**Instrumented Trunk Impairment Scale (iTIS): A Reliable Measure of Trunk Impairment in the Stroke Population**

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**Abstract**  
Background: The Trunk Impairment Scale (TIS) is recommended for use in clinical research to assess trunk impairment post-stroke. However, it is observer dependent and does not consider the quality of trunk movement. To address these challenges, this study proposes an instrumented TIS (iTIS).

Objective: This study aims to investigate the intra-rater and inter-rater reliability of the iTIS in chronic stroke patients.

Method: Trunk impairment was assessed in 20 patients with stroke using the iTIS Valedo system; three sensors were fixed to the skin on the sternum, L1 and S1 levels. Interclass correlation coefficients were used to assess the inter-rater and intra-rater reliability (between days) with 95% CI.

Results: Reliability for the dynamic subscale parameters was good to excellent (intra-rater ICC = 0.60–0.95; inter-rater ICC = 0.59–0.93); however, reliability for the coordination parameters was poor to good (intra-rater ICC = 0.05–0.72) and poor to excellent (inter-rater ICC = 0.04–0.78).

Conclusion: The iTIS demonstrates an acceptable level of reliability for dynamic subscale measurement in research and clinical practice. Further studies could use larger sample sizes and improve the iTIS methodology by employing additional sensors on the limbs to detect compensatory movements.

**Keywords:** Objective assessment, inertial sensor, Trunk Impairment Scale, instru­mented trunk impairment scale, stroke, validity

# **Introduction**

Trunk control has been recognized as an important early predictor of functional recovery after stroke, explaining 45% to 71% of the variance in functional recovery post-stroke (Franchignoni et al. 1997; Verheyden et al. JNNP 2007). Systematic reviews and meta-analyses emphasize the importance of including trunk exercises to improve trunk performance and functional recovery after a stroke (Langhorne et al. 2009; Cabanas-Valdes et al. 2013; Sorinola et al. 2014; Alhwoaimel et al. 2018).

To ensure that any planned treatment is effective, therapists need accurate tools and outcome measures to assess change. Trunk control after a stroke can be measured using clinical tools, such as the Trunk Control Test (TCT) and the Trunk Impairment Scale (TIS)(Collin and Wade 1990; Fujiwara et al. 2004; Verheyden et al. 2004)[.](#_ENREF_25) The TCT and the TIS differ in how they measure trunk control in relation to movements involving the head and extremities. The TCT measures the ability to control the trunk during two movements involving the head and extremities, one when moving from a supine to a side-lying position and the other from a supine to a sitting position. In contrast, the TIS, developed by Verheyden et al. (2004), assesses trunk impairment post-stroke by measuring the ability to control the trunk in a sitting position in both static and dynamic postures without additional movements of the head or extremities. It consists of three sub-sections that assess static sitting balance, dynamic sitting balance and trunk coordination. Following Rasch analysis, the static sitting balance subscale was eliminated, and the scale was renamed TIS Version 2.0 (TIS-V2) (Verheyden and Kersten 2010). Additionally, there is a reported difference in the ability of these tools to differentiate between subjects with stroke: the TCT has been shown to lack discriminative ability (Franchignoni 2003), [whereas the TIS has been reported to have discriminant validity](#_ENREF_7) (Verheyden et al. 2005)[.](#_ENREF_24) For this reason, the TIS-V2 was investigated in this study.

[The TIS-V2](#_ENREF_23) has no ceiling effect and has sufficient psychometric properties along with high concurrent validity (r = 0.83), excellent test-retest reliability (ICC = 0.96) and excellent inter-rater reliability (ICC = 0.99) (Verheyden et al. 2004; Verheyden et al. 2005). The limitations of both versions of the TIS include that the quality of movement is not measured by means of trunk range of motion (ROM) during task performance and that the scales are observer dependent, requiring rater training to increase competence and preclude biasing results. Therefore, an instrumented version of TIS (iTIS) that will address these limitations is warranted.

