Effects of motor imagery combined with action observation training on the lateral specificity of muscle strength in healthy subjects

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(Received 4 March 2019; and accepted 19 March 2019)

ABSTRACT

Unilateral training of both lateral limbs increases unilateral muscle strength, whereas bilateral training increases bilateral muscle strength, a phenomenon known as lateral specificity in resistance training. Although motor imagery (MI) combined with action observation (AO) (i.e., MI + AO) training increases muscle strength, it is not completely understood whether such training increases the lateral specificity of muscle strength in a way resistance training does. To investigate whether MI + AO induces lateral specificity of muscle strength increase, 18 healthy subjects were divided into groups: MI + AO and the control groups. The control group watched a movie of natural scenes for ten minutes per day five times a week for three weeks, whereas the MI + AO group imagined bilateral shoulder flexion while watching a movie of athletes performing bilateral shoulder flexion with barbells or dumbbells, with the same time schedule. The MI + AO group alone showed a significant increase in bilateral shoulder strength at three weeks after the intervention compared with the baseline. Unilateral shoulder strength was not significantly altered. These results suggest that MI + AO training increases muscle strength, providing evidence that similar to resistance training, lateral specificity also exists in MI + AO training.

Skeletal muscle strength decreases due to aging, muscle disuse, orthopedic injuries, etc. Given that no merit is gained from weakened muscle strength, increasing strength during recovery from weakened physical conditions is imperative. Resistance training can counter decrease in muscle strength, and increase in muscle strength has been documented through resistance training with ≥60% of maximal muscle strength (10). Indeed, the finding that unilateral training increases muscle strength mainly in the trained lateral limb, but not in the contralateral untrained limb (14), substantiates the effects induced by training on muscles. Unilateral training of both lateral limbs increases unilateral muscle strength but not bilateral strength, whereas bilateral training increases bilateral muscle strength but not the unilateral strength (9, 24, 32); this phenomenon is known as lateral specificity in resistance training (32). Therefore, exercises may need to be selected considering either bilateral or unilateral, corresponding to that which occurs during daily activities or sports.

Although resistance training increases muscle strength, physically weak individuals experience difficulties in training with heavy weights. For such individuals, motor imagery (MI) combined with action observation (AO) (i.e., MI + AO) is a promising approach for sustaining and/or increasing muscle strength.
MI is a process, wherein actions are simulated mentally without any actual movement. Several studies have shown that MI training induces muscle strength gain, contributes to motor skill acquisition, and leads to improved physical performance (11, 12, 20, 28). These effects were realized through imagined muscle contraction rather than an unimagined process (34). Another paradigm to improve motor skills is observational learning, particularly AO (15). Observational learning, which is the process of acquiring motor skills by passively watching another individual perform a task, is a recommended procedure in neurorehabilitation (4). MI and AO reportedly activate overlapping motor and motor-related brain areas (8). Recent studies have focused on the neurophysiological effects of MI + AO because of the higher motor-cortical activity observed with MI + AO than with either MI or AO alone (8). One study has shown increased pinch-grip strength with MI + AO training than with MI training alone in patients suffering from stroke (31).

Based on previous findings in this domain, we hypothesized that MI + AO training increases muscle strength only in the movement being imagined and observed. Therefore, we investigated whether MI combined with bilateral movement observation increases bilateral and unilateral muscle strengths.

MATERIALS AND METHODS

Subjects. Participants were 18 healthy subjects (male, n = 14; age, 20.9 ± 1.3 years; height, 170.1 ± 4.1 cm; body weight, 60.5 ± 6.9 kg; female, n = 4; age, 18.8 ± 0.5 years; height, 158.9 ± 1.4 cm; body weight, 53.5 ± 5.2 kg) without prior experience of regular resistance training. The subjects were divided into either the control (n = 9) or MI + AO (n = 9) group, both of which included two female subjects. No subject had neuromuscular disorders or functional limitations. All experimental procedures were conducted in accordance with the Declaration of Helsinki. The subjects were informed of the experimental risks and signed an informed consent form approved by the university’s institutional review board. Written informed consent was obtained from all participants before participation.

