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Rapid Communication

Taiji Training Improves Knee Extensor Strength and Force Control in Older Adults

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The purpose of this study was to examine the effects of Taiji training on knee extensor strength and force control in older individuals. Twenty-six healthy older adults (71.9 ± 1.8 years) participated in the study. Sixteen of the older adults (70.2 ± 1.8 years) underwent Taiji training for 20 weeks (experimental group), whereas the other 10 (74.6 ± 1.2 years) served as the control group. For both groups, strength and force control of the knee extensors was assessed twice with an isokinetic dynamometer. Strength was assessed with a maximum voluntary isometric contraction (MVC). Force control was measured as the standard deviation (*SD*) and coefficient of variation (CV) of force during a constant isometric knee extension task at 2%, 30%, 60%, and 90% MVC. For the experimental group, MVC significantly increased (19.5 ± 4.9%) and the CV of force decreased (18.9 ± 3.3%) following Taiji training. Improvements in the CV of force were primarily due to decreases in the *SD* of force (R^2 = .86) rather than increases in strength (R^2 = .12). Furthermore, decreases in *SD* of force were independent of improvements in strength. For the control group, strength, *SD*, and CV of force were not different for the 2 tests. The overall findings suggest that Taiji training improves knee extensor strength and force control in older adults.

SEDENTARY older adults are generally less able to control muscle force compared with young adults with both their upper (1) and lower extremities (2). The functional implication of the inability to control muscle force is impaired movement accuracy (3,4). Traditional strength training has been shown to improve strength and control of force in a hand muscle of older individuals (5). Recent findings, however, disassociate improvements in control of force with improvements in strength. For example, 2 studies that strength-trained the knee extensors longitudinally suggest that the ability of older adults to exert a constant force does not change with training despite a significant increase in strength (6,7).

In contrast, Taiji (also known as Tai Chi), a traditional Chinese martial art that involves a series of slow, fluid movements of the body with the purpose to enhance balance and stability (8), has been shown to improve strength of the knee extensors (9,10) and accuracy of arm movements in older adults (11). Although both isolated strength training (6,7) and Taiji training significantly load the quadriceps muscles, only Taiji involves considerable muscle coordination of the lower body. Because there is evidence that muscle coordination can increase strength (12,13) and lower force fluctuations (11), the purpose of this study was to examine the effect of a 20-week Taiji training program on knee extensor strength and force control in older adults.

Methods

Twenty-six sedentary but physically and cognitively healthy older adults (71.9 ± 1.8 years) participated in the study. Sixteen of the older adults (70.2 ± 1.8 years; 6 men, 10 women) underwent Taiji training for 20 weeks (experimental group), whereas the other 10 (74.6 ± 1.2 years; 5 men, 5 women) served as the control group. The institutional review board for research approved testing protocols with human subjects and each participant signed a consent document.

For both groups, strength and control of force of the knee extensors (nondominant leg) was assessed twice with an isokinetic dynamometer (KIN COM 500H, Chattecx, Chattanooga, TN). For the experimental group, the first session (pre-test) occurred prior to the beginning of the Taiji program, whereas the second session (post-test) occurred 20 weeks later, at the end of the Taiji program. For the control group, the 2 sessions were 1 week apart.

Strength was assessed with a maximum voluntary isometric contraction (MVC) of the knee extensors. To eliminate the effects of gravity, knee flexion angle was set at 90°. Prior to the MVC trials, each participant performed 2 submaximum warm-up trials. For the MVC, each participant was asked to increase their leg extension force as fast as he or she could from 0 N to maximum in a 10-second period. This procedure was performed for 2 trials, with a 60-second rest between trials. The highest force produced for the 2 trials was considered to be the MVC. Each participant received verbal encouragement and visual feedback (they were able to view the gradation of force on a monitor) during the MVC.

