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Exploring an Image Training Method Aimed at Improving Performance in Athletes Comparative Analysis of Excitatory Changes in Spinal Nerve Function between Baseball Pitchers and Non-Baseball Players

Takahiro Takenaka[1]* **and Yuji Nakazumi**[2]

[1]*Department of Occupational Therapy, Heisei College of Health Sciences, Gifu, Japan*
[2]*Department of Social Welfare, Kibi International University, Okayama, Japan*

Abstract

Introduction: The purpose of this study was to explore an effective imaging training method capable of improving the excitability of spinal nerve function in athletes.

Methods: We included healthy men with no history of orthopaedic or neurological injury/disease, including 14 active baseball players and 22 individuals inexperienced in baseball. For an active baseball pitcher and a person who has no baseball experience, we used two imaging methods: just an image of holding the ball and an image of the surface material texture of the ball while holding the ball. The changes in spinal nerve function excitability at this time were compared using these two imaging methods.

Excitability of spinal nerve function was calculated by F/M amplitude ratio using electromyogram.

Results: The analysis allowed us to confirm that the excitability of the spinal cord anterior horn cells was higher following imaging than at rest. It was additionally observed that the excitability of the spinal cord anterior horn cells in the pitcher group was further elevated by the imaging method that included feeling of the ball material texture. In the group without baseball experience, on the other hand, the excitability of the spinal cord anterior horn cells did not differ between the imaging method of simply holding the ball and the imaging method that included feeling the ball material texture.

Conclusions: The results of the present study suggest that it is important to individualize the imaging task based on the type and characteristics of the sport played. Therefore, when image training is applied to athletes, its efficacy may be improved by instructing the athletes to touch their specific sport-related tools and to feel the material texture of said tools during image training.

Keywords: Motor imagery; Touch perception; F-wave

Introduction

In the field of sports, image training has been actively used for improving an athlete's performance. Several prior studies on image training have focused on mental training, including methods to improve an athlete's psychological capabilities (reducing tension, nervousness, and anxiety and improving motivation) [1-4].

Several reports state that repeated practice of image training successfully improves an athlete's performance [5-9]. However, to the best of our knowledge, no effective and standardized image training program has been developed to date.

It is known that image training induces activation of the brain sites that are known to be activated during actual athletic activity [10]. Motor imagery (MI) and motor execution (ME) share a similar neural mechanism, and Jeannerod [11] proposed the concept of functional equivalence between MI and ME.

Several prior studies have demonstrated activation of the cerebral cortex and subcortical areas (that form neural networks for ME) during MI [12-17].

The motor-related regions of the cortex are the supplementary motor area (SMA), ventral premotor cortex (vPMC), dorsal premotor cortex (dPMC), and primary motor cortex (M1). These regions are closely connected via feedback loops to the cerebellum and the cerebral basal ganglia, resulting in their activation during both MI and ME. The parietal lobe is another region involved in both MI and ME [12]. The parietal lobe shows increased activity correlating with the increase of spatial task requirements during MI [13]; however, its excitation during MI is still under debate [14,15]. The site excited varies depending on the image seen. The SMA is excited during sequential motions (e.g., opposing a pair of fingers in sequence or whole-body motions), while the PMC is excited during imaging of movements mediated with a tool, such as stretching the hand toward a tool that serves as a target [16,17].

With excitability increase in cortical function with MI, excitability change in spinal nerve function is also necessary. In the recent years, studies using transcranial magnetic stimulation or evoked electromyograms have demonstrated that excitation of the corticospinal tract and spinal cord motor cells depends on the task and shows significant inter-individual variances [15]. Moreover, no consensus has been reached over whether these cells are excited by MI. A common basic view established currently is that the programmed areas at levels higher than the motor area or the corticospinal tract are activated by MI.

