EFFECT OF LONG-TERM ISOMETRIC TRAINING ON CORE/TORSO STIFFNESS

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ABSTRACT

Lee, BCY and McGill, SM. Effect of long-term isometric training on core/torso stiffness. *J Strength Cond Res* 29(6): 1515–1526, 2015—Although core stiffness enhances athletic performance traits, controversy exists regarding the effectiveness of isometric vs. dynamic core training methods. This study aimed to determine whether long-term changes in stiffness can be trained, and if so, what is the most effective method. Twenty-four healthy male subjects (23 ± 3 years; 1.8 ± 0.06 m; 77.5 ± 10.8 kg) were recruited for passive and active stiffness measurements before and after a 6-week core training intervention. Twelve subjects (22 ± 2 years; 1.8 ± 0.08 m; 78.3 ± 12.3 kg) were considered naive to physical and core exercise. The other 12 subjects (24 ± 3 years; 1.8 ± 0.05 m; 76.8 ± 9.7 kg) were Muay Thai athletes (savvy). A repeated-measures design compared core training methods (isometric vs. dynamic, with a control group) and subject training experience (naive vs. savvy) before and after a 6-week training period. Passive stiffness was assessed on a "frictionless" bending apparatus and active stiffness assessed through a quick release mechanism. Passive stiffness increased after the isometric training protocol. Dynamic training produced a smaller effect, and as expected, there was no change in the control group. Active stiffness did not change in any group. Comparisons between subject and training groups did not reveal any interactions. Thus, an isometric training approach was superior in terms of enhancing core stiffness. This is important since increased core stiffness enhances load bearing ability, arrests painful vertebral micromovements, and enhances ballistic distal limb movement. This may explain the efficacy reported for back and knee injury reduction.

KEY WORDS spine, performance, athleticism, rehabilitation

INTRODUCTION

Core exercises are a staple among athletically trained individuals and clinical populations in an effort to strengthen musculature (35,46), improve muscular endurance (31), reduce low back pain (15,21,36,43), and improve sport performance (19,44). Greater torso stiffness enhances performance through 3 mechanisms. As explained by McGill (29): (a) briefly stiffening the torso proximal to the shoulders and hips transfers the full force and movement of muscles to the distal side of these ball and socket joints resulting in greater limb strength and speed; (b) muscularly stiffening the spinal column enhances its load bearing capacity preventing buckling; and (c) the muscular turgor associated with stiffness creates an armor over vital structures enhancing resilience during contact sports. McGill's explanation builds on the stiffness-stability relationship of the spine described by Bergmark (3) in which muscular stiffness stabilizes the spine against perturbation from external load and movement. This has been demonstrated in athletic tasks, such as strongman events (33), martial arts striking (30), and single leg exercises (47). Although not directly affecting performance, stiffness also arrests micromovements of the spinal joints reducing pain in those with instability.

Typical athletic training programs involve the programming of core exercises to induce long-term strength, speed, and endurance adaptations (14,24,38,45) but little is known if the effect is long lasting. This is the seminal question explored here. Many traditional core training programs involve the use of movement-based torso exercises due to the high level of challenge placed on the core musculature (2,13). Although challenge and subsequent strength adaptations to the core musculature is thought to be great, many of these exercises violate mechanisms found to cause injury to the spine and subject the spine to high shear and compressive loads (9,11,27,41). In contrast, isometric core exercises, based on challenging the core musculature through static braced postures, have also been investigated and when compared with their dynamic counterparts shown to create moderate levels of core activity while minimizing imposed spine loads (1,10,12,32). Given the breadth of data suggesting enhanced core stiffness enhances athleticism, it would be beneficial for athletes to participate in core training regimens

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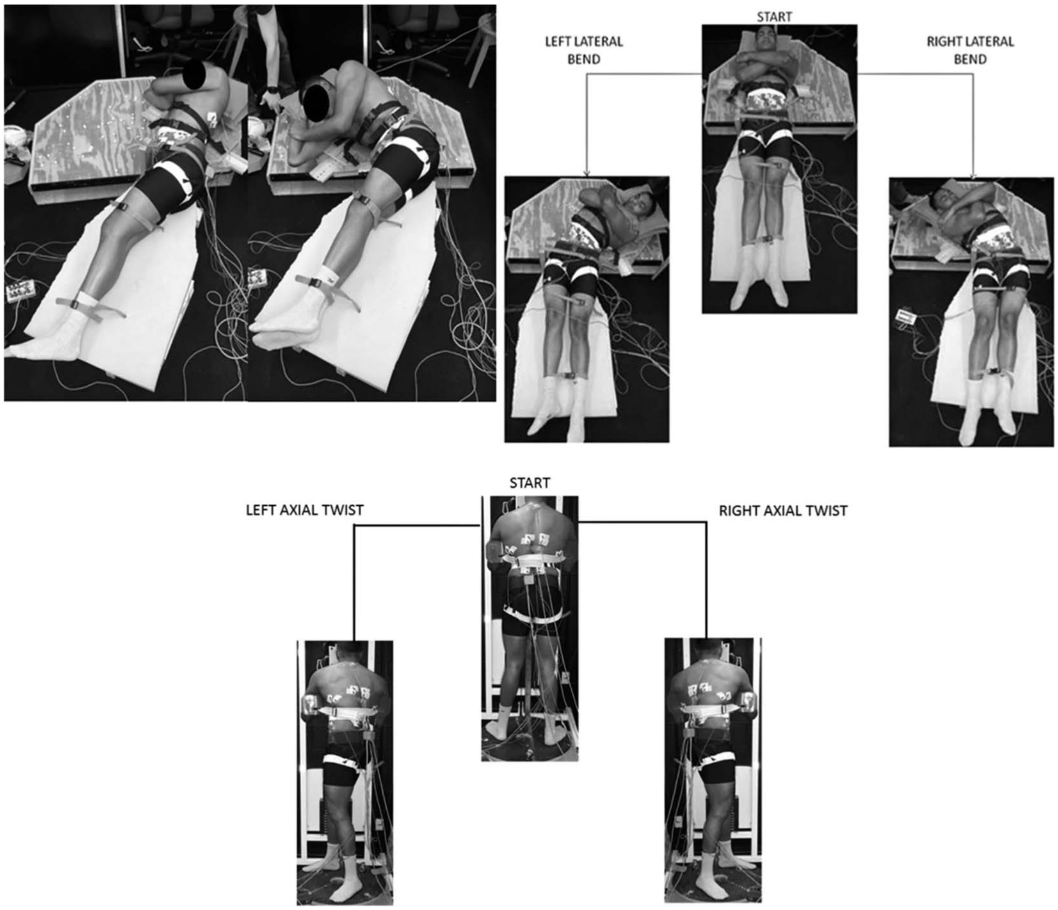

