.
- Thickbroom, G. W., Byrnes, M.L. and Mastaglia, F. L. (1999). Methodology and application of TMS mapping. **Electroencephalography and Clinical Neurophysiology**, suppl 51, 48-54.