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The Effect of Short-Term Swiss Ball Training on Core Stability and Running Economy

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Abstract. Stanton, R., P. Reaburn, and B. Humphries. The effect of short-term Swiss ball training on core stability and running economy. *J. Strength Cond. Res. 18(3):522–528. 2004.*—The purpose of this study was to investigate the effect of a short-term Swiss ball training on core stability and running economy. Eighteen young male athletes (15.5 ± 1.4 years; 62.5 ± 4.7 kg; Σ9 skinfolds 78.9 ± 28.2 mm; $\dot{V}O_{2max}$ 55.3 ± 5.7 ml·kg^{-1}·min^{-1}) were divided into a control ($n = 10$) and experimental ($n = 8$) groups. Athletes were assessed before and after the training program for stature, body mass, core stability, electromyographic activity of the abdominal and back muscles, treadmill $\dot{V}O_{2max}$, running economy, and running posture. The experimental group performed 2 Swiss ball training sessions per week for 6 weeks. Data analysis revealed a significant effect of Swiss ball training on core stability in the experimental group ($p < 0.05$). No significant differences were observed for myoelectric activity of the abdominal and back muscles, treadmill $\dot{V}O_{2max}$, running economy, or running posture in either group. It appears Swiss ball training may positively affect core stability without concomitant improvements in physical performance in young athletes. Specificity of exercise selection should be considered.

Key Words. stability ball, lumbopelvic stability, core strength, run performance

Introduction

Interest in core stability training and the use of Swiss balls has increased dramatically in recent times. Historically, the Greek philosopher Galen wrote that exercise with a ball "is able to give the most intense workout and the gentlest relaxation" (20). Since the late 1980s, education programs outlining the benefits of Swiss ball training have appeared in both the therapeutic and athletic conditioning sectors (7, 11). Proponents of Swiss ball training argue that such training enhances neuromuscular pathways, leading to greater strength, proprioception, and balance (7). Hence, Swiss balls are commonly used in both athletic therapy and conditioning settings (4).

Rutherford and Jones (17) suggest adaptations from Swiss ball training are likely to result in better coordination of synergistic and stabilizer muscles. However, while anecdotal evidence from training journals and the popular press suggests Swiss ball training is effective, there is little empirical data available to support the efficacy of Swiss ball training.

Initial scientific support for Swiss ball training was reported by Vera-Garcia and colleagues (21), who observed greater activation in both the rectus abdominis and external oblique muscles during abdominal curl-up exercises. The authors noted the importance of this finding in relation to specific phases of a lumbar rehabilitation program. Similar findings were reported by Purton and colleagues (16). More recently, Behm and colleagues (5) reported the effect of unstable conditions, as induced by sitting on a Swiss ball, on force production of the knee extensors. Data showed that unstable conditions lead to a reduced force output, reduced agonist muscle activation, and increased antagonist activity during knee extension. Furthermore, the degree of force reduction is exacerbated by greater instability, where the base of support is reduced. Based on these findings, the investigators suggested light to moderate degrees of instability may be more suitable where force production is to be maximized. In contrast, greater instability may be employed where the focus of training is greater balance.

While these earlier studies are of academic interest, from a practitioner perspective, few investigations have examined the effect of Swiss ball training on actual physical performance. Scibek and colleagues (18) investigated the effect of Swiss ball training on core stability and subsequent swim performance. Their results reported enhanced core stability, which did not transfer into improved swim times. Cusi and colleagues (9) used Swiss balls as an intervention to prevent low back and groin injuries in Rugby Union players and observed that players experienced fewer injuries following Swiss ball training. To date, no studies have investigated the use of Swiss balls as an adjunct to run training programs. However, core stability has been reported as essential for optimal run performance. For example, Barnes (3) discusses the use of various methods of strength training for runners. In particular, the author noted the importance of core strength development as the foundation for long-term dynamic muscular strength training and to maximize the propulsive forces developed by the power-producing legs. Furthermore, Barnes (3) described a number of errors in technique related to insufficient core strength and stability, such as excessive movement of the head, rounded shoulders, excessive arm swing, and increased lumbar lordosis. Given the purported benefits of enhanced core stability for runners, it is prudent to undertake a scientific investigation into the effect of Swiss ball training on running performance. Thus, the purpose of this study is to investigate the effect of Swiss ball training on core stability and running economy in an athletic population.

