Original Research

Stability Ball Sitting versus Chair Sitting During Sub-maximal Arm Ergometry

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ABSTRACT

Int J Exerc Sci 5(1) : 16-25, 2012. It was predicted that sitting on a stability ball during arm ergometry would elevate cardiovascular parameters when compared to sitting on a chair and that this would be associated with greater recruitment of trunk and leg skeletal muscles. Methods: Open-circuit spirometry, videotaping, blood pressure, heart rate, and EMG were conducted during rest and four minute stages of 15 W, 30 W, and 45 W using a Monark arm ergometer. Twenty-six apparently healthy adults exercised twice, once sitting on a stability ball and the other sitting on a chair (order randomized), with 45 to 60 minutes of rest between. ANOVA for repeated measures and paired-t testing were used for analysis. Results: Oxygen consumption was significantly 10 to 16% higher during exercise while sitting on the stability ball. There were no significant differences between sitting modes for heart rate, SBP, and DBP. Also, resting and exercise rectus femoris and 45 W external oblique EMGs were significantly higher on the stability ball. Finally, the knee was significantly more extended with the feet farther apart and more forward on the stability ball. Conclusion: The stability ball significantly elevates oxygen consumption during sub-maximal arm cranking without significantly increasing heart rate or blood pressure and this is associated with increased thigh muscle activation and lower leg repositioning.

KEY WORDS: Aerobic arm exercise, electromyography, oxygen consumption, Swiss ball

INTRODUCTION

The stability ball is used in fitness and rehabilitation settings to improve muscular endurance, strength, and flexibility. In addition, attempts have been made to use the stability ball to replace chairs for the home or work place in an effort to improve low back problems. Studies have examined the stability ball's impact on electromyography (EMG) activity during muscular endurance exercises (4, 14, 20) and during sedentary sitting (10, 16, 17) but apparently none have been done with aerobic exercise. Also, the arm ergometer has been used in fitness and rehabilitation settings to improve upper body aerobic fitness (5, 6). Arm ergometry is typically done while sitting on a chair but could be done while sitting on a stability ball. The stability ball might increase core and leg muscle activity to stabilize the body during arm cranking and, in turn, elevate cardiovascular and oxygen uptake parameters.

Apparently no studies have evaluated the physiological responses to aerobic arm exercise while sitting on a stability ball. Therefore, the purpose of this study was to determine if sitting on a stability ball results in greater cardiorespiratory responses to aerobic arm ergometry when compared to sitting on a chair. In addition, we wanted to determine if sitting on a stability ball during exercise affects trunk and leg EMG activity and joint angles.

METHODS

Participants
Apparently healthy young adult participants were recruited from the university community following the University Institutional Review Board's approval. Criteria for participation included absence of cardiac, pulmonary, and metabolic disease, under the age of 40 years, be at least moderately active, and answer no to all questions on the Physical Activity Readiness Questionnaire (1) on the day of testing.

Protocol
Each participant came to the laboratory on two separate days, the second day within one week of the first. The first day began with obtaining written informed consent. Participants then determined which stability ball size to use and the positions of the ball, chair, and feet in relation to the arm ergometer with reference to what was most comfortable for them. Participants then practiced sitting on the ball, cranking at 50 revolutions per minute (rpm), and having their blood pressure (BP) taken. Finally, height and body mass were measured. On the second day participants were first prepared for testing. Each EMG site was vigorously rubbed with a 70% isopropyl alcohol pad then EMG electrodes were placed on the left side rectus femoris, erector spinae, rectus abdominis, and external oblique as described by Cram and Kasman (3). Inter-electrode distance was 2.5 cm and set parallel to muscle fiber alignment. A ground electrode was placed on the left humerus lateral epicondyle. Then for video recordings, bright orange markers (3 cm diameters) placed on black duct tape (4x4 cm) were pressed onto the right side joints, mid-axillary line half way between shoulder and hip, and first thoracic vertebra process (T1). Participants then underwent two arm ergometer tests: one on a chair (not using chair back support) and one on a stability ball. The two tests consisted of four minutes of pre-exercise rest, continuous four-minute stages of exercise at 15 W, 30 W, and 45 W (participant instructed to crank at 50 rpm) followed by a two minute active recovery period. A rest period of 45 minutes to 60 minutes occurred between the tests in which the participants read, did homework, etc. and ingested only water. During rest (pre-exercise), exercise, and recovery, oxygen consumption (VO_2) and heart rate (HR) were continuously monitored. In addition, one of the investigators noted the positions of the feet on the floor grid two minutes into each stage while the video recordings, pedaling rate, and EMG measurements were taken at minute three of each stage for 20 seconds. Also, left arm BP was measured during the last 30 seconds of each stage. Two different experienced technicians measured BP. Each participant was matched to the same

