2007

Bilateral effect of unilateral electroacupuncture on muscle strength

Liping Huang
Tianjin University of Sport

Shi Zhou
Southern Cross University

Zhen Lu
Tianjin University of Sport

Qiang Tian
Tianjin University of Sport

Xia Li
Tianjin University of Sport

See next page for additional authors

Publication details

Huang, LP, Zhou, S, Lu, Z, Tian, Q, Li, X, Cao, LJ, Yu, JH & Wang, H 2007, 'Bilateral effect of unilateral electroacupuncture on muscle strength', *Journal of Alternative & Complementary Medicine*, vol. 13, no. 5, pp. 539-546.

Authors
Liping Huang, Shi Zhou, Zhen Lu, Qiang Tian, Xia Li, Longjun Cao, Junhai Yu, and Hui Wang

THE JOURNAL OF ALTERNATIVE AND COMPLEMENTARY MEDICINE
Volume 13, Number 5, 2007, pp. 539–546

DOI: 10.1089/acm.2007.6250

Bilateral Effect of Unilateral Electroacupuncture on Muscle Strength

LI-PING HUANG, Ph.D.,[1] SHI ZHOU, Ph.D.,[2] ZHEN LU, M.Sc.,[1] QIANG TIAN, M.Sc.,[1]
XIA LI, M.Sc.,[1] LONG-JUN CAO, M.B.,[1] JUN-HAI YU, M.B.,[1] and HUI WANG, M.Sc.[1]

ABSTRACT

Objectives: This study aimed to examine the bilateral effect of 4 weeks of unilateral electroacupuncture on leg muscle strength.

Design: The effect of unilateral electroacupuncture at two selected acupoints, *Zusanli* (ST-36) and *Xiajuxu* (ST-39), which are located on the anterior tibialis muscle, on dorsiflexion strength was evaluated by statistical analyses of the interactions between the muscle strength pre and post 4 weeks of intervention, between the two legs, and between an experimental and a control group.

Settings/location: The trial was carried out in the exercise rehabilitation laboratory at Tianjin University of Sport.

Subjects: Thirty (30) healthy men with an average age of 20.9 ± 2.98 (SD) years were randomly allocated into an electroacupuncture group (EG) and a control group (CG). They were physically active, but without specific strength training or previous experience of acupuncture.

Interventions: Participants in the EG were given 3 sessions of electroacupuncture per week. In each session, the electroacupuncture was applied to the right leg at the acupoints with 8 duty cycles of 1 minute on and 1 minute off, pulse width of 1 millisecond, frequency of 40 Hz, and intensity of 30–40 V. Participants in the CG group kept their normal daily activities without additional intervention.

Outcome measures: The maximum strength in dorsiflexion of each leg was examined by having participants lift weights in the range of motion of ~20° at the ankle joint.

Results: Repeated-measures analysis of variance with Bonferroni adjustment detected significant increase in strength of both legs (right 21.3%, left 15.2%) in the EG ($p < 0.05$) and the increase was significantly higher than that of the CG ($p < 0.05$). The CG showed no significant change (right 3.0%, left 4.8%), post-treatment.

Conclusions: Unilateral electroacupuncture at the selected acupoints improved muscle strength of both limbs. These findings may have implications in physical therapy and rehabilitation settings.

INTRODUCTION

It has been reported that long-term unilateral motor activities can affect not only the strength of the exercised muscle group, but also that of the unexercised homologous muscle group in the contralateral limb, a phenomenon known as cross education.[1–3] Cross education has been reported with various types of resistance training, with the strength gain in magnitudes of 5–25% in the unexercised contralateral limb.[1–3] Most of these studies observed a significant cross-education effect after 4–8 weeks (12–24 sessions) of training at exercise intensities of 60–100% maximal voluntary

[1]Department of Health and Exercise Science, Tianjin University of Sport, Tianjin, China.
[2]Department of Exercise Science and Sport Management, Southern Cross University, Lismore, Australia.

contraction strength (MVC).[1–3] Furthermore, unilateral transcutaneous electrical stimulation (ES) training has also been shown to induce contralateral strength gain.[4–8]

