

Original article

Energy expenditure and muscular activation patterns through active sitting on compliant surfaces

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Abstract

Purpose: To test the effectiveness of sitting surfaces with varied amounts of stability on muscle activity and energy expenditure.

Methods: Using a within-participants repeated measures design, 11 healthy young-adult females (age = 20.0 ± 1.8 years) were measured using indirect calorimetry to assess energy expenditure, and electromyography to assess muscular activation in trunk and leg musculature under 3 different sitting surfaces: flat-firm surface, air-filled cushion, and a stability ball. Data were analyzed using repeated measures analysis of variance with follow-up pairwise contrasts used to determine the specific effects of sitting surface on muscle activation and energy expenditure.

Results: Significantly greater energy expenditure was recorded for the stability ball ($p = 0.01$) and the cushion ($p = 0.03$) over the flat surface (10.4% and 9.6% greater, respectively), with no differences between the ball and the cushion. Both the ball and the cushion produced higher tibialis anterior activation over the flat surface (1.09 and 0.63 root-mean-square millivolts (RMSmv), respectively), while the stability ball produced higher soleus activity over both cushion and flat surfaces (3.97 and 4.24 RMSmv, respectively). Additionally, the cushion elicited higher adductor longus activity over the ball and flat surfaces (1.76 and 1.81 RMSmv, respectively), but no trunk musculature differences were revealed.

Conclusion: Compliant surfaces resulted in higher levels of muscular activation in the lower extremities facilitating increased caloric expenditure. Given the increasing trends in sedentary careers and the increases in obesity, this is an important finding to validate the merits of active sitting facilitating increased caloric expenditure and muscle activation.

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Keywords: Energy metabolism; Electromyography; Female; Posture; Sedentary lifestyle; Workplace

1. Introduction

Sedentary lifestyles have contributed to a myriad of health issues and consequences,^{1,2} including the development of type 2 diabetes,³ reduced muscle mass,⁴ cardiovascular disease,³ weight gain, and obesity.⁵ Increasing physical activity is instrumental in helping to ward off these illnesses and conditions.¹ With as little as 50–150 calories per day helping to control or reduce weight gain,^{6,7} finding ways to increase caloric expenditure in sedentary careers (e.g., office work) is important. Modifications to various sitting surfaces have been made based on the belief that different types of support surfaces and joint positions can increase muscle recruitment levels and potentially influence energy expenditure through greater instability.⁸ One modification to the traditional chair or flat seating surface is the

addition of an unstable support surface (stability ball, cushion, foam padding) under the assumption that this addition will result in an increase in the neuromuscular activation of the involved muscles.^{9–13} Because of the theorized increase in the neuromuscular activation of the musculature, unstable support surfaces have also been thought to enhance the individual's ability to expend more energy while sitting⁸ and may be added to other efforts put forth by the individual to control or lose weight (e.g., diet, exercise).

The stability ball is a popular piece of fitness equipment and has become increasingly utilized in the workplace as an alternative to the traditional office chair.^{13–15} The rationale provided for the use of the stability ball as an alternative to an office chair has been the claim that the support surface might promote core, spine, and upper limb motion thus possibly increasing muscular activity, subsequently increasing core stability and strength.¹³ Additionally, the lower limbs are required to stabilize the body thereby increasing activation of lower extremity musculature. Importantly, a lack of activity in the lower extremity has been

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linked to metabolic abnormalities including reduced action of insulin and muscle lipoprotein lipase.^{16–18} These changes have been evidenced independent of physical activity history and caloric intake. Importantly, studies have indicated that daily engagement in low-level activity has been evidenced at the molecular level,¹⁹ even to the degree that there was no threshold of minimal intensity identified, thus providing additional justification for all levels of physical activity and overall exertion. Facilitating a more active lifestyle and finding additional ways to increase activation of lower limb musculature may help in reducing these deleterious health effects associated with a seated-sedentary lifestyle.

