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# The Effect of Trunk Stability Training on Vertical Takeoff Velocity

**T**runk stability training has recently become a popular concept in sport.<sup>18</sup> We define trunk stability as the ability to maintain active control of spinal and pelvic posture during dynamic loading and movement conditions. Such a definition implies that both neural control and muscle strength are important determinants of trunk stability.<sup>3,20</sup> Although certain muscles have been shown to be primary stabilizing muscles (transversus abdominus, multifidus<sup>2,10,17</sup>), all trunk muscles have a role in stabilizing the trunk.<sup>11</sup>

One common method used to activate the primary stabilizers and control

the pelvis and spine in a neutral posture is the abdominal-hollowing maneuver, as described by Richardson and Jull.<sup>20</sup> These authors have also suggested that

to adequately assess or train trunk stability, specific testing procedures or exercises that activate the primary stabilizers but also involve the other trunk muscles should be performed.<sup>20</sup> We are unaware of empirical evidence regarding the exact mechanism of action of abdominal hollowing or its use during the performance of athletic skills; however, this method is used extensively in clinical settings as both a testing maneuver and a training exercise for the treatment of low back pain.<sup>19</sup> It is also used as a sport training method<sup>16,18</sup>; however, the effect of this type of stability training on athletic performance is not yet known. Recently, Mills et al<sup>16</sup> found that trunk stability training improved vertical jump height and agility scores but found no association between trunk stability scores and performance measures. This group used an ordinal-scale measure of trunk stability, which was likely not sensitive enough to detect small changes in stability. They concluded that because of the lack of association between trunk stability scores and performance scores, the improvements in performance were likely due to an unnamed confounding variable.

We believe that enhancing trunk stability will influence body mechanics and optimize force production for skills that require significant efforts, such as jumping or lifting.<sup>6</sup> In a vertical jump, better

● **STUDY DESIGN:** Randomized controlled trial with repeated measures.

● **OBJECTIVES:** To determine the effect of trunk stability training on vertical takeoff velocity.

● **BACKGROUND:** Trunk stability training is commonly used in sports training programs; however, the effects of stability training on performance enhancement are not known. Trunk stability training may provide a more stable pelvis and spine from which the leg muscles can generate action, may better link the upper body to the lower body, or may enhance leg muscle activation, thus promoting optimal force production during sporting activities such as a vertical jump.

● **METHODS AND MEASURES:** Fifty-five athletes were randomly assigned to 1 of 4 training groups: trunk stability (TS), leg strength (LS), trunk stability and leg strength (TL), and control (CO). Subjects were tested 3 times: at pretraining, after 3 weeks of training, and after 9 weeks of training. A repeated-measures analysis of covariance

(ANCOVA) was used to examine differences among groups for vertical takeoff velocity measured indirectly using a force plate. Pretraining takeoff velocity and body mass were used as covariates.

● **RESULTS:** After 3 and 9 weeks, the training groups were not different from each other. After 9 weeks of training, all 3 training groups had a greater takeoff velocity than the control group ( $P < .05$ ). After 3 weeks of training only the TS group had a greater takeoff velocity than the control group ( $P < .05$ ). Only the TL group increased significantly in vertical takeoff velocity between the third- and ninth-week testing periods ( $P < .05$ ).

● **CONCLUSIONS:** Nine weeks of trunk stability training was similarly effective in enhancing vertical takeoff velocity as leg strength training or the combination of trunk stability and leg strength training. *J Orthop Sports Phys Ther* 2007;37(5):223-231. doi:10.2519/jospt.2007.2331

● **KEY WORDS:** athletic performance, core stability, neural control, vertical jump

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# RESEARCH REPORT

trunk stability may enhance jumping ability. Trunk muscle contraction likely does not directly contribute to maximal force output and therefore has no direct effect on vertical jump. However, we propose that providing a better link between the upper and lower body through a more stable pelvis and spine should help improve jumping ability. Therefore, trunk stability in addition to available leg strength may be important in explaining the variance associated with improvements in performance of vertical jumping.

The purpose of this study was to determine the effect that trunk stability training, leg strength training, or a combination of these 2 types of training have on vertical jump performance. We tested the hypotheses that (1) trunk stability training will improve vertical takeoff velocity in athletes, and (2) trunk stability training combined with leg strength training will produce greater gains in vertical takeoff velocity than either type of training alone.