Figure 1. Frictionless bending apparatus used for passive flexion and extension (top left), lateral bend trials (top right), and frictionless twisting apparatus used for passive axial twist trials (bottom center).

as part of their strength and conditioning programs, but what is the best method of doing so?

Seminal work from Burgess et al. (8) and Kubo et al. (25) suggested that stiffness can be altered in the lower limbs through isometric and plyometric training, but whether residual torso stiffness is created through core training is not known. To the authors' knowledge, so such studies exist examining core stiffness adaptations from training, but examining this effect may prove very useful for athletes to determine the best methods to induce enhanced athleticism associated with core stiffness. From this, specific questions addressed in this study were as follows: can passive torso stiffness be increased, and if so, is it better to use a dynamic exercise program or an isometric one; is there a difference between athletically naive or savvy populations; and in addition, can active stiffness be altered with these 2 approaches to training? It was hypothesized that long-term isometric training would enhance passive and active stiffness to a greater degree than dynamic training or control, and naive subjects would see greater stiffness increases than savvy subjects.

METHODS

Experimental Approach to the Problem

A repeated-measures test/retest protocol was used to examine changes in active and passive stiffness after a 6-week core training protocol consisting of isometric bracing or dynamic movement exercises in 24 male subjects. All subjects were collected and trained between March 2013 and June 2013 during day time hours. As physiological markers of health and performance were not within the scope of the study, controls for nutrition and hydration were not used. Subjects had passive and active stiffness measured before and after a 6-week training or waiting period. After the initial data collection, subjects were divided into an isometric training group, dynamic training group, or control group. Isometric and dynamic training groups performed a training program progressing in intensity based on static bracing exercises

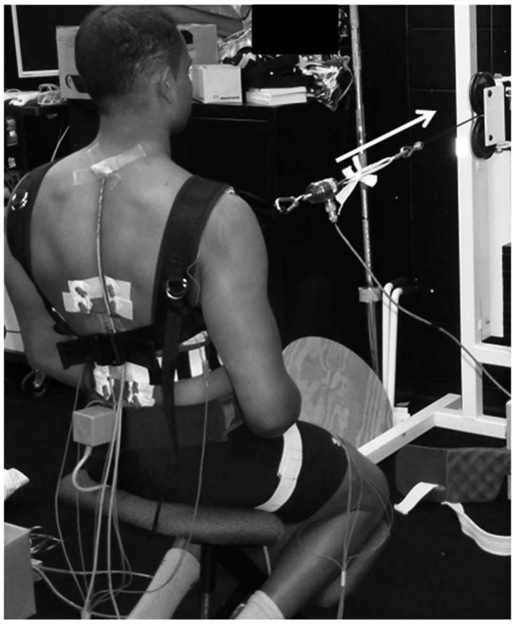

Figure 2. Quick release experimental setup consisting of a chair used to foster a neutral hip and spine posture, harness, electromagnet, and cable stack. The cable pull is shown with the arrow.

and movement/speed-based exercises, respectively. The training/control groups were also evenly divided into "naive" and "savvy" groups (see Subjects for more detail) to determine whether athletically savvy individuals responded differently to training than their naive counterparts.

Subjects

Twenty-four young healthy university-aged males (22.9 ± 2.7 years; range 18-29 years; 1.79 ± 0.06 m; 77.5 ± 10.8 kg) were selected for this study. Of these, 12 subjects (21.7 ± 1.9 years; range 18-26 years; 1.80 ± 0.08 m; 78.3 ± 12.3 kg) were selected with limited experience in physical training and little to no experience in performing core exercises. These are referred to as the exercise "naive" group. The remaining subgroup of 12 subjects (24.2 ± 2.9 years; range 21-29 years; 1.8 ± 0.05 m; 76.8 ± 9.7 kg) was selected from a population of athletes with experience in core training. Inclusion criteria for this subgroup consisted of individuals highly experienced in core training methods, having regularly performed direct core exercises for at least 1 year. This special population consisted of club Muay Thai fighters, a martial art native to Thailand involving standing striking with the fists, elbows, knees, and shins. These are referred to as the "savvy" group. Exclusion criteria for both subgroups consisted of any individuals who have experienced low back pain or injury currently or within the past year. The majority of naive subjects were active in recreational/intramural sports, but had no background in core training and limited experience in physical or weight training. Savvy subjects were trained in Muay Thai boxing for at least 1 year (ranging from 1.5 to 6 years of consistent training) with the majority (10) having competitive amateur records and 2 subjects being provincial and international amateur champions in their respective weight classes.

