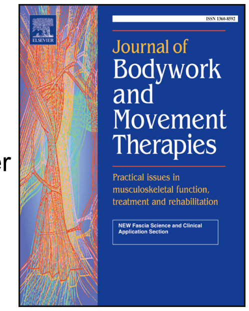
Journal Pre-proof



Test-retest reliability of a novel method for trunk position sense measurement in older adults with and without hyperkyphosis

Fatemeh Keshavarzi, Fatemeh Azadinia, Saeed Talebian, Omid Rasouli

PII: S1360-8592(23)00014-1

DOI: https://doi.org/10.1016/j.jbmt.2023.02.002

Reference: YJBMT 2506

To appear in: *Journal of Bodywork & Movement Therapies*

Received Date: 12 December 2021

Revised Date: 10 October 2022

Accepted Date: 5 February 2023

Please cite this article as: Keshavarzi, F., Azadinia, F., Talebian, S., Rasouli, O., Test-retest reliability of a novel method for trunk position sense measurement in older adults with and without hyperkyphosis, *Journal of Bodywork & Movement Therapies* (2023), doi: https://doi.org/10.1016/j.jbmt.2023.02.002.

Test-retest reliability of a novel method for trunk position sense measurement in older adults with and without hyperkyphosis

Fatemeh Keshavarzi[a], Fatemeh Azadinia*[a], Saeed Talebian[b], Omid Rasouli[c]

[a] Rehabilitation Research Center, Department of Orthotics and Prosthetics, School of Rehabilitation Sciences, Iran University of Medical Sciences, Tehran, Iran. keshavarzifatemeh999@gmail.com

[a] Rehabilitation Research Center, Department of Orthotics and Prosthetics, School of Rehabilitation Sciences, Iran University of Medical Sciences, Tehran, Iran. azadinia.fatemeh@yahoo.com, azadinia.f@iums.ac.ir, ORCID: 0000-0003-2513-7137

[b] Department of Physiotherapy, School of Rehabilitation, Tehran University of Medical Sciences and Health Services, Tehran, Iran. talebian@tums.ac.ir, ORCID: 0000-0002-4945-8085

[c] Department of Neuromedicine and Movement Science, Faculty of Medicine and Health Sciences, Norwegian University of Science and Technology, Trondheim, Norway. omid.rasouli@ntnu.no, ORCID: 0000-0003-2203-1839

Correspondence: Fatemeh Azadinia, Assistant Professor in Orthotics and Prosthetics, Rehabilitation Research Center, Department of Orthotics and Prosthetics, School of Rehabilitation Sciences, Iran University of Medical Sciences, Tehran, Iran; Email: azadinia.f@iums.ac.ir; azadinia.fatemeh@yahoo.com Phone Number: +982122228051

Test-retest reliability of a novel method for trunk position sense measurement in older adults with and without hyperkyphosis

ABSTRACT

Introduction: Although the importance of trunk position sense as a clinical outcome measure related to spinal alignment has been established, there is no study evaluating the reliability of measurement techniques for trunk position sense in older adults. Hyperkyphosis is most prevalent in this population and is associated with adverse consequences.

Objective: This study aimed to investigate the test-retest reliability of a measurement technique consisting of photogrammetry and angle calculation in older adults with and without hyperkyphosis.

Methods: Fifty-three older adults completed the tests. Participants actively reproduced a trunk neutral position (TNP) from both a trunk extended position and a trunk flexed position. Absolute error (AE) and variable error (VE) indices were calculated to quantify position sense acuity. Intraclass Correlation Coefficient was used to estimate relative reliability. Absolute reliability was assessed by calculating Standard Error of the Measurements (SEM) and Minimal Detectable Change (MDC).

Results: The digital photogrammetry showed excellent reliability for horizontal and global components of AE in both hyperkyphosis and control groups while reproducing the TNP from trunk flexion. Also, there was good reliability for AE and VE in the hyperkyphosis group when moving to the TNP from the trunk extension. The MDC values for AE ranged from 0.32 to 0.44 while reproducing the TNP from trunk flexion. The MDC values for AE ranged up to 0.96 when reproducing the TNP from trunk extension.

Conclusion: This study suggests that digital photogrammetry is a reliable method with clinical applicability, which allows the detection of changes after clinical interventions.

Keywords: Hyperkyphosis; Proprioception; Position sense; Reliability; Reproducibility of Results

