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Research article

The effect of instability training on knee joint proprioception and core strength

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Abstract

Although there are many studies demonstrating increased trunk activation under unstable conditions, it is not known whether this increased activation would translate into meaningful trunk strength with a prolonged training program. Additionally, while balance-training programs have been shown to improve stability, their effect on specific joint proprioception is not clear. Thus the objective of this study was to examine training adaptations associated with a 10-week instability-training program. Participants were tested pre-and post-training for trunk extension and flexion strength and knee proprioception. Forty-three participants participated in either a 10-week (3 days per week) instability-training program using Swiss balls and body weight as resistance or a control group (n = 17). The trained group increased ($p < 0.05$) trunk extension peak torque/body weight (23.6%) and total work output (20.1%) from pre- to post-training while the control group decreased by 6.8% and 6.7% respectively. The exercise group increased their trunk flexion peak torque/body weight ratios by 18.1% while the control group decreased by 0.4%. Knee proprioception (combined right and left joint repositioning) improved 44.7% from pre- to post-training ($p = 0.0006$) and persisted (21.5%) for 9 months post-training. In addition there was a side interaction with the position sense of the right knee at 9 months showing 32.1% ($p = 0.03$) less deviation from the reference angle than the right knee during pre-testing. An instability-training program using Swiss balls with body weight as resistance can provide prolonged improvements in joint proprioception and core strength in previously untrained individuals performing this novel training stress which would contribute to general health.

Key words: Instability resistance training, stability, back, abdominals.

Introduction

The Canadian Society for Exercise Physiology position stand on instability resistance training (RT) recommended that for athletes and non-athletes at all levels, ground-based free-weight lifts should form the foundation to train the core musculature (Behm et al., 2010a). These recommendations were based on instability RT research, which demonstrated decreases in force, power, and movement velocity when performing RT under unstable conditions. (Behm et al., 2010b). Decreases in force with instability accompanied by a similar extent of muscle activation suggested that the dynamic motive forces of the muscles (the ability to apply external force) were transferred into greater stabilizing functions (Anderson and Behm, 2004). The limitations on force, power, and performance during instability may be partially attributed to an increase in joint stiffness. Carpenter et al. (2008) and Adkin et al. (2002) indicated that a stiffening strategy was adopted with a threat of instability, which can adversely affect the magnitude and rate of movements. Thus, instability-induced alterations in muscle activation, kinetics and muscle stiffness could have an adverse effect upon proprioception and co-ordination. According to Behm et al. (2010b) the decrements associated with instability devices may not provide as many training advantages as ground based lifting.

However, in the same position stand, the authors indicated that in rehabilitation and general fitness, the utilization of unstable devices has been shown to be effective in decreasing the incidence of low back pain (LBP) and increasing the sensory efficiency of soft tissues that stabilize joints (Behm et al., 2010b). Thus, in addition to the reported benefits of greater instability-induced muscle activation, training on unstable devices might enhance performance by improving proprioception (Anderson and Behm, 2004). The majority of literature examines the effect of proprioceptive training on spinal stability (Carter et al., 2006). There is little information on the effects of instability training (IT) on limb proprioception. The accuracy of discrete ankle inversion was improved following 12 weeks of wobble board training (Waddington et al., 2000). It is not clear whether the training challenges (decreased force, power and increased co-contractions) presented by instability exercises would have positive or negative training effects upon joint proprioception. Improved proprioception enables more accurate movement pattern and helps to prevent injury (Lephart et al., 1997). As knee and ankle injuries are among the most common musculoskeletal injuries (Behm et al., 2010b), effective joint proprioception is essential for adequate joint movement and stability and may play a protective role in acute knee injury. Furthermore, it is unknown how long any possible improvements in joint proprioception may persist following IT.