It has been suggested that cross education can be used as a means of therapy for certain neuromuscular disorders.[1,3] For example, an investigation on postsurgery rehabilitation found that patients who performed prescribed exercise on the unaffected limb demonstrated significantly better recovery of the affected limb than that of the patients who did not perform the contralateral exercise.[9] In an investigation on hemiplegic patients, it has been demonstrated that exercise of the nonplegic limb always evoked electromyographic (EMG) activity in the homologous muscles of the plegic limb that may have beneficial effects on the function of the affected muscles.[10] Interestingly, unilateral therapy for treatment of contralateral conditions has been used in traditional Chinese medicine (TCM) for more than two thousand years. One particular type of practice, *Juci*, involves acupuncture on one side of the body to affect the function of the other side,[11] similar to the concept of cross education. However, the contralateral effects of unilateral acupuncture have rarely been critically examined in well-controlled investigations. The mechanism (in terms of Western medicine) with respect to how acupuncture works is still subject to elucidation, although the practice has been documented as clinically effective or beneficial for many conditions.[12] From the neuroanatomy viewpoint, it has been cited that 50% of all the named acupuncture points are located directly above major nerve trunks and the remaining acupuncture points are located within 0.5 cm from nerve trunks or are identical to the motor points.[13] Investigations using animal models have shown that acupuncture affects secretion of neurotransmitters and neuropeptides in the central nervous system (CNS) that might relate to therapeutic effects.[13–15] In recent years, ES has been utilized jointly with acupuncture.[15,16] The electroacupuncture (or electroneedling) involves applying acupuncture with the addition of electrical pulses to the needles. Normally two needles are used, with at least one of them on an acupoint, to complete the electrical current circuit. It has been suggested that electroacupuncture might be more effective than manual acupuncture, and transcutaneous stimulation delivered via skin electrodes at the acupoints can be as effective as electroacupuncture in some cases.[15] Both manual acupuncture and electroacupuncture techniques are receiving recognition in the West, but they are recommended primarily for pain modulation.[13] Little information is available on the effect of electroacupuncture on skeletal muscle strength in controlled trials in either patients or healthy subjects.

The aim of this investigation was to examine whether repeated unilateral electroacupuncture at two selected acupoints would affect dorsiflexion muscle strength of the stimulated and the contralateral limbs, similar to that observed after voluntary strength training or transcutaneous ES training. Ankle dorsiflexion was chosen as the experimental model for several reasons. First, according to TCM, acupuncture on some of the acupoints may have the effects of retarding muscle atrophy, motor impairment, pain, hemiplegia, and paralysis of the lower extremities.[17] Two of these acupoints, *Zusanli* (labeled as ST-36) and *Xiajuxu* (ST-39), are located on the anterior tibialis muscle (Fig. 1). Therefore, applying electroacupuncture to these acupoints may affect the function of the dorsiflexors. Second, normal function of dorsiflexors is essential for maintaining posture and walking. Injuries or stroke may cause deficiency or loss of function in dorsiflexors, such as drop foot. Validating new methods in treatment and rehabilitation for such conditions has clinical value. Third, the anterior tibialis is the major dorsiflexor and easily accessible for acupuncture, and the dorsiflexion strength can be measured. It was hypothesized that repeated unilateral electroacupuncture at *Zusanli* and *Xiajuxu* could induce strength gain in the stimulated limb and cross-education effect on the nonstimulated contralateral limb.

MATERIALS AND METHODS

Volunteer participants were recruited from university student populations via advertising. Volunteers who met the el-

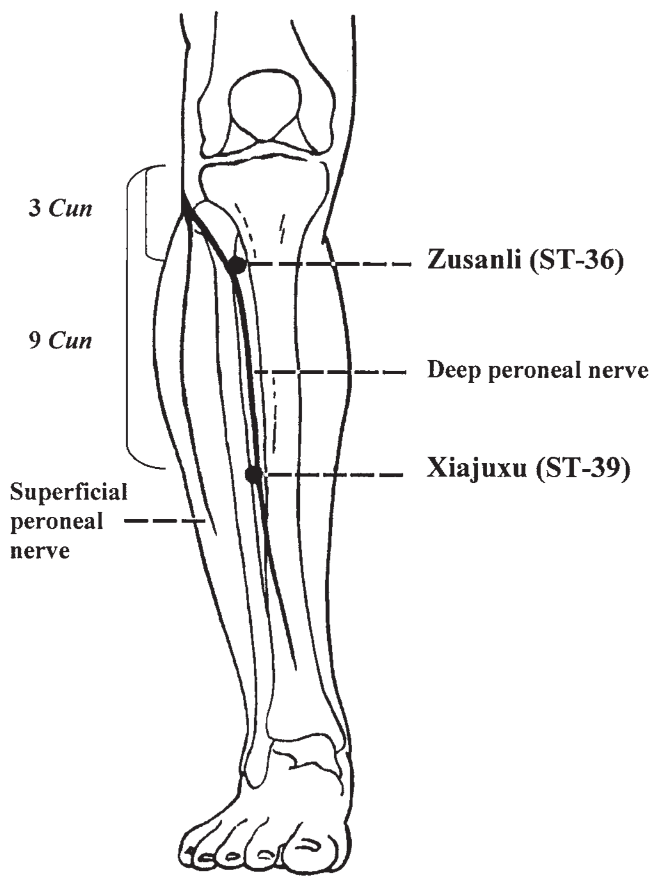

FIG. 1. Location of the acupoints *Zusanli* and *Xiajuxu*.