Trunk movement can be quantified using an optoelectronic measurement system that uses a radiographic approach (Bauer et al. 2015). However, this method has disadvantages, including high cost and the required expert installation of the equipment in an appropriate research environment, which make the method difficult to use in clinical settings. To overcome these limitations, the use of low-cost measuring systems such as inertial measurement units (IMUs) may be useful. The Valedo system (Hocoma, Switzerland) is a wireless movement analysis system that comprises three lightweight sensors (IMUs) worn on the sternal, lumbar and sacral spinal levels to measure trunk movement (Bauer et al., 2015; Hugli et al., 2015). The present study is a cross-sectional, repeated measures observational study designed to investigate the inter-rater and intra-rater reliability of iTIS in participants with chronic stroke.

# **Methods**

**Participants**

Stroke participants were recruited from the University of Southampton, the School of Health Sciences’ Research Participant Register, the Hobbs Rehabilitation Centre and local stroke clubs (Hampshire, UK). The inclusion criteria were that individuals had chronic stroke (more than 6 months), were between 40 to 80 years old, had trunk impairment resulting from the stroke and were able to maintain a seated position for 10 seconds. The exclusion criteria were acute low back pain, history of spontaneous fractures, hip prosthesis, uncontrolled epileptic seizures, implanted ferromagnetic materials or active devices within the body, and skin disease or lesions near the sensor placement. The Ethics Committee of University of Southampton approved this study (ethical approval code: 25280) and all participants signed informed consent.

**Apparatus and measurement protocol**

The Valedo sensors (Hocoma, Switzerland) contain a tri-axillar gyroscope, an accelerometer and magnetometer, a wireless antenna and a signal processing unit. The specifications of the Valedo system indicate that the measurement units are able to record a ±0.1 o range of motion (ROM) over a range of 360 o around all axes (Valedo User Manual, Hocoma). The recorded data are transmitted to a laptop with a 200-Hz sampling frequency. The Valedo system output files show the rotation of the sensors at X, Y and Z directions on the three body planes (sagittal, frontal and transverse) over the duration of the task. The output files were exported to an Excel file.

Three lightweight Valedo sensors were placed using double-sided tape: sensor one on sacral spinal level S1, sensor two on spinal level L1 and sensor three on the sternum (Figure 1). The sensors were placed and removed by the same assessor. The participant was seated on a plinth without any back support, with a hip and knee flexion of 90 degrees, and barefoot with feet resting on the floor. Participants were then asked to perform the 14 TIS Version 2 (cTIS-V2) tasks.

All participants attended two baseline assessment sessions 7 to 10 days apart. In the first session, the TIS was recorded two times with a rest period between them. The first assessments were measured by the first assessor (NA), and the second assessments were measured by the second assessor (FF) to determine inter-rater reliability. In the second assessment session, the TIS data were recorded once by the assessor (NA) for the purpose of intra-rater reliability. The performance of the tasks was also filmed for checking later.

**Development of the instrumented Trunk Impairment Scale (iTIS)**

The parameters of interest for each TIS task were determined by the author and research team (Martin Warner, Ann-Marie Hughes, Ruth Turk and Federico Ferrari) based on the most important movement required for each task and the sensor which captured the most movement. For the dynamic subscale parameters, the degree of range of motion (ROM) of lateral flexion to either the affected or unaffected side was considered. For the coordination subscale, the degree of lumbar and sternal ROM towards both sides was measured, and the symmetry of rotation movement between the affected and unaffected sides was considered. The symmetry between both sides was calculated as a percentage (%) (100% symmetry means that the rotation ROM on both sides is equal). The parameters of interest are presented in Table 1. All parameters were extracted from the exported Excel files mentioned previously using MATLAB (MATLAB R2016a) (MathWorks). The MATLAB algorithms were written by an experienced musculoskeletal biomechanics researcher.

**Table 1: Sensor location, plane of movement and parameters of interest for each TIS-V2 task**

# **Statistical Analysis**

The data were imported into Excel and analysed using IBM SPSS Statistics 24 (SPSS Inc, Chicago, IL). Descriptive statistics were used to summarize the demographic data and the parameters of interest. The normality of data was checked using a Shapiro-Wilks test.