Trunk or core muscles not only have the primary importance of stabilizing the spine for daily activities of living, but also lead to better sports performance and assist in the prevention and treatment of LBP (Faries and Greenwood, 2007; McGill, 2010). Many studies have reported increased trunk muscle activity when performing exercises with unstable environments (Arokoski et al., 2001). On the other hand, there is little research regarding the effect of unstable surface exercises on core strength (Cosio-Lima et al., 2003, Sekendiz et al., 2010). While

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the literature provides many acute instability studies, there are fewer IT studies. A number of studies have conducted IT protocols measuring physiological, functional and athletic performance (Behm and Kibele, 2009; Behm and Sparkes, 2010; Stanton et al., 2004), but did not measure changes in trunk strength. Other studies are of quite short duration (3-6 weeks) showing positive adaptations for lordotic curve stability, postural control (Yaggie and Campbell, 2006) and trunk power (Cowley et al., 2007). Stanforth et al. (1998) conducted a 10-week instability program and also found improved lordotic curve stability but no difference with the traditional training group for trunk endurance. Conversely, Carter et al. (2006) reported improvements in trunk power and endurance with 10 weeks of IT. Sekendiz et al. (2010) described improved trunk flexion and extension strength and endurance with 12 weeks of Swiss ball training. However, there was no control group in this study. Thus, based on the dearth of studies and the contradictory results in the few training studies that examined trunk strength, it would be important to investigate if the reported instability exercise-induced increases in trunk muscle activation transfer into meaningful trunk strength with IT.

Therefore, the purpose of this study was to investigate the effects of Swiss ball (instability) training on isokinetic core strength parameters and knee joint reposition sense (proprioception). It was hypothesized that 10 weeks of IT would result in improved trunk strength and knee proprioception. It was also hypothesized that improvements in knee proprioception would still be present 9 months following training.

Methods

Subjects

Volunteers were university students who took elective courses from the Physical Education and Sports Department. In total, 60 participants participated in the study. Specifically, 43 participants (27 males, 16 females) from the General Physical Conditioning Course (Swiss ball group) and 17 participants (9 males, 8 females) from theoretical courses participated in the study (Table 1). In order to meet the requirements of the course and study, participants had to be healthy, previously inactive individuals with no regular exercise background. A health status and exercise stages of change levels questionnaire was distributed. Ethics approval was obtained from the Human Research Ethics Committee of the University as prescribed by the Helsinki Convention. The informed consent form was signed by the participants. The inclusion criteria were a) no physical activity for a minimum of six months b) absence of neurological, cardiovascular, metabolic, rheumatic or vestibular diseases, c) no injuries or previous surgery on the legs and d) absence of knee instability. 3 subjects (2 male, 1 female) of 47 in the experiment group and 2 (2 male) of 17 in the control group were left leg dominant.

Dependent variables

Dependent variables included a Passive Reproduction of Passive Positioning Protocol (PRPP), which was conducted using a Biodex isokinetic dynamometer (Biodex Medical Systems, Inc. Shirley, NY). The patients were instructed to sit with the knee joint aligned to the axis of rotation. The thigh was fixed with a strap to isolate the movement of the knee joint. Participants were asked to wear shorts to minimize the sensory input of clothes to the skin during testing. Participants were blindfolded.

The participant's leg was placed with an initial angle of 90° of knee flexion for each trial. The participant's leg was then passively moved to the test angle of 45° of knee flexion by the experimenter with an angular velocity of 4°/sec. This position (45° of knee flexion) was held for 3 seconds. The participants' leg was then returned passively to the starting position. This familiarization procedure was performed twice. Following a five second rest period the dynamometer passively moved the participant's leg at 45° of knee flexion at an angular velocity of 2°/s. The participants were instructed to push a stop button when they thought the prescribed angle had been reached. The amount of error, in the participant's ability to match the reference angle, was noted. The average of two values was used for statistical analysis. The PRPP was tested pre-, post-training and was subsequently followed up 9 months later. The subsequent follow-up testing was only conducted with the experimental group.

Trunk extensor\flexor strength was assessed on Biodex System III Isokinetic Dynamometer (Biodex Medical Systems, Inc. Shirley, NY) concentrically at an angular velocity of 90° s^{-1} (10 repetitions)(Karataş et al., 2002). Each participant was positioned on the dynamometer, seated with their back and neck supported with the adjustable pads for safety. Their thighs, pelvis and chest were constrained by rigid pads to prevent pelvic rotation and facilitate isolation of the trunk for flexion/extension testing only (Sekendiz et al., 2007). Knee block position was individually adjusted. Participants were instructed to keep their heads and arms in a fixed position throughout the test. Before measurements, each participant was asked to perform a familiarization test of two repetitions with 10s recovery. Measures included peak torque and total work (over the 10 repetitions). Peak torque was normalized by dividing the peak torque by the participant's body weight.

