BENEFITS OF MOTOR IMAGERY TRAINING ON MUSCLE STRENGTH

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ABSTRACT

Lebon, F, Collet, C, and Guillot, A. Benefits of motor imagery training on muscle strength. *J Strength Cond Res* 24(6): 1680–1687, 2010—It is well established that motor imagery (MI) improves motor performance and motor learning efficiently. Previous studies provided evidence that muscle strength may benefit from MI training, mainly when movements are under the control of large cortical areas in the primary motor cortex. The purpose of this experiment is to assess whether MI might improve upper and lower limbs' strength through an ecological approach and validation, with complex and multijoint exercises. Nine participants were included in the MI group and 10 in the control (CTRL) group. The 2 groups performed identical bench press and leg press exercises. The MI group was instructed to visualize and feel the correspondent contractions during the rest period, whereas the CTRL group carried out a neutral task. The maximal voluntary contraction (MVC) and the maximal number of repetitions (MR) using 80% of the pre-test MVC weight were measured. Although both MI and CTRL groups enhanced their strength through the training sessions, the leg press MVC was significantly higher in the MI group than in the CTRL group ($p < 0.05$). The interaction between the leg press MR and the group was marginally significant ($p = 0.076$). However, we did not find any difference between the MI and CTRL groups, both in the bench press MVC and MR. MI-related training may contribute to the improvement of lower limbs performance by enhancing the technical execution of the movement, and the individual intrinsic motivation. From an applied and practical perspective, we state that athletes may perform imagined muscles contractions, most especially during the rest periods of their physical training, to contribute to the enhancement of concentric strength.

KEY WORDS motor imagery, strength gain, motor performance, upper and lower limbs

INTRODUCTION

It is now well established that skeletal muscle strength gains result from both morphological and neurological adaptations [for review, (6)]. Although some morphological changes (i.e., muscle hypertrophy, myofibrillar growth, and proliferation) usually occur in the later stages of practice (17), neurological adaptations may rather be obtained during the early phase of training. These changes, for example, improved coordination, may enhance the recruitment and the activation of the involved muscles during a strength task (25). Moreover, there is accumulating evidence of a cross-over effect with training of 1 limb that slightly increases strength in the contralateral untrained limb (16,18). This latter finding supports the hypothesis of a central adaptation in response to training (26). As a consequence, voluntary strength may be improved before the muscles exhibit hypertrophy (18). Greater agonist muscle surface electromyography activity accompanied the early strength enhancement, hence bringing further evidence of neural adaptation in the involved muscle (8,16,18).

Taking into consideration that the neurological adaptations after mental practice are quite similar to those elicited by physical practice in the learning processes (14), some experimental studies were designed to investigate whether motor imagery (MI) may be effective to improve muscle strength. MI is the mental representation of an overt action without any concomitant body movement. There is now ample evidence that MI is an effective way to improve motor performance and motor learning, as suggested by the recent MI Integrative Model in Sport [for review, (7)]. Accordingly, Yue and Cole (31) have first provided evidence that MI-related strength gains may depend on changes in the central programming of a maximal voluntary contraction (MVC). The maximal voluntary force of the fifth digit increased by 22% in the MI group. In the same way, a 29.75% increase was observed in the physical practice group, there was a 3.7% increase in the control (CTRL) group. The authors stated the

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hypothesis that the neural changes after mental training occurred at the movement programming level of motor preparation, most likely involving nonprimary cerebral cortical motor areas. The reorganization of cortical areas controlling the movement was thought, in turn, to emphasize the program via the commands through spinal circuitry. Despite some inconsistencies [eg, (12)], further evidence of MI benefits in enhancing strength has been reported by other researchers. Smith et al. (28) found that MI improved the strength of the abductor digits, even though the effect remained less significant than that elicited by physical practice. Zijdewind et al. (32) also provided evidence that MI may be useful in enhancing the voluntary force of the plantar-flexor muscles. They suggested that the effect may be related to the agonist/antagonist coordination, rather than to low-level muscle activation or nonspecific motivational training aspects. Sidaway and Trzaska (27) reported similar results for the ankle dorsiflexor muscles, whereas Ranganathan et al. (24) found that MI improved both distal and proximal muscles voluntary strength of human upper extremities. They further suggested that the mental repetitions of maximal muscle activation made the brain generating stronger signals to muscles. Hence, a stronger central command was thought to recruit the motor units that would otherwise remain inactive under untrained condition, and/or drive the active motor units to higher intensity (higher discharge rate), leading to greater muscle force. Alternatively, training the central nervous system may lead to either remove more effectively or reduce inhibitory input to the motoneurons pool, resulting in increased strength output.

