Differences of spinal kinematics contribution between cervical and multi-segmental thoracic spine during Sit-To-Stand (STS) & Stand-To-Flexion (STF)

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Abstract. Understanding the actual spinal kinematics in completing critical daily activities is utmost important for human being as it can lead for better quality of life. Two of the most common functions which are necessary for human being are standing up and bend forward. Researchers tried to explore the kinematics of human spine during Sit-to-Stand (STS) and Stand-to-Flexion (STF) but most of them only focussed on thoracic and lumbar spine. Literatures of similar study within thoracic spine only divide the region up to three segments thus reducing the accuracy of actual thoracic multi segments behaviours in completing daily task. This paper aims to study the differences of spinal kinematics contribution between cervical and multi-segmental thoracic spine during STS & STF among healthy Asian adults using non-invasive approach. Interclass correlation coefficient (ICC) for both tasks specified during the study showed excellent reliability with all ICC value were above 0.90 (0.932-0.976). During STS, cervical region displayed quicker flexion-extension transition response. Roughly equivalent behaviour was observed within all thoracic segments. Lower thoracic segments (T10-12) exhibited passive increment behaviour upon reaching upright standing compared with other segments. All segments displayed increase of angular displacement during upright standing. Peak of flexion during STF was achieved at 50% phase with latter response within lower thoracic segments (T8-12). Throughout the completion of STF, most of the segments shared approximately identical behaviour with the adjacent segment. The results provide a clear explanation of the healthy spinal condition of asymptomatic adults and may serve for spinal treatment and rehabilitation purposes.

Keywords. Sit-to-stand; Stand-to-flexion; Thoracic multi-segmental; Cervical; Kinematics; Daily tasks.

1. Introduction
Standing up and bend forward are essential functions in humans daily living, which are prerequisites to be independent in completing variety of daily activities. Sit-to-Stand (STS) and Stand-to-Flexion (STF)
maneuvers requires activation of multiple muscles of the lower limb and most notably the stability contribution of the backbone, which is the spine. One of the goals of rehabilitation is to improve the STS ability [1] without limiting the age boundary especially within elderly. Most research on this common daily tasks were only focused on the vertebral and muscle characteristic and contribution’s study within the lower limb (i.e. hip, knee) and lumbar region [2-12], thus overlooking the cervical and thoracic specific contribution.

Sit-to-stand transition require the translational ability to bring the body mass forward from a relatively stable sitting position to a small base of support during upright standing. Specifically, STS transition can be divided to two phases, which are the pre-extension and an extension phases [13, 14]. Initial generation of enough momentum in the horizontal plane is required at the pre-extension phase which used to transfer the upper body mass forward to the feet. As the upper body mass located near to the feet, the mass then pushed in the vertical direction into standing, triggering the extension phase.

Spinal movements are divided into 6 movements, which are flexion, extension, lateral bending (left and right) and rotation (left and right). Rohlmann, Consmuller, Dreischarf, Bashkuev, Disch, Pries, Duda and Schmidt [15] claims that the flexion movement is frequently performed in a person daily activity, which approximately 4400 flexions been performed. Contrary forces affect posterior and anterior structures during forward flexion. The posterior structure (posterior portion of the disc, posterior ligaments, and muscles) are subjected to compression while the anterior are subjected with tension. Posterior outer annulus fibrosus, zygapophyseal joint capsule and posterior ligaments plays a vital function by providing resistance and limited the bending process [16].

In completing daily tasks, cervical region used 20-40% of maximum cervical range of motion [17]. Concurrent cervical and lumbar spine motion with high number of motions was observed when a person doing a bend forward posture (i.e. picking an object up from the floor). There is still limited study exploring the kinematics behaviour of cervical spine during STS and STF using non-invasive approach. The behaviour of thoracic spine in daily tasks has been previously investigated by many researchers [10, 18-23]. Most of the work has only focused on treating thoracic spine as only up to three segments [24] thus suggesting the approach is not the best way in presenting the actual contribution of the thoracic spine in completing daily task. Many hypotheses regarding the contribution of thoracic spine during STS and STF appear to be ill-defined and debatable as the thoracic spine is assumed with the less segments, which have potential to wrongly assesses the actual thoracic kinematic behaviour.