Using the interclass correlation coefficient (ICC) (Pantano et al. 1996), the reliability of the iTIS for the stroke group was determined to be [excellent when ICC](#_ENREF_15) ≥ 0.75, good to fair when ICC = 0.4–0.74 and poor when ICC < 0.4 (Fleiss [2011](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4424474/#ref16)). The intra-rater reliability and inter-rater reliability were assessed using the ICC (2,1) model, and 95% confidence intervals (CI) were calculated for all ICC values. The precision of the measurements was assessed using the standard error of measurement (SEM), which provides values in meaningful units for measuring ROM in degrees and was used to calculate the minimum detectable change (MDC), which is the minimal change that falls outside the measurement error. The SEM and MDC were calculated from the ICC as follows: SEM = SD (√1 - ICC); MDC = 1.96 × √2 × SEM.

# **Results**

**Participants’ characteristics**

Twenty adults with chronic stroke and resulting trunk impairment (mild to severe) were recruited. The participants’ characteristics are presented in Table 2.

**Table 2: Participants’ characteristics**

**Reliability**

1. **Intra-rater reliability**

The ICCs for the intra-rater reliability of the dynamic sitting balance subscale showed excellent between-sessions reliability with an ICC ≥ 0.76 in Tasks 1, 4, 5, 6 and 10. The width of the CI for those tasks was relatively narrow (≤0.58) and did not include the value of 0, indicating statistically significant reliability. Moreover, the SEM for the high-reliability tasks was low (SEM ≤ 1.91), indicating low variability in a test caused by measurement error. The remaining parameters in Tasks 2, 3, 7, 8 and 9 showed good reliability with an ICC between 0.60 and 0.68 (Table 3). Across the coordination subscale, the symmetry showed fair reliability in Tasks 2 and 4 (ICC ≤ 0.50) and poor reliability in Tasks 1 and 3 (ICC < 0.4). The width of the CI for those tasks was relatively large (≥0.81) and included 0, indicating non-significant reliability. Furthermore, the SEM of symmetry in these tasks was high and very near to the value of SD, indicating high variability in a test caused by measurement error.  All remaining coordination subscale parameters showed good to fair reliability with an ICC between 0.45 and 0.72. The results for the MDC showed a relatively small MDC in all parameters except for the symmetry parameters, which revealed a very high value compared to the actual amount of movement, thereby denoting large variability, which is demonstrated by the large SD.

1. **Inter-rater reliability**

The same results were found for the inter-rater reliability of the dynamic sitting balance subscale. The ICCs showed excellent reliability between assessors, with an ICC ≥ 0.76 for all tasks except Tasks 7, 8 and 10 (Table 4). For Tasks 7, 8 and 10, the iTIS parameters showed good between-assessor reliability, with an ICC between 0.59 and 0.70. The CI for those tasks (Tasks 7, 8 and 10) were relatively wider than the CI measured for intra-rater reliability (CI for Tasks 7, 8 and 10 ≥ 0.57), but did not include the value of 0, indicating statistically significant reliability. Furthermore, the SEM for these tasks was relatively high (SEM ≥ 1.62), denoting moderate variability caused by measurement error. Across the coordination subscale, two parameters demonstrated excellent reliability: the average rotation to the unaffected side in Task 1, which had an ICC = 0.76, and the average rotation to the affected side in Task 2, which had an ICC = 0.78. All the remaining iTIS parameters showed a good to fair reliability with an ICC between 0.48 and 0.69. The CI width was high and included the value of 0 in the low-reliability parameters such as symmetry in Task 3, indicating non-significant reliability, while the symmetry in Task 1 showed moderate reliability (ICC = 0.69), had a narrower CI (0.72) and did not include zero, indicating statistically significant reliability.

**Table 3: Intra-rater reliability between two-day sessions for each task**

**Table 4: Inter-rater reliability for each task**

# **Discussion**

The present study demonstrated good to excellent intra-rater and inter-rater reliability of the iTIS in the stroke group.