Recently, and from a more applied perspective, Wright and Smith (30) tested the principle of functional equivalence between MI and motor performance in a biceps curl strength task. Their study primarily aimed to investigate the effect of a PETTLEP (Physical, Environment, Task, Timing, Learning, Emotion, and Perspective)-based MI as compared with a more general MI practice, that is, without focusing on the similarities shared by imagined and physical practice [the PETTLEP model by Holmes and Collins (13)]. Overall, their findings strongly supported the use of a PETTLEP-based imagery in enhancing strength performance, therefore, highlighting the critical importance of the functional equivalence principle (7,19). These findings contrast, however, with many previous data showing that MI was ineffective at improving performance of strength-based tasks (12,29). Ranganathan et al. (24) argued that such absence of strength gain may primarily be explained by differences in the experimental designs, and most especially with regards to the imagery instructions. The use of external visual imagery, requiring the participants to visualize their movements through a third-person perspective, was considered inefficient in enhancing strength performance (23), whereas kinaesthetic imagery was more effective as based upon sensory feedbacks from joints and muscles.

The procedures in previous experiments were specific to muscle groups and contraction types. In most of these studies, the participants were often requested to perform maximal voluntary isometric contractions. The movement involved only 1 joint and was quite distinct from the movements usually performed in sports. Therefore, the main objective of the study was to test whether combining MI with physical training might contribute to improve dynamic strength in bench press and sled leg press. We hypothesized that MI might bring efficiency to physical training and enhance the maximal voluntary concentric force. Second, and with reference to mapping of the primary motor cortex (i.e., the motor homunculus–22), the beneficial effect of MI was expected weaker than that observed in the digit and foot muscles.

METHODS

Experimental Approach to the Problem

A randomized experimental design was used to determine whether combining MI with actual training may be effective to improve strength performance. We thus compared the individual force gains of the upper and lower limb muscles in 2 groups of athletes, using the 2 movements and groups as independent variables. Three dependent variables were selected to test our hypothesis: the MVC, the maximal number of repetition (MR), and anthropometric measures. Although the 2 formers are considered reliable indicators of the concentric strength gains, the later might confirm the hypothesis of a neuronal adaptation without any structural modification of the muscle, i.e., absence of hypertrophy.

Subjects

Twenty-two healthy sport students with a mean age of 19.75 years ($SD = 1.72$) took part voluntarily in this experiment. None of them did perform regular and intensive muscular training in their own competitive activities (soccer = 7, track and field = 5, basketball = 4, tennis = 3, and martial arts = 3). Before the experiment, none of the participants specifically performed MI with the aim of improving motor performance. They were therefore given detailed instructions to perform imagery accurately and efficiently. Half subjects were randomly assigned either in the MI or in the CTRL group. The participants of the MI group performed both imagined and actual contractions during 12 training sessions, whereas the CTRL group performed similar physical practice and was subjected to a neutral task during equivalent time as compared with MI. Three participants (2 in the MI group and 1 in the CTRL group) failed to complete the program due to injuries or for personal convenience. One other participant in the MI group was not able to perform the press-leg movement because of a knee injury, but achieved both trainings and tests for bench press. Experimental procedures were approved by the Ethical Committee of the University. All subjects were explicitly informed of the experimental risks and signed an informed consent document before the investigation, according to the

Declaration of Helsinki. No information about the purposes of the study was given to the participants until after they completed the experiment. As all were more than 18 years old, no parental/guardian consent was needed. Finally, none of the injuries encountered by the participants during the experiment was directly related to the physical training.

Procedures

Before the experiment, each participant of the MI group completed the revised version of the Movement Imagery Questionnaire (10) in a quiet room. The Movement Imagery Questionnaire is made up of 8 movements known to evaluate individual differences in visual (4 tasks) and kinaesthetic (4 tasks) movement imagery. Completing each item required 4 steps. First, the starting position is described. Second, a specific arm, leg, or whole body movement is explained. Then, the participants are requested to physically perform 1 trial. Third, each individual is asked to reassume the starting position and to imagine the movement, using either visual or kinaesthetic imagery alternatively, as requested (without any actual movement). Finally, each participant assigned a score by using a 7-point scale regarding the ease/difficulty associated with representing each movement mentally.

