

The kinematic analysis of the trunk and weight-bearing symmetry in the three planes of movement during the four phases of sit-to-stand in adults with stroke and a community control group – case-control study

By

Hesti Steyn

Thesis presented in partial fulfilment of the requirements for the degree of Masters in Physiotherapy in the Faculty of Medicine and Health Sciences at Stellenbosch University



UNIVERSITEIT  
iYUNIVESITHI  
STELLENBOSCH  
UNIVERSITY

**Supervisor:** Mrs. Gakeemah Inglis-Jassiem, Physiotherapy Division,  
Stellenbosch University

**Co-supervisor:** Mr Adnil Titus, Physiotherapy Division, Stellenbosch  
University

December 2018

## **Declaration**

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Hesti Steyn

December 2018

Copyright © 2018 Stellenbosch University

All rights reserved

## **Abstract**

### **Introduction**

The most frequent functional activity used in everyday life is sit-to-stand. Sit-to-stand (STS) consists of four phases with different pre-requisites for successful completion. The trunk plays an important role in a person with stroke's ability to complete the transition.

### **Objective**

To describe trunk kinematics and weight-bearing symmetry during four phases of STS in three planes of movement in stroke participants and community controls. Secondly, to correlate the trunk impairment scale (TIS) of stroke participants with trunk kinematics and weight-bearing symmetry.

### **Methods**

Fifteen sub-acute stroke participants and fifteen community controls were included. Two inertial measurement units (myoMOTION) were used to capture upper and lower trunk kinematics during the four phases of STS. Phase 1 (P1) is the initiation phase, Phase 2 (P2) seat-off phase, Phase 3 (P3) is the extension phase and Phase 4 (P4) the standing stabilisation phase. MyoPRESSURE (Noraxon) was used to assess kinetics. Data was captured during five repeated STS from a standard chair at self-selected pace. All parameters were analysed in MATLAB (The Mathworks, Natick, MA) using custom built scripts. Differences between case and control groups were calculated using non-parametric testing (95% CI, statistical significance level  $p < 0.05$ ). Correlation coefficients for secondary objectives were calculated using Spearman's rho.

### **Results**

People with stroke (PWS) had a longer total and phases duration except during P2 ( $p < 0.05$ ) but showed decreased vertical acceleration ( $p = 0.001$ ). P1 was characterised by, weight transference onto the affected side as the unaffected foot moved backwards accompanied by thoracic side-flexion ( $p = 0.037$ ). From P2 to P4 the weight was transferred to the unaffected side.

During P1 PWS moved the thoracic segment into rotation and side-flexion ( $p = 0.001$ ) but flexed forward the same distance as the controls at a slower velocity than the control group ( $p = 0.016$ ). The thoracic segment was moved at a high velocity into side-flexion and rotation for seat-off at the start of P2 ( $p < 0.05$ ). The control group displaced the lumbar

segment into side flexion ( $p=0.033$ ) and higher rotation ranges than PWS at seat-off ( $p=0.089$ ). Control participants also showed increased lumbar flexion velocity ( $p=0.026$ ). During P3, PWS showed greater thoracic velocity ( $p<0.05$ ) during side-flexion and rotation displacement ( $p=0.001$ ), but the lumbar segment extended at a slower velocity for the rest of P3 ( $p<0.05$ ). In comparison, the control group had increased lumbar segment side-flexion and rotation ranges compared to PWS ( $p<0.05$ ). During P4, PWS had increased thoracic side-flexion displacement to accompany asymmetrical weight-distribution ( $p=0.008$ ). They deviated laterally with less smooth movement with increased thoracic and lumbar medio-lateral acceleration ( $p=0.001$ ) and Jerk ( $p<0.05$ ). The control group in contrast moved smoother in an anterior direction with increased thoracic antero-posterior (AP) acceleration ( $p=0.001$ ). PWS and control participants had similar lumbar AP acceleration ( $p=0.902$ ).

Total TIS correlated positively with trunk angular velocity in P2, specifically thoracic forward flexion-rotation to the left plus lumbar forward flexion. TIS correlated with increased thoracic flexion displacement during P2. More thoracic extension displacement during P3 correlated with higher dynamic and coordination subscores. Decreased acceleration was associated with increased dynamic subscores. Increased dynamic and coordination subscores on the TIS correlated positively with more thoracic extension at the end of STS.

## **Conclusion**

PWS moved differently during STS compared to community controls. The thoracic segment moved more in frontal and transverse planes with fixation of the lumbar segment; potentially compensating for diminished postural control. Thoracic rotation and side-flexion may have been used to maintain a more central position and movement of the center of mass. The dynamic and coordination subscales of TIS, which highlight distinct impairments of the upper and lower trunk, correlated well with altered trunk kinematics of PWS.

## **Key Words**

Sit-to-stand, stroke, trunk, kinematics, trunk impairment scale

## Opsomming

### Inleiding

Die funksionele aktiwiteit wat elke dag die meeste gebruik word, is sit-tot-staan (STS). STS bestaan uit vier fases en elke fase het verskillende voorvereistes vir suksesvolle voltooiing. Die romp speel 'n belangrike rol in die vermoë van persone met beroerte (PMB) om hierdie oorgang suksesvol te kan voltooi.

### Doel

Om die romp kinematika en gewigdraende asimmetrie gedurende die vier fases van STS in die drie vlakke van beweging in PMB en gemeenskapskontroles te beskryf. Tweedens, om die "Trunk Impairment Scale" (TIS) van deelnemers met hul romp kinematika en gewigdraende simmetrie te korreleer.

### Metodologie

Die gevallestudie het bestaan uit vyftien sub-akute deelnemers met beroerte, en vyftien gemeenskapskontroles. Twee traagheids-metings eenhede (myoMOTION) is gebruik om die boonste en onderste romp kinematika te meet gedurende die vier fases van STS. Fase 1 (F1) is die inleidings fase, Fase 2 (F2) sitplek verlating, Fase 3 is die ekstensie fase en Fase 4 (F4) die staan stabilisasie fase. MyoPRESSURE (Noraxon) is gebruik om die kinetika te meet. Die data is vasgelê gedurende vyf herhalings van STS vanaf 'n gestandaardiseerde stoel teen 'n self-gereguleerde tempo. Alle parameters is met MATLAB (The Mathworks, Natick, MA) geanaliseer deur gebruik te maak van persoonlik ontwerpte formules. Die verskille tussen die gevallegroep en kontrolegroep is bereken deur gebruik te maak van nie-parametriese toetsing (95% CI, statistiese betekenisvolheidsvlak van  $p < 0.05$ ). Die korrelasie koëffisiënte vir sekondêre doelwitte is bereken deur gebruik te maak van Spearman se rho.

### Resultate

PMB het 'n langer STS oorgang en fase tydsduur gehad behalwe gedurende F2 ( $p < 0.05$ ) maar het 'n afname in vertikale versnelling getoon ( $p = 0.001$ ). F1 is gekenmerk deur gewigsoordrag op die geaffekteerde kant, aangesien die ongeaffekteerde voet agtertoe beweeg het. Dit is gevergesel deur torakale sy-fleksie ( $p = 0.037$ ). Van F2 tot F4 was die gewig oorgedra na die ongeaffekteerde kant.

Gedurende F1 het die gevallegroep se torakale segment 'n rotasie en sy-fleksie beweging getoon ( $p=0.001$ ) terwyl die vorentoe fleksie dieselfde afstand as die kontrolegroep verplaas het teen 'n stadiger snelheid ( $p=0.016$ ). Die torakale segment het teen 'n hoër snelheid in sy-fleksie en rotasie beweeg tydens sitplek verlatings F2 ( $p<0.05$ ). Die kontrolegroep se lumbale segment het in hoër sy-fleksie ( $p=0.033$ ) en rotasie verplaas as PMB ( $p=0.089$ ). Die kontrolegroep het ook 'n verhoogte lumbale fleksie snelheid getoon ( $p=0.026$ ). Gedurende F3 het PMB groter torakale snelheid ( $p<0.05$ ) getoon gedurende sy-fleksie en rotasie plaasgevind het. Die lumbale segment het stadiger ekstensie snelheid getoon vir die res van F3 ( $p<0.05$ ). Die kontrolegroep het 'n toename in beide lumbale segment sy-fleksie en rotasie grense gehad in vergelyking met PMB ( $p<0.05$ ). Gedurende F4 het die gevallegroep 'n toename in torakale sy-fleksie verplasing gehad om die ongeaffekteerde sy se gewigsverspreiding te akkommodeer ( $p=0.008$ ). PMB het lateraal afgewyk met 'n minder gladde beweging asook met verhoogde torakale en lumbale ML versnelling. ( $p=0.001$ ) en ruk ( $p<0.05$ ). Die kontrolegroep het in vergelyking 'n gladder beweging in die AP rigting getoon vir die torakale segment ( $p=0.001$ ). Beide die gevallegroep en die kontrolegroep het dieselfde lumbale AP versnelling gehad ( $p=0.902$ ).

Die totale TIS het 'n positiewe korrelasie met die F2 hoeksnelheid getoon vir 'n verhoogde torakale vorentoe fleksie, rotasie na links en lumbale vorentoe fleksie. Die TIS korreleer ook met 'n toename in torakale fleksie grense gedurende F2. Hoër torakale ekstensie gedurende F3 korreleer met 'n toename in die TIS, dinamiese subskaal en koördinasie subskaal lesing. 'n Afname in versnelling word geassosieer met 'n toename in die dinamiese subskaallesing. 'n Toename in beide die dinamiese en koördinasie tellings is positief met meer torakale ekstensie aan die einde van STS.

### **Gevolgtrekking**

PMB beweeg verskillend tydens STS in vergelyking met die gemeenskapskontroles. Die torakale segment beweeg meer in die frontale- en dwarsvlak met fiksasie van die lumbale segment; wat moontlik vergoed vir die verminderde postuurbeheer. Torakale rotasie en sy-fleksie mag gebruik geword het om 'n meer sentrale posisie en beweging van die middelpunt van massa te behou. Die dinamiese en koördinasie-subskale van TIS, dui sekere inkortings van die boonste en onderste romp aan. Dit het goed gekorreleer met die veranderde romp kinematika van die beroerte-deelnemers,

### **Sleutelwoorde**

Sit-tot-staan, beroerte, romp, kinematika, "Trunk impairment scale"

## Acknowledgements

I would like to sincerely thank the following people:

- ✧ The staff of Bishop Lavis Rehabilitation Centre and Delft Community Health Centre for making the time and effort to accommodate me and my research into their busy schedules
- ✧ The staff of the FNB-3D Movement Analysis Laboratory – Stellenbosch University for their guidance and assistance
- ✧ Dr John Cockcroft of the Movement Analysis Laboratory for data analysis
- ✧ Ms Tonya Esterhuizen at the Division of Epidemiology and Biostatistics for statistical analysis and sampling advice
- ✧ Prof Quinette Louw and Mrs Gakeemah Inglis-Jassiem for funding and affording me the opportunity to complete my degree
- ✧ My supervisors Mrs Gakeemah Inglis-Jassiem and Mr Adnil Titus for their patience, guidance, persistence and late nights. I truly appreciate all your efforts.
- ✧ Marti Loots and Christiaan Lamprecht for assisting me once in my data collection and lending a hand
- ✧ My mother, Mrs Tertia Steyn, for assisting me every time with my data collection and ensuring everything ran smoothly. For her unwavering support, love and whom without this thesis would not be possible.
- ✧ Lastly to my father, Prof Herman Steyn, for assisting with the data analysis, unwavering support and love. Thank you for giving me the opportunity to study and improve myself.

## Table of Contents

Declaration	i
Abstract	ii
Opsomming	iv
Acknowledgements	vi
List of Figures	xi
List of Images	xii
List of Tables	xiii
List of Acronyms and Abbreviations	xv
<b>Chapter 1</b> Introduction	<b>1</b>
<b>Chapter 2</b> Literature Review	<b>5</b>
2.1 Stroke in South Africa	5
2.2 Stroke rehabilitation in South Africa	6
2.3 Impact of stroke on function	6
2.4 Impact of stroke on postural stability	7
2.5 Role of the trunk in postural stability	8
2.6 Changes in the transition of sit-to-stand (STS) post stroke	10
2.6.1 Phase 1 of STS: Initiation Phase	10
2.6.2 Phase 2 of STS: Seat-off Phase	10
2.6.3 Phase 3 of STS: Extension Phase	11
2.6.4 Phase 4 of STS: Stabilisation Phase	11
2.7 Measures used to assess biomechanics of STS post-stroke	12
2.8 Scoping review on how IMU have been used to assess trunk kinematics during STS	15
2.8.1. Searching	15
2.8.2.1. Study eligibility	15
2.8.2.2. Study selection and data extraction	16
2.8.2.3. Method of analysis and synthesis	16
2.8.2.4. Search results of the Scoping Review	16
2.8.2. Findings of the scoping review	17
2.8.2.1. The composition of IMU's	17
2.8.2.2. Placement of IMU	17
2.8.2.3. Comparison with gold standard and validation of IMU	18
2.8.2.4. IMU and phases of STS	19
2.8.2.5. IMU and trunk kinematics	19
2.8.2.6. Correlation of IMU with clinical physiotherapy outcome measures	20
	vii



2.8.3. Summary of findings	20
2.9 Rationale for study	21
2.10 Summary of Literature review chapter	21
<b>Chapter 3 Methodology</b>	22
3.1 Research question	22
3.2 Research objectives	22
3.2.1. The primary objectives of the study were;	22
3.2.2. The secondary objectives of the study were;	23
3.3 Study design and setting	23
3.4 Sample size calculation	23
3.5 Study population	24
3.6 Study sample	24
3.7 Eligibility criteria	25
3.7.1 Inclusion criteria:	25
3.7.2 Exclusion criteria:	26
3.8 Instrumentation	26
3.8.1. MyoMOTION	26
3.8.2. MyoPRESSURE	27
3.9 Clinical outcome measures	27
3.9.1. The demographic and stroke-related questionnaire	27
3.9.2. Trunk Impairment Scale	27
3.9.3. Modified Barthel Index	28
3.9.4. Correlation between TIS and mBI	28
3.10 Procedures	29
3.10.1. Pre-test	29
3.10.2. Main study	30
3.11 Data processing	37
3.11.1. Synchronisation of data	40
3.11.2. Accelerometer Calculations	40
3.12 Statistical analysis	43
3.13 Ethical Considerations	44
<b>Chapter 4 Results</b>	45
4.1 Sample description	45
4.2 Temporal parameters of Sit-to-Stand	49
4.3 Kinetic parameters of Sit-to-Stand	50
4.3.1. Weight-distribution between the case and control participants	50

4.3.2.	Total force generated during Sit-to-Stand	52
4.4	Kinematic parameters of Sit-to-Stand	53
4.4.1.	Phase 1 – Initiation of movement	54
4.4.2.	Phase 2 – Seat-off	56
4.4.3.	Phase 3 – Extension	58
4.4.4.	Phase 4 – Stabilisation	61
4.4.5.	Acceleration of the trunk	62
4.5	Correlation with the Trunk Impairment Scale	64
4.5.1	Comparison between Temporal parameters of the trunk and TIS Total score	64
4.5.2	Correlation between kinetic and kinematic parameters of the trunk and TIS total score	64
4.6	Comparison between Parameters of the trunk and TIS Subscale score	68
4.6.1.	Comparison between temporal parameters of the trunk and TIS subscale scores	68
4.6.2.	Correlation between kinetic and kinematic parameters of the trunk and TIS total score	69
4.7	Summary of results	73
<b>Chapter 5</b>	<b>Discussion</b>	75
5.1.	Phase 1 – Initiation of movement	75
5.2.	Phase 2 – Seat-Off	77
5.3.	Phase 3 – Extension	78
5.4.	Phase 4 – Stabilisation	79
5.5.	Trunk acceleration	79
5.6.	Correlation of Trunk kinematics with the Trunk Impairment Scale	81
5.6.1.	Correlation with the total TIS score	81
5.6.2.	Correlation with the Dynamic subscale of the TIS	82
5.6.3.	Correlation with the Coordination subscale of the TIS	84
5.7.	Summary	84
<b>Chapter 6</b>	<b>Conclusion &amp; Recommendations</b>	86
6.1.	Introduction	86
6.2.	Objectives	86
6.2.1.	Primary Objectives	86
6.2.2.	Secondary Objectives	87
6.3.	Clinical significance of the findings	87
6.4.	Limitations of this study	88
6.5.	Recommendations for future research	88

6.6. Summary	89
References	90
List of Addendums	102

## List of Figures

Figure 2.1: Flowchart of literature search and identification of eligible articles	17
Figure 3.1: A Typical Raw THO accelerometer's ML component	40
Figure 3.2: A Typical LPF filtered THO accelerometer's ML component	41
Figure 3.3: A Typical HPF filtered THO accelerometer's ML component	41
Figure 3.4: A Typical THO jerk's ML component	42
Figure 4.1: Study flow diagram detailing participant allocation	46
Figure 4.2: Weight-Bearing distribution of the control participants during the four phases of STS	50
Figure 4.3: Weight-Bearing distribution of the case participants during the four phases of STS	51
Figure 4.4: Comparison of total force distribution (FC) during STS phases	52
Figure 4.5: Positive correlation of thoracic flexion displacement during P4 with the Total TIS score	66
Figure 4.6: Negative correlation between P2 flexion velocity and TIS score	67
Figure 4.7: The positive correlation between the coordination subscale and P2 duration	68
Figure 4.8: Negative correlation between lumbar flexion displacement and the coordination subscale during P3	71
Figure 4.9: Positive correlation between thoracic flexion displacement and the coordination subscale during P4	71
Figure 4.10: P1 thoracic maximum extension velocity during P1	72
Figure 4.11: Thoracic ML sway correlation with the dynamic subscale	73

## List of Images

Image 3.1: MOCAP Marker Placement	31
Image 3.2: IMU Placement	32
Image 3.3: Participant with sensor placement	33
Image 3.4: Sitting Calibration	33
Image 3.5: Standing Calibration	34
Image 3.6: STS Transfer Surface	34
Image 3.7: Start of Phase One	35
Image 3.8: Start of Phase Two	36
Image 3.9: Start of Phase Three	36
Image 3.10: Start of Phase Four	37
Image 3.11: Phase One Marker – Upper Trunk Pitch: Start of forward trunk flexion	38
Image 3.12: Trigger switches for Phase Two (right-sided seat-off triggered the start of phase two)	38
Image 3.13: Start of Phase Three marked at maximum dominant ankle dorsiflexion	39
Image 3.14: Start of Phase Four marked at maximum dominant hip extension	39