In the current study, the intra-rater reliability showed good reliability for all dynamic subscale parameters for the stroke group for Tasks 2, 3, 7, 8 and 9. A possible explanation for reduction of the reliability in Tasks 2 and 3 was the compensatory movements (e.g. using the UL to touch the bed, which led to an increase in the trunk lateral flexion ROM compared to performing the same task without using the UL) by participants during the performance of these tasks. This compensation was observed by the assessor but could not be measured by the setup of the Valedo sensors, as the sensors were only attached to the trunk. Furthermore, the stroke participants used these compensatory movements variably in the first and second assessments (i.e. used in the first assessment but not used in the repeated assessment or used much more in the first assessment compared to the repeated assessment) which could affect reliability.

Another possible factor that might have affected the reliability level is that a few stroke participants (n ≤12) were recorded using the Valedo system during the performance of Tasks 3 and 8 because they had scored 0 on the clinical TIS-V2 in previous tasks, and so they automatically scored 0 without performing the tasks (Tasks 3 and 8). As these results were included in the analysis of this task, the reliability (ICC level) decreased (Bujang 2017).

A possible reason for the reliability levels in Tasks 7, 8 and 9 being affected could be due to less variability in the performance of these tasks; most of the stroke group (n = 14/20) scored 1 on this task, indicating that these tasks challenged participants’ balance less than the previous tasks (Tasks 1 to 6), which could have resulted in a reduced use of compensatory movements. This explanation is supported by Portney and Watkins (2013, p. 607): ‘The variability among subjects’ scores must be large to demonstrate reliability. A lack of variability can occur when samples are homogeneous, when raters are all very lenient or strict in their scoring, or when the rating system falls within a restricted range’.

For the coordination subscale, intra-rater reliability was poor to fair for all parameters in the stroke group. This could have been due to a lack of detail within the TIS instructions, namely the lack of an explicit request for the participants to perform the task symmetrically (Lee et al. 2003; Russek 2004). The assessors gave this instruction: ‘Could you please move your shoulder/knee forwards and backwards until you complete the movement 6 times (3 times for each shoulder/knee), starting from the (right/left) side’. Furthermore, for the symmetry parameter, we measured the extent to which the rotation (degree of ROM) on both sides was identical (%); hence, the reliability of the symmetry parameter only reached the maximum if both sides were rotated equally. Additionally, the rotation in the lower trunk recorded from participants is limited (ROM < 10 degrees), and any error might therefore be magnified and could affect the reliability (Russek 2004). The Valedo system correctly identified the number of rotations for all the coordination subscale tasks, but the ICC was not calculated (as the calculation is dependent on the variability of the test score, which was low across participants and trials in this study).

As for inter-rater reliability, the stroke group demonstrated excellent reliability in most dynamic subscale parameters, except for in Tasks 7, 8 and 10, which revealed moderate reliability. The explanation for good reliability in Tasks 7, 8 and 10 was provided in the previous section. Possible reasons for reduction in the level of inter-rater reliability in certain tasks could be due to human error from palpation during the reapplication of the sensors between repeated sessions. Variability in sensor placement was found to affect inter-rater reliability in a study assessing the reliability of inertial measurement systems when measuring seated spinal postures (Schless et al. 2015)[. However, this contrasts with the results of a previous study which assessed the reliability of the Valedo system in measuring trunk ROM in healthy participants in a standing position. That study tested the system against a gold-standard optoelectronic system and found that the Valedo system showed excellent reliability in measuring trunk flex](#_ENREF_17)ion and lateral flexion to both sides (Bauer et al. 2015).

**Study limitations**

Limitations of this study include that the three sensors used were placed on the trunk, so no compensatory movement by the upper or lower limbs was measured during the task performance, which could affect both intra-rater and inter-rater reliability. In addition, system technical errors may also have affected the reliability results (Stenlund et al. 2014) [as the system crashed during the completion of tasks during certain sessions.](#_ENREF_21) Furthermore, any measurement device designed to quantify spinal movements with sensors attached to the skin could be subject to error due to relative movements between the soft tissues and the vertebrae (Lee et al. 2003).

