Changes in Motor Imagery Along with Improved Skills in a Beginner Baton Twirler: A Single Case Experimental Study Using EEG

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Psychological and physiological indices including introspective reports, visual analogue scales, and electroencephalogram data were used to investigate during motor imagery and skills acquisition, as well as changes in perspectives during motor imagery in a beginner baton-twirler. We also used a single case experimental design and followed the beginner baton-twirler for three years and intermediate twirlers for two years. Their electroencephalograms were monitored while they engaged in motor imagery of actual baton twirling movements and their $\alpha$ and $\beta$ band activities were analyzed as indices of arousal. After completing motor imagery, participants responded to the visual analogue scale inquiring about difficulty, vividness, and controllability of motor imagery. Moreover, participants reported skills they obtained and results of competitions. We observed acquisition of new skills, improved results, increased vividness, better regulation of motor imagery, changes in motor imagery perspective, as well as increased $\alpha$, and decreased $\beta$ band activities. These results suggest that proficiency in skills promoted high quality motor imagery at an adequate arousal.

Keywords: baton twirlers, electroencephalogram (EEG), motor imagery (MI), single case experimental design

1. Introduction

Motor imagery (MI) is defined as psychological rehearsal of motor activity without any motion being observable to a third person (Porro et al., 1996). Numerous studies on MI have been conducted using subjective questionnaires (Hall and Martin, 1997; Isaac et al., 1986). MI studies have focused on two imagery abilities: vividness of imagery based on similarities between participants’ imagery and actual movements, and controllability of imagery based on the degree of control. Expert sport players are reported to have more vividness and regulation of imagery (Orlick and Partington, 1988). In addition, MI has been categorized into two perspectives: first person MI and third person MI. It has been reported that highly competitive players tend to engage in more first person than third person MI (Mahoney and Avener, 1977). Increased competitive ability is known to change the quality and perspective of MI. Although numerous cross sectional studies targeting sport players of various levels have examined differences in MI quality and perspective, longitudinal changes in MI corresponding to acquisition of new skills in beginners remain unknown. In addition, previous studies have focused mainly on relationships between MI and actual movements while simple standing, or during simple arms flexion (Hall and Martin, 1977; Isaac et al., 1986). However, only a few studies have investigated MI during movements particular to sports.

In addition to subjective evaluations using questionnaires, the electroencephalogram (EEG), which enables tracking brain activities during MI has been used to evaluate MI (Ehrlichman and Wiener, 1980; Nam et al., 2011). Moreover, each EEG frequency band has been correlated with psychological activities. It is known for example that $\alpha$ waves with a relatively low frequency of 8-13 Hz increase, whereas $\beta$ waves, which are observed around 14-20 Hz, decrease during relaxation (Marraro et al., 2001). In particular, $\beta$ waves are known to increase
Brain Activity of Baton Twirlers during Motor Imagery

during psychological activity (Dolce and Waldeier, 1974), and α waves are suppressed during imagery (Ehrlichman and Wiener, 1980). Therefore, arousal level can be estimated from the rate of α and β wave appearance during MI of psychological activities and are considered suitable indices for assessing arousal during MI. Louis et al. (2011) reports that arousal level affect MI qualities. It was expected that measuring EEG during MI would provide information regarding central nervous system activity reflecting subjective evaluations, and provide information on neurophysiological mechanisms related to changes in the quality and the perspectives of MI. Therefore, α and β band activities of the EEG were utilized as an index of arousal during MI. In addition, areas such as the primary motor area, which is related to motor output, are known to become activated during MI (Roth et al., 1996). Moreover, each frequency band that reflect the activity of the sensorimotor area related to motor control is known to change during MI (Nam et al., 2011) and occipital areas is known to get activated when engaging in visual imagery (Thompson et al., 2001). In generally, previous studies have been that the negative correlation between cortical activation and the power of α/β wave with EEG and neuroimaging procedures. Negative correlations at the power of α wave has been reported within such as the parietal area, the frontal area (Laufs et al., 2003) and the occipital area (Goldman et al., 2002), or negative correlations at the power of β wave has been reported the sensorimotor area (Yuan et al., 2010). Therefore, this study investigated these areas.