The study spanned over a 6-week period, with participants involved in 3 practice sessions per week (12 sessions throughout the 4-weeks training period), each guided by the experimenter. More specifically, the experiment included 3 phases: pre test, training period, and post-test. During both the pre- and post-test, we collected the MVC, the MR with a 80% weight of the MVC pre-test, and anthropometric measures. At the beginning of the training period, the MI group received instructions to combine kinaesthetic and internal visual imagery throughout the 12 MI sessions. The main objective of the training period focused on increasing the maximal concentric force production for bench press and sled leg press movements. During the physical practice sessions, both the MI and the CTRL groups performed the same actual contractions. The 2 groups only differed in the activities performed during the rest periods immediately after physical practice (ie, MI and neutral cognitive task, respectively, the neutral tasks being selected to never involve the abilities needed to form mental images).

Detailed instructions were given to each participant to correctly perform both imagined and physical practice. Accordingly, the bench press' starting position consisted in lying backside on the bench. The barbell was gripped with hands equidistant from the centre of the bar. The movement consisted on lifting the bar off the pins, lowering it up till the chest, and then pushing it back up until the arms were straight and the elbows locked. Because of the heavy weight and the position of the bar, a "spotting partner" ensured the participant's safety during each movement. Regarding the sled type leg press, the participants sat comfortably and placed their feet on the platform. First, they had to lift the weight with the legs straight and to hold the safety brackets. Then, they lowered the platform until a 90° knee position (Figure 1) and pushed it upward until the legs were straight (without locking their knees to avoid possible injury). Cast iron weight disks were attached directly to the sled, mounted on rails. These machines included adjustable safety brackets that prevented the participants from being trapped under the weight.

We also gave specific instructions before using MI: we read a detailed imagery script to each individual. To ensure that the participants performed the correct exercise, they received the following instructions: "Try to imagine yourself performing the motor sequence with your eyes closed, by perceiving the different movements just as if you had a camera on your head, and feel the body's sensations. You have to see and feel only what you would see and feel if you had to perform this particular skill (bench press or sled leg press). Imagine the movement using the most comfortable way for you, and make sure not to contract your muscles". The number of imagined contractions was dependent on the number of actual trials in the series. The number of physical and imagined contractions was summarized in Table 1.

Furthermore, to ensure that the participants performed the correct expected type of imagery, we requested them to describe the nature of the mental images they attempted to form. During this debriefing, they were instructed to rate the ease/difficulty they encountered to accurately form the mental representation of the movement, using a 6-points Likert-type scale. This was set as follows: 1 = very easy to imagine/feel and 6 = very difficult to imagine/feel (2, 3, 4, and 5 being intermediate levels). Finally, at the end of the experiment, we requested the participants to complete a questionnaire about their opinion about the efficiency of MI.

Dependent Variables

Anthropometric Measures. We collected the circumferences of the arms, the chest, and the thighs before the warm-up of the pre- and the post-test, to ensure that no hypertrophy occurred during the training period. We materialized fixed points to

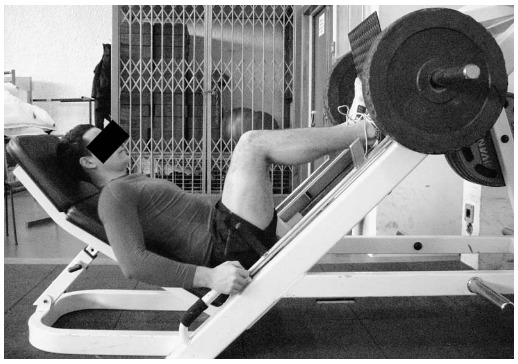

Figure 1. Sled leg press movement.

Table 1. Training program of the imagining group.

