Core Stability Exercises On and Off a Swiss Ball

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Objectives: To assess lumbopelvic muscle activity during different core stability exercises on and off a Swiss ball.

Design: Prospective comparison study.

Setting: Research laboratory.

Participants: Eight healthy volunteers from a university population.

Intervention: Subjects performed 4 exercises on and off a Swiss ball: inclined press-up, upper body roll-out, single-leg hold, and quadruped exercise.

Main Outcome Measures: Surface electromyography from selected lumbopelvic muscles, normalized to maximum voluntary isometric contraction, and median frequency analysis of electromyography power spectrum. Visual analog scale for perception of task difficulty.

Results: There was a significant increase in the activation of the rectus abdominus with performance of the single-leg hold and at the top of the press-up on the Swiss ball. This led to changes in the relation between the activation levels of the lumbopelvic muscles measured.

Conclusions: Although there was evidence to suggest that the Swiss ball provides a training stimulus for the rectus abdominus, the relevance of this change to core stability training requires further research because the focus of stabilization training is on minimizing rectus abdominus activity. Further support has also been provided about the quality of the quadruped exercise for core stability.

Key Words: Abdominal muscles; Electromyography; Exercise; Rehabilitation.

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The Swiss Ball (or gym ball) is widely reported in the recreational training environment to be a training device for core stability exercises.1 However, there is little scientific evidence to support its use.2,3 It is also not clear whether performing an exercise on a Swiss ball has greater benefit than performing the same exercise on a stable surface.

The term core stability is a generic description for the training of the abdominal and lumbopelvic region. To define core stability, the combination of a global and local stability system has been used. The global stability system refers to the larger, superficial muscles around the abdominal and lumbar region, such as the rectus abdominus, paraspinals, and external obliques.4,5 These muscles are the prime movers for trunk or hip flexion, extension, and rotation. Local stability refers to the deep, intrinsic muscles of the abdominal wall, such as the transverse abdominus and multifidus. These muscles are associated with the segmental stability of the lumbar spine during gross whole body movements and where postural adjustments are required.4,6-8

The validity of both the concept of core stability and the optimal training protocols for core stability requires investigation. For example, an exercise such as abdominal hollowing (eg, the drawing-in technique) attempts to emphasize local over global stability.9,10 For long-term core stability exercise programs, this type of exercise neglects the synergistic relation between the muscles of the global and local stability systems. For any movement task that involves the trunk region, it would be wrong to believe that only 1 specific muscle system is actively involved. It is known that 1 muscle cannot be identified as being more important for lumbar stability than another.11 A more appropriate approach to core stability training is to find exercises that incorporate the synergistic relation between the global and local stability systems, but still elicit a satisfactory training effect.

Our purpose in this study was to compare the activation patterns of muscles associated with the global and local stability systems during different core stability tasks on and off a Swiss ball. The exercises did not involve prime movement tasks for the trunk region but permitted us to investigate the synergistic relation between muscles when the overall stability of the lumbopelvic region is challenged by the weight force of the body segments. The hypotheses of this study were (1) the exercises performed on the Swiss ball would have greater levels of muscle activation compared with the stable surface, and (2) the synergistic relationship between the ventrolateral abdominals and erector spinae expressed relative to the activity of the rectus abdominus would not be influenced by the exercise surface.

METHODS

Participants

Eight healthy subjects (4 men, 4 women) from our university volunteered for this study. The mean anthropometric characteristics ± standard deviation (SD) of the men were age, 23.5±2.65y; height, 1.85±.04m; and weight, 81.5±3.42kg; for the women, they were age, 23.5±2.65y; height, 1.64±.07m; and weight, 61.5±2.89kg. No subject was experiencing pain in his/her body when tested, and no subject had experienced a significant episode of low back pain (LBP) within the last 5 years. Informed written consent was received from the subjects before their participation. This study was approved by the Auckland Human Subjects Research Ethics Committee.

Data Recording

All testing was performed in the somatosensory physiology laboratory at the University of Auckland. Skin impedance to the electric signal was reduced to below 5kΩ by (1) shaving excess body hair if necessary, (2) gently abrading the skin with fine grade sandpaper, and (3) wiping the skin with isopropyl alcohol swabs. If the measured impedance was greater than
5kΩ, the surface electrodes were removed and the skin preparation was repeated.