technician for both tests. Stopping of arm cranking to take BP probably underestimates exercising BP (11); therefore, during the exercise BP measurement power output was reduced by half while the participant maintained the 50 rpm with the right arm. Once the BP measurement was completed the participant used both hands again for cranking and the ergometer resistance was adjusted to the next stage. The order of sitting mode was randomized by the following: each odd numbered participant ID number had a coin tossed to determine starting sitting mode; the subsequent even numbered participant was assigned to the other sitting mode.

Equipment

A Monark 881(model 70500, Sweden) arm ergometer was used for exercise testing and calibrated with 2kg before each testing session. The ergometer had a whole number rpm display at eye level, thus a participant was successful at maintaining the pace between an actual rpm of 49.5 and 50.5. To record rpm a small flashlight was attached to the left arm crank and passed a solar cell when the crank was in the forward horizontal position. The voltage spike signal was captured by the BIOPAC system (see below). Participants had two stability balls to choose from: 75 cm diameter or 95 cm diameter (GoFit, L.L.C., Tulsa, OK). A standard classroom chair (44 cm seat height) was used for comparison to the stability ball. VO_2 was measured by open-circuit spirometry (model MAX-I, AEI Technologies, Napervile, IL). The MAX-I was calibrated using 4.00% CO_2, 16.00% O_2, and a three liter syringe before each exercise session. HR was detected by a Polar sensor (model Heart Minder, Polar Electro Oy, Kempelee, Findland) with the receiver connected to the MAX-I computer. Systolic (SBP) and diastolic (DBP) blood pressures were measured with an aneroid sphygmomanometer and a stethoscope (model UA-200, A&D Medical, Toronto, Canada). Ag/AgCl EMG surface electrodes (model T3404, Thought Technology Ltd., Montreal, Canada) were used to capture the EMG signal and amplified using the BIOPAC system (model MP100, Inc., Santa Barbara, California). The signal band width was set at 10 Hz to 500 Hz, the common mode rejection ratio was 110 dB, the gain set at 5000x, and sampling rate at 1,000/sec. Right side and back kinematic data were recorded using two camcorders (model 2R85, Cannon, Lake Success, NY) set at SP recording mode and placed 56.7 cm (right side) and 36.7 cm (back) from the ergometer with 20.0 cm x 20.0 cm scales placed near the mid sagittal and coronal planes. Both cameras had a plum line in view. In addition, a floor grid marked with yellow duct tape (every 1 dm in X and Y directions) was used to determine feet positions.