Methods

Experimental Approach to the Problem

Prior to the commencement of the study, each subject completed 2 familiarization sessions over 7 days to ensure they were comfortable with all study procedures and to minimize any learning effects. Each familiarization trial commenced with a general warm-up consisting of static stretches of the hip and lumbar region prior to instruction of methods of core stability testing, and a 5-minute run at seven km·h^{-1} on a Precor C954 treadmill (Precor, USA, Woodinville, WA) to acquaint each subject to the use of a motorized treadmill. Testing included anthropometric measures, clinical assessment of core stability (Sahrmann test), a Swiss ball prone stabilization core stability test (SBPSCST) and a run to volitional exhaustion on a motorized treadmill to determine $\dot{V}O_{2max}$.

Subjects

Twenty-two male athletes (15.5 ± 1.4 years; 62.5 ± 4.7 kg; Σ9 skinfolds 78.9 ± 28.2 mm; $\dot{V}O_{2max}$ 55.3 ± 5.7 ml·kg^{-1}·min^{-1}) were recruited from within a Basketball and Touch Football School of Excellence in Sport program at a local secondary school. Each subject was familiar with conventional resistance training methods but none had used Swiss balls prior to the study. All completed a Physical Activity Readiness Questionnaire and completed informed consent documents. Those under the age of 18 had informed consent documents countersigned by a parent or legal guardian. Ethical clearance was obtained from the Human Ethics Research Review Panel at Central Queensland University prior to commencement of the study.

Procedures

Anthropometric profiling was performed by an International Society for the Advancement of Kinanthropometry (ISAK) level 1 anthropometrist during the first familiarization session. Skinfolds were taken at the following 9 sites: tricep, subscapular, bicep, iliac crest, supraspinale, mid axilla, abdominal, front thigh, and medial calf using Harpenden skinfold calipers (John Bull Instruments, West Sussex, UK). Stretch stature was measured to the nearest 0.1 cm using a Blaydon stadiometer (Lugarno, New South Wales, Australia). Seated stature was measured with the subject seated on a 40-cm anthropometry box and taken to the nearest 0.1 cm using a Blaydon stadiometer (Lugarno, New South Wales, Australia). Body mass was measured to the nearest 0.01 kg using Wedderburn BWB-600 scales (Tanita Corporation, Tokyo, Japan). Girth measures were assessed to the nearest 0.1 cm using a Lufkin Executive steel tape (CooperTools, Apex, NC). All measures were performed in duplicate according to the methods described by Norton and Olds (13).

A clinical measure of core stability was obtained using the Sahrmann core stability test. The inflatable pad of a Stabilizer Pressure Biofeedback Unit (PBU) (Chattanooga Group, Inc., Hixson, TN) is placed in the natural lordotic curve, while the subject is lying supine, and is inflated to 40 mm Hg. The test consists of 5 levels, with each level increasing in difficulty as follows:

Level 1. From a crook lying position, abdominal presetting is performed. This entails the participant activating the abdominal musculature to brace the trunk in an isometric fashion without movement being produced (1). Once this is achieved, the subject slowly raises one leg to a position of 100° of hip flexion with comfortable knee flexion. The opposite leg is then brought to the same position in the same manner with a change of not more than 10 mm Hg in pressure on the PBU. This position was employed as the start position for subsequent levels of the test protocol. The pressure on the PBU was noted and a reading greater or less than 10 mm Hg above or below this baseline indicated lumbopelvic stability was lost at this level. If the subject could maintain control on the initial, but not the final movement, the subject was graded at 0.5 for that test level.

Level 2. From the start position, the subject slowly lowers one leg such that the heel contacts the ground. Then the leg is slid out to fully extend the knee, and then returned to the start position.

Level 3. From the start position, the subject slowly lowers one leg such that the heel reaches 12 cm above the ground. Then the leg is slid out to fully extend the knee and then returned to the start position.

Level 4. From the start position, the subject slowly lowers both legs such that the heels contact the ground. Then the legs are slid out to fully extend the knees and then returned to the start position.

Level 5. From the start position, the subject slowly lowers both legs such that the heels reach 12 cm above the ground. The legs are then slid out to fully extend the knees and then returned to the start position.

