TITLE:

Impairments in trunk muscles performance and proprioception in older adults with hyperkyphosis

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ABSTRACT

Background and objectives: Thoracic hyperkyphosis is one of the most common postural deformities in the geriatric population. This study investigated whether trunk proprioception, muscle strength, and endurance differ between older adults with hyperkyphosis and the age-matched control group. This study also aimed to explore the association of kyphotic posture with muscle performance, position sense, and force sense.

Methods: Ninety-seven elderly volunteers (61 with hyperkyphosis and 36 normal controls) participated in this cross-sectional study. The kyphosis degree, trunk position sense, force sense, back muscle strength, and endurance were assessed in all participants.

Results: The results showed lower back extensor strength and endurance, also higher force and position sense error in the hyperkyphotic group than the control group. In addition, the findings revealed that back extensor strength and endurance, as well as trunk position sense, were associated with kyphotic posture in the hyperkyphotic group.

Discussion and Implications: This study suggests that back extensor strength and endurance and trunk position sense and force sense are potentially modifiable impairments associated with thoracic kyphosis in older adults with hyperkyphosis. It seems monitoring these potentially contributing factors would be helpful in the assessment and treatment of hyperkyphotic older individuals.

Keywords: Thoracic hyperkyphosis, Posture, Back muscles, Proprioception, Repositioning error

Introduction

The human spine is a complex and unstable mechanical structure that cannot withstand a considerable compressive load without stabilizing muscle force (Crisco, Panjabi, Yamamoto, & Oxland, 1992). In particular, the back extensor muscles are the main supportive muscles due to their antigravity function, whose involvement is essential to maintain the erect posture of the spine (Mika, Unnithan, & Mika, 2005). Therefore, it is theoretically logical that a decrease in the capacity of the paraspinal muscles to stabilize the spine causes its deviation from optimal alignments, such as an excessive increase in the forward curvature of the thoracic spine (i.e., hyperkyphosis) (Granito et al., 2012; Hongo, Miyakoshi, Shimada, & Sinaki, 2012). Thoracic hyperkyphosis can occur at any age but is one of the most common postural deformities in the geriatric population, which may affect up to 40% of the elderly (Di Bari et al., 2004; Kado, Prenovost, & Crandall, 2007). Although age-related hyperkyphosis has a multifactorial etiology (Roghani et al., 2017; Woods et al., 2020), previous studies have suggested trunk extensor muscle weakness as a potential factor in developing and progressing kyphotic posture (Granito, Aveiro, Rennó, Oishi, & Driusso, 2014; Mika et al., 2005). In this regard, several studies have found an inverse correlation between back extensor strength and thoracic hyperkyphosis (Granito et al., 2012; Hongo et al., 2012; Sinaki et al., 1996), and some studies have recommended back extensor strengthening exercise as a conservative management option to improve spinal alignment and reduce kyphosis degree (Bennell et al., 2010; Wilhelm et al., 2012).

Back muscle strength is just one aspect of muscle performance, and another aspect is muscle endurance (i.e., fatigue resistance), which has even more discriminative capability than muscle strength (i.e., maximal voluntary contraction force) (Demoulin, Vanderthommen, Duysens, & Crielaard, 2006). A strong association has been found between back extensor endurance and balance performance in the elderly (Suri et al., 2011). Muscle endurance assesses muscle capacity to sustain an isometric contraction and possibly contributes to the severity of kyphosis because prolonged activation of the back extensors is required to maintain an upright posture throughout the day (McIntosh, Wilson, Affieck, & Hall, 1998). However, the measurement of this parameter has been overlooked in the previous literature.

Feedback control is known to be one of the main approaches to stabilize the spine and prevent it from buckling, meaning that sufficient sensory information needs to be transmitted to the controller, here the central nervous system (CNS), to detect the state of the system (here spine) (Reeves, Narendra, & Cholewicki, 2007). This afferent sensory information, derived from the stimulation of mechanoreceptors embedded in the tendon, ligaments, muscle, joint, and skin, is defined as proprioception, which is processed consciously or subconsciously in the CNS (Röijezon, Clark, & Treleaven, 2015). Conscious sub-modalities of proprioception include joint position sense, movement detection (kinesthesia), and force sense. The muscle force sense evaluates the ability to accurately detect the extent of force output (i.e., muscle tension) and reproduce the force needed to stabilize the spine. The position sense determines the ability to perceive trunk positions in space without visual inputs (Riemann & Lephart, 2002). Since proprioception is a fundamental element of sensorimotor control and plays an essential role in controlling posture and movement (Riemann & Lephart, 2002), any proprioceptive deficits are considered effective in reducing the ability to maintain a neutral spinal posture (Granito et al., 2012). Nevertheless, the assessment of these trunk impairments in the elderly with hyperkyphosis has often been neglected in previous studies.

The association of kyphotic posture with muscle performance and proprioception has not been comprehensively investigated so far in a large population. Identifying potentially modifiable variables of hyperkyphosis can enhance the conservative management of this condition, as targeting these risk factors may reduce the risk of spinal deformities and promote a more neutral spinal posture. Thus, the study aimed to investigate whether muscle performance and trunk proprioception among older adults with hyperkyphosis are different from the age-matched control group. Also, this study sought to investigate the associations between the kyphosis degree and the joint position sense, force sense, trunk muscle strength and endurance in older people.