The exercise biomechanics literature investigating modifications to surface stability has focused on the muscle's response by looking at the amplitude of the electromyography (EMG) signal and the differences between sitting on an unstable support surface compared with a stable support surface.²⁰ A lack of increase in muscle activation has been exemplified in 2 studies demonstrating no difference in trunk muscle activation levels between sitting on a stability ball and sitting on a chair.^{13,15} with another study citing small increases in activity.¹² Previous studies have reported linear increases in center of pressure displacement with increased seat instability thus effecting trunk posture.¹⁴ This evidence of increased center of pressure displacements substantially contributes to the theory behind the prolonged use of a stability ball as a chair. The instability inherent to the ball has been shown to induce trunk motion or require trunk stabilization which would necessitate increased muscular activation²¹ or at the very least constant isometric activation. Despite the equivocal findings of core muscle activation while seated on a stability ball, the trunk must be stabilized and is often undergoing movement^{14,21} which would necessitate muscle activation at some level of the body. The focus of past research has been on trunk musculature; however with the equivocal findings there is a need to assess activity in other muscles, which would likely include lower extremity muscles. Although there is an increase in movement with an unstable support surface it has also been reported that the spine of the individual can become slightly more compressed over that of a stable surface with extended use.¹² The reported compression is certainly a factor to consider when choosing a sitting surface but given the small difference in reported compression (approximately 1.1 mm more compression on the stability ball over a chair), no confirmatory analysis conducted to date and relatively small sample size the clinical significance of those changes may not preclude one from using an unstable support surface.

Air cushions have been widely used to provide comfort and reduce sitting pressure. Air-filled cushions have been used to reduce decubitus ulcers in wheelchair operators by uniformly redistributing pressure across the gluteal muscles.²² However, the effects of sitting on an air cushion on energy expenditure and levels of core and lower extremity muscle activation have not been quantified. The task of sitting on a chair with the support of both the arms and the torso requires minimal levels of muscular activity, thus failing to provide the stimulus necessary to increase the energy expenditure. When individuals sit

with little to no activity an increased level of stress is placed on the passive structures providing support for the torso and the spine.²³ With the added stimulus of an air-filled sitting cushion or stability ball (e.g., multi-dimensional compliant surface) both the level of muscle activation needed to control posture on the compliant surface and the overall metabolic cost would likely increase. Although studies have assessed the impact of the stability ball there have not been studies assessing metabolic cost or muscle activation using a sitting cushion. As a result of the increased activity and corresponding energy expenditure it could be hypothesized that the overall caloric cost of sitting could be increased and help to contribute to the overall daily caloric expenditure. Active sitting is a concept that applies primarily to chairs and stools that allow movement. The premise of active sitting is to allow or encourage the seated occupant to move.¹⁵ Although active sitting can be performed on a stability ball or on an air cushion placed on a chair, it is not generally considered suitable to use a stability ball as a seating surface in many situations (e.g., in the office, in waiting areas). As such the purpose of the study was twofold, first to determine the levels of caloric expenditure using an indirect measure of metabolic function, and secondly to compare the overall level of muscle activity between an active sitting cushion, a stability ball, and a firm sitting surface. It was hypothesized that there could be an increase in energy expenditure through sitting on either the stability ball or the cushion. Additionally given the evidence of increased movement while sitting on a compliant surface control from the interaction with the ground would be necessitated and ultimately we would expect to see an increase in activation of lower extremity musculature as well as upper body musculature to support and stabilize the core.

2. Methods

2.1. Sample

Eleven healthy female subjects (age: 20.0 ± 1.8 years; body height: 167.27 ± 6.48 cm; body mass: 67.14 ± 9.22 kg) were recruited for the study. All subjects had a body mass index (BMI) of less than 30 kg/m^2 . All subjects were free of chronic illness, had no known musculoskeletal injury, were not currently taking medications known to effect balance, and were able to sit for three 10 min sessions while maintaining an upright posture. Additionally, each participant completed an informed consent document outlining the experiment that was approved by the Ball State University Institutional Review Board.