For the purpose of this study, in order to attain each new level of the Sahrmann test, the lumbar spine position had to be maintained as indicated by a change of no more than 10 mm Hg in pressure on the analogue dial of the PBU. Pilot data prior to the commencement of this study reported a reliability coefficient of 0.95 with a TEM of 7.7% for this test.

Prior to the performance of the SBPSCST, subjects were marked using self-adhesive reflective markers identifying the following landmarks: (a) most lateral border of right acromion, (b) most lateral border of the right iliac crest, and (c) lateral epicondyle of the right femur, for identification of hip flexion angle during subsequent video analysis. The test was videotaped in the sagittal plane using a JVC GR DVC 9800 Digital Video Camera (JVC Corp., Tokyo, Japan) mounted on a rigid tripod. Frame rate was set at 50 Hz and the recorded media was later analyzed to determine the time to failure (seconds) by observing the change in hip flexion angle. Failure was defined as a deviation in hip flexion angle of greater than 10° from the hip angle observed at the commencement of the test.

Subjects were required to adopt a push-up position with the elbows locked and the toes placed on the vertical apex of a mediBall Pro Swiss Ball (AOK Health, Sydney, Australia). Ball size for the test was selected such that the subject was parallel to the ground at the commencement of the test. The participant was required to hold this position as stable as possible until failure to maintain position was observed during subsequent video analysis. Hip flexion angle was analyzed using Silicon Coach Pro Software, Version 6.0 (siliconCOACH, Dunedin, New Zealand) every 0.2 seconds for the duration of the test until a deviation of more than 10° from the angle determined at the commencement of the test was observed.

During the SBPSCST, surface electromyographic data (sEMG) were collected from the rectus abdominis (RA), external oblique (EO), and the erector spinae (ES) on the right side of each participant using self-adhesive Ag/AgCl electrodes (Red Dot No. 2258; 3M Medical-Surgical Division, St. Paul, NM) in a bipolar configuration with an interelectrode distance of 10 mm. Prior to electrode placement, cutaneous impedance was reduced by shaving to remove hair, abrading to remove the surface layer of cells, and wiping with an alcohol pad to ensure that all oils, debris, and salts were removed (8). Electrode placement and orientation for the sEMG were according to the methods described by Axler and McGill (2). Electrodes for the RA were placed 3 cm lateral to a point 5 cm superior to the umbilicus. Electrodes for the EO were placed 15 cm lateral to the umbilicus, and electrodes for the ES were placed 3 cm lateral to L3. Data were collected using an AMLAB computer system (Associate Measurement, Sydney, Australia). The signal was amplified by a gain of 1,000 and passed through an analogue-to-digital converter. Sampling rate was set at 1,000 Hz and filtered at 3 Hz (high pass) and 450 Hz (low pass). Raw data were subsequently processed using custom-written LabView (National Instruments, Austin, TX) software. The program required the manual entry of the time to failure to divide the number of data points into 10 segments, each representing 10% of the time to failure. Each segment was then analyzed to extract the median power frequency (MPF) using a fast Fourier transform with a Hanning window and zero padding.

The response of MPF to time was determined using simple linear regression according to the methods described by Sparto et al. (19),

$$\text{MPF} = \text{LS}\cdot\text{time} + \text{IMF},$$

where MPF is the median power frequency in Hz, LS is the linear slope in Hz/%total time, and IMF is the intercept (initial medial frequency). An R^2 value (correlation coefficient) of the linear regression is also reported.

Maximal aerobic power ($\dot{V}O_{2max}$) and running economy (RE) were determined before and after the 6-week Swiss ball training program using an incremental treadmill running test to volitional exhaustion on a Precor C954 motorized treadmill. Oxygen uptake was measured using a MedGraphics Gas Analysis System (MedGraphics, Parkway, MN). The gas analysis system was calibrated prior to each test with reference and calibration gases of known concentrations. The pneumotach was calibrated with ambient air using a 3-L syringe (MedGraphics, Parkway).

