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The effect of alternate training of action observation and motor imagery on cognitive and skill performance

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The purpose of this study was to investigate the effect of alternate action observation and motor imagery training on cognitive performance in working memory and skill performance. Forty-eight beginners with no experience in Taekwondo participated in the experiment. They were randomly assigned to one of four groups: action observation (AO) training group, motor imagery (MI) training group, alternate AO+MI training group (i.e., MI after AO), and a control group. Cognitive performance was measured before and after three days of training, and one day after completion (retention test). After retention test, all participants performed three blocks of Taekwondo roundhouse kick. Results showed that alternate AO+MI training overall was more effective in improving cognitive performance and skill performance after cognitive training than independent AO and MI training. Taken together, the findings suggest that alternate AO+MI training may be considered a more effective training method as compared to AO and MI training alone.

KEY WORDS: Cognitive training, Motor learning, Motor memory, Skill acquisition, working memory.

Action observation (AO) and motor imagery (MI) are simulation states of action (Jeannerod, 2001) that are functionally equivalent to action execution (Filimon, Nelson, Hagler, & Sereno, 2007; Grezes & Decety, 2001; Lotze et al., 1999). Along these lines, AO training and MI training have been used as effective cognitive training methods facilitating motor performance and learning (Driskell, Copper, & Moran, 1994; Ste-Marie et al., 2012).

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Action observation refers to a dynamic state that simulates the observed actions and outcomes through the observation of actions performed by other people (Sale, Ceravolo, & Franceschini, 2014). In particular, in the early stage of skill learning, action observation goes through external stimulus-oriented processing because the information source required for the formation of action representations is provided by external stimuli away from the body (Eaves, Riach, Holmes, & Wright, 2016; Holmes & Calmels, 2008). External stimuli through such action observation influence the formation of action representations and changes in neurophysiological factors (Grezes & Decety, 2001; Kim, Frank, & Schack, 2017). Actually, action observation training has been typically used as an effective cognitive training method for the change of social behaviors as well as improvement of motor skill, strategy, and mental preparation (see meta-analysis by Ashford, Bennett, & Davids, 2006; Bandura, 1986; see Ste-Marie et al., 2012 for review).

Motor imagery refers to rehearsing motor actions mentally without overt physical execution (Jeannerod & Decety, 1995). Motor imagery is subjected to an internal stimulus-oriented process that depends on the internal stimulus of the body since action representations are formed based on the action information in long-term memory (Holmes & Calmels, 2008; Kim et al., 2017). The mechanism of such motor imagery affects not only neurophysiological factors but also the formation of action representations (Decety, 1996; Frank, Land, Popp, & Schack, 2014). Motor imagery training has also been used as an effective cognitive training to enhance the performance and learning of motor skill (see meta-analysis by Driskell et al., 1994; Feltz & Landers, 1983; see Mizuguchi, Nakata, Uchida, & Kanosue, 2012; Murphy, 1994 for review).

Recently, neurophysiological studies on the simultaneous use of AO and MI (AO+MI) showed that the simultaneous AO+MI condition increased the activation of motor-related brain regions and enhanced motor output more than AO condition or MI condition alone (Eaves, Behmer, & Vogt, 2016; Taube et al., 2015; Wright, Williams, & Holmes, 2014). AO goes through the process of external stimulus-oriented bottom-up, in which the information source needed for the formation of action representations is provided externally (Holmes & Calmels, 2008). On the other hand, MI is involved in the processing of the internal stimulus-oriented top-down, in which the information source necessary for the formation of action representations is internally generated (Holmes & Calmels, 2008). In this regard, for beginners who have not had previous task experience, it may be difficult to expect a learning effect through MI since there is no action information stored in long-term memory, which are necessary for motor planning and execution (Mulder, Zijlstra, Zijlstra, & Hochstenbach, 2004). In addition, the effectiveness of AO may be reduced by having difficulty in forming action representations due to the lack of intent to memorize or imitate (Wright, McCormick, Williams, & Holmes, 2016). Given these points, MI during AO may be a way to complement those limitations. Specifically, AO provides visual information about the task needed for MI. As such, MI may contribute to enhancing the intent to remember or imitate during AO. Regarding simultaneous AO+MI, recent works suggested that simultaneous AO+MI training may work more effectively in the early stages of motor skill acquisition than AO or MI training alone (Eaves et al., 2016; Vogt, Rienzo, Collet, Collins, & Guillot, 2013).

However, it is likely that the activation of increased motor-related brain regions during simultaneous AO+MI was actually due to some degree of rotation or transformation of the observed images for MI, rather than functional activities related to the execution of the action (Eaves et al., 2016). A way to reduce the cognitive confrontation of simultaneous AO+MI is to carry out MI after AO, termed alternate AO+MI. This may be considered an effective training method (see Romano-Smith, Wright, Wood, & Wakefield, 2018). More specifically, learners first perceive the information related to task performance from the outside through AO. Subsequently, the learners perform MI after sufficient preparation for the rotation or the transformation of the observed images necessary for MI. As such, learners can concentrate their attention more effectively where needed during MI. The repetition of such a process is expected to contribute to the elaboration of mental representations and increase the efficiency of cognitive activities. Despite this possibility, the effectiveness of alternate AO+MI training has not been systematically tested.