This paper aims to study the differences of spinal kinematics contribution between cervical and multi-segmental thoracic spine during Sit-To-Stand (STS) & Stand-To-Flexion (STF) among healthy Asian adults. This study makes use of marker-based motion capture system to explore the behaviour of spinal during STS and STF. Papi et al. [25] found the spinal segments did not share the same and predictably behaviour in a specific daily task. We hypothesized that the thoracic multi-segmental of 5 segments (in this study) performances are different compared with the performance of defining thoracic as 3 segments during both tasks in healthy Asian adults. Asymptomatic subjects were taken into consideration as study conducted by [26] found the intervertebral angle distributions were less pronounced in upright standing and non-existent in full flexion between healthy and back pain subjects.

1.1. Related work

Inconsistency in the previous studies may results from the variations in the measurement method used to study the cervical mobility and spinal kinematics during sit-to-stand (STS). Research has tended to focus on lower spinal region (i.e. lower thoracic and lumbar spine) rather than highlighting the contribution of cervical region. An additional problem is there is still limited of dynamic study and assessment focusing on the kinematics of cervical and thoracic spine during this task. Most of the time, the cervical region is taken out for the assessment of spinal region during STS. Sforza, Grassi, Fragnito, Turci and Ferrario [27] studied the cervical range of motion by immobilized the trunk with the application of a stick positioned between the elbows thus limiting the thoracic regional contribution. Previous study that considered the adjacent region of the cervical which is the thoracic spine also restrict the whole spine contribution and movement by applying inelastic strap across the pelvis to minimize the
lumbo-sacral region [24]. There is still considerable disagreement with regard to these approach as it limits the actual kinematics of the cervical and thoracic in active spine movements.

2. Method

2.1. Participants
Ten asymptomatic male participants were volunteered for this study. Participants had average age of 24.9 (SD: 5.14) years and BMI of 20.66 kg/m² (SD: 1.68). Inclusion criteria for healthy subjects were no musculoskeletal pathologies, body mass index (BMI; calculated as weight[kg] / height²[m²]) < 25 kg/m², no low back pain symptoms for the preceding of 6 months. All participants were recruited from university population of Shibaura Institute of Technology, Japan. This project had ethical approval from Faculty of Biomedical Engineering committee of the author’s university, Universiti Teknologi Malaysia (UTM) and informed consent was obtained from participants regarding the experimental procedures and any potential risks during the experiment.

2.2. Instrumentation
A 3-D motion capture analysis system with ten high-precision infrared cameras (HWK-200RT camera, Motion Analysis, USA) was used to study the kinematics of the cervical and thoracic spine. The system converted the reflective passive marker’s real time location to three-dimensional coordinates which then used for kinematic analysis. The sampling rate was set at 200 [Hz]. A total number of 18 reflective passive markers (diameter: 10 mm) were attached spinous process of the participants using tape. Two sensors were placed within cervical region (C2 & 7). For thoracic region, twelve markers were placed on the spinous processes underlying from the first to twelfth thoracic vertebra. The placement on all thoracic vertebra were able to be done due to the advantages of using small dimension reflective markers. All the markers were placed by a single certified physiotherapist to reduce the measurement error. Participants were asked to only wear given cap and pants to avoid error resulting from the skin’s movement [28, 29]. Four reference markers were placed on the testing floor as reference points during data analysis. For STS task, an office chair, armless and backless, was adjusted vertically for each subject to obtain the same knee flexion angle (fixed at 90°).

2.3. Procedure
Participants were asked to complete two tasks specified for this study which were sit-to-stand (STS) and stand-to-flexion (STF). Each subject was asked to complete the tasks at self-selected speed with the feet self-positioned over the force platform (no fixed distance between the feet was imposed) for 3 acquisition trials. Interval time between each trial was fixed at 5s. The experimental set up is more or less identical to the one proposed by [7] as shown in figure 1. Before performing the study, participants were asked to practice both tasks specified two to three times each to ensure all of them familiarize with the activities they were asked to perform. The details of motion sequence are as follow:

- **Sit-to-stand, STS**
  Begin from sit (0% of motion completion) to stand (100% of motion completion).