Pairs of electrodes (3M Red Dot, Ag/AgCl electrodes) with a contact diameter of 2cm and a center-to-center distance of 3cm were applied to the following locations on the right side of the body only: the rectus abdominus, 3cm lateral and superior to the umbilicus, arranged along the longitudinal axis; the external obliques, the first electrode was placed at the intersection of a line lateral to the umbilicus and superior to the anterior superior iliac spine (ASIS), with the second electrode arranged so that the bipolar configuration was approximately 45° to the horizontal; the transversus abdominus and internal obliques, approximately 2cm inferior and medial to the ASIS (the muscle fibers of the transversus abdominus and internal obliques are blended at this site, so a distinction between the muscle signals cannot be made in this location); and the erector spinae, located at the level of L4-5, approximately 3cm lateral to the spinous process and arranged along the longitudinal axis. The reference electrode was placed over the superior aspect of the left iliac crest.

**Exercise Procedures**

**Upper-body roll out.** In the prone roll out position, the subject lay with the lower leg and feet only in contact with the surface of the ball (fig 1). The hands were positioned directly underneath the shoulders, with the fingers facing forward. The surface test height (55cm or 65cm) was chosen so that the angle of the shoulder joint and the trunk was approximately 90° (as manually measured with a flexible goniometer). The same surface height was used for both test conditions.

**Inclined press-up.** The top and bottom positions of an inclined press-up on a 65-cm high surface were recorded. The top position was the initial starting point, with the hands placed on the surface directly beneath the shoulder joint, with arms fully extended, and the trunk positioned as far back as possible so that upper-body position could be maintained (fig 1). The position of each subject’s feet was marked and held consistent during all press-up trials. The bottom of the press-up was recorded after the subject had flexed the elbow joint to approximately 90°, lowering the trunk toward the ball but without making contact. The bottom of the press-up was moved into immediately after the collection period from the top of the press-up.

**Contralateral single-leg hold.** The subject lay on a 65-cm high surface with the sacroiliac joint being the most distal part of the trunk supported. The right foot was positioned flat on the floor throughout this task. The left leg was manually assisted to approximately 90° of hip and knee flexion. From this position, the subject was instructed to extend the knee, then extend the hip until the thigh was parallel to the prone trunk position. This position was the isometric test position for this exercise (fig 1).

**Quadruped exercise.** This isometric task was performed in a 2-point stance with a contralateral arm and leg raise (fig 1). The subject was initially positioned in a 4-point stance with knees and hands on the floor (hips flexed to 90° and hands beneath shoulder joint). On a verbal command, the subject flexed the arm and extended the contralateral hip until both upper- and lower-body segments were parallel to the trunk. This position was then held for the 4-second contraction. The command for the alternate limbs to move was given after a
were recorded. Three trials were performed for each movement combination. For the unstable condition, a Swiss ball was placed beneath the subject’s abdomen so that there was contact between the torso and a labile surface. Either a 55- or 65-cm Swiss ball was used, depending on the initial height of the subject in the 4-point stance, to ensure that the trunk position was consistent in comparison with the stable condition.

All test positions were held isometrically for 4 seconds, with the final 3 seconds providing the data to be analyzed. The tasks were always administered in a randomized order. For all tasks, 3 repetitions were performed with a 1-minute rest between each trial. All subjects were familiarized with the tasks before data were recorded.

Data Analysis

All data signals were recorded via a MACLAB® interface unit connected to a Pentium II computer at a sampling frequency of 2000Hz with 16-bit analog-to-digital conversion, a common mode rejection ratio of greater than 96dB at 50Hz, and an input impedance of 100MΩ. The data was digitally filtered (20—500Hz), and the root mean square (RMS) was calculated for the 3 seconds collected for each muscle signal.