Table 1. Eligibility Criteria for Participation

Inclusion criteria	*Exclusion criteria*
Male Full-time boarding students with similar timetable of daily activities No previous experience with acupuncture Physically active, with no regular strength training during the 6 months prior to the study	With known musculoskeletal or neurologic injuries or diseases No commitment to follow the experimental schedule

igibility criteria (Table 1) were numbered by the order of recruitment time to mask their identity, then the numbers were drawn from a container to allocate them into an electroacupuncture group (EG, n = 15) or a control group (CG, n = 15) by the researcher. The mean age of the participants was 20.9 (range 17–29) years. It was not possible to predict the minimum sample size by calculation of statistical power, because there was no reference in the literature that had reported the effects (with mean and SD) of electroacupuncture on muscular strength. Therefore, the sample size was determined according to the outcome of a transcutaneous ES training study on a similar population.[6] All participants gave their consent. The experimental procedure obtained approval by the Human Research Ethics Committee of Southern Cross University, and was carried out in accord with the Helsinki Declaration of 1975.

Participants were all full-time boarding students with similar timetables for daily activities. Participants in both groups were instructed to maintain their normal daily activities, but not to engage in any strength or sport training, which was reinforced by weekly interviews by the researchers. Participants in the CG received no additional treatment, whereas those in the EG received electroacupuncture at the acupoints of *Zusanli* and *Xiajuxu* on the right leg, 3 sessions per week for 4 weeks. *Zusanli* is located at 3 *cun* distance (*cun* is a unit of length relative to patient's body size in TCM. Three-*cun* is the breadth of the patient's index, middle, ring, and little fingers at the level of proximal interphalangeal joint at the dorsum of the middle finger) from the depression below the patella and lateral to the patellar ligament, and one finger breadth lateral to the anterior crest of the tibia.[17] The *Xiajuxu* is located at 9 *cun* distance from the depression below the patella and lateral to the patellar ligament and one finger breadth lateral to the anterior crest of the tibia (Fig. 1). A stainless steel acupuncture needle with diameter of 0.3 mm and length of 50 mm (GB2024-94, Suzhou Medical Appliance Company, Ltd., China) was inserted vertically into the muscle at each acupoint to a depth of 20–30 mm. The acupuncture was performed by a medical doctor (Bachelor of Medicine) whose previous training included 6 months of study of the theory of TCM and acupuncture and 1 month practicum of acupuncture in hospital. He was closely guided during the experiment by an expert who has a Master degree in acupuncture and more than 10 years of practical experience. The needles were manually manipulated to induce a feeling of *de qi* (i.e., "needle sensation," a soreness and numbness sensation but not a sharp pain). Subsequently, a constant-voltage electroacupuncture apparatus (SDZ-II, Suzhou Medical Appliance Company, China) was used to deliver electrical pulses of 1-millisecond width at a frequency of 40 Hz, with a gradually increased intensity to the level of soreness that the participant could tolerate maximally. Forty (40) Hz was chosen because this frequency has been reported to induce fully fused tetanus contraction, as in transcutaneous ES; while not inducing early fatigue and significant discomfort to the participants.[18] The average stimulation intensity was approximately 30 V, whereas some subjects could tolerate up to 40 V. The anode of the stimulator was connected to *Zusanli* and the cathode to *Xiajuxu*. The needles remained at the acupoints for 15 minutes. Intermittent stimulation cycles of 1 minute on, 1 minute off, were applied, with a total of 8 stimulation periods in each session. Participants were instructed not to voluntarily contract the muscle in either limb during the session.

Before and after the 4-week experimental period, both legs of the participants in both groups were tested for dorsiflexion strength. The strength test was performed on a custom-built apparatus (Fig. 2). Participants lay in a supine position with the knee joint angle of 90° and initial ankle joint angle of 15° in plantar flexion. The foot of the participant was strapped into a pulley system, with the range of motion limited to approximately 20°. Participants were instructed to lift weights in 5-kg increments, until failure to complete the dorsiflexion movement. Then the last 5-kg weight was removed and a lighter weight was added with 1-kg increments. The final weight that was successfully lifted was

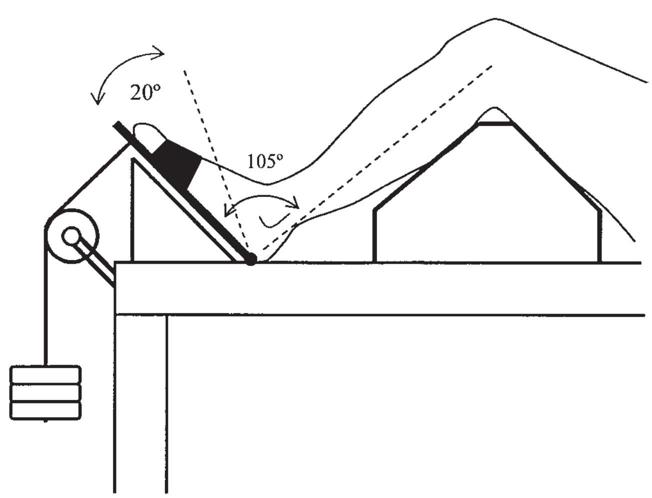

FIG. 2. A sketch of the custom-built testing device for dorsiflexion strength.

