From Mind to Body: Is Mental Practice Effective on Strength Gains? A Meta-Analysis

João Paulo Manochio; Eduardo Lattari; Eduardo Matta Mello Portugal; Renato Sobral Monteiro-Junior; Flávia Paes; Henning Budde; Paulo de Tarso Veras Farinatti; Oscar Arias-Carrión; Mirko Wegner; Mauro Giovanni Carta; Gioia Mura; Nuno Barbosa Ferreira Rocha; Leonardo Ferreira Almada; Antonio Egidio Nardi; Ti-Fei Yuan; Sergio Machado

Abstract

Mental practice is an internal reproduction of a motor act (whose intention is to promote learning and improving motor skills). Some studies have shown that other cognitive strategies also increase the strength and muscular resistance in healthy people by the enhancement of the performance during dynamic tasks. Mental training sessions may be primordial to improving muscle strength in different subjects. The aim of this study was to systematically review and meta-analiyze studies that assessed whether mental practice is effective in improving muscular strength. We conducted an electronic-computed search in Pub-Med/Medline and ISI Web of Knowledge, Scielo and manual searchs, searching papers written in English between 1991 and 2014. There were 44 studies in Pub-Med/Medline, 631 in ISI Web of Knowledge, 11 in Scielo and 3 in manual searchs databases. After exclusion of studies for duplicate, unrelated to the topic by title and summary, different samples and methodologies, a meta-analysis of 4 studies was carried out to identify the dose-response relationship. We did not find evidence that mental practice is effective in increasing strength in healthy individuals. There is no evidence that mental practice alone can be effective to induce strength gains or to optimize the training effects.

Keywords

Mental practice, motor imagery, imagery, strength training, resistance training, muscle strength, strength.

INTRODUCTION

A better understanding of the motor system network is important in the context of sports and exercise prescription, since an optimal combination of resistance training and skill learning is necessary to improve sports performance [1]. Plastic changes in the central nervous system are well documented in relation to the acquisition of new skills [2]. However, such neural adaptations seem to take place mainly in the initial stages of strength training, [3, 4] and their relative role in long term strength increase is still debated. Traditionally, strength gains during the early stages of resistive training are mostly explained by neural adaptations, especially in untrained individuals [5, 6]. Many studies investigating different variables related to neural adaptation strengthen this premise – for instance, initial adaptations to resistive training would include an increase in the amplitude of electromyographic activity, transient increase in firing rate of motor units (MU), cross-education, reduction of antagonist co-activation, and, perhaps, use of imagined contractions [1]. Mental practice (MP) could be defined as the internal reproduction of a given motor act (mental simulation), which is extensively repeated with the intention of promoting learning or improving a motor skill. The MP is the result of a conscious intention of a movement, which is usually unconsciously performed during motor preparation [7, 8], establishing a relationship between motor events and cognitive perceptions [9]. Previous studies have demonstrated that physiological and psychophysical functions would be quite similar within performed and imagined movements, indicating that they rely on related processes [10, 11]. For example, experiments using functional magnetic resonance imaging showed that not only supplementary motor area, premotor cortex area, and cerebellum were activated during imagined movements of hand and fingers, but also the contralateral primary motor cortex [2, 12, 13]. Furthermore, it has been observed that contralateral primary motor cortex is activated during MP of complex movements, supporting previous findings suggesting that this area would play an important role in the complex motor sequences [14, 15]. Other cognitive strategies (concentrated focus of attention, preparatory arousal and self-efficacy statements) besides MP can be applied in resistive training and may influence the increase in strength and muscular resistance [16]. These cognitive strategies may temporarily enhance performance during dynamic tasks that require strength or muscular resistance [16-18]. Considering the MP with a cognitive strategies, the characteristics of a successful MP to optimize the gains within resistive training have not been sufficiently described [19]. Furthermore, it would be useful to analyze the available evidence in which concerns the potential effect of MP on strength gains and training adaptations in healthy adults. Therefore, the aim of this study was to investigate by means of meta-analysis whether MP would be effective to induce gains in muscle strength in healthy adults.

