Neuropsychologia
Volume 42, Issue 7, 2004, Pages 944-956

From mental power to muscle power—gaining strength by using the mind

Vinoth K. Ranganathan [a], Vlodek Siemionow [a,b], Jing Z. Liu [a], Vinod Sahgal [b], Guang H. Yue [a,b,c]

https://doi.org/10.1016/j.neuropsychologia.2003.11.018

Abstract

The purposes of this project were to determine mental training-induced strength gains (without performing physical exercises) in the little finger abductor as well as in the elbow flexor muscles, which are frequently used during daily living, and to quantify cortical signals that mediate maximal voluntary contractions (MVCs) of the two muscle groups. Thirty young, healthy volunteers participated in the study. The first group (N=8) was trained to perform "mental contractions" of little finger abduction (ABD); the second group (N=8) performed mental contractions of elbow (ELB) flexion; and the third group (N=8) was not trained but participated in all measurements and served as a control group. Finally, six volunteers performed training of physical maximal finger abductions. Training lasted for 12 weeks (15 min per day, 5 days per week). At the end of training, we found that the ABD group had increased their finger abduction strength by 35% (P<0.005) and the ELB group augmented their elbow flexion strength by 13.5% (P<0.001). The physical training group increased the finger abduction strength by 53% (P<0.01). The control group showed no significant changes in strength for either finger abduction or elbow flexion tasks. The improvement in muscle strength for trained groups was accompanied by significant increases in electroencephalogram-derived cortical potential, a measure previously shown to be directly related to control of voluntary muscle contractions. We conclude that the mental training employed by this study enhances the cortical output signal, which drives the muscles to a higher activation level and increases strength.

Introduction

Despite extensive reports regarding neural contributions to voluntary strength gains following conventional strength training programs, the exact neural mechanisms underlying human voluntary muscle strength are poorly understood. A common opinion is that gains in voluntary muscle force result from two main factors: neural adaptation and muscle hypertrophy. Strength gains in the early stage of a training program result mainly from changes in the nervous system (Enoka, 1988, Sale, 1988). Additionally, training of one limb is associated with an increase in the voluntary strength of the contralateral untrained muscles, even though the contralateral muscles remained quiescent during training (Houston, Froese, Valeriote, Green, & Ranney, 1983; Yasuda & Miyamura, 1983). The phenomenon of increased strength in the untrained contralateral muscles raises the intriguing possibility that muscle strength may be improved without repetitive muscle activation or without repetitive activation of motor neurons and descending motor pathways. This possibility has not been extensively explored despite its scientific significance and clinical relevance.

Research on motor skill acquisition has demonstrated clearly that mental practice leads to improved performance (Corbin, 1972, Feltz & Landers, 1983). Thus, the neural events controlling the muscle parameters for performance (e.g., amplitude, timing) can be improved through mental practice. This interpretation is supported by evidence that during motor learning, neural activity in various regions of the brain changes according to the level of the motor skill achieved (Karni et al., 1995; Pascual-Leone, Grafman, & Hallett, 1994). One recent study showed that physical training and mental practice of a motor skill resulted in a similar amount of improvement in performance and a similar pattern of adaptation in the primary motor cortex in human participants (Pascual-Leone et al., 1995).

The above-mentioned findings led us to a question: If mental practice of a motor skill can modify neural substrates for physical performance, can mental practice of maximal voluntary contractions (MVCs) alter neural signals for muscle strength? Yue and Cole (1992) trained a group of volunteers with "imagined maximal contractions" of the fifth finger abductor muscle for 4 weeks and found a 22% increase in strength of the muscle. The authors attributed the strength gain to training-induced changes in central programming, although no related central nervous system (CNS) data could be acquired then. It is unknown whether mental training, such as the one employed in this 1992 study, changes the CNS command to muscle. Moreover, because this observation was made on a hand muscle, one might ask whether the strength gain following mental training could be realized in a larger, more proximal muscle group, such as the elbow flexor muscles (Herbert, Dean, & Gandevia, 1998). Distal and proximal muscles differ in the size of cortical representation (Penfield & Rasmussen, 1950), the extent of monosynaptic corticospinal projection (Ghez, 1991, Kuypers, 1981), and the relative contribution of motor unit recruitment and modulation of discharge rate to the gradation of muscle force (DeLuca, LeFever, McCue, & Xenakis, 1982; Kukulka & Clamann, 1981; Milner-Brown, Stein, & Yemm, 1973; Monster & Chan, 1977).