The iTIS would benefit from more explicit instructions and details to improve the reliability of its results. For example, the participant instructions in the cTIS-V2 for the coordination subscale (Tasks 2 and 4) did not encourage participants to rotate their trunk symmetrically, which may have affected the symmetry parameter in those tasks. Another potential factor that could have affected reliability was human error due to palpation while replacing the sensors on the trunk.

**Conclusion and clinical implications**

Good to excellent test-retest reliability was found for most of the iTIS parameters measured. Unlike the cTIS-V2, the iTIS provides much greater information about the quality of trunk movements by detecting small changes in trunk ROM that may not be observed clinically and which may be important in justifying treatment approaches. These findings indicate that the use of iTIS measures in combination with the cTIS-V2 has important potential for enhancing the understanding of trunk impairment and compensatory trunk movements post-stroke. Further studies should explore larger sample sizes and seek to improve the iTIS methodology by using additional sensors on the upper and/or lower limbs to detect compensatory movements.

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**Table 1: Sensor location, plane of movement and parameters of interest for each TIS-V2 task**

|  |  |  |  |
| --- | --- | --- | --- |
| **cTIS-V2 tasks** | **Sensor** | **Parameter of interest** | **Plane of movement** |
| **Dynamic Sitting Balance Subscale** | | | |
| 1 - Touch the bed with the hemiplegic elbow | Sternum | ROM of lateral flexion to affected side (degrees) | Frontal |
| 2 - Repeat item 1 | Sternum | ROM of lateral flexion to affected side (degrees) | Frontal |
| 3 - Repeat item 1 | Sternum | ROM of lateral flexion to affected side (degrees) | Frontal |
| 4 - Touch the bed with the unaffected elbow | Sternum | ROM of lateral flexion to unaffected side (degrees) | Frontal |
| 5 - Repeat item 4 | Sternum | ROM of lateral flexion to unaffected side (degrees) | Frontal |
| 6 - Repeat item 4 | Sternum | ROM of lateral flexion to unaffected side (degrees) | Frontal |
| 7 - Lift pelvis from bed at the hemiplegic side | Sacrum | ROM of lateral flexion to unaffected side (degrees) | Frontal |
| 8 - Repeat item 7 | Sacrum | ROM of lateral flexion to unaffected side (degrees) | Frontal |
| 9 - Lift pelvis from bed at the unaffected side | Sacrum | ROM of lateral flexion to affected side (degrees) | Frontal |
| 10 - Repeat item 9 | Sacrum | ROM of lateral flexion to affected side (degrees) | Frontal |
| **Coordination Subscale** | | | |
| 1 - Rotate upper trunk 6 times | Sternum | Symmetry (%), ROM of average rotation to both side (degrees) and total no. of rotations | Transverse |
| 2 - Repeat Item 1 within 6 seconds | Sternum | Symmetry (%), ROM of average rotation to both side (degrees) and total no. of rotations | Transverse |
| 3 - Rotate lower trunk 6 times | Lumbar | Symmetry (%), ROM of average rotation to both side (degrees) and total no. of rotations | Transverse |
| 4 - Repeat Item 3 within 6 seconds | Lumbar | Symmetry (%), ROM of average rotation to both side (degrees) and total no. of rotations | Transverse |

**Table 2: Participants’ characteristics**

|  |  |
| --- | --- |
| **Characteristics** | **Chronic stroke (N = 20)** |
| **Age (years) (Mean±SD)** | 63.2±11.12  Range: 44–79 |
| **Gender**  Male  Female | 13  7 |
| **Hand dominance**  Right  Left | 17  3 |
| **Affected upper limb**  Right  Left | 5  15 |
| **Trunk Impairment Scale** **(****TIS) (Mean±SD)**  Participants’ scores on the TIS:  ≤10 (poor trunk control)  11–19 (fair trunk control)  ≥20 (good trunk control) | 15.65±2.70  range 10–23  1  18  1 |