Given that the neural activity of the brain is related to the functional activity of mental representations (DeCharms & Zador, 2000), increased neural activity through AO+MI training may indicate a functional enhancement of mental representations. According to the perceptual-cognitive perspective (Hommel, Müsseler, Aschersleben, & Prinzb, 2001; Zentgraf et al., 2009) and cognitive action architecture (CAA) approach (Schack, 2004), mental representations of motor actions stored in long-term memory serves as a cognitive reference like a mental blueprint that guides the execution of actions by engaging in the planning and control of intended motor actions. In particular, from the CAA's viewpoint, the basic action concepts, which are units of action representations linked to the functional and biomechanical demands of motor movements at the level of mental representation, are hierarchically structured and closely linked to the sensory-motor system. The more elaborate the mental representations composed of the conceptual building blocks, the basic motion concepts, the more likely the motor outcome would be improved. Indeed, the mental representations of experts were shown to be more elaborate and well organized than those of beginners (Bläsing, Güldenpenning, Koester, & Schack, 2014; Bläsing & Schack, 2012; Bläsing, Tenenbaum, & Schack, 2009; Lex, Essig, Knoblauch, & Schack, 2015). In addition, in the early stage of motor learning, the mental representational structures of beginners have been shown to be functionally adapted through physical training or motor imagery training (Frank et al., 2014; Frank, Land, & Schack, 2013, 2016).

In terms of mental representations in long-term memory, motor learning can be considered a continuous and functional change of perceptual-cognitive representations. Some previous studies have examined the effect of AO training or/and MI training on the development of mental representation structure and skill performance in the early motor learning stage (Frank, Kim, & Schack, 2018; Frank et al., 2014; Kim et al., 2017). In addition, working memory is responsible for keeping task information temporarily, retrieving information stored in long-term memory, or integrating and processing information to suit the current situation (Baddeley, 2003; Daneman & Carpenter, 1980). In terms of the capacity of working memory in relation to motor learning, the cognitive ability to quickly and accurately interpret and process important information related to action execution in working memory is improved as the learning process progresses (Ste-Marie, 1999; Thomas & Thomas, 1994). In this respect, changes in long-term memory and working memory are likely to be connected, reflecting the process of skill learning.

There have been a few studies examining the changes in mental representation structure according to AO or MI training (Frank et al., 2018, 2014; Kim et al., 2017). To date, however, no studies have investigated the effect of alternate AO+MI training on cognitive performance in working memory and skill performance. In this study, we extended the study of Kim et al. (2017), which compared the effect of AO training and MI training on the development of mental representation structure and skill performance. Specifically, based on the neurophysiological evidence of simultaneous AO+MI and the discussion on an effective combination of AO and MI (see Eaves et al., 2016 for review), we examined the effect of alternate AO+MI training on the improvement of cognitive performance in working memory and skill performance. In this study, it was hypothesized that alternate AO+MI training would lead to greater improvement in the cognitive performance as well as in the skill performance compared to independent AO and MI training since it was expected that AO and MI would complement each other's strengths and weaknesses as mentioned above. In addition, we were interested in a relationship between changes in cognitive performance and changes in skill performance according to different training methods (i.e. AO, MI, alternate AO+MI). Finally, for skill development, we hypothesized that the performance would develop more after cognitive training as compared to no training (Frank et al., 2018).

Materials and Methods

1.1. Participants

Forty-eight participants (36 females, 12 males; M_{age}= 26.38, *SD* = 5.10) were recruited from the local university. The participants were all novices with no previous experience in Taekwondo. They were randomly assigned into four groups according to the statistical random table using sequence and gender: action observation (AO) training group (n = 12, M_{age} = 25.17, *SD* = 4.00, 3 males), motor imagery (MI) training group (n = 12, M_{age} = 25.08, *SD* = 3.11, 3 males), alternate training group of AO and MI (n = 12, M_{age} = 28.00, *SD* = 6.37, 3 males), no training group (n = 12, M_{age} = 27.25, *SD* = 6.15, 3 males). The study was performed in accordance with local ethical guidelines and the ethical standards of the Helsinki Declaration. All participants signed an informed written consent prior to participation in the study.

1.2. Measures

1.2.1. Imagery Ability

The revised version of the Movement Imagery Questionnaire (MIQ-R; Hall & Martin, 1997) was used to determine if participants had adequate visual imagery ability and kinesthetic imagery ability to participate in cognitive training. The MIQ-R is composed of eight items, four items for visual imagery ability and four items for kinesthetic imagery ability, with high internal reliability (Monsma, Short, Hall, Gregg, & Sullivan, 2009). For each of the items, participants executed each of the movements themselves watching one of the eight movements described in the questionnaire on the monitor. Then they were instructed to imagine the movement visually or kinesthetically without any physical movement. Subsequently, participants were asked to rate how easy the visual or kinesthetic imagery was on a Likert scale, ranging from 1 (i.e., very difficult to see or feel) to 7 (i.e., very easy to see or feel).