2.2. Design

To determine the level of muscular activity and metabolic cost of active sitting, 3 different task conditions were measured. The 3 tasks included (1) sitting on a flat surface, (2) sitting on an Automatic Abs air cushion (Licensing Services International, Philadelphia, PA, USA), and (3) sitting on a stability ball (Power Systems Inc., Knoxville, TN, USA). The 3 conditions were assigned in random order and each lasted 10 min with a 5 min break between conditions to allow the subject to adjust. All conditions were performed within the same day with the entire session lasting approximately 90 min.

Subjects sat with their feet flat on the ground and shoulder width apart, with foot position marked on the floor to assure the same placement across the 3 conditions. During testing subjects were asked to sit with knees flexed to 90°, with hands placed on their thighs, back erect, and eyes facing forward. For each 10 min trial subjects watched a neutral video (one that would not evoke emotion or increase heart rate in the subject) while measures of their muscular activity and caloric expenditure were measured. To ensure that the knee position was always at 90°, risers were placed on the ground for the flat and the air-filled cushion trials, where the air-filled cushion was placed on a wooden stool. The sitting height was adjusted for the ball condition through the use of 2 sizes of stability balls (i.e., 55 cm and 65 cm). To standardize the sitting conditions all subjects were verbally guided by the research staff to maintain an upright posture using cues such as “sit up straight”.

2.3. Measures

Muscle activity was measured at 1 min intervals throughout each 10 min condition for a period of 10 s using a Delsys EMG system (CMRR > 92 dB) (Delsys Inc., Boston, MA, USA). Each subject had 6 pairs of surface EMG electrodes (Delsys DE-2.1 Single Differential EMG Electrode) (inter-electrode distance: 1 cm) attached to the external oblique, rectus abdominis, and erector spinae to monitor trunk muscle activation, and to the adductor longus, soleus, and tibialis anterior to monitor lower extremity muscle activation on both the right and left sides of the body, respectively. For EMG measures the electrodes were in line with the direction of the underlying muscle fiber for each muscle. The EMG signals were amplified (gain = 1000) and were collected at 2400 Hz with a bandwidth filter of 20–500 Hz. A reference electrode was placed on the olecranon process. Electrode sites were shaven, lightly abraded, and cleansed with alcohol prior to placement. Vicon Workstation 5.0 (Vicon Inc., Denver, CO, USA) was used to capture the raw EMG signals.

Energy expenditure was measured via open-circuit indirect calorimetry using a metabolic cart (Parvomedics, Sandy, UT, USA). Heart rate was measured using a heart rate monitor (Polar Electro Inc., Lake Success, NY, USA) and transmitted to a receiver on the metabolic cart. Average energy expenditure was calculated based on the rates of oxygen consumption and carbon dioxide production during the three 10 min sitting tasks with sampling occurring every 30 s.

2.4. Analysis

2.4.1. Energy expenditure analysis

Average energy expenditure was calculated based on rates of oxygen consumption during the three 10 min sitting periods.²⁴ Digital data were provided from the sampling of the expired gasses occurring every 30 s. Overall energy expenditure for each of the three 10 min conditions was calculated based on average oxygen consumption across the 10 min sitting period.

2.4.2. Muscular activity analysis

Root-mean-square (RMS) was calculated for each muscle for the 10, 10 s samples taken during each 10 min sitting

condition. A custom C++ program was used to calculate the RMS EMG for each muscle during each trial. Specifically, the following equation was used:

$$\text{RMS} = \left[\left(\frac{1}{T} \right) \times \int_t^{t+T} rEMG(t)^2 dt \right]^{1/2}$$

where $rEMG(t)$ represents the rectified EMG at time t , dt is the sampling rate (1/2400 s), and T is the moving window size of 0.0265 s.