## List of Tables

Table 3.1 Inclusion criteria for the study	25
Table 3.2: Exclusion criteria for the study	26
Table 4.1: Group demographics	46
Table 4.2: Functional independence and trunk impairment of the case group	47
Table 4.3: Comparison of functional independence and trunk impairment as per side affected	48
Table 4.4: Comparison of duration of individual phases and total STS transition	49
Table 4.5: Guide to biomechanical movement planes and correlation to human movements	53
Table 4.6: Guide to biomechanical movement planes and correlation to the direction of velocity	54
Table 4.7: Kinematic parameters of the thoracic segment of the trunk during P1	54
Table 4.8: Kinematic parameters of the lumbar segment of the trunk during P1	55
Table 4.9: Weight-bearing symmetry between the case and control group during P1	56
Table 4.10: Kinematic parameters of the thoracic segment during P2	56
Table 4.11: Kinematic parameters of the lumbar segment during P2	57
Table 4.12: Weight-bearing symmetry between the case and control group during P2	58
Table 4.13: Differences in the side that triggered seat-off	58
Table 4.14: Kinematic parameters of the thoracic segment during P3	59
Table 4.15: Kinematic parameters of the lumbar segment during P3	60
Table 4.16: Weight-bearing symmetry between the case and control group during P3	60
Table 4.17: Kinematic parameters of the thoracic segment during P4	61
Table 4.18: Weight-bearing symmetry between the case and control group during P4	61
Table 4.19: Unscaled Vertical Translation Acceleration	62
Table 4.20: Thoracic acceleration	63
Table 4.21: Lumbar acceleration	63
Table 4.22: TIS score correlation with total force distribution of the case group	64

Table 4.23: Correlation of total TIS score with the angular displacement of the trunk	65
Table 4.24: Correlation of total TIS score with the angular velocity of the trunk	66
Table 4.25: TIS subscale score correlation with phase duration of STS	68
Table 4.26: Correlation of the dynamic subscale score with the angular displacement of the trunk	69
Table 4.27: Correlation of the coordination subscale score with the angular displacement of the trunk	70
Table 4.28: Correlation of the dynamic and coordination subscale score with the angular velocity of the trunk	72
Table 4.29: Correlation of the dynamic subscale score with the acceleration of the trunk	73

## List of Acronyms and Abbreviations

3D	Three-Dimensional
ADL	Activities of Daily Living
AIDS	Acquired Immunodeficiency Syndrome
AP	Anterior-Posterior
ASIS	Anterior Superior Iliac Crest
AUC	Area under the Curve
BI	Barthel Index
BOS	Base of Support
C7	Seventh Cervical Vertebra
CHC	Community Health Centre
CLAV	Clavicle – Sternal notch
COG	Centre of Gravity
COM	Centre of Mass
COP	Centre of Pressure
HIV	Human Immunodeficiency Virus
HPF	High Pass Filter
HREC	Health Research Ethics Committee
ICC	Intraclass Correlation
IMU	Inertial Measurement Unit
L3/4	Third/Fourth Lumbar Vertebra
LPF	Low Pass Filter
LUM	Lumbar (Lower Trunk)
mBI	Modified Barthel Index
ML	Medio-Lateral
MOCAP	Motion Optoelectronic Capture System
P1	Phase One
P2	Phase Two
P3	Phase Three
P4	Phase Four
PiG	Plug-in-Gait



PSIS	Posterior Superior Iliac Crest
PWS	People with Stroke
NCD	Non-Communicable Disease
SA	South Africa
STRN	Sternum
STS	Sit-to-Stand
SU	Stellenbosch University
T10	Tenth Thoracic Vertebra
THO	Thoracic (Upper Trunk)
TIS	Trunk Impairment Scale
VT	Vertical
WB	Weight-Bearing
WBA	Weight-Bearing Asymmetry

# *Chapter 1*

## *Introduction*

Stroke is one of the most fatal neurological diseases worldwide (Mukherjee and Patil, 2011). In recent years there has been a decrease in mortality leading to a larger disabled group (Di Monaco et al., 2010; Mayosi et al., 2009). The critical goal of rehabilitation for people with stroke (PWS) is to decrease the level of disability and to return to their previous level of function within their home, community and in the end, work life (Bryer et al., 2010). The most common neurological deficit post-stroke is hemiparesis, essentially a loss of muscle activity in the limbs on one side of the body. Thorogood et al. (2004) found that 66% of people with stroke need help with a minimum of one activity of daily living (ADL).

The most frequent functional activity used in everyday life is sit-to-stand (STS) (Boukadida et al., 2015; Kuo, Tully and Galea, 2010). It is considered one of the most mechanically demanding tasks as it involves the transfer of the centre of body mass (COM) against gravity from a broad base of support (BOS) to a smaller BOS (Kuo, Tully and Galea, 2010). It is also a prerequisite for successful transfers, standing and for walking (Boukadida et al., 2015, Kuo, Tully and Galea, 2010). Post-stroke a person's ability to perform this daily functional activity independently and safely is often impaired (Boukadida et al., 2015). This is due to various factors of which impaired selective activity in the trunk influenced by hemiparesis, is but one (Karthikbabu et al., 2011).

The trunk is situated between the shoulder and the pelvic girdle, creating a proximal anchor of stability for distal body segments like the arms and legs (Jijimol, Fayaz and Vijesh, 2013; Cromwell et al., 2001). The trunk also provides the centre point of stabilisation for the whole body which helps to keep the body upright against gravity (Jijimol, Fayaz and Vijesh, 2013; Cromwell et al., 2001). It further adjusts the shifting of bodyweight during everyday activities resulting in more dynamic postural adjustments (Zakaria, Rashad and Mohammed, 2010).

During movement, more dynamic postural control is required (Shumway-Cook and Woolcott, 2010). Dynamic postural control can be defined as the ability to maintain the COM within the BOS while the body is exposed to any anticipated or unexpected perturbations (Sirois-Leclerc, Remaud and Bilodeau, 2017). The foundation of postural

control stems from the postural tone in the trunk segments and the trunk musculature responsible for righting and balance reactions (Shumway-Cook and Woollacott, 2010; Davies, 1990). Trunk control is therefore considered a prerequisite for improving balance and weight symmetry in individuals with stroke (Karthikbabu et al., 2011).

Post-stroke the trunk muscles are bilaterally affected unlike unilateral limb hemiparesis (Likhi et al., 2013; Karthikbabu et al., 2012; Ryerson et al., 2008; Karatas et al., 2004). Karatas et al. (2004) found that even mild weakening of trunk muscles in people with stroke interferes with balance, stability and many functional activities. The selective movement between the upper and lower trunk is especially considered crucial for all functional movements (Karthikbabu et al., 2011). It is observed that rotation of the lower trunk is more difficult post stroke and essential for coordination of the trunk to improve the weight-shift ability towards the hemiparetic side (Chung, Kim and Lee, 2013). This impairment in the trunk due to weak trunk musculature leads to difficulties with independent STS (Boukadida et al., 2015; Karthikbabu et al., 2011).

In clinical practice, the Trunk Impairment Scale (TIS) was designed to measure the motor impairment of the trunk post-stroke (Verheyden et al., 2004). It consists of three subscales; static sitting balance, dynamic sitting balance and coordination subscale (Verheyden et al., 2004). Both the dynamic and coordination subscales measure the movement and impairment of the upper and lower trunk segments, namely lateral side-flexion and coordination respectively (Verheyden et al., 2004). Lee et al. (2018) found that the dynamic and coordination subscales can be used as an assessment tool to classify the level of impairment of the trunk in stroke survivors. The TIS has a positive correlation with the sit-to-stand transition (Lee et al., 2018; Kim et al., 2015).

In a review of the literature, Boukadida et al. (2015) identified four phases during the transition of STS in the general population. Phase one (P1) is the initiation of this transition and is characterised by flexion momentum which ends before the thighs rise off the chair or supporting surface. In this phase, anterior displacement of the center of pressure (COP) with the forward movement of the trunk takes place (Dubost et al., 2005). Phase two (P2) begins with seat-off and continues with an anterior and vertical displacement of the COM (Boukadida et al., 2015). Phase three (P3) is known as the extension phase, where the body extends into an erect position. It is initiated after maximal ankle dorsiflexion is achieved and the phase is completed when the hip ceases to extend (Boukadida et al., 2015). Phase four (P4) refers to the stabilisation phase, where overall postural control during the dynamic movement is achieved.

Altered execution of STS in PWS is often characterised by some of the following changes, for example, longer STS duration, asymmetry of body weight support, asymmetry of joint kinematics and changes in velocity and acceleration (Mao et al., 2018; Duclos, Nadeau and Lecours, 2008; Lecours et al., 2008). During P1 PWS may perform trunk forward flexion instead of anterior weight shift and translation of the trunk; the COM displacement is therefore usually less (Messier et al., 2004). During P2, it is reported that the pelvis translated over the non-paretic side while the trunk also continued to deviate in a mediolateral direction towards the non-paretic side (Duclos, Nadeau and Lecours, 2008; Lecours et al., 2008). The extension phase (P3) in PWS is often crudely combined with the stability of P4. There is weight bearing asymmetry (WBA) during P3 as the COM is typically shifted to the non-paretic limb to minimise instability (Genthon et al., 2007). If the COM falls short or overshoots the BOS, an extra step will need to be taken to regain stability (Geurts et al., 2005).

Biomechanical measures of movement attained by motion capture systems provide higher objectivity than subjective observational interpretation and functional assessment of STS (Bagala et al., 2013). The gold standard for kinematic analysis is a motion optoelectronic capture system (MOCAP) (Bauer et al., 2015; Bolink et al., 2015). In contrast to MOCAP, an inertial measuring unit (IMU) is a readily available, low cost, small and a lightweight measure which is easy to use in a person's natural environment (Bolink et al., 2015). IMU's are primarily comprised of accelerometers and gyroscopes. An accelerometer is a type of inertial sensor that measures position, distance and velocity (Oberländer, 2015; Rosário, 2014). In a three-dimensional setting, a tri-axis accelerometer is needed to measure the three planes of movement (Rosário, 2014).

Biomechanically, human movement is analysed in three planes of movement; frontal, sagittal and transverse (Behnke, 2012). In the frontal plane, the movement takes place in the mediolateral axis, a side-ways/lateral movement. In the sagittal plane, the movement takes place in the anteroposterior axis, forwards and backwards movement. Lastly, in the transverse plane, the movement takes place in the proximal-distal axis, a rotational movement. IMU has been validated against the gold standard of MOCAP and can reliably measure various aspects of STS. These include the measurement of STS duration (Janssen et al., 2008a; Najafi et al., 2003); balance control (Janssen et al., 2008b); power of the vertical displacement (Zijlstra et al., 2010); and STS activity recognition (Van Lummel et al., 2012; Taraldsen et al., 2011).

While STS has received much interest in the literature, one aspect that has not been characterised well is the action of the trunk during STS. To date, no study has evaluated the movement of the upper and lower trunk segments during STS in the three planes of movement within the four phases. The TIS has also not been correlated to the phases of STS or the three planes of movement. The current study aimed to investigate the three-dimensional kinematics of the trunk during STS in PWS as well as correlate the trunk kinematics and STS kinetics with the TIS clinical measure.

The following chapter, the literature and scoping review, discusses the findings and limitations of current literature as they pertain to three-dimensional analysis of the trunk in the three planes of movement and within the four phases of STS. Chapter three elaborates on the aims and objectives as well as the methods used to implement and conduct the current study based on the limitations found in current literature. Chapter four describes the results obtained while chapters five and six further discusses and concludes the findings of the current study. Additionally, the last chapter identifies the study's limitations and presents recommendations for future research.

# *Chapter 2*

## *Literature Review*

This review chapter aims to provide an overview of the current literature on the transition of sit-to-stand (STS) in PWS. The chapter further describes the biomechanics of this daily movement activity, including how it has been objectively assessed to date. The role of the trunk during the transition of STS is highlighted in PWS. This chapter should be read in conjunction with the subsequent scoping review, which expands on the use of an inertial measuring unit (IMU) for the assessment of the trunk segment during STS. These two sections of the review chapter contributed to the development of the research study's aims and objectives.

### **2.1 Stroke in South Africa**

Stroke is one of the most fatal neurological diseases (Mukherjee and Patil, 2011). In recent years there has been a decrease in mortality leading to a larger disabled group (Di Monaco et al., 2010; Mayosi et al., 2009). In South Africa (SA) stroke is the leading cause of long-term disability due to higher survival rates and often leads to the significant socioeconomic burden on caregivers as well as the country (Bryer et al., 2010). Stroke mainly affects the older population, but in SA the prevalence amongst the younger generation is also increasing due to HIV and other non-communicable diseases (NCD) (Bryer et al., 2010). This becomes problematic as the younger generation are expected to contribute to the economy of the country (Kuluski et al., 2014). This group should not need to receive rehabilitation and be living with a disability through their most productive work years (Kuluski et al., 2014).

SA is currently burdened with an increase in NCD (Mayosi et al., 2009). The incidence of stroke is 75,000 yearly in SA with 33,500 comprising stroke in rural areas (Maredza, Bertram and Tollman, 2015). Also, the prevention and treatment of NCD by healthcare services are relegated to the more prevalent morbidity and mortality of communicable diseases such as HIV/AIDS and tuberculosis (Mayosi et al., 2009). Tobacco, alcohol, physical inactivity, obesity, hypercholesterolaemia and an unhealthy diet are some risk factors that lead to NCD such as diabetes, respiratory- and cardiovascular disease (Mayosi et al., 2009). In SA a high percentage of the population are overweight and have

poor adherence to hypertension medication (Bertram et al., 2013). The rural prevalence of stroke in SA is 300/100000 (Thorogood et al., 2004). That said, the current leading cause of stroke in rural SA is hypertension (38%) and obesity (20%) (Maredza, Bertram and Tollman, 2015). The male/female ratio of stroke survivors in rural SA is 0.9, and the ratio of these stroke survivors needing help with at least one activity of daily living (ADL) is 1:2 (Thorogood et al., 2004). Pillay-van Wyk et al. (2016) states that in SA, stroke is the second most common cause of mortality after HIV/AIDS as well as the primary cause of disability.

## **2.2 Stroke rehabilitation in South Africa**

Stroke rehabilitation is best managed using an interdisciplinary team and goal-orientated approach (Bryer et al., 2010). The critical goal of rehabilitation for PWS is to decrease the level of disability and to return to their previous level of function within their home, community and at end stage, work life (Bryer et al., 2010). For many who have a significant disability as a result of their neurological deficits post-stroke, just decreasing the burden of care on the family may be the primary aim of rehabilitation (Bryer et al., 2010). Bryer et al. (2010) state that there are many reasons why disability post stroke in SA is so high. This may be as a result of insufficient rehabilitation facilities; reluctance of people to receive or complete rehabilitation due to the potential loss of a disability grant; a lack of transport to attend rehabilitation sessions; and due to a delay in the acute management of stroke (Bryer et al., 2010). The majority of people presenting with stroke in SA receive treatment in the public health sector where there is either a shortage or absence of available inpatient rehabilitation facilities (Bryer et al., 2010). Outpatient rehabilitation in SA rarely achieves the intensity of inpatient rehabilitation (Bryer et al., 2010). In these current under-resourced settings with limited inpatient rehabilitation available, the need to improve home-based care, outpatient and community-based rehabilitation is of great importance (de Villiers et al., 2011; Bryer et al., 2010).

## **2.3 Impact of stroke on function**

Predicting function post stroke is difficult due to the heterogeneous characteristics of people with stroke, yet longitudinal studies have found that most motor recovery occurs within the first ten weeks post stroke (Kwakkel and Kollen, 2013). The most common neurological deficit post-stroke is hemiparesis, a loss of muscle activity. Other deficits post-stroke include altered coordination, proprioception loss, neglect of the hemiparetic side and apraxia (Young and Tolentino, 2009). These deficits result in limitations of ADL

such as brushing teeth, washing, dressing, walking or even merely sitting upright (Young and Tolentino, 2009). Thorogood et al. (2004) found that 66% of PWS need help with a minimum of one ADL. The loss of the ability to care for one's personal needs and functional mobility can result in a loss of self-confidence and dependency on carers (Pendleton and Schultz-Krohn, 2013). Due to this loss of function, the family roles are often disrupted leading to a family member becoming the primary caregiver of the PWS, thereby placing stress on the home's management (Pendleton and Schultz-Krohn, 2013).

Physiotherapy rehabilitation often consists of positioning, independent transfer, early mobilisation, facilitating independence in ADL's and falls prevention (Bryer et al., 2010; Young and Tolentino, 2009). The main aim of rehabilitation is to try and decrease the burden of care on the family with increase of independence (Bryer et al., 2010). Weight shifting and balance retraining is a crucial feature for success in this ADL rehabilitation (Young and Tolentino, 2009).

## **2.4 Impact of stroke on postural stability**

Balance is considered to be a prerequisite for the restoration of ADL and mobility (Young and Tolentino, 2009). Balance is defined as a sensorimotor strategy that coordinates the sensory information (input) with the motor output to maintain control during a position and movement (Shumway-Cook and Woollacott, 2010; Young and Tolentino, 2009). Due to an array of balance disorders, PWS often experience falls and safety risks, especially when the task demands a voluntary shift of the centre of mass (COM) (Chern et al., 2010). COM is defined as the centre point of total body mass (Shumway-Cook and Woollacott, 2010).

Balance is also referred to as postural stability and binds to the concept of postural control with postural orientation (Shumway-Cook and Woollacott, 2010). Postural stability is the process to maintain the control of the COM within the base of support (BOS) during static and dynamic daily activities (Shumway-Cook and Woollacott, 2010). Centre of gravity (COG) is a term used in literature parallel to COM as it is defined as the vertical projection of COM, although these two are different biomechanical concepts. Centre of pressure (COP) is the centre point of total force distribution applied to the supporting surface (Shumway-Cook and Woollacott, 2010).

The demands on postural stability are much lower during the sitting position since the BOS is much larger, i.e. soles and areas between feet plus the buttocks and thighs on the supporting surface. However, standing stability demands are greater due to the COM that has to fall within a reduced BOS, i.e. two feet (Shumway-Cook and Woollacott, 2010). In



quiet stance COP makes constant small oscillations, never remaining still, as it revolves around the COM that continually changes with movement (Rabuffetti et al., 2011; Shumway-Cook and Woollacott, 2010). It could, therefore, be said that postural sway thus refers to the COP pattern and its movement relative to COM (Yamamoto et al., 2015).