- **Stand-to-flexion, STF**
  Begin with upright standing (0% of motion completion) to ventral flexed position (100% of motion completion).
2.4. Data analysis

Data processing was performed by using specified software (Cortex version 6) then converted to Excel file. Customized MATLAB codes (MATLAB 2016b, Chicago IL, USA) were used for data analysis. For statistical analysis, results were analyzed using both MATLAB and SPSS version 22 with alpha level of 0.05. From the processed data, the placement of markers on the subjects’ body was compared with literatures that used X-ray and radiography approaches [30-33] by using image processing method at standing posture to make sure the vertebra locations were correctly assumed. Van Blommestein, MaCrae, Lewis and Morrissey [34] stated that the standing radiographs are the gold standard method for measuring cervical, thoracic and lumbar angles.

The reliability of kinematics of the cervical and thoracic multi segments was assessed using intraclass correlation coefficients (ICC). Shrout and Fleiss [35] calls into question some past agreement of the ICC value above 0.75 shows excellent agreement between measured variables.

The angular displacement of the divided spinal regions was derived using three points coordinate system in MATLAB. As an example, for lower thoracic spine T10-12, the coordinates of markers on the 10th, 11th and 12th thoracic spine were used in the calculation. The thoracic region was further divided to 5 smaller segments. From the results, the mean and standard deviation of angular displacement were calculated for 0 to 100% of motion completion. Each participant displayed difference in time (second) of completion for both STS and STF task. Thus, to normalize the range of initial and end of motion completion, percentage scale was used in this study.

3. Results and discussion

3.1. Kinematics and reliability of spinal region

The repeatability and reliability of the cervical and multi-segments thoracic spine were assessed using interclass correlation coefficient (ICC) for both tasks specified during the study (Table 1). The single most striking observation to emerge from the result was the excellent reliability with all ICC value were above 0.90 (Ranged between 0.932-0.976). The averaged angular displacement and standard deviation at each phase are presented in table 2 (Sit-to-stand, STS) and table 3 (Stand-to-Flexion, STF).
Table 1. Intraclass correlation coefficient (95% CI) of cervical and multi-segments thoracic region during STS and STF tasks.

| Segment   | ICC     | 95% CI       |
|-----------|---------|--------------|
| C2-T1     | 0.944   | (0.820,0.993) |
| T1-4      | 0.961   | (0.864,0.995) |
| T4-6      | 0.956   | (0.845,0.995) |
| T6-8      | 0.970   | (0.905,0.996) |
| T8-10     | 0.975   | (0.921,0.997) |
| T10-12    | 0.969   | (0.902,0.996) |

| Segment   | ICC     | 95% CI       |
|-----------|---------|--------------|
| C2-T1     | 0.932   | (0.743,0.992) |
| T1-4      | 0.973   | (0.896,0.997) |
| T4-6      | 0.976   | (0.908,0.997) |
| T6-8      | 0.965   | (0.864,0.996) |
| T8-10     | 0.968   | (0.873,0.996) |
| T10-12    | 0.964   | (0.827,0.996) |

Table 2. Angular displacement (SD) of the cervical and thoracic multi-segment during Sit-to-Stand, STS task.

| Segment   | 25%     | 50%     | 75%     | 100%    |
|-----------|---------|---------|---------|---------|
| C2-T1     | -15.32±7.39 | -14.29±17.25 | 10.43±9.94 | 27.66±12.15 |
| T1-4      | -27.93±12.33 | -34.63±17.21 | 3.49±16.61 | 31.07±15.45 |
| T4-6      | -30.55±14.42 | -39.99±22.84 | 4.56±19.07 | 32.54±14.48 |
| T6-8      | -31.91±15.87 | -43.35±23.18 | 3.07±15.89 | 26.26±15.00 |
| T8-10     | -33.65±14.97 | -43.53±23.13 | 2.97±16.64 | 20.80±12.27 |
| T10-12    | -34.35±15.48 | -45.09±23.72 | 1.02±16.12 | 6.60±11.64 |

Table 3. Angular displacement (SD) of the cervical and thoracic multi-segment during Stand-to-Flexion, STF task.