All subject recruitment and data collection procedures were performed in accordance with University Office of Research Ethics guidelines. The participants were informed of the purpose and method of the study to ensure that they understood completely, and each provided written informed consent to participate. Participants were also informed that at any time during the data collection or training protocol they were free to withdraw from the study. Written informed consent was gained in agreement with MSSE and ACSM guidelines.

Procedures

Two different methods were used to measure passive and active stiffness. Passive stiffness was assessed through a "frictionless" bending apparatus in 3 planes of motion (sagittal, frontal, and transverse) after Brown and McGill (5,6), whereas active stiffness was measured through a "quick release" mechanism after Brown et al. (7). Active and passive torso stiffness values were collected in 2 data collections, one before and another after a 6-week core training intervention. The training intervention consisted of 3 groups: 1 group performed isometric core exercises, 1 group performed dynamic core exercises, and the control group performed no special exercises during this period. Eight subjects were placed into each group, 4 from the naive subject group and 4 from the savvy subject group.

Passive Stiffness Measurement. Sagittal and frontal plane passive bending trials were performed in which participants were secured at the hips, knees, and ankles on a solid lower-body platform. Each participant's upper body was secured to a cradle with a glass bottom surface, about their upper arms, torso, and shoulders (Figure 1). The upper-body cradle was free to glide overtop of a similar glass surface with precision nylon ball bearings between the 2 structures. This created a frictionless float influenced by gravity and allowed trunk movement about either the flexion-extension or lateral bend axis. Participants laid on their right side for the flexion-extension trials and on their back for the lateral bend trials. Their torsos were supported in each position to ensure that participants adopted and maintained a nondeviated spine posture throughout the testing.

Passive axial twisting trials were performed in a separate apparatus consisting of a rotating wheel platform mounted to a fixed base through ball bearings with a frictionless contact (Figure 1). The participant stood upright on the platform maintaining upright spine posture with their upper body fixed through a harness strap to a vertical post (approximately at the level of T9). Lumbar spine

Table 1. Six-week isometric core training program.

	Week 1		Week 2		Week 3		Week 4	
Exercise	Sets × repetitions	Frequency*	Sets × repetitions	Frequency*	Sets × repetitions	Frequency*	Sets × repetitions	Frequency*
Plank	5 × 5, 4, 3, 2, 1	4	5 × 5, 4, 3, 2, 1	7				
Bird dog	5 × 5, 4, 3, 2, 1	4	5 × 5, 4, 3, 2, 1	7				
Side bridge	5 × 5, 4, 3, 2, 1	4	5 × 5, 4, 3, 2, 1	7				
Torsional buttress			5 × 5, 4, 3, 2, 1	7				
Anterior pallof press					5 × 10 s	4	Same volume, increase load	4
Posterior pallof press					5 × 10 s	4	Same volume, increase load	4
Suitcase hold					5 × 10 s per side	4	Same volume, increase load	4
Antirotation pallof Press					5 × 10 s per side	4	Same volume, increase load	4
Stir the pot								
Inverted row								
Kettlebell unilateral rack walk								
Half kneeling woodchop								

	Week 5		Week 6		
Exercise	Sets × repetitions	Frequency*	Sets × repetitions	Frequency*	Comments
Plank					Focus on quality of core contraction and postural cues. Descending pyramid sets (start at 5 repetitions at 10 s each, next set decrease 1 repetition, continue to decease 1 repetition per set)
Bird dog					
Side bridge					
Torsional buttress					Focus on quality of core contraction and postural cues. Use a hold time before shaking begins, maximum 10 s
Anterior pallof press					Focus on quality of core contraction and postural cues
Posterior pallof press					
Suitcase hold					
Antirotation pallof Press					
Stir the pot	5 × 10 s per direction	4	5 × 10 s per direction	4	Begin on knees, progress to toes. If 10 s is not feasible, train below and progress through the phase

Inverted row	Up to 5 × 10	4	5 × 10	4	If 10 repetitions are not feasible, perform as many repetitions as possible and maintain static posture. Focus on keeping torso straight (avoid hip hiking/sagging)
Kettlebell unilateral rack walk	3 × 30 m walk per side	4	Same volume, increase load	4	Focus on core contraction and upright posture (avoid lateral lean)
Half kneeling woodchop	Up to 5 × 10 per side	4	5 × 10	4	If 10 repetitions are not possible, perform as many repetitions as possible and progress through the phase

*Frequency denoted as number of training sessions per week.

motion was measured with an electromagnetic transducer described below.

During each trial, participants were instructed to "feel completely relaxed, like you are going to sleep." Muscular activation was monitored by multichannel electromyography (EMG) to ensure that a truly passive response was obtained. Subjects easily learned to relax with this feedback. Three trials of each bending direction were performed in a randomized order.