Analysis

The average VO_2 and HR from two and a half minutes to three minutes of rest and each stage of exercise were used to evaluate oxygen requirements and HR response. In addition, HR response was expressed relative to age predicted maximum HR (maxHR = 207 – 0.7*AGE) (8) to give an indication of the relative intensity of the exercise. EMG data were analyzed for the 20-second recording period. Root Mean Square (RMS) EMGs were calculated for each muscle contraction using the BIOPAC software and averaged. Since we only wanted to have an indication if muscle activity was greater on the stability ball and that all comparisons were within subject (and muscle), we did not index EMG values to maximal contraction levels. The average RMS values were used for statistical tests but the percent differences were also calculated: 100 $(RMS_{Ball} - RMS_{Chair}) / RMS_{Chair}$. Videos were displayed on a 26" x 19" television screen and the center of each orange marker was indicated on a transparency. Then lines were drawn for the joint angles and a protractor was used to measure the joint angles to the nearest tenth of a degree. Joint angles and T1 process positions were determined at four right arm crank positions (90° apart). The minimum, maximum, and difference (□ = maximum angle – minimum angle) angles for each joint and the largest lateral displacement for the T1 process over the four arm crank positions were determined at each stage of exercise. Distance between the feet was determined as the difference between floor grid X-axis readings while the floor grid Y-axis was used to determine forward or backward position changes for both feet. From the right side video, sitting height for both sitting modes during the 15W exercise was determined as the perpendicular distance between a horizontal line through the ergometer crank axle and the midpoint of the four crank positions marking the acromial process.

Statistical Analysis

A 2 (sitting mode) x 4 (activity level) and 2 (sitting mode) x 4(crank position) x 4 (power output) repeated measures ANOVAs were used with significance set at $P \leq 0.05$. If a significant main effect for sitting mode was found then paired *t*-tests with Holm's Sequential Bonferroni procedure (9) was used for follow-up analyses. A paired *t*-test was used to determine if there was a significant ($P < 0.05$) sitting height difference between sitting modes. SPSS version 11.5 was used for all statistical analysis. A pilot study indicated that η^2 would be about 0.2 for VO_2. Setting $\eta^2 = 0.2$, Power = 0.80, and $P < 0.05$, an n = 20 would be needed for a repeated measures ANOVA (23).

RESULTS

Table 1 contains the characteristics of the 26 participants recruited for this study. Three of the male participants found the 95 cm stability ball the most comfortable to use while all other males and all females found the 75 cm ball to be more comfortable.

Table 1. Participants' descriptive statistics.

	Females	Males
n	12	14
Age (yrs)	25±8	24±4
Body Mass (kg)	64.8±9.4	81.4±14.6
Stature (cm)	165.3±9.2	178.1±10.7

Mean±SD

Paired *t*-test demonstrated that the seat heights were not significantly different ($P = 0.81$) between the sitting modes (mean ± SD: Chair = 9.5 ± 3.6 cm, Ball = 9.3 ± 2.0 cm). In addition, the participants were able to maintain the 50 rpm for both sitting modes (rpm mean ± SD): Ball—50.6 ± 1.1, 50.4 ± 1.1, 50.3 ± 1.1 and Chair—50.3 ± 0.9, 50.1 ± 1.0, 50.5 ± 1.4, for 15 W, 30 W, and 45 W, respectively.

Table 2 reports the means ± SD for VO_2, HR, and BP during rest and the three stages of exercise for the two sitting modes. VO_2

Table 2. Oxygen consumption, Heart Rate, and Blood Pressure Responses

		VO_2 [1,3,4] mL*min^{-1}	HR [2,3,5] b*min^{-1}	SBP [2,3,5] mmHg	DBP [2,3,5] mmHg
REST	B	353 ±91 [a]	79 ±12	118 ±15	77 ±11
	C	332 ±64	79 ±14	118 ±11	79 ±12
15W	B	553 ±129[b]	89 ±13	123 ±17	80 ±9
	C	478 ±85	88 ±14	122 ±15	82 ±9
30W	B	729 ±127[b]	99 ±14	131 ±17	82 ±8
	C	644 ±100	98 ±16	127 ±13	81 ±10
45W	B	952 ±138[b]	114 ±18	136 ±18	85 ±8
	C	865 ±88	113 ±22	135 ±16	86 ±10

B: Sitting on Stability Ball, C: Sitting on Chair. Mean ± SD. **Repeated Measures ANOVA:** Sitting Mode [1]$P < 0.001$, [2]$P \geq 0.416$; Power Output [3]$P \leq 0.005$; Interaction [4]$P = 0.010$, [5]$P \geq 0.199$. **Paired *t*-test** B versus C: [a]$P = 0.085$, [b]$P<0.001$

Table 3. Percentage Ball EMG above Chair.

