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The effect of short-term isometric training on core/torso stiffness

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ABSTRACT

"Core" exercise is a basic part of many physical training regimens with goals ranging from rehabilitation of spine and knee injuries to improving athletic performance. Core stiffness has been proposed to perform several functions including reducing pain by minimising joint micro-movements, and enhancing strength and speed performance. This study probes the links between a training approach and immediate but temporary changes in stiffness. Passive and active stiffness was measured on 24 participants; 12 having little to no experience in core training (inexperienced), and the other 12 being athletes experienced to core training methods; before and after a 15 min bout of isometric core exercises. Passive stiffness was assessed on a "frictionless" bending apparatus and active stiffness assessed via a quick release mechanism. Short-term isometric core training increased passive and active stiffness in most directions for both inexperienced and experienced participants, passive left lateral bend among experienced participants being the exception ($P < 0.05$). There was no difference between the inexperienced and experienced groups. The results confirm that the specific isometric training exercise approach tested here can induce immediate changes in core stiffness, in this case following a single session. This may influence performance and injury resilience for a brief period.

ARTICLE HISTORY

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KEYWORDS

Core; spine; stiffness; performance; rehabilitation; handedness of Muay Thai boxers

Introduction

A spine unsupported by any stiffening agents, such as muscle, cannot bear load as it will buckle (Crisco, Panjabi, Yamamoto, & Oxland, 1992). One role of the torso or core musculature (for the purposes here: muscles proximal to the ball and socket hip and shoulder joints) has been thought to stiffen the torso to prevent motion, enhancing motion of the distal limb segments (McGill, 2016) and reducing back pain (Ikeda & McGill, 2012). The focus of this study was to assess whether specific exercise is able to create immediate changes in stiffness. Greater stiffness through the contribution of passive tissues and muscular activation allows for it to bear more load but only to a point before reaching a critical buckling level (Bergmark, 1987). Muscles, when active, create both force and stiffness (Brown & McGill, 2005). Joint compression is a well-documented mechanism of enhancing joint stability throughout the body (Cholewicki & Vanvliet, 2002; Morris, Lucas, & Bresler, 1961; Wuelker, Korell, & Thren, 1998) – again up to a point. In addition, the girdle of muscle stiffness also enhances load bearing (Brown & McGill, 2005; Cholewicki, McGill, & Norman, 1991; McGill, McDermott, & Fenwick, 2008; Vera-Garcia, Brown, Gray, & McGill, 2006). The link to pain reduction appears to be linked to stiffening and reducing joint micro-movements that trigger pain (McGill, 2016). Based on Hooke's law ($F = kx$), muscle activation patterns can be reproduced and probed during various provocative tests for their ability to modulate stiffness (k), joint micro-movement (x), and pain. For example, Ikeda and McGill (2012) demonstrated that low back pain could be resolved immediately by tuning the appropriate muscle stiffness and

controlling movement to avoid pain triggers specific to an individual. Muscle stiffness modulated by activation level shows immediately the amount of stiffness that is sufficient to reduce pain but not too much such as to trigger load-modulated pain.

Thus, evidence suggests that greater torso stiffness stiffens the spinal column, enhancing the ability to bear load and in cases of back pain, can change the pain. Studies of stabilization exercise however, have assessed so called "stabilization exercises" on "back pain groups." The flaw in this approach is that many of the exercises were called stabilization exercises were actually destabilising (see Kavcic, Grenier, & McGill, 2004a; for estimates of stability for different exercises, and, Kavcic, Grenier, & McGill, 2004b; for the effect of different muscle activation strategies on quantitative stability). Further, any back pain group is highly non-homogeneous such that stabilization exercises may help those with spines lacking joint stability from injury or deconditioning, yet will make a person with an overly stable (pathologically stiff) back worse. Instead, any review of the efficacy of stabilization exercise, or any other intervention, must sub-categorise the people into subgroups based on specific features (see McGill, 2016 for a thorough discussion of this topic). Strategies to enhance spinal stability via training the core musculature has influenced athletic training (Bliss & Teeple, 2005; Kibler, Press, & Sciascia, 2006; Nesser, Huxel, Tincher, & Okdada, 2008; Willardson, 2007) and in clinical settings to reduce spine joint micro-movements and back pain (e.g., Gardner-Morse & Stokes, 1998, 2001; Panjabi, 2003; van Dieen, Cholewicki, & Radebold, 2003). In contrast, this study aimed at assessing the effect of exercises to create

stiffness and stability, together with spine sparing movement strategies in a way that minimises spine load, akin to similar investigations by Suni et al. (2006) in military populations. The approach described in this paper has also been shown to influence athletic performance when trained over several weeks (Lee & McGill, 2015).

This study focused on assessing the ability of three exercises that were designed, and proven, to enhance torso stiffness around the spine, while imposing minimal load cost on the spine (McGill, 2016). The issue is whether these exercises can acutely affect torso stiffness. While, to the authors' knowledge, no experiments testing this ability have been performed, other investigations into isometric training and resultant tendon stiffness adaptations in the lower limbs were performed in the past by Kubo, Kanehisa, Kawakami, and Fukunaga (2001) and Burgess, Connick, Graham-Smith, and Pearson (2007). They found that isometric exercises for the lower limbs increased tendon and muscle stiffness properties supporting the notion that inherent stiffness can be altered through training. Thus the specific purpose of this study was to assess whether passive and active torso stiffness is influenced with short-term specific isometric exercises, whether passive and active torso stiffness are influenced differently, and whether the training regimen affects inexperienced populations differently than experienced populations in terms of their familiarity with core stiffness training. These two subgroups based on training experience were formed to investigate whether those who are accustomed to physical training require higher demands to elicit adaptations.