Following a 5-minute warm-up at 7 $km\cdot h^{-1}$, the treadmill protocol commenced at a running speed of eight $km\cdot h^{-1}$. The workload was increased by one $km\cdot h^{-1}$ every minute until volitional fatigue. The maximal oxygen uptake was considered the highest oxygen volume recorded during the last minute of exercise. Criteria for attainment of $\dot{V}O_{2max}$ included two of the following (10):

a. a plateau in $\dot{V}O_2$ despite an increase in workload,
b. an RER value $>$1.15,
c. volitional exhaustion,
d. attainment of age-predicted maximal heart rate (220 − age),
e. rating of perceived exertion $>$17.

The velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) was recorded for later analysis. Heart rate was monitored throughout the protocol via Polar Beat (Polar Electro, Kemple, Finland) telemetric heart-rate monitor and was recorded manually on data sheets.

Running economy ($ml\cdot kg^{-1}\cdot min^{-1}$) was calculated using linear regression. A graph of $\dot{V}O_2$ versus running speed was plotted and the regression equation for the line of best fit was used to calculate RE at 60, 70, 80, and 90% of $v\dot{V}O_{2max}$. Running economy was reported as the volume of oxygen consumed at 60, 70, 80, and 90% of $v\dot{V}O_{2max}$.

The treadmill run to volitional exhaustion was videotaped in the sagittal plane using a Sony DCR-TRV 6 digital video camera (Sony Corp., Tokyo, Japan) mounted on a rigid tripod filming at 25 Hz. The recorded media was later analyzed to determine trunk angle relative to the vertical using the previously described markers, at right foot strike during the last 10 seconds of each stage. Trunk angle relative to the vertical were analyzed using Silicon Coach Pro, Software Version 6.0, (siliconCOACH, Dunedin, New Zealand). Both mean trunk angle relative to vertical for the duration of the $\dot{V}O_{2max}$ test ($\theta\dot{V}O_{2max}$) and mean trunk angle relative to the vertical at $v\dot{V}O_{2max}$ ($\theta v\dot{V}O_{2max}$) are reported.

Following initial testing, the 22 subjects were assigned to either a control or experimental group. Groups were matched on core stability using the results of the initial Sahrmann clinical test of core stability. During the 6-week intervention period, both the control and the experimental groups continued to perform their normal physical training, which consisted of skills training and run-based conditioning, each performed twice per week. During this time, the experimental group performed additional physical training according to the following protocol.

The experimental group undertook 6 weeks of additional physical training using the Swiss ball. Each participant was provided with a Swiss ball, sized such that, when they were seated on the vertical apex of the ball, the thighs were slightly above horizontal. Each participant was provided with a training card (Table 1) outlining the number of sets and repetitions of each exercise to be performed and detailed instruction for each exercise. Training was performed twice per week at the School of Excellence gymnasium during normal training times. Each Swiss ball training session took approximately 25 minutes to complete and was supervised by the principal investigator to ensure compliance and to maintain optimal exercise technique.

Statistical Analyses

Statistical analyses comprised descriptive statistics to identify means and standard deviations for each variable of interest. A 2 (control, experimental) by 2 (pre, post) analysis of variance (ANOVA) with repeated measures was performed to determine the effect of training and time on each parameter measured. Where a main effect was observed, a least significant difference (LSD) post hoc contrast was conducted to identify the source of the difference.

Pearson's product moment correlations (R) were used to identify any relationship between Sahrmann scores, $\dot{V}O_{2max}$, $v\dot{V}O_{2max}$, $\theta\dot{V}O_{2max}$, and $\theta v\dot{V}O_{2max}$.

Statistical analysis was conducted using the Statistical Package for the Social Sciences (SPSS), V11.0. An alpha level of $p \leq 0.05$ was considered statistically significant for all analyses. Statistical power equations to determine a minimum study population at the $p \leq 0.05$ level with a power of 0.9 revealed a sample of 5 subjects was required.

