Muscular Response of Females with Kyphosis in Balance Recovery from Postural Perturbation

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ABSTRACT

Purpose: This study aimed to determine muscular response in balance recovery after postural perturbation among females with increased thoracic kyphosis.

Methods: This is a quasi-experimental study. A total of 12 female students with thoracic kyphosis (>40 degrees) and 12 matched controls were selected to participate in the study. Each subject underwent unexpected perturbation from anterior, posterior, right, and left directions with eyes open and eyes closed conditions while standing on a movable plate, triggered by a weight equivalent to 10% of the subjects' body weight. Then, the electromyography activity of some selected muscles was measured. SPSS version 19.0 and Analysis of variance (ANOVAs) with repeated measures were used for data analyses ($P<0.05$).

Results: Significant effects after perturbation were observed with regard to the activation of rectus femoris ($P<0.001$), biceps femoris ($P<0.001$), tibialis anterior ($P<0.005$), gastrocnemius medialis ($P=0.032$), and gluteus maximus ($P<0.001$). Whereas, no impact was seen in activities of erector spinae ($P=0.461$) and rectus abdominal muscles ($P=0.224$). Also the results showed increase in muscles activities when the eyes is closed compared to open eyes condition ($P<0.05$). Activities of all muscles were significantly higher in kyphotic group in comparison with control group. However, these differences were statistically significant regarding gastrocnemius medialis ($P=0.007$), gluteus maximus ($P=0.033$), and rectus abdominus ($P=0.010$).

Conclusion: Proximal muscles activity was higher in kyphotic subjects than normal subjects during balance recovery after postural perturbation.

Keywords:
Kyphosis,
Posture, Balance,
Electromyography

1. Introduction

Loss of balance in dynamic position and inability to restore it results in people's falling, which is one of the common and sometimes costly problems in human beings [1]. In the United States, nearly 300000 hip fractures occur as a result of falling, which incurs over 10 billion dollars cost to the country's health system [2]. Another report stated that the rate of deaths due to falling was 7.5 per 100000 of Canada population in 1991 [3]. Numerous studies have been carried out to identify factors associated with loss of balance such as the relationship between weight or body mass index [4-6], age [3, 7], and deformity of spine like kyphosis in static or dynamic equilibrium conditions [8, 9]. The number of studies on kyphosis deformity, despite its high prevalence, is limited.

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Human spine is composed of 4 curvatures (cervical, thoracic, lumbar and sacrum) and curvature of greater than 40 degrees in the thoracic spine is called kyphosis [10]. This complication can lead to musculoskeletal problems and increase the risk of bone fractures in the elderly up to 70% [11, 12]. Some studies report reduced quality of life, increasing dissatisfaction with the health condition, and physical problems among the kyphotic subjects [8]. Even some reports suggest a positive relationship between risk of death and kyphosis intensity owning to a decrease in vital capacity of people [13, 14].

Several studies indicate a relatively high prevalence of kyphosis. In a study conducted to determine deformity of the spine in Iranian students, it was found that more than 21% of boys and 15% of girls suffer from kyphosis [15]. In some studies, this amount rises in women [16, 17]. Also, in investigating the prevalence of deformity among students of Chamran and Isfahan universities, kyphosis prevalence was estimated to be 14% and 20.3%, respectively [18, 19].

After comparing balance performance of the kyphotic youth in the sagittal plane with the normal matched control subjects, it was reported that people with kyphosis had lower capacity to maintain body balance [20]. To better understand the dynamic balance, Anbarian et al. tried to study the mechanism of restoring body balance against sudden acceleration in sagittal plane in kyphotic subjects and stated that kyphotic subjects had poor performance of postural control compared with normal group. These people represent a different response and strategy to return the balance after applying external acceleration compared to normal individuals [21]. Earlier, Boot has stated that the overcurvature of the dorsal spine moves the body mass center forward and down so that (for balance maintenance) the person must compensate by changes in lower limb joints and flex the knee [22].