Quick Release Trials. During quick release trials, participants were placed in a semiseated position in a restraint jig that restricted hip and lower limb motion while leaving the trunk free to move in all directions (Figure 2). This has been shown to foster a neutral spine posture and elastic equilibrium for the hips and spine (39). Participants were statically preloaded anteriorly with a 16-kg mass, applied through a cable at the level of T7, which was randomly released without the participant's prior knowledge through an electromagnet (Job Master Magnets, Oakville, Canada). Participants were instructed to use core bracing techniques to prevent displacement after release. This trial was repeated 3 times.

Instrumentation

Electromyography. Electromyography signals were collected on unilateral core musculature using pregelled, disposable, monopolar Ag-Cl disc-shaped surface electrodes (30 mm diameter, Medi-traceTM 100 Series Foam Electrodes, Covidien, MA, USA) placed on the skin over each muscle of interest (rectus abdominis, external oblique, internal oblique, latissimus dorsi, upper erector spinae, lower erector spinae). The purpose of EMG collection was to verify that core muscular activation was below 5% to ensure a passive response. In fact, postprocessing of data revealed that all trials turned out to be below 3% maximal voluntary contraction (MVC). Electromyography data were not used for any other purpose. Briefly, normalized signals were obtained as follows. Signals were amplified (±2.5 V; AMT-8, Bortec, Calgary, Canada; bandwidth 10–1,000 Hz, common mode rejection ratio = 115 db at 60 Hz, input impedance = 10 GX) and sampled at 2,048 Hz, low-pass filtered with a 500-Hz rectified and low-pass filtered at 2.5 Hz (single pass second order) to mimic the frequency response of torso muscle after Brereton and McGill (4); and normalized to the maximum voltage produced during MVC trials to produce a linear envelope mimicking the muscle force output; a technique used many times before (6). Maximal voluntary contractions were obtained using 3 postures: (a) a modified sit-up position in which participants isometrically attempted to produce trunk flexion, side bend, and twist motions against resistance; (b) isometric trunk extension while cantilevered in a prone position over the edge of a table (Biering-Sorensen position) against external resistance; and (c) isometric wide grip pull-up posture in which the subject attempted to isometrically pull against a horizontal bar while being resisted with instructions of

TABLE 2. Six-week dynamic core training program.

	Week 1		Week 2		Week 3		Week 4	
Exercise	Sets × repetitions	Frequency*	Sets × repetitions	Frequency*	Sets × repetitions	Frequency*	Sets × repetitions	Frequency*
Curl up	Up to 5 × 10	4	5 × 10	7				
Superman	Up to 5 × 10	4	5 × 10	7				
Side curl up	Up to 5 × 10 per side	4	5 × 10 per side	7				
Twisting curl up	Up to 5 × 10 per side	4	5 × 10 per side	7				
Advanced curl up (limbs extended)					Up to 5 × 10	4	5 × 10	4
Back extension					Up to 5 × 10	4	5 × 10	4
Russian barbell twist					Up to 5 × 10 per side	4	5 × 5–10 per side	4
Curl up twitch								
Superman twitch								
Lateral medicine ball throw								
Rotational medicine ball throw								

	Week 5		Week 6		
Exercise	Sets × repetitions	Frequency*	Sets × repetitions	Frequency*	Comments
Curl up					Focus on quality of muscular contraction; visualize muscular activation throughout motion
Superman					
Side curl up					
Twisting curl up					
Advanced curl up (limbs extended)					Begin with 5 × 5 and progress repetitions to 10. If 10 repetitions per side is too easy add weight
Back extension					
Russian barbell twist					
Curl up twitch	Up to 5 × 10	4	5 × 10	4	Begin unweighted and focus on twitch speed and rate of activation/relaxation
Superman twitch	Up to 5 × 10	4	5 × 10	4	
Lateral medicine ball throw	Up to 5 × 10 per side	4	5 × 10 per side	4	Ball velocity comes from torso movement, not arms
Rotational medicine ball throw	Up to 5 × 10 per side	4	5 × 10 per side	4	Ball velocity comes from torso movement, not arms

*Frequency denoted as number of training sessions per week.

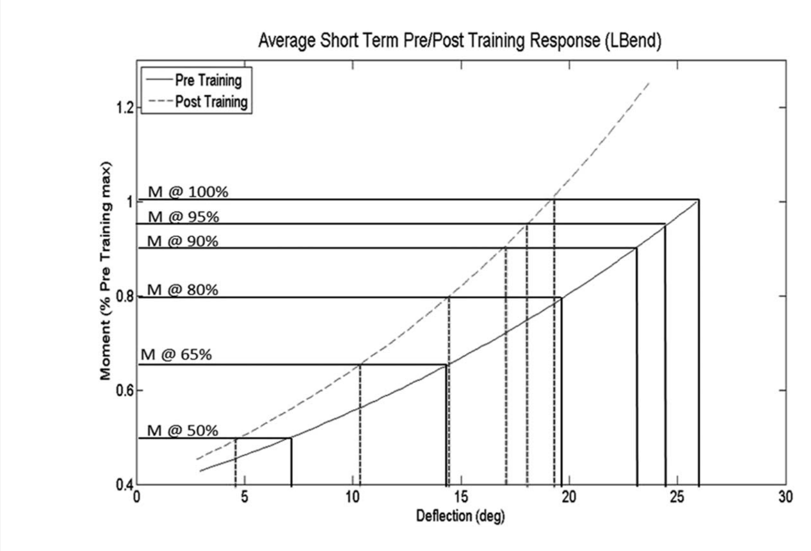

Figure 3. Curve fit moment/deflection data of pre- and post-training. Data were taken at 50, 65, 80, 90, 95, and 100% of peak pretraining moment.

maintaining a maximally tight grip and attempting to "bend the bar" while pulling vertically.