Results

Prior to the commencement of the study, there were no statistically significant differences between the control and experimental groups for the Sahrmann score, height, seated height, body mass index (BMI), sum of skinfolds

TABLE 1. Swiss Ball training program.*

		Ultimate strength and conditioning											
		1		2		3		4		5		6	
	Week:	1	2	1	2	1	2	1	2	1	2	1	2
	Workout:	Sept.	Sept.	Sept.	Sept.	Sept.	Sept.	Sept.	Sept.	Oct.	Oct.	Oct.	Oct.
Exercise	Date:	4	6	11	13	18	20	25	27	2	4	9	11
Lunge (tick as completed)	Weight	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Sets	2	2	2	2	2	2	2	2	3	3	3	3
	Reps	8	8	8	8	10	10	10	10	8	8	8	8
	Tempo	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1
	Rest	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min
Supine lateral roll (tick as completed)	Weight	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Sets	2	2	2	2	2	2	2	2	3	3	3	3
	Reps	8	8	8	8	10	10	10	10	8	8	8	8
	Tempo	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1
	Rest	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min
Alternating superman (tick as completed)	Weight	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Sets	2	2	2	2	2	2	2	2	3	3	3	3
	Reps	8	8	8	8	10	10	10	10	8	8	8	8
	Tempo	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1
	Rest	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min
Forward roll on knees (tick as completed)	Weight	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Sets	2	2	2	2	2	2	2	2	3	3	3	3
	Reps	8	8	8	8	10	10	10	10	8	8	8	8
	Tempo	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1
	Rest	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min
Supine 2 leg bridge (tick as completed)	Weight	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Sets	2	2	2	2	2	2	2	2	3	3	3	3
	Reps	8	8	8	8	10	10	10	10	8	8	8	8
	Tempo	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1
	Rest	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min
Supine Russian twist (tick as completed)	Weight	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Sets	2	2	2	2	2	2	2	2	3	3	3	3
	Reps	8	8	8	8	10	10	10	10	8	8	8	8
	Tempo	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1	1/1/1
	Rest	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min

* Sept. = September; Oct. = October

TABLE 2. Descriptive statistics (mean ± *SD*) for control and experimental groups prior to 6 wk of Swiss Ball training.*

Group	Control (n = 11)	Experimental (n = 11)
Age (y)	15.5 ± 1.5	15.6 ± 1.3
SSF_9 (mm)	74.2 ± 20.6	83.5 ± 36.1
BMI (kg/m²)	21.0 ± 2.3	20.9 ± 2.2

* SSF_9 = sum of 9 skinfolds; BMI = body mass index.

(SSF), or $\dot{V}O_{2max}$. Descriptive statistics for the control and experimental groups are shown in Table 2.

Due to circumstances not related to the study (nonadherence to training), 4 subjects, 1 from the control group and 3 from the experimental group, did not complete the study. Therefore, the final data were collected on 18 subjects. Statistical analyses revealed no significant difference, for any descriptive measure (age, mass, stature, seated stature, SSF_9, BMI, or Sahrmann test) between those who completed the study and those who withdrew. Data for these withdrawn subjects were excluded from further analysis; thus, final data analysis was conducted on 8 experimental and 10 control subjects. Based on the power calculated above and the nonadherence of subjects to the study, the remaining 8 experimental and 10 control subjects provided sufficient power for the study.

Analysis of the experimental group data showed that, of the 8 remaining experimental subjects, 6 completed all 12 training sessions, 1 completed 10 training sessions, and 1 completed 8 training sessions within the required time frame for the study. Thus, across all experimental group subjects, 11.3 ± 1.5 training sessions were completed out of 12. Compliance was calculated as the percentage training sessions completed divided by the number of training sessions required to be completed, multiplied by 100%. Data revealed a compliance rate of 93.8%.

The pre- and postanthropometric data for control and experimental groups are shown in Table 3. Repeated measures ANOVA yielded no statistically significant effect of group or time for stature or seated stature. However, repeated measures ANOVA revealed a statistically significant effect of group and time for body mass ($p < 0.05$).

Figure 1 shows the results of the Sahrmann test of core stability for the control and experimental groups before and after 6 weeks of Swiss ball training. Repeated measures ANOVA yielded a statistically significant ($p < 0.05$) result for test and test × group. Post hoc LSD contrasts revealed no statistically significant within-group difference for the control group nor between group differences pretraining. A statistically significant within-group difference was observed pre/post for the experimental group ($p < 0.05$). Furthermore, a statistically significant between-group difference was observed following training ($p < 0.05$).

Figure 2 shows the results of the time to failure on the

TABLE 3. Anthropometric data for the control and experimental groups before and after 6 wk of Swiss Ball training.