TABLE 2. MAXIMUM DORSIFLEXION STRENGTH IN THE ELECTROACUPUNCTURE (EG) AND CONTROL (CG) GROUPS PRE AND POST 4 WEEKS EXPERIMENTAL PERIOD

Limb	*Group*	*Pre (kg)*	*Post (kg)*	*Mean difference (kg)*	*95% CI for difference (kg)*	p	*Effect size****
Stimulated	EG	27.64 (4.52)	3321 (6.31)*	5.57	3.20–7.94	0.00**	1.015
(Right)	CG	25.07 (4.17)	25.73 (4.74)	0.67	−1.62–2.96	0.56	0.148
Unstimulated	EG	28.29 (4.20)	32.21 (4.76)*	3.93	2.01–5.85	0.00**	0.873
(Left)	CG	25.80 (4.16)	26.80 (3.71)	1.00	−0.86–2.86	0.28	0.254

Values in the Pre and Post columns are means with standard deviations in brackets. CI, confidence interval.
*Significantly ($p < 0.05$) different from the CG.
**Significantly changed after 4 weeks of electroacupuncture.
***Cohen's d effect size for within-subject difference, $d = (\text{Mean}_{post} - \text{Mean}_{pre})$/pooled standard deviation.[40]

recorded as the maximum dorsiflexion strength. A minimum of 1-minute recovery was allowed after each contraction.

Analysis of variance (ANOVA) with repeated measures was utilized to examine the interactions between groups (EG and CG), legs (left and right), and pre–post-treatment (electroacupuncture or control period). If a significant interaction was detected, Bonferroni adjustment was applied in *post-hoc* analysis to compare the mean values. An alpha level of 0.05 was set for statistical significance. These statistical analyses were performed using SPSS software, version 11.5 (Chicago, IL). The descriptive data of mean, standard deviation, confidence interval, and effect size are reported.

RESULTS

One participant in the EG discontinued during the trial because of a personal reason; therefore, the results of 14 participants in the EG and 15 in the CG were used in statistical analysis. The ANOVA with repeated-measures analysis detected a significant interaction between groups and pre–post-treatment ($p = 0.004$), and significant between-subject effect for groups ($p = 0.005$) and within-subject effect for pre–post-treatment ($p = 0.000$). The *post-hoc* analysis indicated that there was a significant increase of strength in both legs of the EG ($p = 0.000$) after the 4 weeks of treatment (Table 2). The strength of the stimulated (right) limb increased by 21.3%, whereas that of the nonstimulated (left) limb increased by 15.2%. In contrast, the CG showed no significant change of strength ($p > 0.05$) in either the right (3.0%) or the left leg (4.8%) after the same period of time (Table 2). There was no significant between-leg difference in strength within each group, neither pre- nor post-treatment. The strength change of each individual participant is demonstrated in Figure 3. Comparisons between the groups indicated that the strength of the EG after the intervention was significantly higher than that of the CG in both the right ($p = 0.001$) and the left ($p = 0.002$) legs, whereas no significant between-group difference was detected at baseline ($p > 0.05$) (Table 2). There were no adverse events reported during the experiment.

DISCUSSION

The novel finding in this study was that 12 sessions of electroacupuncture at the selected acupoints resulted in an improved muscular strength in both the stimulated and nonstimulated limbs. The finding appears to support the hypothesis that the intervention has an effect of cross education in strengthening muscles.

A limitation of this investigation is that it was unable to identify whether the increased muscle strength was caused by a general effect of ES, similar to that observed in previous transcutaneous stimulation training studies, or a specific effect of acupuncture and/or ES at the purposefully selected acupoints. In most of the previous studies that demonstrated cross education utilizing unilateral ES training, the stimulation was applied over a muscle belly, not always on a specific acupoint.[4–8] It has been generally accepted that transcutaneous ES activates motor nerve fibers, rather than directly activating muscle fibers, because the nerve fibers have higher excitability than muscle fibers.[19] Both acupoints *Zusanli* and *Xiajuxu* are above the deep peroneal nerve that innervates the dorsiflexors, and near the superficial peroneal nerve that has cutaneous branches to the anterior–lateral aspect of the leg. The needle electrodes should be able to deliver stimulation pulses effectively to these nerves as well as to the muscle fibers adjacent to the needles. Therefore, it can be speculated that the electroacupuncture as used in the present study might have stimulated the nerve trunk or fibers that caused the training effect. However, the design of this study did not allow a verification of any unique or additional effect from electroacupuncture with comparison to transcutaneous stimulation. In addition, although this study took inspiration from the principle of *Juci*, it was not fully in compliance with the theory and practice of TCM. In the theory of TCM, a treatment is supposed to be effective only for individuals who have an imbalance of *qi* (i.e., a disorder in the body system). We did not collect data with respect to the balance of *qi*, whereas the subjects in this study were apparently healthy. In practice, electroacupuncture is not exactly the same as the traditional manual acupuncture with