MATERIALS AND METHODS

Elegibility Criteria

The structure of the methods in this study will follow the proposals of PRISMA (Preferred Reporting Items is Systematic reviews and Meta-Analyses). Thus, we will adopt the PICOS (population, intervention, compared to control group, outcomes and study design) recommendation to determine the elegibility. 1. Population: healthy young men and/or women, physically active or not, without any neurological disorders or mental disease, aged 18 to 40 years; 2. Intervention: individuals submitted to a condition of MP isolated; 3. Compators: a control group (i.e., placebo) that have not been received MP intervention; 4. Outcomes: manifestations of muscle strength will be analyzed; 5. Study design: randomized controlled trials and nonrandomized studies that evaluated the effects of chronic mental practice.

Sources

For the collection of studies the electronic databases MEDLINE / PubMed, ISI Web of Knowledge and SciELO will de accessed. Experts on the subject of the present study were also contacted to send articles. To find additional articles, all tables were examined for evidence of previous systematic reviews and found references to randomized controlled trials as necessary. In addition, we analyzed the references of all selected articles. The search was terminated on 20 February 2014.

Search

The keywords used were: Motor Imagery AND Strength Training, Motor Imagery AND Force, Motor Imagery AND Weight Lifting, Mental Practice AND Strength Training, Mental Practice

AND Force, Mental Practice AND Weight Lifting, Movement Imagery AND Weight Lifting, Movement Imagery AND Strength Training, Movement Imagery AND Strength.

Selection of Studies

The selection of studies was performed by two independent researchers that in case of disagreement sought a consensus on the selection. The evaluation consisted of a selection of studies by analysis of the title, followed by analysis of the summary and then the analysis of the full text. With the disagreement between the two researchers, a third one was requested to finish the process. Relevant articles were obtained and assessed for inclusion and exclusion criteria described above.

Data Collection

The following data were extracted from the articles: sample size, participant characteristics, configuration of MP, setting the strength training (intensity, number of sets and repetitions, duration of contractions, rest interval between sets, weekly and total duration), measures of force used in the main studies and significant results. In addition, several other information about the methods and outcomes were collected. These procedures were performed by two independent investigators, who reached a consensus in case of disagreement.

Exclusion Criteria

We excluded articles that had no intervention of MP, those who used other interventions associated with MP the could create a risk of bias in the study. We excluded studies that did not have a control group, the samples of the elderly, children and adolescents, individuals with mental illness or neurological disease that could create a risk of bias in the study. The studies that did not detail the statistical procedure applied, or not presented the results of measurements of muscle strength before and after specific interventions.

Statistical Analysis

We estimated the pooled effect size by standardized mean differences, as the selected studies used different scales of measurement. According to Higgins and Green [20], I2 statistics under 40% suggest that heterogeneity among studies might not be important. Values over 75% indicate considerable heterogeneity, which was the case for the SMD. For this reason we used random effects models that take into account the variance between studies. Forest plots were used to present these findings. They were built in a way that the point estimates (SMD) and 95% CI of individual studies were graphically displayed in each line and the pooled measure was shown at the bottom. Larger Horizontal lines indicate less precise studies (small effect). The columns to the right present the numerical findings and the relative weights received by each study in the process of combining them. Estimates with p values ≤ 0.05 were considered statistically significant whilst values between 0.06 and 0.10 were suggestive of association. All analyses were performed using Stata 10.0.

RESULTS

Based on the defined criteria, a total of 689 articles were found in the search conducted in the literature (44 in Pubmed, 631 ISI Web of Science and in 11 SciELO, 3 in manual search). After the screening, 50 are removed for duplicate, 552 articles were excluded for title or abstract, because they are not related to the theme. The exclusion of the other articles was due to the following factors: use of transcranial magnetic stimulation (TMS) as a tool for intervention [21-23], patients with injuries or disease [24-30], and MP combined with strength training as an intervention for patients with neurological disorders [31, 32], others interventions with MP [33-40], dates without standard deviation [41-45] acute effects [46]. Thus, 4 studies were selected which were properly met the criteria for this review. Fig. (1) describes the selection process of the studies included in this meta-analysis. The characteristics of these studies are described in Table 1. The heterogeneity of the studies was high (I2 = 89.7%). The result indicated that there was no significant difference between mental practice and control conditions in increasing strength -0.10 (95% CI: -1.46 to 1.24) (Fig. 2).