1. Introduction

Proprioception is commonly used to describe afferent neural information derived from the stimulation of mechanoreceptors in joints, tendons, muscles, ligaments, and skin (Sherrington 1952). This sensory information is transmitted to the central nervous system (CNS) for processing and integration with other somatosensory, visual and vestibular information (Shumway-Cook and Woollacott 1995). Conscious components of proprioception include joint position sense (JPS), kinesthesia (detection of joint movement), and force sense (ability to detect the amount of muscle tension accurately) (Kandel et al. 2000, Riemann and Lephart 2002, Roijezon et al. 2015). Among these proprioception components, perception of position and relative orientation of body parts in space, called JPS, play an essential role in attaining and maintaining optimal body alignment (Dolan and Green 2006, Granito et al. 2012, Korakakis et al. 2017, Wong et al. 2019). Accordingly, there is evidence that JPS is associated with thoracic kyphosis angle in the elderly with hyperkyphosis (Granito et al. 2012). It is unclear whether a decline in proprioception information is a predisposing factor to this spinal deformity or, conversely, changes in muscle length and even muscle endurance (i.e., fatigue resistance) and the consequent decrease in muscle spindle excitability due to hyperkyphotic posture have led to abnormal afferent information originating from muscle receptors and consequently impaired proprioception (Taimela et al. 1999, Reddy et al. 2012, Boucher et al. 2015, Larson 2018). In any case, people appear to be trapped in a vicious circle, and impaired trunk position sense has reduced the ability to maintain an upright spinal posture in the elderly with hyperkyphosis. Age-related hyperkyphosis is associated with significant health consequences such as decreased respiratory function, impaired physical performance, gait, and balance disturbances, and, consequently, increased risk of falls and mortality (Katzman et al. 2010, Roghani et al. 2017). Thus, detection and monitoring of potential contributing factors to the development or progression of hyperkyphosis in older adults is vital (Britnell et al. 2005). Proprioception is considered an important clinical outcome measure in this population (Granito et al. 2012, Keshavarzi et al. 2022a, Keshavarzi et al. 2022b), especially since rehabilitation programs can contribute to proprioception improvement (Hosseinabadi et al. 2020). Therefore, valid and reliable measurement techniques for assessing proprioception are essential for clinicians to monitor interventions' effectiveness.

The JPS is assessed by repositioning accuracy, which measures a person's ability to actively and/or passively reproduce a predetermined target position. The error in reproducing the target position is defined as a repositioning accuracy error. Previous literature suggests that JPS assessment during active movement is functionally more relevant than assessment during passive movement by an external device, as these conditions stimulate both joint receptors and muscle receptors (Rix and Bagust 2001, Strimpakos et al. 2006). Various methods such as electrogoniometry, isokinetic dynamometry, dual inclinometer, 3-Space Fastrak, and digital photography were employed to evaluate JPS in different body segments like shoulder, knee, ankle, and spine (Swinkels and Dolan 1998, Brumagne et al. 1999, Relph and Herrington 2015, Ghamkhar et al. 2018, Hosseinabadi et al. 2020). Among these methods, digital photography is cost-effective, accessible, and easy to use and seems to have more clinical applicability with good reliability for evaluating JPS in various body segments (Smith et al. 2013, Ghamkhar et al. 2018, Mousavi-Khatir et al. 2018). Although this technique has clinical applicability, because of having a time-consuming computation method, it may not be used by clinicians. However, researchers may benefit from digital photography as a reliable, safe, and inexpensive method in research settings. To the best of our knowledge, there is no study evaluating the reliability of measurement techniques for trunk position sense in older adults. Accordingly, the purpose of the present study was to investigate the test-retest reliability of digital photography in the elderly with or without hyperkyphosis.

2. Methods

2.1.Participants

The present cross-sectional study was conducted between April 2020 to October 2020 at the School of Rehabilitation Sciences, XXXX University of Medical Sciences. The sample size was estimated as at least 22 participants per group based on the guideline presented by Bujang (Bujang and Baharum 2017), assuming the null hypothesis value of ICC = 0.5 (any values less than 0.5 indicate poor reliability is considered clinically unacceptable), α value of 0.05 and test power of 80% ($\beta = 0.2$) for two replicated measurements (twice by the same rater). Considering possible dropouts, 30 participants per group were invited to participate in the present study. A convenience sample of older adults with and or without hyperkyphosis was recruited through public announcements; 30 older adults with hyperkyphosis and 30 age-matched controls. Older adults over the age of 60 years who could stand and walk without assistance were included. The inclusion criteria were a thoracic kyphosis above 50 degrees for the hyperkyphosis group and below 50 degrees for the control group (Boseker et al. 2000). 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, or history of taking medicines affecting the CNS. All participants underwent a comprehensive physical examination by an experienced physical therapist to assess eligibility criteria. Participants received information regarding the study procedure and then signed written informed consent. The Ethics Committee at XXXX University of Medical Sciences approved the study (XXXX).

2.2. Examiner and outcome assessments

All measurements were performed by the first author (F.K.), who was a PhD candidate in Orthotics and Prosthetics with over three years of clinical experience and ample practice in photogrammetry assessments. For the test-retest intrarater reliability assessment, the measurements were repeated at a one-week interval in completely homogeneous conditions (concerning the examiner, time, location, light and ambient temperature, camera position, and individual position). The examiner was blinded to her own prior results.

2.3. Measurement of the thoracic kyphosis degree

Thoracic kyphosis degree was measured using photogrammetry examination as described previously (Porto and Okazaki 2017, Azadinia et al. 2021). Participants wore an open-back gown, and spinous processes of the seventh cervical (C_7) and twelfth thoracic (T_{12}) vertebrae were detected by palpation and marked by a pencil. 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 stood 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 with 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).

2.4.Position sense measurement

Position sense was assessed by the active angle reproduction test, which measures a person's ability to reproduce a predetermined target position. To evaluate repositioning, female participants wore a sports bra, and male participants removed their upper body clothing during the test. The participants sat on an adjustable chair in their normal upright posture. This chair had a short backrest to limit lumbopelvic motion. The contact of the participant's lumbopelvic region to the chair's backrest was monitored by a switch mounted on the chair's backrest that turned 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 placed to the C_7 spinous process. The camera was located at a 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 were asked to adopt their neutral upright posture and focus on this posture and maintain this position for 5 seconds. In this condition, a photograph was taken using the camera.