Three factors contribute to static standing balance specifically, i.e. body alignment, muscle tone and postural tone (Shumway-Cook and Woollacott, 2010). Body alignment is defined as the ideal postural alignment of the whole body where a state of equilibrium between different body segments/limbs are maintained with the least use of internal energy (Shumway-Cook and Woollacott, 2010). Muscle tone is the resistance to which a muscle counteracts lengthening in a resting state (Masi et al., 2010). Movement is essential in life, even when remaining still our muscles continue to be active to keep the COM inside the BOS. That is why we do not fall when standing upright because our anti-gravity postural muscles are contracting to counteract the force of gravity; this is called postural tone (Shumway-Cook and Woollacott, 2010).

Davies (1990) has suggested that postural tone in the trunk segment is the key element for control of postural stability in the erect position. This erect position is considered a static position as the base of support is not changing, but the postural control is dynamic as small impulsive sway movements, seen as the COP movement, is caused by the postural tone counteracting gravity (Shumway-Cook and Woollacott, 2010). This is best seen in standing, our calf muscles contract to shift the COP forwards on the ankle and the shin muscle contract to shift the COP backwards (Le Mouel and Brette, 2017).

When we start to move our limbs or whole body, more dynamic postural control is needed. Dynamic postural control can be defined as the ability to maintain the COM within the BOS while the body is exposed to any anticipated or unexpected movements (Sirois-Leclerc, Remaud and Bilodeau, 2017). Therefore, the foundation of postural control stems from the postural tone in the trunk segments and the trunk musculature responsible for righting and balance reactions (Shumway-Cook and Woollacott, 2010; Davies, 1990).

## **2.5 Role of the trunk in postural stability**

The trunk, which is situated between the shoulder and pelvic girdle, creates a proximal anchor of stability for both distal body segments, i.e. the arms and legs (Jijimol, Fayaz and Vijesh, 2013; Cromwell et al., 2001). In the lower limbs when one foot lifts off the ground, the pelvis needs a centre point of stabilisation in order to maintain balance (Davies, 1990). This centre point of stabilisation is the lower trunk which keeps the body upright and

adjusts the weight-shift during the dynamic postural adjustment (Zakaria, Rashad and Mohammed, 2010). Just so the upper limbs need a mobile yet stable proximal anchor to perform various actions such as reaching (Davies, 1990). Reaching leads to an increase in the movement of the upper trunk to gain reach distance as well as to return to starting position (Jeon, Lee and Kim, 2015). Hence it is deduced that proximal stability will facilitate distal mobility and control of the limb, in this case, the arm movement.

The trunk muscles need a stable origin to act efficiently, which is the pelvis, lumbar spine, thorax spine or the central aponeurosis depending on which part of the trunk is being moved (Karthikbabu et al., 2011). The rotation of the trunk is not a single task but requires the static holding of the contralateral muscles to stabilise the central aponeurosis allowing the antagonist to shorten and rotate the pelvis or thorax forwards (Karthikbabu et al., 2011). This selective movement between the upper and lower trunk is crucial for all functional movements (Karthikbabu et al., 2011). It is observed that rotation of the lower trunk is more difficult post stroke and essential for coordination of the trunk to improve the weight-shift ability towards the hemiplegic side (Chung, Kim and Lee, 2013).

Trunk control has recently been identified as the key factor in human balance, control and mobility (Vette et al., 2014). It can be defined as the ability of truncal muscles to allow the body to remain erect, shifting weight and performing selective movements to keep the COP within the BOS during static and/ or dynamic postural adjustments (Jung et al., 2014; Karthikbabu et al., 2012; Karthikbabu et al., 2011). Trunk control has also been identified as an essential early predictor for motor and functional recovery or outcome after stroke (Karthikbabu et al., 2011; Verheyden et al., 2011; Genthon et al., 2007; Kwakkel and Kollen, 2013). Likhi et al. (2013) also found that trunk impairment post-stroke played a more significant role in determining the overall function post-stroke than upper or lower limb impairments.

Contrary to common belief, the trunk muscles are affected bilaterally in people with hemiplegia (Likhi et al., 2013; Karthikbabu et al., 2012; Ryerson et al., 2008; Karatas et al., 2004). This is because the truncal muscles have bilateral hemispheric innervation from the motor cortex (Tanaka, Hachisuka and Ogata, 1998). When a unilateral pathology occurs, such as a stroke, the hemiparetic person may be able to remain in an erect position due to the advantageous bilateral innervation of the trunk (Tanaka, Hachisuka and Ogata, 1998). Arguably, this bilateral innervation post stroke of the trunk leads to the unaffected side of the trunk also being affected by the stroke (Karthikbabu et al., 2012). Bohannon, Cassidy and Walsh (1995) showed that trunk muscle strength is impaired multi-directionally in

PWS. Karatas et al. (2004) found that even mild weakening of trunk muscles interfere with balance, stability and functional activity. Trunk control is, therefore, a prerequisite for improving balance and weight symmetry (Karthikbabu et al., 2011).

## **2.6 Changes in the transition of sit-to-stand (STS) post stroke**

The most frequent functional activity used in everyday life is STS (Boukadida et al., 2015; Kuo, Tully and Galea, 2010). It is considered one of the most mechanically demanding tasks as it involves the transfer of body mass against gravity from a large BOS to a small BOS (Kuo, Tully and Galea, 2010). It is also a prerequisite for successful transfers, standing and gait (Boukadida et al., 2015, Kuo, Tully and Galea, 2010). Post-stroke a person's ability to safely perform this daily functional activity independently is often impaired (Boukadida et al., 2015). This is due to various factors of which impaired selective activity in the trunk segments influenced by hemiparesis, is but one (Karthikbabu et al., 2011).

In a review of the literature by Boukadida et al. (2015), four phases during the transition of STS in general population were identified, each of which will now be described in more detail.

### **2.6.1 Phase 1 of STS**

Phase one (P1) is the initiation of this transfer and is characterised by flexion momentum which ends before the thighs rise off the chair or supporting surface. This phase has been associated with an anticipatory motor strategy since there is anterior displacement of the COM with the forward movement of the trunk (Dubost et al., 2005). The forward flexion is a result of lumbar and hip flexion while accompanied by cervical and thoracic extension (Kuo, Tully and Galea, 2010). Thoracic extension accompanied by the forward lumbar flexion is also vital to keep gaze horizontal (Kuo, Tully and Galea, 2010). Adequate strength and coordination is needed to generate sufficient trunk velocity to accelerate the whole body for a successful seat-off phase but also limited to avoid anterior instability at the end of motion (Dubost et al., 2005).

### **2.6.2 Phase 2 of STS**

Phase two (P2) begins with seat-off and continues with the anterior and vertical displacement of COM (Boukadida et al., 2015). At the start of P2, the body begins to rely on dynamic stability as the accumulating momentum requires a significant degree of

control to contain the COM displacement within the BOS (Fujimoto and Chou, 2014). Here the momentum is transferred from the upper body to the total body as the thighs lift off the seat. The thoracic region goes from an extension to a quick flexion movement along with lumbar flexion during this phase (Fotoohabadi, Tully and Galea et al., 2010).

### **2.6.3 Phase 3 of STS**

Phase three (P3) is known as the extension phase, where the body extends into an erect position. It is initiated after maximal ankle dorsiflexion is achieved and the phase is completed when the hip ceases to extend (Boukadida et al., 2015). As the hip ceases to extend, small oscillations between flexion and extension take place to stabilise the moving body (Schenkman et al., 1990). The primary task of this phase is to translate the body vertically while remaining in a roughly stable position, i.e. maintaining the COM within the BOS. Here the lumbar region starts extending before hip and knee extension (Kuo, Tully and Galea, 2010).

### **2.6.4 Phase 4 of STS**

Phase four (P4) refers to the stabilisation phase, where overall postural control during the dynamic movement is achieved. P4 starts with maximal hip extension and when hip extension velocity has reached  $0^\circ/\text{s}$  (Boukadida et al., 2015). It is here where the position and velocity of COM determine the stability of stance within the BOS or whether the person will require a forward step to gain stability (Shumway-Cook and Woollacott, 2010). The direction of postural sway is also characteristic of control; mediolateral (ML) sway involves hip and trunk control whereas anteroposterior (AP) sway involves ankle control (Mancini et al., 2012, Shumway-Cook and Woollacott, 2010). Schenkman et al. (1990) stated that the end of P4 is difficult to define as postural sway must take place during static standing in order to maintain erect. This is supported by Stevermer and Gillette (2016) that stated stabilisation starts from maximal hip extension until all stability is attained. Participants remained standing at the end of the transition for five seconds to conclude the STS as no standard exists for termination of STS measurement (Stevermer and Gillette, 2016).

Overall, PWS use different movement strategies during STS due to the asymmetrical deficits they have post-stroke (Duclos, Nadeau and Lecours, 2008). According to Davies (1990) people with hemiplegia often sit with a posterior pelvic tilt to compensate for the abdominal weakness. As the pelvis provides a BOS for trunk mobility, a fixed pelvis that is posteriorly rotated would limit lumbar mobility and therefore COM displacement, especially

in an anterior direction (Messier et al., 2004; Davies, 1990). A decrease in COM displacement could prevent a successful initiation of the STS transfer (Davies, 1990). During P1, they may perform trunk forward flexion instead of anterior weight shift and translation of the trunk; the COP displacement is therefore usually less than that of an average person ( $p=0.01$ ) (Messier et al., 2004). The COP and shoulders may move more towards the unaffected side before seat-off showing a trunk displacement towards the unaffected side during this phase (Lecours et al., 2008; Duclos, Nadeau and Lecours, 2008; Mazzà et al., 2006). This type of compensatory movements and changes in displacement of the COP may even start before seat-off. Duclos, Nadeau and Lecours (2008) found that the COP was deviated 78% more to the non-paretic side during spontaneous feet positioning for PWS even before the STS was initiated.

It has also been reported that during the seat-off movement of P2 for PWS, the pelvis translated over the non-paretic side while the trunk continued to deviate in a mediolateral direction towards the non-paretic side (Duclos, Nadeau and Lecours, 2008; Lecours et al., 2008). The COM deviated 50% more to the non-paretic side at the end of seat-off movement than in healthy persons (Duclos, Nadeau and Lecours, 2008). This can be attributed to less weight-bearing ability of the paretic limb during this phase (Lecours et al., 2008; Messier et al., 2004). This asymmetrical pattern is suggested to be an adaptive motor strategy that ensures an effective STS transition is still possible in PWS (Roy et al., 2006). This adaptive motor strategy is the adjustment of the motor response for maintenance of dynamic postural control to ensure a successful movement (Chern et al., 2010; Shumway-Cook and Woollacott, 2010).

The extension phase (P3) in PWS is often crudely combined with the stability of P4. The fourth phase is to regain stability in standing after the dynamic movement of STS, where the COP needs to fall back into the BOS (Boukadida et al., 2015). If the COP falls short or overshoots the BOS, an extra step will need to be taken to regain stability (Geurts et al., 2005). This is correlated with WBA as the COM is typically shifted to the non-paretic limb to minimise instability (Gentton et al., 2007). Cheng et al. (1998) found that PWS have a more substantial COP sway in the mediolateral direction during the entire transition and this was considered indicative of poor dynamic postural stability.

## **2.7 Measures used to assess biomechanics of STS post-stroke**

Biomechanical measures of movement attained by motion capture systems provide higher objectivity than subjective observational interpretation and functional assessment (Bagala

et al., 2013). The gold standard for kinematic analysis is a motion optoelectronic capture system (MOCAP) (Bauer et al., 2015; Bolink et al., 2015; Cuesta-Vargas, Galán-Mercant and Williams, 2010). These systems are expensive, time-consuming and usually found in a laboratory as they are quite cumbersome (Bauer et al., 2015; Adame et al., 2012). These factors limit the analysis of patients in a clinical setting as it cannot be used in daily rehabilitation (Bauer et al., 2015).

In contrast, an inertial measuring unit (IMU) is a readily available, low cost, small, lightweight measure which is easy to use in a patient's natural environment (Bolink et al., 2015). There are several advantages of using an IMU over MOCAP: it is easily attached to the body without hindering motion; it performs well under varying velocity conditions and it does not have shadowing problems as markers are not videoed (Millor et al., 2014). MOCAP is also constrained to a fixed laboratory as numerous cameras are needed to record the data from light reflector markers on the body. IMU however does not need cameras to record the data as the unit itself against the body part records the data (Millor et al., 2014). The MOCAP measures absolute, and relative body segmental orientation and position in a fixed reference frame, meaning it measures the angles from one body segment to the other as the markers for measurement are explicitly placed on the joints. IMU outputs are relative to the angles between segments and their displacement, acceleration and velocity (Millor et al., 2014). This means that the IMU measures from segment to segment on which the sensor is placed (e.g., foot; shin; thigh) and why calibration and placing of the IMU are so essential for segment orientation.

IMU's are primarily comprised of accelerometers and gyroscopes. An accelerometer is a type of inertial sensor that measures position, distance and velocity (Oberländer, 2015; Rosário, 2014). In a three-dimensional setting, a tri-axis accelerometer is needed to measure the three planes of movement; i.e. frontal, sagittal and transverse planes (Rosário, 2014). In the frontal plane, the movement takes place in the mediolateral axis, a side-ways/lateral movement (Behnke, 2012). In the sagittal plane, the movement takes place in the anteroposterior axis, forwards and backwards movement (Behnke, 2012). Lastly, in the transverse plane, the movement takes place in the proximal-distal axis, a rotational movement (Behnke, 2012). A gyroscope is a sensor that measures angular displacement and angular velocity (Oberländer, 2015; Rosário, 2014). These two sensors together give us valuable information on the linear and angular kinematics of the body segments (Millor et al., 2014).



The anatomical placement of sensors and the quality of an IMU system are of absolute importance (Bolink et al., 2015). The axes of the sensor must align with the axes of the body segment being tested. When placing the sensor, one should take care to avoid placing it on a significant active skeletal muscle as the sensor will move with the muscle and not remain in position (Kong et al., 2016). Also, the difference in people's size and weight when placing a sensor is crucial as it can introduce measurement error (Bolink et al., 2015). As found in a systematic review by Cuesta-Vargas et al. (2010), the degree of accuracy and reliability is site and task-specific when using an IMU. The IMU has been validated to measure STS duration (Janssen et al., 2008a; Najafi et al., 2003); balance control (Janssen et al., 2008b); power of the vertical displacement (Zijlstra et al., 2010); and STS activity recognition (Van Lummel et al., 2012; Taraldsen et al., 2011).

Since no objective measure can dynamically assess the COM, the COP is most often measured making use of a force plate (Cretual, 2015; Rosário, 2014). As the body sways, the force plate detects and records the movement of the COP in anteroposterior (AP) and mediolateral (ML) directions (Rosário, 2014). The review by Rosário (2014) concluded that the force plate should not be used on its own to assess compensatory mechanisms, fall predictions and musculoskeletal conditions due to the broad range of postural control and motor abilities of numerous conditions. Soangra and Lockhart (2012) also found that it is not feasible to compare the exact values of a force plate (which measures kinetic parameters of movement), with IMU (which measures kinematic parameters) as different variables are obtained. It has been recommended that force plate data be used in conjunction with segment motion analysis (IMU) to analyse body sway (Rosário, 2014; Soangra and Lockhart, 2012).

Pressure mapping is an excellent source of COP measurement (Cretual, 2015). Our feet provide the main surface of contact with the environment during standing and walking (Razak et al., 2012). How we distribute pressure is an important factor related to gait instability and improving balance (Razak et al., 2012). Pressure mapping can also provide information on the difference in limb-loading patterns and reflect the weight-shifting capability of an individual (Chern et al., 2010). This is important in PWS as one of the deficits post-stroke is altered weight distribution due to hemiparesis and loss of postural control (Young and Tolentino, 2009).

Chou et al. (2003) used force platforms to measure the COP distribution during STS and found that compared to healthy participants, PWS had a substantial increase in ML sway of their COP. The AP sway of COP in healthy participants was more prominent than that of

the ML direction as STS is a functional activity essentially in an AP direction (Chou et al., 2003). The direction of postural sway is also characteristic of control; i.e. ML sway involves hip and trunk control whereas AP sway involves ankle control (Mancini et al., 2012; Shumway-Cook and Woollacott, 2010). Cheng et al. (1998) also found that in healthy subjects the AP sway was more prominent whereas PWS had more ML sway. This could also be ascribed to decreased trunk control in all planes of movement but especially the frontal plane that moves in the mediolateral axis for PWS (Na et al., 2016).

## **2.8 Scoping review on how IMU have been used to assess trunk kinematics during STS**

A scoping review was conducted to answer the question, “How have IMU been used to assess trunk kinematics during sit-to-stand in people with stroke and healthy people?”

### **2.8.1. Searching**

A search was conducted to identify relevant scientific publications regarding the use of IMU to assess trunk kinematics during STS in healthy individuals and people with stroke. The scoping review was conducted from April 2016 and last searches repeated on 29 April 2018 by one researcher. Seven online databases accessed through Stellenbosch University were searched, namely: CINAHL - EBSCOhost, Cochrane Library - Wiley, IEEE Explore, Pedro, Pubmed, Science Direct and Scopus.

The search terms used are listed below:

1. “sit-to-stand”
2. #1 AND (sensor OR IMU OR “inertial measurement unit”)
3. #2 AND “Torso”[MeSH]
4. #3 AND “biomechanical phenomena”[MeSH]
5. #2 AND (trunk OR thorax OR pelvis)
6. #5 AND (biomechanic\* OR kinematic\*)

#### **2.8.2.1. Study eligibility**

The following in- and exclusion criteria were applied to identify eligible articles.

a) Inclusion criteria

- Written in English



- Published between January 1995 – April 2018
  - IMU's used to assess trunk kinematics
  - People with stroke
  - Healthy individuals (adults older than 18)
- b) Exclusion criteria
- Paediatric and animal studies
  - Foreign language
  - Sensors not being IMUs
  - If STS and trunk kinematics were not measured, only mentioned.

#### **2.8.2.2. Study selection and data extraction**

One reviewer independently screened and evaluated the titles, abstracts and then full texts of all articles identified by applying the search strategy described above. Full-text articles were retrieved by accessing electronic journals or directly via the databases, and where needed by emailing the authors directly. Any uncertainty regarding selection and data extraction were resolved by consensus discussion with the study supervisors.

#### **2.8.2.3. Method of analysis and synthesis**

The included articles were assessed for homogenous data, such as comparable patient populations, outcome measures and sensors used. The results from the analysis will be summarised in a narrative form below.