Methods

Twenty-four young healthy university aged males (22.9 ± 2.7 years, 1.79 ± 0.06 m, 77.5 ± 10.8 kg) were selected for this study. Of the total sample population, 12 participants (21.7 ± 1.9 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. Exclusion criteria for this subgroup consisted of any individuals who had experienced low back pain or injury currently or within the past year.

Another subgroup of twelve participants (24.2 ± 2.9 years, 1.8 ± 0.05 m, 76.8 ± 9.7 kg) was selected from a population of athletes experienced 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 was club Muay Thai fighters. Exclusion criteria for this subgroup consisted of any individuals who have experienced low back pain or injury currently or within the past year.

All participants' recruitment and data collection procedures were performed in accordance with University Office of Research Ethics guidelines.

Data collection

Stiffness measures were collected during a single data collection. Passive stiffness was assessed via a "frictionless" bending apparatus in three anatomical planes of motion (sagittal, frontal, and transversal) (after Brown & McGill, 2005, 2008) while

active stiffness was measured in the sagittal plane via a "quick release" mechanism (after Brown, Vera-Garcia, & McGill, 2006). These active and passive stiffness tests were performed before, and after, a 15-min training session of isometric core exercises.

Passive trials

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(a,b)]. The upper body cradle was free to glide over-top of a similar glass surface with precision nylon ball bearings between the two structures. This created a frictionless surface and allowed trunk movement about either the flexion-extension or lateral bend axis. Participants lay on their right side for the flexion-extension trials (Flex, Ext), and on their back for the lateral bend trials (left and right lateral bend denoted as LBend and RBend, respectively). Their torsos were supported in each position to ensure that participants adopted and maintained a non-deviated spine posture throughout the testing.

Passive axial twisting trials (left and right axial twist denoted as LTwist and RTwist, respectively) were performed in a separate apparatus consisting of a rotating wheel platform mounted to a fixed base via ball bearings with a frictionless contact [Figure 1(c)]. The participant stood upright on the platform maintaining upright spine posture with their upper body fixed via a harness strap to a vertical post (approximately at the level of T9). Lumbar spine motion was measured with an electromagnetic transducer described in the following.

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 remain below 5% maximum voluntary contraction (MVC). Participants easily learned to relax with this feedback. Three trials of each bending direction were performed in a randomised order.

Quick release trials

The quick release mechanism consisted of a seated apparatus that restricted hip and lower limb motion while leaving the trunk free to move in all directions, and a chest harness attached to a 16 kg mass, adapted from the setup used by Sutarno and McGill (1995) and Brown et al. (2006) (Figure 2). This seated posture has been shown to foster a neutral spine posture and elastic equilibrium for the hips and spine (Sutarno & McGill, 1995). Participants sat in the apparatus and were anteriorly pre-loaded with a static 16 kg mass, applied via the harness at the level of T7, which was randomly released without the participant's prior knowledge via an electromagnet (Job Master Magnets, Oakville, Canada). Participants were instructed to use core-bracing techniques to prevent displacement following release. This trial was repeated three times.