| Segment   | 25%     | 50%     | 75%     | 100%    |
|-----------|---------|---------|---------|---------|
| C2-T1     | -19.36±13.26 | -42.82±11.10 | -41.79±1.66 | -39.58±31.16 |
| T1-4      | -23.33±13.82 | -50.55±11.29 | -41.12±6.60 | -37.83±30.82 |
| T4-6      | -23.67±21.38 | -61.13±17.72 | -60.26±3.61 | -54.48±45.56 |
| T6-8      | -23.52±22.36 | -61.16±19.25 | -63.28±1.14 | -61.51±48.94 |
| T8-10     | -19.02±25.48 | -55.30±23.31 | -68.15±7.53 | -68.52±54.17 |
| T10-12    | -12.50±26.76 | -47.72±25.66 | -65.02±11.19 | -68.67±54.07 |

3.2. Sit-to-stand STS

The results revealed the difference of multi-segmental behaviours (change in angular displacement) within thoracic region. This findings substantiates previous findings in the literature [36]. The sitting posture compress the intervertebral disk thus resulting to lower spinal height compared to upright
standing. The results from figure 2(a) revealed the increment of angular displacement within all segments (cervical and thoracic T1-12). Lower thoracic segment showed the least increment which is due to the anatomical structure at the thoracolumbar joint and the nearest to the lumbar region. These (lower thoracic and lumbar) regions responsible to support upper body weight (torso, head, hands, etc.) resulting to lower angular displacement increment during upright stand.

As shown in figure 2(a), the transition of flexion-extension occurred at the middle of STS with cervical region displayed quicker transition response. Similar behaviour within thoracic segments was also observed with the upper thoracic segment (T1-4) displayed the least change of angular displacement within the thoracic region. Peak of increment was observed at 75% of motion completion at all segments including cervical region (Figure 2 (b)). The least change in angle increment of flexion-extension was observed at the middle (50%) of motion transition. The results showed increment in angular displacement during upright standing with the least increment occurred within lowest thoracic segment, T10-12. Other thoracic segments displayed approximately equivalent percentage of contribution toward upright standing, especially within upper thoracic segments (T1-6).

3.3. Stand-to-Flexion, STF

The results revealed differences between thoracic multi-segmental influence during STF. Cervical and upper thoracic region had the least contribution during STF compared with the other segments. This result has further strengthened our conviction that the thoracic multi segments did not share the same behaviour of flexion-extension during daily STS and STF tasks. In contradiction with earlier finding [24], we did not found the upper thoracic segment (T1-4) to have higher contribution during STF compared with the lower segments (T4-12). Curiously, the results also revealed the conversion of flexion-extension which occurred only within cervical and T1-8 segments roughly at the middle of motion transition.

During STF, most of the segments reach peak of flexion at 50% phase with lower thoracic segments (T8-12) showed latter behaviours which achieved approximately during 75% phase (Figure 3(a)). The curve characteristic of the top thoracic segment (T1-4) displayed approximately similar behaviours with cervical region. The middle thoracic segments (T4-6 and T6-8) showed approximately identical curve with greater extension occurred within T6-8 segment. Cervical and upper thoracic segment (T1-4) showed the least segmental flexion-extension increment throughout STF task. T8-10 and T10-12 segments shared identical curve pattern with T8-10 showed higher change in angular displacement. Peak increment of extension was observed within early motion transition (25-50%) as presented in figure 3(b).
4. Conclusion
The present study showed that the cervical and thoracic multi segments have difference in segmental contribution in completing STS and STF tasks. All segments tend to implement an “ideal” spinal transition from flexion-extension at 50% of motion completion during both STS and STF tasks. In completing STS task, equal contribution was observed within all thoracic segments. Only top thoracic segment (T1-4) was found to have higher correlation with the cervical region during bending task. The present results support the importance of highlighting the spinal contribution of multi-segmental rather in carrying out daily tasks.