Torso Kinematics. Three-dimensional lumbar spine motion was recorded using an electromagnetic tracking system (Isotrak, Polhemus, Colchester, VT, USA) with the source secured over the sacrum and the sensor over T12 (6). The trunk motion data were sampled digitally at 60 Hz and dual-pass filtered (effective fourth order 3 Hz low-pass, zero lag, Butterworth) (4).

Applied Moment. To obtain passive stiffness, the moments applied to the torso were calculated as the product of the force applied perpendicular to the distal end of the upper-body cradle, and the distance between the point of force application and the L4/L5 disc for the bending trials; or the radius of the rotating platform for twisting trials. Active stiffness measurements were obtained as the product of the moment arm of the cable applied at the level of T7, to the level of L4/L5, and the cable force. Force was recorded with an inline force transducer (Transducer Techniques Inc., Temecula, CA, USA) and digitally

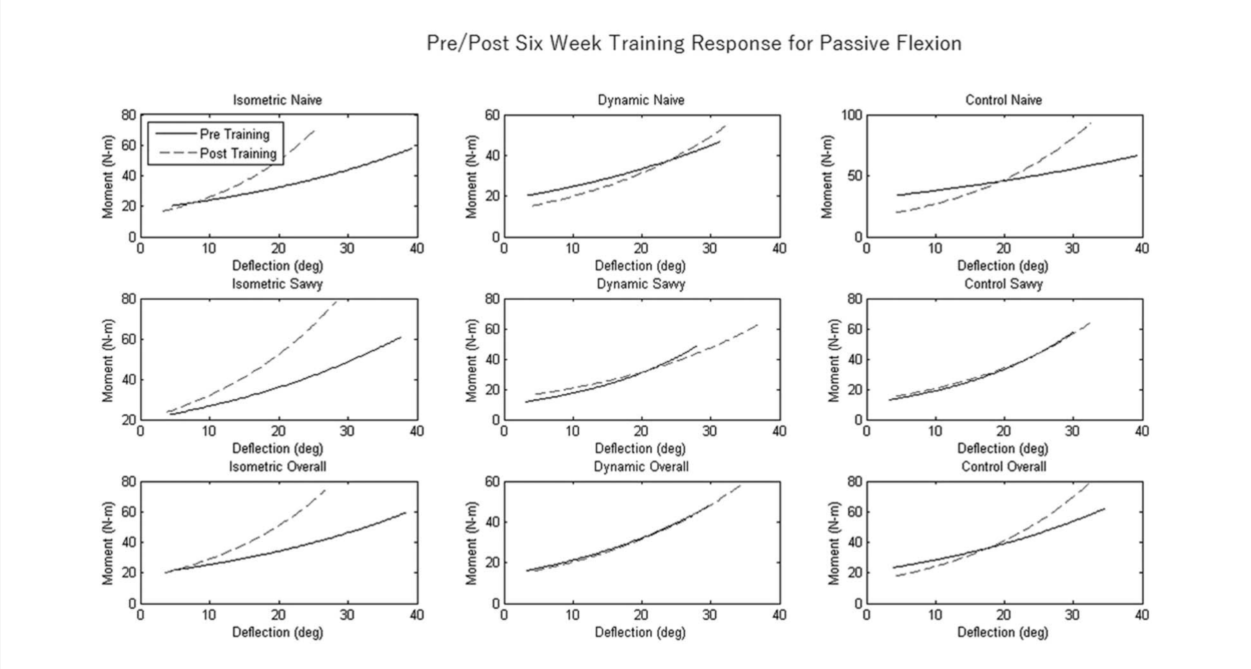

Figure 4. Summary stiffness curves for passive flexion trials with applied moment (N·m) plotted on the y-axis and deflection (degrees) on the x-axis. Top left: naive isometric group. Middle left: savvy isometric group. Bottom left: Overall isometric. Top middle: Naive dynamic group. Center: savvy dynamic group. Bottom middle: Overall dynamic. Top right: Naive control group. Middle right: savvy control group. Bottom right: Overall control.