DISCUSSION

Our study aimed to determine the strength gains from the MP isolated compared to control groups. MP is admittedly able to improve motor gestures and sports skills [46]. There is also evidence that the brain areas involved when a movement is performed are also active during an imagined movement, and that performance on a motor task can be enhanced by MP [47-50]. Being strength gains in the early stages of training, more related to neural aspects [51-54], aspects as theses leads us to believe that the gains initial strength can occur even in the absence of movement.

Methodological DifferencesBetween Studies

Different musculature were used among the selected items, which may have contributed to the discrepancies in the results. Schackel et al. [55] used the hip flexors, finding 24% in the MP group and 28% in physical group increases in power with no statistical difference between them, Sidaway et al. [56] used the dorsiflexors finding no statistically similar results of 17% increase for PM and 25% for group strength, Yue and Cole [57] found gains in flexor and abductor musculature of the 5th metacarpal phalangeal finding 32 and 28% increase result statistically lower than the group that did strength training, finally De Ruiter Et al. [58], analyzed the effects of MP on the flexors and knee extensors, finding gains of around 8%, both in groups and in the strength of mental practice. This difference in gains between the musculature can be attributed to the degree of trainability of each muscle, for those less used in task force would possess a greater range of variation as the ratio of distance to the cerebral cortex and the extent of the corticospinal projection monosináptica. Regarding the training time used in the selected studies, the periods used were more than four weeks [56-58] while Shackel et al. [55] used only two weeks. However the number of sessions seems to have been more decisive because Shackel et al. found good results even with only two weeks when using 5 weekly sessions, Yue and Cole [57] conducted the largest number of sessions to train 5 times a week for 4 weeks. Sidaway et al. [56] and De Ruitter et al. [58] used the frequency of 3 times a week for 4 weeks were studies that observed with smaller increases 8% and 17%, respectively. Regarding the experimental groups, only Schackel [55] used a sample of individuals trained in strength, while Yue and Cole [57], Sidaway et al. [56] and De Ruitter et al. [58] performed the PM with untrained individuals, all groups consisted of groups of 10 Sidaway et al. [56] unless you have studied with only 8 subjects in each group, in all the papers mentioned groups were composed of men and women. As the stay time of strength gains, none of the 4 selected studies verified the data after a period of detraining. But as observed in other studies of Ranganathan et al. [43] that after 12 weeks of the end of the training session, they were still above the initial values. Lebon et al. [31] demonstrated that the strength gains remained one week after the end of the workout.

Comparison with Other Studies

Dootchai [59] and Herbert [60] showed that the MP held with the elbow flexors, while the first observed 44% profit the second found only 6%, both studies performed with 3 sessions per week for 8 weeks, with a total of 24 sessions both studies had a higher number of sessions that the studies analyzed in this review, however while Dootchai [59] got great increase Herbert [60] found no significant difference in pre and post conditions. Methodological limitations as to the lack of a control group in the study of Dootchai [59] prevented the inclusion of these in the meta-analysis. Zijdewing et al. [41] used the plantar flexors in a study of 7 week and 5 week sessions, meeting 36% of earnings, higher than the group that trained force, although this has played a workout unsupervised unlike a traditional strength training, which pushed the wall with feet sitting on a cushion. The MP was also studied in combination with traditional training, Lebon et al. [31], compared the two groups strength training only (ST) and its combination with strength training (ST + MP) MP for four weeks, where the group MP + ST performed the MP in the interval between sets of a periodized strength training. The leg press and bench press were performed, significant difference was found in levels of force only on the leg press exercise, this result contradicts the hypothesis of the gains from the MP are higher in areas of higher cortical representation. According to the author, the results can be associated with the magnitude generally greater burden on lower limb exercises and perception of relatively greater effort imposed by such exercise so that mental practice in this range exercise can be generated increased levels of motivation and the regulation of anxiety [61]. Even with experiments demonstrating that mental practice has made gains superior strength to control groups [57, 58] and similar to the group strength [55, 56], the metaanalysis to accomplish this result was not seen. Due to the diversity of methodologies used in the studies, such as frequency, volume and different musculature, found a high discrepancy in the results, making it difficult to establish useful recommendations for the use of MP. Strength gains found may be due to greater familiarization exercises, since favorable results were found in strength gains also in the control groups. Thus we can not assert that mental practice is an effective alternative to provide strength gains, but its application can be an alternative in cases where the impossibility of performing strength training option for maintaining strength during short periods there detraining or as an adjunct to traditional strength training variable.