The visual analogue scale (VAS) was used for assessing difficulty, vividness, and controllability of MI in order to examine effects exerted by changes in movement on MI during actual sports settings. Moreover, we longitudinally examined basic skills that were acquired, as well as the results of competitions, in order to investigate the process of improvements in competitive ability. Therefore, changes in EEG and VAS were evaluated along with competitive ability. Changes in MI were observed using physiological and psychological indices during the process of learning a new sport by a novice player. We hypothesized that there would be changes in the MI perspective from the third person to the first person MI (Mahoney and Avener, 1977); that the quality of MI would improve (Orlick and Partington, 1988), and that EEG would change in the process of developing competitive ability (the decrease of α wave and increase of β wave).

2. Method

2.1. Participants

The participant in the present study was a female student in the baton twirling team of a physical education university. We measured her EEG on nine occasions, beginning just after she started college at 18 years of age and practicing in baton twirling as a beginner. She had played basketball for five years previously, but was new to baton twirling and other related sports such as dance and gymnastics. We also measured the EEG of five female intermediate level twirlers on two occasions, simultaneously with the first (mean age 19.2 ± 0.4 years; mean years of experience, 9 ± 4 years) and fifth (mean age 20.2 ± 0.4 years, mean years of experience 10 ± 5 years) measurements of the beginner, and compared their data. All participants were right-handed (Edinburgh Handedness Inventory, mean of laterality quotient 90 ± 5.8: Oldfield, 1971).

Practice was held four times a week during the study period and lasted three hours per practice session. Moreover, none of the participants had engaged in special imagery training and had never been told to engage in related activities.

We explained the study verbally and in writing prior to commencing each of the nine EEG measurements of the beginner and the two measurements of intermediate twirlers, and obtained their informed consent. The study was conducted in accordance with the Helsinki Declaration and was approved by the institutional review board at the Osaka University of Health and Sport Sciences (the approval code: 12-3).

2.2. Experimental task and environment

The study was conducted in a soundproof room with participants sitting on a reclining chair with an armrest. Their task was to imagine baton twirling movements related to their individual performance and raise a hand to notify the end of imagery. The content of MI was the solo which is performed, in the latest competition, and therefore, was different across sessions. They were requested to imagine as vividly as possible in the first person perspective as...
if they performed the movements as far as possible. The identical procedure was used for the beginner and intermediate twirlers.

2.3. EEG

The study period for intermediate baton twirlers was two years, and two recordings were conducted simultaneously with the first and fifth measurements of the beginner. The EEG was recorded between 10:00 and 16:00, the recording lasted for two hours. The EEG was measured with the Alliance Works V3.6.1R (Nicolet Biomedical Japan Inc., Japan) and analyzed with Atamap II (KISSEI COMTEC Inc., Japan). The EEG signal was recorded from Ag/AgCl scalp electrodes following the international 10-20 system, which specifies 13 electrode locations on the scalp, Fz, F3, F4, Cz, C3, C4, Pz, P3, P4, T3, T4, O1, and O2. Both earlobes electrodes served as the reference. In order to eliminate artifacts caused by Electrooculogram (EOG), the electrodes were placed vertically, 1 cm above the left eyebrow and 1 cm below the eyelid, as well as horizontally, 1cm lateral from the left and right canthus. Resistance was set to below five kΩ. Measurements one second after commencing MI and five seconds before finishing MI were excluded from the analysis because of possible artifacts.

2.4. Psychological indices: VAS, introspective reports, baton twirling skill acquisition, and competition results

After finishing EEG measurements, participants’ imagery ability was assessed using the VAS responses to question regarding (1) difficulty (How hard was it to imagine?), (2) vividness (How vivid was your MI?) and (3) controllability of MI (How well could you control your MI?). Maximum and minimum values for each question in the VAS were written on the right and left sides of a 100 mm horizontal line and participants marked the point that best expressed their subjective feelings. In addition to these questions, participants provided an introspective report about MI using free writing.