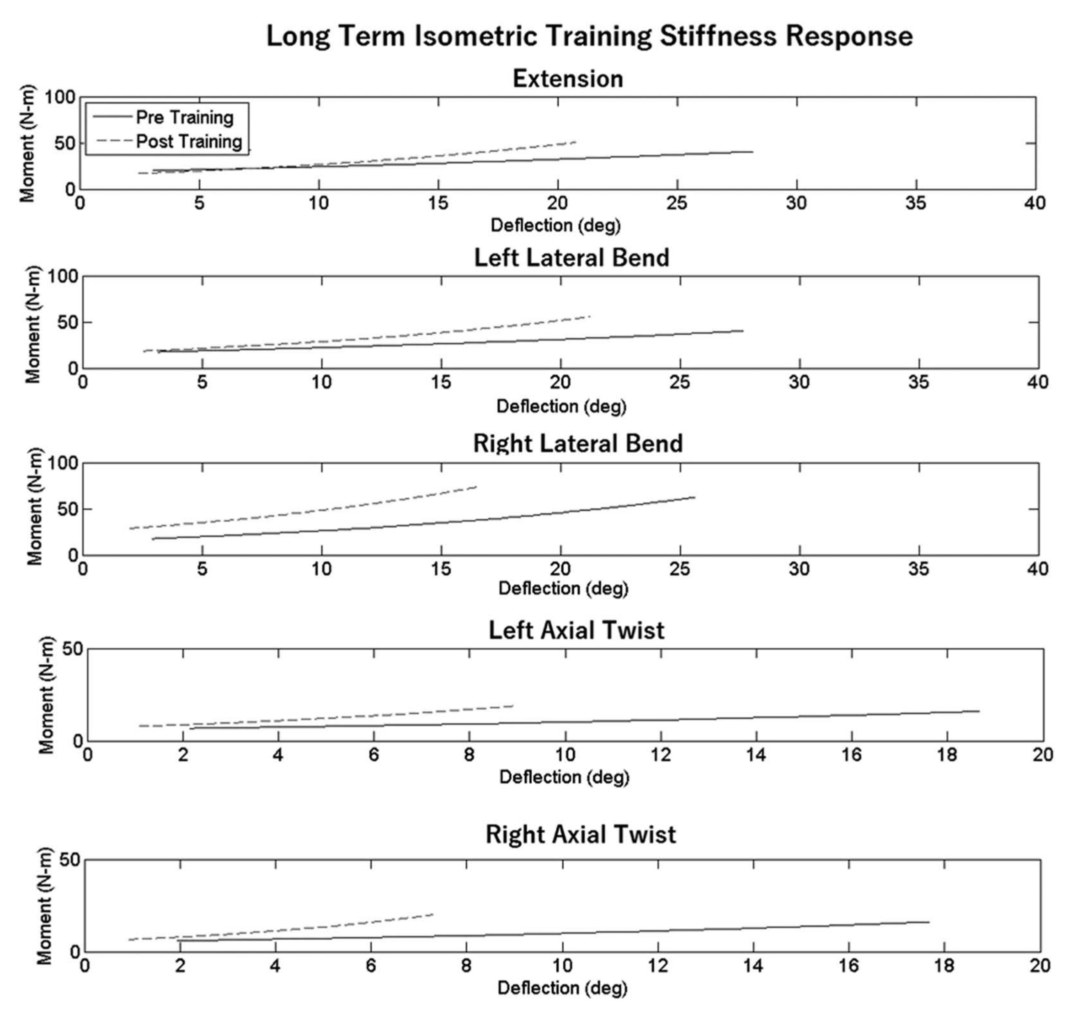

Figure 5. Summary of preisometric/postisometric stiffness curves for passive extension, left lateral bend, right lateral bend, left axial twist, and right axial twist (top to bottom); applied moment (N·m) is denoted on the y-axis and deflection (degrees) on the x-axis. The curves plotted represent training response for all subjects.

sampled at 2,160 Hz. Force signals were dual-pass filtered (effective fourth order 3 Hz low-pass Butterworth). Both the linear enveloped EMG and force signals were downsampled to 60 Hz to match the trunk motion data.

Core Training Protocols. Subjects were trained for 6 weeks using either isometric or dynamic core exercises (the control group did not train). All subjects were asked to refrain from performing any core exercises outside of those assigned by researchers during the study. The Isometric training group performed static exercises designed to challenge the core musculature through bracing cues. The dynamic training group performed exercises based on torso movement. Both training programs were periodized to increase challenge every 2 weeks, dividing each program into 3 phases (Tables 1 and 2 for a description of the progressive programs).

Moment Angle Relationship and Measurement of Stiffness

Passive Trials. The applied moment and corresponding trunk angle were normalized in time to ensure equal trial length across all trials and participants. Trunk angles were normalized as a percentage of the maximum range of motion that participants were able to obtain in the pretraining bending trials. Exponential curve fits of the following form were performed for each trial type:

$$M = \lambda e^{\phi\vartheta},$$

where M is the applied moment (N·m), λ and ϕ are curve fitting constants, and ϑ is the angular displacement of the