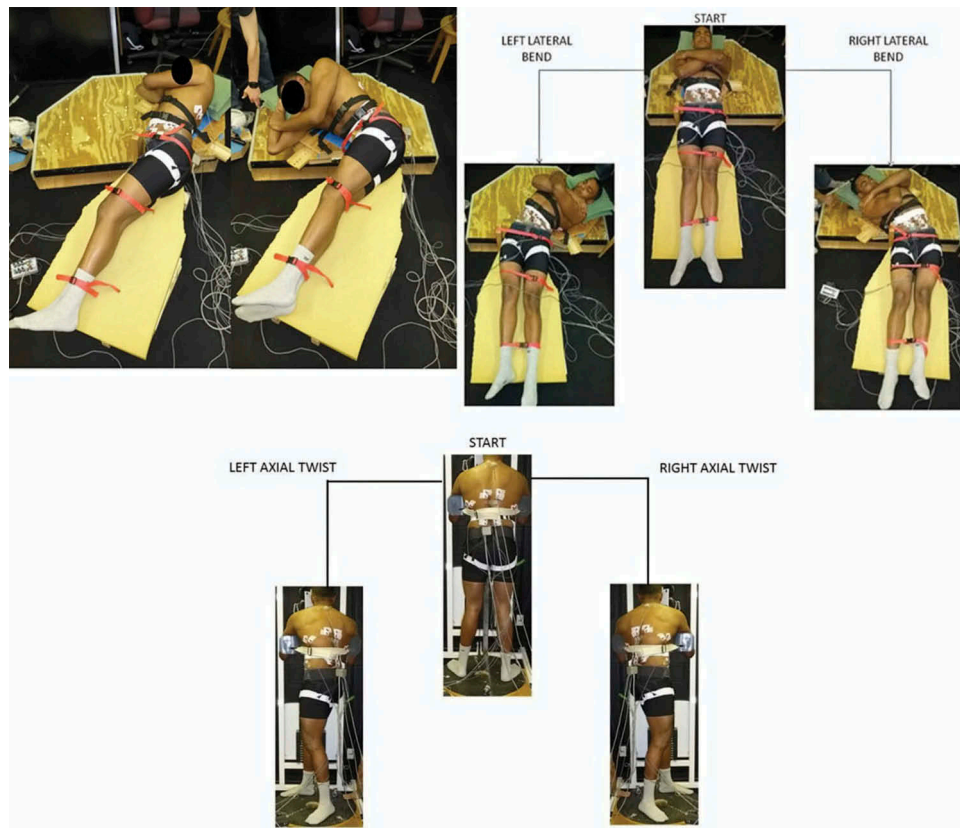


Figure 1. Frictionless bending apparatus used for passive (a) flexion/extension, (b) lateral bend, and (c) axial twist trials.

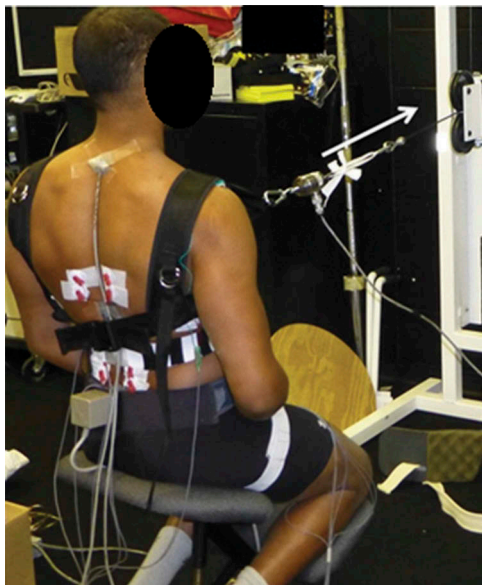


Figure 2. Quick release experimental setup consisting of a chair used to foster a neutral hip and spine posture, a chest harness, and a horizontal cable in series with an electromagnet and weight stack. The arrow points in the direction of load application through the cable.

Instrumentation and data collection

EMG

EMG signals were collected on unilateral core musculature using pre-gelled, disposable, monopolar Ag–Cl disc-shaped

surface electrodes (30-mm diameter, Medi-trace™ 100 Series Foam Electrodes, Covidien, MA, USA) placed on the skin over each muscle of interest (rectus abdominis [RA], external oblique [EO], internal oblique [IO], latissimus dorsi [LD], upper erector spinae [UES], lower erector spinae [LES]). Signals were amplified (± 2.5 V; AMT-8, Bortec, Calgary, Canada; bandwidth 10–1000 Hz, common mode rejection ratio (CMRR) = 115 dB at 60 Hz, input impedance = 10 GX) and sampled at 2048 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 (1998); and normalised to the maximum voltage produced during MVC trials to produce a linear envelope mimicking the muscle force output; a technique used many times before (Brown & McGill, 2008). MVCs were obtained using three postures: (1) a modified sit-up position in which participants isometrically attempted to produce trunk flexion, side bend and twist motions against resistance, (2) isometric trunk extension while cantilevered in a prone position over the edge of a table (Biering–Sorensen position) against external resistance, (3) isometric wide grip pull-up posture in which the participant attempted to isometrically pull against a horizontal bar while being resisted with instructions of maintaining a maximally tight grip and attempting to “bend the bar” while pulling vertically.

The purpose of EMG collection was to verify that the activation states of the participant’s muscles were below 5% to ensure a passive response. In fact, post processing of data

revealed all trials turned out to be below 3% MVC. EMG data was not used for any other purpose.

Trunk 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 for the flexion/extension trials, and the source over the lower abdomen at a level slightly below the ASIS and the sensor over the xiphoid process for the lateral bend trials (after Brown & McGill, 2008). The trunk motion data was sampled digitally at 60 Hz and dual-pass filtered (effective fourth order 3 Hz low-pass, zero lag, Butterworth) (after Brereton & McGill, 1998).

Applied moment

The moments applied to the torso were obtained by 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; and the level of T7 to the level of L4/L5 for quick release trials. Force was recorded with a force transducer (Transducer Techniques Inc., Temecula, CA, USA) and digitally sampled at 2160 Hz. Force signals were dual-pass filtered (effective fourth order 3 Hz low-pass Butterworth). Both the linear enveloped EMG and force signals were down-sampled to 60 Hz to match the trunk motion data.

Core-training protocol

Participants performed three isometric core exercises; plank, side bridge and bird dog (Figure 3); each performed for five sets of 10 s holds. Coaching was provided by the researcher so that exercise technique and bracing cues were standardised among all participants, after McGill and Karpowicz (2009).