The participants were then asked to perform maximum flexion and extension without any pain or discomfort and without detaching the lumbo-pelvic from the chair's backrest at their preferred speed while maintaining a neutral neck position. Then, 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 a photograph was captured by the camera. The participants received no feedback on their performance. Six trials were repeated for each direction from trunk flexion or trunk extension to the neutral position. The order of trunk flexion or extension was chosen randomly. Participants were blindfolded to remove visual clues. We evaluated position sense at least three hours after waking up to minimize the effects of diurnal variation. Participants were also asked to refrain from strenuous physical activity for 24 hours before testing. also eating or drinking for 2 hours before testing.

The photograph records were imported into Paint software. The marker position in the Paint software for each photograph was extracted on the abscissa (X-axis) and ordinate (Y-axis) in pixels and converted to centimeters. Then, in a custom-made program developed in Excel, using these two values (i.e., horizontal components or the projection on the X axis, and vertical component or the projection on the Y axis), 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 (Figure 2). Absolute error (AE) and variable error (VE) indices were calculated to quantify position sense acuity. The AE measures the overall accuracy of repositioning performance, which has been reported as the primary outcome measure in previous studies(Strimpakos et al. 2006, Mousavi-Khatir et al. 2018). Higher AE values indicated less accurate repositioning performance. The VE determines 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.

2.5.Statistical analysis

SPSS Version 22 was used for the statistical analysis. All the data were encoded to prevent bias in data analysis and to blind the statistician. Normal distribution of variables was assessed by the Shapiro-Wilk test and histograms. Paired t-test or Wilcoxon signed-rank test was performed on measurements obtained in test and retest sessions to verify the absence of systematic bias. A two-way random model of the Intraclass Correlation Coefficient ($ICC_{2,3}$) was used to estimate relative reliability. The classification proposed by Koo and Li (Koo and Li 2016) was used to interpret the relative reliability indices; ICCs < 0.5 were considered as poor, 0.5< ICC <0.75 as moderate, 0.75< ICC <0.90 as good, and > 0.90 as excellent. Absolute reliability was assessed by calculating the Standard Error of the Measurements (SEM), which is an estimate of the error value associated with the measurement (SEM = $SD \times \sqrt{1 - ICC}$) and it is also used to calculate the Minimal Detectable Change (MDC = $\sqrt{2} \times 1.96 \times SEM$). The MDC shows how much change is needed to ensure that the resulting change is not a mere measurement error and that a real change in position sense has occurred. The significance level was set at 0.05.

3. Results

Fifty-three older adults (30 with hyperkyphosis and 23 normal age-matched controls) completed both measurement sessions. Table 1 presents the demographic characteristics of the participants. There were no significant differences between position sense errors between the test and retest sessions, indicating the absence of systematic bias (Table 2). The digital photogrammetry showed excellent relative reliability for horizontal and global components of AE (ICC= 0.92-0.96) and moderate reliability for its vertical component (ICC= 0.51-0.65) in both hyperkyphosis and control groups while reproducing the neutral trunk position from a flexed position. Moreover, the findings revealed excellent and good reliability (ICC= 0.76-0.94) of reproducing the neutral position from a flexed position for horizontal and global components of VE in the hyperkyphosis and control groups, respectively, and moderate reliability (ICC= 0.56-0.62) for its vertical component in both groups.

Also, these findings showed good relative reliability for vertical, horizontal, and global components of AE and VE in the hyperkyphosis group when moving to the neutral trunk position from the trunk extended position (ICC= 0.80-0.87). In the control group, there was good relative reliability (ICC= 0.84-0.89) for horizontal and global components of AE and global component of VE. Also, the control group had excellent reliability for the horizontal component of VE (ICC= 0.92) and moderate reliability (ICC= 0.69-0.74) for vertical components of AE and VE when reproducing the neutral trunk position from the trunk extended position. The results of the test-retest analysis are reported in Table 3, including ICC with 95% confidence interval (CI), SEM, and MDC.

4. Discussion

The current study aimed to evaluate the test-retest reliability of a new approach of digital photogrammetry and angle calculation through trigonometrically to measure trunk position sense in the elderly with and without hyperkyphosis. The findings generally suggested moderate to excellent reliability of repositioning accuracy measurements for the trunk's global, vertical and horizontal components during actively reproducing neutral position sense in the elderly with and without hyperkyphosis.

Some researchers have recently examined correlations between hyperkyphotic posture and proprioceptive deficit and changes in trunk position sense after clinical interventions (Granito et al. 2012, Hosseinabadi et al. 2020, Keshavarzi et al. 2022a, Keshavarzi et al. 2022b). These researchers suggested that trunk position sense can be a potentially modifiable impairment associated with age-related hyperkyphosis (Granito et al., 2012; Keshavarzi et al., 2022b). Hosseinabadi et al. (2020) reported a decrease in AE as a result of 3 months of orthotic treatment.

Also, Keshavarzi et al. (2022a) observed a significant increase in both AE and VE values in the control group who did not receive intervention for age-related hyperkyphosis.