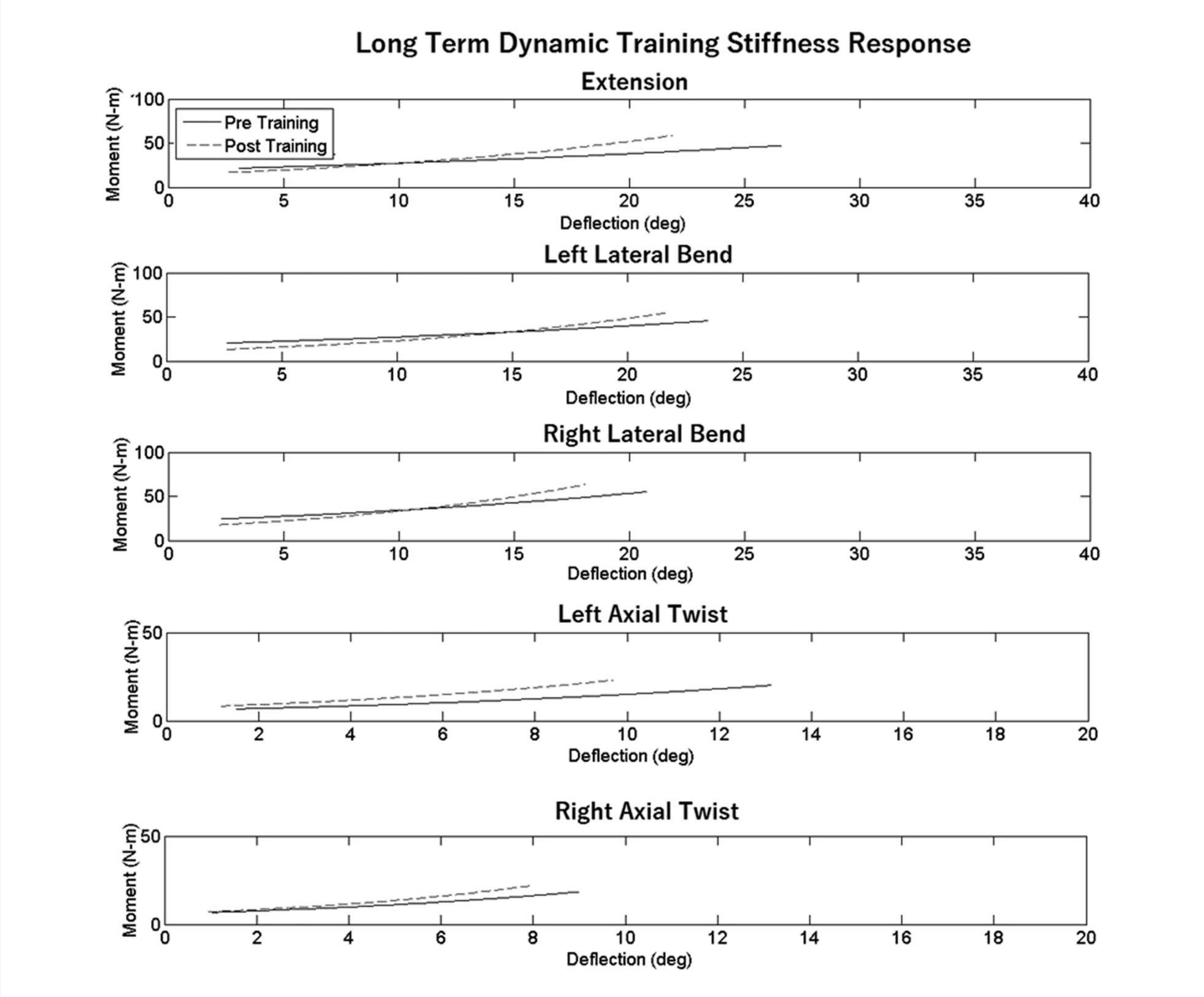

Figure 6. Summary of predynamic/postdynamic stiffness curves for passive extension, left lateral bend, right lateral bend, left axial twist, and right axial twist (top to bottom); applied moment (N·m) is denoted on the y-axis and deflection (degrees) on the x-axis. The curves plotted represent training response for all subjects.

torso. The calculated moment was normalized as a percentage of the maximum applied moment of the pretraining trials and calculated at 50, 65, 80, 90, 95, and 100% of pretraining peak moment for pre- and post-training conditions (Figure 3).

Quick Release Trials for Active Stiffness. On magnet and force release, an event was detected from the load-cell signal by visually identifying when the force-time slope changed. Over the next 250 milliseconds, the force at release and the peak angular displacement of the lumbar spine were obtained to calculate a gross stiffness measure, after Sutarno and McGill (39). A gross lumbar measure of stiffness (N·m/degree) was then obtained from the following equation:

$$k = \frac{M}{\vartheta},$$

where k represents the stiffness calculated from the slope of the moment (M) and absolute angular deflection (ϑ) curve.

Statistical Analyses

Statistical tests were performed using IBM SPSS Statistical software (version 19, IBM, Corp., Somers, NY, USA). $3 \times 2 \times 2$ repeated-measures analysis of variance (3 training group levels, 2 subject group levels, and before and after training) was conducted for comparing range of motion values at each specific instance of applied moment before and after the training protocol (50, 65, 80, 90, 95, and 100% of pretraining applied moment). Where applicable, post hoc analyses were performed using the Tukey HSD test when a significant effect was detected with statistical significance set at $p \leq 0.05$. To the researchers' knowledge, no studies currently exist examining stiffness adaptations with core training, thus it is difficult to establish intra-class correlations and statistical power.

RESULTS

An example from Figure 4 illustrates the overall effects for the passive flexion test. The biggest changes were observed in the isometric training group, regardless of subject group.

Isometric Training

Significant stiffness increases were measured in both savvy and naive populations after 6-week isometric training for the majority of bending tests and at multiple levels of applied moment ($p \leq 0.05$). In naive subjects, only extension and right lateral bending stiffness did not significantly increase (although right lateral bending stiffness at 80% of applied moment was significantly different from pretraining conditions) (Figure 5). The majority of trials showed stiffness increases near end range of motion; flexion stiffness increased significantly at 95% of applied moment and beyond while left lateral bending and right axial twisting stiffness showed significant increases at 80% of applied moment and beyond. Only left axial twist stiffness increased at all levels of applied moment. Savvy subjects experience similar results to their athletically naive counterparts after 6-week isometric training. Extension and right lateral bending stiffness were shown to not significantly change but significant differences were experienced for all other directions. Interestingly, savvy subjects experienced greater magnitude of changes in flexion and left axial twist stiffness near end range of motion than the naive subjects ($p < 0.001$ at 95% of applied moment and beyond for flexion, and $p < 0.01$ at 90% of applied moment and beyond for right axial twist). Active stiffness did not significantly change in either subject group after long-term isometric training.