#### **2.8.2.4. Search results of the Scoping Review**

The process of selection and a final number of eligible articles analysed to answer the research question of the scoping review is illustrated in the flow diagram below.

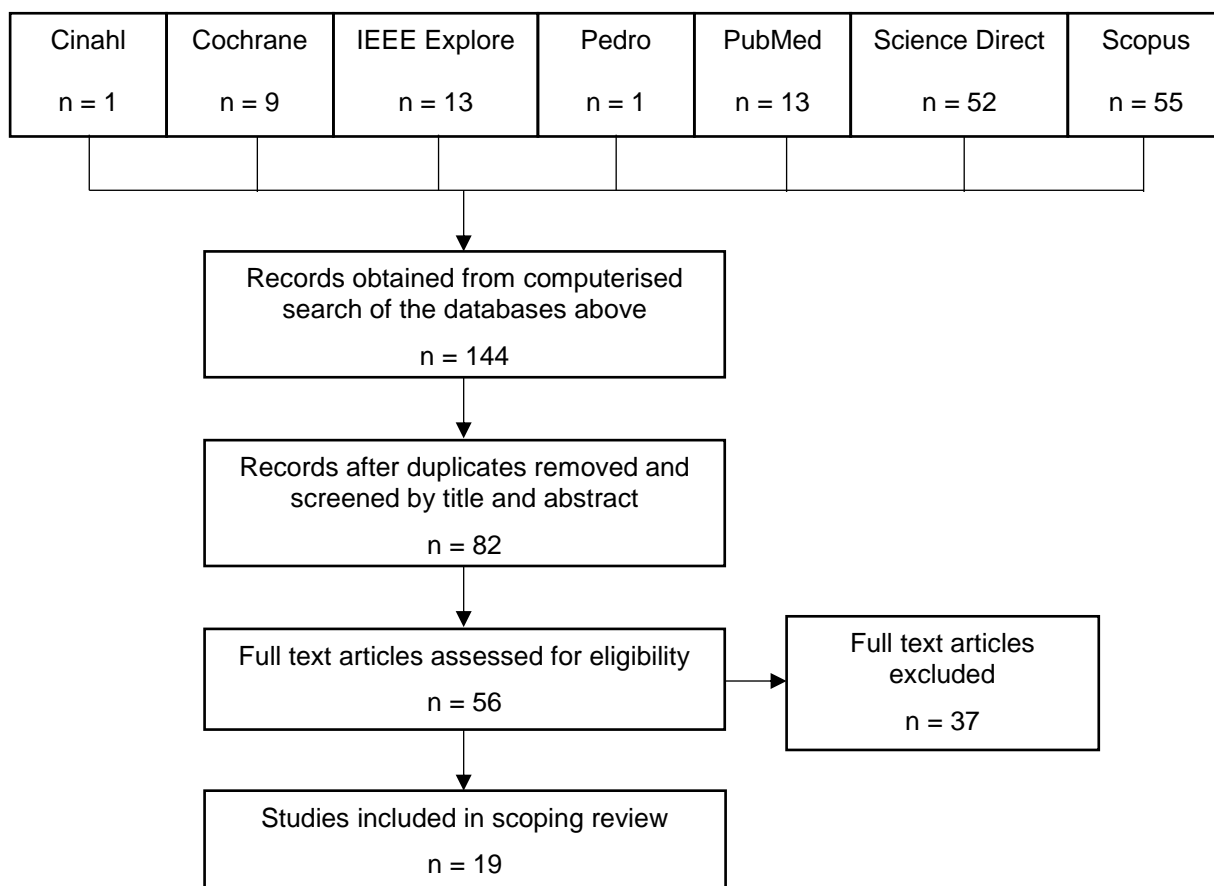


Figure 2.1: Flowchart of literature search and identification of eligible articles

## 2.8.2. Findings of the scoping review

Of the 19 eligible articles assessing the biomechanics of sit-to-stand, only four assessed the trunk kinematics in PWS with IMU (Na et al., 2016; Taraldsen et al., 2011; Janssen et al., 2008a; Janssen et al., 2008b).

### 2.8.2.1. The composition of IMU's

An IMU generally consists of an accelerometer or/and gyroscope or/and magnetometer. Only three articles used a combination of all three these types (Bolink et al., 2015; Couthard et al., 2015; Zijlstra et al., 2010) and four articles used accelerometers alone (Na et al., 2016; Taraldsen et al., 2011; Janssen et al., 2008a; Janssen et al., 2008b). The remaining eleven articles used a combination of accelerometers and gyroscopes.

### 2.8.2.2. Placement of IMU

Eleven articles placed the IMU on the sternum to measure the trunk. Seven articles reported placement on the lumbar spine (Van Lummel et al., 2018; Walgaard et al., 2016; Van Lummel et al., 2016; Na et al., 2016; Coulthard et al., 2015; Van Lummel et al., 2013;

Van Lummel et al., 2012; Giansanti et al., 2007). The specific location of L4/5 or L2 were highlighted in some of these articles, but the rest were less specific and merely referred to the lower lumbar area. Two articles placed it between the posterior superior iliac spines (PSIS) while one positioned it above the major trochanteric femoris to measure the kinematics of the pelvis (Bolink et al., 2016; Zijlstra et al., 2010). Only two articles used two sensors placed on different areas of the trunk and pelvis, i.e. one placed on the sternum and the other sensor on the lumbar spine and PSIS (Coulthard et al., 2015; Zijlstra et al., 2010).

### **2.8.2.3. Comparison with gold standard and validation of IMU**

Eight of the articles did not compare the IMU against other objective movement measurement systems – MOCAP and force plates. Soangra and Lockhart (2012) compared force plates and IMU. They found that it was not feasible to compare the values of a force plate (kinetic data) with IMU (kinematic data) as different biomechanic variables are obtained. It is best to combine the two motion analysis systems to measure body sway (Soangra and Lockhart, 2012). Thus most studies validated the IMU against the gold standard of MOCAP (Walgaard et al., 2016; Bolink et al., 2015; Aissaoui, Ganea and Aminian, 2011; Zijlstra et al., 2010; Giansanti et al., 2007; Simcox et al., 2005, Najafi et al., 2003).

Bolink et al. (2015) compared IMU (between PSIS) against the gold standard (MOCAP) and a good agreement was found between the two systems for trunk displacement. Some differences were highlighted such as a root mean square error (RMSE) of  $4.44^\circ$  for pelvic ROM in the frontal plane and  $8.89^\circ$  for pelvic ROM in the sagittal plane. The RMSE in the sagittal plane exceeded the  $5^\circ$  measurement error threshold, and researchers are therefore advised to use results in this plane with caution. In contrast, Simcox et al. (2005) however found an RMSE of  $4.5^\circ$  for sagittal plane trunk displacement when the IMU was positioned on the sternum in comparison to the MOCAP. A high correlation ( $r=0.98$ ) was found for vertical displacement of the trunk with the IMU placed on the sternum (Najafi et al., 2003). In Janssen et al. (2008a) the duration of STS was validated with no significant difference found between the two systems, i.e. IMU and MOCAP.

Taraldsen et al. (2011) found that using a sensor on the sternum could identify the position the person is in, e.g., lying and sitting, unlike a single thigh sensor that views it as an inactive position. Najafi et al. (2003) found that the IMU had a 93% sensitivity and 82% specificity for STS activity recognition against MOCAP when placed on the sternum.

Godfrey et al. (2011) found similar results with the IMU on the sternum as Najafi et al. (2003), with a sensitivity of 89% and specificity of 93%. A reason for a higher specificity could be due to an improved gyroscope (tri-axial) used in Godfrey et al. (2011). Ganea et al. (2011) found that placing the IMU on the sternum resulted in good sensitivity to the duration of the STS transition (0.92) as well as the smoothness of transition (0.92) when comparing between frail elderly and healthy elderly.

#### **2.8.2.4. IMU and phases of STS**

Van Lummel et al. (2018) identified the same four phases described in the literature review by Baukadida et al. (2010). However, phases one and two were combined into a flexion phase while phase three and four were combined into an extension phase for analysis. Only the sagittal plane of movement, i.e. AP direction, trunk angular range and velocity were calculated and described. Van Lummel et al. (2016) also grouped the different phases of STS into flexion and extension phases but only analysed phase duration. Giansanti et al. (2007) also identified the same four phases but only measured sagittal plane trunk kinematics. This study, however, was a validation study, and no other planes of movement were assessed and reported on. Van Lummel et al. (2012) and Walgaard et al. (2016) made use of trigger switches on the chair to aid in the identification of phase two or the seat-off phase but not within the construct of the four STS phases.

#### **2.8.2.5. IMU and trunk kinematics**

Van Lummel et al. (2012) found that the best predictor of the seat-off phase was the maximum anteroposterior (AP) velocity. The velocity is transferred by trunk forward flexion in the initiation of STS causing an AP displacement of the centre of mass (COM). This further showed that the COM moves forward and slightly downwards during a successful STS transition. After seat-off, the COM moves upwards. The sensor identifying this motion was placed at the level of L2. In Van Lummel et al. (2013) during the flexion phase between healthy young (124.62°/s) and older (91.62°/s) participants a significant difference in trunk velocity was found ( $p=0.001$ ). The extension phase angular velocity was not significant ( $p=0.323$ ) between the two groups (Van Lummel et al., 2013). In the study by Zijlstra et al. (2010), three sensors were used to find which correlated best with COM vertical acceleration. The pelvis sensor had the best correlation with COM vertical acceleration and power than either the sternum or PSIS sensor (Zijlstra et al., 2010). Na et al. (2016) tested acceleration of COM and total STS duration between healthy and stroke participants. Statistically significant differences were found for AP and ML acceleration

between the stroke and control group ( $p=0.001$ ). No study found in this scoping review reported on the comparison of the upper and lower trunk kinematics.

#### **2.8.2.6. Correlation of IMU with clinical physiotherapy outcome measures**

In the study by Janssen et al. (2008b) the Postural Assessment Scale for Stroke Patients (PASS) was used to classify PWS into subgroups differentiating between those with good versus poor balance. A correlation was found between poor balance and temporal variables of the STS transition; where a longer STS duration and increased acceleration was observed in the poor balance subgroup. Na et al. (2016) tested PWS with the TIS and Berg Balance Scale (BBS). The purpose of the study was to compare the acceleration of the COM during STS between PWS and healthy controls (Na et al., 2016). No correlation was made between the acceleration and the TIS or BBS (Na et al., 2016). Thirty stroke participants were tested with a TIS score of 14.2(6.7) and a BBS score of 42.9(6.7). The only comment made in the study was that all three balance direction planes must be considered during STS retraining and a particular focus on the ML plane of balance (Na et al., 2016).

#### **2.8.3. Summary of findings**

The results of this scoping review showed a number of gaps in the literature as to the use of IMU's in PWS to measure trunk kinematics in multiple planes of movement within the different phases of STS. This information is especially needed since each phase has a specific objective leading to a successful STS transition. To date, no study has also been conducted to correlate trunk impairment to changes in ML sway (frontal plane) and AP displacement of COM (sagittal plane) during the different phases of STS.

The recommendation is that a study is needed to assess trunk kinematics in PWS during an STS transition with multiple sensor placements to determine how each phase is achieved and the impact trunk impairment may have on this transition.

## **2.9 Rationale for study**

STS is the most common functional activity and forms the pre-requisite to many different daily activities like walking (Verheyden et al., 2006). The ability to be independent in this transition is, therefore, an important goal for PWS during their rehabilitation. While STS in stroke has received much attention in clinical research, an in-depth look at the trunk during each phase of STS and within each plane of movement has not yet been reported on. The trunk is our centre point of stability, and recruitment of the trunk musculature takes place before limb movement (Karthikbabu et al., 2011). The loss of selective trunk movement as seen in PWS leads to compensatory mechanisms during execution of STS. Our study aims to address this lack of descriptive information of the trunk in PWS as well as look at how trunk impairment plays a role during STS.

## **2.10 Summary of Literature review chapter**

In summary, stroke in SA is causing a rise in disability leading to the higher socioeconomic burden on the economy and carers. Optimising rehabilitation within SA is essential. STS is the most repeated functional activity used in everyday life and is impaired after a stroke. Trunk control is considered the primary anchor that stabilises the distal limbs during movement. The ability to control the selective trunk movement for a successful STS is impaired post-stroke. In PWS, it is unclear how the selective movement of the upper and lower trunk occurs during the four phases of STS within the three planes of movement. IMUs are a good validated form of motion analysis and easily portable. It is yet to be correlated with how trunk impairment, with the TIS, correlates with various parameters of movement. The next chapter will expand on the methods employed to analyse the trunk kinematics and kinetic parameters as well as the correlation with the TIS.

# *Chapter 3*

## *Methodology*

The study protocol was approved by the Health Research Ethics Committee of Stellenbosch University, South Africa (Addendum A). The authors declare that they have no affiliations with or financial involvement in any organisation with a direct financial interest in the matter or resources used in this study. This chapter presents the research question, study objectives, study structure, study population, sampling and instrumentation. The procedure, data analysis and ethical considerations are also described.

### **3.1 Research question**

What is the difference in trunk kinematics and weight-bearing symmetry between people with stroke and a community control group in the three planes of movement during the four phases of Sit-To-Stand (STS)?

### **3.2 Research objectives**

The primary and secondary objectives of the study are listed below.

#### **3.2.1. The primary objectives of the study were;**

##### **3.2.1.1. To compare the differences between adults with stroke and a community control group during the four phases of STS with regards to:**

- 3.2.1.1.1 The angular displacement of the trunk segment in the frontal, sagittal and transverse planes using two IMU's
- 3.2.1.1.2 The angular velocity of the trunk segment in the frontal, sagittal and transverse planes using two IMU's
- 3.2.1.1.3 The acceleration of the trunk segment in the frontal, sagittal and transverse planes using two IMU's
- 3.2.1.1.4 The total duration of the transition of sit-to-stand
- 3.2.1.1.5 The duration of each phase during sit-to-stand

**3.2.1.2. To compare the difference in weight bearing (WB) symmetry between adults with stroke and a community control group during the transition of STS using a pressure mat.**

**3.2.2. The secondary objectives of the study were;**

**In the case participants:**

3.2.2.1 To correlate the kinematic data (angular displacement, velocity and acceleration of the trunk segment) attained from the IMU and WB asymmetry with the total score on the Trunk Impairment Scale.

3.2.2.2 To correlate the kinematic data (angular displacement, velocity and acceleration of the trunk segment) attained from the IMU and WB asymmetry with the scores of the subscales (Dynamic, Coordination) of the Trunk Impairment Scale.

### **3.3 Study design and setting**

A case-control study design was used to answer the research question. The study design was chosen as it starts with people who already had a stroke making the data collection less resource intense, i.e. potentially quicker and inexpensive (Lewallen and Courtright, 1998). As no other research has been done on the above question and objectives, this study design is appropriate to establish control data for comparison. The participants were tested within a known environment without adding any intervention. Their controls were chosen from a similar socio-economical background giving them the same risk factors as the case participants of developing a stroke.

Participants were recruited and data collected at two community health care centres offering out-patient physiotherapy services in the Tygerberg Hospital catchment area; i.e. Delft Community Health Centre (CHC) and Bishop Lavis Rehabilitation Centre. Recruitment sites were approved by the Western Cape Department of Health (Addendum B). Karl Bremer Hospital and Elsies River CHC were also approved but no participants were successfully recruited.

### **3.4 Sample size calculation**

The optimum sample size was estimated using the Power Analysis Statistical Software (PASS) (Hintze, 2013). The sample size was calculated for the primary objectives making



use of previous estimates from available, published studies. In all estimations, a 95% level of significance was specified and at least 80% power.

Galli et al. (2008) were used to calculate the sample size. When assessing for frontal plane statistical significance, group sizes of five per group provided 85% power. The sagittal plane group sizes of eight provided 85% power, and the transverse plane needed 20 per group to provide 85% power. However, due to the study mentioned above having had an uneven healthy and stroke participants as well as using different points of measurement, it was hypothesised that 15 participants per group would be sufficient enough to detect statistical significance between the case and control group for our study.

Janssen et al. (2008b) were also used to calculate a sample size focusing on detecting a statistical significance for acceleration between the case and control group. It was found that four participants per group were needed to detect a difference between case and control groups. Using Galli et al. (2008) for a total duration of STS between groups, a sample size estimation of seven per group was required. Taking the above into account again a sample size of 15 per group would have provided adequate power to detect a statistical significance for our study. We could not find comparative data from previous studies on the other objectives of our study. Additionally, 15 participants per group were deemed a logistically feasible number given the scope of this study.

### **3.5 Study population**

The population of interest included PWS who were residing in communities and attending out-patient physiotherapy services.

### **3.6 Study sample**

The case and control groups had to adhere to the inclusion and exclusion criteria in order to participate in the study. Cases and controls were related with regards to the community in which they lived. The control group comprised family members of the case group or members of the same community. They were therefore similar in regards to lifestyle and socio-economic background.

### 3.7 Eligibility criteria

#### 3.7.1 Inclusion criteria:

The inclusion criteria for both the case and control groups are detailed in Table 3.1.

Table 3.1 Inclusion criteria for the study

Case Group	Control Group
<ul style="list-style-type: none"> <li>• Adult (&gt;18years) males &amp; females with the first-ever stroke</li> <li>• Between onset &amp; within six months post stroke</li> <li>• Present with a single incident leading to hemiparesis affecting the right or left side of the body.</li> <li>• Able to follow simple two-part verbal instruction as assessed by a physiotherapist.</li> <li>• Sitting independently, without back support.</li> <li>• Be able to come from sitting to standing without assistance from another person or armrests.</li> </ul>	<ul style="list-style-type: none"> <li>• Adult (&gt;18years) males &amp; females</li> <li>• No history of a previous stroke</li> <li>• Be able to stand up from sitting independently</li> <li>• Must live in the same catchment area as case group to ensure that participants come from the same socioeconomic environment.</li> </ul>

### 3.7.2 Exclusion criteria:

The exclusion criteria for both the case and control groups are detailed in Table 3.2.

Table 3.2: Exclusion criteria for the study

Case Group	Control Group
<ul style="list-style-type: none"> <li>• No history of cardiac conditions and pacemakers as these devices are a contraindication to the use of the MyoMOTION IMU (Noraxon, 2015).</li> <li>• No prior disability due to previous orthopaedic and neurological conditions.</li> <li>• No bilateral motor signs as the non-paretic side will also be observed for possible compensatory strategies.</li> <li>• Any allergies to plaster tape as it may be used to attach the MyoMOTION IMU onto the patient.</li> </ul>	<ul style="list-style-type: none"> <li>• No history of cardiac conditions and pacemakers as these devices are a contraindication to the use of the MyoMOTION IMU (Noraxon, 2015).</li> <li>• No prior disability due to previous orthopaedic and neurological conditions that affect their ability to come from sit-to-stand independently.</li> <li>• Any allergies to plaster tape as it may be used to attach the MyoMOTION IMU onto the patient.</li> </ul>

## 3.8 Instrumentation

The MyoMOTION and MyoPRESSURE were used to collect data pertaining to the two primary objectives of the study, i.e. trunk motion and WB symmetry during STS.