Moment angle curves

Passive trials

The applied moment and corresponding trunk angle were measured for each trial and normalised in time to ensure equal trial length across all trials and participants. Trunk angles were normalised as a percentage of the maximum range of motion (ROM) that participants were able to obtain in the pre-training bending trials. Exponential curve fits of the following form were performed for each trial type after Brown and McGill (2005):

$$M_p = \lambda e^{\phi \vartheta_p},$$

where M_p is the applied passive moment (N · m), λ , and ϕ are curve-fitting constants and ϑ_p is the passive angular displacement of the torso (degree). The calculated moment was normalised as a percentage of the maximum applied moment (denoted as "M") of the pre-training trials and calculated at

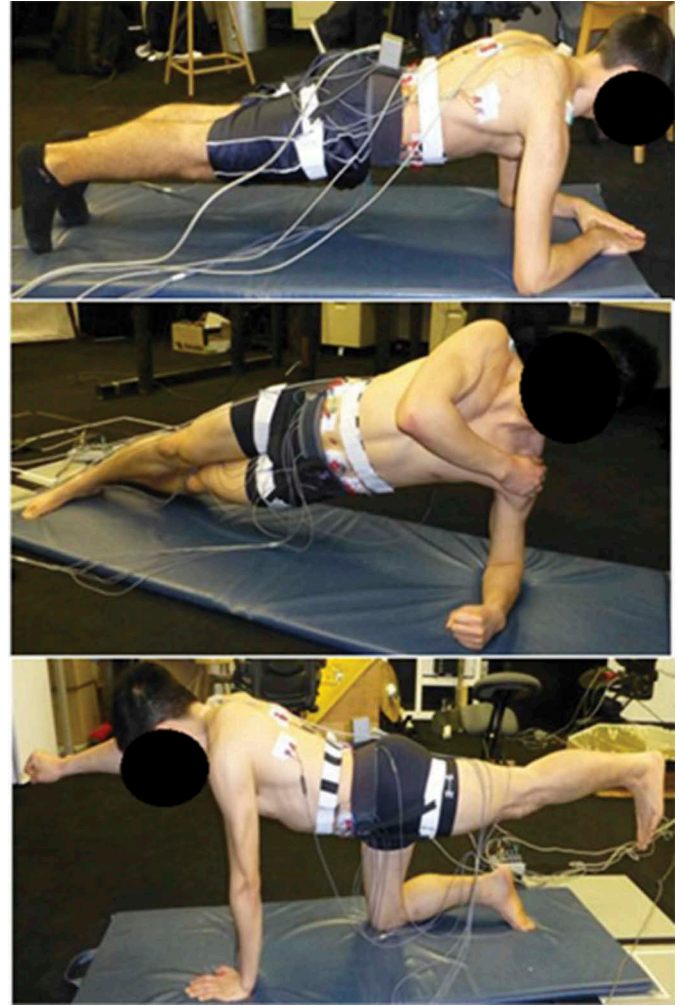


Figure 3. Three isometric exercises used in the short-term training protocol. Top: plank. Middle: side bridge. Bottom: bird dog.

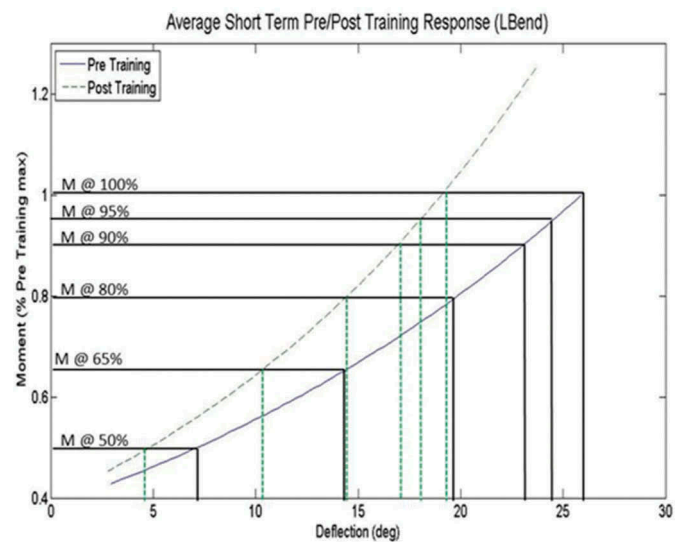


Figure 4. Curve fit moment/deflection data of pre- and post-training. Solid horizontal lines show where data was taken at 50%, 65%, 80%, 90%, 95% and 100% of peak pre-training moment. Solid vertical lines show the corresponding range of motion (ROM) values of the pre-training plot. Dashed vertical lines show the corresponding ROM values of the post training plot. Matched pre- and post-training ROM values at each moment percentage were compared to determine any significant changes pre- and post-training.

50%, 65%, 80%, 90%, 95% and 100% of pre-training peak moment for pre- and post-training conditions (Figure 4).

Quick release trials

A custom coded computer algorithm (MATLAB Version r2012a; The MathWorks Inc., Natick, MA, USA) was used to detect the instance of sudden release. According to the algorithm the release was considered to occur when the slope of the force–time signal decreased by greater than one standard deviation compared to the previous time point. Each trial was visually checked against the computer-derived timing to ensure that the onset of force perturbation was meaningful. The force at release and the peak angular displacement of the lumbar spine in the first 250 ms after sudden loading were recorded in every trial to obtain a gross stiffness measure, after Sutarno and McGill (1995). The release moments (N · m) were calculated as the products of the release force (N) and the moment arms representing the point of application of the release force in either the frontal (flexion moment) or transverse (twist moment) planes. A gross lumbar measure of stiffness (N · m degree⁻¹) was then obtained from the following equation:

$$k_a = \frac{M_a}{\vartheta_a},$$

where k_a represents the active gross lumbar stiffness calculated from the slope of the applied moment (M_a , N · m) and absolute angular deflection (ϑ_a , degree) curve.