	Control		Experimental	
	Pre	Post	Pre	Post
Body mass (kg)	66.0 ± 9.9*	67.6 ± 10.1†	58.0 ± 3.7	57.4 ± 3.4
Stature (cm)	176.2 ± 13.7	176.2 ± 14.0	170.0 ± 7.2	170.5 ± 7.1
Seated stature (cm)	91.3 ± 5.0	91.1 ± 4.5	87.5 ± 3.9	87.3 ± 3.9

* Result significantly different from experimental group pretraining ($p < 0.05$).
† Result significantly different from experimental group posttraining and significantly different from control group pretraining result ($p < 0.05$).

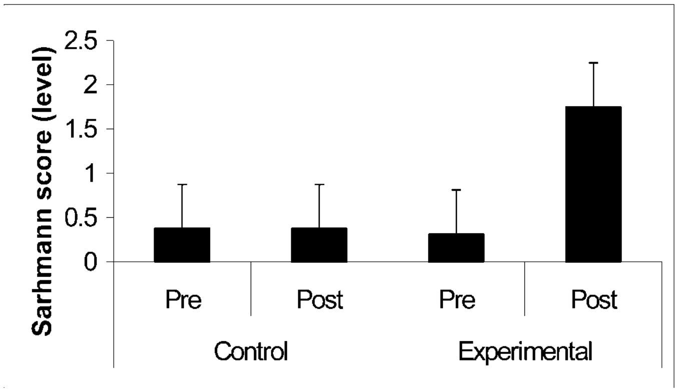

FIGURE 1. Sahrmann test of core stability data for the control and experimental groups before and after 6 weeks of Swiss ball training (* = result significantly different from control group posttraining result [$p < 0.05$]; # = result significantly different from experimental group pretraining result [$p < 0.05$]).

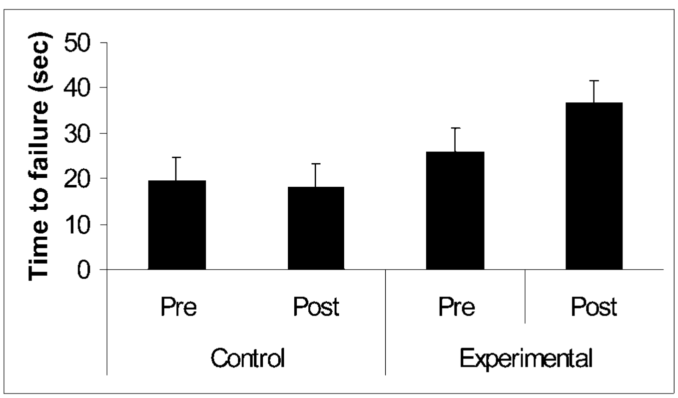

FIGURE 2. Swiss ball prone stabilization core stability test data for the control and experimental groups before and after 6 weeks of Swiss ball training (* = result significantly different from control group posttraining result [$p < 0.05$]; # = result significantly different from experimental group pretraining result [$p < 0.05$]).

SBPSCST. Repeated measures ANOVA revealed a statistically significant group × time interaction. Post hoc tests revealed a statistically significant within-group difference pre/post for the experimental group ($p < 0.05$). Furthermore, a statistically significant between-group difference was observed following training ($p < 0.05$).

Repeated measures ANOVA of the spectral analysis of the sEMG data from the RA, EO, and ES revealed no statistically significant main effect of time or group for LS, R^2, or IMF. Pearson's product moment correlations revealed no statistically significant relationships between spectral data and Sahrmann scores.

Repeated measures ANOVA revealed no statistically significant main effect of group or time for $\dot{V}O_{2max}$ or $v\dot{V}O_{2max}$.

Repeated measures ANOVA also revealed statistically significant differences between $\dot{V}O_2$ at each running velocity (60, 70, 80, 90; $v\dot{V}O_2$max). However, no statistically significant main effect of group or time was observed for $\dot{V}O_2$ at any running velocity.

Repeated measures ANOVA revealed no statistically significant main effect of group or time for either $\theta\dot{V}O_{2max}$ or $\theta v\dot{V}O_{2max}$. Pearson's product moment correlations revealed that no statistically significant correlation existed between $\theta\dot{V}O_{2max}$ and Sahrmann score, $\dot{V}O_{2max}$, $v\dot{V}O_{2max}$, or RE at any speed nor between $\theta v\dot{V}O_{2max}$ and Sahrmann score, $\dot{V}O_{2max}$, $v\dot{V}O_{2max}$, or RE at any speed.