1.2.2. Cognitive Performance

As a measure of working memory, the cognition movement chronometry (CMC) test was used. Schack (2004) developed the CMC test to expand an experimental paradigm developed by Sternberg (1969) in cognitive psychology to sports psychology. In the present study, the CMC test provided data on processing speed and accuracy of information about Taekwondo roundhouse kick in working memory. More specifically, eight Taekwondo roundhouse kick stills were selected based on basic action concept, which is distinguished from each other functionally and biomechanically. The selected stills were the Taekwondo roundhouse kick participants watched, but the model was different. The purpose of this task was to evaluate how quickly and accurately the participants perceive and judge randomly presented stills. Participants were asked to memorize the images for five seconds. After five seconds, the presented images were not visible on the screen. Subsequently, the eight images were presented on the screen one by one in random order. Participants were asked to judge as quickly and accurately as possible whether each of the presented images belonged to those that they had attempted to memorize for five seconds. Specifically, participants were instructed to press the left or right key on the keyboard as quickly and accurately as possible when the images were presented on the computer screen. Their accuracy and response time were automatically stored on the computer. The same procedure was repeated five times from level one to level five, with an increasing number of images to be memorized (i.e., level one: one image; level five: five images). The CMC test program used in this experiment was created by an open-source experiment builder (Mathôt, Schreij, & Theeuwes, 2012) to track the accuracy of the judgment and the response time.

1.2.3. Skill Performance

All participants performed ninety trials of Taekwondo roundhouse kick over three blocks. Their performance was video-recorded. Two experts from South Korea with 5th Dan black belt (i.e., more than ten years of experience) in Taekwondo watched the recorded scenes and rated the accuracy of the performance according to specific criteria (see Table 1 for rating

TABLE I
Evaluation Criteria For The Taekwondo Roundhouse Kick (Lee, 2006)

Action phase	**Assessment items**					
	Very good 5	**Good 4**	**Moderate 3**	**Poor 2**	**Very poor 1**	**Score**
Preparation	1. The left foot is stepped toward a target 2. Both knees are bent about 15 degrees 3. The right pelvis and shoulders are angled 45 degrees toward a target 4. Both fists are placed in front of the chest 5. The gaze is toward a goal					1-5
Strike 1	1. The right heel is lifted from the ground 2. The left supporting sole does not move on the ground 3. The right shoulder and pelvis simultaneously rotate 110 degrees toward a target 4. Both arms do not go far beyond the centerline of the torso 5. The upper body is not bent					1-5
Strike 2	1. The supporting left heel rotates counterclockwise by 160 degrees 2. The right foot and knee are folded close to the knee of the left support foot 3. The right knee that kicked is kneeling down inside and the pelvis and torso rotate forward 160 degrees at the same time 4. The knee and ankle are extended at the same time as turning to a target 5. The hip does not fall back, and the instep is extended at a 130-degree angle					1-5
Recovery	1. The kicking foot is pulled and folded forward the support foot 2. The landing of the kicking foot is one step ahead 3. The spacing of the feet after landing is not too wide or narrow 4. The fists of both arms are located in front of the chest 5. The gaze is toward a goal					1-5

criteria). The two raters were kept blind regarding the identity of the group and test block, and the recorded video clips were provided in random order. The Taekwondo roundhouse kick was divided into preparation step, kicking step 1, kicking step 2, and finishing step. Each step was scored from a minimum score of 1 (very poor) to a maximum score of 5 (very good).

1.2.4. Post-Experimental Questionnaire

Participants in the training groups during the three-day training period were asked to complete a post-training questionnaire after each day's training. The main purpose of the post-training questionnaire was to examine participants' motivation and the ease to perform the training according to the instructions. In other words, the main purpose of the questionnaire was to exclude data from participants who had very low motivation and very high difficulty based on the scores of the questionnaire. Specifically, participants were asked to respond on 7-point Likert scales indicating their level of motivation during the training (i.e., 1 = very demotivated, 7 = very motivated, "How motivated did you feel during the practice") and how easy or difficult it was to perform the training (i.e., 1 = very easy, 7 = very difficult, "How easy was it for you to perform action observation or motor imagery or alternate action observation and motor imagery").

1.3. Procedure

The procedure of this study included a pre-test, a treatment period, a post-test, and a retention test (see Table II).

1.3.1. Pre-Test

First, all participants were asked to complete the MIQ-R (Hall & Martin, 1997) to verify that they had adequate visual and kinesthetic movement imagery abilities to participate in cog-

Table II
Experimental Procedure By Group And Measurement Time

	Pre-test	**Training**	**Post-test**	**Retention test**
Group	Day 1	Day 2 Day 3 Day 4	Day 4	Day 5
Alternate AO+MI (*n* = 12)	CMC MIQ	AO+MI training 90 times per day (AO 45 + MI 45)	CMC	CMC Skill test
AO (*n* = 12)	CMC MIQ	AO training 90 times per day	CMC	CMC Skill test
MI (*n* = 12)	CMC MIQ	MI training 90 times per day	CMC	CMC Skill test
Control (*n* = 12)	CMC MIQ	No training	CMC	CMC Skill test

Note. CMC (Cognition and Movement Chronometry): the psychometric method for measuring the accuracy and speed of cognitive performance. MIQ (Movement Imagery Questionnaire): the imagery questionnaire to assess visual, kinesthetic, and overall imagery abilities of participants. Skill test: physical performance of Taekwondo roundhouse kick.

nitive training. A pre-test was conducted the day before the experimental treatment to assess the initial level of cognitive performance for the Taekwondo roundhouse kick. Specifically, in the pre-test, all participants read and signed the informed consent form. The participants were then instructed to observe a video clip twice to provide minimal basic information about Taekwondo roundhouse kick, considering that they were inexperienced novices. Subsequently, participants performed a CMC (Cognition and Movement Chronometry) test to measure their cognitive performance, specifically the processing speed and accuracy of the information in working memory associated with the roundhouse kick (Schack, 2004).