Statistical analysis

Statistical tests were performed using IBM® SPSS® Statistical software (Version 19, IBM Corporation, Somers, New York, NY, USA). Comparisons of stiffness, inferred from ROM values at each specific instance of applied moment, before and after the short-term training protocol were made using paired *t*-tests. Effects of training experience (inexperienced vs. experienced) were assessed with a two way repeated measures ANOVA (two training experience levels). Where applicable, *post hoc* analyses were performed using the Tukey HSD test when a significant effect was detected ($P < 0.05$). To the researchers' knowledge no studies currently exist examining stiffness adaptations with core training, thus is it difficult to establish a sample population for suitable statistical power. However, a measure of effect size was performed (Cohen's *d* for *t*-tests and η^2 for ANOVA) was calculated to determine the strength of the difference between each condition.

Statistical analysis was performed on ROM data for corresponding percentages of applied moment. As stiffness is directly proportional to applied moment and inversely proportional to ROM, shorter ROM values at the same applied moment would infer greater stiffness.

Results

Passive and active stiffness measures changed after short-term isometric core training within both inexperienced and experienced populations. A sample moment/deflection curve for the flexion trial is shown in Figure 5. However, no significant

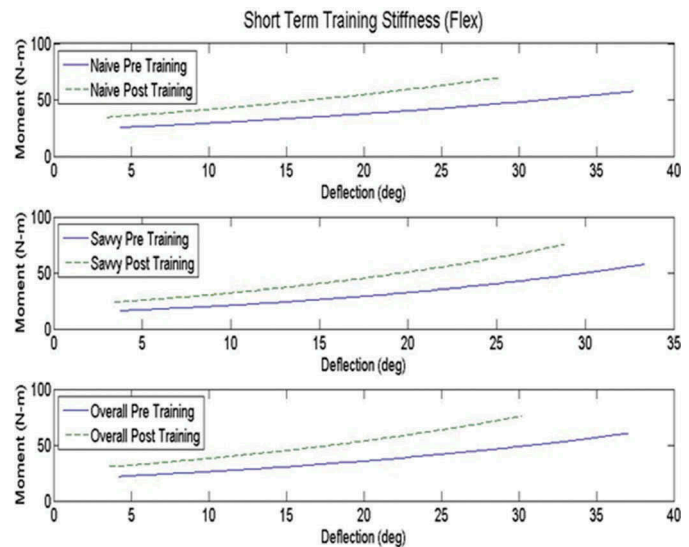


Figure 5. Summary of pre/post short-term stiffness curves for passive flexion trials highlight training response in inexperienced (top), experienced (middle) and all (bottom) participants; stiffness values (N · m degree⁻¹) on the Y-axis and range of motion (%ROM) on the X-axis.

differences in response were detected between the two groups. After training, the inexperienced group experienced reductions in torso deflection during flexion, RBend, LTWist, and RTWist trials ($P < 0.05$, Cohen's *d* between 0.7 and 0.8) at all points along the moment/deflection curve, while Extension and LBend trials experienced changes further along the moment/deflection curve, after 50% or 65% of the applied pre-training moment. It should be also noted that greater changes were measured further along the curve ($P < 0.01$ for inexperienced LBend at 65% and greater, Cohen's *d* between 0.7 and 0.8; $P < 0.001$ for Flexion, RBend, LTWist, and RTWist at 65% and greater, Cohen's *d* between 0.7 and 0.8). Active stiffness also increased after training in inexperienced populations ($P < 0.05$, Cohen's *d* = 0.8).

Reductions in torso deflection after training were measured throughout the moment/deflection curve for experienced Flexion ($P < 0.01$, Cohen's *d* between 0.7 and 0.8) and RTWist ($P < 0.01$ @ 50%, $P < 0.005$ at all other points, Cohen's *d* between 0.7 and 0.8). Decreased torso deflection further along the moment/deflection curve was measured during experienced Extension ($P < 0.05$ @ 90% and beyond, Cohen's *d* between 0.75 and 0.8), RBend ($P < 0.01$ @ 65%, $P < 0.001$ beyond, Cohen's *d* between 0.7 and 0.8) and LTWist ($P < 0.001$ @ 65%, $P < 0.01$ beyond, Cohen's *d* between 0.7 and 0.8) trials. Active stiffness also increased after training ($P < 0.05$). No significant changes were measured for any points for the LBend trial ($P < 0.05$).

No differences were measured between inexperienced and experienced groups.

These results are summarised in Figure 6, and Tables 1 and 2.