Although the importance of trunk position sense as a clinical outcome measure related to spinal alignment has been well established, there is no study evaluating the reliability of measurement techniques for trunk position sense in older adults. In the present study, the test-retest reliability of the trunk to the neutral position test, regardless of whether the starting position was a trunk flexed or extended posture, was good to excellent for AE in its global and horizontal components in both groups, albeit the ICCs were higher when moving from the trunk flexed position to the neutral position. However, concerning its vertical component, it ranged from moderate to good depending on movement directions and groups. Also, the reliability for VE was higher in its global and horizontal components than its vertical component. Muscle spindles of contracting muscles contribute to repositioning ability (Gandevia et al. 1992), and better reliability results from a trunk flexed than extended position can be attributed to differences in the number of muscle spindles and consequently in repositioning abilities of different muscle groups involved in performing these movements (Brumagne et al. 2000). The dorsal paraspinal muscles (i.e., the multifidus and the erector spinae), which support the spine, and act as trunk extensors, activate during movement from the trunk flexed position to the neutral position (Neumann 2016). These dorsal paraspinal muscles have a higher density of spindles than the trunk flexors (such as the Rectus Abdominis) which activate during movement from a trunk-extended position to the neutral position (Cao et al. 2009). AE and VE values were higher in the elderly with hyperkyphosis than in the age-matched controls. These findings are consistent with the previous literature and support impaired spinal position sense in older adults with hyperkyphosis compared with age-matched controls (Granito et al. 2012, Keshavarzi et al. 2022).

The ICC values obtained in this study were slightly higher than those previously reported for a similar measurement technique. However, in those two studies, within-day test-retest reliability of cervicocephalic relocation test with an average of 10 trials was assessed in healthy adolescents (Pinsault et al. 2008, Mousavi-Khatir et al. 2018). Furthermore, different demographic characteristics of participants, regional differences, such as the number of joints involved in producing spinal movement or the density of mechanoreceptors in the muscles of that area, may justify a slight discrepancy between our results and those previously reported (Pinsault et al. 2008, Mousavi-Khatir et al. 2018). In addition, the number of repetitions also affects the JPS test results. In the studies by Pinsualt et al. (Pinsault et al. 2008) and Mousavi Khatir et al. (2018), an average of 10 trials was used for reliability analysis.

On the other hand, both studies examined within-day test-retest reliability, meaning that all measurements occurred on the same day, whereas we evaluated test-retest reliability with a time interval of 7 days. Some confounding factors, such as learning, fatigue, and postural changes, may affect reliability measurements in a time interval between sessions (Ghorbani et al. 2020). However, reproducibility with a time interval of 7 days is not long to be affected by postural changes and not short to be affected by learning. Also, test-retest reliability within one session cannot evaluate the reproducibility of digital photogrammetry for follow-up purposes.

In the previous literature, various methods have been employed to measure spinal position sense, but it seems that digital photography has higher reliability than others. For example, the ICC values observed in the present study were different from those reported by Petersen et al. (Petersen et al. 2008) using a designed reposition sense device. The device designed by those authors consisted of two-meter sticks, one vertical and one horizontal, and a sliding mechanism, which measured the horizontal and vertical displacement of the spinous process of the marked vertebrae (Petersen, Zimmermann et al. 2008). They also calculated the reproduction angle using a trigonometric equation and found poor reliability (ICC= 0.38) for their designed device. Our reliability findings were also substantially higher than those reported for other spinal repositioning measurement techniques, such as electrogoniometry and 3-Space Fastrak (Swinkels and Dolan 1998, Brumagne, et al. 1999).

We have also extracted the SEM and MDC values to show the real changes needed following clinical interventions. These values were low for AE, especially while reproducing a trunk neutral position from the flexed position, indicating this technique's high absolute reliability. Both AE and VE were lower in the present study than those obtained in other studies (Pinsault et al. 2008, Mousavi-Khatir et al. 2018). However, They used different methods such as the experimental procedure, body segment, and the study population. Our SEM values for AE were lower than those reported for other spinal repositioning measurement techniques in previous studies, indicating the superiority of the absolute reliability of the measurement technique used in the present study compared to other techniques (Swinkels and Dolan 1998, Brumagne et al. 1999, Petersen, et al. 2008). The MDC values for both AE and VE were lower while moving the trunk from a flexed position than moving from an extended position. The abovementioned assumption regarding the difference in muscle spindle density in the trunk flexors and extensors can justify these findings.

4.1.Limitation

This study did not assess inter-rater reliability because the aim was to evaluate the reproducibility of digital photogrammetry for measuring trunk repositioning accuracy during follow-up, which does not require multiple assessors. Further research is needed to evaluate the inter-rater reliability of the photogrammetric technique. Also, the concurrent validity of this technique should be evaluated to reveal how well spinal position sense measured by digital photogrammetry correlates with other techniques such as electrogoniometry and 3-Space Fastrak.

5. Conclusion

This study suggests that the measurement technique consisting of digital photography and angle calculation through trigonometry is a reliable, low-cost, easy-to-perform method with clinical applicability, which allows for detecting changes following clinical interventions.

5.1.Clinical relevance

- Digital photogrammetry is a reliable method for measuring trunk position sense in the elderly with and without hyperkyphosis.
- This reliable and low-cost technique has another advantage; unlike other techniques, the measurement device has no contact with the body and therefore does not generate additional cutaneous inputs.

Acknowledgments

The authors would like to thank all participants for their valuable contributions.

Competing interests

The authors declare that they have no competing interests.