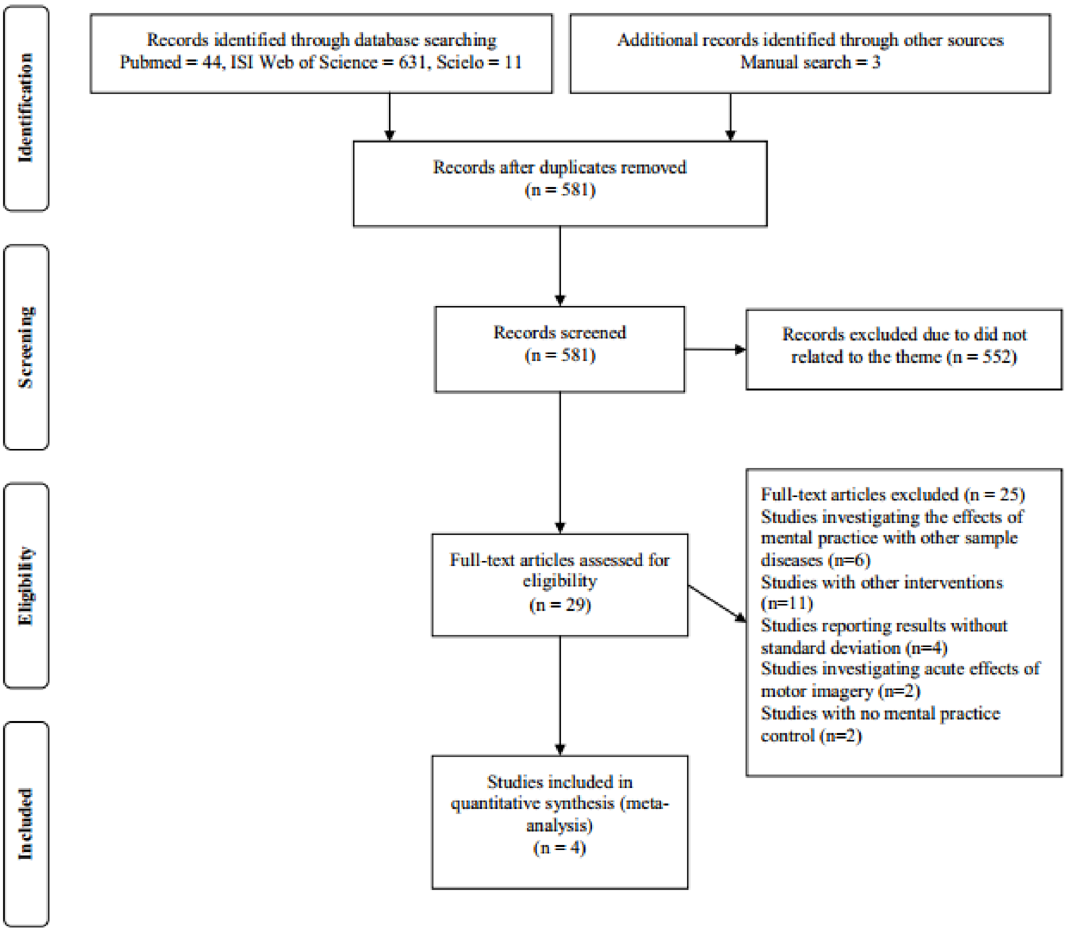

Fig. (1). Flow chart for the articles included in the meta-analysis.