Regarding excitation of the spinal cord anterior horn cells during an MI task, Suzuki et al. [18] reported that the excitatory elevation of spinal

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***Corresponding authors:** Takahiro Takenaka, Department of Occupational Therapy, Heisei College of Health Sciences, 180 Kurono, Gifu City, Gifu Prefecture, Japan, Tel: +81 58 234 3324; Fax: +81 58 234 7333; E-mail: t.takenaka@heisei-iryou.ac.jp

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nerve function during MI is affected by the descending fibers from the cerebral cortex. As proof of the influence of the pyramidal tract, Lift et al. [19] and Lotze et al. [20] reported activity of the SMA, PMC, cerebellum, and cerebral basal ganglia during MI, indicating that each of these areas is involved in MI, resulting in increased excitability of the spinal cord anterior horn cells mediated by the corticospinal tract. Furthermore, regarding the influence of the extrapyramidal tract, it is considered that the excitability of the spinal cord anterior horn cells is elevated via the medullary reticular formation tract and the rubrospinal tract because the MI, SMA, PMC, and cerebellum are projected into the medullary reticular formation and the cerebellum is projected into the red nucleus. Thus, the phenomenon of excitation of the spinal cord anterior horn cells during imaging has been gradually discovered.

The magnitude of increase in athletic performance achieved through image training is considered to be smaller than the increase achieved through actual physical training [6]. However, it is believed that when athletes cannot undergo physical training due to injury or other reasons, image training is an effective method for maintaining and improving athletic performance.

In this study, we attempted to investigate the changes in the excitability of the spinal cord anterior horn cells following image training. For this study, we chose to focus on baseball, as it is one of the most popular sports in Japan. Baseball places considerable strain on the shoulders and elbows in players, resulting in a particularly high frequency of injury, especially in pitchers.

Our previous study reported the results of image training in 10 baseball pitchers [21]. The present study was therefore undertaken as a re-evaluation of the same topic in a larger number of subjects and using a modified analytical method. In addition, the same two imaging methods were practiced by subjects without experience of baseball (non-baseball players) to compare the results with those from the active baseball pitchers.

The purpose of this study was to explore an effective imaging training method capable of improving the excitability of spinal nerve function in athletes. This would enable them to maintain and improve their performance even when they cannot train, such as after an injury.

Subjects and Methods

Subjects

We included healthy men with no history of orthopaedic or neurological injury/disease, including 14 active baseball players (right-handed pitchers) aged 20.6 ± 3.67 years (mean ± SD) and 22 right-handed individuals inexperienced in baseball (20.05 ± 0.95 years). The control subjects were deemed right-handed if their laterality score was 100 in the prior Edinburgh handedness test [22].

The purpose and methods of this study were informed both orally and in writing to the target individuals prior to the study; men who volunteered for participation were selected as the subjects in this study. The study protocol was reviewed and approved in advance at the institutional review board of the facility to which the author belonged (H27-25).

We used two imaging methods for the active baseball pitchers–an image of a person holding a baseball and an image of the ball surface material texture, while actually holding the ball. The changes in the excitability of spinal nerve function were compared between these two imaging methods. In addition, the same two imaging methods were practiced by subjects without any experience of baseball to compare the results with those from the active baseball pitchers (Figure 1).

Methods

Regarding measurement of the F wave during imaging of the ball-holding motion, the excitability of the spinal cord anterior horn cells may be affected by the inter-individual differences in imaging capability. For this reason, the imaging capability of each subject (the capability for controlling the mental image rotation), i.e. the extent of image controlling ability, was first evaluated. For this measurement, each subject practiced the hand's mental rotation task with the use of the application available on the website (Neuro Orthopaedic Institute Australasia Recognise Online), In this application, 20 consecutive images of the right and left hands are presented at random [23]. The subject is required to answer whether the right or left hand has been presented. The mean correct answer rate and the mean reaction time were measured for the right- and left-hand image presentations. A longer reaction time is known to indicate a lower capability of sports imaging [24].

Next, for assessing excitability of the spinal cord anterior horn cells, the F wave was recorded with an electromyograph MEB-9402 (Nihon Kohden, Tokyo, Japan). During this assessment, the subject sat on a chair and placed the forearm and hand on the table, with the shoulder joint set in the intermediate internal/external rotation/slightly bent