Procedures. Considering that the subjects did not often perform daily maximal bilateral shoulder flexion, we could exclude the possible influence of neural adaptations to shoulder flexion, and therefore, bilateral shoulder flexion was utilized to assess the effect of MI + AO. One week before the MI + AO training, maximal voluntary contraction (MVC) strength during bilateral and unilateral shoulder flexion was measured using an isometric dynamometer (TKK5401; Takei Scientific Instruments Co. Ltd., Niigata, Japan) (30). Thereafter, the subjects were divided into control and MI + AO groups such that the average values of bilateral MVC strength during shoulder flexion were more or less identical between the groups.

Intervention. The control group watched a movie of natural sceneries, including mountains and rivers, for 10 min a day and five times a week for three weeks. Concurrently, the MI + AO group watched a movie of athletes performing high-intensity bilateral shoulder flexion by using barbells or dumbbells following a schedule similar to that for the control group. The frequency of bilateral shoulder flexion in the movie was 260 times per 10 min. Subjects in the MI + AO group were instructed to imagine actually performing bilateral shoulder flexion when watching the movie. Before the MI + AO intervention, subjects underwent electromyography (EMG) to confirm that viewing the movie did not induce any muscle activation in the biceps brachii and anterior deltoideus, considered to be the main anatomical components activated during shoulder flexion. Neither movies for both groups contained any music or sound. Unilateral and bilateral shoulder strengths were measured every seven days throughout the experimental period. Although the subjects were able to watch the movie any day of the week, they were instructed to watch the movie a day before measuring shoulder strength.

Shoulder strength measurement. Individual measurements of muscle strength were conducted at the same time of the day to reduce the effects of diurnal variations on maximal muscle strength in a randomized order with a 10-min rest period between bilateral and unilateral tests. The details of the methodology have been described elsewhere (30). Briefly, subjects were seated on a chair with their back rested straight on a backrest to fix their trunks during measurements. Thereafter, they performed one repetition of maximal shoulder flexion for 3 s at 90° of wrist pronation and 0° of elbow extension (full extension of the elbow). The obtained peak value was defined as the maximal strength.

Evaluation of bilateral force deficit. Bilateral force deficit is a neuromuscular phenomenon, wherein the
maximal voluntary muscle strength during simultaneous bilateral muscle contractions is less than the sum of the right and left unilateral contractions (16, 17, 26). According to Secher et al. (29), bilateral force deficit can be caused by the limited ability of the central nervous system to simultaneously activate all agonistic and synergistic muscles during bilateral contractions. However, other studies have suggested that bilateral force deficit is heavily influenced by interhemispheric or reciprocal inhibition (17, 27). As per the intervention of the MI + AO group, we hypothesized that bilateral, but not unilateral, shoulder flexion strength would increase in the MI + AO group, thereby improving the bilateral force deficit. The present study utilized data from both right and left unilateral and bilateral tasks to calculate the bilateral index (BI) as follows:

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\text{BI} = \frac{\text{bilateral strength}}{\left(\text{left unilateral strength} + \text{right unilateral strength}\right)}
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Accordingly, a BI >1.00 indicated that the sum of the right and left bilateral values was greater than that of the unilateral values (bilateral force facilitation), whereas a BI <1.00 indicated that the sum of the right and left bilateral values was less than that of the unilateral values (bilateral force deficit).

Electromyography (EMG) recording. EMG signals during bilateral and unilateral maximal voluntary contractions (MVCs) in shoulder flexion were recorded from the biceps brachii and anterior deltoideus (ME6400; Nihon Medix, Tokyo, Japan). EMG signal data obtained from the side that was found to have a larger force deficit during bilateral contractions were analyzed. Bipolar surface electrodes (Ambu Blue Sensor M-00-S/50; Nihon Medix) were placed over the muscle bellies with a constant inter-electrode distance of 30 mm. EMG data were band-pass filtered at frequencies between 8 and 500 Hz and then sampled at 1000 Hz. The values obtained were averaged per 10 ms to exclude artifacts. EMG was performed on day 0 and on the last day of the experimental period. Although shoulder flexion is achieved using multiple muscles, the ratio at which each muscle contributes to shoulder flexion is thought to differ among individuals. Correspondingly, the peak values of electromyography (PVEs) in the lateral head of the biceps brachii and anterior deltoideus were obtained and the results were averaged. The mean PVE for both muscles was determined by dividing bilateral PVE by unilateral PVE.