To identify the reasons and improve restoring the balance in kyphotic subjects, the mechanism of restoring the balance in these patients compared with healthy individuals must be understood. Given the importance and key role of muscular performance in balancing the body in dynamic positions, it can help to understand the mechanism of restoring the balance. Literature review in this area, show some serious gaps, especially with regard to studies on women and girls. Understanding the differences in the control of body balance in patients with abnormal spinal curvature compared to normal people as well as the electrical activity of the muscles will be effective in treatment and restoring the balance of kyphotic subjects. So, this study aimed to assess muscular response in balance restoration in kyphotic girls in sudden postural perturbation compared with those with normal curvature of the spine. This study was designed in 2 conditions of eyes open and eyes closed to determine the effect of visual information on balance restoration too.

2. Materials & Methods

Participants

A total of 24 female students from Bu-Ali Sina University were selected through sample of convenience method and participated in this Causal-Comparative study that was conducted in 2012. Participants were divided into two groups namely, kyphotic (n=12) and control (n=12) groups based on their amount of thoracic curvature. Subjects were assigned into kyphotic group if they had increased thoracic kyphosis (>40 degrees). Subjects with curvature of the thoracic spine less than 40 degrees were assigned as the normal group. The normal group included age, weight, body mass index (BMI) and gender- matched subjects in order to eliminate the concurrent effects between groups. The curvature of the spine was calculated by a flexible ruler. The spinal curvature was calculated in accordance with the method described in the study [20, 22, 23] and references reported in the literature.

The inclusion criteria were that the subjects should: 1) Be right leg-dominant female; 2) Not previously treated neither surgically nor conservatively due to kyphosis; 3) No leg length discrepancy or lower extremity deformities.

Exclusion criteria (assessed by a questionnaire and medical examination) consisted of: 1) Professional athletes with a history of regular exercise and sports activities in particular fields; 2) Visual impairment, hearing and neuromuscular disease; 3) Any history of surgery (non-cosmetic); 4) Skeletal disorders or malalignment except exist of thoracic kyphosis angle greater that 40 degrees for kyphotic group. For all participants in this study, the research objectives and confidentiality of results were explained and informed consent was obtained.

Procedures

All participants were referred to lower limb biomechanics laboratory of Bu-Ali Sina University at certain times. Electromyography activity of some selected trunk and lower limb muscles, including erector spinae, rectus abdominus, rectus femoris, biceps femoris, tibialis anterior, gastrocnemius medialis, and gluteus maximus was recorded. Average muscle activity in 4 seconds after the perturbation was considered as the activity of the muscle.

In order to do the test, the body hair was completely shaved and cleaned with cotton and alcohol in areas of electrodes installed. Then, the subjects were asked to stand on a movable plate that was able to move freely. This plate was connected with a rope to the weight that the subjects were unable to see. It weighed 10% of body mass of subjects and hanged at a height of 70 cm from the surface of the ground. With the sudden release of the weight, balance of the subject was disturbed and until restoration of balance, her muscular activity data were recorded (Figure 1) [24].

Electromyography (EMG) activities of selected muscles were recorded using a 16 channel EMG system (Biomonitor ME6000 T16, Mega Electronics Ltd., Kuopio, Finland). After cleaning and abrasion of the skin, Ag/AgCl disposable surface EMG electrodes were attached in line with the muscle fibers over the muscles using single differential electrodes with an inter-electrode distance of 2 cm and according to the SENIAM (European Recommendations for Surface Electromyography) protocol [24]. Earth electrodes were installed on the bones of tibia and superior iliac spine. Sampling frequency of 2000 Hz was considered. To normalize the collected raw signals, the participants did repetitions of maximum voluntary isometric contraction. For this purpose, raw EMG data were analyzed with root mean square method. To analyze the raw data obtained from surface electrodes, the Mega Win 3.0.1 software and bypass filter 10 to 500 Hz were used. In the end, to normalize signals, root mean square information of every muscle was divided by the maximum voluntary isometric contraction of the muscle and then multiplied by 100.

Each trial was done in the 4 directions of anterior, posterior, right, and left with eyes open and eyes closed conditions. To reduce random errors, every experiment was performed in each scenario listed for each subject and repeated 3 times and the average of the 3 repetitions was recorded as muscle activity of subjects. In addition, to eliminate systematic error, a certain time was allocated for recognition and familiarity with the test by subjects and a practice test was performed before the start of the real experiments.

Subjects were asked to stand comfortably on the movable plate and have the fewest possible moves in the time of trial. In the event that the subjects would take steps to maintain the balance, we reran the tests. The subjects had 1 minute break between each test. Since the passage of time might lead to learning and disturbance in test results, the order of different positions of trials was designed randomly.