Materials and Methods

Study Participants

The present cross-sectional observational study was conducted between April 2020 to October 2020 at the School of Rehabilitation Sciences, Iran University of Medical Sciences. Using G-power software 3.0.1 (Franz Faul, University of Kiel, Kiel, Germany), the sample size was estimated at 68 (34 subjects per group) with $\alpha = 0.05$, power = 0.8, and effect size = 0.61 (the effect size was estimated based on means and standard deviations of outcome measures from our pilot study, and the smallest effect size was considered for sample size calculation). However, 97 older adults, including 61 older adults with hyperkyphosis and 36 older adults without hyperkyphosis, were ultimately recruited. Adults over the age of 60 who could stand and walk without assistance were included in the study. Exclusion criteria were history of fractures, surgery or trauma to the spine, inflammatory diseases such as ankylosing spondylitis, rheumatoid arthritis, spinal deformities other than hyperkyphosis, cardiopulmonary disease, severe osteoporosis, CNS disease, neuromuscular disorders, diabetic neuropathy and history of taking drugs affecting muscle strength or CNS. The participants received information regarding the study's aims and procedure and then signed written informed consent. To assess eligibility criteria, all participants underwent a comprehensive physical examination by an experienced physical therapist. The physical therapist also measured the degree of thoracic kyphosis. Based on the degree of kyphosis, the participants were divided into two groups of hyperkyphosis (kyphotic angle of more than 50 degrees) and normal age-matched control (kyphotic angle of less than 50 degrees). Then, an assessor, who was blind to the group allocation, measured the primary outcome measures, including trunk position sense, force sense, and trunk muscle strength and endurance. The study protocol was approved by the Human Ethics Committee at the Iran University of Medical Sciences (No: IR. IUMS.REC.1398.276) and followed the principles of the Declaration of Helsinki.

Measurement of the Thoracic Kyphosis Degree

Thoracic kyphosis degree was measured using photogrammetry examination as described in the previous literature (Porto, Okazaki, 2017). Participants took off their upper body clothing and wore an open back gown. Spinous processes of the seventh cervical (C_7) and twelfth thoracic (T_{12}) vertebrae were detected by palpation and marked by a pencil on the skin. Then custom-made lightweight 3-cm long markers were adhered vertically to the skin by double-sided adhesive tape on the spinous processes of the C_7 and T_{12} vertebrae. The participants were asked to stand barefoot in their habitual standing position. The legs were shoulder-width apart, the arms were flexed, and the fists were placed on the clavicle. The camera was fixed at a distance of one meter from the participant's body, but its height was adjusted according to each person's height so that the camera lens was centered on the mid-thoracic vertebrae and the whole spine length was in view. Three photographs were taken by a Nikon camera (Nikon D5300, 24.2-megapixel, Nikon, Thailand) from the right side of the participants during inhalation. Digital photographic records were imported to AutoCAD software. The angle formed between the intersections of the straight-line extensions drawn from the markers at the C_7 and T_{12} vertebrae was measured as the thoracic kyphosis angle (TKA).

Position Sense

Position sense was assessed by the active angle reproduction test, which measures a person's ability to reproduce a pre-determined target position. To evaluate the repositioning test, female participants were asked to wear a sports bra and male participants were asked to remove their upper body clothing during the test. The participants were instructed to sit on an adjustable chair in their normal upright posture. This chair had a short backrest to limit lumbo-pelvic motion. The contact of the participant's lumbo-pelvic region to the chair's backrest was monitored by a switch mounted on the chair's backrest that turns a light. The hips and knees were at 90° flexion, the arms were crossed over the chest, and the fingertips touched the shoulder. A custom-made lightweight 3-cm long marker was adhered to the spinous process of C_7 by double-sided adhesive tape. The camera was located at the height of 1 meter from the ground and a distance of 1 meter from the imaginary line perpendicular to the chair's backrest (Figure 1). The right side of the participant's body was facing the camera. The participants adopted their neutral, upright posture, focused on this posture, and maintained this position for 5 seconds. In this condition, a photograph was taken using the camera. The participants then performed maximum flexion and/or extension without any pain or discomfort and without detaching the lumbo-pelvic region from the chair's backrest at their preferred speed while maintaining a neutral neck position. Later, they relocated the initial neutral position as accurately as possible, informing the examiner by pressing the handheld button of the laser pointer in their left hand, and the camera then captured a photograph. The participants received no feedback on their performance. Six trials were repeated for each direction from trunk flexion to neutral position or from trunk extension to a neutral position. The order of trunk flexion or trunk extension was chosen randomly. The participants were blindfolded to remove the effect of visual clues. To minimize the effects of diurnal variation, we evaluated position sense at least three hours after waking up. In addition, the participants were asked to avoid strenuous physical activity for 24 hours before testing and eating or drinking for 2 hours before testing.