2.5. Statistics

Using a within-subject study design all participants were assessed on each measure and data assessing the effect of sitting surface (i.e., stability ball, cushion, flat) on energy expenditure were analyzed using a one-way repeated measures analysis of variance (ANOVA). To assess the effect of sitting surface on muscular activity a 6×3 (muscle \times surface) repeated measures ANOVA was used. Follow-up pairwise comparisons were performed, where appropriate. For all tests the significance level was set at $p \leq 0.05$. All statistical tests were conducted using SPSS (Version 22.0; IBM Corp., Armonk, NY, USA).

3. Results

3.1. Energy expenditure

All individuals were able to complete all testing trials and conditions. Prior to data analysis, it was determined that assumptions of sphericity were not violated. Mean \pm SD values for the measure of energy expenditure (collected at 30 s intervals over the course of 10 min of sitting) were 16.50 ± 2.01 kcal/10 min, 16.14 ± 2.27 kcal/10 min, and 14.62 ± 2.51 kcal/10 min for the ball, cushion, and flat surface, respectively. Results from the repeated measures ANOVA for energy expenditure revealed significant differences between the 3 surfaces ($F(2, 20) = 5.26$, $p = 0.015$). More specifically follow-up pairwise comparisons revealed that the caloric expenditure on the flat surface was less than either the ball ($p = 0.01$) or the cushion ($p = 0.02$). However there was no significant difference between the energy expenditure of the ball and cushion ($p = 0.60$).

3.2. Muscular activity

Results from the repeated measures ANOVA for muscular activation revealed a significant effect for surface ($F(2, 20) = 10.23$, $p = 0.001$) and significant effect for the muscle ($F(5, 50) = 6.74$, $p < 0.001$). However, the higher-order interaction effect between surface and muscle was also significant ($F(8.6, 86.01) = 3.64$, $p = 0.001$). The interactive effect indicated that the individual muscles were impacted differently by the various sitting surfaces. Fig. 1 shows that the upper body musculature (i.e., rectus abdominis, external obliques, erector spinae) was not impacted differently by the 3 sitting surfaces. However, lower body musculature (i.e., adductor longus, soleus, tibialis anterior) did demonstrate differential effects across the 3 sitting surfaces. The cushion demonstrated increased levels of activation for the adductor longus when

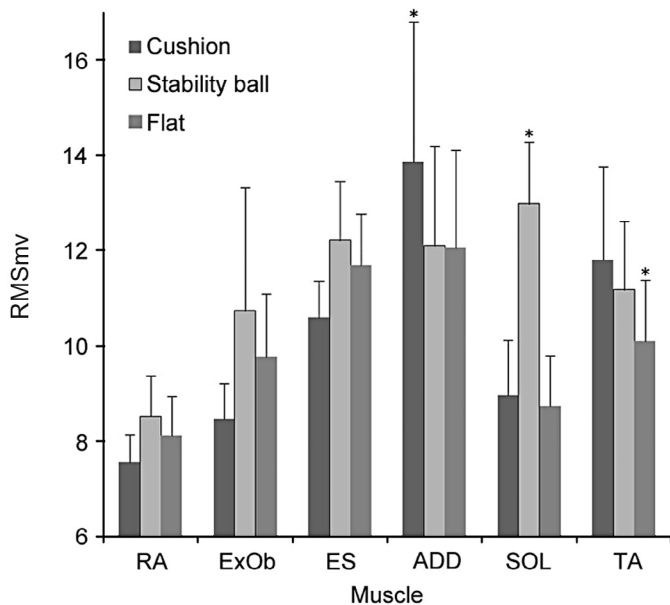


Fig. 1. Electromyographic activation patterns for upper (RA, ExOb, ES) and lower (ADD, SOL, TA) body musculatures while sitting on varied sitting surfaces. * $p < 0.05$, compared with the other 2 sitting surfaces within group. ADD = adductor longus; ES = erector spinae; ExOb = external obliques; RA = rectus abdominis; RMSmv = root-mean-square millivolts; SOL = soleus; TA = tibialis anterior.

compared to the ball and flat conditions while the soleus elicited higher activation levels for the ball condition over either the cushion or the firm surface ($p < 0.05$). Finally, both the ball and the cushion surfaces demonstrated increased levels of activation over that of the flat surface for the tibialis anterior muscle ($p < 0.05$).