Discussion

Short-term isometric core training increased passive and active stiffness in both inexperienced and experienced

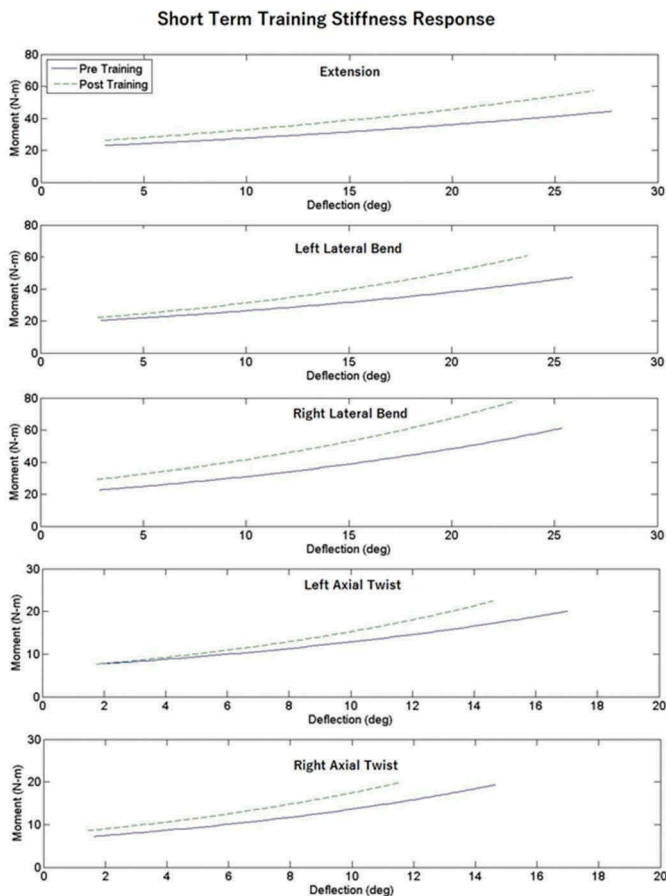


Figure 6. Summary of pre/post short-term stiffness curves for passive extension, left lateral bend, right lateral bend, left axial twist and right axial twist (top to bottom); applied moment ($\text{N} \cdot \text{m}$) is denoted on the Y-axis and deflection (degree) on the X-axis. The curves plotted represent training response for all participants.

populations, while there was no difference in response between the two groups. Passive stiffness increased naturally near the maximum applied moment in almost all bending tests experienced.

All bending trials for both participant groups experienced increases in stiffness at least one point along the moment/deflection curve after training, except left lateral bend trials for experienced participants. This exception is most likely related to variability within the study population given that the reported means pre/post-training (Table 2) are similar but standard deviations were measured at 40–50% of the mean indicating high variances between individual participants. While, on average, group differences existed there was a variety in response among individuals; some participants experienced little to no changes in stiffness (labelled non-responders) while others experienced substantial increases in stiffness and reduction in passive ROM (labelled responders or in some cases “super-responders”). For example, during passive left lateral bend trials experienced participants reduced ROM by 2.5 ± 7.2 degrees at 100% of applied moment, three times greater than the mean response. An example comparing an athletically experienced “non-responder” and inexperienced “super-responder” reveals differences in stiffness as a response to training (Figure 7).

Despite undergoing the same core-training programme as all participants the non-responder showed little change in pre/post-stiffness values. Not surprisingly, this participant was self described as performing bodyweight core exercises almost daily and regularly performing barbell exercises involving load bearing of the torso up to four times per week. In contrast, the “super responder” exemplifies a greater stiffness increase following training, noted by the distinct decrease in end ROM for the same moment applied. Unlike the non-responder, this participant was self described as being an “on and off” recreational weight lifter but had not been physically active for 4 months prior to the start of the study. It is reasonable that participants with experience in torso muscle training of the type used here that have been shown to create robust spine stability (Kavic et al., 2004a) would be expected to not respond to low level core exercises as well as untrained participants.

Immediate changes in stiffness suggest the mechanism would not involve adaptations in passive structures, such as ligaments, but rather tissues such as muscle that are modulated by physiological and neurological factors. For example, Kubo et al. (2001) and Burgess et al. (2007) suggested that remodelling of collagen structures following isometric training enhanced stiffness but this occurred over multiple weeks and not just a single session. During post-test follow-up with participants, several reported perceived “warmth” and a “pump-like” feeling within the core musculature. It is possible this feeling could be due to hyperaemia following sustained isometric contraction (after Laughlin, Korthuis, Duncker, & Bache, 1996), engorging the musculature with blood, stiffening the muscle. Alternatively, the short-term training session could have induced a post activation potential like effect. Here, periods of sustained maximum contraction (Gossen & Sale, 2000; Vandervoort, Quinlan, & McComas, 1983) or repeated submaximal stimulus (MacIntosh & Willis, 2000) induce an overflow of calcium ions (Ca^{2+}) potentiating affected musculature by enhancing contraction strength, rate of force development and twitch potentiation (French, Kraemer, & Cooke, 2003; Gossen & Sale, 2000; Gullich & Schmidtbleicher, 1996). However, the isometric exercises in the cited literature differ from the isometric contractions performed by participants in this study in that they were not maximal contractions, and the cited studies examined the effects only on limb musculature.

The results of this study are relevant to the exercises, dosage, and participant demographics utilised in this study. A limitation of comparing core stability exercises is that the term “stabilization exercise” means different things to different people. This is an important distinction, especially when reviews of low back stabilization have stated that there is strong evidence that “stabilization exercises” are not more effective than any other form of active exercises in the long term (Smith, Littlewood, & May, 2014). For the purpose of this study, we defined core stability exercise as isometric core exercises, which create stability while minimising spine load by sparing the spine from excessive motion. Investigation of spine loads experienced during these exercises has confirmed this definition (Axler & McGill, 1997; Kavic et al., 2004b). Further, the training protocol utilised in this study is not

Table 1. Summary of torso stiffness measures for the inexperienced group.