The photograph records were imported into the Paint software. The marker position in the paint software for each photograph was extracted on the abscissa (X-axis) and ordinate (Y-axis) in pixel, and then converted to centimeters. Then, in a customized program developed in Excel, using these two values, the global components (i.e., the linear length extending from the reference point to the marker location) were calculated by the equation of $R = \sqrt{x^2 + Y^2}$. Using trigonometric laws (i.e., tangent^{-1} $R/_{100}\,cm$), repositioning errors were calculated in degrees (Figures 2 A-B). Absolute error (AE) and variable error (VE) indices were applied to quantify position sense acuity. The AE is a measure of the overall accuracy of repositioning performance, which has been reported as the primary outcome measure in most previous studies (Mousavi-Khatir et al., 2018; Strimpakos et al., 2006). This measure shows how close the person's responses are to the target, which is measured by calculating the average absolute deviation between the person's responses and the target. The best possible score for repositioning accuracy is zero, and higher AE values indicate less accurate repositioning performance. The VE is a measure of the consistency (i.e., variability) of repositioning. This index quantifies the variability of participants' performance around their mean response. Higher VE values indicate less consistent repositioning performance. The AE and VE indices along the global, horizontal and vertical components were calculated in degrees.

<Figures 1and 2 about here>

Back Muscle Strength (Maximal Voluntary Contraction Force)

Back extensor strength was measured by the “S” shape load cell in a sitting position. Our designed setup consisted of a chair with a 25 cm high backrest, with two vertical bars firmly attached to the backrest, a board with a hole in the center to hold the load cell mounted on the vertical bars, with the height of the board and the load cell adjusted to the vertical bars according to the height of the participants via a rail bar (Figure 3). For the convenience of the participants and to minimize the local bony pressure, the load cell was covered with a pad of high-density foam. Before the test, a warm-up of the back extensor muscles was performed for 2 minutes, and the load cell was calibrated before each data collection. The participants sat on the chair, their hips and knees flexed 90 degrees, and their thighs were parallel to the seat. The arms were crossed on the abdomen, and the height of the chair was designed so that the participants’ feet were off the ground. In order to restrain movement, the leg, thigh, and pelvis were tightened with inelastic belts and straps. After positioning the participant on the chair in the neutral, upright posture, the load cell position was adjusted on the vertical bars to align with the spinous process of the T_7 vertebra. The participants were asked to gradually increase their backward force over 1-3 seconds upon hearing a “beep” sound, and then maintain the maximum force for 5 seconds and gradually relax over 1-3 seconds. To prevent fatigue, a 30-second pause was given until the start of the subsequent trial. For each trial, peak back extensor force (kg) was recorded. If the maximum trial was more than 5% higher than either of the previous two trials, an additional trial would be conducted. Three successive trials were performed. Participants were familiarized with the testing procedure by performing a practice trial before data recording. All assessments were performed following a standardized procedure. During each effort, the participants received verbal encouragement and visual feedback (displaying force output on the monitor) to achieve maximum force.

<Figure 3 about here>

Trunk Muscle Endurance Test

Trunk muscle extensor endurance was assessed by three different methods, including designed load cell setup, Ito test, and timed loaded standing (TLS) test.

Muscle Endurance Measured via Load Cell

After measuring the maximum extensor force, a 30-minute rest was considered to minimize the effect of fatigue on the outcome measure. The participants were then asked to perform a sustained contraction at 50% of their maximum force to assess back muscle endurance. After a single familiarization trial, three endurance trials with 30-second rest between trials were performed, followed by recording maximum endurance time (in seconds). During the endurance test, the test would stop when the person could not maintain more than 40% of their maximum force.

Ito Test

This is a prone trunk holding test as a modification of the Biering-Sorenson method (Ito et al., 1996). The participants were placed in a prone position with a small pillow under their lower abdomen with their arms at their sides (Figure 4). The participants lifted their sternum off the ground upon hearing the “start” command. During the test, they needed to maintain maximum flexion of the cervical spine and contract the gluteal muscles to stabilize the pelvis. The participants were asked to hold this position as long as they could, but not more than a 300-second limit. Duration was recorded in seconds using a handheld stopwatch.

<Figure 4 about here>

Timed Loaded Standing (TLS) Test

Shipp et al. (Shipp et al., 2000) designed a reliable and valid measure of the combined trunk and arm endurance test called the timed loaded standing (TLS) test for people with vertebral osteoporosis. TLS measures the length of time a person can stand, holding a 1-kg dumbbell in each hand with shoulders flexed up to 90 degrees, elbows extended, and wrists in neutral pronation/supination.

Force Sense

To assess force sense, the position of the participants was exactly what they had adopted to measure back muscle strength by designed load cell setup. Moreover, 50% of participants' maximal force was considered as the target force for the force reproduction task. First, for familiarization, while receiving visual feedback, they were asked to generate 50% of their maximum force and then hold it for 5 seconds, focus on the amount of applied force, and memorize it. Then, visual feedback was removed for data recording, and participants were asked to generate the same amount of force and notify the examiner when they reach the target force and hold it for 5 seconds. No verbal encouragement was provided during this force reproduction task, and the test environment was completely quiet. A one-minute pause was given between trials to minimize the effect of muscle fatigue on participants' performance. The force sense was described using the AE and VE indices. The AE was quantified by initially calculating the absolute difference between participants' peak force in each trial and the pre-determined target force, and then the average values of these deviations. The VE value was obtained by calculating the difference between participants' peak force per trial and their average score.