## METHODS

### Subjects

SIXTY-SIX VOLUNTEER ATHLETES (28 males and 38 females) not actively training with the type of stability training employed in this study were recruited from the following area sport organizations, clubs, and teams: basketball, dance, running, football, hockey, martial arts, rowing, rugby, slow pitch, soccer, swimming, athletics, and volleyball. Subjects were excluded from the study if they had present or recent (within 12 months) lower back pain or lower extremity injury that required treatment or that might have inhibited performance or become exacerbated with testing or training. Of the original 66 subjects, 55 successfully completed the study. Four subjects (1 from the control group, 1 from the leg strength training group, and 2 from the trunk stability training group) dropped out due to reasons not related to the study. The remaining 7 subjects who dropped out (2 from the control group,

TABLE 1

SUBJECT DEMOGRAPHICS\*

	Training Group				Total (n = 55)
	TS (n = 14)	TL (n = 14)	LS (n = 13)	CO (n = 14)	
Males/females	6/8	6/8	3/10	5/9	20/35
Age (y)	23 ± 3	23 ± 4	21 ± 3	24 ± 4	23 ± 3
Height (cm)	172 ± 9	174 ± 10	167 ± 10	173 ± 10	171 ± 10
Body mass (kg)	75.3 ± 19.5	75.1 ± 15.4	69.7 ± 12.6	75.5 ± 16.4	74.0 ± 15.9
Years in sport (y)	5.9 ± 5.1	7.1 ± 4.6	4.7 ± 2.2	6.8 ± 4.6	6.1 ± 4.3

Abbreviations: CO, control group; LS, leg strength training group; TL, combined trunk stability and leg strength training group; TS, trunk stability training group.

\*Data presented as mean ± SD.

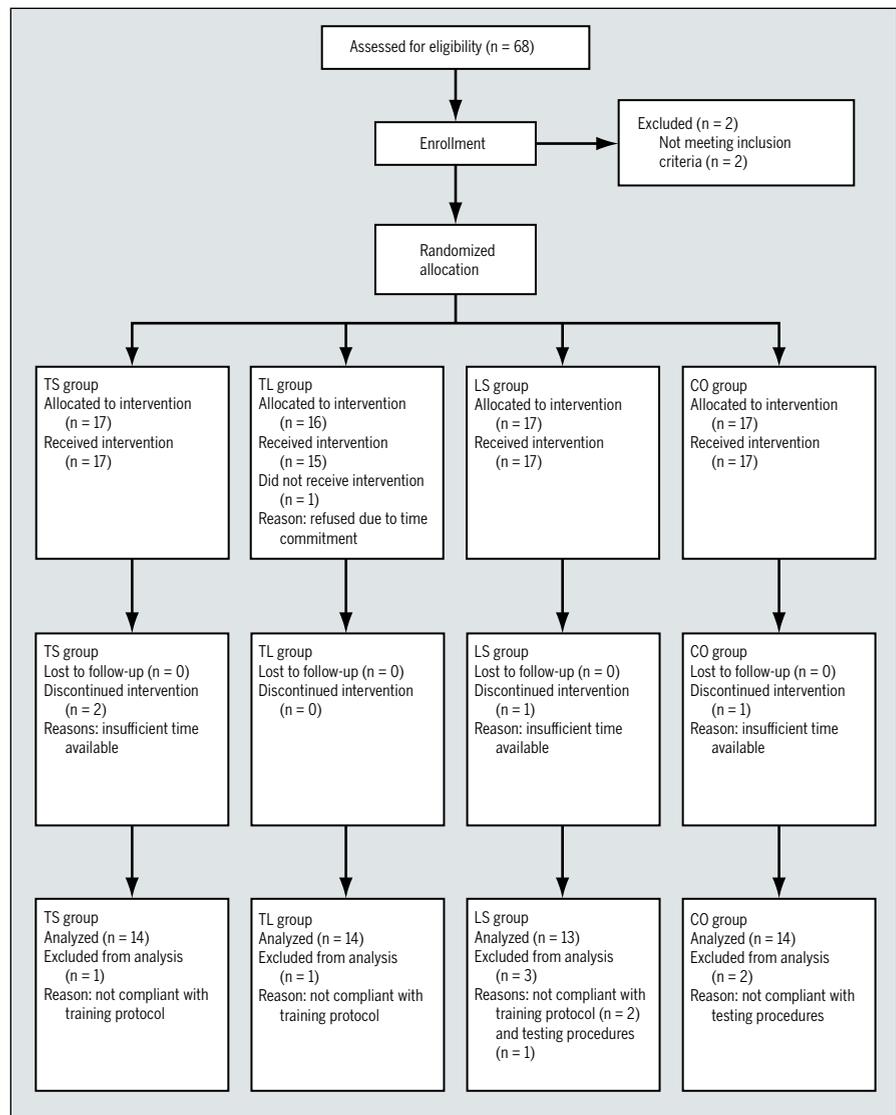


FIGURE 1. Flow of subjects through the phases of the randomized controlled trial. Abbreviations: CO, control group; LS, leg strength training group; TL, combined trunk stability and leg strength training group; TS, trunk stability training group.

3 from the leg strength training group, 1 from the trunk stability training group, and 1 from the trunk stability and leg strength training group) were not compliant with the training program or the testing procedures. Subjects were considered not fully compliant if less than 6 training sessions occurred over any of the 3-week training periods. Subject descriptive data are presented in **TABLE 1**. All subjects signed a consent form approved by the University of Saskatchewan's Advisory Committee on Ethics in Human Experimentation.

### Experimental Design

Subjects were randomly assigned to 1 of 4 groups: trunk stability training (TS), leg strength training (LS), combination of trunk stability and leg strength training (TL), and nontraining control (CO). Subjects in the 3 training groups were given a periodized 9-week training program and were instructed to perform their respective programs 3 times per week (**FIGURE 1**). Each subject attended a monitoring session every 3 weeks to determine weight adjustments, exercise progressions, and compliance, and to deal with potential problems during training.