**Table 3: Intra-rater reliability between two-day sessions for each task**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **cTIS-V2 tasks** | **Parameter of interest** | **Mean**  **(average)** | **Mean diff.** | **SD** | **ICC2,1** | **95% CI** | **SEM** | **MDC** |
| **Dynamic Sitting Balance Subscale** | | | | | | | | |
| Task 1 | ROM of lateral flexion to affected side (degrees) | 25.93 | 1.21 | 2.67 | 0.95 | 0.86–0.98 | 0.59 | 1.64 |
| Task 2 | ROM of lateral flexion to affected side (degrees) | 27.21 | 0.98 | 5.05 | 0.58 | -0.26–0.91 | 3.27 | 9.06 |
| Task 3 | ROM of lateral flexion to affected side (degrees) | 26.40 | 3.95 | 2.75 | 0.68 | -0.10–0.95 | 1.55 | 4.3 |
| Task 4 | ROM of lateral flexion to unaffected side (degrees) | 34.9 | 0.04 | 2.46 | 0.78 | 0.50–0.91 | 1.15 | 3.19 |
| Task 5 | ROM of lateral flexion to unaffected side (degrees) | 30.56 | 1.33 | 4.51 | 0.82 | 0.42–0.95 | 1.91 | 5.29 |
| Task 6 | ROM of lateral flexion to unaffected side (degrees) | 33.72 | 0.42 | 4.33 | 0.84 | 0.38–0.96 | 1.73 | 4.8 |
| Task 7 | ROM of lateral flexion to unaffected side (degrees) | 19.98 | 3.12 | 4.81 | 0.60 | 0.15–0.83 | 3.04 | 8.43 |
| Task 8 | ROM of lateral flexion to unaffected side (degrees) | 20.29 | 0.41 | 5.19 | 0.66 | 0.27–0.86 | 3.02 | 8.37 |
| Task 9 | ROM of lateral flexion to affected side (degrees) | 18.61 | 1.08 | 3.98 | 0.60 | 0.13–0.81 | 2.51 | 6.96 |
| Task 10 | ROM of lateral flexion to affected side (degrees) | 17.89 | -0.12 | 2.47 | 0.80 | 0.50–0.92 | 1.1 | 3.05 |
| **Coordination Subscale** | | | | | | | | |
| Task 1 | Symmetry (%) | 79.82 | -4.61 | 16.75 | 0.30 | -0.16–0.67 | 14.01 | 38.83 |
| ROM of average rotation to affected side (degrees) | 22.1 | -2.93 | 5.14 | 0.62 | 0.21–0.84 | 3.16 | 8.76 |
| ROM of average rotation to unaffected side (degrees) | 20.32 | 2.07 | 4.69 | 0.66 | 0.30–0.85 | 2.73 | 7.57 |
| Task 2 | Symmetry (%) | 84.3 | 2.38 | 10.23 | 0.50 | -0.01–0.80 | 7.23 | 20.04 |
| ROM of average rotation to affected side (degrees) | 23.3 | -1.13 | 4.33 | 0.72 | 0.40–0.88 | 2.29 | 6.35 |
| ROM of average rotation to unaffected side (degrees) | 20.19 | 2.5 | 7.19 | 0.52 | 0.09–0.78 | 4.98 | 13.8 |
| Task 3 | Symmetry (%) | 77.61 | -6.33 | 23.92 | 0.05 | -0.42–0.50 | 23.31 | 64.61 |
| ROM of average rotation to affected side (degrees) | 8.89 | 1.31 | 3.9 | 0.60 | 0.16–0.83 | 2.46 | 6.82 |
| ROM of average rotation to unaffected side (degrees) | 8.54 | 0.6 | 3.7 | 0.70 | 0.35–0.87 | 2.02 | 5.6 |
| Task 4 | Symmetry (%) | 79.25 | -9.89 | 14.56 | 0.41 | -0.11–0.76 | 11.18 | 30.99 |
| ROM of average rotation to affected side (degrees) | 9.74 | 2.35 | 4.02 | 0.45 | 0.02–0.75 | 2.98 | 8.26 |
| ROM of average rotation to unaffected side (degrees) | 8.41 | 0.72 | 4.43 | 0.65 | 0.25–0.86 | 2.62 | 7.26 |

**Mean diff. = mean difference; SD = standard deviation; ICC = interclass correlation coefficient; SEM = standard error of measurement; MDC= minimal detectable change**