Table 1. Participant characteristics. Data are means (±SD).

	Experimental group (n=43)		Control group n=(17)	
	♂ (n=27)	♀ (n=16)	♂ (n=9)	♀ (n=8)
Age	21.67 (1.51)	21.81 (1.16)	23.44 (2.87)	23.25 (1.67)
Height	1.73 (.06)	1.64 (.05)	1.74 (.04)	1.63 (.07)
Pre-Weight	72.67 (9.41)	57.18 (12.18)	77.00 (9.69)	57.5 (11.74)
Post-Weight	71.44 (9.38)	57.25 (11.76)	76.33 (9.71)	57.25 (12.84)
BMI	24.19 (2.91)	21.08 (3.85)	25.20 (2.93)	21.60 (3.50)

Training program

Swiss ball training was conducted 3 days (Mon-Wed-Fri) per week for 10 weeks. Each participant was given a ball that was sized in accordance to their height. The size of the ball was conducive to achieving >90° angle at both the hip and knee. The stability balls were either 55 or 65 cm in height. The volume of exercise was kept consistent for each individual. The exercise program progressed in difficulty by increasing the sets and repetitions (week 1: 2 sets of 6 repetitions to week 10: 3 sets of 14 repetitions) or duration (week 1: 2 sets of 30s to week 10: 2 sets of 60s). The exercise program progressed in difficulty by increasing the repetitions. Before each workout, participants warmed up with a 6-8 minute run at approximately 8 km/hr. Active dynamic stretching of the neck, shoulders, trunk, hips, quadriceps, hamstrings, abductor, and adductor muscles followed the run. Dynamic stretching has been reported to either facilitate or have no adverse effects upon subsequent performance (Behm and Chaouachi, 2011). Stretching exercises were also performed during the session and at the completion of each session. Rest intervals were approximately 30 seconds. All of the sessions were instructed and supervised by the same trainer. Exercises were all performed on Swiss balls and included abdominal crunch, back extensions, supine hamstring curls, squats (Swiss balls supporting the back) to a position where thighs were parallel to the floor, and standing and kneeling on the Swiss balls. These exercises have been described by Sekendiz et al. (2010). The control group was told not to participate in any organized or structured exercise and to continue their daily activities.

Statistical Analysis

Multivariate ANOVA (MANOVA) was used for pre-tests scores to test baseline equivalence between exercise and control groups. The effects of 10 weeks of Swiss ball exercises on trunk extension strength were examined by performing 2 x 2 (Group: exercise/control X time: pre/post-test) mixed design repeated measures of MANOVA. Univariate ANOVA's were conducted in order to interpret main effect(s) and/or interaction effects. α level was set as 0.05. Paired sample t-tests were performed to examine independent changes for both the exercise and the control group from pre- to post-measurements.

Proprioception data was analyzed using the knee angle degree difference from the reference angle. A 3 way univariate ANOVA (2x2x2) with repeated measures on the time component was utilized. The 3 factors included groups (experimental and control), time (pre- and post-training) and side (right versus left knee). Significant interactions were identified using a Tukey post-hoc test. All statistics were performed with the SPSS Version 19 software.

Results

Trunk extension strength scores are shown in Table 2. The MANOVA indicated non-significant multivariate group effects at the commencement of the training program (Wilks' Lambda=.96, F (3, 56) =0.77, $p > 0.05$. η^2= 0.04). These results indicated that there was no initial significant difference between exercise and control group for peak torque/body weight, total work and agonist-antagonist ratio scores.

The trunk extension results indicated significant multivariate effects for time (Wilks' Lambda=0.76, F (3, 56) =5.77, $p < 0.02$. $\eta^2 = 0.24$) and group x time interaction (Wilks' Lambda=0.54, F (3, 56) =15.97, $p < 0.01$. $\eta^2 = 0.46$). However, no significant multivariate effect for group (Wilks' Lambda = 0.92, F (3, 56) = 1.69, $p > 0.05$. $\eta^2 = 0.08$) were found.