DISCUSSION

The purpose of the present study was to examine the effect of a 6-week Swiss ball training program on core stability and running economy in an athletic population. The present data suggest that 6 weeks of Swiss ball training significantly improves core stability as measured by the Sahrmann test and significantly improves time to failure in the SBPSCST. However, these improvements in core stability occur in the absence of significant alterations in the electromyographic fatigue status of the RA, EO, or ES. Furthermore, despite these significant improvements in core stability, running performance, as measured by $\dot{V}O_{2max}$, $v\dot{V}O_{2max}$, or RE at speeds of 60, 70, 80, or 90% $v\dot{V}O_{2max}$, show no statistically significant changes following 6 weeks of Swiss ball training. Finally, no statistically significant changes in running posture are observed following 6 weeks of Swiss ball training. However, the results of this study may only be applicable to the population under investigation.

To our knowledge, this is the first empirical study to examine the effects of Swiss ball training on physical performance, as measured by running economy, in an athletic population. While Swiss balls remain a popular adjunct to training for many athletes and anecdotal evidence supports their widespread use, the results of the present study do not support current anecdotal evidence. Thus, more research is warranted to investigate the mechanisms and protocols for Swiss ball use. In addition, while a wealth of anecdotal evidence supports the use of Swiss ball training to enhance physical performance, this has not been substantiated by valid scientific investigation.

There exists an infinite set of exercises that may be performed on the Swiss ball. The difficulty of these exercises may be modified by altering lever length, base of support, or load distribution. In addition, other resistance modalities may be used in conjunction with the Swiss ball, including barbells and dumbbells, resistance bands, or cable devices. These options make the appropriate selection of exercises based on specific adaptations required to enhance physical performance somewhat difficult. Nonetheless, the prolific use of Swiss balls in physical therapy and athletic preparation warrants further investigation to validate their use in physical training programs.

The present study has produced a number of findings of interest. First, the control group demonstrated a statistically significant increase in body mass over the course of the intervention period. However, given the age of the subjects, this is likely a function of normal growth and maturity. Second, data from the present study support the notion that Swiss ball training improves core stability as determined by both the Sahrmann test and the SBPSCST. Scibek and colleagues (18) reported statistically significant improvements in core stability in college-aged swimmers following a similar training intervention to the one employed in this study. The former study employed a more aggressive measure of core stability. The investigators used a modified supine supported position, where the subjects' head and shoulders were supported on a Swiss ball placed on a force plate and the feet were placed on a stabilization trainer, thus giving two unstable bases of support. Despite this, the findings of the former and current studies yielded statistically significant improvements in core stability. This may reflect the concept that Swiss ball training improves core stability irrespective of the measure used. While no reliability data were reported for the duel unstable base test used by Scibek and colleagues, it appears that either test may be a useful measure of core stability to monitor adaptations to Swiss ball training.

To date, no published study has investigated the effect of Swiss ball training on electromyographic muscular fatigue parameters. In the present study, no statistically significant differences in IMF or LS were observed in the experimental group following 6 weeks of Swiss ball training. Purton and coworkers (16) reported that the crunch exercise performed on the Swiss ball elicits a greater electromyographic response in the external obliques when compared with an Ab-Roller crunch. Thus, it could be hypothesized that Swiss ball training may lead to improved recruitment of the core musculature. Indeed, proponents of Swiss ball training have argued adaptations resulting from this type of training occur primarily in the nervous system (6, 15). However, the present data suggest no increase in IMF of the RA, EO, or ES following 6 weeks of Swiss ball training. Despite this, results from the present study suggest that neural adaptations in other muscles, such as the pectorals or latissimus dorsi, may have occurred. Further research is required to confirm this. An increased time to failure on the SBPSSCST was observed for the experimental group, suggesting a slowing or decline in the rate of fatigue because a delay in fatigue occurred with no concomitant change in electromyographic fatigue parameters of the muscles under investigation, perhaps as a result of more efficient load sharing within and between core muscles. Alternatively, increased contractility of the muscles used to stabilize the body in this position may require the recruitment of fewer motor units. Further research is required to explore these hypotheses.