### Testing Protocols

Dependent variables of vertical jump takeoff velocity, trunk stability, and estimated leg press strength were assessed at 3 time points: before training, after 3 weeks of training, and after 9 weeks of training. The second assessment was selected after 3 weeks of training to coincide with the transition between the first and second training phases (described below). Prior to baseline testing, education sessions were held for all subjects to achieve familiarization of the testing procedures and to provide instruction in the proper muscle activation pattern required for the modified double straight leg-lowering (DSL) test. Previous research<sup>9</sup> and observations during pilot testing indicated that most subjects cannot begin trunk stability testing until they have been given the opportunity to practice

achieving the muscular activation pattern that is required for proper testing. Following the education session, subjects were tested on 3 measures: DSL, vertical jump, and leg press.

### Education Session

All subjects attended a 10-minute education session immediately prior to testing. A similar session, as originally designed by Hagins et al,<sup>9</sup> was modified for the purposes of this study to allow for practice of the DSL test and to learn how to maintain trunk stability. Sessions were completed by showing a video of an investigator instructing the proper technique and having subjects practice along with the video. Satisfactory performance was reviewed and techniques were refined for each subject after the video session.

The first activity was in 4-point kneeling. Subjects performed a maximal range posterior pelvic tilt and associated lumbar flexion followed by a maximal range anterior pelvic tilt and associated lumbar extension. The subjects were then asked to find a comfortable position in the midrange, in which their lumbar spines were in a slightly forward-curved position. This was deemed to be the neutral position for that subject. Subjects were instructed in the abdominal-hollowing maneuver, as described by Richardson and Jull.<sup>20</sup> Subjects were allowed time to practice this maneuver.

The second activity was to perform the same actions described above in supine lying. Subjects performed maximal anterior and posterior pelvic tilts and then found their neutral position. The abdominal hollowing maneuver was again performed and practiced.

The final activity was explanation and practice of the movements and positions required for the DSL test. Subjects were instructed regarding the purpose and methods of the DSL testing procedures, followed by the opportunity to practice the movement.

During the practice of the testing procedures, subjects were supervised closely to ensure that the hollowing maneuver

was performed properly and inappropriate compensation did not occur. Performance was successful if the movement pattern was achieved without elevation of the shoulders from the table, flexion or extension of the neck, or anterior or posterior tilting of the pelvis.<sup>8</sup>

### Modified Double Straight Leg-lowering (DSL) Test

Maintaining a neutral lumbar spine and pelvis is an important concept in the development of trunk stability. A neutral position increases the internal stability of the spine<sup>3</sup> and increases trunk muscle co-activation to a greater degree than a non-neutral position, which helps to maintain trunk stability.<sup>7,15</sup>

Previous use of the DSL required subjects to flatten the lumbar spine against a hard surface and maintain that position.<sup>12</sup> In the current study, trunk stability was assessed using a modified DSL test in a neutral pelvis and spine starting position.

A sphygmomanometer was placed within a Plexiglas support constructed so that, when placed under the subject's lumbar spine, the support created a relatively neutral lumbar curve. The sphygmomanometer was inflated to 40 mmHg,<sup>23</sup> then removed, maintaining a constant level of inflation. This procedure was completed before each trial for each subject, to ensure proper inflation. Subjects were positioned in supine on a hard table with their arms crossed on their chests. An electronic goniometer (Lafayette Instrument Co, Lafayette, IN) was placed at the hip joint so that the axis was adjacent to the middle of each subject's greater trochanter. The stationary arm was placed horizontally and the moving arm was secured along a line corresponding with the subject's femur to measure hip angle. The examiner held the subject's legs at 70° from horizontal. The inflated sphygmomanometer was inserted under the subject's lumbar spine and the subject was instructed to adjust the pressure on the sphygmomanometer by hollowing the abdomen<sup>20</sup> and alter-

ing pelvic tilt to achieve 40 mmHg. The subject then attempted to maintain the abdominal-hollowing maneuver and 40 mmHg on the sphygmomanometer while slowly lowering the legs. The angle from horizontal at which the pressure deviated more than  $\pm 10$  mmHg from the target pressure of 40 mmHg was recorded. Because there is a nonlinear relationship between the angle of leg lowering achieved and the torque at the hip joint, the angle achieved was converted into a value that represents the relative leg gravitational torque (RLGT) that would be created at the hip joint due to the weight of the legs. This value is expressed as a percentage of the total potential torque that would be created if the legs were held horizontal (a perfect score) as follows:  $RLGT = \cos\theta \times 100\%$ , where  $\cos\theta$  is the cosine of the maximal achieved angle of the lowered legs.

Three trials were recorded with a 1-minute break between trials. The best score was used in the analysis. In our preliminary work (10 subjects), we determined that test-retest reliability for the modified DSLL was high, based upon an intraclass correlation coefficient of 0.98 (95% confidence interval [CI]: 0.93-0.99).