4.1. Limitations and future works
We aware that our research may have two limitations. The first is due to small number of subjects. Given that this finding is based on only ten male subjects, the results from such analyses should, therefore, be treated with considerable as this profile only represents a minor fraction of the daily sagittal alignment in Asian sedentary society. The second is the palpation method used to identify spinal vertebral location used in this study. The method use is relying on finding the spinous process of specific vertebrae using palpation method by certified physiotherapist. The anatomical difference of the spinous process did affect the palpation especially within the thoracic region as this region has longer distance difference between actual vertebral location and the spinous process. These limitations highlight the difficulty of collecting data on spinal behavior on kyphosis and lordosis during critical daily activities. For future works, wider range of subjects should be considered to study the gender, age and BMI with spinal behaviors. The findings of present study might be important to develop dynamic orthotic devices and increase the awareness of the biomechanical challenges that spinal structures and implants face in real-life. Furthermore, long-term assessments of spinal alignment and motion during daily life can provide valid data on spinal function and can reveal the importance of influential factors.

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References
[1] Tanaka R, Ishii Y, Yamasaki T and Kawanishi H 2019 Measurement of the total body center of gravity during sit-to-stand motion using a markerless motion capture system Medical Engineering & Physics 66 91-5
[2] Alqhtani R S, Jones M D, Theobald P S and Williams J M 2016 Investigating the contribution of the upper and lower lumbar spine, relative to hip motion, in everyday tasks Manual Therapy
[3] Alqhtani R S, Jones M D, Theobald P S and Williams J M 2015 Correlation of lumbar-hip kinematics between trunk flexion and other functional tasks Journal of manipulative and physiological therapeutics 38 442-7

[4] Yoshioka S, Nagano A, Hay D C and Fukashiro S 2012 The minimum required muscle force for a sit-to-stand task Journal of Biomechanics 45 699-705

[5] Widhalm K, Stumm T and Hurkmans E J 2015 Coordination of the hip and lumbar spine during sit-to-stand in healthy young subjects Gait & Posture 42 S50-S1

[6] Tully E A, Fotoohabadi M R and Galea M P 2005 Sagittal spine and lower limb movement during sit-to-stand in healthy young subjects Gait & Posture 22 338-45

[7] Sibella F, Galli M, Romei M, Montesano A and Crivellini M 2003 Biomechanical analysis of sit-to-stand movement in normal and obese subjects Clinical Biomechanics 18 745-50

[8] Pourahmadi M R, Ebrahimi Takamjani I, Sarrafzadeh J and Jaberzadeh S 2018 Test-retest reliability of sit-to-stand and stand-to-sit analysis in people with and without chronic nonspecific low back pain Annals of Physical and Rehabilitation Medicine 61 e153

[9] ppersiel P, Robbins S and Preuss R 2018 Movement variability in adults with low back pain during sit-to-stand-to-sit Clinical Biomechanics 58 90-5

[10] Ignasiak D, Rueger A and Ferguson S J 2017 Multi-segmental thoracic spine kinematics measured dynamically in the young and elderly during flexion Hum Mov Sci 54 230-9

[11] Fotoohabadi M R, Tully E and Galea M 2006 Sagittal kinematics of the hip-spine interaction during sit-to-stand in healthy subjects Journal of Biomechanics 39 S542

[12] Bohannon R W, Bubela D J, Magasi S R, Wang Y-C and Gershon R C 2010 Sit-to-stand test: Performance and determinants across the age-span Isokinetics and exercise science 18 235-40

[13] Carr J H and Gentile A M 1994 The effect of arm movement on the biomechanics of standing up Human Movement Science 13 175-93

[14] Shepherd R B and Gentile A 1994 Sit-to-stand: functional relationship between upper body and lower limb segments Human movement science 13 817-40

[15] Rohlmann A, Cons Muller T, Dreischarf M, Bashkuev M, Disch A, Pries E, Duda G N and Schmidt H 2014 Measurement of the number of lumbar spinal movements in the sagittal plane in a 24-hour period European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society 23 2375-84

[16] Rathore M, Sharma D, Sinha M B, Siddiqui A and Trivedi S 2014 A focused review–thoracolumbar spine: anatomy, biomechanics and clinical significance Indian Journal of Clinical Anatomy and Physiology Vol 1

[17] Cobian D G, Daehn N S, Anderson P A and Heiderscheit B C 2013 Active cervical and lumbar range of motion during performance of activities of daily living in healthy young adults Spine 38 1754-63