We categorized baton twirling skills into three types in accordance with general classification of skills in baton twirling competition: aerial (throwing the baton in the air), roll (rolling the body without holding the baton), and contact material (rotating the baton with fingers or hands). Once per year, we asked participants to describe skills that they had acquired and to assign them to above three types, because baton twirling skills are overlapped among types. We also asked participants to write-down information about competitions that they had participated, including the type of competition, the section attended, and the results.

2.5. Procedure

The study period for the beginner baton twirler was three years (from 18 to 20 years of age) and during this period, nine recordings were conducted every four months.

Participants sat in a reclining chair. Then, the procedure of the study was explained while the electrodes were being attached. In order to confirm the stability of EEG waves, the EEG was recorded with eyes closed for three minutes. Then, we recorded the EEG with participants’ eyes open and closed for thirty seconds each, in order to confirm the presence of EOG. Then, when participants were relaxed EEG was recorded for five minutes with eyes closed, which was followed by MI with eyes closed. EEG measurements and frequency analysis of MI were conducted from one second after commencing MI to five seconds before finishing MI. Participants were told not to move as far as possible during the measurements. After finishing MI, participants responded to the VAS about MI and provided the retrospective report about MI in free writing.

2.6. Recording method

EEG was recorded at a sampling frequency of 250 Hz and band-pass filtered with cutoffs of 0.5 and 30 Hz. We eliminated intervals with EOG artifacts from the analysis, and calculated the power spectrum value by high speed Fourier transformation at 512 points for the EEG. Thereafter, we categorized the bands into four types of waves, δ waves (2-3 Hz), θ waves (4-7 Hz), α waves (8-13 Hz), and β waves (14-30 Hz), and calculated the proportion of each bands from δ to β waves power as a percentage (Yordanova et al., 1998). Previous studies have examined α waves during MI (Ehrlichman and Wiener, 1980), as well as α and β waves as a possible index of arousal level (Marrufo et al., 2001; Petruzzello et al., 1991). Therefore, in this study,
we have presented the results of $\alpha$ and $\beta$ waves. We converted 1 mm in the VAS to 1 point, with a total of 100 points, and calculated the points from the left end of the line to where the participants marked the line.

### 2.7. Data analysis

A single case experimental design generally requires a stable baseline period and clear differences in measures between the baseline and intervention periods (Bear 1977; Parsonson and Bear, 1978). Therefore, the present study followed an AB design, which has been utilized in single case experimental designs, by considering first year (the first to fourth session) as the baseline period and the second (the 5th to 7th session) to the third year (the 8th to 9th session) as the intervention period. The baseline period was determined by the stability of EEG and VAS, the acquisition of skills, and the results of competitions. The baseline stabilities were confirmed (both averages of two sessions in the first half and those in the second half of the baseline period were within grand average value of 4 sessions in the baseline period $\pm 15\%$.) with reference to previous studies (Perone, 1991; Sidman, 1960). After calculating means and standard deviations for the first year, we drew two horizontal lines to indicate the area between $\pm 2$ S.D., such that it included results from second to third year (the 5th to 9th session) according to the method proposed by Post et al. (2012). When the data of second and third years pointed above or below these lines on two or more consecutive occasions, we considered that there has been a change. Moreover, we drew approximate lines to examine differences in slopes. This procedure was applied to EEG of MI when the participants were relaxed with closed eyes and VAS data. We calculated means and standard deviations of EEG and VAS scores for first and the second session for intermediate twirlers, and conducted a pre and post $t$-test. The significance level was defined as $p = .05$.