### Vertical Jump

Vertical takeoff velocity from a force platform (Advanced Medical Technology Inc, Watertown, MA) was used to assess vertical jump ability. A wooden bar was placed across the subject's shoulders and the subjects held the bar to control arm movement. The subject stepped onto the platform and was instructed to perform a maximum effort countermovement vertical jump. Three trials were recorded with a 1-minute rest between trials for recovery. The best score was used in the analysis. The vertical ground reaction force ( $F_y$ ), as measured by the force plate during the vertical jump, was sampled at 200 Hz and stored on a computer. The stored ground reaction force history was then numerically integrated using the following equation, to allow the determination

of the vertical takeoff velocity ( $v_f$ ):

$$(1) \int_{t_i}^{t_f} (F_y - mg) dt = m\Delta v$$

$$(2) v_f = v_i + \frac{\int_{t_i}^{t_f} (F_y - mg) dt}{m}$$

where  $F_y$  is vertical ground reaction force recorded by force plate,  $g$  is gravitational acceleration ( $-9.81 \text{ m/s}^2$ ),  $m$  is the subject's mass,  $v_i$  is initial velocity while standing motionless on the force plate (ie,  $v_i = 0$ ),  $v_f$  is final velocity upon foot separation from the force plate,  $t_i$  and  $t_f$  are the times at  $v_i$  and  $v_f$ . As is evident from equation 2, vertical takeoff velocity,  $v_p$ , directly reflects the vertical ground reaction impulse generated by the subject. The peak vertical height of the jumper's center of mass can be directly determined from the vertical takeoff velocity if the height of the jumper's center of mass at the moment of foot separation from the force plate is known. As such, calculations of the actual peak height of the jump would be contaminated with additional error from inaccuracies in determining the location of the subject's center of mass at takeoff, as well as from in-air changes in center of mass relative to the whole body (posture, rotational torque, arm movement, etc). The change in vertical distance of the center of mass, however, was estimated from takeoff velocity to provide a clinically based indicator of training effectiveness and to allow better interpretation of our data.

### Leg Press

A 35° inclined seated leg press was used to predict the 1-repetition maximum (1RM) for each subject. Each subject completed a 5-minute warm-up at a low to moderate intensity using a cycle ergometer prior to beginning the leg strength testing. Subjects were seated on the leg press with the seat adjusted so that the starting knee angle was 70° from the fully extended

position as measured manually using a goniometer. The subject placed his/her feet approximately 40 cm apart to align with markers on the leg press platform. A strap was positioned across the subject's anterior superior iliac spines to attempt to control pelvic stability externally and minimize the influence of the trunk musculature during testing. The subject performed 2 warm-up sets of 10 repetitions at a low weight, with a 1-minute rest between sets. After a 2-minute rest following the second warm-up set, the subject performed progressive repeated maximal trials until a maximum of less than 10 repetitions was performed. Standardized motivation was given to all subjects. Between 1 and 4 trials were completed by the subjects on each testing day, and 2 minutes were allowed for recovery between trials. Using the final number of repetitions performed at that load, 1RM was estimated from the following formula<sup>22</sup>:  $1RM = (\text{weight lifted})(0.033)(\text{repetitions}) + \text{weight lifted}$ . This formula uses multiple repetitions (muscle endurance) to estimate strength and is not without error (standard error of the estimate, 11.5 kg).<sup>22</sup> This option was chosen because it was deemed safer than actual 1RM testing given that not all of our athletes had specific strength training experience.

### Trunk Stability Training (TS) Program

The TS program was designed to achieve progressively increasing global stability demands while maintaining local stability around a neutral spine posture. Three phases of training, each 3 weeks in duration, were progressed by increasing the demands on the global stability system (TABLE 2). Phase 1 consisted of basic trunk stability exercises with a low external load. The focus of this phase was control of movement and pelvic position while performing low-load lower extremity movements. Subjects in the TS and TL groups were instructed to maintain the abdominal-hollowing maneuver and a relatively neutral lumbar spine while performing all exercises. Subjects performed each stability exercise for 3 sets of 5 rep-