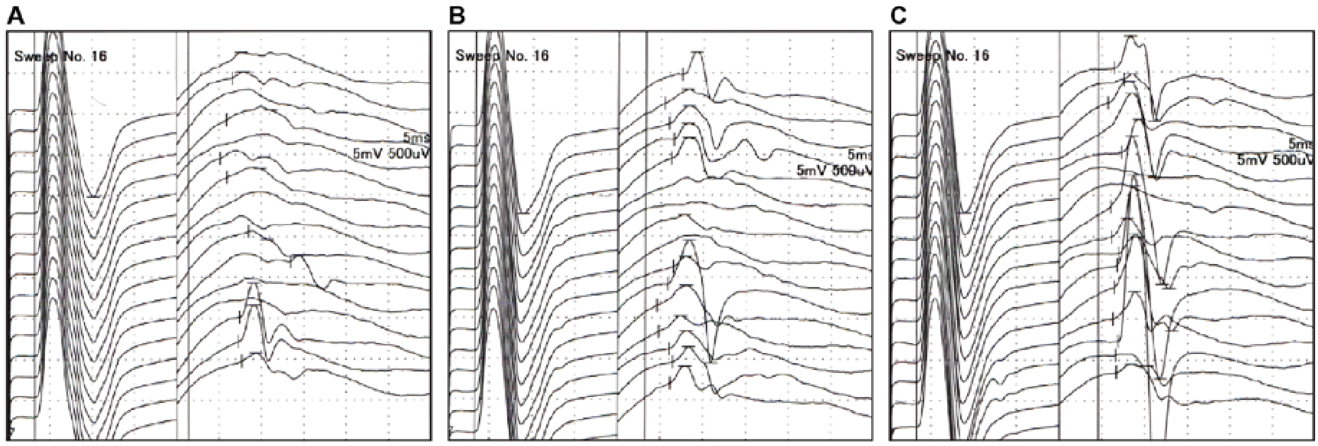

Figure 1: F wave during each task by baseball pitchers.

position and the elbow joint bent by about 60 degrees. In accordance with the method described by Kimura [25], the median nerve was maximally stimulated at the wrist joint, and the F wave was recorded from the right abductor pollicis brevis muscle using the belly tendon method. The stimulation interval was 1 Hz, and records were taken for 16 consecutive sessions. The band path was set at 1 Hz to 3 KHz. The mean amplitude of the F wave was calculated from the records of 16 sessions of stimulation, and the ratio of F wave amplitude to the simultaneously recorded M wave amplitude was calculated. This ratio was deemed the F/M amplitude ratio.

First, to measure the F wave at rest, the subject gently placed the hand on a ball and assumed a functional limb position (thumb opposed). Then, the following ball-holding image tasks were practiced at random. Task 1: Recording the F wave during imaging of holding a plain ball with isometric contraction (maximum contraction) in the functional limb position (the thumb-opposing position with the hand gently placed on the ball). Task 2: Recording the F wave during imaging with isometric contraction (maximum contraction in the functional position, i.e. the thumb-opposing position with the hand gently placed on a proper baseball) while feeling the seam and material of the ball. The diameter of the ball used for Task 1 was equal to that of the ball for Task 2, but the ball used for Task 1 had no seam. Immediately after each task, the clarity of imaging capability was evaluated with the Movement Imagery Questionnaire-revised (MIQ-R) prepared by Hall et al. [26,27] using the 7-item Kinesthetic Imagery Scale (Figure 1).

During each task of ball-holding imaging, each subject was orally instructed to avoid hand/finger movement and straining. Measurement was started after confirming absence of straining with the electromyographic wave pattern.

Statistical analysis

One-way analysis of variance (ANOVA) and Tukey honestly significant difference test (Tukey HSD) were employed for statistical analysis. Comparison of F/M amplitude ratio among three settings (rest, Task 1, and Task 2) was conducted. The Wilcoxon test was used for evaluation of imaging capability. Data were analysed with SPSS Statistics (Tokyo Japan, IBM Co., Ltd.) 24.0. A $p<0.05\%$ was regarded as statistically significant.

Results

Mental rotation task

In prior evaluation of the imaging capability (mental image rotation control capability) of each subject, the mean correct answer rate in the baseball pitcher group was 89.29 ± 10.72% for the right-hand image and 85.71 ± 7.56% for the left-hand image. Thus, there was no significant difference in the correct answer rate between the right and left hands in the group consisting of pitchers (all right-handed).

In the group without baseball experience, the mean correct answer rate was 87.27 ± 9.85% for the right-hand image and 85.27 ± 13.17% for the left-hand image, without a significant difference between the right and left hands.

The mean reaction time to the image in the pitcher group was 1.28 ± 0.31 seconds for the right-hand image and 1.31 ± 0.30 seconds for the left-hand image, without a significant difference between the right and left hands. The same parameter for the group without baseball experience was 1.39 ± 0.48 seconds for the right-hand image and 1.34 ± 0.40 seconds for the left-hand image, without a significant difference between the right and left hands.

