Mind Over Matter: Mental Training Increases Physical Strength

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This study tested whether mental training alone can produce a gain in muscular strength. Thirty male university athletes, including football, basketball and rugby players, were randomly assigned to perform mental training of their hip flexor muscles, to use weight machines to physically exercise their hip flexors, or to form a control group which received neither mental nor physical training. The hip strength of each group was measured before and after training. Physical strength was increased by 24% through mental practice (p = .008). Strength was also increased through physical training, by 28%, but did not change significantly in the control condition. The strength gain was greatest among the football players given mental training. Mental and physical training produced similar decreases in heart rate, and both yielded a marginal reduction in systolic blood pressure. The results support the related findings of Ranganathan, Siemionow, Liu, Sahgal, and Yue (2004).

The idea of using mental practice to enhance performance has recently become common. In this procedure, participants are asked to rehearse a motor or cognitive skill by using mental imagery of themselves performing it successfully, without any overt behavior or muscular activity on their part. In the field of sports psychology, websites and books now proliferate which promote mental training to enhance athletic performance (e.g., Cohn, 2006; Ungerleider, 1996). Professional teams today often utilize mental training programs for their athletes, and some have suggested that mental strength training should receive as much emphasis as physical training.

There are now several hundred papers in the literature which support the idea that prior mental practice produces measurable gains in skilled performance, for both cognitive and physical tasks, as summarized in meta-analyses by Feltz and Landers (1983) and Driskell, Copper, and Moran (1994). Concurrent mental set or mood may also of course influence motivation and skilled performance either positively, as shown by improved scores for speed and accuracy in subjects who adopt a positive mental attitude (e.g., Ainscoe & Hardy, 1997; Spencer & Norem, 1996), or negatively, as shown by reduced scores when the test

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instructions include anxiety-inducing cues (e.g., Steele & Aronson, 1995).

However, the more controversial claim has also been made that prior mental training alone can also substantially increase performance in a task which requires simple muscular strength, as opposed to skill or fine motor control in space and time (Cupal & Brewer, 2001; Reiser, 2005; Smith, Collins, & Holmes, 2003; Smith & Collins, 2004). This claim has yet to be validated conclusively, partly because methodological issues abound. The claimed effect is, however, conceptually similar to experimental demonstrations that hypnosis can produce various physiological changes, such as wart-removal or breast enlargement (Barber, 1984; Ewin, 1992; Willard, 1977), and is also parallel to the many findings in the field of medicine that mental changes can create measurable physical benefits, such as recovery of ovulation produced by psychotherapy (Berga, Marcus, Loucks, Hlastala, Ringham, & Krohn, 2003), or reduction in blood pressure induced by classical music (Chafin, Roy, Gerin, & Christenfeld, 2004). Mental practice is now recommended during treatment in some medical cases (e.g., stroke recovery; Bell & Murray, 2004). The influential bio-informational theory of Lang (1979), which suggests that in mental training the prepositional content of mental imagery can directly modify the efferent activity of the brain, provides a possible conceptual basis for this claim.

Ranganathan, Siemionow, Liu, Sahgal, and Yue (2004) have recently tested in detail whether strength gains in the little finger abductor and elbow flexor muscles may be produced by mental training. They also examined the cortical functions that control contractions of these muscle groups, as well as EMGs, blood pressure, and heart rate. After mental training it was found that the finger abductor group muscles had significantly increased their abduction strength by 35% above baseline, or 40% when measured four weeks after the training had ended. (The physical training group increased in finger abduction strength by 53%). The elbow flexion group increased their strength by 13.5%; however, this value was not statistically significant. The authors conclude that mental training enhances the cortical output signal, causing a higher activation level and an increase in strength, although the EMG signal is not measurably affected by training.

The present experiment tests the same general hypothesis by using a different muscle group, the hip flexors, to determine whether a measurable gain in strength may be induced through mental training. Representing a modified version of the study by Ranganathan et al. (2004), this experiment attempted to replicate their central finding in a shorter time frame of two weeks, as opposed to 12 weeks. Hip flexion uses primarily the iliacus and psoas muscles (Andersson, Nilsson, Maá,

& Thorstensson, 1997), and was selected because these muscles cannot readily be exercised in other contexts or with free weights.