Data from the present study support the earlier work of Scibek and colleagues (18), who reported no improvement in physical performance as measured by swim times following 6 weeks of Swiss ball training. It is possible that the addition of Swiss ball training to an existing training schedule may induce additional fatigue. However, it is unlikely that the low volume of additional training used in the current study would impact on endurance-training performance as measured in the present study.

The addition of resistance or strength training has typically shown an improvement in run performance by improving running economy (12, 14). It is possible that the explosive or high-intensity strength training methods employed in these previous studies preferentially stimulated the fast-twitch muscle fibers. In contrast, the Swiss ball training used in the present study, with its slow, controlled movements, may target predominately slow-twitch postural muscles. Therefore, Swiss ball training may not elicit the same performance advantage compared with explosive or high-intensity strength training.

The present study observed no significant change in $\theta\dot{V}O_{2max}$ nor $\theta v\dot{V}O_{2max}$ following 6 weeks of Swiss ball training. Williams and Cavanagh (22) report that the most economical runners have trunk flexion angles of approximately 5.9° with less economical runners having a lesser trunk flexion angle. Athletes in the present study report trunk flexion angles of between 9.12 ± 4.79° and 10.40 ± 5.42° during the run to volitional exhaustion. This may reflect the difference in training ages of the athletes in the 2 studies or the variation in running styles. No correlation between trunk angle and running economy at any speed was observed in the present investigation.

The failure to observe an improvement in the physical performance of the experimental group, as measured by running economy, may reflect the current training status of the athletes, the exercise selection, or the loading parameters. It is possible that, for moderately trained athletes such as those engaged in the current study, the nature of their existing training elicits a training effect on the core musculature that is optimal for the athletes' current level of physical performance. However, this is unlikely because no correlation between core stability and any measure of physical performance was observed.

It is possible that the Swiss ball exercises utilized in this study fail to induce specific adaptation required to enhance run performance. The principle of specificity should reflect position specificity, timing, and functional specificity. Therefore, the selection of Swiss ball exercises that recruit the core musculature in the manner required for running may have elicited specific adaptation, leading to enhanced run performance, e.g., exercises performed in a unilateral, single-leg support, standing position, where the arms are held in a manner similar to running. Further research investigating the recruitment patterns of Swiss ball exercises is required to support this suggestion.

Finally, the loading parameters employed for the Swiss ball training program used in the present study may not reflect that required for improving core muscular function. The overload based on the number of sets and repetitions performed in the present and previous abdominal training studies may be too few to elicit a significant training effect on the ability to stabilize the body during running. A shift to a time-based exercise performance or much higher repetition range than currently used may be required to enhance the performance of low-force, repeated quasi-isometric contractions of the core musculature during running. Further research is required to investigate this suggestion.

In summary, the results of this study suggest that 6 weeks of Swiss ball training improves core stability without concomitant changes in electromyographic fatigue parameters of the RA, EO, and ES muscles. Furthermore, 6 weeks of Swiss ball training do not improve run performance as measured by $\dot{V}O_{2max}$ or running economy at submaximal speeds, nor posture during treadmill running to volitional exhaustion.

Practical Applications

Data from the current study suggest that, while Swiss ball training may positively affect core stability, physical performance as defined by $\dot{V}O_{2max}$, $v\dot{V}O_{2max}$, or running economy, is not enhanced. Furthermore, muscle fatigue as detected by sEMG appears unaffected by 6 weeks of Swiss ball training. However, it should be understood that the findings of this study may only be applicable to the population under investigation. Furthermore, while the findings of this study may contradict the current thoughts and practices of strength and conditioning professionals, coaches, and athletes, it does not necessarily discourage the use of Swiss balls because evidence from this and previous investigations demonstrate that core stability is improved by the inclusion of Swiss ball training into an existing training program (18). Thus, the use of Swiss balls in therapeutic or rehabilitation programs may be warranted. To date, their contribution to enhanced physical performance remains unanswered and future studies should investigate the manipulation of program variables and exercise selection.

In light of the findings of this study, the use of Swiss ball training either alone or as an adjunct to other physical training to enhance core stability appears promising. However, whether gains in core stability achieved through such training are converted to enhanced physical performance remains to be demonstrated. Further research is required to determine the effectiveness of Swiss ball training for the enhancement of physical performance.

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