		Rectus Femoris	External Oblique	Rectus Abdominis	Erector Spinae
REST	%	532 ±163	17 ±20	2 ±6	9 ±14
15W	%	704 ±122	12 ±6	5 ±5	3 ±8
30W	%	799 ±142	26 ±8	11 ±7	4 ±9
45W	%	566 ±136	18 ±6	9 ±9	4 ±10

Mean ±SD

was significantly higher by 10% to 16% on the stability ball than on the chair for all three stages of exercise. However, HR and BP were not different between the two sitting modes. Participant HR averaged, as a percentage of age predicted maximum HR, 47%, 52%, and 60% on the stability ball and 46%, 52% and 59% on the chair for the 15 W, 30W, and 45W, respectively.

Examining muscle activation differences, repeated measures ANOVA found a significant sitting mode effect ($P< 0.001$) for the rectus femoris and external oblique ($P = 0.011$). Paired *t*-tests demonstrated that the stability ball was significantly higher than the chair for all stages ($P = 0.004$ for rest and $P < 0.001$ for three stages of exercise) in the rectus femoris and only at 45 W for the external oblique ($P = 0.011$). The rectus

Table 4. Right Hip and Knee Angles and Upper Back Lateral Displacement.

		MaxHip degree	Max Knee degree [1]	Δ Hip degree	Δ Knee degree	Back cm
15W	B	98 ±9	100 ±13[a]	6 ±4	1 ±2	2 ±1
	C	96 ±11	86 ±13	6 ±3	0 ±2	3 ±1
30W	B	98 ±10	103 ±15[a]	6 ±4	1 ±2	3 ±1
	C	98 ±10	85 ±12	7 +3	0 ±2	3 ±1
45W	B	99 ±10	103 ±16[a]	7 ±4	1 ±4	3 ±1
	C	97 ±10	86 ±12	7 ±5	0 ±2	4 ±1

B: Sitting on Stability Ball, C: Sitting on Chair. Mean ± SD. Δ = Maximum – Minimum angle.
[1] **Repeated Measures ANOVA:** Sitting mode effect $P<0.001$.[a]B versus C **Paired *t*-test:** $P< .001$

Table 5. Right Elbow and Shoulder Angles at Four Right Crank Positions

	15W		30W		45W	
	Ball	Chair	Ball	Chair	Ball	Chair
ELBOW[1]						
HD[2]	140 ±11	139 ±19	140 ±11	141 ±12	141 ±13	142 ±13
VI	114 ±12	115 ±12	114 ±12	113 ±12	114 ±10	113 ±15
HP	82 ±11	86 ±13	83 ±9	86 ±12	85 ±10	87 ±10
VS	108 +10	108 +13	107 +13	108 +16	112 +13	113 +13
SHOULDER[1]						
HD[2]	65 ±10	64 ±10	64 ±9	66 ±10	64 ±9	65 ±10
VI	38 ±8	37 ±14	36 ±10	36 ±11	35 ±8	36 ±11
HP	29 ±9	26 ±8	27 ±9	28 ±9	25 ±9	29 ±9
VS	56 ±8	55 ±10	55 ±8	58 ±10	56 ±8	58 ±11

[1] Degree Mean ± SD. [2] HD = Horizontal Distal, VI = Vertical Inferior, HP = Horizontal Proximal, VS = Vertical Superior.

abdominis and erector spinae EMGs did not have a significant main effect for sitting mode (P = 0.070, P = 0.799, respectively). Table 3 contains the percent difference between the stability ball and chair for left side trunk and leg EMGs.