Statistical Analysis

Statistical analyses were performed using SPSS software. All data were encoded to blind the statistician and prevent analysis bias. Shapiro-Wilk test and residual plot assessment were executed to verify the normal distribution of variables. Independent t-test or Mann-Whitney U-test were used for between-group comparisons of demographic and dependent variables. Spearman correlation test was performed to examine the correlation between thoracic kyphosis angle and other outcome measures. Correlation size was interpreted as follows: 0.00 – 0.10 negligible, 0.10 – 0.39 weak, 0.40 – 0.69 moderate, 0.70 – 0.89 strong, 0.90 – 1.00 very strong correlation (Schober, Boer, Schwarte, 2018). The level of statistical significance was set at $p < 0.05$.

Results

A total of 167 older adults (114 women and 53 men) were screened from April to October 2020, and 97 of them (61 older adults with hyperkyphosis and 36 older adults without hyperkyphosis) were eligible and willing to participate in this cross-sectional study (Figure 5). Demographic variables followed a normal distribution pattern in both groups with no significant between-group differences (Table 1). None of the dependent variables of TKA, JPS, force sense, and back muscle strength and endurance showed a statistically normal distribution in neither group. Some dependent variables, including TKA, JPS, force sense, and back muscle strength and endurance, were not normally distributed. Mann-Whitney U test showed significant differences in JPS, force sense, back muscle strength and endurance between the groups (Table 2). The AE and VE values were higher in the force reproduction assessment and repositioning test for the elderly with hyperkyphosis, indicating poor proprioception in them compared with the control group. In addition, peak extensor force (i.e., muscle strength) and endurance time in the elderly with hyperkyphosis were lower than the age-matched control group. There were moderate negative correlations between TKA with muscle peak extensor force and endurance time of the TLS test, also weak negative correlations between TKA and endurance time for the Ito test and designed load cell setup. Furthermore, these findings showed positive correlations between TKA and JPS (i.e., AE and VE indices) for horizontal and global components, especially when reproducing a neutral trunk position from a trunk flexed position (Table 3).

<Figure 5 about here>

<Tables 1-3 about here>

Discussion

The purpose of the current study was to investigate whether trunk proprioception, muscle strength, and endurance differ between the elderly with hyperkyphosis and the age-matched control group. This study also aimed to explore associations of kyphotic posture with muscle performance, position sense, and force sense. The results showed that the elderly with hyperkyphosis had lower back extensor strength and endurance and higher force sense error and position sense error than the control group. Moreover, the results revealed associations between kyphotic posture and trunk position sense, back extensor strength and endurance.

Lower back extensor strength in the elderly with hyperkyphosis compared to the controls and its correlation with the kyphotic posture found in the present study supports the previous body of literature (Granito et al., 2012; Hongo et al., 2012; Mika et al., 2005; Sinaki et al., 1996). Previous studies have suggested the association of back extensor muscle weakness and greater thoracic kyphosis angle (Granito et al., 2012; Sinaki et al., 1996). However, the causality relationship is unclear due to the cross-sectional design of those studies. The decrease in back muscle strength and in the ability of these muscles to extend the thoracic spine may cause development and progression of this deformity (Greig, Bennell, Briggs, & Hodges, 2008), or conversely, kyphotic posture has a detrimental effect on the force-generating capacity of these muscles through changes in length-tension relationships, force vector orientation and moment arm length (McGill, Hughson, & Parks, 2000; O’Sullivan et al., 2002; Tveit, Daggfeldt, Hetland, & Thorstensson, 1994). Thus, this ineffectual muscle force generation, in turn, may cause further progression of spinal deformity and trap the patient in a vicious circle.

Comprehensive assessment of muscle performance should include strength, endurance, and muscle force reproduction in addition to traditional assessments. However, these aspects of muscle performance have often been overlooked in the previous literature. Therefore, it is impossible to compare the finding of lower back muscle endurance with the previous literature. It is well-known that back extensor muscles are the main supportive factors of the spine and their prolonged activation is required to maintain the upright posture of the spine throughout the day due to their antigravity function (Balzini et al., 2003; Granito et al., 2012). Increased forward spinal curvature and leaning forward in the elderly with hyperkyphosis may elevate the demand on back extensor muscles to maintain an upright posture, resulting in fatigue and decreased ability to sustain isometric contraction (i.e., poorer back muscle endurance) (Takahashi, Kikuchi, Sato, & Iwabuchi, 2007). In this regard, Enomoto et al. (Enomoto et al., 2012) suggested higher lumbar erector spinae muscle activity and consequent muscular fatigue in people with age-related lumbar kyphosis.

Reduced back muscle endurance (BME) hypothesis suggests reduced muscle activity as a contributing factor in poorer BME (Roghani et al., 2017). This view justifies the reduction of back extensor activity based on flexion-relaxation response to flexed trunk posture, and adopting a flexed posture increases the demand on passive spinal structures and relaxes the back extensor muscles (Callaghan & Dunk, 2002; O’Sullivan et al., 2002), which in the long run leads to deconditioning of the back musculature (Callaghan & Dunk, 2002; O’Sullivan et al., 2002). In addition, the literature suggests that emotional status may mediate BME test performance (Edmondston et al., 2011). Since the kyphotic posture itself may be associated with psychological factors such as depression (Balzini et al., 2003; Smith, O’Sullivan, Campbell, Straker, 2010), lower

BME in the elderly with hyperkyphosis may be partly attributable to emotional status. In the present study, the endurance time of the TLS and Ito tests showed the highest and the lowest correlation with TKA, respectively. This finding confirms the evidence that upper limb and torso weight may be a confounding factor in a prone trunk holding test such as the Ito test (Juan-Recio, Barbado Murillo, López-Valenciano, & Vera-García, 2014). On the other hand, although the TLS test is defined as a combined measure of trunk and arm endurance, electromyography findings indicate that the endurance time in the TLS test is strongly associated with erector spinae fatigue (Newman, Newman, Hughes, Vadher, & Barker, 2018).