### 3. Results

#### 3.1. EEG

The average time of MI across all sessions was $88.6 \pm 24.4$ seconds for the beginner and $85.1 \pm 9.8$ seconds for intermediates. The $\alpha$ and $\beta$ waves during the relaxation with closed eyes for the beginner are shown in Figure 1. No changes in these waves during the three years. Figure 2 shows changes in $\alpha$ and $\beta$ waves of the beginner during the three years. The horizontal axis shows the number of sessions with black dots indicating $\alpha$ and white dots indicating $\beta$ waves. Moreover, broken lines indicate first year’s mean $\pm 2$ S.D. of $\alpha$ waves and the solid lines indicate first year’s mean $\pm 2$ S.D. of $\beta$ waves. It can be seen that $\alpha$ waves in Fz, F3, F4, Cz, Pz, P3, P4, O1, and O2 increased from the first year to the second and the third year, whereas $\beta$ waves in Fz, F3, F4, P3, P4, O1, and O2 decreased in the second and the third year as compared to the first year. On the other hand, no differences were observed when $\alpha$ and $\beta$ waves of intermediate twirlers were compared between first and second sessions, $p > .05$ (Figure 3). Therefore, it is suggested that changes in the EEG observed could be specific to the beginner.

#### 3.2. Visual Analogue Scale

Figure 4 shows the VAS score of imagination ability of MI in the beginner. The horizontal line indicates the number of sessions. We drew the lines from the first to the second and the third year, which indicated mean $\pm 2$ S.D. of the first year. It can be seen (1) the difficulty of MI decreased in the second and the third year (Figure 2A), whereas (2) vividness and (3) controllability increased (Figure 2B, C).

Results of VAS scores of MI ability among intermediate twirlers were (1) the difficulty (first session, $M = 39$, $S.D. = 10.4$), second session, $M = 42.2$, $S.D. = 8.9$), (2) vividness (first session, $M = 65.8$, $S.D. = 10.1$; second session, $M = 65.6$, $S.D. = 5.0$), and (3) controllability (first session, $M = 66.2$, $S.D. = 10.0$, second session, $M = 61.4$, $S.D. = 7.0$). It can be seen that no differences in responses were observed between first and second sessions for any of the questions, $p > .05$.

#### 3.3. Introspective reports on skills acquisition and competition results

Introspection about MI in free writing by the beginner in the first session: “since I have just started baton twirling, imagery itself is difficult.” The second session: “I learned the movements by looking
Figure 1  EEG during the relaxation with closed eyes of the beginner (N = 1)
The EEG of a beginner baton twirler measured in each electrode. The vertical axis indicates percent content, and
the horizontal axis indicates the session number. Lines indicate the two standard deviation confidence intervals of
first, second and third years for α (dotted line) and β waves (solid line).

Figure 2  EEG during the MI of the beginner (N = 1)
The EEG of a beginner baton twirler measured in each electrode. The vertical axis indicates percent content, and
the horizontal axis indicates the session number. Lines indicate the two standard deviation confidence intervals of
first, second and third years for α (dotted line) and β waves (solid line).
Figure 3  EEG during the MI of intermediates (N = 5)
The mean content for EEG intermediate baton twirlers measured in each electrode. The vertical axis indicates percent content, and the horizontal axis indicates the session number. Error bar indicates standard deviation across the participants.

Table 1  Skills acquisition process of the beginner.
Three types of skills acquired by the beginner in each year: aerial, roll and contact material.

<table>
<thead>
<tr>
<th>Year</th>
<th>Aerial</th>
<th>Roll</th>
<th>Contact material</th>
</tr>
</thead>
<tbody>
<tr>
<td>The first year</td>
<td>Toss, One spin, Flat toss</td>
<td>Double elbow, Fishtail,</td>
<td>Thumb flip</td>
</tr>
<tr>
<td>The second year</td>
<td>Cartwheel, Two spin, Flat one spin</td>
<td>Angel roll, Layout</td>
<td></td>
</tr>
<tr>
<td>The third year</td>
<td>Illusion, Flat two spin</td>
<td>—</td>
<td>Blind catch</td>
</tr>
</tbody>
</table>

at my seniors. Because of that or for another reason, it was difficult to imagine in a subjective manner.” The third session: “I started learning new skills, so the image was more difficult than before.” The fourth session: “it was difficult to imagine the scenes of competitions. I lost my concentration in the middle.” The fifth session: “when I imagined detailed movements such as finger movements, my perspective changed from an objective to a subjective one, changing as if I were performing the movement.” The sixth session: “I imagined skill with a different timing from what I actually did in a practice.” The seventh session: “I could vividly imagine. I think I was able to image more clearly than in the last time, but I was not able to move the image as I wanted to.” The eighth session: “the number of objective imagery decreased; instead I could use more subjective imagery.” The ninth session: “I think the imagery was close to what I intended to imagine. I was more focused than usual.”