Session day	Movements	Rest time (min)	MI training (concentric contractions)
1 2 3	5 serials of 5 repetitions at 80% of MVC	3	During each rest period: 4 × 5
4 5 6	4 × 3 at 90% of MVC	5	During each rest period: 7 × 3
7 8 9	1 × 95%, 2 × 90%, 3 × 85%, 5 × 80%, 7 × 75%	4	First rest-period: 15 × 1, second: 10 × 2, third: 8 × 3, fourth: 4 × 5, fifth: 3 × 7
10 11 12	7 × 70%, 5 × 80%, 3 × 90%, 5 × 80%, 7 × 70%	4	First rest-period:3 × 7, second: 4 × 5, third: 7 × 3, fourth: 4 × 5, fifth: 3 × 7

Four exercises were performed during 12 sessions, 1 per day. During each rest-period, the participants were instructed to imagine the movement and the contractions generated, depending upon the actual serial performed previously.

ascertain a good reliability of the monitoring during the post-test. Accordingly, we considered the distance between the distal point of the collarbone and the circumference point as a reliable landmark for the arm, whereas the distance between the upper extremity of the patella and the circumference point was marked for the thigh. All measures were performed by the same experimenter.

Maximal Voluntary Contraction and Maximum Number of Repetitions. We determined the best mark by the load, which could be lift only on time during both the pre- and the post-test using an incremental test for the bench press, and for the leg press. We asked all participants to lift the maximal charge 1 time, each incremental attempt being separated by a 5-minute resting period from the next trial, to let the cardiorespiratory function recovering basal values. Two days after the MVC test, the participants were asked to lift the MR, 2 attempts for the bench press and one for the leg press, with a weight corresponding to 80% of their pre-test MVC. This test determined the individual endurance force of a specific movement, hence leading greater possibility to observe possible strength gains after MI.

Statistical Analyses

We used Student independent *t* tests to compare the 2 groups during each condition. We carried out the Student paired *t* tests to examine the evolution of the dependent variables from the pre- to the post-test. In accordance with the primary objective of this study, we also performed a univariate analysis of covariance to compare the post-test performance among the 2 groups. The pre-test scores were here used as a covariate in the model. Finally, moderate effect sizes (ES) with 95% confidence intervals were calculated using Cohen *d* (1) on the average difference between the data recorded during the pre- and post-test. We presented the results as mean (± *SD*) and the significance threshold was set at $p \leq 0.05$.

RESULTS

Strength Performances

First, as far as the initial performance of each group was considered (pre-test), the independent *t* tests showed no significant difference between the MI and the CTRL groups ($p > 0.05$), whatever the movement (bench press or leg press), the strength test (MVC or MR), and the anthropometric measures (right and left arms, thighs, and chest). We summarized these results in Table 2.

Second, during the post-test, the MI and the CTRL groups lifted, respectively, 73.28 kg (9.13) and 71.25 kg (11.44) during the bench press test, and 287.23 kg (66.86) and 239.50 kg (46.33) during the leg press test. At 80% of the pre-test MVC, the MI group achieved 13 repetitions (3.04) during the bench press test and 37 repetitions (8.80) during the leg press test, whereas the CTRL group performed 13.4 (2.41) and 29 repetitions (7.56), respectively, at the same percentage. The 2 groups improved strength significantly from the pre- to the post-test, whatever the movement (bench press or leg press) and the test (MVC or MR). The maximal concentric strength increased in both groups. The MI and CTRL groups improved their result by 9% and 12% in the bench press and by 26% and 21% in the leg press, respectively. By contrast, we found no significant difference when comparing the anthropometric measures between the pre- and the post-test for the lower and upper limbs ($p > 0.05$). Table 2 summarizes the experimental variables and statistical computations.

The analysis of covariance provided evidence of a significant interaction ($F_{1,15} = 4.764$, $p = 0.045$, ES (d) = 1, large effect, 95% confidence interval: $0.04 < d < 2$) between the leg press MVC and the group variable (MI *vs.* CTRL).

TABLE 2. Strength performances during the pre- and the post-test in each group.