Concerning proprioception, the present study's findings showed impaired spinal position sense and force sense in the elderly with hyperkyphosis compared with the control group. Since the muscle spindles of contracting muscles play an important role in providing sensory information for the awareness of trunk position and muscle tension (Gandevia, McCloskey, & Burke, 1992), impaired position sense and force sense in the elderly with hyperkyphosis may be partly explained by back extensor muscle dysfunction. For example, there is evidence that decreasing endurance and increasing the fatigability of the back muscles may disrupt the afferent input provided by muscle spindles and cause poor proprioception (Taimela, Kankaanpää, & Luoto, 1999). In this regard, previous studies have shown that muscle fatigue has degraded the position sense and force sense in different regions of the body (Boucher, Abboud, Nougarou, Normand, & Descarreaux, 2015; Taimela et al., 1999; Vuillerme, Boisgontier, 2008). Besides, given that muscle spindles are sensitive to changes in muscle length, the back muscle lengthening as a result of constant forward bending may have caused mechanoreceptor dysfunction (Dolan & Green, 2006).

The present study results indicate the multifactorial etiology of age-related hyperkyphosis and confirm this geriatric syndrome is not equivalent to vertebral fracture. This study also suggests that back extensor strength and endurance, and trunk position sense and force sense are potentially modifiable impairments associated with thoracic kyphosis in the elderly. Although the factors examined in the present study together account for approximately 60% of age-related hyperkyphosis, the effects of other factors on kyphosis, including intervertebral disc degeneration, decreased spinal extension mobility, and low bone mineral density, should not be overlooked.

Limitation

The gold standard for measuring TKA is the Cobb radiographic method, but it is not safe because of radiation exposure. So, we measured TKA by photogrammetry technique which provided a safe and accurate measure of thoracic kyphosis. Furthermore, for assessing trunk position sense, the target was set in neutral trunk posture, and movement was performed only in the sagittal plane. However, given that kyphotic posture occurs in the sagittal plane and affects soft tissues in this plane, we chose to assess in the sagittal plane because the ability to return from a trunk flexed and or extended posture was more relevant than the movement in the transverse or frontal planes.

Conclusion

The results of this study suggest reduced trunk position sense, force sense, and back muscle strength and endurance in older adfults with hyperkyphosis, and these characteristics are correlated with the kyphosis degree. Thus, it seems that monitoring these potentially contributing factors would be beneficial in assessing and treating older hyperkyphotic individuals. Clinical studies are needed to investigate relevant interventions to improve these factors over time.

Competing interests

The authors declare that they have no competing interests.

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REFERENCES

Balzini, L., Vannucchi, L., Benvenuti, F., Benucci, M., Monni, M., Cappozzo, A., & Stanhope, S. J. (2003). Clinical characteristics of flexed posture in elderly women. Journal of the American Geriatrics Society *51*(10), 1419-1426.

Bennell, K. L., Matthews, B., Greig, A., Briggs, A., Kelly, A., Sherburn, M., . . . Wark, J. (2010). Effects of an exercise and manual therapy program on physical impairments, function and quality-of-life in people with osteoporotic vertebral fracture: a randomised, single-blind controlled pilot trial. BMC Musculoskeletal Disorders *11*(1), 1-11.

Boucher, J.-A., Abboud, J., Nougarou, F., Normand, M. C., & Descarreaux, M. (2015). The effects of vibration and muscle fatigue on trunk sensorimotor control in low back pain patients. Plos One Journal *10*(8), e0135838.

Callaghan, J. P., & Dunk, N. M. (2002). Examination of the flexion relaxation phenomenon in erector spinae muscles during short duration slumped sitting. Clinical Biomechanics *17*(5), 353-360.

Crisco, J., Panjabi, M., Yamamoto, I., & Oxland, T. (1992). Euler stability of the human ligamentous lumbar spine. Part II: Experiment. Clinical Biomechanics *7*(1), 27-32.

Demoulin, C., Vanderthommen, M., Duysens, C., & Crielaard, J.-M. (2006). Spinal muscle evaluation using the Sorensen test: a critical appraisal of the literature. Joint Bone Spine Journal *73*(1), 43-50.

Di Bari, M., Chiarlone, M., Matteuzzi, D., Zacchei, S., Pozzi, C., Bellia, V., . . . Marchionni, N. J. (2004). Thoracic kyphosis and ventilatory dysfunction in unselected older persons: an epidemiological study in Dicomano, Italy. Journal of the American Geriatrics Society *52*(6), 909-915.

Dolan, K. J., & Green, A. (2006). Lumbar spine reposition sense: the effect of a 'slouched'posture. Journal of Manual Therapy *11*(3), 202-207.

Edmondston, S., Björnsdóttir, G., Pálsson, T., Solgård, H., Ussing, K., & Allison, G. J. M. t. (2011). Endurance and fatigue characteristics of the neck flexor and extensor muscles during isometric tests in patients with postural neck pain. *16*(4), 332-338.