The mean RMS activity over the 3 seconds was expressed as a percentage of a maximum voluntary contraction (MVC) performed for each muscle signal before the experiment. The maximum trunk flexor activation (rectus abdominus) was performed by a resisted sit-up task, while resisted trunk rotation (external obliques) and extension tasks (erector spinae) were also performed. The abdominal hollowing task was specifically performed for the transversus abdominus–internal obliques. The abdominal hollowing task was specifically performed by a resisted sit-up task, while resisted trunk rotation (external obliques) and extension tasks (erector spinae) were also performed. The abdominal hollowing task was specifically performed for the transversus abdominus–internal obliques site, although the maximum activation obtained from either this contraction or the resisted rotation was used to define the MVC for this signal. Two trials were performed for each MVC task, with 2 minutes rest allowed between each trial. The average of the 2 trials provided the value for normalization.

Frequency Spectrum

The median frequency (MF) of the electromyographic power spectrum was calculated for each muscle signal for each trial with a fast Fourier transform (FFT; 512-point Hamming window). The MF was calculated as the point where the area of the FFT-derived spectrum was halved.

RESULTS

Table 1 shows the reliability data among the 3 trials for each test position. The ICC represents the relative variability between trials, and the standard error of the mean the absolute variability. All tasks and positions had strong ICC reliability between trials, apart from 2 tasks for the rectus abdominus (unstable roll-out; stable press-up bottom position).
Electromyographic Amplitude Comparison Between Surfaces and Tasks

Table 2 shows the RMS amplitude results expressed as a percentage of MVC. For the transversus abdominus and internal obliques, the activation at the top of the press-up on the unstable surface had the greatest activation. This activity differed significantly from the same position on the stable surface (P<.05). For comparison of the tasks for the transversus abdominus and internal obliques on the Swiss ball, the activity at the top of the press-up was significantly greater than the activity for the transversus abdominus and internal obliques for both positions in the quadupled exercise (P<.05). There were no differences between the tasks for the activity of the transversus abdominus and internal obliques on the stable surface.

For the activity of the rectus abdominus, there were significant differences between the surfaces for both the press-up top position and the single-leg hold, with the higher activity recorded on the unstable surface (P<.05). The activity of the rectus abdominus during the aforementioned unstable surface tasks was significantly greater than the activity for the rectus abdominus in any of the other test positions (P<.05). There were no differences between the tasks on the stable surface for rectus abdominus activation.

There were no differences between the surfaces for the activity of the external obliques and erector spinae during any task. There were no significant differences between the tasks for the external obliques activity. For the erector spinae, the activity recorded during the quadupled exercise with left arm and right leg raise differed significantly from the activity measured during all other tasks (P<.05). The activity during the right arm/left leg quadupled exercise was significantly different from the remaining tasks also (P<.05). This pattern was consistent for both test surface conditions.

Task Difficulty

The unstable press-up was rated as the most difficult task performed in this experiment (82.75±4.43), and this rating differed significantly from the rating of the press-up performed on the stable surface (51.13±16.98, P<.05) (fig 2). The only other exercise that showed a difference between the surfaces was the roll-out task, with the unstable surface being rated as the more difficult task to perform (unstable, 43.88±9.26; stable, 31.75±9.47; P<.05).

Ratio of Muscle Activity Compared With the Rectus Abdominus

The ratio of the transversus abdominus and internal obliques to the rectus abdominus activity did not change between the surfaces for any of the tasks (fig 3). The ratio of activity of the external obliques compared with the rectus abdominus changed between the test surfaces for the press-up at the top position (stable, 5.58±1.6; unstable, 1.87±0.6; P<.05) and for the single-leg hold (stable, 3.34±1.15; unstable, 1.61±0.90; P<.05). The ratio of activity between the external obliques and rectus abdominus was significantly lower on the unstable surface for these tasks, indicating a greater relative activity level of the rectus abdominus. In the erector spinae–rectus abdominus comparison, there was reduced relative activity of the erector spinae compared with the rectus abdominus on the unstable surface for the top of the press-up position (stable, 1.48±0.4; unstable, 0.37±0.14; P<.05) and for the single-leg hold (stable, 1.16±0.36; unstable, 0.44±0.27; P<.05).