Funding

The authors would like to thank the XXXX University of Medical Sciences for the partial financial support of this study (grant number: XXXX).

Figure Legends:

Figure 1. The experimental setup for trunk repositioning test.

Figure 2. Quantifying of angle reproduction.

C: Camera; O: Initial reference position; OC= 100cm, Distance between camera from initial marker position; M: Marker location during repositioning test; OM = R: Repositioning error in centimeters; X: Abscissa of M; Y: Ordinate of M; α = tangent^{-1} ${}^{X}/_{100}\,cm$; β = tangent^{-1} ${}^{Y}/_{100}\,cm$; θ = tangent^{-1} ${}^{R}/_{100}\,cm$

REFERENCES

Azadinia, F., Hosseinabadi, M., Ebrahimi, i., Mohseni-Bandpei, M.-A., Ghandhari, H., Yassin, M., Behtash, H., Ganjavian, M.-S. (2021). "Validity and test–retest reliability of photogrammetry in adolescents with hyperkyphosis." Physiotherapy Theory and Practice,1-9.

Boseker, E.H., Moe, J.H., Winter, R.B. and Koop, S.E., (2000). Determination of “normal” thoracic kyphosis: a roentgenographic study of 121 “normal” children. Journal of Pediatric Orthopaedics, 20(6), pp.796-798.

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

Britnell, S. J., Cole, J. V., Isherwood, L., Stan, M. M., Britnell, N., Burgi, S., ... & Watson, L. (2005). Postural health in women: the role of physiotherapy. Journal of obstetrics and gynaecology Canada, 27(5), 493-500.

Brumagne, S., Cordo, P., Lysens, R., Verschueren, S., & Swinnen, S. (2000). The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain. Spine, 25(8), 989-994.

Brumagne, S., Lysens R., and Spaepen, A. (1999). "Lumbosacral repositioning accuracy in standing posture: a combined electrogoniometric and videographic evaluation." Clinical Biomechanics. **14**(5): 361-363.

Bujang, M. A. and Baharum, N (2017). "A simplified guide to determination of sample size requirements for estimating the value of intraclass correlation coefficient: a review." Archives of Orofacial Science. **12**(1).

Cao, D. Y., Pickar, J. G., Ge, W., Ianuzzi, A., & Khalsa, P. S. (2009). Position sensitivity of feline paraspinal muscle spindles to vertebral movement in the lumbar spine. Journal of neurophysiology, 101(4), 1722-1729.

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

Gandevia, S., McCloskey, D., and Burke, D. (1992). "Kinaesthetic signals and muscle contraction." Trends in neurosciences **15**(2): 62-65.

Ghamkhar, L., Kahlaee, A.H., Nourbakhsh, M.R., Ahmadi, A., Arab A.M. (2018). "Relationship between proprioception and endurance functionality of the cervical flexor muscles in chronic neck pain and asymptomatic participants." Journal of Manipulative and Physiological Therapeutics. **41**(2): 129-136.

Ghorbani, F., Kamyab, M., & Azadinia, F. (2020). Smartphone applications as a suitable alternative to CROM device and inclinometers in assessing the cervical range of motion in patients with nonspecific neck pain. Journal of chiropractic medicine, 19(1), 38-48.

Granito, R. N., Aveiro, M. C., Renno, A. C. M., Oishi, J. (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.

Hosseinabadi, M., Kamyab, M., Azadinia, F., Sarrafzadeh, J. (2020). "Effect of a Spinomed orthosis on balance performance, spinal alignment, joint position sense and back muscle endurance in elderly people with hyperkyphotic posture: A randomized controlled trial." Prosthetics and Orthotics International. **44**(4): 234-244.

Kandel, E. R., Schwartz, J. H., Jessell, T. M., Siegelbaum, S., Hudspeth, A. J., and Mack, S. (2000). Principles of neural science, McGraw-hill New York.

Katzman, W. B., Wanek, L., Shepherd, J. A., & Sellmeyer, D. E. (2010). Age-related hyperkyphosis: its causes, consequences, and management. Journal of Orthopaedic & Sports Physical Therapy, 40(6), 352-360.

Keshavarzi, F., Azadinia, F., Talebian, S., Khalkhali Zavieh, M., & Rasouli, O. (2022a). Effect of a semi-rigid backpack type thoracolumbar orthosis on thoracic kyphosis angle and muscle performance in older adults with hyperkyphosis: a randomized controlled trial. Disability and Rehabilitation, 1-10.

Keshavarzi, F., Azadinia, F., Talebian, S., & Rasouli, O. (2022b). Impairments in trunk muscles performance and proprioception in older adults with hyperkyphosis. Journal of Manual & Manipulative Therapy, 1-9.

Koo, T. K. and Li, M.Y. (2016). "A guideline of selecting and reporting intraclass correlation coefficients for reliability research." Journal of chiropractic medicine **15**(2): 155-163.

Korakakis, V., Giakas, G., Sideris, V., Whiteley, R. (2017). "Repeated end range spinal movement while seated abolishes the proprioceptive deficit induced by prolonged flexed sitting posture. A study assessing the statistical and clinical significance of spinal position sense." Musculoskeletal Science and Practice **31**: 9-20.

Larson, D. J. and Brown S.H. (2018). "The effects of trunk extensor and abdominal muscle fatigue on postural control and trunk proprioception in young, healthy individuals." Human movement science. **57**: 13-20.