1.3.2. Experimental Treatment

Participants in the experimental groups took part in either observation training or imagery training, or an alternate training for 90 trials a day for three days. The control group did not take part in any training.

1.3.2.1. Action observation training group. Participants assigned to the action observation training group sat in a chair in front of a computer monitor (21 inch LCD monitor with 1280 × 1024 resolution) and were asked to observe the scene of the roundhouse kick of Taekwondo shown on the monitor as attentive as possible during action observation without any actual movement. The video for the observation consisted of a scene in which a skilled male model of similar age to the participants correctly performed the roundhouse kick. The model was a black belt Taekwondo player with more than 10 years of Taekwondo training. The video was displayed in real-time from a frontal and third-person perspective that the model and observer were facing each other. Participants have trained 90 trials a day for three days.

1.3.2.2. Motor imagery training group. Participants assigned to the motor imagery training group also sat on the chair in front of the computer monitor and heard from the experimenter about their tasks. Then, participants were asked to imagine the roundhouse kick as clearly and vividly as possible without any actual movement according to the instructions on the monitor. Specifically, when the monitor showed the instruction "Be ready", participants prepared the imagery and pressed the start button as soon as ready. Then, they started the imagery with eyes closed at their own pace and pressed the stop button after finishing the imagery. The motor imagery was performed based on the information provided in a short video about Taekwondo roundhouse kick before the pretest. Participants were provided with information on first-person and third-person perspectives and were instructed to use their preferred perspectives during motor imagery. In this way, participants performed 90 trials a day for three days.

1.3.2.3. Alternate AO+MI training group. Participants in the alternate AO+MI training group sat on a chair in front of the monitor and listened to the task from the experimenter, just like participants in other training groups. Action observation training and motor imagery training were performed alternately. Specifically, participants were asked to observe the scene of Taekwondo roundhouse kick displayed on the monitor as attentive as possible without any physical movement, and then imagine the roundhouse kick action as clearly and vividly as possible. Participants performed 90 trails (i.e., 45 trials of observation and 45 trials of imagery) daily for 3 days.

1.3.2.4. Control group. Participants in the control group visited the lab for three days and read books that were not related to Taekwondo for the same amount of time as the training time of participants in the training group.

1.3.3. Post-Test and Retention Test. The post-test of CMC measures was conducted immediately after the end of the three-day training, and the retention test of CMC measures was carried out the next day after the post-test. The CMC measurement procedure was the same as the pre-test. In addition, participants' performance of the roundhouse kick was assessed only after retention test of CMC measures. Participants performed three blocks of 30 roundhouse kicks, with a 5-minute break in between blocks. Their performance was video-recorded for further analysis.

1.4. Data Analysis

1.4.1. Imagery Ability

One-way ANOVA on MIQ-R scores was performed to examine differences in visual imagery ability, kinesthetic imagery ability, and overall imagery ability among the four groups, respectively. For post-hoc testing, pairwise comparisons with Bonferroni correction were used. The significance level of all analysis was 5%.

1.4.2. Cognitive Performance

Two-way ANOVA (four groups × three test sessions) was performed on the accuracy and response times of cognitive performance with repeated measures of the second factor. In addition, further analysis was conducted with a one-way ANOVA to investigate differences between groups by test sessions and vice versa. The Bonferroni correction for the threshold was performed.

1.4.3. Skill Performance. The accuracy of the Taekwondo roundhouse kick was analyzed using the average data of the scores evaluated by the two experts based on the specific evaluation criteria (Lee, 2006). To analyze the accuracy, two-way ANOVA (four groups three blocks) was performed with repeated measures on the second factor. For post-hoc testing of a significant interaction, a one-way ANOVA was performed to examine differences between groups by block and vice versa. The Bonferroni correction for multiple comparisons was performed.

1.4.4. Post-Training Questionnaire. Two-way ANOVA (three training groups × three test sessions) on motivation and ease to follow the instructions were performed with repeated measures of the last variable.

1.4.5. Correlation.

Two-tailed Pearson's correlation analysis was performed to examine a correlation between the change in cognitive performance and the change in skill performance across the whole test session by training type. The accuracy value of cognitive performance and the accuracy score of skill performance were used for the correlation analysis.