Group	Condition		Pre-test	Post-test	*t*	*p*
MI, *n* = 9	Bench press	MVC (kg)	67.05 (9.07)	73.28 (9.13)	9.968	<0.001
		MR	9.22 (2.11)	13 (3.04)	4.554	<0.002
	Leg press	MVC (kg)	227.46 (66.85)	287.23 (66.86)	8.553	<0.001
		MR	19.25 (6.16)	37 (8.80)	7.230	<0.001
	Anthropometric measures (cm)	Right arm	29.33 (2.08)	29.44 (1.76)	0.555	0.59, NS
		Left arm	28.94 (2.07)	29 (1.78)	0.359	0.73, NS
		Chest	90.94 (2.77)	91.94 (1.86)	2.028	0.08, NS
		Right thigh	54.37 (2.73)	55.12 (2.49)	1.620	0.15, NS
		Left thigh	53.75 (2.88)	54.5 (2.62)	1.984	0.09, NS
CTRL, *n* = 10	Bench press	MVC (kg)	63.5 (11.25)	71.25 (11.44)	11.196	<0.001
		MR	10.5 (2.41)	13.4 (2.41)	10.474	<0.001
	Leg press	MVC (kg)	197.5 (44.61)	239.5 (46.33)	9.239	<0.001
		MR	16.2 (9.44)	29 (7.56)	5.358	<0.001
	Anthropometric measures (cm)	Right arm	28.20 (1.73)	28.35 (1.58)	1.152	0.28, NS
		Left arm	28.15 (1.68)	28.2 (1.58)	0.318	0.76, NS
		Chest	91.1 (3.59)	91.1 (3.85)	0.000	1.00, NS
		Right thigh	53.15 (3.67)	53.25 (3.22)	0.408	0.69, NS
		Left thigh	52.9 (3.54)	53.05 (3.18)	0.474	0.65, NS

The MVC in kg, and the MR at 80% of the pre-test MVC, were found to increase in both groups (MI and CTRL) between the 2 tests. No significant difference was found, however, regarding the anthropometric measures (cm). Median data (Standard Deviations) are reported. The significant threshold was set at $p \leq 0.05$. MI = motor imagery; CTRL = control; MR = maximal number of repetitions; MVC = maximal voluntary contraction; NS = nonsignificant; MS = marginally significant.

Mean performances were 287.23 kg (66.86) and 239.5 kg (46.33), respectively (Figure 2). A marginally significant interaction ($F_{1,15} = 3.624$, $p = 0.076$, ES (d) = 0.7, medium effect, 95% confidence effect: $-0.3 < d < 1.6$) was also found between the leg press MR and the group variable, mean MR being greater in the MI group (37 [8.80]) as compared with the CTRL group (29 [7.56]). In contrast, no significant difference emerged from bench press performances ($F_{1,16} = 2.330$, $p > 0.05$, NS, ES (d) = 0.8, large effect, 95% confidence interval: $-0.2 < d < 1.7$, in the MVC and $F_{1,16} = 0.759$, $p > 0.05$, NS, ES (d) = 0.5, medium effect, 95% confidence interval: $-0.4 < d < 1.4$, in the MR). Finally, we found no significant change regarding the anthropometric measures. Both dependent variables and statistical analyses during the post-test are summarized in Table 3.

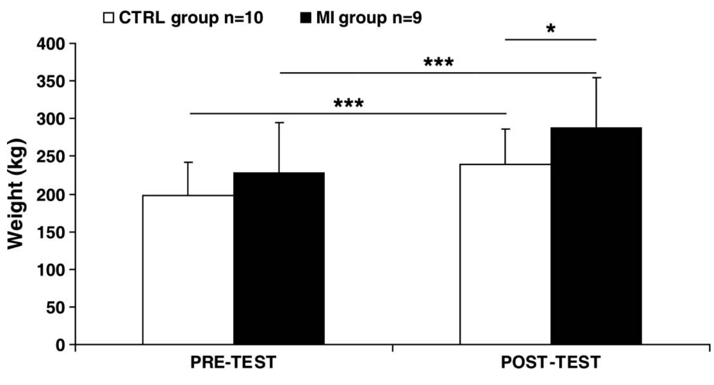

Figure 2. Maximal voluntary contraction in the leg press movement. Although both groups, CTRL and MI, enhanced MVC between pre- and post-test, the performance in the press-leg MVC of MI group was significantly higher than that of the CTRL group. $*p < 0.05$, $***p < 0.001$. CTRL = control; MI = motor imagery.

Assessment of MI Use

During the debriefing after the MI sessions, the participants reported how they dealt with the instructions outlined in the scripts, even though they experienced more difficulty to use kinaesthetic imagery than with visual imagery. However, none reported changing the imagery script to suit individual needs. The mean MI evaluation, using the 6-point Likert-type scale, was 4.66 (0.72). There was a significant difference between the 12 sessions ($F_{11,88} = 4.526$, $p < 0.001$), the first and the last MI evaluation session being 4.13 (0.56) and

TABLE 3. Intergroup comparison of strength gain during the post-test.