**Table 4: Inter-rater reliability for each task**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **cTIS-V2 tasks** | **Parameter of interest** | **Mean**  **(average)** | **Mean diff.** | **SD** | **ICC2,1** | **95% CI** | **SEM** |
| **Dynamic Sitting Balance Subscale** | | | | | | | |
| Task 1 | ROM of lateral flexion to affected side (degrees) | 25.18 | 1.59 | 1.72 | 0.93 | 0.78–0.97 | 0.45 |
| Task 2 | ROM of lateral flexion to affected side (degrees) | 23.65 | 2.02 | 4.48 | 0.94 | 0.71–0.98 | 1.09 |
| Task 3 | ROM of lateral flexion to affected side (degrees) | 26.66 | 0.46 | 1.66 | 0.89 | 0.55–0.97 | 0.55 |
| Task 4 | ROM of lateral flexion to unaffected side (degrees) | 34.04 | 1.02 | 2.71 | 0.76 | 0.48–0.90 | 1.32 |
| Task 5 | ROM of lateral flexion to unaffected side (degrees) | 29.28 | 3.03 | 3.36 | 0.86 | 0.33–0.96 | 1.25 |
| Task 6 | ROM of lateral flexion to unaffected side (degrees) | 34.24 | 0.23 | 2.64 | 0.93 | 0.75–0.98 | 0.69 |
| Task 7 | ROM of lateral flexion to unaffected side (degrees) | 20.84 | 1.14 | 6.5 | 0.59 | 0.18–0.82 | 4.16 |
| Task 8 | ROM of lateral flexion to unaffected side (degrees) | 19.82 | 2.35 | 5.53 | 0.67 | 0.01–0.73 | 3.17 |
| Task 9 | ROM of lateral flexion to affected side (degrees) | 18.43 | 2.33 | 5.77 | 0.90 | 0.74–0.96 | 1.82 |
| Task 10 | ROM of lateral flexion to affected side (degrees) | 17.4 | 2.94 | 2.97 | 0.70 | 0.31–0.88 | 1.62 |
| **Coordination Subscale** | | | | | | | |
| Task 1 | Symmetry (%) | 80.53 | -7.33 | 9.74 | 0.67 | 0.16–0.88 | 5.59 |
| ROM of average rotation to affected side (degrees) | 22.26 | 0.16 | 8.37 | 0.58 | 0.18–0.81 | 5.42 |
| ROM of average rotation to unaffected side (degrees) | 20.95 | 2.12 | 7.07 | 0.76 | 0.48–0.89 | 3.46 |
| Task 2 | Symmetry (%) | 86.06 | 2.7 | 14.81 | 0.04 | -0.55–0.47 | 14.51 |
| ROM of average rotation to affected side (degrees) | 24.02 | 0.87 | 6.69 | 0.78 | 0.53–0.90 | 3.13 |
| ROM of average rotation to unaffected side (degrees) | 21.63 | 2.17 | 6.25 | 0.67 | 0.34–0.85 | 3.59 |
| Task 3 | Symmetry (%) | 75.39 | 6.9 | 21.07 | 0.48 | -0.04–0.80 | 15.19 |
| ROM of average rotation to affected side (degrees) | 9.25 | -0.08 | 3.89 | 0.65 | 0.28–0.84 | 2.3 |
| ROM of average rotation to unaffected side (degrees) | 8.44 | 0.92 | 3.7 | 0.65 | 0.29–0.84 | 2.18 |
| Task 4 | Symmetry (%) | 78.07 | -3.3 | 14.99 | 0.52 | 0.05–0.80 | 10.38 |
| ROM of average rotation to affected side (degrees) | 9.94 | 2.21 | 3.73 | 0.69 | 0.30–0.87 | 2.07 |
| ROM of average rotation to unaffected side (degrees) | 8.35 | 0.79 | 3.86 | 0.60 | 0.21–0.82 | 2.44 |

**Mean diff. = mean difference; SD = standard deviation; ICC= interclass correlation coefficient; SEM = standard error of measurement; MDC = minimal detectable change**



**Figure 1: Sensor placements**