MF Analysis

The significant results from the MF analysis of the power spectrum are presented in table 3. There were no other significant differences between tasks or surfaces for any muscle or
between the first and third trials to indicate that there was no fatigue influence on the results of this experiment. There was a significant decrease in the MF for the rectus abdominus from the unstable press-up at the top compared with the unstable press-up bottom position ($P<.05$). The MF also differed significantly for the 2 different movements performed for the quadruped exercise for the signal obtained from the erector spinae. The left arm and right leg MF for both test surface conditions were significantly higher as compared with the right arm and left leg ($P<.05$).

**DISCUSSION**

In this study, we compared the activation levels of muscles of the lumbopelvic region during the performance of tasks on and off a Swiss ball. We also examined the relation between the external obliques, transversus abdominus and internal obliques, erector spinae, and rectus abdominus by comparing the relative activity levels. Our results provide evidence supporting our hypothesis that the performance of tasks on the Swiss ball would lead to greater activation levels when compared with the
stable surface. There was also evidence to suggest that specific exercises involve different synergistic relationships between the muscles and that the Swiss ball can directly influence those relationships. This suggests that there should be a variety of exercises for a core stability training program.

Surface Comparison

Exercising on the Swiss ball increased the activity for the rectus abdominus and transversus abdominus and internal obliques at the top of the press-up. There were no differences between the surfaces for either muscle at the bottom of the press-up. This suggests that the Swiss ball increased the perturbation to the trunk when the body’s center of mass (COM) was further away from the labile surface. However, in the rollout position, in which the COM is also away from the labile surface, there was no difference between the surfaces for muscle activity. This may be because of the greater contact area between subject and surface for the rollout, with the entire shank remaining in contact with the surface, compared with just the palms of the hands in contrast for the press-up. If the rollout position was held with only the feet in contact with the ball, the reduction in contact area may be enough to cause increases in muscle activity. Subjects rated both the rollout and press-up as being more physically difficult when performed on the unstable surface. This suggests that there are other muscles associated with the rollout (e.g., muscles of the shoulder girdle) that may have increased activity over that elicited on a stable surface. However, the only muscles of interest in this study were those of the lumbopelvic region that are associated with core stability.

The result of the MF analysis suggests that the difference in the rectus abdominus activation levels between the top and bottom positions of the unstable press-up may result from muscle fatigue. This is because of the lower MF in the bottom position compared with that at the top of the unstable press-up. A shift in MF toward the lower end of the frequency spectrum has been associated with neuromuscular and physiologic measures of fatigue such as decreases in pH and decreases in motor unit conduction velocity and firing rates.13,17 The greater perceived difficulty of the unstable press-up in comparison with the stable press-up may be attributed to the influence of muscular fatigue.

The activity of the rectus abdominus was also greater during the single-leg hold performed on the Swiss ball. This supports our previous research in which we investigated a double-leg hold that found increased rectus abdominus activity on the unstable surface (unpublished data, 54.9 ± 16.23; stable, 42.63 ± 14.37; unpublished data, 2003). The increased activation of the rectus abdominus could be attributed to the greater hip flexion torque required to maintain the static equilibrium of the body on the Swiss ball. The weight force of the leg causes torque about the hip that challenges the stability of the body, and this is counterbalanced by the activation of the hip flexors. An increase in hip flexor activation (rectus abdominus) is required to prevent the reactive movement of the ball to the weight force of the leg. From this it may be concluded that the Swiss ball causes instabillity when a body segment is away from the center of the ball sufficient to increase the activity of a prime mover associated with the task. The single-leg hold was used in this study to cause a reactive rotation of the ball about the longitudinal axis of the body that may have increased the activity of the ventral abdominals. Previous research found no difference between the surfaces for the activation of the ventral abdominals, because these muscles cannot produce a hip flexion or extension torque (unpublished data, 2003). In the present study, there was no change in activation of the oblique muscles with performance of the single-leg hold on the unstable surface. This indicates that the weight force of the single-leg hold was insufficient to elicit an increase in oblique activity on the Swiss ball.

Clinical Relevance

Previous research has emphasized in previous research that the motor control and rehabilitation training of the ventral abdominals is successfully achieved with exercises that minimize activation of the rectus abdominus.9,10,13,18 Activation of the ventral abdominals has been associated with sacroiliac joint laxity.19 Performance of the drawing-in technique has also been associated with the feed-forward activation of the transversus abdominus before rapid limb movement.17 It has been proposed that attempting to train lumbar stability by placing importance on 1 set or group of muscles is not viable. Research has shown that no single muscle can be identified as being more important for spinal stability than another during a range of trunk movement tasks.21 The exercises evaluated in this study provided no clear evidence for an obvious pattern of muscle recruitment associated with the performance of lumbar stabilization exercises.