TABLE 2

DESCRIPTION OF TRUNK STABILITY EXERCISES

Exercise	Position	Movement
Phase 1		
1. Heel slides	Supine, hooklying	Slide heel and straighten leg (hip and knee extension), hold, and return; repeat with opposite leg
2. Single leg lowering	Supine, thighs vertical, knees bent to 90°	Lower and straighten 1 leg (hip and knee extension), hold above mat, and return; repeat with opposite leg
3. Knee-outs	Supine, hooklying	Keep feet in place and lower 1 knee out to the side (hip external rotation), hold, and return; repeat with opposite leg
4. Quadruped arm lifts	Quadruped	Raise 1 arm forward (shoulder flexion), hold, and return; repeat with opposite arm
5. Back extensions	Prone, arms behind head	Raise shoulders just off the mat (spinal extension), hold, and return
Phase 2		
1. Single leg lowering	As per phase 1	As per phase 1
2. Diagonal leg lowering	As per single leg lowering	Lower and straighten 1 leg at 45° diagonal (hip and knee extension, hip external rotation), hold, and return; repeat with opposite leg
3. Side-supports on knees	Sidelying, elbow supporting shoulder, hips in neutral, knees bent to 90°	Lift hips off ground until body is in a straight line (spinal side flexion), hold, and return
4. Quadruped arm and leg lifts	Quadruped	Lift 1 arm forward (shoulder flexion) and lift the opposite leg backward (hip and knee extension), hold, and return; repeat with opposite limbs
5. Prone arm and leg lifts	Prone, arms straight at 180° shoulder flexion	As per phase 2, quadruped arm and leg lifts
Phase 3		
1. Double leg lowering	Supine, legs held vertically	Lower both legs (hip extension), hold, and return
2. Diagonal leg lowering	As per phase 2	As per phase 2
3. Side-supports on feet	Sidelying, elbow supporting shoulder, hips in neutral, knees fully extended	As per phase 2 side supports on knees
4. Quadruped arm and leg lifts	As per phase 2	As per phase 2
5. Prone arm and leg lifts with back extension	As per phase 2	Lift both arms (shoulder flexion, back extension) and both legs (hip extension and back extension), hold, and return

etitions. For each repetition, subjects were instructed to move only as far as they could without any pelvic movement. At the point where they felt their pelvis

start to move, the movement was stopped and the position held for 5 seconds. The time to reach maximum load and to return to the starting position was 1 second.

The load was increased by increasing the horizontal distance of the lever arm of the limb away from the body, to the degree that they were able, without losing pelvic control. There was a 10-second rest between each repetition and a 1-minute rest between each set.

Phase 2 involved progressively more difficult exercises. The focus of phase 2 was to increase the external load requirements while still maintaining local cocontraction. The guidelines for sets, repetitions, and rests remained the same.

The focus of phase 3 was to maximize the strength requirement for global stability while maintaining local control and cocontraction. Subjects now performed each repetition for an 8-second hold, with a 15-second rest between each repetition and a 2-minute rest between sets.

### Leg Strength (LS) Training Program

Each subject in the LS group performed the same exercises over the 9-week period. Seated leg press (combined hip and knee extension), seated knee extension (90° to full extension), and prone leg curl (knee flexion from full extension keeping hips on the bench) exercises were performed 3 times per week. Phase 1 was the anatomical adaptation phase where subjects trained with high repetitions at a low, submaximal load to allow for non-contractile tissue adaptation.<sup>5</sup> Exercises were performed for 3 sets of 10 repetitions. The initial load was approximately 75% of 1RM and subjects were instructed to adjust the load so that only 10 repetitions were achieved on every set. Tempo was slow and controlled. There was a 90-second rest between sets. Phase 2 was the transition to maximum-strength phase. Exercises were performed for 4 sets of 6 repetitions. The initial load was set at 85% of 1RM and adjusted as required to maintain 6 repetitions. There was a 3-minute rest between sets. Phase 3 was the maximum-strength phase. Exercises were performed for 4 sets of 4 repetitions at a load of 90% 1RM. There was a 3-minute rest between sets.

## Trunk Stability and Leg Strength Training (TL) Program

Subjects in the TL group performed both the TS and LS programs. The LS program was performed prior to, but on the same day as, the TS program.

## Control (CO) Group

Subjects in the CO group were tested on all of the measures used for the other groups but did not complete any training protocol within the confines of this study.

## Statistical Analysis

Statistical analysis compared the training effects of each group on vertical takeoff velocity. Vertical takeoff velocity was analyzed using a 4-by-2 ANCOVA (group by repeated measures for time) with SPSS for Windows Version 10.0.5. Both pre-training scores and body mass were used as covariates. Trunk stability (DSLL) and leg press strength were analyzed using an ANCOVA (with repeated measures for time), with initial scores and body weight as covariates. When statistical significance was evident ( $P < .05$ ), post hoc tests were completed using simple main effects. To determine the relative impact of leg strength and trunk stability on takeoff velocity, a Pearson correlation analysis was performed at each of the 3 time points. Effect sizes were computed using omega squared ( $\omega^2$ ). All analyses were completed using  $\alpha < .05$  and reported as adjusted mean  $\pm$  SE, unless otherwise indicated.

## RESULTS

**UNADJUSTED MEAN SCORES FOR VERTICAL takeoff velocity, DSLL, and estimated leg press strength are presented in TABLE 3.**

### Vertical Takeoff Velocity

Adjusted group means at each time period for vertical takeoff velocity are presented in **FIGURE 2**. There was a significant group-by-time interaction ( $P = .008$ ,  $\omega^2 = 0.16$ ) for vertical takeoff velocity. Simple main effect analysis revealed that there were