[18] Narimani M and Arjmand N 2018 Three-dimensional primary and coupled range of motions and movement coordination of the pelvis, lumbar and thoracic spine in standing posture using inertial tracking device Journal of Biomechanics 69 169-74

[19] Singla D, Veqar Z and Hussain M E 2017 Photogrammetric Assessment of Upper Body Posture Using Postural Angles: A Literature Review Journal of Chiropractic Medicine 16 131-8

[20] Kluszczyński M, Wąsik J, Ortenburger D, Zarzycki D and Siwik P 2017 Prognostic value of measuring the angles of lumbar lordosis and thoracic kyphosis with the Saunders inclinometer in patients with low back pain Polish Annals of Medicine 24 31-5

[21] Porto A B and 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 21 986-94

[22] Ignasiak D, Rueger A and Ferguson S J 2017 Multi-segmental thoracic spine kinematics measured dynamically in the young and elderly during flexion Human Movement Science 54 230-9
[23] Barrett E, O'Keeffe M, O'Sullivan K, Lewis J and McCreesh K 2016 Is thoracic spine posture associated with shoulder pain, range of motion and function? A systematic review *Manual Therapy* 26 38-46

[24] Tsang S M H, Szeto G P Y and Lee R Y W 2014 Altered spinal kinematics and muscle recruitment pattern of the cervical and thoracic spine in people with chronic neck pain during functional task *Journal of Electromyography and Kinesiology* 24 104-13

[25] Papi E, Bull A M J and McGregor A H 2019 Spinal segments do not move together predictably during daily activities *Gait & Posture* 67 277-83

[26] Viggiani D, Gallagher K M, Sehl M and Callaghan J P 2017 The distribution of lumbar intervertebral angles in upright standing and extension is related to low back pain developed during standing *Clinical Biomechanics* 49 85-90

[27] Sforza C, Grassi G, Fragnito N, Turci M and Ferrario V F 2002 Three-dimensional analysis of active head and cervical spine range of motion: effect of age in healthy male subjects *Clinical Biomechanics* 17 611-4

[28] Roghani T, Khalkhali Zavieh M, Rahimi A, Talebian S, Dehghan Manshadi F, Akbarzadeh Baghban A, King N and Katzman W 2017 The Reliability of Standing Sagittal Measurements of Spinal Curvature and Range of Motion in Older Women With and Without Hyperkyphosis Using a Skin-Surface Device *Journal of Manipulative and Physiological Therapeutics* 40 685-91

[29] Kuo Y-L, Tully E A and Galea M P 2008 Skin movement errors in measurement of sagittal lumbar and hip angles in young and elderly subjects *Gait & Posture* 27 264-70

[30] Tokgoz N, Uçaş M, Bilir Erdogan A, Kılıç K and Ozcán C 2014 Are Spinal or Paraspinal Anatomic Markers Helpful for Vertebra Numbering and Diagnosing Lumbosacral Transitional Vertebrae? *vol 15*

[31] McKinnis L N 2013 *Fundamentals of Musculoskeletal Imaging*: F. A. Davis Company

[32] Kim K H, Park J Y, Kuh S U, Chin D K, Kim K S and Cho Y E 2013 Changes in Spinal Canal Diameter and Vertebral Body Height with Age *Yonsei Med J* 54 1498-504

[33] Weber U, Pfirrmann C W, Kissling R O, Hodler J and Zanetti M 2007 Whole body MR imaging in ankylosing spondylitis: a descriptive pilot study in patients with suspected early and active confirmed ankylosing spondylitis *BMC Musculoskeletal Disorders* 8 20

[34] Van Blommestein A S, MaCrae S, Lewis J and Morrissey M 2012 Reliability of measuring thoracic kyphosis angle, lumbar lordosis angle and straight leg raise with an inclinometer *Open Spine Journal*

[35] Shrout P E and Fleiss J L 1979 Intraclass correlations: uses in assessing rater reliability *Psychological Bulletin* 86 420

[36] Johnson M B, Cacciatore T W, Hamill J and Van Emmerik R E 2010 Multi-segmental torso coordination during the transition from sitting to standing *Clinical Biomechanics* 25 199-205