No subject from the baseball experience group (the pitcher group) or the group without baseball experience showed a markedly low correct answer rate or a markedly long reaction time.

F/M amplitude ratio

The F/M amplitude ratio and standard deviation for each task in the pitcher group are shown below in Table 1.

A significantly higher F/M ratio was seen during Task 1 and Task 2 than at rest (significantly higher during Task 2 than during Task 1).

In the analysis of variance, the P value for inter-group difference was 0.000, and equal variance (0.721) was confirmed using the Levence test. Multiple comparison using the Tukey HSD revealed significant elevation of the F/M amplitude ratio with isometric contraction imaging when a comparison was made between rest and Task 1. Moreover, when comparing the F/M amplitude ratio between rest and Task 2, the F/M amplitude ratio was significantly higher during imaging.

When a comparison was made between Task 1 and Task 2, the F/M amplitude ratio was significantly higher during Task 2 imaging (holding the ball while feeling the ball seam and material).

The F/M amplitude ratio and standard deviation for each task in the baseball inexperienced group are shown below in Table 2.

A significantly higher F/M ratio was seen during Task 1 and Task 2 than at rest (no significant difference between Task 1 and Task 2).

When the analysis of variance was conducted, the P value for inter-group difference was 0.008, and equal variance (0.054) was confirmed using the Levence test. Multiple comparison using the Tukey HSD revealed significant elevation of the F/M amplitude ratio with isometric contraction imaging when comparison was made between rest and Task 1. Moreover, when comparing the F/M amplitude ratio between rest and Task 2, the ratio was significantly higher during imaging.

When comparison was made between Task 1 and Task 2, there was no difference in the F/M amplitude ratio, indicating that no change is caused by the imaging of holding the ball while actually feeling the ball seam and material.

Evaluation of clarity after imaging

When clarity of the image after each task was evaluated with the MIQ-R scale, the median for the pitcher group was 4.5 (quartile range 4-5) during Task 1 and 3 (quartile 3-4) during Task 2. In the group

	Rest	Task 1	Task 2	Each task's F/M amplitude ratio (%)	95% confidence interval	
				Mean ± SD	Lower limit	Upper limit
Rest	–	$.005^{**}$	$.000^{**}$	1.2148 ± 0.77964	0.7646	1.6649
Task 1		–	$.031^{*}$	2.1122 ± 0.67295	1.7237	2.5008
Task 2			–	2.8152 ± 0.65731	2.4356	3.1947

Table 1: F/M amplitude ratio for each task and p value of multiple comparisons (baseball pitcher group).

	Rest	Task 1	Task 2	Each task's F/M amplitude ratio (%)	95% confidence interval	
				Mean ± SD	Lower limit	Upper limit
Rest	–	$.046^{*}$	$.009^{**}$	0.842 ± 0.587	0.5817	1.1022
Task 1		–	.796	1.4822 ± 0.8395	1.11	1.8544
Task 2			–	1.6516 ± 1.1099	1.1595	2.1437

Table 2: F/M amplitude ratio for each task and p value of multiple comparison (group without baseball experience).

without baseball experience, it was 3.5 (quartile 3-5) during Task 1 and 4 (quartile 2.75-5.25) during Task 2. There was no significant difference in this parameter between Task 1 and Task 2 in either of the two groups.

Discussion and Conclusion

Evaluation of the excitability of the spinal cord anterior horn cells uses H and F waves recorded from the test muscles following transcutaneous electrical stimulation of the nerves that control these muscles. In the upper limbs, few muscles stably emit H waves [28]; therefore, the F wave is usually recorded. The name "F wave" was first used in 1950 when Magladery and McDougal [29] reported the response with long latency period using this name (it was named the "Foot Wave" as it was first recorded using the foot muscles). Subsequently, it was discovered that this wave can be recorded from the nerves all over the body, not just those in the foot. Because the F wave can be recorded easily, it is now widely used during clinical evaluation.