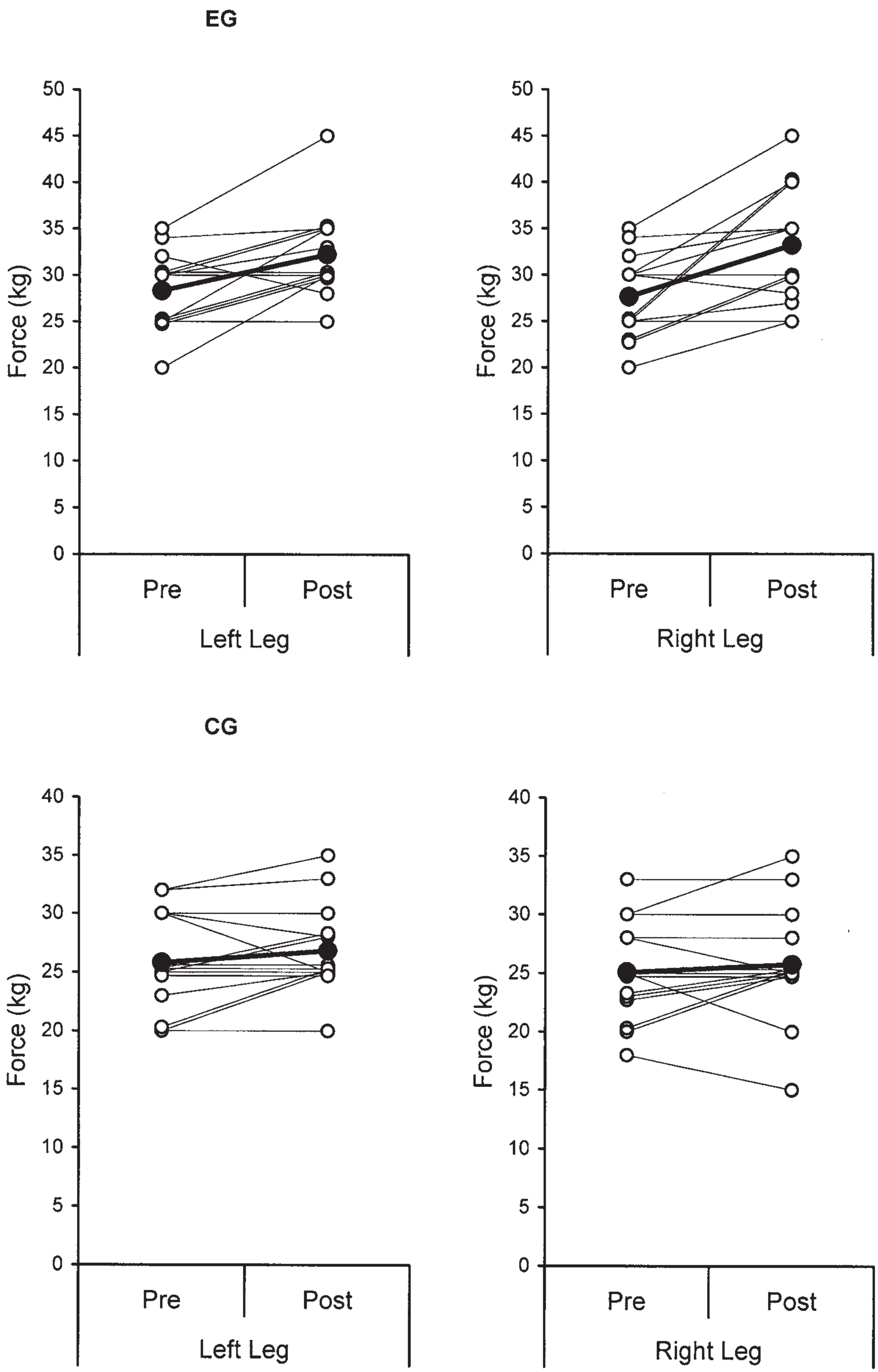

FIG. 3. Changes in maximum dorsiflexion strength of the right and left legs, before and after the 4 weeks of the experimental period, in the electroacupuncture (EG, n = 14) and control (CG, n = 15) groups. The open circles and thin lines represent individual data, and the filled circles and thick lines represent the group means.

respect to the nature of the stimulation. Future studies are needed to compare the effects of electroacupuncture, transcutaneous ES, and manual acupuncture at these acupoints and at nonacupoints, to clarify whether acupuncture or ES at these acupoints has a unique effect on muscle strength.