Table 1 shows skills acquired by the beginner during three years. This participant reported the skills that were acquired in free writing, which are listed by three basic categories of baton twirling skills, aerial, roll, and contact material. During the first year, for aerial, the participant acquired the toss (throwing up the baton in the air), one spin (spin once while throwing up the baton in the air), and flat toss (throwing the baton horizontally to the
The vertical axis shows the VAS score, and the horizontal axis shows the session number. Figure 2A: The difficulty of MI by the beginner. The black dots are changes in VAS score, the solid lines indicate the two standard deviation confidence interval of first (first to forth sessions), second, and third years. Approximate lines were drawn for the first year and second and third years. Figure 2B: The vividness of the MI in the beginner. The white dots indicate changes in VAS scores, and dotted lines indicate the two standard deviation confidence interval, of first (first to forth sessions), second, and third years. An approximate line was drawn for the first year and second and third years. Figure 2C: The controllability of the MI in the beginner. The black squares indicate changes of VAS scores, and the dotted lines indicate the two standard deviation confidence interval of the first (first to forth sessions), second, and third years. Approximate lines were drawn for the first year and second and third years.

The participant acquired behind (managing the baton in the back of the body) and practiced to improve the skills learned in the first year for contact material. During the third year, the participant acquired illusion (step and swing leg in fan motion over as body bows down. 1/2 of a cartwheel.) and flat two spin (spin twice while throwing the baton horizontal to the floor). For the roll, the participant practiced the skills learned in the previous years, thus no new skill was acquired. For the contact material, the participant acquired blind catch (catch the baton without looking at it). Throughout these three years, the skill level increased gradually. The intermediate participants reported they practiced skills that they had already acquired, as well as combinations of those skills, instead of new skills. Results of competitions with technical evaluation (Table 2) improved in the beginner. In the third year, the participant played in the national competition as a part of a team of four, instead of as an individual. It was considered that the competitive performance of the beginning baton twirler improved over the three-year period.

4. Discussion

4.1. EEG

The hypothesis of this study was not supported. Areas corresponding to medial (Fz, Cz, Pz), left and right frontal areas (F3, F4), and parietal areas (P3, P4), and occipital areas (O1, O2) indicated an increase in the percentage of $\alpha$ wave content and a decrease in $\beta$ wave content from the second to the third year in the beginner. Since the content of MI was that of the solo performance in the latest competition, it was expected that MI would reflect the skill level. Moreover, an increase in $\alpha$ wave and a decrease of $\beta$ wave were observed in Fz, F3, and F4 that corresponded to the frontal lobe, compared to between the first year and the
second to third year. The frontal lobe is closely related to executive function. In particular, dorsolateral prefrontal cortex corresponded to F3 and F4 is responsible for the main role of its function (Grafman and Litvan, 1999). Tekin and Cummings (2002) reported that dorsolateral prefrontal cortex is associated with the maintenance and switching of attention. The increased percentage of $\alpha$ waves and decreased percentage of $\beta$ waves during the second to third year suggest that MI was performed in the second and third years, by relaxation and middle arousal levels. Moreover, an inverted-U hypothesis was proposed to explain the relationship between arousal and $\alpha$ waves (Hori, 2008). In addition, the decrease of difficulty in MI and improvement in controllability indicated by VAS might reflect the ability to conduct controllable and vivid MI at an optimal arousal level, without spending too many cognitive resources for MI. Furthermore, the values for the frontal areas changed significantly in the fifth session, which might reflect improvements in imagery quality for detailed movements described in the introspective report. These results suggest the possibility that the activity of frontal area might be in the state of relaxation and middle arousal level by the high quality of detailed movements.