Enomoto, M., Ukegawa, D., Sakaki, K., Tomizawa, S., Arai, Y., Kawabata, S., . . . Okawa, A. (2012). Increase in paravertebral muscle activity in lumbar kyphosis patients by surface electromyography compared with lumbar spinal canal stenosis patients and healthy volunteers. Clinical Spine Surgery *25*(6), E167-E173.

Gandevia, S., McCloskey, D., & Burke, D. (1992). Kinaesthetic signals and muscle contraction. Trend in Neurosciences *15*(2), 62-65.

Granito, R. N., Aveiro, M. C., Renno, A. C. M., Oishi, J., Driusso, P. (2012). Comparison of thoracic kyphosis degree, trunk muscle strength and joint position sense among healthy and osteoporotic elderly women: a cross-sectional preliminary study. Archives of Gerontology and Geriatrics *54*(2), e199-e202.

Granito, R. N., Aveiro, M. C., Rennó, A. C. M., Oishi, J., & Driusso, P. (2014). Degree of thoracic kyphosis and peak torque of trunk flexors and extensors among healthy women. Revista Brasileira de Ortopedia *49*(3), 286-291.

Greig, A. M., Bennell, K. L., Briggs, A. M., & Hodges, P. W. (2008). Postural taping decreases thoracic kyphosis but does not influence trunk muscle electromyographic activity or balance in women with osteoporosis. Journal of Manual Therapy *13*(3), 249-257.

Hongo, M., Miyakoshi, N., Shimada, Y., & Sinaki, M. (2012). Association of spinal curve deformity and back extensor strength in elderly women with osteoporosis in Japan and the United States. Osteoporosis International *23*(3), 1029-1034.

Ito, T., Shirado, O., Suzuki, H., Takahashi, M., Kaneda, K., Strax, T. E. (1996). Lumbar trunk muscle endurance testing: an inexpensive alternative to a machine for evaluation. Archives of Physical Medicine and Rehabilitation *77*(1), 75-79.

Juan-Recio, C., Barbado Murillo, D., López-Valenciano, A., & Vera-García, F. J. (2014). Field test to assess the strength of trunk muscles. Apunts. Educación Física y Deportes (117), 59-68.

Kado, D. M., Prenovost, K., & Crandall, C. (2007). Narrative review: hyperkyphosis in older persons. Annals of Internal Medicine *147*(5), 330-338.

McGill, S. M., Hughson, R. L., & Parks, K. (2000). Changes in lumbar lordosis modify the role of the extensor muscles. Journal of Clinical Biomechanics *15*(10), 777-780.

McIntosh, G., Wilson, L., Affieck, M., & Hall, H. (1998). Trunk and lower extremity muscle endurance: normative data for adults. Journal of rehabilitation outcomes measurement *2*(4), 20-39.

Mika, A., Unnithan, V. B., & Mika, P. (2005). Differences in thoracic kyphosis and in back muscle strength in women with bone loss due to osteoporosis. Spine *30*(2), 241-246.

Mousavi-Khatir, R., Talebian, S., Toosizadeh, N., Olyaei, G. R., Maroufi, N. (2018). Disturbance of neck proprioception and feed-forward motor control following static neck flexion in healthy young adults. Journal of Electromyography and Kinesiology *41*, 160-167.

Newman, M., Newman, R., Hughes, T., Vadher, K., & Barker, K. (2018). Is the timed loaded standing test a valid measure of back muscle endurance in people with vertebral osteoporosis? Osteoporosis International *29*(4), 893-905.

O'Sullivan, P. B., Grahamslaw, K. M., Kendell, M., Lapenskie, S. C., Möller, N. E., & Richards, K. (2002). The effect of different standing and sitting postures on trunk muscle activity in a pain-free population. Spine *27*(11), 1238-1244.

Porto, A. B., Okazaki, V. H. A (2017). Procedures of assessment on the quantification of thoracic kyphosis and lumbar lordosis by radiography and photogrammetry: A literature review. Journal of Bodywork and Movement Therapies *21*(4), 986-994.

Reeves, N. P., Narendra, K. S., & Cholewicki, J. (2007). Spine stability: the six blind men and the elephant. Clinical Biomechanics *22*(3), 266-274.

Riemann, B. L., & Lephart, S. (2002). The sensorimotor system, part I: the physiologic basis of functional joint stability. Journal of Athletic Training *37*(1), 71.

Roghani, T., Zavieh, M. K., Manshadi, F. D., King, N., Katzman, W. (2017). Age-related hyperkyphosis: update of its potential causes and clinical impacts—narrative review. Aging Clinical and Experimental Research *29*(4), 567-577.

Röijezon, U., Clark, N. C., & Treleaven, J. (2015). Proprioception in musculoskeletal rehabilitation. Part 1: Basic science and principles of assessment and clinical interventions. Journal of Manual Therapy *20*(3), 368-377.

Schober, P., Boer, C., Schwarte, L. A. (2018). Correlation coefficients: appropriate use and interpretation. Anesthesia & Analgesia *126*(5), 1763-1768.

Shipp, K., Purser, J., Gold, D., Pieper, C., Sloane, R., Schenkman, M., & Lyles, K. (2000). Timed loaded standing: a measure of combined trunk and arm endurance suitable for people with vertebral osteoporosis. Osteoporosis International *11*(11), 914-922.