Condition		CTRL group, n = 10	MI group, $n = 9$	F	p
Bench press	MVC (kg)	71.25 (11.44)	73.28 (9.13)	2.330	0.15, NS
	MR	13.4 (2.41)	13 (3.04)	0.759	0.40, NS
Leg press	MVC (kg)	239.5 (46.33)	287.23 (66.86)	4.764	<0.05
	MR	29 (7.56)	37 (8.80)	3.624	0.08, MS
Anthropometric measurements (cm)	Right arm	28.35 (1.58)	29.44 (1.76)	0.413	0.53, NS
	Left arm	28.2 (1.58)	29 (1.78)	0.294	0.60, NS
	Chest	91.1 (3.85)	91.94 (1.86)	3.460	0.16, NS
	Right thigh	53.25 (3.22)	55.12 (2.49)	2.510	0.08, MS
	Left thigh	53.05 (3.18)	54.5 (2.62)	2.187	0.13, NS

Higher strength gains were observed in the leg press MVC after MI, whereas a marginally significant improvement was found in the MR of the same movement. No other difference reached significance. Median data (SD) were reported. F = force of the analysis of variance test. The significant threshold was set at $p \leq 0.05$. MI = motor imagery; MS = marginally significant; MR = maximal number of repetitions; MVC = maximal voluntary contraction; NS = nonsignificant.

5.09 (0.82), respectively. The participants estimated that they were thus more able to form accurate images of their movements at the end of the experiment. Yet, each participant encountered personal difficulty to imagine the different exercises. Interestingly, only 2 students clearly reported that MI may have contributed in improving strength per se, whereas the others supposed that MI was more helpful to impact the technical execution of the correct movement. Finally, all thought that MI contributed to improve the quality of the concentration phase and to enhance self-confidence and motivation for the forthcoming event.

DISCUSSION

The primarily aim of this experiment was to investigate whether MI is effective in enhancing strength through an ecological experimental paradigm. Based on previous data from the literature, it was hypothesized that MI should contribute to improve strength in complex and multijoint exercises. The main result was that MI associated with physical training resulted in selective increased strength in the MI group, as compared with the participants who did not perform the mental program training. Such effect was observed in the lower-limb movement but not in the upper-limb movements as well. The large effect size related to both MVC and MR of leg press confirmed the potential MI effect to facilitate strength gain.

First, the results provided evidence that MI did contribute to improve strength of leg muscles without any macroscopic structural change, the training period remaining too short to impact muscle sizes, and to activate hypertrophy mechanisms. The absence of anthropometric difference confirmed that such increase could not be explained by morphological adaptations. Interestingly, previous researches dealing with the effects of MI on voluntary strength of both distal and proximal muscles have highlighted the neural origin of strength gain, occurring before muscle hypertrophy (24,27,28,31,32). In these experimental studies, the efficacy of the MI intervention seemed to be proportionally dependent upon the corresponding cortical area surface of the muscle on the primary motor cortex. Hence, the strength gain after mental practice was expected to be greater in muscles having large assigned cortical areas in the primary motor cortex. As no significant imagery-related effect was observed in the upper limb muscles, which have nonetheless larger cerebral areas compared with lower limbs, this hypothesis stating that MI may elicit some cerebral reorganizations driving the motor units to a higher intensity and/or leading to the recruitment of motor units that remain otherwise inactive, remained to be questioned.