2. Results

2.1. Imagery Ability

For visual imagery ability ($F_{(3,44)} = 1.279$, $p = 0.293$, $\eta_p^2 = 0.080$) and kinesthetic imagery ability $F_{(3,44)} = 2.768$, $p = 0.053$, $\eta_p^2 = 0.159$), the main effect of group was not statistically significant. For overall imagery ability, the main effect of group was also not statistically significant $F_{(3,44)} = 2.471$, $p = 0.074$, $\eta_p^2 = 0.144$). Overall, all groups showed an average of five or more on the three imagery ability scales. These results indicate that there was no statistically significant difference in visual, kinesthetic, and overall imagery abilities between the four groups. Furthermore, considering that a score of five points means "somewhat easy to see or feel", the results show that participants in each group had adequate movement imagery abilities to participate in cognitive training (Smith & Collins, 2004; Smith, Wright, & Cantwell, 2008). No one was dropped from the experiment due to the lack of imagery ability scores.

2.2. Post-Training Questionnaire

For motivation, there were no statistically significant interaction effect ($F_{(4,66)} = 0.320$, $p = 0.864$, $\eta_p^2 = 0.019$), no statistically significant main effect of group $F_{(2,33)} = 0.155$, $p = 0.857$, $\eta_p^2 = 0.009$), and no statistically significant main effect of test session $F_{(2,66)} = 3.026$, $p = 0.055$, $\eta_p^2 = 0.084$). The mean score of each training group was 5.33 (*SD* = 1.24) (i.e., rather motivated; alternate AO+MI training), 5.36 (*SD* = 1.17) (i.e., rather motivated; AO training), and 5.44 (*SD* = 1.08) (i.e., rather motivated; MI training). In addition, for ease, there were also no statistically significant interaction effect ($F_{(4,66)} = 0.628$, $p = 0.644$, $\eta_p^2 = 0.037$), no statistically significant main effect of group ($F_{(2,33)} = 3.070$, $p = 0.060$, $\eta_p^2 = 0.157$), and no statistically significant main effect of test session $F_{(2,66)} = 1.441$, $p = 0.244$, $\eta_p^2 = 0.042$). The mean score for each training group was 5.03 (*SD* = 1.48) (i.e., rather easy; alternate AO+MI training), 6.00 (*SD* = 0.89) (i.e., easy; AO training), and 5.20 (*SD* = 1.19) (i.e., rather easy; MI training).

2.3. Cognitive Performance

For accuracy, a two-way analysis of variance (ANOVA) was used. The two-way ANOVA revealed a statistically significant interaction $F_{(6,88)} = 2.236$, $p = 0.047$, $\eta_p^2 = 0.132$) meaning that the differences in accuracy between the groups may have varied depending on the test session, or vice versa (see Table III and Figure 1). First, the result of the post-hoc test on the differences between the groups by test session showed that there was no statistically significant difference between the groups in the pre-test ($p = 0.954$). Howe-

TABLE III
Descriptive Data On The Accuracy Of Cognitive Performance By Group And Session

Variable	Group	Session	Mean	Standard Deviation	Corresponding 95% Confidence Interval	
					Lower Bound	Upper Bound
Accuracy (Score)	AO	Pre	73.542	6.864	67.372	79.711
		Post	77.083	6.895	71.623	82.544
		Retention	80.833	9.905	75.740	85.926
	MI	Pre	75.208	8.010	69.039	81.378
		Post	80.000	10.923	74.540	85.460
		Retention	82.708	5.786	77.615	87.801
	AO+MI	Pre	72.792	16.904	66.622	78.961
		Post	86.875	8.266	81.415	92.335
		Retention	88.167	7.111	83.074	93.260
	Control	Pre	73.958	7.266	67.789	80.128
		Post	75.125	10.825	69.665	80.585
		Retention	76.542	11.153	71.449	81.635

ver, the accuracy of alternate AO+MI training group was statistically higher than the control group in both the post-test ($p = 0.021$, $\eta_p^2 = 0.289$) and retention test ($p = 0.020$, $\eta_p^2 = 0.296$). Second, the result of the post-hoc test on the differences between the test sessions by group showed that the accuracy of

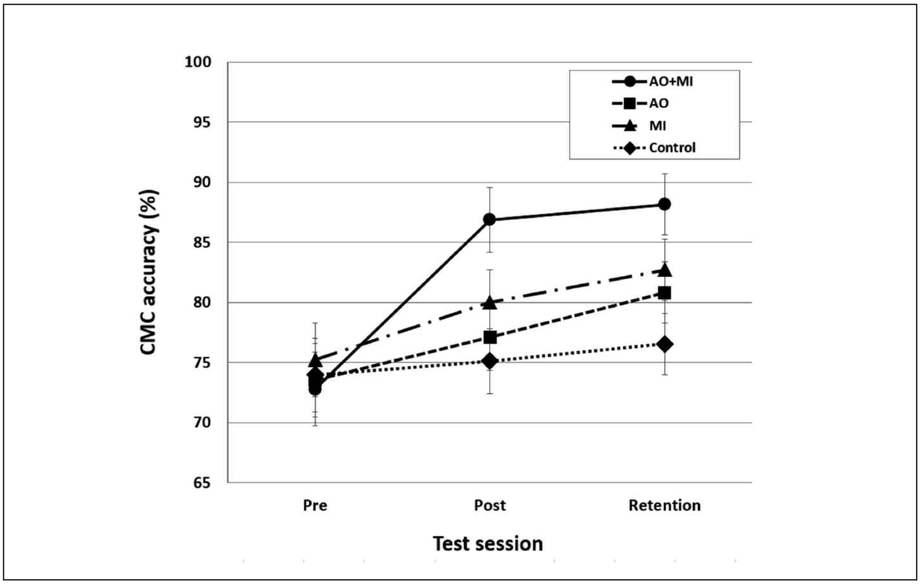

Fig. 1. - The accuracy of cognitive performance across group and test session. Error bars indicate standard errors.