TABLE 3		UNADJUSTED MEAN SCORES FOR EACH GROUP AND EACH VARIABLE OVER EACH PERIOD*			
Test/Time	TS	TL	LS	CO	
<b>VJ (m/s)</b>					
Baseline	2.22 $\pm$ 0.31	2.39 $\pm$ 0.31 <sup>†</sup>	2.17 $\pm$ 0.25	2.33 $\pm$ 0.40	
3 wk	2.38 $\pm$ 0.39	2.45 $\pm$ 0.30	2.23 $\pm$ 0.25	2.29 $\pm$ 0.35	
9 wk	2.38 $\pm$ 0.36	2.59 $\pm$ 0.34	2.31 $\pm$ 0.26	2.27 $\pm$ 0.31	
<b>DSLL (%)</b>					
Baseline	62.9 $\pm$ 17.7 <sup>†</sup>	67.6 $\pm$ 18.1	69.0 $\pm$ 21.7	72.1 $\pm$ 18.5	
3 wk	79.3 $\pm$ 15.4	82.7 $\pm$ 16.1	72.3 $\pm$ 22.5	76.0 $\pm$ 17.4	
9 wk	89.7 $\pm$ 13.2	94.7 $\pm$ 7.7	75.2 $\pm$ 26.7	76.3 $\pm$ 14.8	
<b>Estimated LP (kg)</b>					
Baseline	182.7 $\pm$ 93.0	194.3 $\pm$ 59.7 <sup>‡</sup>	177.2 $\pm$ 70.1	163.8 $\pm$ 67.9	
3 wk	196.0 $\pm$ 98.7	197.9 $\pm$ 61.1	197.4 $\pm$ 66.5	162.2 $\pm$ 54.5	
9 wk	190.7 $\pm$ 93.0	220.0 $\pm$ 73.5	209.0 $\pm$ 76.5	164.2 $\pm$ 69.4	

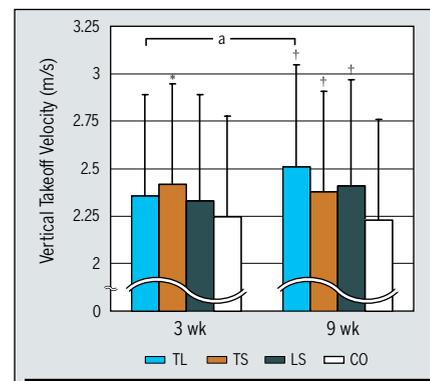
*Abbreviations: CO, control group; DSLL, double straight leg lowering test; LP, leg press; LS, leg strength training group; TL, combined trunk stability and leg strength training group; TS, trunk stability group; VJ, vertical takeoff velocity.*  
 \*Data presented as mean  $\pm$  SD.  
<sup>†</sup>Significant difference from LS at baseline.  
<sup>‡</sup>Significant difference from CO at baseline.

no differences between the 3 training groups at either testing period; however, at the 9-week test, all 3 training groups had significantly greater takeoff velocity than the CO group. After the 3-week period, only the TS group had significantly greater takeoff velocity than the CO group (mean  $\pm$  SE adjusted scores, 2.42  $\pm$  0.53 versus 2.25  $\pm$  0.53 m/s, respectively;  $P = .03$ ). Across groups, only the TL group increased vertical takeoff velocity between the third and ninth weeks of training. **FIGURE 3** shows the change for each group in the unadjusted vertical takeoff velocity scores between the pretraining score and the score at each testing period. **TABLE 4** shows the estimated change in vertical distance of the athletes' center of mass.

### Modified Double Straight Leg-Lowering Test (DSLL)

Pretraining body mass was found to be nonsignificant in our ANCOVA for DSLL and was removed from the analysis. There was a significant group-by-time interaction ( $P = .02$ ,  $\omega^2 = 0.11$ ). Simple main effects revealed that the TL and TS groups exhibited significant increases in trunk stability scores between the third-week and ninth-week testing periods (mean  $\pm$

SE adjusted scores, 82.9%  $\pm$  2.6% versus 94.8%  $\pm$  2.7% [ $P < .0001$ ] and 83.3%  $\pm$  2.6% versus 92.6%  $\pm$  2.7% [ $P < .0001$ ], respectively). At the 3-week and 9-week testing periods, the TS and TL groups had significantly greater trunk stability scores than the LS and CO groups. At the end of both periods, there was no significant dif-



**FIGURE 2.** Vertical takeoff velocity scores for each training group after 3 and 9 weeks of training. Data are presented as adjusted mean scores and standard error from the analysis of covariance. (a) Significant difference between 3 and 9 wk of training ( $P < .05$ ). \*Significant difference between TS training group and control group at wk 3 ( $P < .05$ ). †Significant difference between each of the 3 training group and control at 9 wk. Abbreviations: CO, control group; LS, leg strength group; TL, combined trunk stability and leg strength training group; TS, trunk stability group.

**TABLE 4**

**ESTIMATED VERTICAL CHANGE IN THE LOCATION OF CENTER OF MASS (CM) DURING THE VERTICAL JUMP\***

Time	TS	TL	LS	CO
Baseline	24.8 ± 7.6	29.1 ± 7.6	24.2 ± 5.7	28.3 ± 10.5
3 wk	29.6 ± 9.6	30.9 ± 7.6	25.7 ± 5.7	27.3 ± 8.5
9 wk	29.6 ± 8.9	37.3 ± 9.1	30.1 ± 6.1	26.3 ± 7.3
3-wk change	4.8 ± 2.2	1.4 ± 1.9	1.6 ± 2.0	-1.0 ± 3.6
9-wk change	4.8 ± 1.6	8.2 ± 3.2	5.9 ± 1.8	-2.0 ± 3.8

Abbreviations: CO, control group; LS, leg strength training group; TL, combined trunk stability and leg strength training group; TS, trunk stability training group.