Statistical analyses. All values are expressed as mean ± standard deviation (SD). Data were examined using a two (condition) × four (time of measurement) analysis of variance for the interaction and main effects. When statistical significance was identified, Student’s t-test was used to compare the groups and Tukey–Kramer post-hoc test was used for comparisons within the same group. An alpha-value of <0.05 was considered statistically significant for all comparisons, and SPSS software (IBM SPSS Statics 23; IBM Corp., Armonk, NY, USA) was used for all calculations.

RESULTS

Characteristics of the bilateral force deficit

The bilateral indices (BIs) for shoulder flexion at day 0 were 0.89 ± 0.06 and 0.88 ± 0.04 in the control and MI + AO groups, respectively. As described in the methodology section, the BI <1.00 indicated that the sum of the right and left bilateral values was less than that of the unilateral values (bilateral force deficit). All subjects in this study showed bilateral force deficit as the BI of <1.00 for this dataset.

Increased bilateral strength during shoulder flexion after MI + AO training

Although the control group showed no changes in bilateral shoulder strength throughout the experimental period, the MI + AO group showed a significant increase (P < 0.05) in strength at three weeks compared with the baseline (Fig. 1A). A significant interaction (condition × time of measurement) was not observed. The unilateral shoulder strength in both groups did not change throughout the experimental period (Fig. 1B).

Improved bilateral force deficit after MI + AO training

The MI + AO group showed a significant improvement (P < 0.05) in bilateral index (BI) at three weeks compared with the baseline (Fig. 2). On the other hand, the control group showed a modest, but not significant, increase in BI throughout the experimental period, which can be attributed to the outliers, including one subject in the control group who showed large improvements in bilateral force deficit at one and two weeks (Fig. 2). Moreover, because all subjects in the MI + AO group showed improvements in bilateral force deficit at three weeks, the SD of the data at three weeks was minimal. A significant interaction (condition × time of measurement) was not observed.
resulting in BI close to 1.00, also exhibiting improved bilateral force deficit (3, 32). Although unilateral resistance training increases unilateral muscle strength, it has not been shown to improve the bilateral force deficit (3, 32). Muscle strength gains, including bilateral force deficit, may be exerted by the nervous system through neural adaptation as suggested by the aforementioned studies. Moreover, the activation level of the cortical output signal has been suggested as a critical determinant of both resistance exercise- and mental imagery-induced increases in muscle strength (6, 33).

As discussed previously, bilateral and unilateral training mainly increases bilateral and unilateral strengths, respectively (32). Additionally, the specificity of training, e.g., angle and velocity specificity of training, identified as the lateral specificity of training (32), affects resistance training (2, 3, 5, 13, 19). Whether the lateral specificity of training exists

Changes in the peak value of electromyography (PVE)
Both groups showed no significant changes in PVE associated with the intervention (Fig. 3).

DISCUSSION
In the present study, subjects who imagined bilateral shoulder flexion while watching a movie comprising scenes of high-intensity bilateral shoulder flexion exercises showed increased bilateral, but not unilateral, muscle strength. These results are in harmony with the established findings. Botton et al. (3) reported that unilateral resistance training induces higher unilateral strength gains than bilateral strength gains, resulting in bilateral index (BI) of <1.00 leading to greater bilateral force deficit. The corollary is also true since bilateral resistance training induces higher bilateral strength gains than unilateral strength gains, resulting in BI close to 1.00, also exhibiting improved bilateral force deficit (3, 32). Although unilateral resistance training increases unilateral muscle strength, it has not been shown to improve the bilateral force deficit (3, 32). Muscle strength gains, including bilateral force deficit, may be exerted by the nervous system through neural adaptation as suggested by the aforementioned studies. Moreover, the activation level of the cortical output signal has been suggested as a critical determinant of both resistance exercise- and mental imagery-induced increases in muscle strength (6, 33).
Muscle strength increase without weight training

Fig. 2 MI + AO training improves bilateral force deficit. *Significant difference (P < 0.05) vs. day 0, Mean ± SD (n = 9 for each group), BI: bilateral index.