For the assessment of force control, the setup was identical to that of the MVC task. Based on MVC force, 4 target forces (%MVC) were computed: 2%, 30%, 60%, and 90% MVC. These forces were selected primarily to identify the level of activation that muscle force control might improve following Taiji training. Each target force and the force exerted by the participant were displayed as a horizontal line (different colors) on the monitor. The

Table 1. Strength and Force Control During the Pre-Tests and Post-Tests for Each Group

	Pre-Test	Post-Test
MVC (N)		
Experimental	400.7 ± 38.3	478.8 ± 45.8*
Control	339.9 ± 26.4	344.1 ± 25.5
SD of force (N)		
Experimental	5.82 ± 0.67	5.09 ± 0.56
Control	4.91 ± 0.70	5.27 ± 0.79
CV of force (N)		
Experimental	3.97 ± 0.32	3.21 ± 0.29
Control	3.24 ± 0.28	3.62 ± 0.36

Notes: * Indicates significant differences between Experimental and Control group. MVC = maximum voluntary isometric contraction; SD = standard deviation; CV = coefficient of variation.

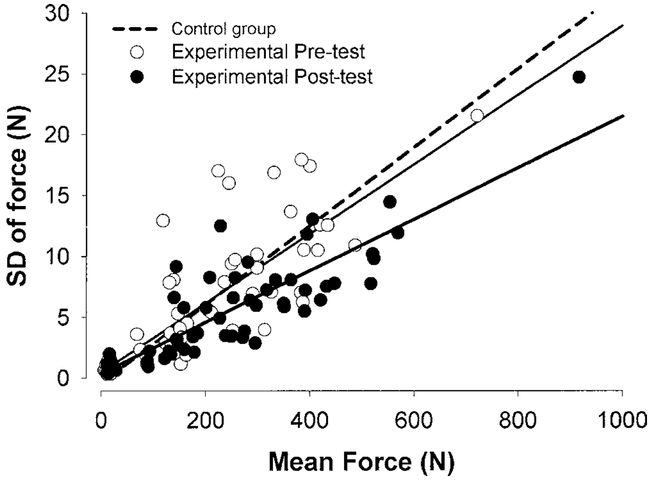

Figure 1. Fluctuations in force as a function of absolute force. Older individuals exhibited significantly lower fluctuations in force following (○; dark solid regression line) compared with prior (●; light solid regression line) to Taiji training. The control group did not change for the 2 tests (dotted regression line).

presentation of the 4 target forces was random. Participants were instructed to match the leg extension force to the target force and, with visual feedback, to maintain a constant level of force for 5 seconds. At the fifth second, visual feedback was eliminated and the participant was asked to maintain the same leg extension force for another 3 seconds. Participants were given 2 practice trials prior to the data collection trial and a rest period of ~60 seconds between trials. This procedure was repeated for each target force. Standard deviation (*SD*) and coefficient variation (CV) of force was calculated in the force output obtained from 2 seconds immediately after visual feedback was eliminated. Further information about the strength and force control assessment can be obtained from a previous publication (14).

The experimental group engaged in Taiji training for 20 weeks, 3 times per week, 1 hour per session, while under the supervision of an individual with 25 years of Taiji teaching experience. Twelve forms of Chen-style Taiji were used, which involved control of the upper and lower body in all directions and involved only light-to-moderate intensity. Further information regarding the Taiji training has been published previously (15).

The dependent variables of the study were the MVC, mean force, *SD* of force, and CV of force. Two designs were used. First, to test the differences as a function of % MVC, the mean, *SD*, and CV of force were examined using a 3-factor complete factorial analysis of variance (ANOVA) (2 groups × 2 tests × 4 percentage targets) with repeated measures on test and target force levels. Second, to test the differences as a function of absolute force level (strength increased thus absolute force in targets increased) the MVC and CV of force were examined using a 2-factor complete factorial ANOVA (2 groups × 2 tests), with repeated measures on tests (SPSS 9.0; SPSS, Inc., Chicago, IL). A linear regression analysis was used to determine the association between the change in force fluctuations and strength. The probability level for all statistical tests was .05. Data are reported as means ± *SE* (standard error).