Univariate ANOVAs for trunk extension measures were then conducted in order to interpret the significant multivariate time and group x time interaction effects. Follow-up ANOVA results revealed significant time effects for peak torque/body weight (F (1, 58) = 13.64, $p < 0.05$, $\eta^2 = 0.19$) and total work scores (F (1, 58) = 6.80, $p < 0.05$, $\eta^2 = 0.11$), whereas no significant time effect was found for agonist-antagonist ratio scores (F (1, 58) = 0.65, $p > 0.05$, $\eta^2 = 0.01$). Overall (both groups combined), peak torque/body weight and total work increased 8.2% and 6.4% from pre- to post-training respectively. Similarly, group x time interaction indicated significant results for peak torque/body weight (F (1, 58) = 46.91, $p < 0.05$, $\eta^2 = 0.45$) and total work scores (F (1, 58) = 29.44, $p < 0.05$, $\eta^2 = 0.34$) but not for agonist antagonist peak torque ratio scores (F (1, 58) = 3.01, $p > 0.05$, $\eta^2 = 0.05$). The trained group increased trunk extension peak torque/body weight by 23.6% whereas the control group decreased by 6.8%. The trained group also increased their total work output from pre- to post-training by 20.1% while the control group decreased 6.7%.

Univariate ANOVAs for the multivariate 'group effect', on the other hand, showed non-significant differences between exercise and control group for peak torque/body weight (F(1,58) = 2.23, $p > 0.05$, $\eta^2 = 0.04$), total work (F(1,58) = 0.68, $p > 0.05$, $\eta^2 = 0.01$).

Table 2. Isokinetic trunk extension and flexion strength parameters. Data are means (±SD).

	Exercise (n=43)		Control (n=17)	
	Pre test	Post test	Pre test	Post test
Isokinetic trunk extension strength				
Peak Torque/BW	321.8 (79.7)	397.9 (78.4) *	333.6 (121.7)	310.8 (114.9)
Total Work	1491 (561)	1791 (503) *	1561 (698)	1455 (654)
Ratio	72.3 (17.7)	70.0 (11.4)	78.7 (26.7)	85.0 (28.4)
Isokinetic trunk flexion strength				
Peak Torque/BW	234.1 (53.0)	276.5 (61.5) *	238.1 (52.4)	237.1 (42.1)
Total Work	974 (337)	1062 (338) *	893 (393)	947 (335)

Ratio refers to the ratio of trunk extension to trunk flexion peak torque / body weight scores. Asterisks (*) represent significant (p<0.05) differences between pre- and post-training exercise groups.

Descriptive characteristics of the trunk flexion strength scores are provided in Table 2. MANOVA results for pretest scores showed non-significant differences (Wilks' Lambda=.97, $F(2,57) = 0.93$, $p > 0.05$. $\eta^2 = 0.03$) between the exercise and the control group in terms of their peak torque/body weight and total work scores indicating that both groups had similar pre-test values.

The MANOVA trunk flexion results did show significant multivariate effects of time (Wilks' Lambda = 0.81, $F(2, 57) = 6.36$, $p < 0.05$. $\eta^2 = 0.18$) and group x time interaction (Wilks' Lambda = 0.84, $F(2, 57) = 5.43$, $p < 0.05$. $\eta^2 = 0.16$). However, no significant multivariate effect for group (Wilks' Lambda = 0.97, $F(2, 57) = 0.80$, $p > 0.05$. $\eta^2 = 0.03$) were found.

Follow up ANOVA results revealed significant time effects for peak torque/body weight ($F(1, 58) = 9.30$, $p < 0.05$, $\eta^2 = 0.14$) and total work scores ($F(1, 58) = 9.80$, $p < 0.05$, $\eta^2 = 0.14$). Overall, peak torque/body weight ratios and total work increased 8.7% and 7.6% respectively. Similarly, group x time interaction indicated significant results only for peak torque/body weight ($F(1, 58) = 10.26$, $p < 0.05$, $\eta^2 = 0.15$) and but not for total work scores ($F(1, 58) = 0.54$, $p > 0.05$, $\eta^2 = 0.09$). The exercise group increased their peak torque/body weight ratios with training by 18.1% while the control group decreased by 0.4% after 10 weeks.