Table 1. Characteristics of the selected studies.

References	Sample	Control (CONT)	Mental Practice (MP)	Movement	Strength Test	Outcomes
De Ruiter *et al.* [59]	CONT (n=10, 5 male, 5 female, mean age 18-24); MP (n=10, 5 male, 5 female, mean age 18-24).	The CONT performed the same procedures on pre- and post- muscular strength training than MP group.	Each session of MP was composed of 10 fast repetitions of knee extension; MP was different at each week (*i.e.*, visual or kinesthetic); 3 sessions of 15 min per week, during 4 weeks.	Knee extension	3 MVC of knee extensors (90 ° and 120º), 4 min of interval among each contraction; 2 sets of 5 fast MVC of knee extensions (90º and 120º), 1 minute of interval among repetitions and 3 min among sets.	Increase in MP for extension (165.8+44.5 to 181.3+50.2) and flexion (58.1+14.7 to 64.7+14.6) when compared to CONT, extension (156.8+34.7 to 149.8+41.6) and flexion (61.8+13.7 to 62.9+18.4).
Shackell and Standing [56]	CONT (n=10 male, mean age = 21.3); MP (n=10 male, mean age =19.8).	Participants of CONT were initially evaluated on strength, as well as MP, however, they were asked to do not return until the end of two weeks of experiment.	5 times per week during 2 weeks. Each session lasted 15 min, composed of 4 sets of 8 repetitions of hip flexion followed by 60 seconds of interval.	Hip flexion	Pre and post measurement of hip flexor strength measured by 1RM	Increase in strength, MP =24%, and Cont = 3,2%
Sidaway and Trzaska [57]	CONT (n=8, gender no specified, mean age = 22.7); MP (n=8, gender no specified, mean age = 22,7).	If assigned to the CONT, subjects did not participate in any form of practice during the 4 weeks of the experiment and received the same muscular test as the MP group.	MP of ankle dorsiflexion, 3 sets of 10 reps, identical to CONT.	Ankle Dorsiflexion	Maximum peak torque of ankle dorsiflexion	An increase in torque by 17.13% after MP and a decrease by -1.77% after CONT were found.
Yue e Cole [58]	CONT (n=9, gender no specified, mean age 21-29); MP (n=10, gender no specified, mean age 21-29).	Subjects were evaluated before and after training. They were instructed strictly to avoid any physical exercise or mental training of the hypothenar muscles during the time period between the pre- and post-test.	MP of abductor of the fifth digit of the metacarpophalangeal joint, 5 times per week during 4 weeks.	Finger Abduction and Flexion	MVIC of abductor muscles of the right fifth digit of the metacarpophalangeal	An increase in abduction by 22% and in flexion by 32% was found in MP. For CONT, an increase in abduction by 3.6% and a decrease in flexion by - 5,2% was verified.

Note: MP = Mental Practice; ST = Strength Training; 1RM = One Repetition Maximum; ULLS = Unilateral Lower Limb Suspension; CONT = Control; MVIC = Maximal Voluntary Isometric Contractions; MVC = Maximal Voluntary Contraction.