Results

The experimental and control groups had similar MVC prior to the Taiji training; however, MVC force was significantly higher for the experimental group following Taiji training (see Table 1). For the experimental group, the MVC significantly increased ($p < .01$; 19.5 ± 4.9%), whereas the CV of force significantly decreased ($p < .01$; 18.9 ± 3.3%) when the data was tested as a function of absolute force (Figure 1). Only the CV of force approached statistical significance as function of %MVC ($p = .05$; Table 1). For the experimental group, decreases in the CV of force as a function of absolute force were weakly associated with improvements in strength ($R^2 = .12$; $p < .05$; Figure 2A) and strongly associated with decreases in the *SD* of force ($R^2 = .86$, $p < .001$; Figure 2B). The decreased *SD* of force following Taiji training, furthermore, was not associated with increases in strength ($R^2 = .02$; $p > .1$; Figure 2C). The MVC, *SD* of force, and CV of force did not change significantly for the control group ($p > .1$) as a function of %MVC or absolute force (Table 1).

Discussion

There were two major and novel findings from this study. First, older individuals who participated in the Taiji program became stronger and improved their ability to control force with the knee extensors. Second, improvements in force control were not associated with improvements in strength. Because force fluctuations impair movement accuracy (3,4), the resulting functional implications would be that older individuals could perform movements of the lower body with more accuracy.

The results of this study support previous literature, which also indicated significant strength improvements of the knee extensors following Taiji training (9,10). This study, however, is the first to indicate isometric force increases. This finding is very interesting because Taiji training was performed in gravity-dependent positions with changes in rate of force production and range of motion, whereas knee extensor testing was not gravity dependent and unaffected by rate of force production. Improvements in isometric MVC may be due to the significant use of the knee extensors to produce slow and controlled movements of the body during Taiji movements. Previous studies suggest that increasing the strength of a muscle group is most evident when the training involves movements that are minimally constrained (12,13). It is possible, therefore, that the individuals who participated in the Taiji program increased their knee extensor strength by moving the load of the body in various directions.

Force control improved (decreased CV of force) following Taiji, and improvements were primarily due to decreases in force fluctuations (*SD* of force; $R^2 = .86$) rather than improvements in strength ($R^2 = .12$). In addition, decreased force fluctuations were not associated with improvements in strength. The results support earlier research (6,7), which suggested that traditional strength training did not improve force control of the knee extensors in older adults.

The disassociation between strength improvements and force control suggests that motor learning and skill improvement may be responsible for the observed decreases in force fluctuations. Three previous findings in different muscle groups also point to that conclusion. First, when participants learned to roll 2 metal balls clockwise and counterclockwise in their palm using independent and coordinated movements of their fingers, force control was improved but not strength (16). Specifically, participants reduced the fluctuations in force during a low intensity pinch (<20% MVC) and improved their ability to accurately displace a small object with the hand. Second, when older individuals practiced Taiji, which does not significantly load muscles in the upper body, they were better able to control force and were more accurate in making arm movements than prior to Taiji practice (11). Third, recent findings suggest that the ability of older adults to exert precise force with a hand muscle improved independent of the load used (17,18). For example, 2 weeks of light-load training (10% maximum) decreased force fluctuations and discharge rate variability of the motor units in parallel without any strength improvements (18). An additional 4 weeks of heavy-load training (80% maximum) increased strength but did not change force fluctuations or discharge rate variability.

A potential neural mechanism that could increase knee extensor strength and decrease fluctuations in force independently is muscle coordination. Performing movements that are minimally constrained, such as Taiji, involves the coordination of various muscles. Such unconstrained training can improve both the amplitude and timing of muscle activation (coordination) and increase muscle strength (12). Furthermore, when the activation of the agonist and antagonist muscles is not time-locked (synchronized), coactivation is improved, which can decrease fluctuations in force (19,20). It is possible that the older individuals following Taiji may have learned to improve coactivation of the agonist and antagonist muscles and thus improve both strength and force control.