alternate AO+MI training group was statistically higher in the post-test (p = 0.043, $\eta_p^2 = 0.433$) and retention test (p = 0.014, $\eta_p^2 = 0.530$) than in the pre-test. The accuracy of the MI training group was statistically higher in the retention test than in the pre-test (p = 0.020, $\eta_p^2 = 0.505$). However, both the AO training group (p = 0.062) and the control group (p = 0.599) did not show any statistically significant difference in accuracy between the test sessions (i.e., pre-test, post-test and retention test). In addition, the main effect of test session ($F_{(2,88)} = 15.562$, $p < 0.001$, $\eta_p^2 = 0.261$) was statistically significant. The post-hoc test on the main effect of test session (i.e., pre-, post-, and retention test) showed that the accuracy of the post-test (p = 0.003, η_p^2 = 0.195) and the retention test ($p < 0.001$, $\eta_p^2 = 0.331$) was statistically higher than that of the pre-test. The main effect of group ($F_{(3,44)} = 2.167$, $p = 0.105$, $\eta_p^2 = 0.129$) was not statistically significant.

For response time, a two-way analysis of variance showed that the main effect of group was not statistically significant ($F_{(3,44)} = 0.800$, $p = 0.501$, η_p^2 = 0.052) whereas the main effect of test session ($F_{(2,88)} = 13.566$, $p < 0.001$, η_p^2 = 0.236) was statistically significant. The post-hoc test on the main effect of test session (i.e., pre-, post-, and retention test) showed that the response time of the retention test was statistically shorter than that of the pre-test ($p < 0.001$, $\eta_p^2 = 0.231$) and post-test ($p < 0.001$, $\eta_p^2 = 0.323$). In addition, there was no statistically significant interaction between the two factors ($F_{(6,88)} = 1.136$, p = 0.348, $\eta_p^2 = 0.072$).

2.4. Skill Performance

For the accuracy of Taekwondo roundhouse kick, a two-way analysis of variance showed that both the main effect of group $F_{(3,44)} = 4.089$, $p = 0.012$, $\eta_p^2 = 0.218$) and the main effect of block ($F_{(2,88)} = 22.407$, $p < 0.001$, = 0.337) were statistically significant. The post-hoc test on the main effect of group showed that the accuracy of alternate AO+MI training group was statistically higher than that of the MI training group ($p = 0.047$, $\eta_p^2 = 0.218$) and the control group ($p = 0.024$, $\eta_p^2 = 0.243$). In addition, the post-hoc test on the main effect of block showed that the accuracy was statistically higher in block 2 than in block 1 ($p = 0.004$, $\eta_p^2 = 0.164$) and in block 3 compared to block 2 (p < 0.001, $\eta_p^2 = 0.261$). However, the interaction of group and block was also statistically significant $F_{(2,88)} = 2.320$, $p = 0.040$, $\eta_p^2 = 0.137$) meaning that the differences in accuracy between the groups may vary depending on the block, or vice versa (see Table IV and Figure 2). First, the result of the post-hoc test on the differences between the groups by block showed that there was no statistically significant difference between the groups in block 1 (p = 0.109). However, the accuracy of alternate AO+MI training group was statistically higher in block 2 than the MI training group ($p = 0.001$, $\eta_p^2 = 0.478$) and the control group ($p = 0.002$, $\eta_p^2 = 0.416$). In block 3, there was no stati-

TABLE IV
Descriptive Data On Skill Performance By Group And Session

Variable	Group	Session	Mean	Standard Deviation	Corresponding 95% Confidence Interval	
					Lower Bound	Upper Bound
Skill Performance (Score)	**AO**	**Block1**	2.149	0.511	1.865	2.433
		Block2	2.273	0.581	1.975	2.572
		Block3	2.660	0.721	2.243	3.077
	MI	**Block1**	1.754	0.491	1.470	2.038
		Block2	1.847	0.550	1.548	2.145
		Block3	2.523	0.762	2.106	2.940
	AO+MI	**Block1**	2.200	0.568	1.916	2.484
		Block2	2.743	0.558	2.444	3.041
		Block3	2.836	0.766	2.419	3.253
	Control	**Block1**	1.928	0.360	1.644	2.212
		Block2	1.909	0.320	1.611	2.208
		Block3	2.138	0.607	1.720	2.555