METHOD

Participants

Thirty male undergraduate students, who were football, basketball and rugby players at Bishop's University, were used as participants (18, 7 and 5 subjects, respectively). Of these 30 participants, 10 were randomly assigned to a mental training group which mentally practiced hip flexions. Ten more participants were assigned to a physical training group, which exercised using a hip flexor weight machine. A further 10 participants formed a control group, which was given no mental or physical training. The subjects' ages, heights, and body weights are summarized in Table 1, while Table 2 indicates that their pre-test scores fall into the healthy-normal range for blood pressure and pulse.

TABLE 1 Subject Characteristics in the Mental Training, Physical Training, and Control Groups

	Mental		Physical		Control	
	M	*SD*	*M*	*SD*	*M*	*SD*
Age in years	19.8	1.40	19.2	1.23	21.3	2.45
Height (cm)	190.0	4.22	185.7	7.63	85.1	9.68
Body weight (lb)	218.7	36.39	213.2	36.07	216.9	51.08

n = 10 for each group

As an incentive to take part in the study, the participants were rewarded with one Blast protein bar for each 15 minute session.

Materials

Subjects were measured pre-training and post-training in each condition to determine whether strength gain occurred. A hip flexor weight machine (Atlanta Precision), measuring pounds of force in increments of 5 lb from a baseline of 30 lb, was employed to assess initial and final strength, as well as being used in the training process for the physical training group. An electronic sphygmomanometer (Physio Logic Automatic Inflation) was utilized to measure systolic and diastolic blood pressure together with heart rate, and a balance beam scale was used to weigh each participant.

Procedure

Each participant was tested for strength at the beginning and the end of the study, using a hip flexor task. In this task, the subject stands next to a padded bar and attempts to raise his left leg sideways while the weight of the bar is varied by the experimenter, the final weight achieved being the measure of strength.

TABLE 2 Scores Obtained Pre- and Post- Mental Training, Physical Training, and Control Treatment, for Weight Lifted in Hip Flexions (lb), Blood Pressure (mmHg), and Heart Rate (beats per min)

	Mental		Physical		Control	
	M	*SD*	*M*	*SD*	*M*	*SD*
Weight lifted (pre)	135.0[ac]	25.5	127.5[bd]	30.2	171.5[cd]	47.3
Weight lifted (post)	167.0[a]	376.0	163.5[b]	37.7	177.5	43.7
Blood pressure, systolic (pre)	131.4	13.2	135.9	12.7	128.8	7.0
Blood pressure, systolic (post)	128.1	9.7	133.8	8.9	129.3	8.1
Blood pressure, diastolic (pre)	79.6	9.8	89.7	9.0	85.7	5.3
Blood pressure, diastolic (post)	78.1	6.5	86.0	8.3	84.4	6.0
Heart rate (pre)	59.2[e]	5.8	61.8[f]	6.6	63.1	4.8
Heart rate (post)	58.3[e]	5.5	60.0[f]	6.6	63.2	5.5

n = 10 for each group; $^{abf}p < .01$; $^{cde}p < .05$

All testing was performed on an individual basis by a female experimenter (EMS). Participants were recruited at random in a university sports center, during personal workouts, or before/after team practices. After each participant had given informed consent, he was randomly assigned to the mental training, physical training or control group. During the first session, the experimenter recorded the participant's height, body weight, age, blood pressure, heart rate, and initial weight lifted. Subjects in the mental or physical training condition were instructed as specified below, and asked to return every working day for the following two weeks at 10:00 a.m., 2:00 p.m., or 4:00 p.m., to receive further instruction. Participants in the control condition were tested for strength initially, as for the other two groups; however, they were told not to return until the end of the two week study period. At the end of two weeks, all participants were again tested for blood pressure and heart rate, and then repeated the weight-lifting task. Participants were thanked and debriefed following the last testing session. There were no drop-outs.