Cz corresponds to the primary motor, premotor areas and supplementary motor area. Although MI is different from when a person is actually engaging in real movements, these areas are known to activate while a person is engaging in first person MI (Roth, et al., 1996). The brain activities during MI are similar to those when engaging in actual sports (Luft et al., 1998). The present study analyzed content percentage of brain waves, and therefore, it is difficult to refer to the degree of activation. However, changes such as the increase in the percentage of $\alpha$ and the decrease in the percentage of $\beta$ waves were observed in this area. Furthermore, the introspective report that the MI perspective changed from third to first person MI from second to third years suggest that brain activity during MI could have been similar to when engaging in actual movements. These results suggest that changes in MI per-

Table 2 Competitions attended by the beginner. Summary of competitions attended by the beginner are shown by competition name, competition type, part within competition and results.

<table>
<thead>
<tr>
<th>Competition</th>
<th>Competition type</th>
<th>Part within competition</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Contest</td>
<td>Technical evaluation for the national competition</td>
<td>The first place</td>
</tr>
<tr>
<td>Osaka regional contest</td>
<td>Preliminary competition for the Kansai regional competition</td>
<td>Beginner (Solo twirl$^1$)</td>
<td>The first place</td>
</tr>
<tr>
<td>Kansai regional contest</td>
<td>Preliminary competition for the national competition</td>
<td>Introductory (Two batons$^2$)</td>
<td>The first place</td>
</tr>
<tr>
<td></td>
<td>Technical evaluation for the national competition</td>
<td>Contest (General)</td>
<td>The second place (Pass the preliminary section)</td>
</tr>
<tr>
<td>Osaka regional contest</td>
<td>Preliminary competition for the Kansai regional competition</td>
<td>Preliminary section for the national competition (General)</td>
<td>The second place (Pass the preliminary section)</td>
</tr>
<tr>
<td>Kansai regional contest</td>
<td>Preliminary competition for the national competition</td>
<td>Intermediate (Solo twirl$^1$)</td>
<td>The second place (Pass the preliminary section)</td>
</tr>
<tr>
<td>National competition</td>
<td>Preliminary section for the national competition</td>
<td>Contest (General)</td>
<td>The second place (Pass the preliminary section)</td>
</tr>
</tbody>
</table>

1 Solo twirl: Individual performance of the baton technique using one baton.
2 Two batons: Individual performance of the baton technique using two batons.
3 Dance twirl: Individual performance of the combination of the baton technique and dance in the music.
perspective indicated by psychological indices were reflected in the EEG, which is a physiological index and corroborates the results of psychological indices. On the other hand, there were no changes in the EEG at C3 and C4 corresponding to the sensorimotor area. It is possible that the beginner had practiced basketball and therefore had experienced a certain level of MI ability. The reason for not observing differences in EEG at C3 and C4 across the sessions could be because the sensorimotor areas had, to some extent, been activated from the first year.

O1 and O2 that correspond to the occipital area indicated a significant increase in $\alpha$ wave percentage after the seventh session. The occipital area is activated when engaging in visual imagery with closed eyes (Thompson et al., 2001). The percentage of $\beta$ waves decreased and that of $\alpha$ waves increased; furthermore, the participant wrote in her introspective report that "objective imagery decreased". Visual third person MI decreased whereas first person MI increased, which is more of a musculoskeletal sensation, and this would have led to increases in the percentage of $\alpha$ waves and a decrease in $\beta$ waves. Moreover, P3, Pz, and P4 are known to reflect input from the optic area (Mishkin et al., 1983). The percentages of $\alpha$ and $\beta$ waves recorded at O1, O2, P3, Pz, and P4 changed similarly with sessions. Although no stimulation was presented when her eyes were closed, the third person MI might have affected those waves. Therefore, changes in $\alpha$ and $\beta$ waves in these areas might have reflected changes in MI perspective.