Statistical analyses

To describe the sample and characteristics of the subjects, ANOVAs with repeated measures of within group factor (the person's eyes and subject's position on movable plate) and a between-group factor (normal or kyphotic groups) followed by Bonferroni post hoc test were applied. As in repeated measures ANOVA, dependent variables should be normal in each cell of between-subject design. Also, variance-covariance matrix between dependent variables across each factor should meet the sphericity assumption; Mauchly's test and the sphericity assumption were checked. Where the sphericity assumption is violated (i.e. $P<0.05$), the Huynh-Feldt correction for degree of freedoms in repeated measures ANOVA were used.The normality assumption were checked by Shapiro-Wilk test. The significance level was set at $P<0.05$. The statistical software SPSS version 19 was used for statistical analyses.

3. Results

Two research groups did not show significant differences in some variables such as age, height, weight, and body mass index except in the amount of thoracic curvature in the sagittal plane (Table 1).

In this study, activation of the erector spinae, rectus abdominus, rectus femoris, biceps femoris, tibialis anterior, gastrocnemius medialis, and gluteus maximus following an external perturbation in both groups of normal and kyphotic individuals were compared. This comparison was carried out in 8 different test positions with the combination of 2 conditions during perturbation (eyes open or closed) and direction of perturbation (anterior, posterior, right, or left). Summary of the results for these muscles in 2 groups are shown in Figure 2.

Repeated measures analysis showed that the perturbation direction had a significant impact on the muscle activity of rectus femoris ($F=12.865$, $df=3, 69$; $P<0.001$), biceps femoris ($F=9.569$, $df=2.217, 50.999$; $P<0.001$), tibialis anterior ($F=5.685$, $df=2.176, 50.057$; $P=0.005$), gastrocnemius medialis ($F=3.637$, $df=2.102, 48.354$; $P=0.032$), and gluteus maximus ($F=8.883$, $df=3, 69$; $P<0.001$), in such a way that the activity of the muscles depend on perturbation direction. However, the results of this study showed that erector spinae ($F=0.827$, $df=2.38, 54.729$; $P=0.461$) and rectus abdominus ($F=1.493$, $df=3,69$; $P=0.224$) muscles do not have correlation with the direction of perturbation.

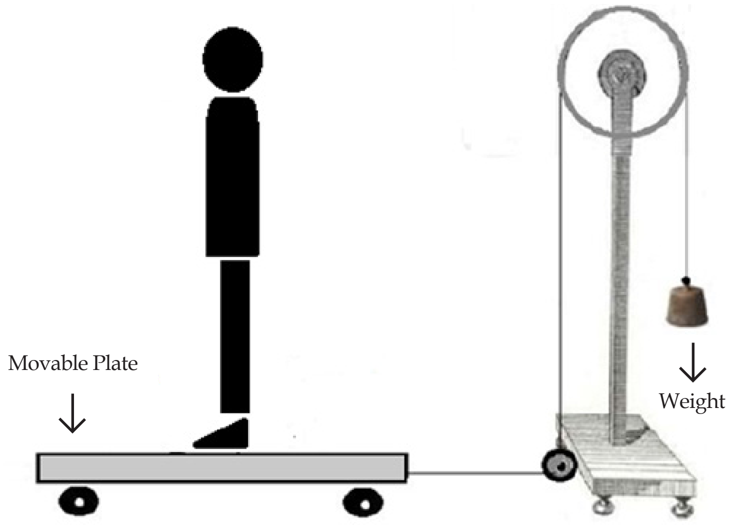

Figure 1. The implementation of the test.

PHYSICAL TREATMENTS

The results showed the impact of open or closed eyes conditions on the activity of all 7 muscles in a way that in closed eyes condition, muscle activity increased significantly compared to open eyes condition (P<0.05).

The results indicated that normal and kyphotic subjects showed different muscle activities in response to external perturbation at different directions (anterior, posterior, right, and left). But these changes were not statistically significant. Similar to this result, healthy and kyphotic subjects had muscle activation in open or closed eyes conditions during perturbation but comparison of statistical patterns indicated no statistical significance (P>0.05).