Kinematic data are reported in Table 4 and Table 5. Table 4 contains the right knee, right hip, and the upper back lateral displacement results over the four right crank positions. For the back displacement we had technical problems with the camcorder that excluded 10 of the participants from this observation. The maximum knee angle over the four arm crank positions was found to be significantly higher for the ball than the chair for all stages of exercise. However, there were no significant repeated measures ANOVA main effects for sitting mode with the back lateral displacement (P = 0.527), maximum hip angle (P = 0.660), hip Δ angle (P = 0.565), and knee Δ angle (P = 0.428). Table 5 presents the right elbow and shoulder angles for the four different arm crank positions. Repeated measures ANOVA had non-significant main effects for sitting mode with the elbow (P = 0.663) and shoulder (P = 0.492).

In addition to the above video results, feet positions were examined by direct observations. Repeated measures ANOVA demonstrated significant sitting mode main effect for the distance between the feet ($P < 0.001$), right foot forward position ($P < 0.001$), and the left foot forward position (P = 0.002). Paired-t tests demonstrated that the feet were significantly ($P < 0.001$ for all conditions) farther apart by 1.3 dm to 1.5 dm, the right foot significantly ($P \leq 0.003$ for all conditions) more forward by 0.8 dm to 1.0 dm, and the left foot significantly ($P \leq 0.015$ for all conditions) more forward by 0.6 dm to 0.9 dm while sitting on the stability ball compared to chair sitting.

DISCUSSION

This is the first study to investigate the effects of sitting on a stability ball during sub-maximum arm ergometry on cardiorespiratory, EMG, and kinematic parameters. Sitting on the stability ball resulted in significantly higher VO_2 (10% to 16%) and rectus femoris EMG during exercise, with the feet being more forward and farther apart. The elevated exercise VO_2 while sitting on the stability ball was likely due, in part, to greater muscle recruitment, this is supported by the higher rectus femoris EMG. Factors that influence VO_2 during arm exercise include its greater inefficiency when compared to leg exercise (6, 12, 18). The addition of the stability ball appears to increase this inefficiency. Another influence is the proportion of arm to leg work with arm-plus-leg exercise. VO_2 is elevated at a given power output when arm supports a high proportion of the rate of work (21). The higher leg muscle activity observed with the stability ball during arm ergometry would probably still remain a smaller proportion of effort and, therefore, have VO_2 determined primarily by the arm work. Revolution rate can also influence arm cranking VO_2 (18) but participants in this study had a set rpm and consistently maintained the 50rpm for all exercise levels and for both sitting modes.

One interesting finding in this study was that despite VO_2 being 10% to 16% higher with stability ball sitting during exercise, HR was not significantly different. One factor affecting HR during exercise is limb involvement, HR is typically higher with aerobic arm exercise when compared to leg exercise at a given power output (7, 13, 22) while HR response to arm-plus-leg exercise at a given power output is affected by the proportion of the arm to leg work (21). The predominance of arm movement over leg activity in this study probably determines HR. When examining the impact of HR on oxygen delivery by using Fick's equation for cardiac output (solving for VO_2 and using stroke volume and HR for cardiac output), this implies that stroke volume, blood oxygen content difference or both were higher during stability ball sitting to supply the additional VO_2. Stroke volume changes are thought to be small with arm exercise because of the smaller influence of venous return (18). However, since the leg muscles were probably more active on the stability ball in this study, as evidenced by greater rectus femoris EMG activity, it is possible that increased peripheral venous return occurred due to leg muscle pump action. Another possibility could be increased uptake of oxygen by the leg muscles with their increased activity.

BP and the Rate Pressure Product (RPP) are generally higher at a given power output for arm exercise when compared to leg exercise (12, 18). However, cardiac output appears to be the same (12, 18). These observations indicate that peripheral resistance and myocardial oxygen uptake are possibly higher for the arm exercise. In this study, BP was not significantly different between the two sitting modes and may indicate, with the higher VO_2 (and use of Fick's equation again only with mean arterial pressure and total peripheral resistance for cardiac output), that peripheral resistance may be lower on the stability ball. This could be due to vasodilatation of more active leg muscles. Another possibility again is that oxygen content difference was higher. Measuring cardiac output during this kind of testing would help to clarify the stroke volume, vascular resistance, and oxygen content difference issues.