Mousavi-Khatir, R., Talebian, S., Toosizadeh, N., Olyaei, G. R., and Maroufi, N. (2018). "The effect of static neck flexion on mechanical and neuromuscular behaviors of the cervical spine." Journal of Biomechanics **72**: 152-158.

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.

Neumann, D. A. (2016). Kinesiology of the musculoskeletal system-e-book: foundations for rehabilitation. Elsevier Health Sciences.

Petersen, C. M., Zimmermann, C. L., Cope, S., Bulow, M. E., Ewers-Panveno, E.J. (2008). "A new measurement method for spine reposition sense." Journal of NeuroEngineering and Rehabilitation **5**(1): 9.

Pinsault, N., Fleury, A., Virone, G., Bouvier, B., Vaillant, J., Vuillerme, N. (2008). "Test-retest reliability of cervicocephalic relocation test to neutral head position." Physiotherapy Theory and Practice. **24**(5): 380-391.

Porto, A. B., Okazaki, V. H (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.

Reddy, R. S., Goparaju, S., Sanghvi, P., Vaza, Y. J. (2012). "Correlation between lumbar extensor muscle endurance and lumbar proprioception." International Journal of Health Sciences & Research. **2**(1): 20-26.

Relph, N. and Herrington, L.J. (2015). "Interexaminer, intraexaminer, and test-retest reliability of clinical knee joint-position-sense measurements using an image-capture technique." Journal of sport rehabilitation. **24**(2).

Riemann, B. L. and Lephart, S.M. (2002). "The sensorimotor system, part I: the physiologic basis of functional joint stability." Journal of athletic training. **37**(1): 71.

Rix, G. D., Bagust, J.J. (2001). "Cervicocephalic kinesthetic sensibility in patients with chronic, nontraumatic cervical spine pain." Archives of physical medicine and rehabilitation. **82**(7): 911-919.

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.J. (2015). "Proprioception in musculoskeletal rehabilitation. Part 1: Basic science and principles of assessment and clinical interventions." Manual Therapy. **20**(3): 368-377.

Sherrington, C. (1952). The integrative action of the nervous system, CUP Archive.

Shumway-Cook, A. and Woollacott, M.H. (1995). "Theory and practical applications."

Smith, T. O., Davies, L., and Hing, C.B. (2013). "A systematic review to determine the reliability of knee joint position sense assessment measures." The knee. **20**(3): 162-169.

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

Swinkels, A. and Dolan, P. J. S. (1998). "Regional assessment of joint position sense in the spine." Spine. **23**(5): 590-597.

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

Wong, A. Y., Chan, T. P., Chau, A. W., Cheung, H. T., Kwan, K. C., Lam, A. K., Wong, P. Y., Carvalho, D. J. (2019). "Do different sitting postures affect spinal biomechanics of asymptomatic individuals?" Gait & posture. **67**: 230-235.

Table 1. Demographic characteristics of participants.

	Hyperkyphosis group (n=30)	Normal control group (n=23)
Sex (Male/Female)	6/24	10/13
Age (year)	68.3 ± 5.2	67.2 ± 4.6
Height (cm)	160.5 ± 7.7	162.9 ± 7.7
Body weight (kg)	67.2 ± 13.5	68 ± 10.1
Body mass index (kg/m^2)	25.8 ± 3	25.6 ± 3.6
Thoracic kyphosis angle (degree)	68.7 ± 7.9	40.6 ± 5.2

Note. Values are shown in mean ± standard deviation or number.

Table 2. Descriptive statistics for trunk position sense on test and retest sessions.