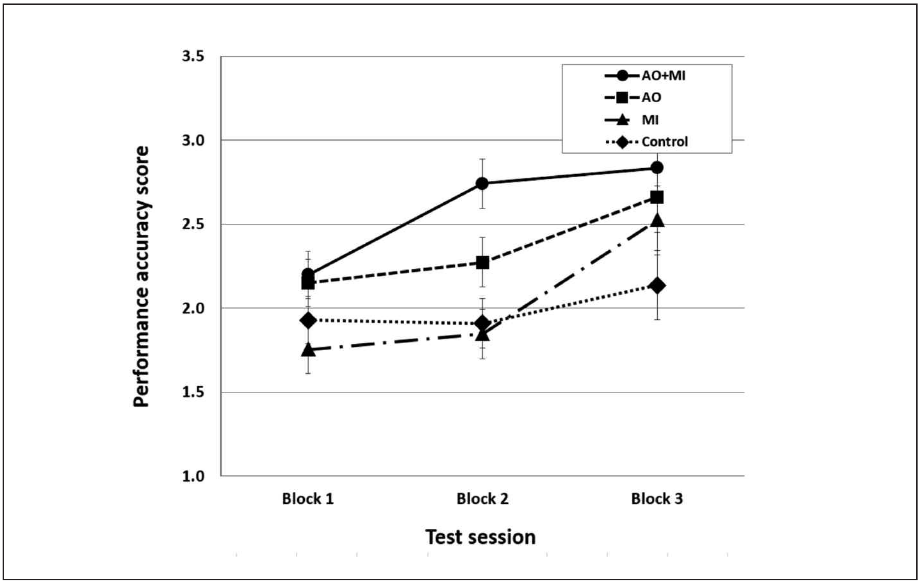

Fig. 2. - The accuracy of skill performance across group and test session. Error bars indicate standard errors.

stically significant difference between groups (p = 0.120). Second, the result of the post-hoc test on the differences between the blocks by group showed that the accuracy of alternate AO+MI training group was statistically higher in block 2 than in block 1 (p = 0.001, η_p^2 = 0.679) and such improvement was maintained in block 3 (p = 1.000). The accuracy of the AO training and MI training group was statistically higher in block 3 than in block 1 (p = 0.015, = 0.524), (p < 0.001, η_p^2 = 0.748) and in block 3 than block 2 (p = 0.015, = 0.476), (p < 0.001, η_p^2 = 0.800), respectively. However, the control group did not show any statistically significant difference in accuracy between the blocks p = 0.225).

2.5. Correlation.

For alternate AO+MI training group, the Pearson correlation the change in the accuracy of cognitive performance and the change in the accuracy of skill performance (r = 0.423, n = 36, p = 0.010) was statistically significant. For the AO training group, it was also revealed that the correlation between changes in cognitive performance and skill performance (r = 0.30, n = 36, p = 0.009) was statistically significant. However, in the case of the MI training group and the control group, there was no statistically significant correlation between changes in the two performances.

3. Discussion

The purpose of this study was to examine the effect of alternate AO+MI training on cognitive performance in working memory and skill performance. It was hypothesized that alternate AO+MI training would lead to greater improvement in the cognitive performance as well as skill performance than independent AO and MI training due to the complementary nature of AO and MI training. In addition, we hypothesized that the relationship between changes in cognitive performance and skill performance across test session may vary according to the method of cognitive training and that the skill performance would develop more after cognitive training as compared to no training. Overall, the results of the present study support set hypotheses.

First of all, regarding the cognitive performance, the present results showed that the interaction between the group and the test session (i.e., pre-, post-, and retention test) was significant in the accuracy of the cognitive performance. More specifically, the accuracy of alternate AO+MI training group was significantly improved in the post-test compared to the pre-test, and such improvement was maintained in the retention test. In the case of the MI training group, the accuracy of the retention test was significantly higher than that of the pre-test. In contrast, the AO training and control group did not show any difference between the measurement times. However, the AO training group showed a somewhat stronger effect size ($\eta_p^2 = 0.397$, $p = 0.080$) compared to the control group ($\eta_p^2 = 0.046$, $p = 0.599$). Comparing AO with MI, the result of this study implies that MI may be more effective in the efficiency of information processing in working memory than AO. In addition, it was found that only alternate AO+MI training group was significantly more accurate than the control group in the post-test and retention test. Present findings show that cognitive training, such as alternate AO+MI and MI training, can be effective in the accuracy of processing information related to task performance in working memory. In addition, we found the potential applicability of AO training, which showed larger effect sizes than the control group.

With regards to the response time of the cognitive performance, the interaction between the group and test session was found to be not significant. Many studies that have attempted to study the expert-novice paradigm to definite characteristics of experts as compared to novices have shown that experts possess broader and more complete knowledge than novices (Abernethy, Thomas, & Thomas, 1993; Del Villar, González, Iglesias, Moreno, & Cervelló, 2007; Iglesias, Moreno, Santos-Rosa, Cervelló, & Del Villar, 2005; Ste-Marie, 1999). Regarding cognitive capacity, experts have more accurate, organized and structured knowledge than novices and have the cognitive ability to make quicker and more appropriate decisions based on that knowledge (see meta-analysis by Mann, Williams, Ward, & Janelle, 2007). Considering this fact, the reason for no interaction of response time in this study is probably that three days of training may not be sufficient for the novice learners to significantly improve the speed of decision making through training. However, the accuracy result of cognitive performance shows that cognitive training is increasingly improving the cognitive capacity of novice learners.