### 3.8.1. MyoMOTION

An inertial measuring unit (IMU) by Noraxon was used to test the trunk motion of all participants. It is a feasible wireless portable 3D Kinematic motion measuring system and is easily attached to the body without hindering normal motion. The IMU is made up of a tri-axial accelerometer, gyroscope and magnetometer (Oberländer, 2015). The use of an IMU, therefore, enables measurement of angular displacement, angular velocity and acceleration of body segments. Nine IMU's were used in this study. Two to measure the trunk, one to measure the pelvis and six to measure the lower limbs, refer to Image 3.2 for the sensor placements. Our primary objective (2.1.1) was answered by using this instrument. All secondary objectives listed under 2.2 were answered using data generated by this instrument.

### **3.8.2. MyoPRESSURE**

MyoPRESSURE is another portable product of Noraxon; this pressure plate detects the plantar pressure distribution of each foot during the transition of STS as well as the centre point of pressure (COP) related analysis. As the body sways during a movement, the pressure plate measures the COP movement and the weight-bearing symmetry. This instrument was used to answer our primary objective (2.1.2) and how the weight-bearing symmetry differs between the case and control participants. WBA in PWS is the shift of body mass towards the unaffected side and causes an increase in postural sway during quiet stance (Tasseel-Ponche, Yelnik and Bonan, 2015).

## **3.9 Clinical outcome measures**

A short self-developed questionnaire was utilised to gather demographic and stroke-related information from each participant. The TIS and the modified Barthel Index (mBI) are clinical outcomes measures and were used to gather information on trunk movement and functional independence of PWS in the case group.

### **3.9.1. The demographic and stroke-related questionnaire**

See Addendum D and E for example of this questionnaire. It was essential to establish the dominant side of the control participant for data analysis as well as their previous medical history to assess eligibility for the study. For the case participants, previous dominant side as well as side affected was needed for the analysis of the data. It was also needed to find out if they used any assistive devices and frequency of daily use.

### **3.9.2. Trunk Impairment Scale**

The TIS was developed by Verheyden et al. (2004) and is specifically used in people with stroke. The scale consists of three sections: static sitting balance, dynamic sitting balance and coordination (Appendix F). It assesses the quality of movement by observing compensatory and selective trunk movements during sitting (Verheyden et al., 2006).

The internal consistency of the TIS is a Cronbach's  $\alpha$  between 0.65 and 0.86, giving it an acceptable to a good value (Verheyden et al., 2004). The inter-rater reliability is excellent with an ICC score between 0.85 and 0.99. The test-retest examiner measurement error is high (-2.90, 3.68) in contrast to the inter-examiner measurement error of -1.84, 1.84 (Verheyden et al., 2004). Liao et al. (2015) used the TIS to assess trunk control in PWS

and correlated it with results from the MOCAP. The link reported was, the larger the angular velocity during trunk extension the higher the TIS score (Liao et al., 2015).

The TIS is a tool often used in clinical practice for the evaluation of PWS. It gives the clinician information regarding the person's trunk movement and limitations. Due to our treatment setting being in a clinic or rehabilitation centre, not a laboratory, correlating the TIS to objectives measurable outcomes, derived from the IMU, may enhance the treating physiotherapist's clinical reasoning and lead to the adaption of interventions. The TIS has confirmed correlation with gait, functional ability and balance with minimal ceiling effect making it easy to repeat in the long run (Kim et al., 2015).

### **3.9.3. Modified Barthel Index**

The Barthel Index (BI) was designed to assess the functional independence of a patient and has been used since as early as 1955 (Salter et al., 2013; Shah, Vanclay and Cooper, 1989). Ten functional activities are scored with the total BI being out of 100. The original version had a three code scoring system: unable to perform a task (score of 0), needs assistance (score for different items 0/5/10) and fully dependent (score of 5/10/15) (Shah, Vanclay and Cooper, 1989). It lacked sensitivity to detect smaller changes of improvement in PWS so Shah, Vanclay and Cooper (1989) developed a mBI with a five code scoring system: unable to perform task (score of 0), attempts task but unsafe (score of 1/2/3), moderate help required (score of 3/5/8), minimal help required (score ranges from 4/8/12) and fully dependent (score ranging from 5/10/15). This resulted in improved sensitivity and reliability of the mBI to detect the level of functional independence within an ADL (Shah, Vanclay and Cooper, 1989). This OM can detect in which activity assistance is required (Salter et al., 2013). We used the mBI for its improved sensitivity and reliability which allows an excellent overall clinical picture of the participant's everyday function. See Addendum G for the mBI used in the study.

### **3.9.4. Correlation between TIS and mBI**

The construct validity of TIS also shows a strong correlation ( $r = 0.89$ ) with the mBI when used in combination with each other (Verheyden et al., 2004). Kim et al. (2015) studied the relationship between trunk impairment and functional prognosis using the TIS (and sub-sections) with the mBI. They found that the dynamic sub-section of the TIS was good at predicting the function score of the mBI (Kim et al., 2015). They concluded that the dynamic stability section of the TIS assesses the ability to perform lateral trunk movements

which are essential for performing daily functional activities (Kim et al., 2015). This finding is further supported by previous studies (Van Nes et al., 2009; Karatas et al., 2004).

## **3.10 Procedures**

### **3.10.1. Pre-test**

#### **3.10.1.1. Participant recruitment**

A patient with a stroke who met the inclusion criteria of the study was recruited from a private neurological physiotherapy practice to test the procedures that were planned for the main study. A relative of the patient acted as his control. Both these individuals gave consent to be tested without any compensation. Both participants were known to the primary researcher who worked in the private neurological physiotherapy practice.

#### **3.10.1.2. Process**

All testing equipment was taken to the pre-test participant's home, and data collection was completed in the home setting. The participants were weighed and their heights measured for the calibration data. The primary researcher completed both the mBI and the TIS. Five times STS were recorded with calibration taking place before each STS trial.

#### **3.10.1.3. Outcome of pre-test**

When the pre-test data was reviewed, changes were needed in equipment set-up and participant preparation to ensure reliable data was recorded and to optimise calibration processes:

- It was decided with the Stellenbosch University movement analysis laboratory bio-engineers that the pressure mat placement needed to be altered for the main study for data processing.
- Due to soft tissue variations on people, the primary researcher was advised to apply the pelvic sensor with the pelvic strap or to apply it on the pelvis with double-sided tape to ensure accuracy. It was also imperative that the first trial's data of each participant be checked for the above mentioned pelvic marker otherwise the data would not be recorded accurately for the rest of the trials.
- Calibration videos were also needed in both sitting and standing position before STS trials. The capture of photos with all the body markers with proper alignment was also needed for post-processing of the data.

## **3.10.2. Main study**

### **3.10.2.1 Recruitment of participants**

Participants were recruited using the physiotherapists and occupational therapists working at the two out-patient physiotherapy centres. The potential participants were screened by these therapists during their usual treatment sessions to identify if they met the inclusion criteria of this study. If deemed appropriate, the clinicians would gain permission from the patient to forward their names to the primary researcher. The clinicians then contacted the primary researcher with potential participants' contact details. Telephonic contact was made with the potential participants and a date and time were arranged for testing. If there was a problem contacting the participants telephonically, the out-patient physiotherapist arranged a time for the primary researcher to meet the potential participants at the visiting centre to gain permission for testing. The potential participants were asked who usually accompanied them to the clinic, a family member for example, who could serve as a potential control participant. These potential control participants were also telephonically screened by the primary researcher, according to the inclusion criteria, and if permission were granted would then be recruited to partake in the study. The family member or carer acted as a community control participant as they matched the case participant with regards to similar catchment area and socio-economic background. If there was no suitable community control, a worker from the same catchment area at the clinic was screened for inclusion.

### **3.10.2.2 Demographic and stroke-related Questionnaire and Outcome Measures**

Once participants completed the written informed consent, the primary researcher interviewed each participant to complete the demographic and stroke-related questionnaire. Thereafter, the primary investigator and participant completed the mBI. Next, their trunk impairment was assessed using the TIS. The TIS was performed by sitting on a broad low plinth, also referred to as a "Bobath" plinth, available at the centres without back and arm support; thighs making full contact with the bed, feet hip distance apart and flat on the floor. The knee angle should be 90° with arms resting on the legs. This is the standardised starting position as explained by Verheyden et al. (2004).



### 3.10.2.1 Participant preparation

Anthropometric measurements including height and weight were taken by the primary researcher using the same scale and tape measure for every participant. All participants wore tight clothing and if unable to dress appropriately; the researcher provided clothing suitable for testing. Participants had to be barefoot during data collection.

### 3.10.2.2 Sensor placement

The Plug-in-Gait (PiG) model (Vicon Motion System Limited, Oxford, UK) is used as the standard measure for gait analysis. Due to the MyoMOTION sensors-to-body calibration process, the PiG model offers a standardised procedure for the identification and placement of 22 body markers, of which the eight markers allocated to the trunk and pelvis were used in our study. Four markers defined the trunk – cervical spinous process 7 (C7), Sternal notch (CLAV), thoracic spinous process 10 (T10), the Xiphoid process of the sternum (STRN). The last four markers that defined the pelvis included the bilateral Anterior Superior Iliac Crest (ASIS) and bilateral Posterior Superior Iliac Crest (PSIS). These markers, refer to Image 3.1, where placed on the participants before testing by the primary researcher and an anterior, posterior, left and right-sided photograph was taken. These photographs were used in the post-processing of the data for quality control.

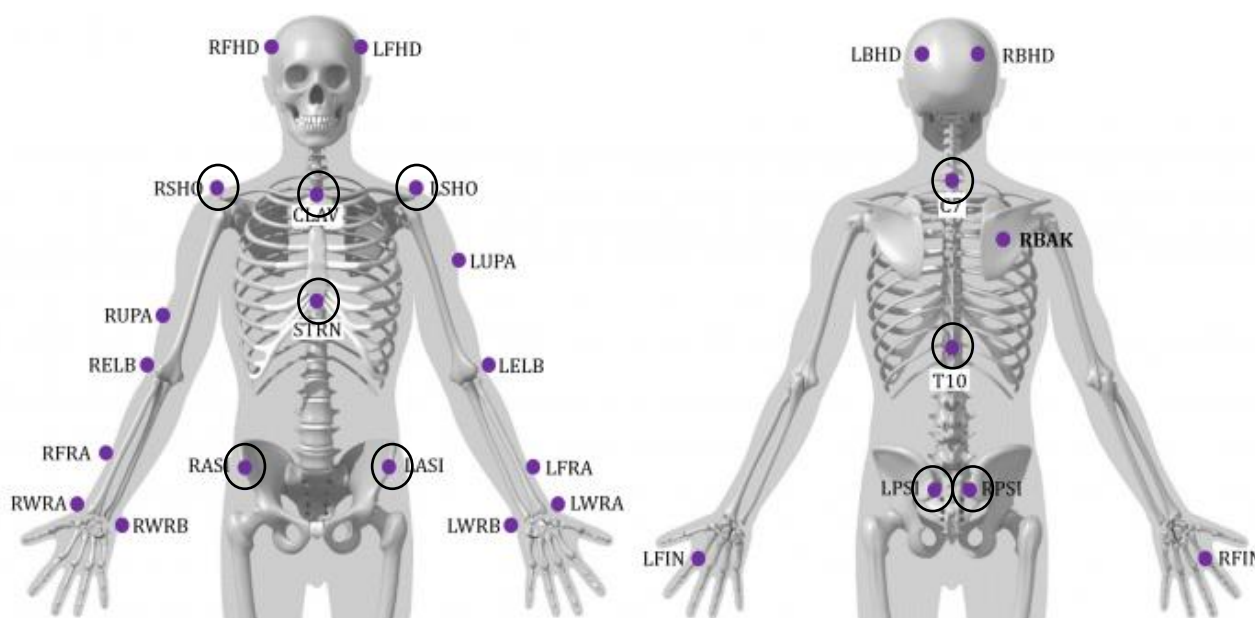


Image 3.1: MOCAP Marker Placement

Bauer et al. (2015) suggested that multiple IMU's should be used to assess the trunk segment. We, therefore, placed one on the sternum and another between the lumbar spinous processes of 3 and 4 (L3-L4). The exact IMU placement for the trunk was



informed by the literature reviewed during the Scoping review (See Chapter 2). The sternum sensor was placed to represent the thoracic segment of the upper trunk and the lumbar sensor for the lower trunk (Bolink et al., 2015, Janssen et al., 2008b, Giansanti et al., 2007, Simcox et al., 2005). All nine sensors, refer to Image 3.2 and Image 3.3, were used and placed on each participants' trunk, pelvis and lower limbs. The lower limb sensors were placed as per MyoMOTION standard for calibration (Noraxon, 2015).

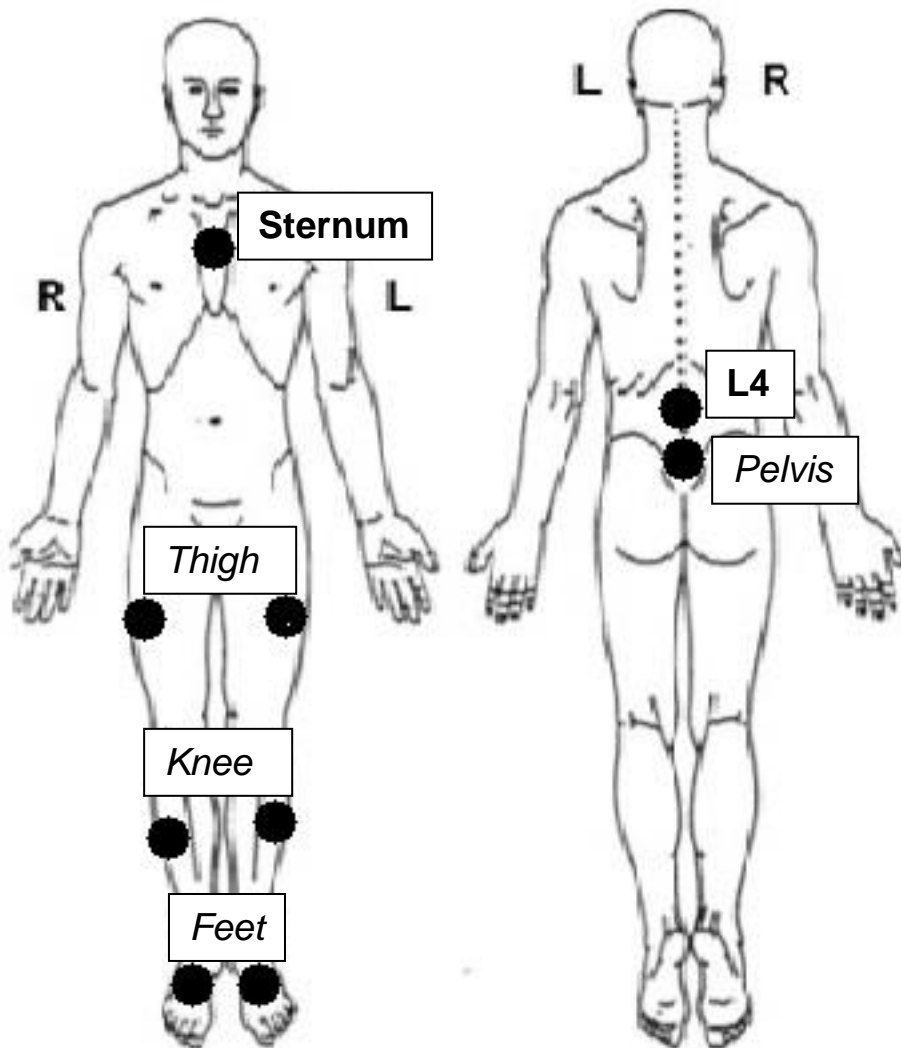


Image 3.2: IMU Placement

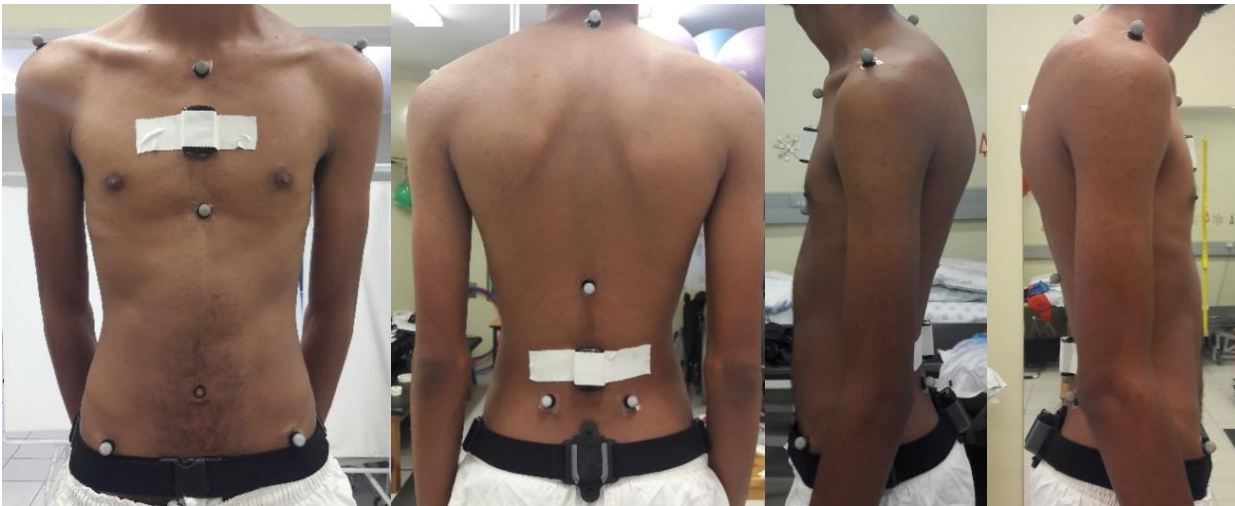


Image 3.3: Participant with sensor placement

### 3.10.2.3 Calibration before data collection

System calibration is needed to determine sensor-to-segment alignment. This is needed to orientate the sensor relative to the body segment it is attached to. The MyoResearch 3.10 Noraxon system takes the height and weight measurements that the researcher inputs before testing and derives the bone measurements. A still standing reference frame is used, and the lower body sensors align with each other to create a 3D skeleton of the participant. Calibration was first performed in the sitting position where after a short sitting video was captured, refer to Image 3.4. After that, a standing position was calibrated with arms down the side, and a short standing video was captured, refer to Image 3.5. Both calibration videos were taken as it is the start and finished positions of the STS movement. The standing calibration was performed for each participant before each STS trial on a wooden block to cancel any magnetic distortion that could affect the sensor calibration, refer to Image 3.6.