All four EMG sites for both sitting modes were higher with increasing exercise intensity. This is consistent with other studies that involved synchronous and asynchronous arm cranking (19) and backward cranking and forward cranking (2). However, this study found that trunk EMGs were not significantly affected by sitting mode except for the external oblique at 45W. Other studies comparing the chair versus ball were only at rest and reported that EMG measures during five to 60 minutes of sitting on a stability ball can be significantly different from chair sitting (10, 16, 17). Exercise studies have only investigated muscular endurance and compared EMG activity during traditional protocols with EMG activity during modified protocols incorporating the stability ball. Results in these studies have been mixed (4, 14, 20). We have not been able to find any research involving aerobic exercise with stability ball use. In the current study, the rectus femoris EMG measures were consistently higher with the stability ball indicating greater muscle activity for possibly stabilizing the hip region.

Our kinematic data appear to indicate that the arm, shoulder, and hip angles and lateral movement of the upper trunk were not significantly affected by stability ball sitting though for both sitting modes the upper back lateral movement increased about 30% from rest to 45W. The upper body may be as stable as it can be due to the fixed position of the arm ergometer, even forward and backward cranking are not significantly different in arm and shoulder kinematics (2). However, the lower body may need to be stabilized because of the ball; in this study it is achieved by extending the lower legs out, placing the feet farther apart, and recruiting more leg muscle.

The implications of this study could affect weight loss/management programs, exercise intensity prescription, and rehabilitation programs that include arm ergometry. The higher exercising VO_2 while sitting on the stability ball implies greater energy expenditure when compared to chair sitting. This is significant because arm exercise uses a smaller muscle mass than leg exercise and, therefore, the energy expenditure potential will be smaller for weight loss/management programs. The addition of the stability ball could increase energy expenditure by 10% or more. For example, using the 45W results and assuming 20 minutes of exercise per session with three sessions per week, an additional 1/6 kg of fat could be used in a year by exercising on the stability ball instead of on a chair. This represents about 15% of the annual weight gain (about 0.9 kg) (15) in adults. The higher stability ball VO_2 could also cause an exercise intensity prescription problem. For example, if a 75 kg individual was limited to no more than 5.5 METs for exercise and was told that 25 W was their upper limit on the arm ergometer (1) but the individual replaced a stability ball for a chair, that individual's exercising MET level would then be 6 or higher. Finally, RPP has been observed to be higher at a given power output for arm exercise when compared to leg exercise (12, 18) and indicates a greater myocardial oxygen demand. This may limit the level of arm ergometry intensity in cardiac ischemic individuals. However, the current study demonstrated that BP and HR are not significantly affected by sitting on the stability ball, implying that myocardial oxygen uptake is not significantly affected. This could mean that one can increase the aerobic/metabolic demands of arm exercise with the stability ball without increasing the oxygen demands of the heart. This could be significant for cardiac rehabilitation programs if these results are confirmed in this population.

This study was limited to sub-maximal exercise, young apparently healthy adults, only examined four EMG sites and did not index them to maximal levels, and did not analyze the lower back for lateral movements on the stability ball. In addition, though the average sitting heights were not significantly different between the stability ball and chair, there was no control for seat height. It turned out that by chance about a third of the heaviest participants sat a little lower on the ball while about a third of the smallest participants sat a little higher on the ball. Within these limitations, this study's results indicate that for apparently healthy young male and female adults, sitting on the stability ball during sub-maximum arm ergometry significantly elevates oxygen consumption without significantly affecting cardiovascular parameters and that this is associated with lower leg repositioning and increased thigh muscle activity.

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