These present results suggested that there are three MI systems in the brain. One is the system that gradually changes during activities between sessions, similar to changes in the VAS at F3, Fz, F4 and Cz. These activities might reflect the optimal arousal levels during MI, and could be observed one year after the participant started to practice baton twirling. Another is the system that is centered on C3 and C4. This system might reflect the activities of the motor cortex during MI, and might not change between sessions due to a certain level of imagery ability. The last one is the system that is centered on the parietal and occipital areas and reflect the perspective of MI (third or first person MI). It is likely that this system does not change without long-term training.

4.2. Introspection and VAS score

MI is discussed from the perspective of VAS score and free writing. The VAS score of the beginner’s MI task indicated a decrease in difficulty over the three years, as well as an improvement in controllability and vividness. Introspections of the participant in the first through forth sessions of the first year mainly described difficulties in MI of baton twirling as a whole, possible because of the process of learning a new sport. In particular, the participant aimed to learn a skill based on visual information, since writing in the introspective report after the second session that “I learned to watch the movements of seniors”. The participant had attempted to learn skills by observing the movements of other people in actual settings. It is noteworthy that the perspective of MI changed in the fifth session, and she wrote more details regarding the contents of skills. Mahoney and Avener (1977) has reported that higher the skills of a player, the more often players engage in first person MI. The beginner in the present study also experienced a change in her perspective of MI as her skills improved. The VAS score also indicated a decrease in the difficulty of MI and an increase in vividness from the fifth session. In the seventh session, the participant reported that she was able to have vivid imagery, but was unable to control the imagery as much as she wanted. From the second to third year, her ideal form was relatively substantiated; furthermore, she tried to engage in MI that was suitable for her, which was reflected in the report. In the eighth session, the report indicated that she could use many first person MI, and improve the quality of MI. The introspective report of the ninth session indicated that the participant had clear and ideal MI and she could engage in MI that was close to her ideal, suggesting that she started developing an ideal form in actual movements, as could be seen in improvements in the results of her competitions.

No differences in the VAS scores were observed in intermediate twirlers. However, their scores of vividness, and the controllability were higher than those of the beginner. It is considered that intermediate twirlers already had a clear and ideal form of skills. Furthermore, no improvements in MI content or competitive ability seem to correspond to no changes in VAS scores for intermediate twirlers.

The VAS scores for difficulty in the beginner and
in intermediates were similar, but scores for vividness and controllability were very different in the second and the third year. These data demonstrated that intermediates could perform MI of higher quality with the same degree of difficulty as the beginner. It is suggested that an ideal type of skills was more clear in the intermediates. On the other hand, MI quality in the beginner was relatively limited, because the ideal type of skill was unclear. Therefore, the beginner should evaluate vividness and controllability less than intermediates.

5. Conclusion

This study examined changes in MI, simultaneously with skills acquisition by a beginner. EEG and VAS were used as indices of changes in MI. Results of competitions and assessments of skills acquired by a beginner, indicated improved skills and competitiveness during the three-year study period. Results also indicated improvements in the vividness and controllability of MI. Moreover, introspective reports suggested that the participant gradually learned to manage first person MI, rather than third person MI. Furthermore, there were increases of skills, competitiveness, and quality of MI, along with an increase in $\alpha$ band and a decrease of $\beta$ band EEG activity. In particular, comparing the first and the second to third year indicated significant changes in the brain activity and quality of MI. Concurrently, introspective report indicated that the participant learned to engage in first person MI from the second to the third year. Moreover, an inverted-U hypothesis was proposed to explain the relationship between arousal and performance (Malmo, 1959) as well as between arousal and $\alpha$ waves (Hori, 2008). However, an inverted-U hypothesis has not been reported for $\beta$ waves. Results of this study suggested that the participant learned to engage in vivid and controllable MI by relaxation and middle arousal simultaneously with improvements in skills and competitiveness. Therefore, it is conceivable that the relationship of inverted-U between quality of MI and $\alpha$ waves existed. The present study however, is a single case experiment. Changes observed in the present study could be unique to baton twirling, due to special characteristics of this sport. Moreover, these results are limited in that they refer to the function of each area. To increase the validity of the study, it would be necessary to investigate changes in MI during other sports and make measurements by using different techniques, such as functional magnetic resonance imaging.

References