Concerning the outcome of skill performance (i.e., the accuracy of Taekwondo roundhouse kick), skill performance across three blocks (i.e., thirty trials per one block) after retention test was assessed to measure the development of performance after previous cognitive training. It was found that the accuracy of alternate AO+MI training group was significantly higher in the second block than the MI training group and the control group. These results suggest that alternate AO+MI training may be relatively more effective in learning skills. A possible explanation for the effect of alternate

AO+MI is that the change of cognitive capacity in working memory, which was improved effectively due to alternate AO+MI training, may have some influence on the level of motor output. The results of the cognitive performance through alternate AO+MI training in this study support such an assertion.

Lastly, the correlation between cognitive performance and skill performance was examined. The results showed that there was a significant positive correlation between the two variables (i.e., CMC accuracy and skill performance score) in alternate AO+MI training group. AO training group also showed a positive correlation between cognitive performance and skill performance. In contrast, it was revealed that for the MI training group and the control group, the correlation between the two variables was not significant. This difference in the results of AO and MI can be interpreted as the difference in the degree of sophistication or organization of the functional link between cognitive and physical aspects. In other words, if the practice period is longer, it can be interpreted that the potential learning effect of AO might be greater than that of MI. Therefore, these results imply that AO-related training, such as alternate AO+MI training or AO training, may have contributed to a functional link between cognitive capacity in working memory and motor output. Considering that the participant's task was to perform Taekwondo roundhouse kick accurately, AO-related training, which externally provided visual images, may be more effective in performing the skill rather than MI training, which may be difficult for novice learners to form action representations (Tsukazaki, Uehara, Morishita, Ninomiya, & Funase, 2012), As such, it seems that cognitive performance and skill performance are functionally well connected by AO-related training.

AO and MI are different types of motor simulation (Jeannerod, 2001). AO is external stimulus-oriented, which is dependent on external environmental information, whereas MI is internal stimulus-oriented, which depends on internal body information (Holmes & Calmels, 2008). Both simulations activate the motor-related brain regions that are involved in the actual execution of the imaged or observed action without movement (Filimon et al., 2007; see meta-analysis by Hardwick, Caspers, Eickhoff, & Swinnen, 2018; Lorey et al., 2013; Lotze et al., 1999). Concerning the combination of AO and MI, the cognitive effect of alternate AO+MI in this study can be indirectly supported by the results of previous neurophysiological studies of simultaneous AO+MI (Wright et al., 2018). Neurophysiological activation increased by simultaneous AO+MI was found to be greater than that by independent AO or MI (Sakamoto, Muraoka, Mizuguchi, & Kanosue, 2009; Taube et al., 2015). Furthermore, simultaneous AO+MI showed stronger electrophysiological activity in the rostral prefrontal cortex compared to other conditions (i.e., static AO+MI, pure AO, and pure MI; Eaves et al., 2016). Given that the rostral prefrontal cortex is most likely involved in cognitive information processing to align dual action simulations (Burgess et al., 2007; Eaves et al., 2016), the simultaneous AO+MI may be more effective for the efficiency of cognitive information processing. However, considering that simultaneous AO+MI can undergo cognitive confrontation, which requires simultaneous mental rotation or transformation of the observed images for MI (Eaves et al., 2016), alternate AO+MI of this study could give learners abundant time to prepare the images required for subsequent MI after observation. As such, it is likely that the procedure has contributed to the cognitive and behavioral effects of alternate AO+MI training.

Taken together, the findings of this research provide insight into the effect of alternate AO+MI training as well as a link between the changes in perceptual-cognitive level and in motor outcome by showing the influences of AO, MI, and alternate AO+MI training on cognitive performance in working memory and skill performance. One of the main findings to emerge from this study was that alternate AO+MI training overall was more effective in improving cognitive performance and skill performance than independent AO and MI training, showing a strong connection between the two parameters (i.e., CMC accuracy and skill performance accuracy). Therefore, the findings of the present study suggest that alternate AO+MI training may be considered an effective method for facilitating improvements in perceptual-cognitive and skill performance as compared to AO and MI training alone. To our knowledge, the present study is the first to examine the effects of alternate AO+MI training on the development of cognitive and skill performance in motor action and the relationship between them. Nevertheless, there are some limitations in generalizing the findings of this study. First, it was difficult to confirm the change in skill performance directly because the skill test was carried out after the retention test of cognitive performance. Second, not only the training period was short, but also the consideration of the gender of participants, the skill level of the model, the direction of modeling, and the viewing perspective of motor imagery were somewhat insufficient. Third, if two evaluators of skill performance have different opinions, some bias may be caused. Therefore, future research needs to consider these limitations more clearly and verify current findings. In addition, regarding the study on different AO+MI training schedule, Romano-Smith et al. (2018) has examined the effects of simultaneous and alternate AO+MI training on aiming performance. For additional behavioral evidence, further research needs to examine the effects of different training schedules of AO and MI (i.e., simultaneous AO+MI, alternate AO+MI, and intensive AO+MI) on perceptual-cognitive performance and skill performance over the course of motor skill learning or relearning.

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