Mental Training

The mental training was carried out for two weeks, with five training sessions of 15 min each per week. During each training session the participant was instructed to mentally envision himself using the hip flexor machine for four sets of eight repetitions, each set being followed by a 60 second period of rest. During each session, he was instructed to imagine himself using the hip flexor machine and increasing the lifted weight by five pounds each day. It was emphasized to the participant that this mental exercise was not simply a visualization of himself performing the task, but that he was required mentally to imagine an increase in weight lifted with each five pounds added. This mental process is referred to by Ranganathan et al. (2004) as "visualization-guided brain activation training." Five pound increments were used in order to provide a change for each session that could be readily imagined. In this process, the mental training subjects were asked to first visualize themselves standing on the platform attached to the hip flexor machine. The subjects were then requested to imagine themselves extending their left leg sideways as far as they could within their range of motion.

Physical Training

Physical training was the same as the mental training, except that each step was physically carried out by the subject instead of being mentally visualized. An additional weight was added only every three sessions, as the available weights on the hip flexor machine increased by 15 lb steps. As in the other two conditions, pre-training and post-training tests were administered to evaluate muscular strength.

A third group of subjects did not mentally or physically exercise their hip flexors, but were given the same pre-training and post-training muscular strength test as the other groups.

Because physiological responses such as heart rate and blood pressure commonly decrease with training, these variables were also recorded at the start and the conclusion of the study to indicate possible changes.

RESULTS

Effect of Mental and Physical Training on Hip Strength

Descriptive statistics for weight lifted, blood pressure, and heart rate, before and after training, are given in Table 2. To examine the effect of training type on strength, a 3 × 2 mixed ANOVA (training type × practice) was performed on the scores for weight lifted, showing that hip strength overall was higher for the post-test than the pre-test, $F(1, 27) = 33.1$, $p = .001$. Strength overall did not differ significantly between the three types of training, $F(2, 27) = 1.85$, $p = .18$. A Training Type × Practice interaction was found, $F(2, 27) = 4.81$, $p = .016$. This occurred because mental and physical training both produced substantial increases in strength, of 32 lb and 36 lb respectively, whereas the control treatment yielded a nonsignificant increase of only 6 lb, $t(9) = 1.50, p = .168$. These means are shown in Figure 1.

When tested individually, the increases in strength produced by mental training and by physical training were both statistically reliable, $t(9) = 3.40, p = .008$; $t(9) = 4.61, p = .001$. These two increments did not differ significantly, $t(18) = .327, p = .75$.

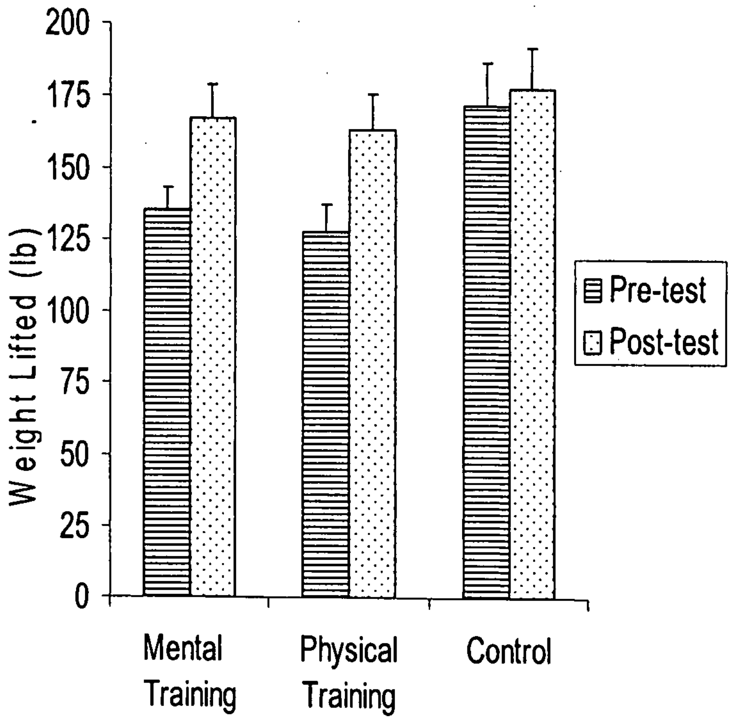

FIGURE 1 Mean weight (lb) lifted in hip flexion task, before and after mental training, physical training control, and control treatment. Error bars represent the standard error of the mean.