It has been reported that ES training is effective in improving muscle strength.[8,17,19] For the muscles being stimulated, the mechanisms that have been proposed for the strength gain include (1) adaptations to overloading of the muscle that cause hypertrophy and changes in metabolic characteristics; (2) neural adaptations caused by afferent inputs; and (3) preferential recruitment of fast-twitch muscle fibers based on the theory of reversal in the order of motor unit recruitment.[19–21] Based on the protocol in this trial, it is unlikely that muscle hypertrophy was the major reason for the observed strength gains, although muscle size was not measured. The stimulation intensity used in this study was lower than that in most other ES studies on large muscles. The contraction force induced by electroacupuncture was not monitored for each participant during the experiment. However, pilot investigation on a small number of subjects showed that the contraction force (in static contractions) induced by the electroacupuncture was not more than 35% MVC (unpublished data in our laboratory). This level of contraction was well below the recommended intensity of 70% MVC and training period of 4 weeks for producing measurable muscle hypertrophy.[22]

Second, it has been shown that ES at submaximal levels, for example, at 65% MVC,[6] can induce strength gains similar to that induced by voluntary training at the same or higher contraction intensities.[6,19,21,23] If there is no evident muscle hypertrophy, it would indicate that a unique mechanism might be involved in neural adaptation to ES training that is different from the adaptation to voluntary training. It is conceivable that this unique mechanism, although still unclear, would relate to the effects of afferent inputs associated with the stimulation. Cumulative evidence indicates that afferent inputs during acupuncture, electroacupuncture, or transcutaneous ES may activate various supraspinal regions in the CNS,[24,25] affect secretion of neurotransmitters or neuropeptides,[14,26,27] and alter excitability and plasticity of the motor system.[28,29] For example, one recent study demonstrated that acupuncture with the "lifting and thrusting technique" at the acupoint *Shousanli* (LI-10) on the right forearm for 10 to 15 minutes significantly facilitated the transcranial magnetic stimulation evoked potential (MEP) recorded from the right first dorsal interosseous muscle.[28] The effect remained evident for 5–15 minutes after the needle was removed. Furthermore, needling at a sham point resulted in a depression of MEP amplitudes, indicating that acupuncture at the acupoint might have a unique effect on the excitability and plasticity of the motor cortex.[28] It has been demonstrated that cutaneous stimulation may have an excitatory effect on high-threshold motor units and an inhibitory effect on the low-threshold motor units,[29] indicating that mechanisms at the spinal cord level might have also contributed to the adaptations to ES training.

Third, whether the effectiveness of electroacupuncture in strength gain is caused by a preferential recruitment of fast-twitch motor units cannot be verified in the present study. In a recent review by Gregory and Bickel (2005), the authors challenged the theory of reversal in the order of motor unit recruitment during neuromuscular ES.[30] One of the arguments presented by these authors was that, because there are many factors that may affect the current flow (e.g., skin impedance, subcutaneous fat, and peripheral nerve orientation, etc.), the responses to transcutaneous stimulation would be different from that of a direct stimulation on motor nerves as observed in *in vitro* or *in situ* animal studies. The electroacupuncture used in the present study delivered stimulation more directly to the nerve and muscle fibers without the potential interferences as identified by Gregory and Bickel.[30] Whether the electroacupuncture, with the potential effects of afferent inputs on spinal motor neuron pool,[29] is more effective than cutaneous ES in recruiting large nerve fibers, possibly of fast-twitch motor units, would be an interesting question for future investigations.

The contralateral effect of unilateral strength training is commonly regarded as a neural adaptation, because there has been little evidence of muscle hypertrophy in the unexercised contralateral muscle while its strength is improved.[31–33] The potential neural mechanisms that have been proposed include diffusion of impulses between two hemispheres, coactivation via bilateral corticospinal pathways, postural stabilization or learning in coordination, and afferent modulation. These adaptations might involve both supraspinal and spinal mechanisms.[1–3] However, no consensus has been achieved on a dominant mechanism for the bilateral adaptation.[1–3] Electroacupuncture over a muscle or a nerve trunk would activate any afferent and efferent nerve fibers when reaching their excitation thresholds. The afferent inputs can reach various compartments in the CNS, and cause neural and humoral responses,[13–15] yet reports on the effects of acupuncture on motor activity, particularly muscle strength, are scarce.[34,35]