4. Discussion

The findings from this study demonstrated an increase in caloric expenditure as well as increased muscle activation in lower body muscles when sitting on a stability ball or an air cushion over that of a flat non-compliant surface during 10 min sitting periods. These findings suggest that sitting on a stability ball or air cushion did indeed promote “active” sitting or the dynamic change in sitting that involves frequent postural adjustments thereby increasing caloric expenditure most likely through increased muscular activity. Although there was a significant increase in calories expended when sitting on a stability ball or an air cushion compared to the non-compliant flat surface, there was no significant difference in calories expended between the 2 compliant surfaces tested. Based on the numbers from this study in healthy young adult females, sitting on either of the 2 unstable surfaces while maintaining an upright stable position was able to account for more than half of an energy balance suggested to contribute to weight gain and obesity.⁷

In an attempt to determine the potential source of changes in energy expenditure, activation levels from 6 muscles were monitored during sitting. Previous studies have suggested using the stability ball as an alternative to an office chair to promote core, spine, and upper limb motion and potentially increase

muscular activity.¹³ However, similar to other investigations,^{15,25} increased levels of muscle activity were not seen in the core muscles but rather, the current study demonstrated increased activity in lower extremity muscles. To facilitate stabilization of the core and spine, changes in force application are required through ground reaction forces²¹ thus requiring activity in lower extremity muscles. In the current investigation subjects were required to sit in an erect posture across all sitting surfaces and postural adjustments were able to be made either through the interaction between their feet and the floor or their hands and legs. The result was similar muscle activation levels in the upper body and differential effects in lower body musculature. Given the reports indicating that activity, regardless of the level of activation, in the lower extremities is needed to help increase the action of insulin and muscle lipoprotein lipase,^{16–18} the muscle activation patterns from the current study may extend beyond the role of increased metabolic activity. It is important to note that although we recorded increases in EMG activity while seated in an erect posture it is unknown what effect a more slouched posture would elicit. However, given that postural changes could still need to stem from changes in ground reaction forces the effects would likely to be similar.

Largely, prior studies have looked at the stability ball for its value in rehabilitation and fitness.^{9–11} A small number of studies have examined the use of a stability ball as an alternative to an office chair^{12,13,15,26} and even fewer studies have examined changes in caloric expenditure.^{8,27} Similarly, there is a lack of literature on the air cushion with previous research assessing increased comfort and sitting pressure in semi-truck drivers and wheelchair operators.²² Extending the utility of an air cushion to using it as a way to convert an otherwise sedentary task into a more active task is an interesting question. As a way to increase energy expenditure at work other studies have tested the efficacy of a “walk-and-work” desk where the individual would walk during times where they would normally be sitting (i.e., computer work).²⁷ A large increase in energy expenditure was found (approximately 100 kcal/h) but the “walk-and-work” desk is not widely available or plausible in many situations. Other studies have demonstrated positive increases in energy expenditure using stability balls,⁸ but the practicality of sitting on a large ball in an office setting may not be considered acceptable or plausible. As an alternative the air cushion is also a multi-dimensional compliant surface, much like the stability ball, and may be considered a more convenient and practical method to promote active sitting, one that can be used anywhere there is a chair. With the similar impact on energy expenditure found between the stability ball and the air cushion its use is further justified over that of the stability ball.