Sinaki, M., Itoi, E., Rogers, J. W., Bergstralh, E. J., Wahner, H. W. (1996). Correlation of back extensor strength with thoracic kyphosis and lumbar lordosis in estrogen-deficient women. American Journal of Physical Medicine & Rehabilitation *75*(5), 370-374.

Smith, A. J., O'Sullivan, P. B., Campbell, A. C., Straker, L. M. (2010). The relationship between back muscle endurance and physical, lifestyle, and psychological factors in adolescents. Journal of Orthopaedic & Sports Physical Therapy *40*(8), 517-523.

Strimpakos, N., Sakellari, V., Gioftsos, G., Kapreli, E., Oldham, J. (2006). Cervical joint position sense: an intra-and inter-examiner reliability study. Gait & posture *23*(1), 22-31.

Suri, P., Kiely, D. K., Leveille, S. G., Frontera, W. R., Bean, J. F. (2011). Increased trunk extension endurance is associated with meaningful improvement in balance among older adults with mobility problems. Archives of Physical Medicine and Rehabilitation *92*(7), 1038-1043.

Taimela, S., Kankaanpää, M., & Luoto, S. (1999). The effect of lumbar fatigue on the ability to sense a change in lumbar position: a controlled study. Spine *24*(13), 1322.

Takahashi, I., Kikuchi, S.-i., Sato, K., & Iwabuchi, M. (2007). Effects of the mechanical load on forward bending motion of the trunk: comparison between patients with motion-induced intermittent low back pain and healthy subjects. Spine *32*(2), E73-E78.

Tveit, P., Daggfeldt, K., Hetland, S., & Thorstensson, A. (1994). Erector spinae lever arm length variations with changes in spinal curvature. Spine *19*(2), 199-204.

Vuillerme, N., Boisgontier, M. (2008). Muscle fatigue degrades force sense at the ankle joint. Gait & Posture *28*(3), 521-524.

Wilhelm, M., Roskovensky, G., Emery, K., Manno, C., Valek, K., & Cook, C. (2012). Effect of resistance exercises on function in older adults with osteoporosis or osteopenia: a systematic review. Physiotherapy Canada *64*(4), 386-394.

Woods, G. N., Huang, M. H., Lee, J. H., Cawthon, P. M., Fink, H. A., Schousboe, J. (2020). Factors Associated With Kyphosis and Kyphosis Progression in Older Men: The MrOS Study. Journal of Bone and Mineral Research *35*(11), 2193-2198.

Table 1. Demographic characteristics of participants.

	Hyperkyphosis group (n=61)	Normal control group (n=36)
Sex (Male/Female)	49/12	25/11
Age (year)	68.02 ± 5.59	66.72 ± 4.45
Height (cm)	160.5 ± 7.08	162.63 ± 6.87
Body weight (kg)	68.38 ± 12.81	68.02 ± 9.46
Body mass index (kg/m^2)	26.38 ± 3.12	25.74 ± 3.59

Table 2. Mean ± SD, and comparison of the dependent variables between two groups.

			Hyperkyphosis group (n= 61)	Normal control group (n= 36)	p-value
Thoracic kyphosis angle			72.19 ± 9.20	41.35 ± 4.84	<0.001
Maximal extensor force / muscle strength			24.59 ± 10.62	37.47 ± 15.01	<0.001
Back extensor endurance measured via load cell			52.39 ± 35.60	99.58 ± 90.74	0.005
Endurance time of Ito test			123.96 ± 96.87	197.05 ± 91.60	<0.001
Endurance time of TLS test			97.88 ± 72.55	175.36 ± 93.25	<0.001
Force sense		**AE**	3.09 ± 2.28	1.88 ± 1.00	0.012
		VE	1.87 ± 1.44	1.33 ± 0.87	0.105
Reproduction trunk neutral position from a trunk flexed position	**Horizontal**	**AE**	1.10 ± 0.70	0.71 ± 0.46	0.001
		VE	2.43 ± 1.60	1.60 ± 1.21	0.001
	Vertical	**AE**	0.29 ± 0.34	0.27 ± 0.22	0.794
		VE	0.66 ± 0.79	0.57 ± 0.34	0.633
	Global	**AE**	1.20 ± 0.74	0.94 ± 0.61	0.044
		VE	2.62 ± 1.70	1.62 ± 0.94	0.001
Reproduction trunk neutral position from a trunk extended position	**Horizontal**	**AE**	1.68 ± 0.98	0.99 ± 0.66	<0.001
		VE	3.67 ± 2.31	2.48 ± 1.59	0.011
	Vertical	**AE**	0.38 ± 0.29	0.47 ± 0.37	0.241
		VE	0.87 ± 0.68	0.96 ± 0.67	0.420
	Global	**AE**	1.78 ± 0.96	1.29 ± 0.69	0.020
		VE	3.82 ± 2.28	2.63 ± 1.59	0.012

Table 3. Correlation analysis of thoracic kyphosis angle with, back extensor strength, endurance, position sense and force sense.