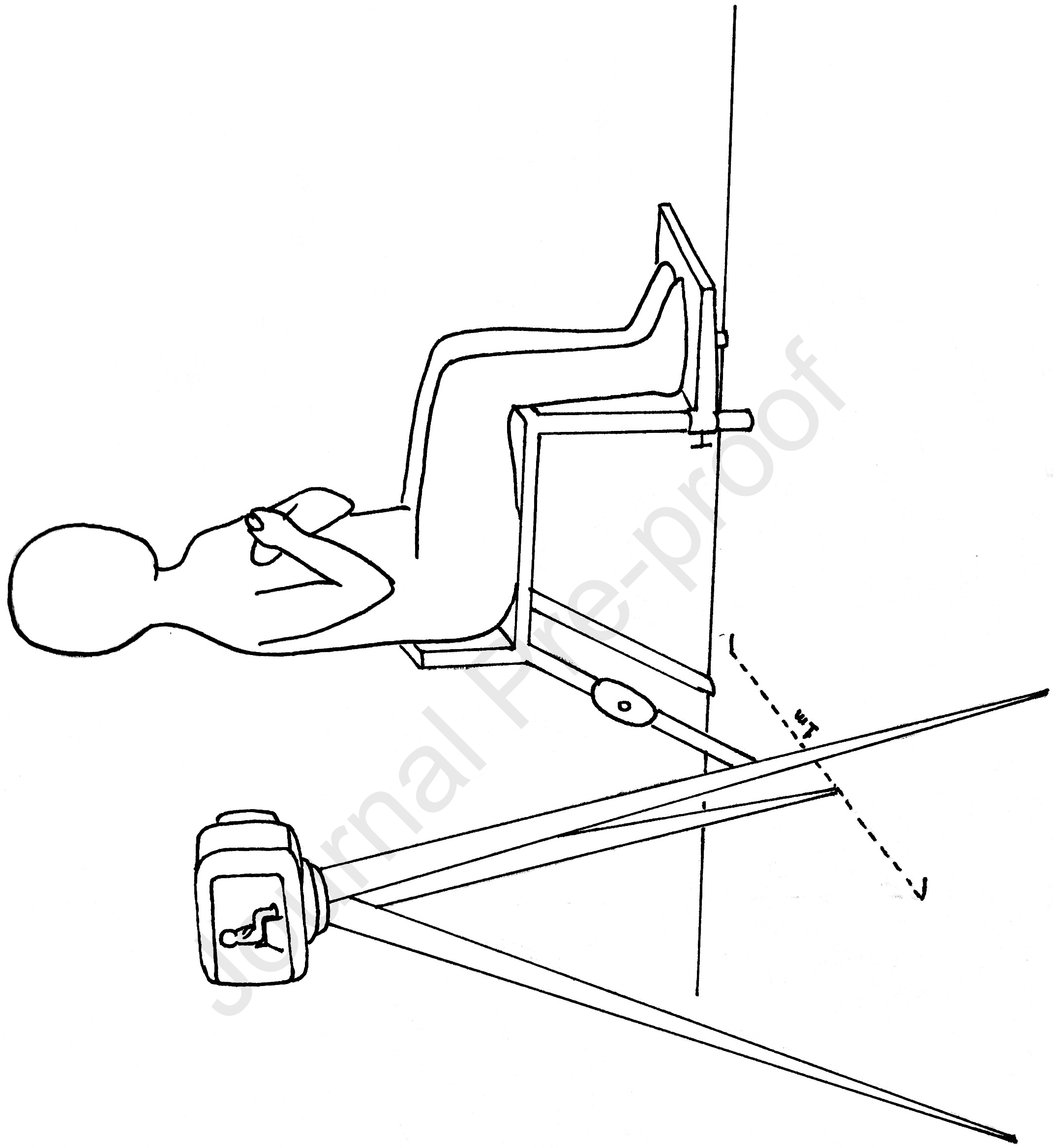
			Hyperkyphosis group (n=30)			Normal control group (n=23)		
			Session 1 (mean ± SD)	**Session 2 (mean ± SD)**	**p-value**	**Session 1 (mean ± SD)**	**Session 2 (mean ± SD)**	**p-value**
Reproduction of a trunk neutral position from a trunk flexed position (degree)	**Horizontal (X)**	**AE**	0.92 ± 0.54	0.88 ± 0.66	0.245	0.77 ± 0.50	0.79 ± 0.43	0.592
		VE	2.01 ± 1.22	2.08 ± 1.43	0.504	1.84 ± 1.41	1.70 ± 0.98	1.00
	Vertical (Y)	**AE**	0.26 ± 0.28	0.24 ± 0.21	0.504	0.25 ± 0.19	0.28 ± 0.22	0.22
		VE	0.59 ± 0.65	0.53 ± 0.34	0.959	0.56 ± 0.35	0.62 ± 0.41	0.487
	Global	**AE**	1.02 ± 0.56	0.98 ± 0.65	0.530	0.91 ± 0.59	0.95 ± 0.63	0.390
		VE	2.19 ± 1.28	2.12 ± 1.48	0.644	1.78 ± 0.99	1.91 ± 0.94	0.153
Reproduction of a trunk neutral position from a trunk extended position (degree)	**Horizontal (X)**	**AE**	1.44 ± 0.98	1.27 ± 0.96	0.262	1.03 ± 0.68	0.92 ± 0.64	0.378
		VE	3.08 ± 2.30	3.19 ± 2.05	0.254	2.65 ± 1.68	2.72 ± 1.77	0.670
	Vertical (Y)	**AE**	0.38 ± 0.31	0.44 ± 0.36	0.120	0.50 ± 0.44	0.56 ± 0.44	0.543
		VE	0.88 ± 0.71	1.02 ± 0.79	0.082	0.99 ± 0.80	1.23 ± 1.01	0.073
	Global	**AE**	1.58 ± 0.94	1.41 ± 0.94	0.262	1.30 ± 0.71	1.34 ± 0.68	0.693
		VE	3.31 ± 2.25	3.37 ± 1.98	0.393	2.85 ± 1.67	2.91 ± 1.76	0.523