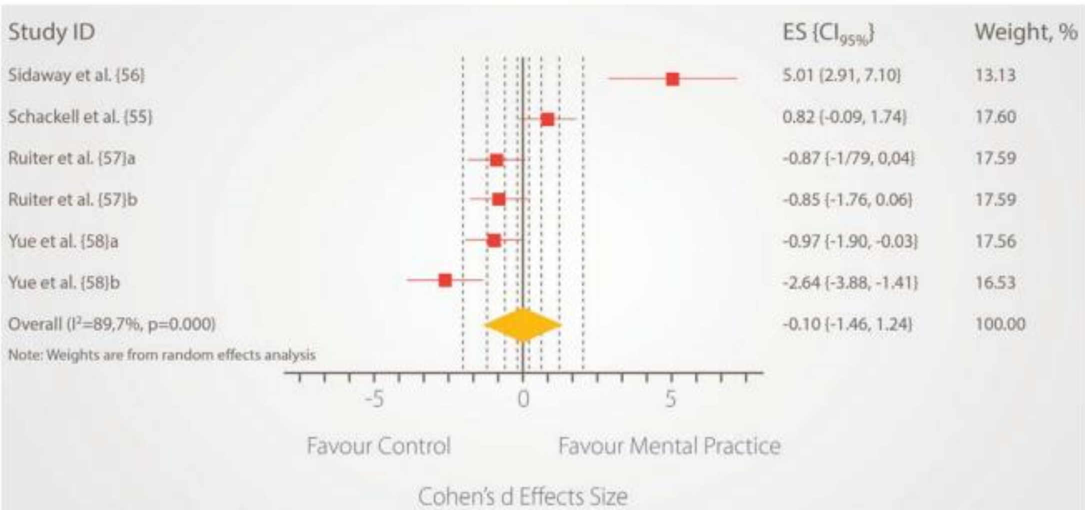

Fig. (2). Meta-analysis of studies assessing the effect of mental practice on strength.

CONCLUSION

The current evidence does not show that MP alone can be effective to induce strength gains. However it may be used to optimize the training effects when combined to resistive training protocols. The possible factors underlying the MP effects are not well defined, and may be related to an increase in regional brain blood flow and functional magnetic resonance imaging signal, reflecting an increase in synaptic activity, changes in motor unit recruitment, synchronization, or firing rate. This information is useful for practitioners in the fields of motor rehabilitation, sports training, and motor learning.

LIST OF ABBREVIATIONS

MP = Mental Practice

REFERENCES

[1] Gabriel DA, Kamen G, Frost G. Neural adaptations to resistive exercise: mechanisms and recommendations for training practices. Sports Med 2006; 36(2): 133-49.

[2] Jeannerod M. Neural simulation of action: a unifying mechanism for motor cognition. Neuroimage 2001; 14: 103-9.

[3] Fadiga L, Fogassi L, Pavesi G, et al. Motor facilitation during action observation: a magnetic stimulation study ndations for training practices. Sports Med 2006; 36: 133-49.

[4] Lorenzo J, Ives JC, Sforzo GA. Knowledge and imagery of contractile mechanisms do not improve muscle strength. Percept Mot Skills 2003; 97: 141-6.

[5] Folland JP, Williams AG. The adaptations to strength training: Morphological and neurological contributions to increased strength. Sports Med 2007; 37: 145-68.

[6] Moritani MA, De Vries HA. Neural factors versus hypertrophy in the time course of muscle strength gain. American J Physical Med 1979; 58: 115-30.

[7] Decety J, Grèzes J. Neural mechanisms subserving the perception of human actions. Trends Cogn Sci 1999; 3: 172-8.

[8] Lotze M, Cohen LG. Volition and imagery in neurorehabilitation. Cogn Behav Neurol 2006; 19: 135-40.

[9] Jackson PL, Doyon J, Richards CL, et al. Potential role of mental practice using motor imagery in neurological rehabilitation. Arch Phys Med Rehabil 2001; 82: 1133-41.

[10] Deiber MP, Ibanez V, Honda M, et al. Cerebral processes related to visuomotor imagery and generation of finger movements studied with positron emission tomography. Neuroimage 1998; 7: 73-85.

[11] Ruby P, Decety J. Effect of subjective perspective taking during simulation of action: a PET investigation of agency. Nat Neurosci 2001; 4: 546-50.

[12] Lotze M, Montoya P, Erb M, et al. Activation of cortical and cerebellar motor areas during executed and imagined hand movements: an fMRI study. J Cogn Neurosci 1999; 11: 491-501.

[13] Michelon P, Vettel JM, Zacks JM. Lateral somatotopic organization during imagined and prepared movements. J Neurophysiol 2006; 95: 811-22. [14] Gerardin E, Sirigu A, Lehéricy S, et al. Partially overlapping neural networks for real and imagined hand movements. Cereb Cortex 2000; 10: 1093-104.