			Thoracic kyphosis angle		
			p-value	**r**	r^2
Maximal back extensor force / muscle strength			<0.001	-0.40	0.16
Muscle endurance measured via load cell			<0.001	-0.38	0.14
Endurance time of Ito test			0.028	-0.22	0.04
Endurance time of TLS test			<0.001	-0.43	0.18
Force sense		**AE**	0.004	0.28	0.07
		VE	0.117	0.16	0.02
Reproduction trunk neutral position from a trunk flexed position	**Horizontal (X)**	**AE**	<0.001	0.40	0.16
		VE	<0.001	0.42	0.17
	Vertical (Y)	**AE**	0.898	-0.01	0.0001
		VE	0.79	-0.02	0.0004
	Global	**AE**	0.002	0.31	0.09
		VE	<0.001	0.41	0.16
Reproduction trunk neutral position from a trunk extended position	**Horizontal (X)**	**AE**	0.001	0.32	0.10
		VE	0.016	0.24	0.05
	Vertical (Y)	**AE**	0.253	-0.11	0.01
		VE	0.42	-0.082	0.006
	Global	**AE**	0.053	0.19	0.03
		VE	0.040	0.20	0.04

FIGURES

Figure 1. The experimental setup for trunk repositioning test.

Figure 2. Assessing isometric back extensor strength and endurance using the designed setup.

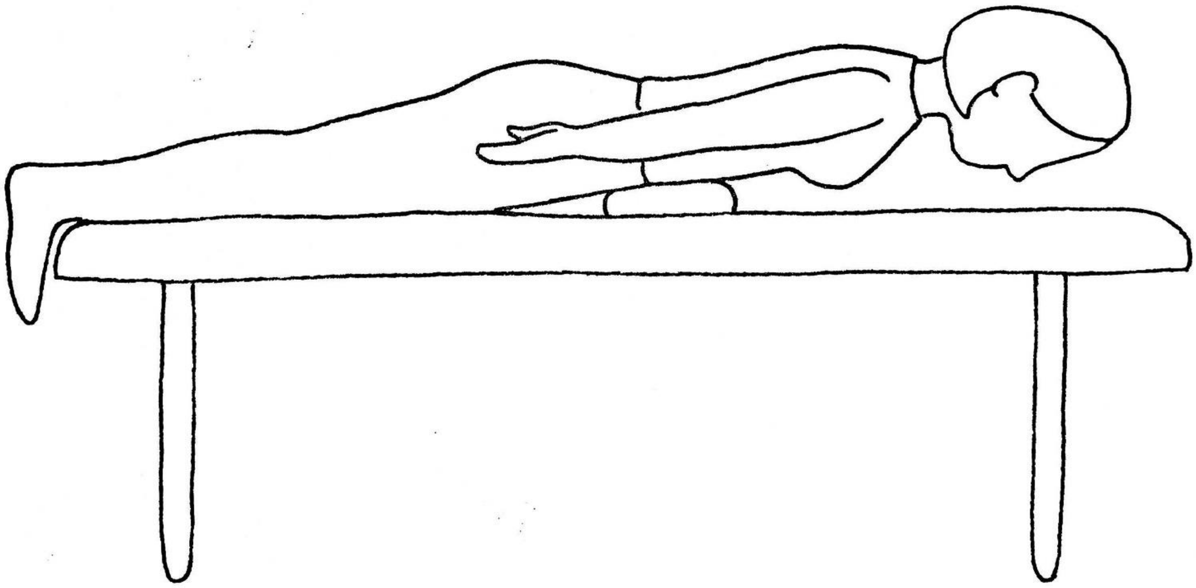

Figure 3. The test position of the Ito test.

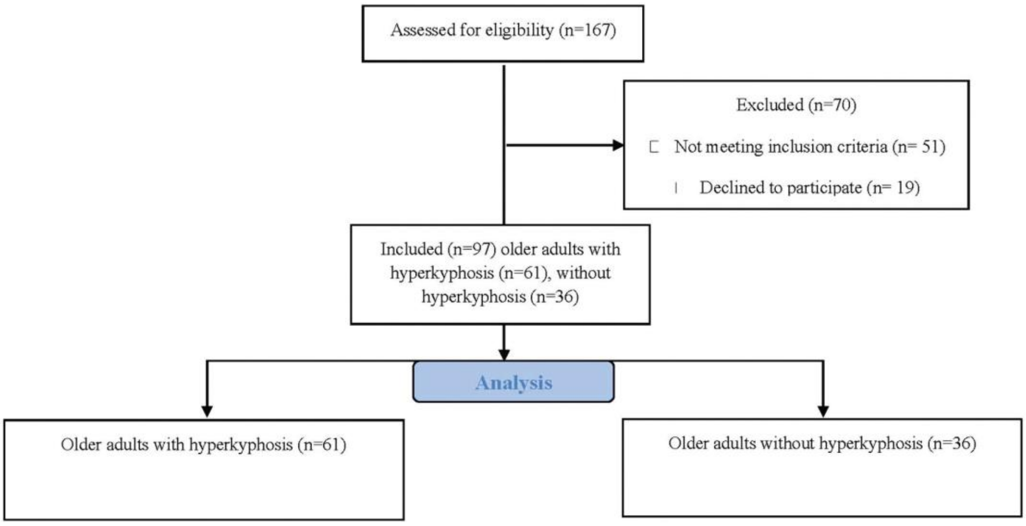

Figure 4. Flow diagram of participants' screening.