Bending direction	Range of motion (degree)											
	50% Applied moment (pre)	50% Applied moment (post)	65% Applied moment (pre)	65% Applied moment (post)	80% Applied moment (pre)	80% Applied moment (post)	90% Applied moment (pre)	90% Applied moment (post)	95% Applied moment (pre)	95% Applied moment (post)	100% Applied moment (pre)	100% Applied moment (post)
Flexion	19.7 ± 8.1	10.5 ± 8.2**	22.1 ± 10.4	13.3 ± 8.3***	25.9 ± 12.7	18.3 ± 8.9**	31.8 ± 11.4	21.7 ± 9.3***	34.2 ± 11.2	23.8 ± 9.4***	35.6 ± 11.2	24.9 ± 9.3***
Extension	12.4 ± 8.2	4.5 ± 0.8	16.0 ± 9.8	9.0 ± 2.1	20.0 ± 11.4	13.7 ± 6.0*	21.0 ± 11.8	16.0 ± 8.7*	23.9 ± 11.2	19.2 ± 9.4*	25.6 ± 11.1	21.0 ± 10.1*
RBend	13.9 ± 4.8	9.6 ± 3.5**	17.0 ± 4.3	12.2 ± 4.5***	18.8 ± 7.7	14.8 ± 6.4***	22.1 ± 6.3	17.4 ± 6.7***	23.6 ± 5.7	18.7 ± 6.8***	24.5 ± 5.5	19.4 ± 6.9**
LBend	10.7 ± 7.2	8.4 ± 6.8	13.6 ± 6.4	11.1 ± 6.1**	17.3 ± 8.9	13.8 ± 7.6**	21.6 ± 9.4	16.8 ± 8.2**	23.6 ± 9.8	18.2 ± 8.5**	24.7 ± 10.0	18.9 ± 8.7**
RTwist	5.2 ± 3.0	2.4 ± 1.5**	7.4 ± 3.2	4.3 ± 1.8***	9.1 ± 4.2	5.7 ± 3.2***	10.5 ± 4.7	7.0 ± 3.6***	11.1 ± 5.0	7.5 ± 3.8***	11.5 ± 5.1	7.9 ± 3.9***
LTwist	6.5 ± 2.4	4.8 ± 2.0*	8.1 ± 3.4	5.5 ± 3.0***	10.8 ± 4.5	7.7 ± 4.0***	12.3 ± 5.3	8.9 ± 4.7***	13.0 ± 5.6	9.5 ± 5.0***	13.4 ± 5.9	9.8 ± 5.2***
Stiffness (N · m degree ⁻¹)												
Active	Pre						Post					
	3.3 ± 1.2						1.6 ± 1.1*					

Measures are represented by torso range of motion (degree) at specific intervals of pre-training applied moment for passive tests (flex, ext, LBend, RBend, RTwist), and by angular stiffness (N · m degree⁻¹) for the active stiffness test.

*Denotes a statistically significant difference ($P < 0.05$) than the pre-training condition.

**Denotes a statistically significant difference ($P < 0.01$) than the pre-training condition.

***Denotes a statistically significant difference ($P < 0.005$) than the pre-training condition.

Table 2. Summary of torso stiffness measures for the experienced group.

Bending direction	Range of motion (degree)											
	50% Applied moment (pre)	50% Applied moment (post)	65% Applied moment (pre)	65% Applied moment (post)	80% Applied moment (pre)	80% Applied moment (post)	90% Applied moment (pre)	90% Applied moment (post)	95% Applied moment (pre)	95% Applied moment (post)	100% Applied moment (pre)	100% Applied moment (post)
Flexion	19.5 ± 8.0	10.5 ± 2.6**	23.3 ± 8.5	13.6 ± 3.5**	27.6 ± 9.7	18.5 ± 4.1**	28.4 ± 11.7	20.9 ± 5.1**	30.1 ± 11.1	22.1 ± 5.5**	31.1 ± 10.9	22.8 ± 5.8**
Extension	15.9 ± 7.1	18.7 ± 11.9	19.6 ± 8.4	22.2 ± 12.0	18.6 ± 9.1	16.7 ± 12.1	25.5 ± 7.7	20.6 ± 11.2*	28.7 ± 8.0	22.4 ± 11.1*	30.5 ± 8.4	23.4 ± 11.2*
RBend	14.1 ± 11.0	11.1 ± 5.7	13.9 ± 10.3	9.9 ± 7.6*	17.6 ± 10.5	12.8 ± 8.2**	20.5 ± 10.5	15.1 ± 8.4**	21.7 ± 10.6	16.2 ± 8.5**	22.5 ± 10.6	16.8 ± 8.6**
LBend	13.6 ± 7.2	13.6 ± 8.2	15.7 ± 6.9	15.8 ± 7.3	16.9 ± 8.1	15.8 ± 7.3	19.5 ± 8.2	18.0 ± 7.4	21.6 ± 8.1	19.4 ± 7.1	22.8 ± 8.3	20.2 ± 7.0
RTwist	7.5 ± 3.5	3.5 ± 1.6**	9.0 ± 4.0	5.1 ± 2.3***	12.3 ± 4.3	7.9 ± 2.8***	14.2 ± 4.6	9.4 ± 3.3***	15.0 ± 4.7	10.2 ± 3.5***	15.5 ± 4.8	10.6 ± 3.6**
LTwist	6.9 ± 2.3	5.9 ± 1.9	9.4 ± 2.9	7.3 ± 2.4**	13.5 ± 3.3	10.1 ± 2.9***	15.8 ± 3.8	11.6 ± 3.4***	16.9 ± 4.1	12.4 ± 3.6***	17.5 ± 4.3	12.8 ± 3.7***
Stiffness (N · m degree ⁻¹)												
Active	Pre						Post					
	3.2 ± 1.8						1.9 ± 1.6*					