Kyphosis effect on muscle activity showed that the mean muscle activity of kyphotic subjects is greater than the mean value in normal subjects. The results showed that the mean (SD) activation of the rectus femoris, bicep femoris, tibialis anterior, gastrocnemius medialis, erector spinae, gluteus maximus, and rectus abdominus muscles were respectively 3.059 (1.697), 2.151 (1.353), 7.428 (2.510), 2.436 (1.319), 2.503 (2.292), 1.785 (0.788), and 2.142 (0.762) units higher in kyphotic group than those activities in the normal group. Nonetheless, these differences were significant only with regard to gastrocnemius medialis muscle (F=8.755, df=1, 23; P=0.007), gluteus maximus (F=5.133, df=1, 23; P=0.033), and rectus abdominus (F=7.889, df=1, 23; P=0.010).

Bonferroni post hoc test showed that the changes of the rectus femoris muscle activity when the perturbation is applied from the right or left (P=0.935), right or posterior (P=0.980), and left or posterior (P=0.322) were not significantly different from each other. However, the paired comparison of the entire directions of perturbation indicated a significant difference between the performance of the rectus femoris muscle (P<0.05).

Table 1. Descriptive statistics of kyphotic and normal subjects.

Variables	Groups	Mean	SD	Minimum	Maximum	P-value
Age (years)	Kyphotic normal	23.67 23.77	1.723 1.964	21 22	28 27	0.891
Height (cm)	Kyphotic normal	162.58 160.85	6.842 3.087	157 152	167 183	0.432
Weight (kg)	Kyphotic normal	58.58 56.15	6.721 6.094	44 46	65 67	0.353
BMI (kg/m^2)	Kyphotic normal	22.11 21.67	1.647 1.9	17.63 19.4	23.8 24.34	0.542
Kyphosis amount (degrees)	Kyphotic normal	59.50 37.31	6.557 5.544	49 28	74 39	0.001*