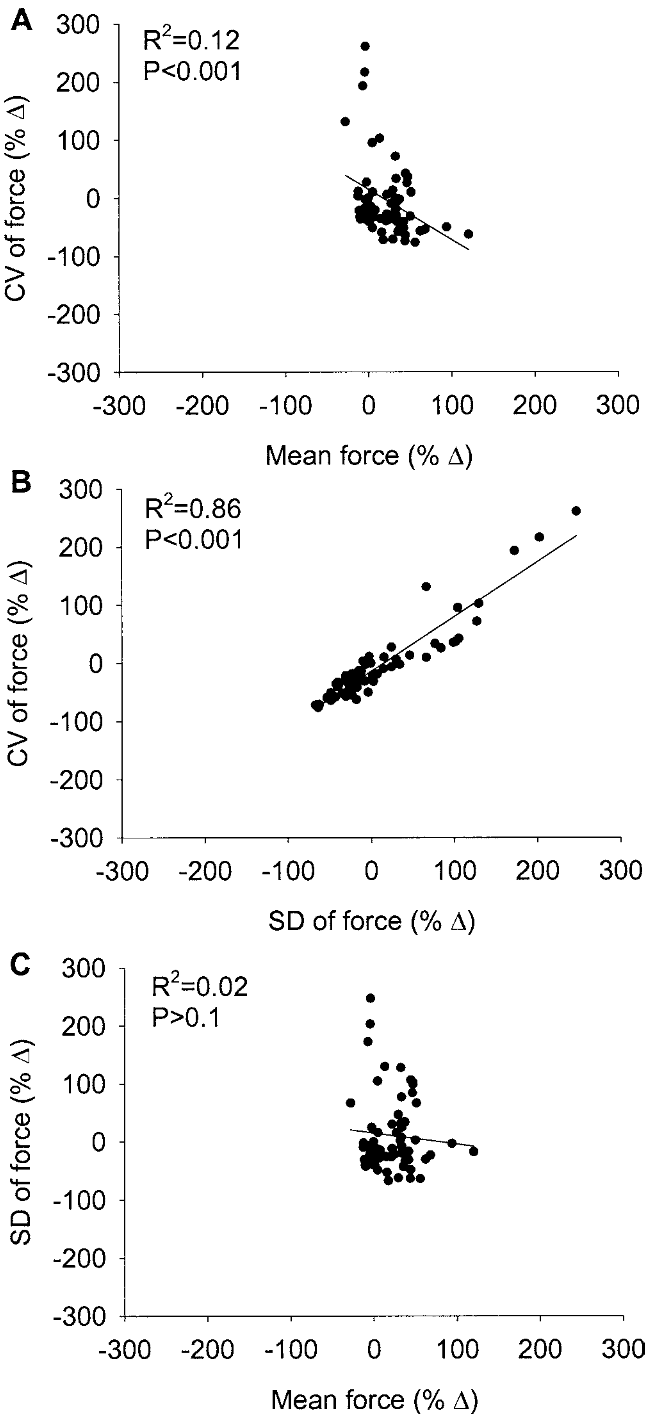

Figure 2. Relations among change in mean force, standard deviations (*SD*) of force, and coefficient of variation (CV) of force. Values are expressed as percent change ([{post-test/pre-test} × 100] – 100). The change (decrease) in CV of force with Taiji training was weakly associated with changes in mean force (**A**, $R^2 = .12$) and strongly associated with changes (decrease) in *SD* of force (**B**, $R^2 = .86$). The change in *SD* of force, however, was not associated with changes in the mean force (**C**, strength increase).

Summary

Results of this study indicate that older individuals can become stronger and have a better force control with the knee extensors following Taiji training. It appears that the major contributor to the improvements in force control is lowering fluctuations in force independent of improving strength. Although improvement in muscle coordination is a potential explanation, further research is needed to identify the neural mechanisms responsible for the independent improvement in strength and force control with skilled training.

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