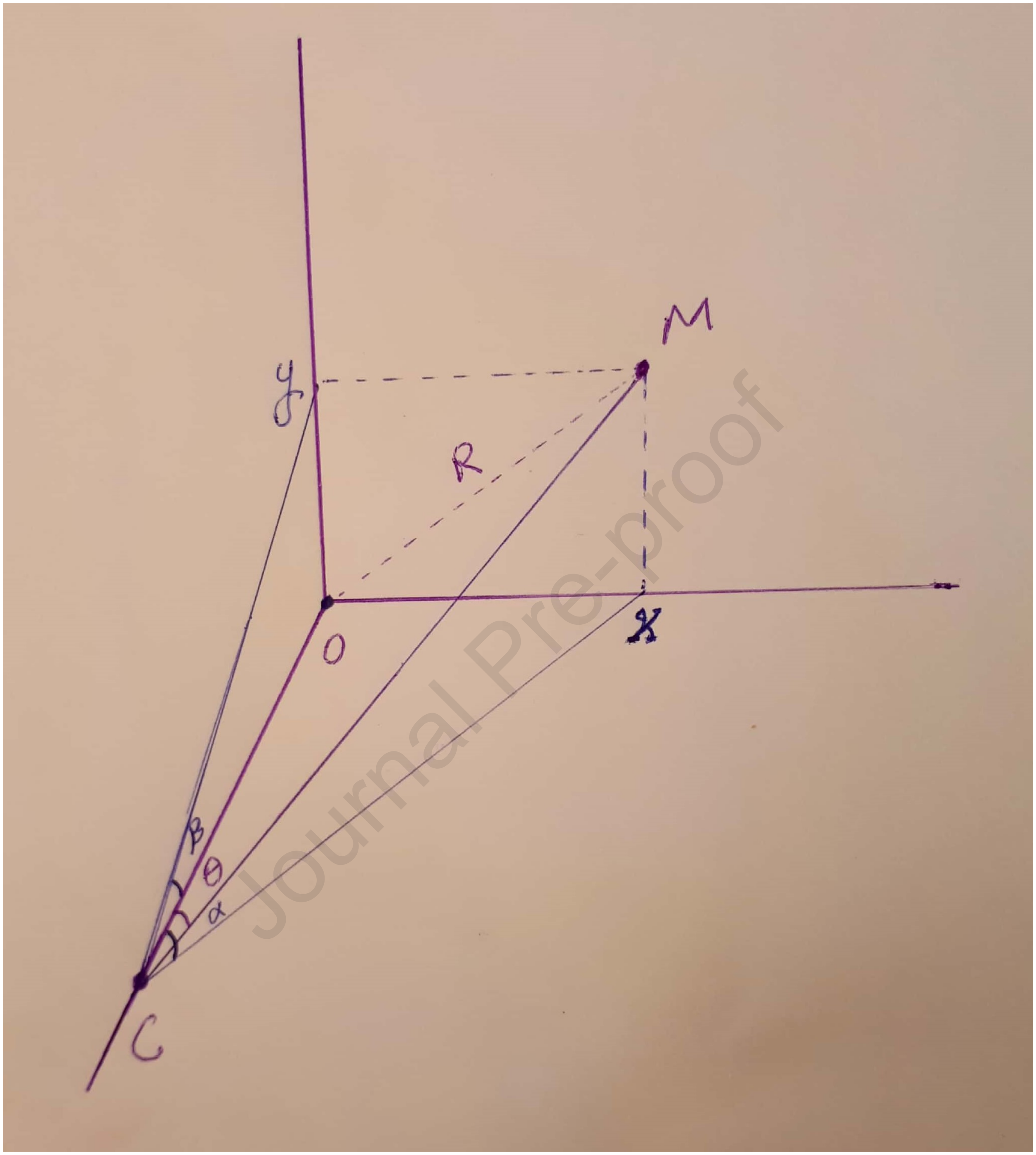
Note. Values are shown in mean ± standard deviation.
AE: Absolute Error; VE: Variable Error.

Table 3. Test-retest reliability of trunk position sense measurements.

			Hyperkyphosis group (n=30)			Normal control group (n=23)		
			ICC (95% CI)	**SEM**	**MDC**	**ICC (95% CI)**	**SEM**	**MDC**
Reproduction of a trunk neutral position from a trunk flexed position (degree)	**Horizontal (X)**	**AE**	0.95 (0.89 – 0.97)	0.12	0.32	0.94 (0.86 – 0.97)	0.12	0.33
		VE	0.94 (0.88 – 0.97)	0.29	0.80	0.76 (0.45 – 0.90)	0.69	1.90
	Vertical (Y)	**AE**	0.65 (0.25 – 0.83)	0.16	0.44	0.51 (-0.17 – 0.79)	0.13	0.35
		VE	0.56 (0.06 – 0.79)	0.43	1.18	0.62 (0.11 – 0.84)	0.21	0.57
	Global	**AE**	0.92 (0.84 – 0.96)	0.15	0.41	0.96 (0.90 – 0.98)	0.11	0.30
		VE	0.92 (0.84 – 0.96)	0.36	0.99	0.87 (0.69 – 0.94)	0.35	0.96
Reproduction of a trunk neutral position from a trunk extended position (degree)	**Horizontal (X)**	**AE**	0.87 (0.74 – 0.94)	0.35	0.96	0.87 (0.71 – 0.94)	0.24	0.66
		VE	0.87 (0.73 – 0.94)	0.82	2.26	0.92 (0.82 – 0.96)	0.47	1.29
	Vertical (Y)	**AE**	0.81 (0.61 – 0.91)	0.13	0.35	0.74 (0.40 – 0.89)	0.22	0.60
		VE	0.80 (0.59 – 0.90)	0.31	0.85	0.69 (0.30 – 0.87)	0.44	1.21
	Global	**AE**	0.86 (0.71 – 0.93)	0.35	0.96	0.84 (0.63 – 0.93)	0.28	0.77
		VE	0.86 (0.72 – 0.93)	0.83	2.29	0.89 (0.75 – 0.95)	0.55	1.51

ICC: Intraclass Correlation Coefficient; SEM: Standard Error of Measurement; MDC: Minimal Detectable Change; AE: Absolute Error; VE: Variable Error.




M
y
R
O
x
β
θ
α
C