For proprioception (knee position sense) there were significant group ($F(1, 58) = 5.22$, $p = 0.02$), time ($F(1, 58) = 13.03$, $p = 0.0006$) and group x time ($F(1, 58) = 9.30$, $p = 0.0006$) effects. Main effect for groups showed that the experimental group (4.6° ± 2.9) achieved a 26.3% smaller deviation from the reference angle than the control group (5.8° ± 4.7). A main effect for time demonstrated a 22.5% improvement from pre- (5.8° ± 4.3) to post-training (4.5^0±3.3). The group x time interaction illustrated a 44.7% improvement in repositioning of the knee with the experimental group pre-scores (5.9° ± 3.4) improving following training (3.3° ± 2.5) which persisted (21.5%) into the follow-up testing (4.6° ± 3.3). In addition there was a side interaction with the position sense of the right knee at follow-up showing 32.1% significantly ($p = 0.03$) less deviation from the reference angle than the right knee during pre-training testing (Figure 1). The reason why follow-up assessment was not conducted with control group that was difficult to recruit the same control subjects 9 months later. Since the pre-post-tests for the controls were not significantly different. It was unlikely that the controls would have improved over a 9 month period without training.

Discussion

The most important findings of this study were that a 10-week general instability RT program using body weight as a resistance significantly improved knee proprioception and trunk flexion and extension strength in a previously sedentary population. Furthermore, the improved knee joint proprioception persisted for 9 months following training.

The concept of training specificity would suggest that improvements in knee proprioception would be most effectively achieved with a training program that involved the same posture, velocity, and movement (Behm and Sale, 1993). Although two of the six exercises in the training program included knee flexion and extension movements (squats and supine hamstring curl), they were not performed in a similar seated stable position as used in testing. Thus, a general IT program using only Swiss balls was effective in improving knee proprioceptive sense. As impaired joint position sense (proprioception) may be a risk factor for recurrent injuries (Baltacı and Kohl, 2003) the present findings have important training and prehabilitation implications.

Swiss balls provide unstable conditions that may stimulate proprioceptors to provide feedback for the maintenance of balance and detection of body position (Cooke, 1980; Soderman et al., 2000; Verhagen et al., 2005). Instability induces acute changes in muscle-tendon unit length, tension, and neuromuscular activity, which challenge the ability to detect (proprioception) and to respond (efferent activity) to changes in balance (Anderson and Behm, 2005; Heitkamp et al., 2001; Magnusson et al., 1996). The use of closed kinetic chain exercise such as squats, standing and kneeling on Swiss balls and crunches involve multi-joint & multi-planar movements which facilitate the integration of proprioceptors which are responsible for joint direction and position (Rogol et al., 1998). Balance training can increase the sensitivity of the feedback pathway, shorten onset times, and improve sensitivity of the position sense.

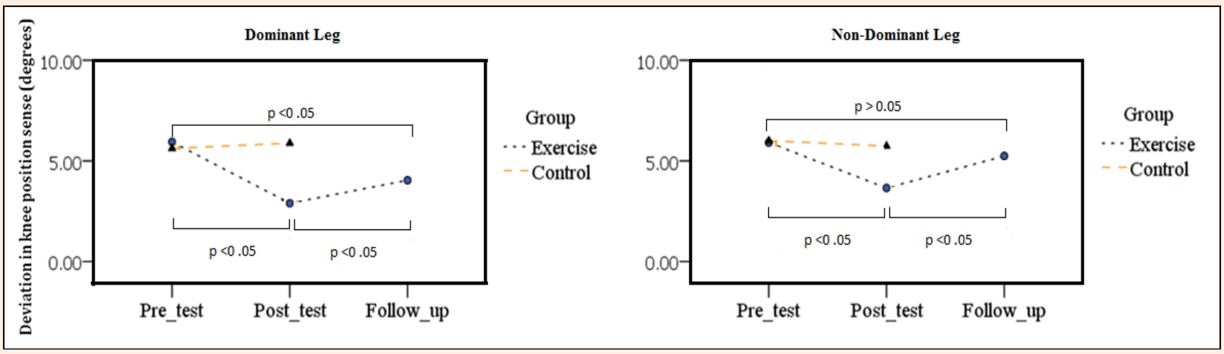

Figure 1. Training-induced changes in knee proprioception (repositioning). The "y" axis indicates the deviation or change from the reference angle (45^0).