The F wave represents the complex muscle action potentials arising from stimulation of motor nerve fibers that induce retrograde impulses leading to re-firing from the spinal cord anterior horn motor neurons and subsequent formation of anterograde impulses. However, such re-excitation does not occur in all neurons. Even in neurons capable of being re-excited, re-excitation does not occur in response to each stimulation. Re-excitation of the same neuron can occur in response to only one out of about 10-100 stimulations. For this reason, when records are taken with surface electrodes, re-excitation of only several motor units at maximum is recorded in response to one stimulation; moreover, the latency, amplitude, and waveform vary from one stimulation to another.

The M wave, sometimes called "complex muscle cation potentials," is an outcome of surface recording of the total of all action potentials of the muscles, which usually have several hundreds of motor units, while several unit potential waveforms can be identified from F wave. For this reason, the amplitude of the F wave is only 1% to 5% of the M wave amplitude; the waveform of the M wave is multiphasic and unstable, varying greatly in latency from one stimulation to another. However, following about 10 sessions of stimulation, the minimum latency of the F wave usually becomes almost constant and its reproducibility is quite excellent. This means that if the stimulation is repeated 10 times, at least one stimulation causes excitation of the most rapid motor nerve fiber through retrograde stimulation. The minimal latency of the F wave is dependent on the probability for excitation by the retrograde stimulation of motor neurons; this feature differentiates this test from other nerve conduction tests.

The F wave amplitude is proportional to the number of spinal cord anterior horn cells that re-fire in response to stimulation. Its amplitude varies depending on the waveform and is not consistent. However, the normal value of the ratio of mean F wave amplitude to maximum M wave amplitude (F/M amplitude ratio) is consistent to some extent. For this reason, the F/M amplitude ratio was used for analysis in this study.

When the mental rotation task was practiced before recording the F wave, no subject showed a marked delay in response (markedly long reaction time). For this reason, all the subjects were included in the statistical analysis. The analysis allowed us to confirm that the excitability of the spinal cord anterior horn cells was higher following imaging than at rest. It was additionally observed that the excitability of the spinal cord anterior horn cells in the pitcher group was further elevated by the imaging method that included feeling of the ball material texture, which is similar to the findings from our preceding study [21]. In the group without baseball experience, on the other hand, the excitability of the spinal cord anterior horn cells did not differ between the imaging method of simply holding the ball and the imaging method that included feeling the ball material texture.

We need to bear in mind that recognition of the material texture during daily living is always preceded by visual information and that information about the object to be touched is needed as prior knowledge. The baseball pitchers involved in the present study are considered to have had sufficient prior information needed for visual recognition of the ball because they use the ball routinely. Furthermore, since pitchers tend to pay considerable attention to the feel of the ball when they handle it (i.e., the seam and material) during pitching, they are more likely to recognize the ball seam and to texture. Klatzky et al. [30] reported that specific visual information, such as surface irregularity or smoothness, induces a desire to touch a specific object. Based on this finding, we may state that better imaging is possible if the seam texture of the ball is recognized while holding the ball. In the group without baseball experience, the subjects had seldom touched the ball before and the only imaging method possible for them was simply holding the ball. For the individuals who touch a baseball for the first time, the input of stimulus to the tactile sense is unlikely to produce a more real image of ball holding. For this reason, excitation of the spinal cord anterior horn cells is difficult to achieve by these individuals even when the imaging covers the material texture. Holmes et al. [31] proposed a PETTELEP model consisting of 7 elements (physical, environment, task, timing, learning, emotion, and perspective) to enable more effective MI, stating that simply instructing the individual to generate an image of physical activity is not sufficiently effective. For the same reason, it is necessary to customize the imaging task based on the experience, life history, and the nature of the sport involved of individual athletes when image training is applied. The results of the present study suggest that it is important to individualize the imaging task based on the type and characteristics of the sport played.

Wang et al. [32] reported that during image training of athletes focused on the sport they were involved in, the motor evoked potential amplitude was larger during actually touching the sport-related tool than when nothing was touched or held. This phenomenon was strongly observed in experienced badminton, tennis, and baseball players, suggesting that during long-term use of tools, the neural infrastructure involved in the formation of tool touch-produced pressure sense and motor commands is reinforced. Therefore, when image training is applied to athletes, its efficacy may be improved by instructing the athletes to touch their specific sport-related tools and to feel the material texture of said tools during image training. We hope that the findings from the present study will provide valuable information to sports trainers, rehabilitation staff, and athletes when image training is adopted as a method of rehabilitation during any period where physical training is not feasible.

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Conflicts of Interest

The authors have no conflicts of interest to report.

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