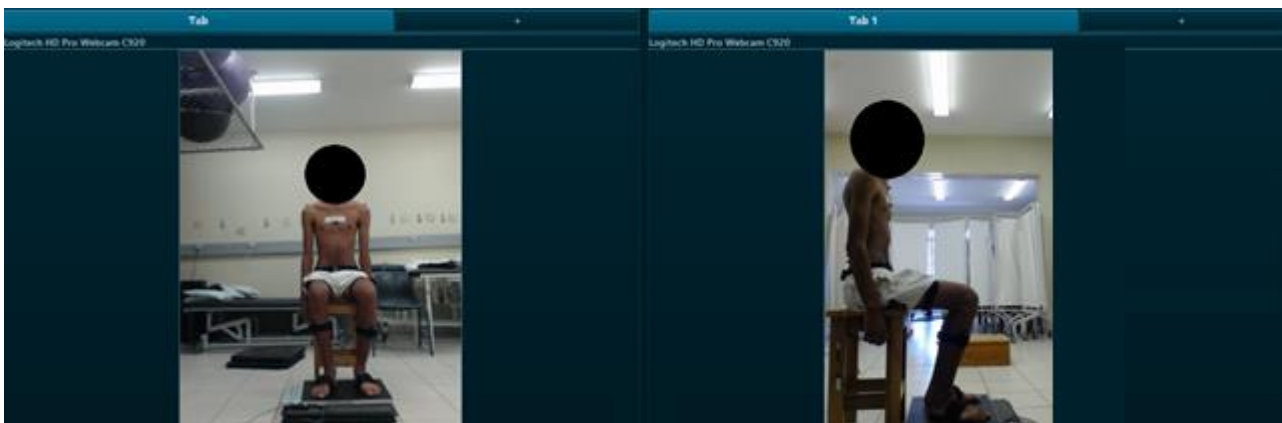


Image 3.4: Sitting Calibration

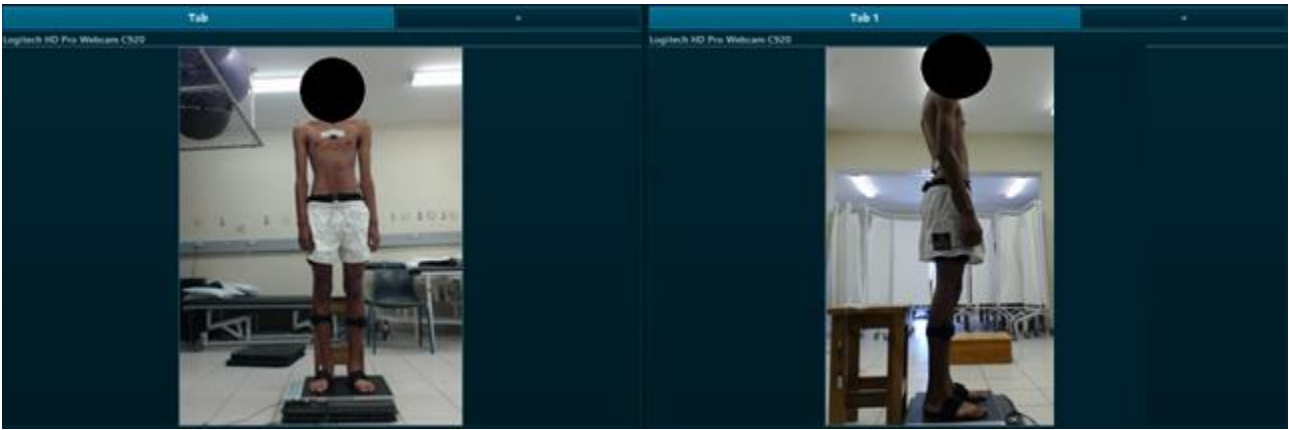


Image 3.5: Standing Calibration

#### 3.10.2.4 The surface used for STS transfer during data collection

The same wooden chair was used for every participants' STS trials during data collection. To achieve 90° of knee flexion, rubber mats were placed under each participant's feet until their different hip-knee-ankle ratio met this criterion. Two trigger switches were placed on the chair to measure the start of phase two of the STS transfer, also known as "seat-off". Markings on the chair were made to ensure continuity of placement. The same wooden step was used in-between each trial for calibration purposes, refer to Image 3.6.



Image 3.6: STS Transfer Surface

#### 3.10.2.5 Data capture of STS trials

Participants were instructed to sit on a wooden stool with arms crossed over the body, away from the sensor. Each participant sat on the same wooden chair with half of the thigh supported and the hips and knees at 90° flexion. The feet were positioned parallel on the pressure mat. This was the standard starting position for each participant per STS trail. The participants were to stand up when the primary researcher verbally announced: "Go".

The participants were instructed to stand up at a self-selected speed and remain standing looking forward till the primary researcher said “Stop”. This was normally at +/-18sec as to allow enough time to objectively measure the start of phase four (maximum hip extension of the dominant/non-hemiplegic side) and allow the ten seconds needed before the end of the trial. No attempt was made by the primary researcher to restrict or direct the movement strategies each participant used during the STS transfer. It is recognised that the feet position may change during the STS trial as the weight is shifted during each phase of STS. Five STS trials were taken per participant with a rest taken in-between as needed. Image 3.7 to Image 3.10 below illustrates the various starting positions of each phase provided by the video image, MyoMOTION and the MyoPressure systems:

- a) In the top left side panel is the anterior view video image of the participant
- b) In the top right side panel is the lateral view video image of the participant
- c) In the bottom left side panel is the anterior MyoMOTION view of the participant calibrated with the sensors
- d) In the bottom right side panel is the lateral MyoMOTION view of the participant calibrated with the sensors
- e) In the bottom middle panel is the MyoPressure illustration of bilateral feet

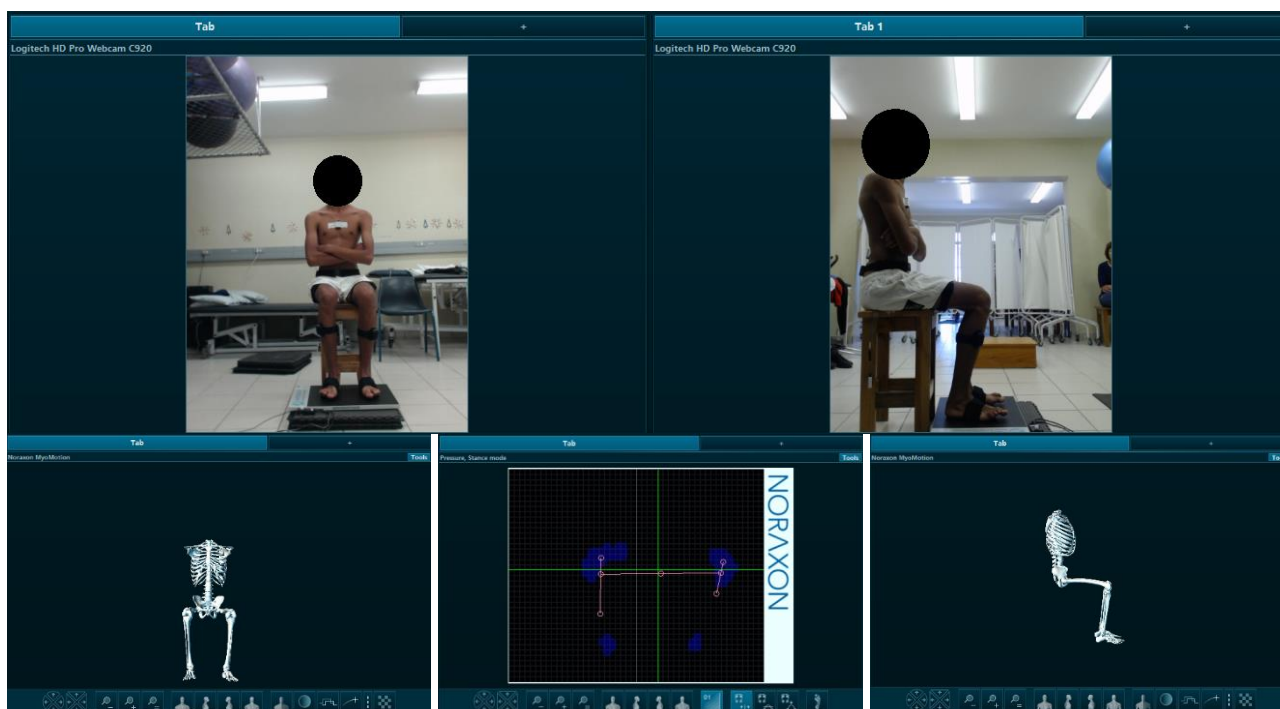


Image 3.7: Start of P1

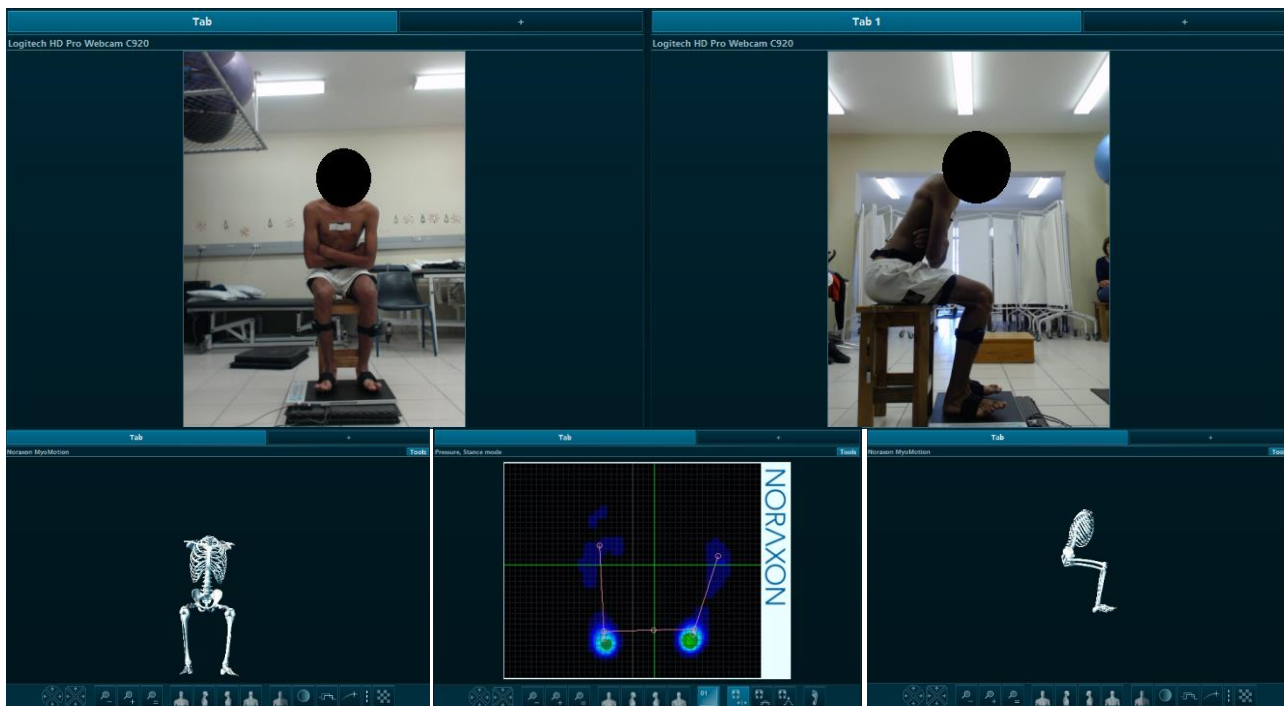


Image 3.8: Start of P2

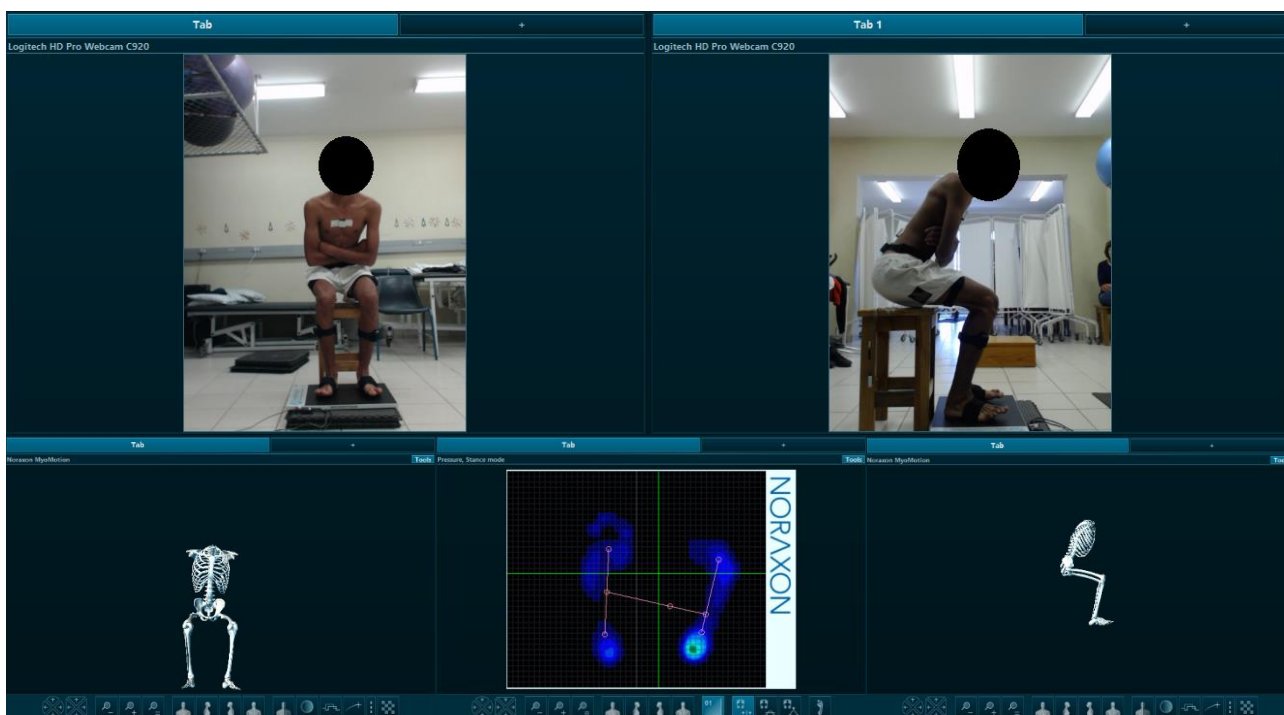


Image 3.9: Start of P3



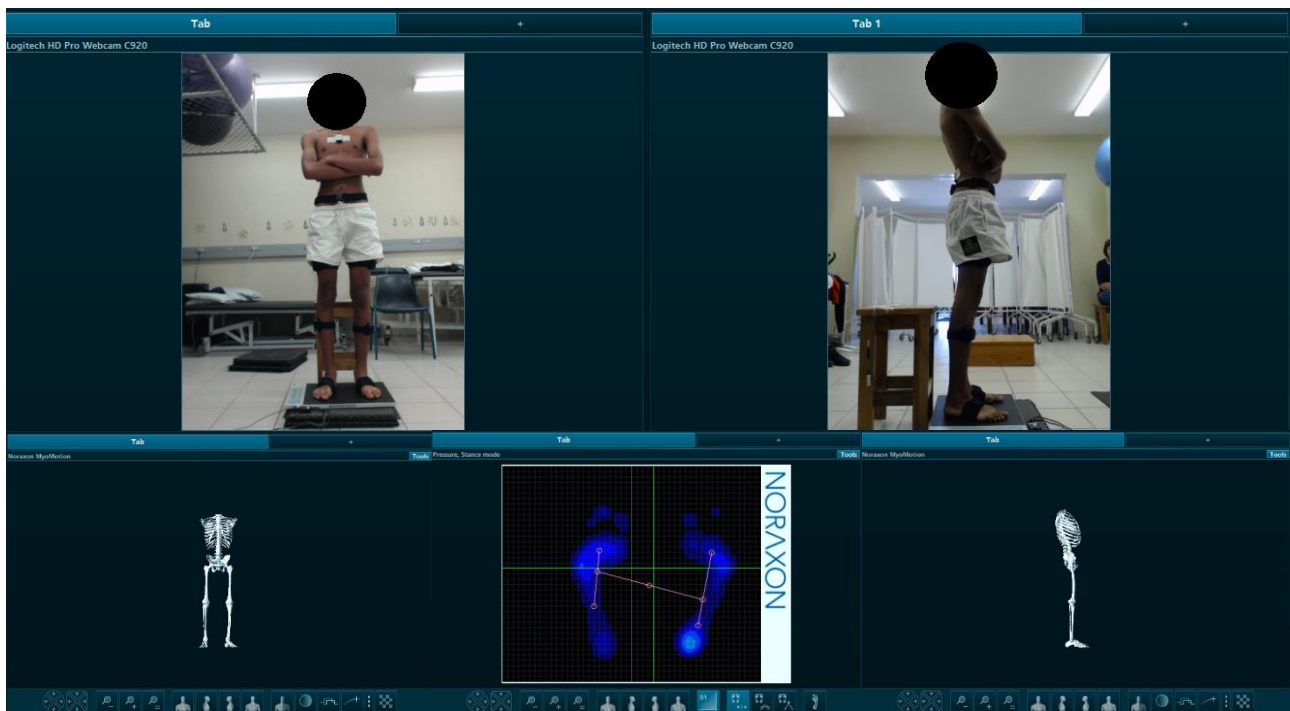


Image 3.10: Start of P4

### 3.11 Data processing

Before analysis, the primary researcher took each STS trial and manually marked each phase of the STS movement in the MyoMotion program wherein the trials were recorded. The raw orientation angles, anatomical angles, trigger switches and video recordings were used to do the markings. P1 was marked at the beginning of trunk flexion. P2 was marked at the moment the trigger switches on the wooden chair were deactivated with the seat-off from the chair. P3 was marked at the end of maximum ankle dorsiflexion of the dominant/non-hemiplegic side, whereas the start of P4 was marked as the maximum hip extension of the dominant/non-hemiplegic side. The end of the complete transition marked ten seconds after the maximum hip extension was achieved.