\*Data calculated from unadjusted vertical takeoff velocity scores over each time period (mean ± SD) as well as the 3- and 9-wk change scores (mean ± 95% confidence interval).

ference between the LS and CO groups or between the TS and TL groups. At each of the times there was no relationship between takeoff velocity and trunk stability scores (initial testing period:  $r = 0.098$ ,  $P = .782$ ; 3-week testing period:  $r = 0.128$ ,  $P = .463$ ; 9-week testing period:  $r = 0.139$ ,  $P = .442$ ).

**Estimated Leg Strength**

There was a significant group-by-time interaction for estimated leg strength ( $P = .02$ ,  $\omega^2 = 0.12$ ). Only the TL and LS groups had a significant increase in estimated leg strength between the 3-week and the 9-week testing periods (mean ± SE adjusted scores, 187 ± 15 versus 208 ± 18 kg [ $P$

= .002] and 195 ± 15 versus 211 ± 18 kg [ $P = .021$ ], respectively). At the 3-week testing period only the LS group was significantly different from the CO group ( $P = .034$ ). At the 9-week testing period, both the TL and the LS groups had significantly greater estimated strength than the CO group ( $P = .006$  and  $.003$ , respectively), but not from each other ( $P = .767$ ). Estimated leg strength was significantly correlated with takeoff velocity at all 3 testing periods (initial testing period:  $r = 0.610$ ,  $P = .032$ ; 3-week testing period,  $r = 0.686$ ,  $P = .028$ ; 9-week testing period:  $r = 0.740$ ,  $P = .012$ ).

**DISCUSSION**

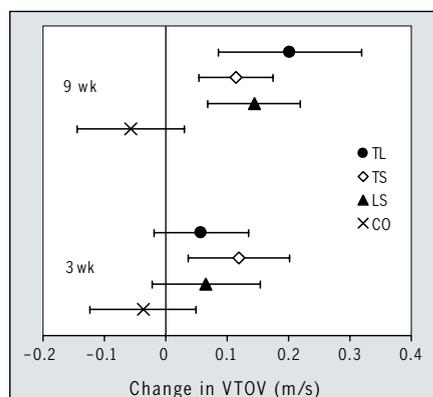
**T**HE IMPORTANT RESULTS OF OUR study were (a) at the end of 9 weeks of training, all 3 training groups had greater vertical takeoff velocity than the control group, (b) there were no significant differences in vertical takeoff velocity scores between any of the 3 training groups at 3 or 9 weeks, (c) only the TS group had a statistically greater vertical takeoff velocity than the CO group at the 3-week period, and (d) only the TL group had a statistically significant change in takeoff velocity from the 3-week to the 9-week periods.

These findings support our first hypothesis that trunk stability training would improve vertical takeoff velocity in athletes. However, the increase in vertical takeoff velocity with stability training alone was not statistically different from

those observed by leg strength training or by combined trunk and leg training. Stability training was, therefore, similarly effective in enhancing jumping ability as both leg strength and combined training after 9 weeks of training. These findings, therefore, do not support our second hypothesis that combined training would improve takeoff velocity to a greater degree than either leg strength or trunk stability training alone. It should be noted, however, that the relatively small sample size in each group and, consequently, a low effect size might have contributed to our inability to detect differences between groups at each test period. **FIGURE 3** shows that, although statistical significance between groups was not attained, at 9 weeks the mean change in takeoff velocity for the TL group was at, or near, the upper 95% confidence limit for the other 2 training groups. As well, **TABLE 4** shows that the TL group increased their estimated change in vertical distance covered by the center of mass by 8.2 versus 5.9 cm in the LS group. These data warrant further study to examine if various protocols of combined trunk stability and leg strength training result in significantly greater gains in jumping ability than leg strength training alone.

After 3 weeks of training, there were no significant differences in vertical takeoff velocity scores between the 3 training groups. However, small sample sizes limit the interpretation of this result. The change scores shown in **FIGURE 3** suggest that the only systematic improvement after 3 weeks at the 95% CI limit was in the TS group, as the confidence limits for the LS and TL groups included the zero or no change value.