[15] Kuhtz-Buschbeck JP, Mahnkopf C, Holzknecht C, et al. Effect or independent representations of simple and complex imagined finger movements: a combined fMRI and TMS study. Eur J Neurosci 2003; 18: 3375-87.

[16] Tod D, Iredale F, Gill N. 'Psyching-Up' and Muscular Force Production. Sports Med 2003; 33: 47-58.

[17] Shelton TO, Mahoney MJ. The content and effect of ''psychingup'' strategies in weight lifters. Cogn Ther Res 1978; 2: 275-84.

[18] Tod DA, Iredale KF, McGuigan MR, et al. ''PSYCHING-UP'' enhances force production during the bench press exercise J Strength Cond Res 2005; 19: 599-603.

[19] Schuster C, Hilfiker R, Amft O, et al. Best practice for motor imagery: a systematic literature review on motor imagery training elements in five different disciplines. BMC Med 2011; 9: 75.

[20] Higgins JP, Green S. Cochrane Handbook for Systematic Reviews of Interventions. Chichester, Wiley, 2008; vol 8, p. 649.

[21] Li S, Latash ML, Zatsiorsky VM. Effects of motor imagery on finger force responses to transcranial magnetic stimulation. Brain Res Cogn Brain Res 2004; 20(2): 273-80.

[22] Liang N, Funase K, Narita T, et al. Effects of unilateral voluntary movement on motor imagery of the contralateral limb. Clin Neurophysiol 2011; 122(3): 550-7.

[23] Zschorlich VR, Köhling R. How Thoughts Give Rise to Action - Conscious Motor Intention Increases the Excitability of TargetSpecific Motor Circuits. PLoS One 2013;8(12): e83845.

[24] Maruff P, Wilson P, Currie J. Abnormalities of motor imagery associated with somatic passivity phenomena in schizophrenia. Schizophr Res 2003; 60(2-3): 229-38.

[25] Malouin F, Richards CL, Durand A, et al. Added value of mental practice combined with a small amount of physical practice on the relearning of rising and sitting post-stroke: a pilot study. J Neurol Phys Ther 2009; 33(4): 195-2002.

[26] Page SJ, Levine P, Hill V. Mental practice as a gateway to modified constraint-induced movement therapy: a promising combination to improve function. Am J Occup Ther 2007; 61(3): 321-7.

[27] Müller K, Bütefisch CM, Seitz RJ, et al. Mental practice improves hand function after hemiparetic stroke. Restor Neurol Neurosci 2007; 25(5-6): 501-11.

[28] Lagueux E, Charest J, Lefrançois-Caron E, et al. Modified graded motor imagery for complex regional pain syndrome type 1 of the upper extremity in the acute phase: a patient series. Int J Rehabil Res 2012; 35(2): 138-45.

[29] Imbiriba LA, Rodrigues EC, Magalhães J, et al. Motor imagery in blind subjects: the influence of the previous visual experience. Neurosci Lett 2006; 400(1-2): 181-5.

[30] Malouin F, Richards CL, Doyon J et al. Training mobility tasks after stroke with combined mental and physical practice: a feasibility study. Neurorehabil Neural Repair 2004; 18(2): 66-75.

[31] Lebon F, Collet C, Guillot A. Benefits of motor imagery training on muscle strength. J Strength Cond Res 2010; 24(6): 1680-7.

[32] Reiser M, Büsch D, Munzert J. Strength gains by motor imagery with different ratios of physical to mental practice. Front Psychol 2011; 2: 194.

[33] Ito M. Functional equivalence for response programming of actually performing vesus imagining movements. Percept Mot Skills 1999; 88(3 Pt 1): 941-51.

[34] Anwar MN, Tomi N, Ito K Influence of motor imagery on learning under comples external dynamics. Conf proc IEEE Eng Med Biol Soc 2009; 2009: 5926-9.

[35] Lorenzo J, Ives JC, Sforzo GA. Knowledge and imagery of contractile mechanisms do not improve muscle stregth. Percept Mot Skills 2003; 97(1): 141-6.