Measures are represented by torso range of motion (deg) at specific intervals of pre-training applied moment for passive tests (flex, ext, LBend, RBend, LTwist, RTwist), and by angular stiffness (N · m degree⁻¹) for the active stiffness test.

*Denotes a statistically significant difference ($P < 0.05$) than the pre-training condition.

**Denotes a statistically significant difference ($P < 0.01$) than the pre-training condition.

***Denotes a statistically significant difference ($P < 0.005$) than the pre-training condition.

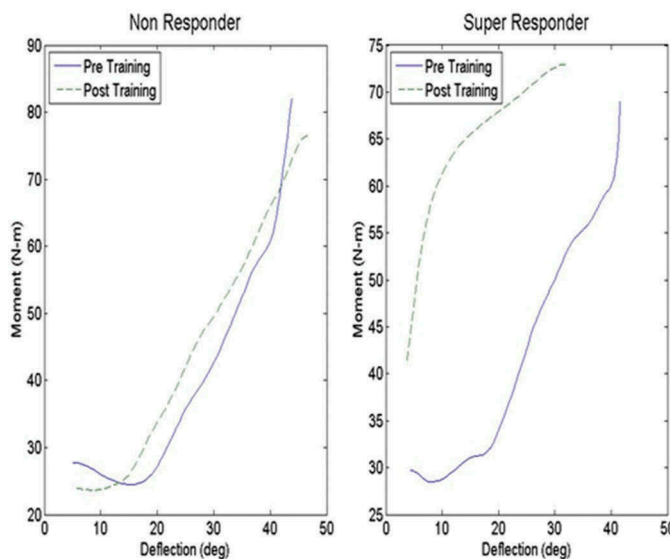


Figure 7. Example raw passive stiffness curves during left lateral bend of a “non-responder” (left) and “super-responder” (right). The non-responder participant belonged to the athletically trained subgroup and self described as regularly performing bodyweight core exercises almost daily and barbell exercises involving heavy external load and load bearing through the torso four times per week. The super-responder was self described as an on and off recreational weight lifter but had not been performing any exercise regularly for four months prior to the start of the study. Note the 15° decrease in ROM after short-term core training. Applied moments were similar but significant decrease in end ROM is observed in this figure.

typical of those used in other cited core-training research. The strategy of using multiple sets of ten second holds was proposed as a method of training endurance without the muscles cramping from oxygen starvation and acid buildup, while maintaining impeccable form to maintain bracing and movement patterns (McGill, 2016). Another limitation is related to the homogeneity of the study population. Back pain populations may be non-homogenous due to the fact that back pain typically has a root mechanical flaw and cannot be treated as “non-specific” pain (McGill, 2016). Thus, any training intervention may improve pain in some participants but worsen it in others. This study examined the effects of isometric core exercise on non-pained participants in order to homogenise the study population and the results should be interpreted as such. Stiffening an uninjured spine may improve stability characteristics as demonstrated here, but stiffening an already stiff spine may in fact increase pain.

The results of this study suggest that a single bout of isometric core exercises have a significant effect on stiffening the core musculature. Enhanced muscular activation and stiffness allows the spine to bear greater loads (Cholewicki et al., 1991), and thus these results begin to provide insight for the use of short duration isometric core exercises in clinical and athletic applications. For example, the use of the short-term protocol before practice or competition may prove beneficial for athletes who are required to bear high external loads and create distal mobility during sport, or before any load bearing tasks in clinical populations suffering from injuries pertaining to spinal instability. Evidence exists that core stiffness can be trained after a six week duration (Lee & McGill, 2015); this work now shows similar adaptations can be made with just a single

bout of training, though the lasting stiffness effects are still unknown. Further, this study now adds to the body of work pertaining to the use of isometric core exercises in clinical settings (McGill & Karpowicz, 2009; Suni et al., 2006), and adds credence to the use of isometric core exercises in lumbar stabilization programmes.

Conclusions

This appears to be the first study which quantifies the immediate effect of core muscle training on torso stiffness. Increased core stiffness will be of interest to those wanting to enhance load bearing of the spine, together with minimising painful micro movements. Insight now exists for the use of isometric core exercises in enhancing core stiffness in the short and long term (Lee & McGill, 2015). How this occurs, and for how long the changes last are questions for the future. Furthermore, more understanding is needed as to whether the mechanism of enhanced stiffness could be vascular, neural or mechanical in nature. While Ikeda and McGill (2012) showed some patients experience immediate reduction in back pain symptoms with torso muscle stiffness coaching, more work is required to better understand who will benefit and for how long.

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