Recent evidence from functional magnetic resonance imaging (fMRI) indicates that ES, electroacupuncture, or manual acupuncture at selected acupoints may cause bilateral activation in a number of structures in the brain.[24,36,37] Transcutaneous stimulation over *Zusanli* (ST-36) and *Sanyinjiao* (SP-6) of the left leg induced a bilateral increase of fMRI signals in the primary and secondary somatosensory areas, insula, ventral thalamus, cerebellum, and several other regions in the brain.[33] Another study reported that electroacupuncture at *Zusanli* resulted in more widespread bilateral changes of fMRI signals in the brain than manual acupuncture and placebo-like tactile control stimulation. The authors suggested that electroacupuncture could activate more somatosensory receptors and nerve fibers; therefore, more structures in the brain were activated than those in response to manual acupuncture and the tactile control stimulation.[24] Although such changes in fMRI signals may not reveal the exact mechanisms that are responsible for the improved muscle strength, they support the early hypothesis and the evidence from cortical magnetic field changes [38] that there is a bilateral coactivation during unilateral voluntary and stimulated muscle contractions. Together with the evidence of altered focal cortical motor excitability in response to somatosensory inputs,[1,39] it suggests that supraspinal mechanisms may be involved in the cross education induced by the electroacupuncture.

Furthermore, there have been reports that electroacupuncture and transcutaneous ES at acupoints may affect the secretion of neurotransmitters and neuropeptides in the CNS.[13–15,26,27] Whether and how these neural–humoral factors are involved in mediating neural plasticity in somatic motor function remain to be examined.

In summary, the present study has provided novel evidence for the bilateral effect of unilateral electroacupuncture on muscle strength in healthy young men. The finding of improved strength in both the stimulated and nonstimulated limbs would have clinical implications, particularly in physical therapy and rehabilitation for injuries, surgical procedures, or other conditions that might have restricted the mobility and affected motor function of one limb. The study has also raised several interesting questions with respect to the potential neural mechanisms of cross education and electroacupuncture that warrant further research.

ACKNOWLEDGMENTS

This project was partially supported by a Special Research Grant from Tianjin Municipal Government, China, and an Internal Research Grant of Southern Cross University, Australia. The authors appreciate the guidance on acupuncture given by Dr. Qing-Wen Li, Tianjin University of Sport.

REFERENCES

1. Hortobagyi T. Cross education and the human central nervous system. IEEE Eng Med Biol Mag 2005;24:22–28.
2. Munn J, Herbert RD, Gandevia SC. Contralateral effects of unilateral resistance training: A meta-analysis. J Appl Physiol 2004;96:1861–1866.
3. Zhou S. Chronic neural adaptations to unilateral exercise: Mechanisms of cross education. Exerc Sport Sci Rev 2000;28: 177–184.
4. Tachino K, Susaki T, Yamazaki T. Effect of electro-motor stimulation on the power production of a maximally stretched muscle. Scand J Rehabil Med 1989;21:147–150.
5. Cabric M, Appell H-J. Effect of electrical stimulation of high and low frequency on maximum isometric force and some morphological characteristics in man. Int J Sports Med 1987;8: 256–260.
6. Zhou S, Oakman A, Davie A. Effects of unilateral voluntary and electromyostimulation training on muscular strength on the contralateral limb. Hong Kong J Sports Med Sports Sci 2002;14:1–11.
7. Singer K. The influence of unilateral electrical muscle stimulation on motor unit activity patterns in atrophic human quadriceps. Aust J Physiother 1986;32:31–37.
8. Hortobagyi T, Scott K, Lambert J, et al. Cross-education of muscle strength is greater with stimulated than voluntary contractions. Motor Control 1999;3:205–219.
9. Stromberg BV. Contralateral therapy in upper extremity rehabilitation. Am J Phys Med 1986;65:135–143.
10. Mills VM, Quintana L. Electromyography results of exercise overflow in hemiplegic patients. Phys Ther 1985;65: 1041–1045.
11. Lin YP, Pan L. Current research on Juci [in Chinese]. Yun Nan J Traditional Chin Med Mater Med 2004;25:41–43.
12. World Health Organization. Acupuncture: Review and analysis of reports on controlled clinical trial. Albany, NY: World Health Organization, 2002.
13. Balogun JA, Biasci S, Han L. The effects of acupuncture, electroneedling and transcutaneous electrical stimulation therapies on peripheral haemodynamic functioning. Disabil Rehabil 1998;20:41–48.
14. Han JS. Acupuncture: Neuropeptide release produced by electrical stimulation of different frequencies. Trends Neurosci 2003;26:17–22.
15. Ulett GA, Han S, Han JS. Electroacupuncture: Mechanisms and clinical application. Biol Psychiatry 1998;44:129–138.
16. Shen J. Research on the neurophysiological mechanisms of acupuncture: Review of selected studies and methodological issues. J Altern Complement Med 2001;7(suppl 1):S121–S127.
17. Beijing College of Traditional Chinese Medicine, Shanghai College of Traditional Chinese Medicine, Nanjin College of Traditional Chinese Medicine, The Acupuncture Institute of the Academy of Traditional Chinese Medicine. Essentials of Chinese Acupuncture. Beijing, China: Foreign Languages Press, 1980.
18. Solomonow M. Restoration of movement by electrical stimulation: A contemporary view of the basic problems. Orthopedics 1984;7:245–250.
19. Hainaut K, Duchateau J. Neuromuscular electrical stimulation and voluntary exercise. Sports Med 1992;14:100–113.
20. Delitto A, Snyder-Mackler L. Two theories of muscle strength augmentation using percutaneous electrical stimulation. Phys Ther 1990;70:158–164.
21. Enoka RM. Muscle strength and its development. New perspectives. Sports Med 1988;6:146–168.
22. American College of Sports Medicine. Position stand on progression models in resistance training for healthy adults. Med Sci Sports Exerc 2002;34:364–380.
23. Lake DA. Neuromuscular electrical stimulation. An overview and its application in the treatment of sports injuries. Sports Med 1992;13:320–336.
24. Napadow V, Makris N, Liu J, et al. Effects of electroacupuncture versus manual acupuncture on the human brain as measured by fMRI. Hum Brain Mapp 2005;24:193–205.
25. Kong J, Ma L, Gollub RL, et al. A pilot study of functional magnetic resonance imaging of the brain during manual and