On the Noraxon Research program, the upper trunk pitch – forward trunk flexion is visible in Image 3.11. The negative curve illustrates the forward trunk flexion. The P1 marker has been marked at the millisecond where the forward trunk flexion movement starts.

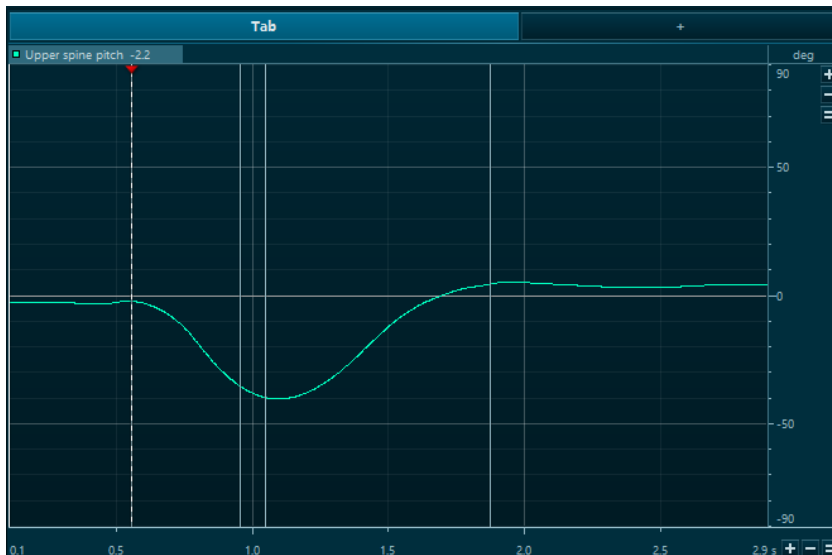


Image 3.11: P1 Marker – Upper Trunk Pitch: Start of forward trunk flexion

The value of the two trigger switches starts at 4000 (1000x4 switches per side) when the participants are fully sitting on the switches. When the last trigger switch is zero, the start of P2 was marked as seen in Image 3.12.

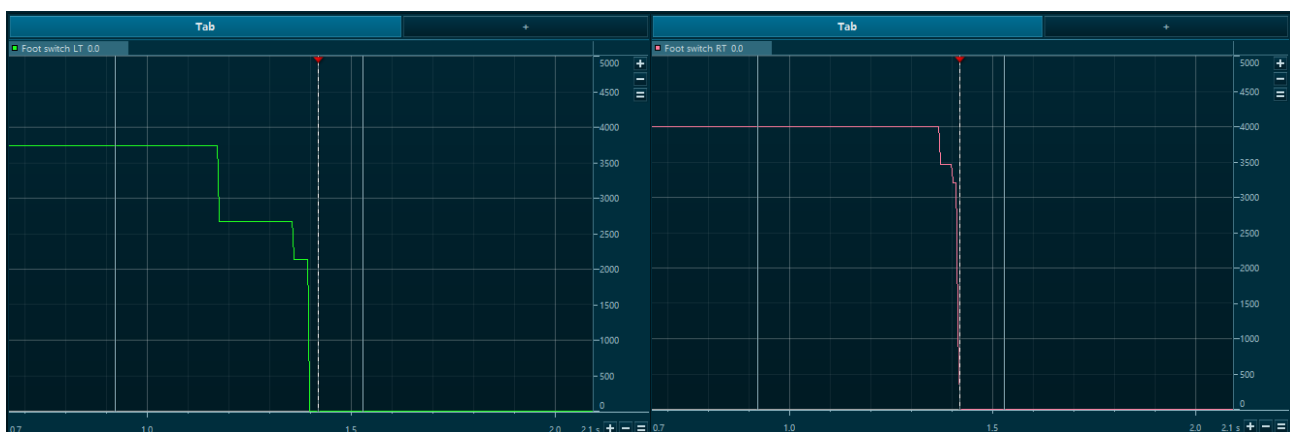


Image 3.12: Trigger switches for P2 (right-sided seat-off triggered the start of phase two)

The dominant side of the control participant and the unaffected side of the case participants are used to mark the maximum ankle dorsiflexion and the start of P3. Image 3.13 illustrates the MyoResearch panel used to mark P3.

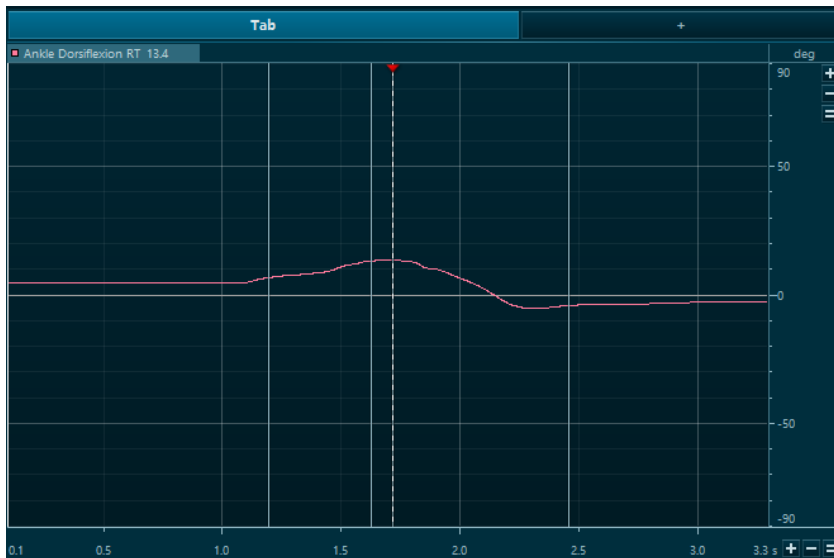


Image 3.13: Start of P3 marked at maximum dominant ankle dorsiflexion

The dominant side of the control participant and the unaffected side of the case participants are used to mark the initial maximum hip extension at the start of P4. Since the participants stabilise during P4 various degrees of hip extension and flexion may occur. For this reason, the first maximum hip extension has been consistently marked. Image 3.14 illustrated the MyoResearch panel used to mark P4.

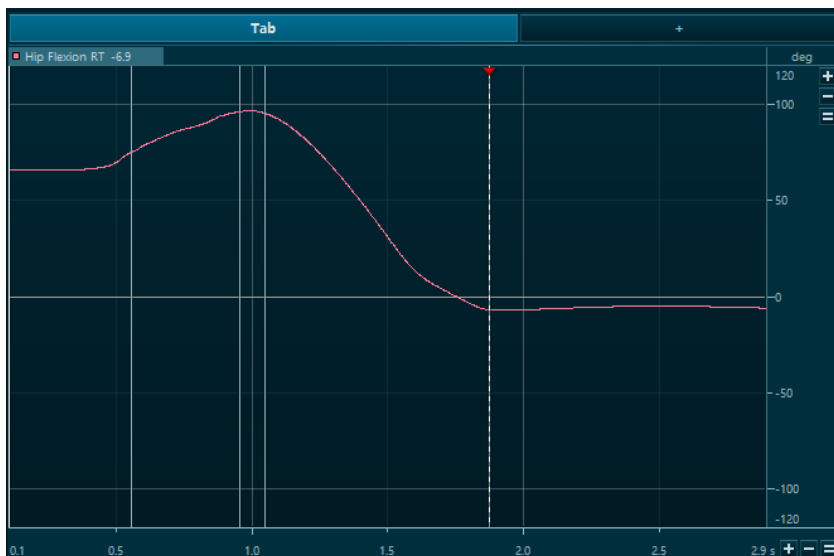


Image 3.14: Start of P4 marked at maximum dominant hip extension



### 3.11.1. Synchronization of data

The biomechanical analysis software used was the MyoResearch software. It synchronises all data recordings and processing of both the MyoMOTION and the MyoPressure systems. Trunk kinematics in the three different planes and temporospatial parameters were performed in MATLAB (The Mathworks, Natrick, MA) using custom-built scripts by the bio-engineers of the FNB-3D Movement Analysis Laboratory – Stellenbosch University.

### 3.11.2. Accelerometer Calculations

The 3-axis accelerometer vector data (units in  $\text{m/s}^2$ ) was sampled at 400 Hz from the thorax (THO) and lumbar (LUM) locations on all participants. The 3-axis channels sampled were of the ML, VT and AP (X/Y/Z) directions. The raw sensor accelerometer sampled data  $\vec{a}_{RAW}(k)$  was then filtered by:

a low pass filter (LPF) with all frequencies below 2 Hz retained and above 2 Hz removed to give  $\vec{a}_{LPF}(k)$ , and

a high pass filter (HPF) with all frequencies above 1 Hz retained and below 1 Hz removed to give  $\vec{a}_{HPF}(k)$ .

Figure 3.1 shows a typical raw accelerometer's ML component as measured from the THO sensor. Figures 3.2 and 3.3 show the LPF and HPF filtered data of the raw ML component in figure 1.

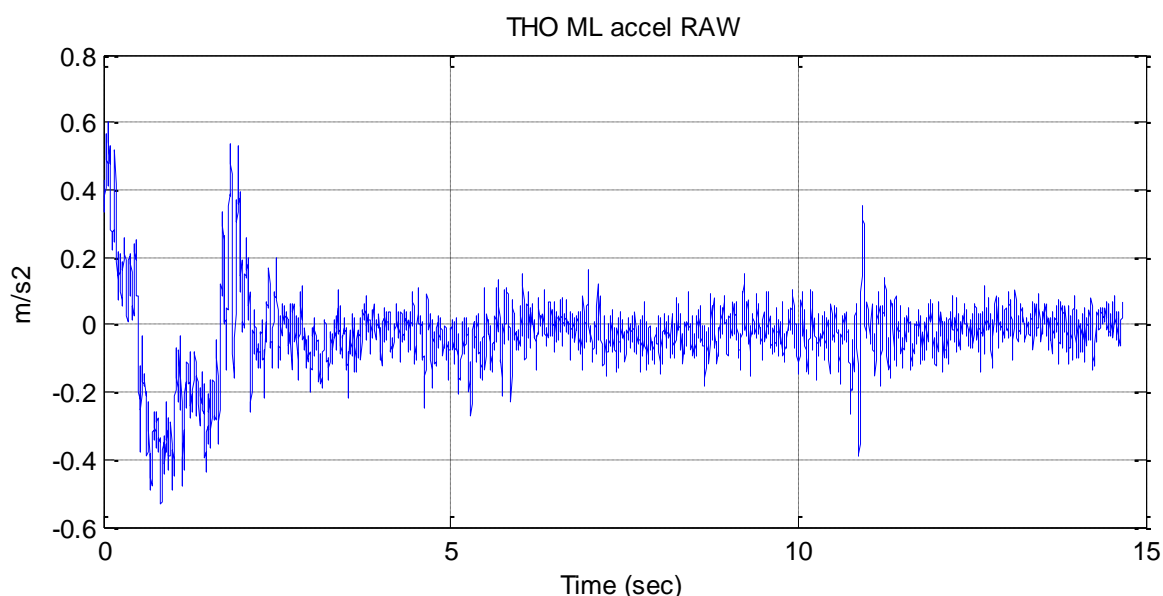


Figure 3.1: A Typical Raw THO accelerometer's ML component

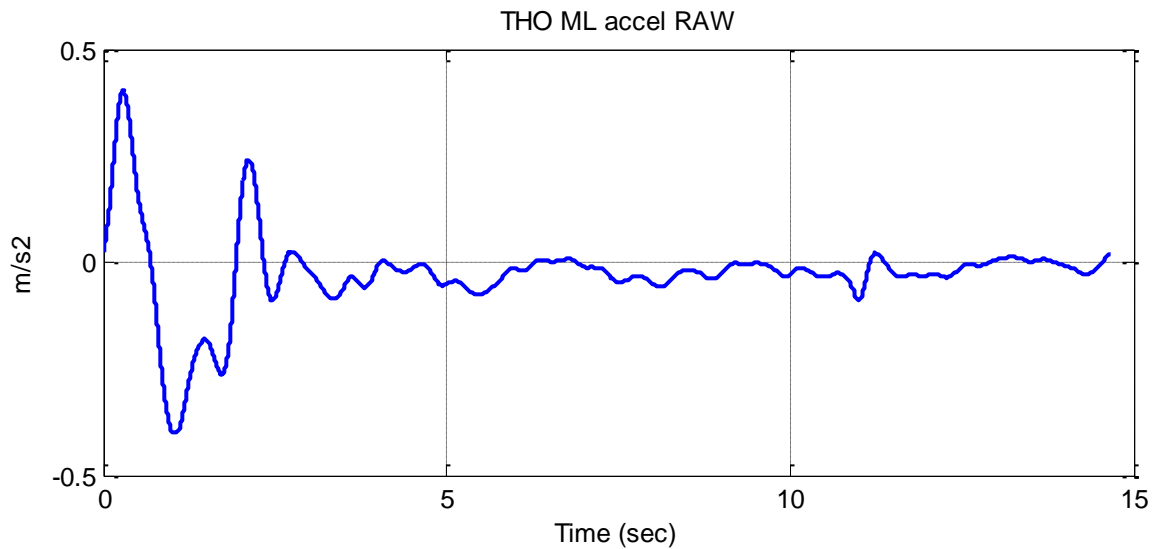


Figure 3.2: A Typical LPF filtered THO accelerometer's ML component

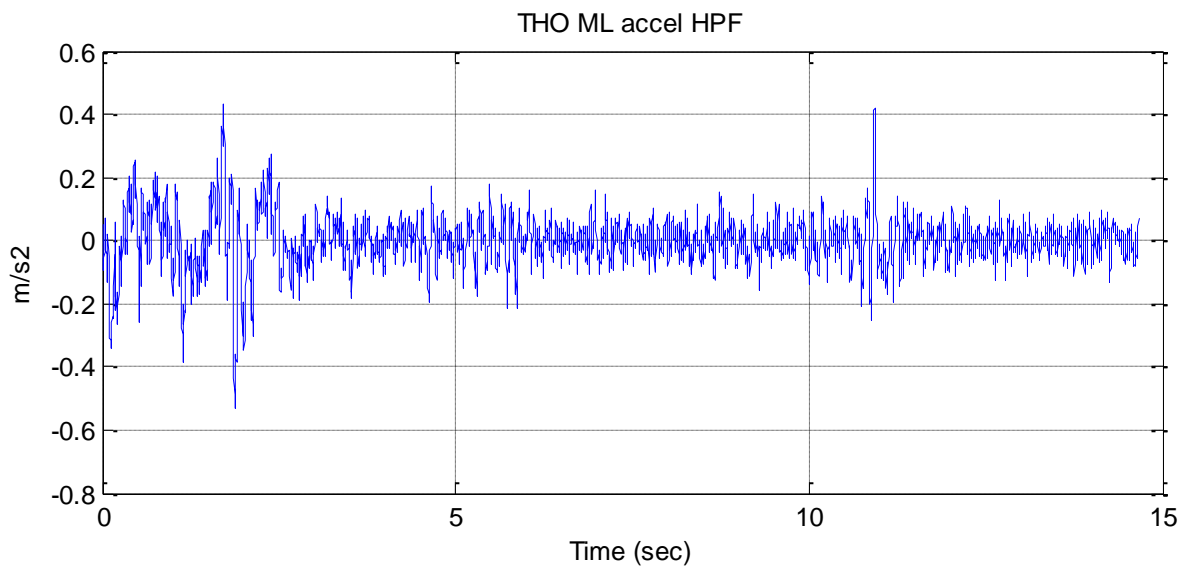


Figure 3.3: A Typical HPF filtered THO accelerometer's ML component

The jerk vector data  $\vec{j}(k)$  was then computed by taking the discrete derivative of the low pass filtered accelerometer sampled data:

$$\vec{j}(k) = (\vec{a}_{LPF}(k) - \vec{a}_{LPF}(k-1)) / \Delta t \quad [1]$$

with,

$$\Delta t = 0.0025 \text{ sec (sample time)}$$

Figure 3.4 shows the jerk vector's ML component of the LPF filtered accelerometer data of Figure 3.2.

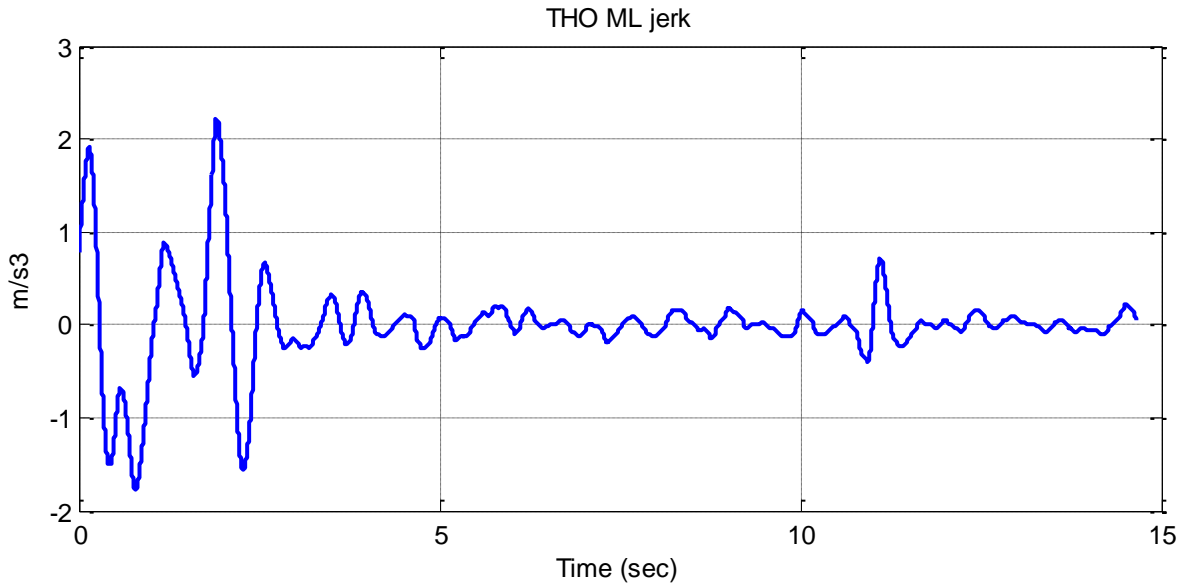


Figure 3.4: A Typical THO jerk's ML component

The transverse plane's (ML and AP components) accelerometer vector's magnitude was then computed to compare the case participant's acceleration magnitude in this plane to the control participants. According to the literature, Equation [1] and [2], the transverse plane presents the most substantial differences between stroke and control participants (Na et al., 2016; Janssen et al., 2008b). As only the higher frequency content in the acceleration is of importance, only the high pass filtered vector components are used for the magnitude calculation:

$$\|\vec{a}_{transverse}\| = \sqrt{(a_{HPF}^{ML})^2 + (a_{HPF}^{AP})^2} \quad [2]$$

The area under curve (AUC) parameter is then computed by time integration (discrete summation) of the transverse plane's acceleration of Equation [2] between the time index  $t_2$  (at seat-off) to time-index  $t_4$  (at arrival in standing position):

$$AUC = \sum_{t_2}^{t_4} \|\vec{a}_{transverse}(t)\| \Delta t \quad [3]$$

The units of AUC will be m/s and is an indication of the average velocity magnitude in the transverse plane.