Our study was not designed to investigate the mechanisms of improvements in jumping ability with trunk stability training. Subjects were not asked to attempt an abdominal-hollowing maneuver during each vertical jump and we did not measure the degree of change in trunk stability, muscle activation, or spinal/pelvic biomechanics during the jumps. Therefore, we do not know the exact



**FIGURE 3.** Change scores for unadjusted vertical takeoff velocity scores (VTOV) for each training group from the pretraining value. Data are presented as unadjusted mean change from the pretraining value and 95% confidence intervals. Abbreviations: CO, control group; LS, leg strength training group; TL, trunk stability and leg strength training group; TS, trunk stability training group.

mechanisms by which vertical takeoff velocity was increased with trunk stability training. As well, to our knowledge, there is no existing evidence to suggest that abdominal hollowing actually occurs during a vertical jump. We speculate, however, that trunk stability training may optimize the ability of the leg muscles to produce force by providing a stable base from which those muscles can contract<sup>13</sup> or by enhancing the neural drive to the leg muscles.<sup>21</sup> The first 3 weeks of trunk stability exercises had low muscular loading and were designed to increase the overall awareness and control of trunk and pelvic position. As well, because muscle structural changes with resistance training usually occur after longer periods, it is likely that the improved vertical takeoff velocity in the TS group after only 3 weeks was due to a change in neuromuscular control or movement pattern rather than a muscular structural change.<sup>21</sup>

There may be a theoretical end point to the amount of enhancement of vertical jump performance that can be achieved with trunk stability training alone. This model of performance enhancement is limited by the strength of the appropriate leg muscles. Despite a significantly improved trunk stability score and no change in leg strength at both the 3- and 9-week tests, the TS group increased vertical takeoff velocity only after 3 weeks of training, but not subsequently (**FIGURE 3**). This finding supports the view that TS training may only optimize the ability of the leg muscles to produce force and that optimal trunk stability may have been achieved after 3 weeks of training. This is important when considering that training programs are usually done for long periods. Further study is required before conclusions can be reached regarding this proposed model of performance enhancement.

The results of this study support the findings of Mills et al,<sup>16</sup> who examined the effect of a 10-week trunk stability training program on vertical jumping ability. These authors used a combination of mat and therapy ball exercises to train

trunk stability. Trunk stability training was similar to the present study in that abdominal hollowing was emphasized in each exercise. Additionally, our protocol emphasized maintaining a neutral spine position during training. Vertical-jumping ability was assessed by subjects performing a vertical jump and marking a wall at peak jump height. Trunk stability was assessed by a progressive 5-stage test that involved increasingly difficult single and double leg-lowering maneuvers, while maintaining an abdominal hollow and preventing a change in pressure under the lumbar spine similarly to the present study. Similar to the present study, Mills et al<sup>16</sup> found that trunk stability training increased vertical jumping ability and that there was no association between trunk stability score and vertical height. They concluded that because of the lack of association, the improvements in vertical jump were due to an unnamed confounding variable and not to trunk stability.<sup>16</sup>

Although the present study showed similar results, we do not completely agree with these conclusions. Although the modified DSLL is likely a good measure of trunk stability, we believe that it does not fully detect the many subtle changes in trunk stability that occur with multidirectional stability training. The DSLL tests local muscular stability with global stability involving the trunk flexors superimposed. The stability required during a vertical jump movement would likely involve the trunk extensors as global stabilizers. We are unaware of any graded test that would adequately measure trunk stability in this fashion. Considering these factors, we are not surprised at a lack of association between stability and performance, but believe that our results do support the use of trunk stability training for enhancing jumping performance in athletes. However, this enhancement of performance is not superior to that of leg strength training and further investigation is required to elucidate any benefit of combining trunk stability training with leg strength training.

There are a few potential limitations regarding the generalization of our results. First, the nature of the experimental design was such that there were a small number of subjects in each group and that stratification for sport history or gender was not performed. Additionally, there were a disproportionate number of male dropouts, particularly from the LS group. These factors combined reduced our statistical power and have likely influenced our ability to detect between-group differences.

Second, this study examined the effect that a trunk stability training program using mat exercises and a leg strength training program using machines had on vertical jump performance. There are many training methods available that claim to enhance trunk stability. Other methods such as Pilates exercises, Swiss Ball, or Theraball exercises and conventional dynamic abdominal exercises have been used to enhance stability.<sup>14,16</sup> The results of the present study apply only to the mat exercises used within the study.

Third, in training for increased vertical jump, most training programs would incorporate high-velocity training using exercises that are more specific to the mechanics of jumping. Comparison of these training methods shows that for functional strength gains, free weights using a movement pattern similar to the movement to be improved are superior to machine training.<sup>14</sup> A free-weight squat exercise was not used in this study to avoid excessive trunk activity and to help control for training technique. The comparison of results obtained using trunk stability exercises to that of a more functional-strengthening exercise program may yield different results.

The results of our study provide initial evidence that should help guide performance enhancement training program design. As well, these results should spark further interest and research in biomechanics and motor control to provide some insight into the importance of examining subtle changes in training and skill techniques and to determine

the exact effects and mechanisms of trunk stability training for performance enhancement.

## CONCLUSIONS

**T**HE RESULTS OF THIS STUDY INDICATE that 9 weeks of trunk stability training, leg strength training, or combined trunk stability and leg strength training were similarly effective in enhancing an athlete's vertical jump. Further study is required to determine the ongoing effects related to combining trunk stability training and leg strength training and the potential mechanisms of performance enhancement with stability training. Preceding resistance training with a stability-training program could be another focus of future interventions. ●

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