* P<0.01

PHYSICAL TREATMENTS

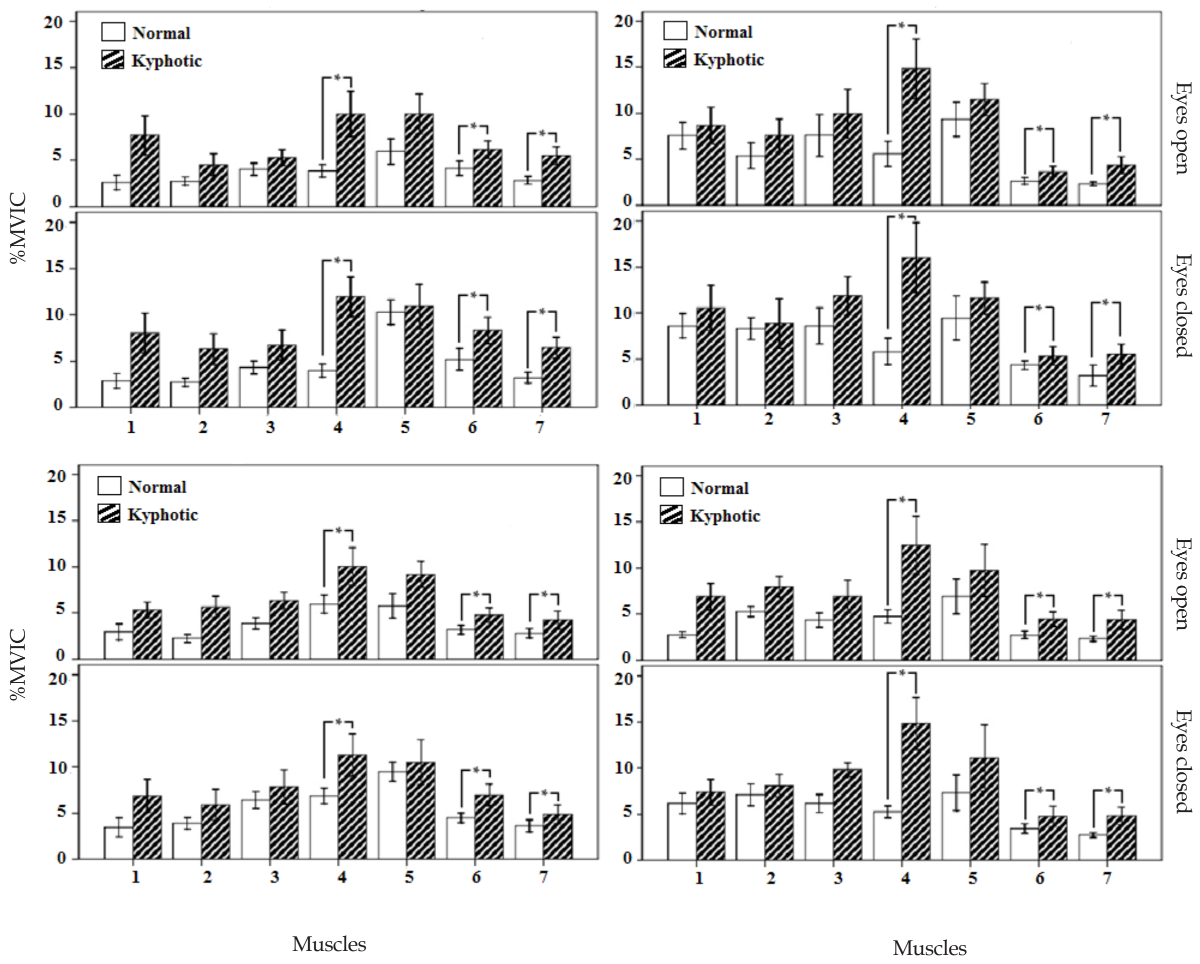

Figure 2. Mean (±2SE) muscle activities of rectus femoris, bicep femoris, tibialis anterior, gastrocnemius medialis, erector spinae, gluteus maximus and rectus abdominus in normal and kyphotic subjects in 8 designed experimental positions with codes 1 through 7 on the horizontal axis.

* P<0.05.

Paired comparison of muscle activation of bicep showed no statistically significant changes when perturbation applied from the right or left to the moving plate (P=0.992) or from the anterior or posterior. There were significant differences in EMG activity of the biceps femoris muscle in other directions of perturbation (P<0.05).

Bonferroni post hoc tests for paired comparisons of tibialis anterior muscle activation in different directions showed that when perturbation is applied from the right or anterior, a significant difference was observed in the tibialis anterior muscle function (P=0.015). Other paired comparisons did not show a significant difference in the performance of this muscle.

Bonferroni post hoc test showed only a marginal difference in the performance of gastrocnemius medialis muscle for perturbation from anterior or the right (P=0.065). The paired comparison of gluteus maximus muscle activation in different directions showed that in the perturbation from the right or anterior direction (P=0.003) and the right or posterior (P=0.002), there were significant differences. In other cases, there was no significant difference in muscle function (P>0.05).

4. Discussion

The aim of this study was to assess the response of selected muscles in restoring balance after postural perturbation in kyphotic girls. The normal group comprised individuals with the normal thoracic curvature of the spine matched in terms of sex, age, and weight with those having kyphosis deformity. In this study, 4 directions of anterior, posterior, right, and left were selected for the dynamic postural perturbation, which resembles the natural conditions of perturbation applied to individuals in the workplace. Also, it is suitable for normal postural fluctuations, to which investigators pay attention to evaluate the balance performance.

According to the results of this study, the proximally muscle activities in kyphotic individuals are greater than those in normal subjects. The study of Balzini and colleagues and also Cook`s study about the relationship between balance and postural perturbation showed that an increase in thoracic kyphosis associates with a reduced ability to maintain balance of those with osteoporosis [12, 25] and this condition increases the chance of fracture in these people as a result of falling [26]. Given that about 60% of the weight of the body is in the trunk and according to what Yuan and colleges stated [27], the increased curvature of the spine in the sagittal plane to the anterior would result in displacement of center of mass (CoM) to the front of the reliance surface and therefore increases the chances of losing one's balance.

Therefore, individuals with spinal deformity in sagittal plane need more muscle activity to maintain and restore their balance after postural perturbation. Based on the previous studies, increasing kyphosis changes the CoM, resulting in threatened balancing. In this situation, the kyphotic individual turns to the compensatory mechanisms such as using lower extremity joints, tilting pelvis, and raising trunk to the back to improve the balance by moving the center of gravity to the natural location.

But resorting to these compensatory mechanism is concomitant with biomechanical and physiological changes which would be problematic. Of these problems are uneconomical use of muscles or postural deviations. On the other hand, increase in kyphosis is considered as a compensation of postural disorders such as scoliosis, or muscular and neurological disorders. However, kyphosis certainly and naturally changes (even as a compensatory mechanism) muscle ability or function compared to normal subjects with regard to the main issue examined in this study.