[36] Lebon F, Rouffet D, Collet C, et al. Modulation of EMG power spectrum frequency during motor in agery. Neurosci Lett 2008; 435(3): 181-5.

[37] Anwar MN, Tomi N, Ito K. Motor imagery facilitates force field learning. Brain Res 2011; 1395: 21-9.

[38] do Nascimento OF, Nielsen KD, Voigt M. Movement related parameters modulate cortical activity during imaginary isometric plantar flexions. Exp Brain Res 2006; 171(1): 78-90.

[39] Guillot A, Lebon F, Rouffet D, et al. Int J Psychophysiol 2007; 66: 18-27.

[40] Anwar MN. Trial-by-trial adaptation of movements during mental practice under force field. Khan SH Comput Math Methods Med 2013; 2013: 109497.

[41] Zigdewind I, Toering ST, Bessem B, et al. Effects of imafery motor training on torque production of ankle pantar flexor muscles. Muscle Nerve 2003; 28(2): 168-73.

[42] Herbert RD, Dean C, Gandevia SC. Effects of real and imagined training on voluntary mmuscle activation during maximal isometric contractions Acta Physiol Scand 1998; 163(4): 361-7.

[43] Ranganathan VK, Siemionow V, Liu JZ, et al. From mental power to muscle power--gaining strength by using the mind. Neuropsychologia 2004; 42(7): 944-56.

[44] Chaiwanichsiri D, Tangkaewfa S, Janchai S, et al. Effects of imagery-weight exercise. J Med Assoc Thai 2006; 89(8): 1260-4.

[45] Cornwall MW, Bruscato MP, Barry S. Effect of mental practice on isometric muscular strength. J Orthop Sports Phys Ther 1991; 13(5): 231-4.

[46] Richardsons A. Mental practice: a review and discussion. II. Res Q 1967; 38(2): 263-73.

[47] Mulder T. Motor imagery and action observation: cognitive tools for rehabilitation. 2007; 114(10): 1265-78.

[48] Hanakawa T, Immisch I, Toma K, et al. Functional properties of brain areas associated with motor execution and imagery. J Neurophysiol 2003; 89: 989-1002.

[49] Feltz DL, Landers DM. The effects of mental practice on motor skill learning and performance: a meta-analysis. J Sport Psychol1983; 5: 2557.

[50] Pascual-Leone A., Nguyet D, Cohen LG, et al. Modulation of muscle responses evoked by transcranial magnetic stimulation during the acquisition of new fine motor skills. J Neurophysiol 1995; 74: 1037-45.

[51] Enoka RM. Muscle strength and its development. New perspectives. Sports Med 1988; 6(3): 146-68.

[52] Sale DG. Neural adaptation to resistance training. Med Sci Sports Exerc 1988; 20(5 Suppl): S135-45.

[53] Moritani T, deVries HA. Neural factors versus hypertrophy in the time course of muscle strength gain. Am J Phys Med 1979; 58: 115-30.

[54] Farthing JP, Borowsky R, Chilibeck PD, et al. Neuro-physiological adaptations associated with cross-education of strength. Brain Topogr 2007; 20: 77-88.

[55] Shackell EM, Standing LG. Mind Over Matter: Mental Training Increases Physical Strength. N Am J Psychol 2007; 9: 189-200.

[56] Sidaway B, Trzaska AR. Can mental practice increase ankle dorsiflexor torque? Phys Ther 2005; 85: 1053-60.

[57] Yue G, Cole KJ. Strength increases from the motor program: comparison of training with maximal voluntary and imagined muscle contractions. J Neurophysiol 1992; 67: 1114-23.

[58] De Ruiter CJ, Hutter V, Icke C, et al. The effects of imagery training on fast isometric knee extensor torque development. J Sports Sci 2012; 30: 166-74.

[59] Dootchai C, Sarissa T, Siriporn MD, et al. Effects of ImageryWeight Exercise. J Med Assoc Thai 2006; 89: 322-9.

[60] Herbert RD, Dean C, Gandevia SC. Effects of real and imagined training on voluntary muscle activation during maximal isometric contractions. Acta Physiol Scand 1998; 163: 361-8.