To explain this inconsistent and unexpected MI-related effect, an alternative plausible explanation may be provided. Indeed, MI has been shown to serve both cognitive and motivational functions operating on general and specific levels to enhance performance (7,11,21). The cognitive components of such analytic MI framework tap into technical skill improvement and refer to the imagery of game strategies, whereas the motivational components refer to the use of goal-oriented responses and the management of arousal level. Especially, MI may contribute to improve performance by enhancing intrinsic motivation and individual self-confidence, and by regulating anxiety related to a competitive event (2,19). It may thus be hypothesized that MI impacted the individual ability to improve self-confidence and motivation to enhance strength in a greater extent than its effect on the technical key components of the movement per se. Increasing motivation is, among others, one of MI functions in the field of motor skill learning (7). Self-reports' of the participants confirmed that they were more confident to perform the movement successfully after MI. Furthermore, it is well established that imagery-based interventions can reduce anxiety (15). The participants reported that leg press training was here more physically painful and uncomfortable than bench press exercise (this being probably due to the difference in the weight the participants lifted in each of the 2 movements). The MI-related reduction of the apprehension regarding the maximal weight to be lifted may have been more effective for the lower limbs than for the upper body movement, mean weight being, respectively, 287.23 kg (±66.86) and 73.28 kg (±9.13) during the post-test. Such hypothesis is linked to the specific effects of MI on the focused attention during the preparation phase of the movement. During this period, athletes perform final adjustments to their attentional/activation set, which seem essential to perform their best attempt. As suggested by Feltz and Landers (5) and Hall et al. (9), MI may be a reliable technique to improve the quality of the preparation period by increasing the level of attention and thus to be more efficient in subsequent performance. From an applied perspective, strength gains would be here more directly related to the psychological effects of MI rather than to pure physiological adaptations resulting in greater motor units activation and cerebral cortex reorganization across time.

Although the present study did not provide evidence that MI is a valuable technique in improving muscle strength in an applied sport training perspective, it remains a promising tool offering a training alternative to improve motivation and self-confidence, to reduce physical training and prevent overtraining. Also, MI may contribute to limit strength loss during stroke or when injured athletes remain inactive. Accordingly, Newsom et al. (20) provided evidence that MI was effective in preventing strength loss of wrist flexion/extension after short-term muscle immobilization. Likewise, Cupal and Brewer (3) showed greater knee strength and less reinjury anxiety and pain after MI-related rehabilitation during the rehabilitation period after anterior cruciate ligament stroke. Hence, both the neural adaptation resulting in greater synchronization of motor units in muscles having large corresponding cortical areas in the primary motor cortex and the enhancement of motivation, self-confidence, and level of attention may be of particular interest, including MI program in force gain training, even in an injuries' rehabilitation therapy. Further researches involving other muscle groups would still be essential to ascertain the efficiency of MI included in applied strength gain training and to understand in greater details the mechanisms underlying MI and its influence on neurological changes.

PRACTICAL APPLICATIONS

The combination of MI and physical practice has been extensively shown to be more efficient than physical practice alone, although the use of MI alone is usually not sufficient to outperform the effect of physical practice (4,5). Based on present results and from a practical viewpoint, using MI in weightlifting may substantially contribute to diversify exercises, the primarily goal of MI being to improve the intrinsic motivation and the individual athlete's arousal level. Although MI should be considered a complement to the physical training, rather than a substitute, we state that this technique could be ideally performed during the rest periods of actual training sessions. Mental practice might be a reliable alternative when physical training is reduced or not possible (injuries, weather conditions, equipment failure…). Some instructions should however be respected to perform MI efficiently. Coaches have to provide advices and instructions to athletes before performing mental contractions. Above all, athletes have to focus on the muscles involved in movement execution. Moreover, it has been demonstrated that the use of internal visual and kinaesthetic imagery was more effective to increase strength (23).

Athletes implementing MI use do not have to be high skilled in their activity. Indeed, MI could be a reliable approach to the learning process in novices. Alternatively, elite athletes could use MI to improve movement efficiency and particularly strength, by combining MI with physical training. After several years of practice, they will probably take advantage of their experience to visualize and feel actual muscle contractions and joint tension, as this information is actually perceived during physical performance. Even with little MI practice, this method could be more efficient by differentiating the load during imagined contractions (for example, pressure of the bar in the hands, effort more or less painful…) to form a more realistic image of actual practice. Furthermore, the coaches have to pay attention to the temporal equivalence between imagined and physical execution to avoid altering the technical execution of a motor skill. The spatial and temporal characteristics of the motor sequence should thus be preserved during MI. The speed at which a movement is mentally rehearsed should correlate with its actual time. Mental chronometry is the way to measure the duration of an imagined sequence and is therefore an effective indicator of MI tasks. Moreover, when the advice is to carry out the movement faster or slower, MI may contribute to reach this objective. Finally, the athletes have to respect the number of actual rehearsals per serial during MI: the less the repetitions in a serial, the more serials of imagined contractions during the rest period (Table 1 as an example of training program including both actual and imagined movements). This temporal parameter and other instructions are further described in the MI Integrative Model in Sport (7). On the basis of the literature mentioned above and the findings of the present study, MI may thus be considered a reliable complement to conventional physical training procedures.

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