electroacupuncture stimulation of acupuncture point (LI-4 Hegu) in normal subjects reveals differential brain activation between methods. J Altern Complement Med 2002;8:411–419.
26. Ma SX, Ma J, Moise G, Li XY. Responses of neuronal nitric oxide synthase expression in the brainstem to electroacupuncture Zusanli (ST 36) in rats. Brain Res 2005;1037:70–77.
27. Pan B, Castro-Lopes JM, Coimbra A. Activation of anterior lobe corticotrophs by electroacupuncture or noxious stimulation in the anaesthetized rat, as shown by colocalization of Fos protein with ACTH and beta-endorphin and increased hormone release. Brain Res Bull 1996;40:175–182.
28. Lo YL, Cui SL, Fook-Chong S. The effect of acupuncture on motor cortex excitability and plasticity. Neurosci Lett 2005;384:145–149.
29. Garnett R, Stephens JA. Changes in the recruitment threshold of motor units produced by cutaneous stimulation in man. J Physiol (London) 1981;311:463–473.
30. Gregory CM, Bickel CS. Recruitment patterns in human skeletal muscle during electrical stimulation. Phys Ther 2005;85: 358–364.
31. Farthing JP, Chilibeck PD. The effect of eccentric training at different velocities on cross-education. Eur J Appl Physiol 2003;89:570–577.
32. Munn J, Herbert RD, Hancock MJ, Gandevia SC. Training with unilateral resistance exercise increases contralateral strength. J Appl Physiol 2005;99:1880–1884.
33. Lagerquist O, Zehr EP, Docherty D. Increased spinal reflex excitability is not associated with neural plasticity underlying the cross-education effect. J Appl Physiol 2006;100:83–90.
34. Pelham TW, Holt LE, Stalker R. Acupuncture in human performance. J Strength Cond Res 2001;15:266–271.
35. Toma K, Conatser RR, Gilders RM, Hagerman FC. The effects of acupuncture needle stimulation on skeletal muscle activity and performance. J Strength Cond Res 1998;12: 253–257.
36. Zhang WT, Jin Z, Luo F, et al. Evidence from brain imaging with fMRI supporting functional specificity of acupoints in humans. Neurosci Lett 2004;354:50–53.
37. Hui KK, Liu J, Makris N, et al. Acupuncture modulates the limbic system and subcortical gray structures of the human brain: Evidence from fMRI studies in normal subjects. Hum Brain Mapp 2000;9:13–25.
38. Kristeva R, Cheyne D, Deecke L. Neuromagnetic fields accompanying unilateral and bilateral voluntary movements: Topography and analysis of cortical sources. Electroencephalogr Clin Neurophysiol 1991;81:284–298.
39. Kaelin-Lang A, Luft AR, Sawaki L, et al. Modulation of human corticomotor excitability by somatosensory input. J Physiol (Lond) 2002;540(pt 2):623–633.
40. Rosnow RL. Effect sizes for experimenting psychologists. Can J Exp Psych 2003;57:221–237.

Address reprint requests to:
Shi Zhou, Ph.D.
Department of Exercise Science and Sport Management
Southern Cross University
P.O. Box 157
Lismore, NSW 2480
Australia

E-mail: shi.zhou@scu.edu.au