Given the high levels of obesity and sedentary behaviors in today’s society, there is a pressing need to make positive changes against environmental forces that are producing these effects. It is estimated that a persistent positive energy balance between 50 kcal/day and 150 kcal/day contributes to weight gain and, furthermore, the obesity epidemic.^{6,7} Consequently, a 50–150 kcal/day increase in energy expenditure can help safeguard the population against weight gain. Along with obesity, the sedentary nature of work is increasing and it is estimated

that more than half of the workforce in developed countries is seated working at computers.²⁸ Evidence from the current study suggests that replacing the office chair with a stability ball or an air cushion and maintaining an upright posture can be helpful in increasing caloric expenditure. Innovative and effective approaches for obesity prevention and treatment are being sought to increase activity in the workplace. Sitting on an air-filled cushion or stability ball instead of a conventional office chair resulted in an average of 1.36 additional calories expended over a 10 min period or approximately 8 calories per hour. Extending this to a typical 8 h workday, the total could be in the range of 65 calories. Although this number is likely to vary from day to day and between individuals there is still an energy expenditure over and above that of firm surface sitting. Daily, the estimated amount is within the range of the negative energy balance suggested to safeguard against weight gain.^{6,7} Contrasting this level of energy expenditure to the average participant in this study (i.e., 67.14 kg) is equivalent to walking 1 km at a pace of 4 km/h. Despite the small number of calories expended on the unstable surfaces, over the course of weeks, months or even years it could amount to the calories to burn more than 4–5 pounds of fat in a year, although further investigations are needed to test this further. While the current study was conducted using healthy young adult females with a BMI of less than 30 kg/m², in an attempt to increase the efficacy of the EMG measures obtained and to reduce the likelihood of orthopedic injuries/ailments as well as to eliminate any potential sex effect on the findings, the energy expended would vary depending on a number of factors including body size, shape, fitness level, gender, and even age. Despite the potential for variance a number of studies have now demonstrated how overall body movement increases while sitting on unstable surfaces, and in order to control this movement muscular contractions are required which would require energy to be expended. An additional factor to consider when using air-filled sitting surfaces is that some people may respond differently to varying pressures based on their mass/weight and structural makeup. To help offset this effect, the current study measured the circumference of the stability ball prior to each subject beginning the study. Similarly, the air cushion was inflated to the same level throughout the study. Individuals wishing to use an air cushion to engage in “active sitting” should monitor its inflation to ensure its continued effectiveness. Future studies should further investigate the differential effect of varying levels of inflation to determine the best caloric response while still maintaining sitting comfort.

Although this was a starting point for assessing the notion of active sitting using a specific population, future studies should also include males and a wider range of BMIs for both males and females as well as across various age ranges and over longer time periods (e.g., 1–2 h). Additionally, while there will likely be varying degrees of effectiveness, the physics of maintaining the stability of the moving trunk will require energy to be expended regardless of the individuals’ size, shape, or sex. Participants in this study were asked to sit up straight and maintain that position during testing. While this position might be encouraged it is not how all individuals would sit throughout

the workday. As such future studies should assess the activation patterns and energy expenditures while adopting a less erect posture. Finally, due to the obesity epidemic and the correlation with predominately sedentary work, a similar study using obese subjects could prove to be beneficial.

5. Conclusion

The findings from this study revealed that more energy is expended by sitting on a compliant surface over that of a firm and stationary surface; however, the increased levels of muscular activation were shown to be a function of increased leg muscle activity rather than trunk muscles. Further, the use of an air-filled seat cushion increased energy expenditure as much as the stability ball compared to a firm stationary surface, and may be a more practical alternative due to its smaller size and ease of storage. Although the difference in caloric expenditure was relatively small over the course of this study, the cumulative level becomes considerable when extrapolated over the course of the average workday and beyond.

Authors’ contributions

DCD participated in data collection, performed the statistical analysis, and revised the manuscript; RKS performed the data collection and processing and drafted the original manuscript; HW assisted in data interpretation and collection and in revising the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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