Dynamic Training

The results of 6-week dynamic training yielded far fewer stiffness changes in both subject groups (Figure 6). Only right lateral bend at all moment levels except at 80% for naive subjects, left axial twist at 90% of applied moment and beyond for savvy populations, and a single significant difference at 90% of applied moment in extension showed differences after dynamic training ($p \leq 0.05$). No significant differences in active extension stiffness were experienced after long-term dynamic training.

Control groups did not experience any significant changes in response after the 6-week period, within each subject group for all directions and between subject groups.

DISCUSSION

The results suggest that the isometric exercise approach was superior in enhancing torso stiffness over the dynamic approach in a 6-week trial. Both the naive and savvy groups responded similarly to training. These findings generally agree with the results of previous work investigating isometric training on tendon stiffness in the lower limbs performed by Burgess et al. (8) and Kubo et al. (25) respectively. However, the Burgess work differed in that they reported increases in tendon stiffness with dynamic lower limb training, whereas this study's dynamic protocol did not show such changes.

It was possible that the 6-week protocol could have caused physical adaptations of hypertrophy and strength gain. However, if this were true, one would have expected similar stiffness gains with the dynamic training approach. Some evidence exists that some components of the core musculature experienced thickness increases after selected trunk strengthening exercises, including the bird dog and side bridge isometric exercises (42). Perhaps this is linked to the muscular hypertrophy/time under tension relationship–greater time under tension has been shown to increase skeletal muscular hypertrophy (23,32,37). Obviously, time spent under muscular contraction was much higher when performing isometric exercises. For example, a 10-second plank requires continual peak activation of anterior core musculature for the full 10-second period, whereas a 10-repetition curl up incorporates a duty cycle resulting in far less time under tension. In addition, sharp increases in passive stiffness near-maximum applied moments were measured in isometrically trained subjects. Burgess and Kubo both proposed that after training, collagen structures remodeled similar to that with muscular hypertrophy, and demonstrated by Michna (34) and Zamora and Marini (48). An alternate explanation is that the 6-week program stimulated neural changes and a residual stiffness. Although active stiffness was not significantly affected, training journals kept by subjects revealed a perception of training effects. Comments of being better able to control activation of specific core and hip musculature were common in both isometric and dynamic groups. These comments may be related to increased voluntary muscular activation levels after resistance exercise. Garfinkel and Cafarelli showed increases in MVC after 8 weeks of isometric limb training (16); not only did muscular cross-sectional area increase but increased EMG amplitude during MVC trials was also observed. Other groups have reported similar findings where multiweek periods of resistance training resulted in increased EMG amplitude during maximal exertions (17,22,24).

The results suggest that isometric core training is superior to dynamic training for enhancing torso stiffness. Enhanced core stiffness allows the spine the bear greater loads (10) and express greater distal limb athleticism (26). The next step would be to examine specific changes in athletic performance.

To the author's knowledge, no research investigating training-related changes in core stiffness have been performed. Thus, without existing values to estimate statistical power, it was not possible to establish a suitable sample population. However, the work performed provided statistically supported evidence of isometric training effects on core stiffness laying the groundwork for more investigations into adaptations from specific training styles.

PRACTICAL APPLICATIONS

This is the first study that quantified the effects of multiweek core training programs to enhance torso stiffness. Isometric training was superior to dynamic training to enhance core stiffness. Given the enhancement of limb athleticism, this study gives some foundation to the practice of including isometric core exercises into athletes' training regimens and pregame warm-up. In fact, isometric core exercise programs are part of successful injury prevention programs (40).

Some coaches argue that performing compound load bearing exercises, such as squats and deadlifts, are sufficient for core activation but authors contend that an isometric core regimen is superior for creating 3-dimensional spinal stability. Although these compound exercises require substantial activation of the core musculature (18), the stability challenge lies mainly in the sagittal plane. Many athletic tasks involve stability about the frontal and transverse planes; consider a football player who sprints 5 yards forward and powerfully cuts left. If lateral core stiffness is insufficient, energy leaks causing buckling at the torso compromises speed and increases known injury mechanisms of spine bending under load (28) and knee valgus buckling (20). In essence, when sufficient core stiffness is lacking, athlete movement becomes inefficient and manifested by performance decrements and increased injury risk. In addition, coaches must carefully monitor loads experienced by the athlete during sport and strength and conditioning training. Exceeding tissue tolerance by loading the athlete too frequently or too greatly increases the odds of tissue injury (26). This is where the beauty of the isometric core exercises come into play; athletes may develop core stiffness attributes while minimizing imposed loads to the spine (1,10,23), freeing up capacity to put toward sport practice. With the low spinal loads experienced during these exercises, athletes can perform these almost daily as done during the study training period. The researchers believe that a 15- to 45-minute isometric training regimen when used in conjunction with a strength and conditioning program creates the core stability necessary to allow the athlete to fully express their athleticism.

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