Co-contractile activity may increase when training on unstable support surfaces (Behm et al., 2010a; Anderson and Behm, 2004). Behm et al. (2002) reported that resisted plantar flexion and leg extension muscle actions performed under unstable conditions experienced 30.7% and 40.2% greater antagonist activity than when stable, respectively. Increased co-contractile activity reportedly can improve motor control and balance (Engelhorn, 1983) helping to control the limb position when producing force (Behm et al., 2010a). Hence this 10-week IT program provided sufficient general challenges to the proprioceptive system and motor control to induce specific knee position sense training adaptations in a previously sedentary population.

The positive knee position sense training adaptations were still evident 9 months post-training. Although statistically there was an overall improvement in knee proprioception, it was the right knee that demonstrated significantly less deviation from the reference angle, whereas the left knee while numerically better than pretest was not significant. As the right leg was the dominant limb with most participants, there may be a more persistent training effect with the dominant side. During training and post-training, there may have been an increased reliance on the dominant limb permitting a greater training perseverance.

The present training study was also effective for providing a positive strength training adaptation for trunk strength. Both trunk flexion and extension strength measures significantly improved with training. Greater trunk activation with unstable versus similar stable exercises is well documented (Behm et al., 2010a). However there are few IT studies, which have examined trunk strength training adaptations (Carter et al., 2006; Sekendiz et al., 2010; Cowley et al., 2007). Other IT studies have shown significant limb strength and sport performance gains but did not monitor changes in trunk strength (Behm and Kibele, 2009; Behm and Sparkes 2010). It is important to note that improvements in trunk strength in the present study were accomplished without the use of external resistance. The use of body mass as a resistance under unstable conditions was effective at improving trunk flexion (18%) and extension (24%) strength measures.

While performing exercises on an unstable surface, the motor control system initiates the co-activation of both global and local muscles to stabilize the spine to maintain balance (Carter et al., 2006). Traditional stable exercises such as a sit-up performed on a mat have focused on improving the performance of global musculature, not local system (Faries, 2007). Maintaining stability while performing a movement with a Swiss ball has been reported to mainly activate the local stabilizing muscles (Cooke, 1980). The greater integration and recruitment of both global and local muscles with unstable RT could lead to meaningful trunk strength by improving motor control and a greater spectrum of muscle activation.

The strengthening of trunk stabilizing muscles is an important consideration for activities of daily living such as bending, twisting or lifting (Behm et al., 2010a). Weak trunk musculature has been found to be an important risk factor for LBP problems (Carpenter and Nelson, 1999). Participants with a history of LBP had weaker trunk muscle strength when compared to those who had not experienced LBP (Lee et al., 1995). Faries (2007) explained that training the core musculature improves the robustness of the stabilizing system, providing protection against spinal injuries. This study demonstrates that IT using body mass as a resistance can be an effective training regimen to increase core strength in a previously inactive population.

Conclusion

A general 10-week IT program utilizing Swiss balls and body mass as a resistance proved effective for improving knee proprioception as well as trunk flexion and extension strength in previously inactive individuals. The present study demonstrates that the use of body weight as a resistance under unstable conditions can provide significant improvements in knee proprioception (for as long as 9 months after training) and trunk strength for the untrained population that should contribute to general health and functionality.

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Key points

- Although traditional free weight resistance exercises have been recommended as most beneficial for improving strength and power in athletes (Behm et al., 2010b), an IT program using Swiss balls and body weight as a resistance may provide an alternative starting point for the sedentary untrained population.
- As it is well documented that force or strength is decreased when unbalanced (Behm et al., 2010b) and balance-training programs improve balance (Behm and Kean 2006), this type of instability RT program can provide significant adaptations to improve trunk strength especially with the untrained.
- This type of training should also be incorporated into a new program as the improvements in joint proprioception may help protect from joint injuries over a protracted period.
- The finding that improved joint proprioception persists for months after training should be emphasized to those individuals whose training is regularly or inconsistently interrupted.

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