Similar results were reported by Anbarian and associates [21]. They reported that with perturbation in the sagittal plane, the fluctuations in movement domain of ankle, knee, and thigh joints in individuals with increased thoracic kyphosis are greater than those in subjects with normal thoracic curvature. Vaskanklous et al. study also showed that the ability to maintain and restore the balance in the elderly with hyperkyphosis (>50 degree) is less than normal older people that is consistent with the results obtained in this study. Previous studies have stressed on the role of visual information in normal subjects or those with disorders like cerebral palsy [28] and uncoordinated movements [29]. The study of Hosseininejad et al. also showed that although balance training has a positive effect on postural control, the condition of open or closed eyes of the individual is effective in balance [30]. In a recently conducted study by Siegel and colleagues on the elderly, it was stressed that visual information is effective on the amplitude of CoM and CoP (Center of Pressure) [31]. Likewise, Patel and colleagues reported that the elimination of visual information leads to increased muscle activities of the tibialis anterior and the gastrocnemius medialis.

In confirmation of previous studies, this study also found that removal of visual information leads to an increase in muscle activity of all 7 examined muscles to maintain and restore the balance. This impact was observed on both normal and kyphotic individuals in 4 perturbation directions. Several studies that compared the balance performance in people with deformities in both eyes open and eyes closed situations have often discussed the role of visual information and the impact of the deformity separately. These studies paid less attention to this issue that whether the removal of this information has the same effect on the balance of two groups or the needs of different groups to this information differs. The results showed that the role of visual information (status of eyes open versus eyes closed) does not have significant difference in the muscle activity to restore balance in both normal and kyphotic groups.

Several studies have pointed out the cooperation of muscles in balance. The study of Ting and Mac Fressin and Tors Oviedo and colleagues indicated that to maintain static balance and in response to the perturbation from different directions, the muscles show reactions. Other studies have shown that the direction of the force applied to the land is associated with muscle synergies [32, 33]. In this study, it was observed that the perturbation direction is significantly effective on the rectus femoris and most of the muscle activity occurs when the perturbation is applied from the anterior direction.

When the movable plate is moving forward, the individual is inclined backward. The anterior muscles, including the rectus femoris muscle show more activity to return the center of body mass into reliance surface and this muscle activity is greater when perturbation exerts from the back or sides. In order to justify these findings, it appears that the rectus femoris muscle due to its role in hip joint flexion, increases its activity in response to backwards movement of the body (in response to the perturbation) and to create hip flexion to return the trunk to its place before the perturbation.

To maintain balance before the predictable gait perturbation, the primary and main muscles involved in balance control are proximal muscles (hip/trunk) [34], while in the study of Tang et al. on balance control during the gait perturbation, distal muscles (hip/knee) are of particular importance to deal with the gait perturbation [35]. Although in this study static balance of subjects was examined, the obtained results were the same as the findings of the studies on dynamic balance.

In the present study, it was observed that the lower extremity muscles (tibialis anterior, gastrocnemius medialis, biceps femoris, rectus femoris and gluteus maximus) show sensitivity to perturbation orientation change, while trunk muscles (rectus abdominus and erector spinae) despite slight changes in muscle activity, did not show remarkable sensitivity to perturbation. It is to be noted that changes in muscle activity in response to external stimulus (postural perturbation in this research) do not directly assess the balance performance, but it may indicate the strategy and the pattern of the central nervous system to activate the muscles related to the stimulus.

Previous studies have expressed lower balance performance in kyphotic subjects compared to normal subjects. In this study, the activity of the muscles in a dynamic position that disturb daily balance was evaluated. Of course, this information in combination with other data such as kinematic, physiological, and muscle timing analysis can reveal more accurate interpretation about the balance in the face of postural perturbation.

In conclusion, EMG activity of the muscles studied in kyphotic subjects was higher than that of normal ones. It was also observed that the removal of visual information increased muscle activity in both normal and kyphotic groups. Postural perturbation applied from different directions leads to different muscle behaviors in subjects with thoracic kyphosis compared to normal people. Muscle function should be considered in motor planning for improving the balance of kyphotic subjects.

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