It should be noted that due to sampling variation, the control group was stronger in the pre-test than both the mental training group, $t(18) = 2.15, p = .046$, and the physical training group, $t(18) = 2.48, p = .023$. By the end of training, however, it was no stronger than these groups, $t(18) = .56, p = .57$ and $t(18) = .77, p = .45$, respectively.

The subjects' pre- and post- training scores in the control group were highly correlated, $r(8) = .964, p = .001$. Within the mental and physical training groups, this correlation was .60 and .76, $p = .066$ and .011, respectively.

Strength Changes in Players of Different Sports

The eighteen subjects who played football were compared against the others, who played basketball or rugby; these latter were pooled, due to the small number of subjects in these categories: 7 and 5, respectively. A 3 × 2 × 2 mixed ANOVA (training type × practice × sport category) indicated that there was a significant Practice × Sport interaction, $F(1, 24) = 5.23, p = .031$. This interaction represented the larger improvement that training produced in the footballers compared to the other athletes. In the mental training group, this gain in strength was 44.17 and of 13.75 lb, respectively, whereas in the physical training group, the strength of the footballers and the other athletes increased by 42.5 and 26.25 lb, respectively. At the pre-test before training, the hip strength of the football players at 146.1 lb was intermediate between that of the basketballers and the rugby players (130 and 170 lb, respectively). Their body weight at 221.4 lb was also intermediate among the three groups (198.4 and 222.8 lb, respectively). The positive effects of mental training are not due to the number of football players being greater for this group, since there were 6 football players in each of the three training groups. There was no Training type × Practice × Sport interaction, $F(4, 21) = .27, p = .89$.

Effect of Mental and Physical Training on Blood Pressure and Heart Rate

In two 3 × (2) mixed ANOVAs, no significant changes in systolic or diastolic blood pressure (mmHg) were observed from the pre-test to the post-test, $F(1, 27) = .86, p = .36$, and $F(1, 27) = 1.37, p = .25$ respectively. However, systolic pressure dropped by 3.3 and 2.1 mmHg respectively during the mental and physical training conditions, whereas it increased trivially by 0.5 mmHg for the control condition. This reduction in systolic pressure, while non-significant for each group alone ($p > .05$), is reliable for the two training groups pooled, $\chi^2(1) = 5.0, p = .025$. No reliable trend was found for diastolic changes.

A 3 × 2 mixed ANOVA indicated a significant effect of training in reducing heart rate, shown as a Heart rate × Training type interaction, $F(2, 27) = 5.15, p = .013$. This interaction represents a significant pulse decrease in the mental and physical groups during training, of 0.9 and 1.8

beats per minute respectively, as compared to an increase in the control group of 0.1 bpm. The mental and physical training groups did not differ significantly regarding this decrease in heart rate, according to the Scheffé test, $p = .71$. No difference between football players and other athletes was found in blood pressure or heart rate as a function of training, all $p > .10$. An association was noted between the subjects' pre-test heart rate and their weight, pooled over all conditions, $r(28) = .67$, $p = .001$. However, no significant correlations were found between strength changes and heart rate, weight, age, or height, all $p > .05$.

DISCUSSION

The present data indicate that while only a trivial and non-significant gain in strength occurred for the control subjects, who performed no physical or mental exercises during the study, both the mental and the physical training treatments caused a significant increase in the weight that subjects could lift in hip flexions. This increase in strength was similar between the two training groups, and was substantial (23.7% and 28.3%, respectively). It also resembles the magnitude of the effect reported by Ranganathan et al. (2004), and supports the central conclusions of that study. Since the present experiment differs from the study of Ranganathan et al. in employing a novel and larger muscle group, with short-term isotonic rather than long-term isometric training and some changes in methodology, these positive results support the external validity of Ranganathan's findings. The results also correspond to the conclusions of Reiser (2005), although this latter study obtained an increase in bench press strength of only 5.7% from mental training, and 14% from physical training.