The quadruped exercise with contralateral arm and leg raise replicated the pattern of activity suggested for appropriate motor control training of the ventral abdominals.9,23 The ratio of muscle activity expressed relative to the rectus abdominus was the highest for each muscle for this task. Research has shown that the quadruped exercise had the highest measured stability index as compared with several other core stability exercises.21 It has also been shown that the activity of the obliques is consistently greater than that of the rectus abdominus when extra resistance is added to the limbs for this task.22 Therefore, the quadruped exercise fulfills the requirement for a stabilization exercise with minimal rectus abdomi-
nus activity in comparison with other muscles of the lumbopelvic region. The abdominal drawing-in task and quadruped exercise may be an effective combination of exercises for training the local stability system. Use of the Swiss ball was insufficient to change the activity patterns associated with this task.

The activity level of the external obliques was unchanged regardless of the task or surface. This supports previous findings that external oblique activity is unaffected by the task performed. Muscle activity up to 30% of MVC is required for an aerobic training effect to be achieved for the abdominal muscles when the task is repeated. The activity level of the external obliques was approximately 40% for all tasks, suggesting that these exercises provide a training effect for this muscle that is not enhanced by use of a Swiss ball.

The main effect of the Swiss ball was to increase the activity of the rectus abdominus to greater than 30% of MVC at the top of the press-up and during the single-leg hold. This suggests that the Swiss ball is a sufficient stimulus to provide a training effect for the rectus abdominus. The relation of rectus abdominus activity to external oblique and erector spinae activity was influenced by this increase in activity, meaning that the synergistic relationship between these muscles has been altered. Our study found that the relative activity of the rectus abdominus increased in comparison with the external obliques and erector spinae on the unstable surface for the aforementioned tasks (see table 2, fig 3). As previously stated, Richardson et al. emphasize minimal activation of the rectus abdominus in comparison with other lumbopelvic muscles for stability exercises. If this is true, then an intervention that increases the activity of the rectus abdominus and changes the synergistic activation patterns between the muscles may not be appropriate as a lumbar stability exercise.

The quadruped exercise showed a difference in the MF between the opposite movement directions for the right erector spinae muscle signal, with the right leg and left arm being significantly higher than the opposite movement. The right leg and left arm movement also elicited a greater activation level for this muscle in comparison with the opposite side of the task. This difference was found for both test surface conditions. The MF difference may be attributed to the different muscle length of the erector spinae with the different movements. Previous research has found that when the erector spinae are lengthened, there is a decrease in the MF. The shortening of this muscle associated with the isometric hip extension of the right leg is probably why there is a difference between the opposite sides for the MF.

A strength of the methodology of this experiment is that the electromyography normalization procedures were done in a prone position similar to that used during the exercises. Therefore, the relative activity levels measured during the Swiss ball exercises reflects the maximal activity obtained in a similar position. A potential limitation of the normalization procedures we used is that they were based on MVC. It is recognized that for patients with LBP, the same exercise may lead to a greater relative activity level as a result of a distorted MVC. This can be dealt with in a rehabilitation setting by beginning with a lower number of repetitions of exercises that a patient can successfully perform and that elicit a greater relative intensity. The utility of the MVC, as used in this study, was to allow normalization of muscle activity levels for comparison between surfaces and to show that the exercises studied can provide an effective training stimulus.

CONCLUSIONS

The exercises presented here address issues regarding core stability training. The quadruped exercise replicates a pattern of activity deemed appropriate for training the local stability system, with minimal activity of the rectus abdominus as compared with other lumbopelvic muscles. In comparison, the Swiss ball increased rectus abdominus activity for the single-leg hold and at the top of the press-up. The unstable press-up was also deemed to be the most physically difficult task. A question to be addressed in future research is whether the increase in the rectus abdominus activity caused by the Swiss ball is beneficial or whether minimizing rectus abdominus activity is the priority for a core stability training program.

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