Fig. 3 MI + AO training did not cause a significant change in electrical muscle activity. Mean ± SD (n = 9 for each group), PVE: peak values of electromyography

in MI + AO was unclear. In this study, we demonstrated that subjects who imagined bilateral shoulder flexion while watching a movie comprising scenes of high-intensity bilateral shoulder flexion exercises showed increased bilateral muscle strength only, thus indicating the presence of lateral specificity of training in MI + AO.

Several studies on motor skill acquisition have demonstrated that mental practice leads to improved performance (12, 20) and motor skills can be achieved or influenced by watching the action of others (18). On the basis of the aforementioned studies, the increase in bilateral shoulder flexion strength in the MI + AO group during the intervention is believed to be induced, in part, by motor skill acquisition for bilateral shoulder flexion.

We particularly noted that all subjects in the MI + AO group showed increased bilateral indices (BIs), thus indicating that MI + AO was an effective approach for gaining muscle strength and improving the bilateral force deficit within a short duration of three weeks. Although few subjects in the control group showed certain degree of improvement in bilateral force deficit, such improvements were insignificant because it is plausible that these individuals showed some improvements in bilateral force deficit even with only a few seconds of weekly maximal bilateral muscle contractions.

The muscle electrical activity was not significantly altered in the MI + AO group despite improvements in bilateral force deficit. This finding is in contrast with the earlier studies showing a concomitant reduction in electrical activity during bilateral exertions (21, 25) and shoulder flexion (30). In contrast, Comwell et al. (7) showed no concomitant relationship between muscle strength and muscle...
electrical activity during the bilateral exertion of protagonist muscles. Since agonistic and antagonistic muscles influence shoulder flexion strength, we measured peak values of electromyography (PVEs) at the biceps brachii and anterior deltoideus. However, as elbow flexors and extensors are simultaneously activated during elbow flexion \((1, 22)\), it is plausible that changes in other muscle PVEs may have occurred in the present study, and could be assessed in future studies.

There are a few possible limitations in the present study. Firstly, the small sample size may have limited the generalizability of the findings of the study. Secondly, the demographics and health status of the subjects in this study represented a young and healthy population. Although MI + AO training is thought to be a useful approach for increasing muscle strength in older and/or physically impaired individuals, there are limited data on the effects of MI + AO training in this particular population. Sun et al. \((31)\) reported that MI + AO training improves pinch-grip strength of upper limb in older patients with stroke. Marusic et al. \((23)\) reported that rehabilitation with MI + AO training after hip surgery in older individuals effectively improves physical functional outcomes. Based on these reports and the findings of the current study, it could be postulated that MI + AO may serve to improve muscle strength for physically weak individuals who experience difficulty of training with heavy weights. Nevertheless, future studies incorporating motor stimulation are warranted with a large population of older and/or physically weak individuals.

In conclusion, the findings of the present study indicate that MI + AO (imagining bilateral shoulder flexion while watching a movie comprising scenes of high-intensity bilateral shoulder flexion) for 10 min a day, five times a week increased bilateral, but not unilateral, shoulder flexion strength without any resistance training and also improved the bilateral force deficit after three weeks of intervention. Because our results indicate the presence of lateral specificity in MI + AO, which is similar to that in resistance training, individuals who employed MI + AO training should be cognizant of the presence of lateral specificity in MI + AO. Lastly, MI + AO may provide an avenue for physically compromised individuals to regain muscle strength in performing routine activities.

Acknowledgments

The authors acknowledge the subjects who volunteered for this study.

DISCLOSURE STATEMENT

The authors report no conflicts of interest or external funding sources to disclose.

REFERENCES

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