The data presented by Ranganathan et al. (2004) suggest that the basis of the mental training effect is central rather than peripheral: substantial changes in EEG occur in mental training and correlate well with the observed strength increase. The same conclusion applies to the recent observation of changes in brain function as a result of mental practice in a finger-tapping task (Nyberg, Eriksson, Larsson, & Marklund, 2006). However, muscular action potentials during imagery also have often been reported (e.g., Shaw, 1940). Many past studies have found reductions in blood pressure and heart rate after either physical exercise or mental relaxation training (e.g., Amigo, Gonzalez, & Herrera, 1997; Pawlow & Jones, 2002), but the effect of mental exercise on these measures has not been reported previously. Although the reductions found here for heart rate and systolic pressure both reached statistical significance, as they were not large these findings call for replication. Also, the measurement of blood pressure may be problematic, as it is intrinsically labile and varies with many extraneous variables including stress, nervousness, fatigue, etc. (McAlister & Straus, 2001); therefore it is necessary to assume that these intruding factors function similarly across training conditions.

Although the present data clearly support the experimental hypothesis, assuming that the participants followed the specified protocol, possible demand characteristics of the task and experimenter effects should be considered (Orne & Evans, 1965; Rosenthal, 1976). While a conscious effort was made by the test administrator to keep from suggesting any expected trends to the participants, the increase in final strength scores conceivably could be due to the participant's desire to produce positive results, or from criterion shifts influencing the point at which he decides that he cannot increase his effort due to discomfort (Rollman, 1979). Such unwitting experimenter effects and demand characteristics of the task are emphasized, for example, by the effects of expectancy upon relaxation-induced blood pressure lowering (Agras, Horne, & Tayor, 1982). However, the persistence of the mental training effect in the study by Ranganathan et al. (2004) several weeks after the training period had ended, and the strong effects of mental training observed upon cortical motor potentials, argue against any simple dismissal of the phenomenon as an artifact, although further analysis of alternative hypotheses is still called for. There is also the empirical problem that some studies report positive results for the effects of mental training on strength (Yue & Cole, 1992; Yue, Wilson, Cole, & Darling, 1996), while others do not (Herbert, Dean & Gandevia, 1998), a discrepancy which possibly may be attributed to uncontrolled incidental factors such as the superiority of internal over external imagery (Ranganathan et al., p. 954; Hinshaw, 1991/1992; Wang & Morgan, 1992).

While not part of the experimental hypothesis, the strength gain of each subject in relation to his chosen sport was also examined. Greater benefits were found among the football players than the other athletes, for both physical and mental training. This effect is of some interest, as the football players were no stronger at the pre-test than the other subjects, nor heavier. Therefore the greater absolute increase in strength observed for football players also represents a greater percentage increase.

This study used only male participants, to control subject gender as a variable which might interact with the gender of the experimenter (always female in this case), but presumably to the same extent in each training condition. Future research in this area ideally would use both male and female participants, as well as male and female experimenters.

The hip flexor exercise was chosen as a means of measuring strength gain based on the fact that this muscle group is one that none of the athletes had previously and consciously made any effort to exercise. It seemed logical to predict that greater strength gain could be demonstrated in a muscle group that rarely is used rather than one that is already well exercised before the study. The high correlation between the hip flexion scores obtained before and after the control treatment indicates that this measure shows statistical reliability here, although this is not always the case (Emery, Maitland, & Meeuwisse, 1999). The much lower correlations found after training may be attributed to the marked variations that occur between different individuals in response to the same training program (Bouchard, An, Rice, Skinner, Wilmore, Gagnon, Pérusse, Leon, & Rao, 1999).

It would be valuable to conduct simultaneous mental and physical practice, to examine their combined effect on strength gain, as is sometimes recommended in the literature on mental practice (Jackson, Doyon, Richards, & Malouin, 2004). It is hoped that subsequent studies with prolonged mental training will explore the limits of the effect, and provide more evidence as to the ultimate powers of mental imagery. However, stating the issue as one of mind over matter sets up an unnecessary dichotomy since all mental states are intrinsically embodied as physical events in the nervous system, if we reject the existence of disembodied mind and accept central state theory (Armstrong, 1968). Therefore, rather than referring to the conventional 'mind over matter', we may summarize the present results as showing the power of CNS activity over long-term muscular strength.

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