A recent mental imagery study (Herbert et al., 1998) aimed to improve elbow flexor muscle strength found no significant difference in strength changes between mental training and control groups after the training program. This could be due to the relatively small cortical representation of the muscles and monosynaptic corticospinal projection to their motoneuron pools mentioned above. In addition, the elbow flexor muscles are frequently used for daily activities and may be considered as "highly trained" with little room for neural adaptation-induced strength improvements. Finally, there was a possibility that the instruction given to the training subjects for mental imagery was external imagery type that produces little physiological responses (Lang, 1979; Lang, Kozak, Miller, Levin, & McLean, 1980; Wang & Morgan, 1992) and is not as effective in enhancing muscle force as internal imagery training (Ranganathan, Kuykendall, Siemionow, & Yue, 2002). If the subjects indeed performed the imagery training with mental processes similar to those described by external imagery in the study of Herbert et al. (1998), then the question of whether voluntary strength of large, proximal muscle groups such as elbow flexors could be improved by mental training was still an unsettled issue.

The purpose of this study was to determine the effects of mental training that uses internal or kinesthetic imagery on voluntary strength of the fifth finger abductor (a distal muscle) and the elbow flexors (a proximal muscle group) of the dominant arm and quantify the mental training-induced cortical signal alterations. We chose the little finger abductor based on an assumption that this muscle is used relatively less frequently during daily living and thus has a greater capacity for training-induced strength improvements compared with the elbow flexor muscles. Preliminary results of the study have appeared in abstract form (Ranganathan, Siemionow, Sahgal, & Yue, 2001).

Section snippets

Subjects

Thirty young, healthy, right-handed, previously untrained subjects participated in this study. Of the 30, 16 (age, 29.7±4.8 years; weight, 68.9±15 kg; height, 168.6±10 cm; eight women) were initially recruited and were randomly assigned to either mental training of finger abduction (ABD) or elbow flexion (ELB) group. To compare the effects of no practice, a control (CTRL) group of eight subjects (age, 30.1±4.1 years; weight, 74.8±19 kg; height, 166.6±11 cm; four women) was recruited later, and …

Strength gains following mental training

Both mental training groups increased their muscle strength significantly. The abduction strength of the little finger (ABD group) increased almost linearly throughout the training. At the end of the training (12 weeks), the improvement was 35% (F=10.3, P<0.001) compared to pre-training values. However, the greatest gain (40%) was not achieved until 4 weeks after the training had ended (Fig. 2A). The strength gain in the ABD group was significantly different (P<0.05) from the changes seen in …

Mechanisms contributing to the mental training-induced strength gains

The key findings of this study were that mental training increases voluntary strength of both distal and proximal muscles of human upper extremities and the strength improvements accompanied elevations of time-locked (to MVC trials) cortical potential (MRCP). Based on the MRCP data (Fig. 3, Fig. 4, Fig. 5), we are confident that the primary mechanism underlying the strength increase is a mental training-induced enhancement in the central command to muscle. The data suggest that repetitive …

Acknowledgements

This study was supported by NIH grants NS-35130 and HD-36725 to G.H.Y., and by departmental research funds of Physical Medicine and Rehabilitation at the Cleveland Clinic Foundation. We thank our colleagues Drs. Joan Fox and Russell Vanderboom for comments on a draft of this manuscript, Dr. Amrik Shah for assistance with statistical analysis and Dr. Zuyao Shan, Luduan Zhang, Jamie McDougall, and Tristta Kuykendall for assisting in the data collection and analysis. …

References (44)

J. Decety *et al.*
Vegetative response during imagined movement is proportional to mental effort
Behavioural Brain Research (1991)

C. Deschaumes-Molinaro *et al.*
Relationship between mental imagery and sporting performance
Behavioural Brain Research (1991)

C.G. Kukulka *et al.*
Comparison of the recruitment and discharge properties of motor units in human brachial biceps and adductor pollicis during isometric contractions
Brain Research (1981)

Y. Wang *et al.*
The effect of imagery perspectives on the psychophysiological responses to imagined exercise
Behavioral Brain Research (1992)

G.H. Yue *et al.*
Brain activation during human finger extension and flexion movements
Brain Research (2000)

J. Atha
Strengthening muscle
Exercise and Sport Sciences Reviews (1981)

R.A. Berger
Comparisons of the effect of various weight training loads on strength
Research Quarterly (1965)

B. Carolan *et al.*
Adaptations in coactivation after isometric resistance training
Journal of Applied Physiology (1992)

Corbin, C. B. (1972). Mental practice. In W. P. Morgan (Ed.), Ergogenic aids and muscular performance (pp. 93–118). New...

T.H. Dai *et al.*
Relationship between muscle output and functional MRI-measured brain activation
Experimental Brain Research (2001)

View more references

Cited by (257)