The average acceleration magnitude (JERK) parameter in the transverse plane will be calculated by time integration of the transverse plane's jerk vector magnitude:

$$JERK = \sum_{t_2}^{t_4} \|\vec{j}_{transverse}(t)\| \Delta t \quad [4]$$

with,

$$\|\vec{j}_{transverse}\| = \sqrt{(j_{ML})^2 + (j_{AP})^2} \quad [5]$$

The various participants performed the STS movement at various speeds/forces depending not only on whether they had a stroke or not but most likely also influenced by their age, gender, agility and muscle power. It is therefore essential to scale their STS accelerometer-derived parameters with their averaged accelerometer vector magnitude as measured by both the thoracic and lumbar sensors. The total averaged accelerometer vector magnitude, or intensity (*INTENSE*) parameter is then calculated for each participant as:

$$INTENSE = \frac{1}{n} \sum_{t_2}^{t_4} (\|\vec{a}_{THO}(t)\| + \|\vec{a}_{LUM}(t)\|) / 2 \quad [6]$$

with,

$n$  = number of samples between  $t_2$  and  $t_4$

$$\|\vec{a}_{THO}\| = \sqrt{(a_{THO\_RAW}^{ML})^2 + (a_{THO\_RAW}^{VT})^2 + (a_{THO\_RAW}^{AP})^2} \quad [7]$$

$$\|\vec{a}_{LUM}\| = \sqrt{(a_{LUM\_RAW}^{ML})^2 + (a_{LUM\_RAW}^{VT})^2 + (a_{LUM\_RAW}^{AP})^2} \quad [8]$$

The *INTENSE* parameter of each participant is then used to calculate an average intensity for all the participants tested (PWS and control) and then by taking the ratio of each participants intensity over the average intensity a scale factor can be calculated to calibrate the STS accelerometer and derived parameters (*AUC* and *JERK*) for all participants during the data analysis. The scale factor for participants *P0xx* can be calculated as:

$$SCALE(P0xx) = INTENSE(P0xx) / \overline{INTENSE(All)}$$

with,

$$\overline{INTENSE(All)} = \sum INTENSE(P0xx)$$

$xx = 1$  to  $m$  (the number of participants tested)

### 3.12 Statistical analysis

IBM SPSS version 23 was used to analyse the data. The average of the five sit-to-stand data was used for statistical analysis. A p-value <0.05 was considered as statistically significant. The primary objectives used parametric bivariate analysis and entailed Chi-square tests to compare categorical predictors between the cases and controls, whereas t-tests and Levene's test were used to compare continuous data between cases and controls. A 95% Confidence Interval was also used to analyse the data.

Nonparametric tests were also used to analyse the data due to sit-to-stand being a personal and diverse transition. For this study's primary objectives, we decided to comment in the results chapter on the non-parametric testing only. The Mann-Whitney test was used to compare the differences between the two independent groups. It is a non-parametric test of the null hypothesis used to calculate a p-value  $<0.05$  for statistical significance.

Spearman's rho, non-parametric test, was used to analyse the data applicable to the secondary objectives. It measured the strength of association between the TIS total and subscale scores with the various parameters measured for the primary objectives. A strong correlation coefficient is between -1.0 to -0.5 or 1.0 to 0.5. A moderate correlation is -0.5 to -0.3 or 0.3 to 0.5. A weak correlation is -0.3 to -0.1 or 0.1 to 0.3. No correlation or very weak is -0.1 to 0.1. This results chapter of this study only reports on the strong correlation coefficient relationships.

### **3.13 Ethical Considerations**

Approval for this study was obtained from the Health Research Ethics Committee of Stellenbosch University as well as the Western Cape Provincial Research Health Committee (S16/05/095). The nature of the study and all the procedures were explained to the potential participants. Written informed consent was obtained before data collection commenced. The written informed consent was available in Afrikaans, English and isiXhosa (Addendum C). Participation in the study was voluntary, and the participants knew they had the right to withdraw from the study at any time during the testing. Each participant was allocated a number to ensure anonymity with only the primary researcher knowing who corresponded with what number. Screens were used during testing to ensure the privacy of the participants in the space used for testing. Breaks were taken in-between testing as needed by the participants. Water and something to eat was given during the rest break. Data was stored on two separate memory sticks that were kept in a safe under each participant's code. The one memory stick was stored at the FNB-3D Movement Analysis Laboratory – Stellenbosch University, Tygerberg Campus. The other memory stick was kept with the primary researcher. All photos taken of the participants did not include their faces or were cropped out with saving on the memory sticks. All data attained will be used anonymously for any future publications.

# *Chapter 4*

## *Results*

The results chapter describes the demographic information of all participants. The analysis of data derived from the clinical outcomes measures used with case participants, i.e. the TIS and modified Barthel Index (mBI) scores are also reported here. The differences between the case and community control group with regards to the primary objectives of the temporal, kinetic and kinematic parameters during the STS transition are reported. The secondary objectives of the study are addressed with the comparison of the TIS scores of case participants with the various parameters related to these primary objectives.

### **4.1 Sample description**

The allocation process of participants for this study together with the number of participants in each group is detailed in Figure 4-1. Of the initial 36 potential participants screened between January 2017 and May 2018, 32 met the inclusion criteria, provided informed consent and were subsequently recruited into the study. Upon review of the data and the sensitivity of the instruments to body mass artefacts, two participants' data could not be used which resulted in a final sample size of 30 participants, i.e. 15 in each group.

There were five male and ten females in the case group of which eight had left hemiplegia, and seven had right hemiplegia. Nine males and six females were in the control group with four being left side dominant and eleven right side dominant. The average age of the case group was 56.53 years (36-80) and 46.87 years (19-70) for the control group. No statistically significant differences were found regarding the ages of the two groups  $p=0.058$  (t-test). See Table 4.1 for group data.

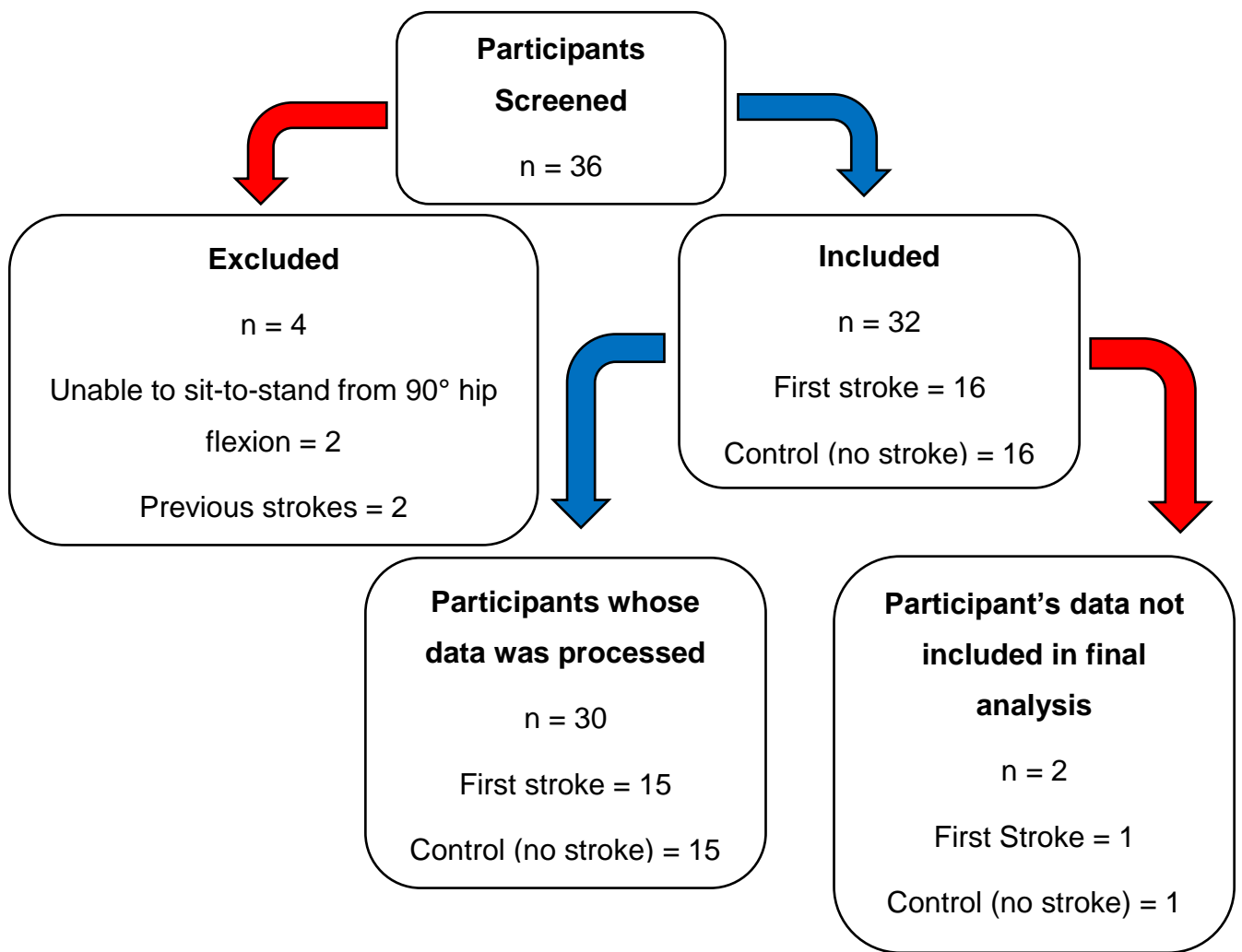


Figure 4.1: Study flow diagram detailing participant allocation

Table 4.1: Group demographics

	<b>Case group (n=15)</b>	<b>Control group (n=15)</b>
<b>Gender (Ratio Male:Female)</b>	5:10	9:6
<b>Age (Mean; SD)</b>	56.53 (9.8)	46.87 (16.2)

Ten of the case participants were tested within three months post-stroke (13-85 days), and five were tested within six months (108-157days) post-stroke. See Table 4.2 for case group data related to functional independence and trunk impairment outcome measures. Only three case participants were fully independent when tested with the mBI, eight were slightly dependent, and four were moderately dependent. The case participants scored a mean of 15.7 (11-19) out of 23 when tested with the TIS. Their mean performance on the static sitting balance subscale was 6.9 (6-7) out of 7. For the dynamic sitting balance subscale the score was 7.3 (3-10) out of 10 with the upper trunk side-flexion 4.4 (2-6) out of six and the lower trunk side-flexion 2.9 (1-4) out of four. The coordination subscale scored 1.5 (1-4) out of 6 with the upper trunk rotation 1.1 (1-2) out of three and the lower trunk rotation 0.4 (0-2) out of three.

Table 4.2: Functional independence and trunk impairment of the case group

<b>Modified Barthel Index Score (mBI Score)</b>		
<b>Categories of dependence (mBI Score range)</b>	<b>n=15</b>	<b>Mean (Range)</b>
Moderate Dependence (61-90)	n=4	81.25 (72-90)
Slight Dependence (91-99)	n=8	94.88 (93-98)
Independence (100)	n=3	100 (100)
<b>Trunk Impairment Scale (TIS)</b>		
<b>TIS Subscales</b>	<b>n=15</b>	<b>Mean (SD)</b>
<b>Static</b> Sitting Balance (/7)	n=15	6.9 (0.4)
<b>Dynamic</b> Sitting Balance (/10)	n=15	7.3 (2.0)
<b>Upper Trunk</b> (/6)	n=15	4.4 (1.5)
<b>Lower Trunk</b> (/4)	n=15	2.9 (1.1)
<b>Coordination</b> (/6)	n=15	1.5 (0.8)
<b>Upper Trunk</b> (/3)	n=15	1.1 (0.4)
<b>Lower Trunk</b> (/3)	n=15	0.4 (0.6)
<b>Total TIS Score:</b> (/23)	n=15	15.7 (2.3)



Table 4.3 aims to distinguish the case group into the two hemiparetic sides. Overall these two groups had similar values. The mean for both groups is within the “slight dependence” category on the mBI, i.e. 91/100 for left and 93.71/100 for right-sided hemiparesis respectively. The only difference of note is that of the dynamic subscale of the TIS, where the left hemiparetic group had a mean of 7.88/10 while the right hemiparetic group scored 6.71/10. That is one point difference on the TIS total score.

Table 4.3: Comparison of functional independence and trunk impairment as per side affected

	<b>Left Hemiparesis (n=8)</b>	<b>Right Hemiparesis (n=7)</b>
<b>mBI Score</b>	91 (72-100)	93.71 (81-100)
<b>TIS Score (/23)</b>	16	15.43
<b>Static Subscale (/7)</b>	6.75 (6-7)	7
<b>Dynamic Subscale (/10)</b>	7.88 (4-10)	6.71 (3-8)
<b>Coordination Subscale (/6)</b>	1.38 (1-2)	1.71 (1-4)

*Abbreviations:* mBI: Modified Barthel Index; TIS: Trunk Impairment Scale

## 4.2 Temporal parameters of Sit-to-Stand

The temporal parameters of the sample are summarised in Table 4.4 to illustrate the differences between the case and control group. It includes the duration of each phase and the total duration of the STS transition. It does not include P4 as data collection was pre-set at ten seconds for each participant in this phase. The duration of the STS phases for the case group was all significantly longer than the control group although no significance was found during P2. A statistical difference was found during the initial part of the movement (P1) and the extension phase of STS (P3). It took the case group longer to reach seat-off in P2, bending the trunk forward, when compared to the control group. Coming up into upright standing in P3, i.e. extension of the trunk and lower body, also differed between the groups ( $p=0.002$ ). The most time was spent during P3 for both the case and control group. The total duration of the STS transition also showed a statistical difference ( $p=0.002$ ) with the lengthier duration of the case group.

Table 4.4: Comparison of duration of individual phases and total STS transition

Duration (s)	Case Group (n=15) Mean (SD)	Control Group (n=15) Mean (SD)	P-Value
Phase 1 – Initiation	0.86 (0.26)	0.68 (0.24)	0.026*
Phase 2 – Seat Off	0.41 (0.15)	0.30 (0.13)	0.067
Phase 3 – Extension	1.79 (0.59)	1.17 (0.40)	0.002*
Total duration	3.06 (0.76)	2.15 (0.59)	0.002*

\*Significance at  $p<0.05$

\*\*Significance at  $p<0.001$

### 4.3 Kinetic parameters of Sit-to-Stand

The kinetic parameters of STS were summarised using means and standard deviations for each participant group. The kinetic parameters are divided into two categories, i.e. weight-distribution (Addendum I) and total force (Addendum J) exerted during STS.

#### 4.3.1. Weight-distribution between the case and control participants

For analysis, the pairing of the affected side of the case group with the non-dominant side of the control group was made. The unaffected side of the case group was paired with the dominant side of the control group. The pairing was needed as stroke affects the body and limbs typically unilaterally; the analysis may be distorted should it not be taken into account. During P1, P3 and P4 a statistical difference was found in weight distribution between the case and control group (Addendum I). The control group had roughly equal percentage weight distribution between their two feet for all the four phases of STS (Figure 4.2). The case participants, however, had more weight distributed on the affected limb while sitting (Figure 4.3). From P2 till the end of the STS the weight-distribution shifted to the unaffected side, especially during the extension phase (P3) of the transition (Figure 4.3).

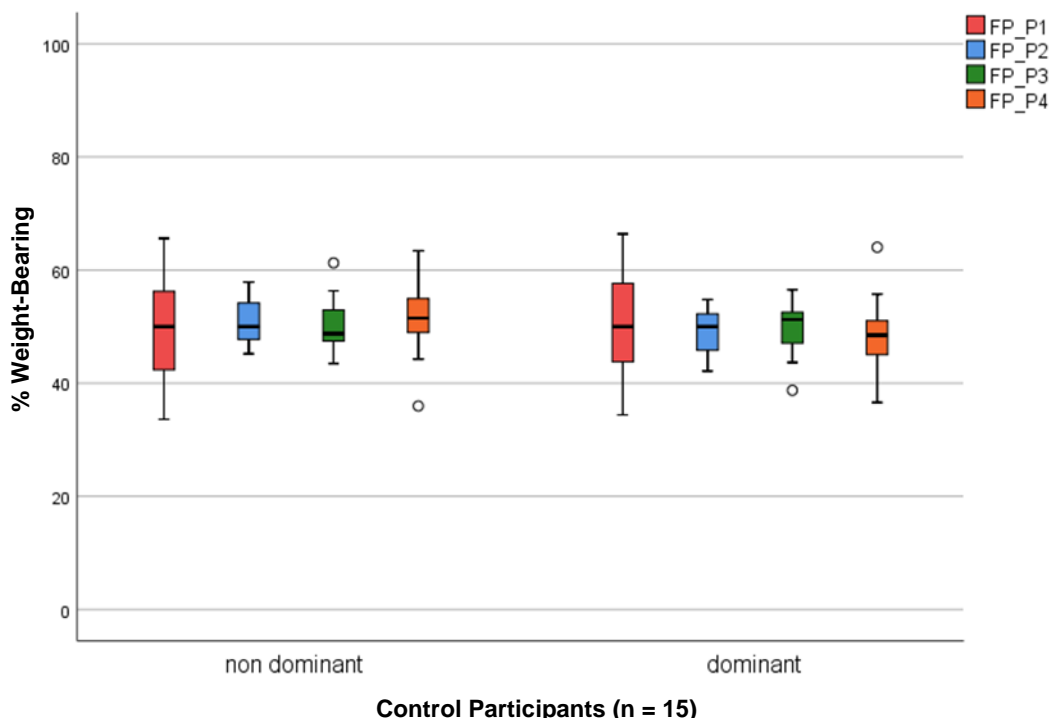


Figure 4.2: Weight-Bearing distribution of the control participants during the four phases of STS

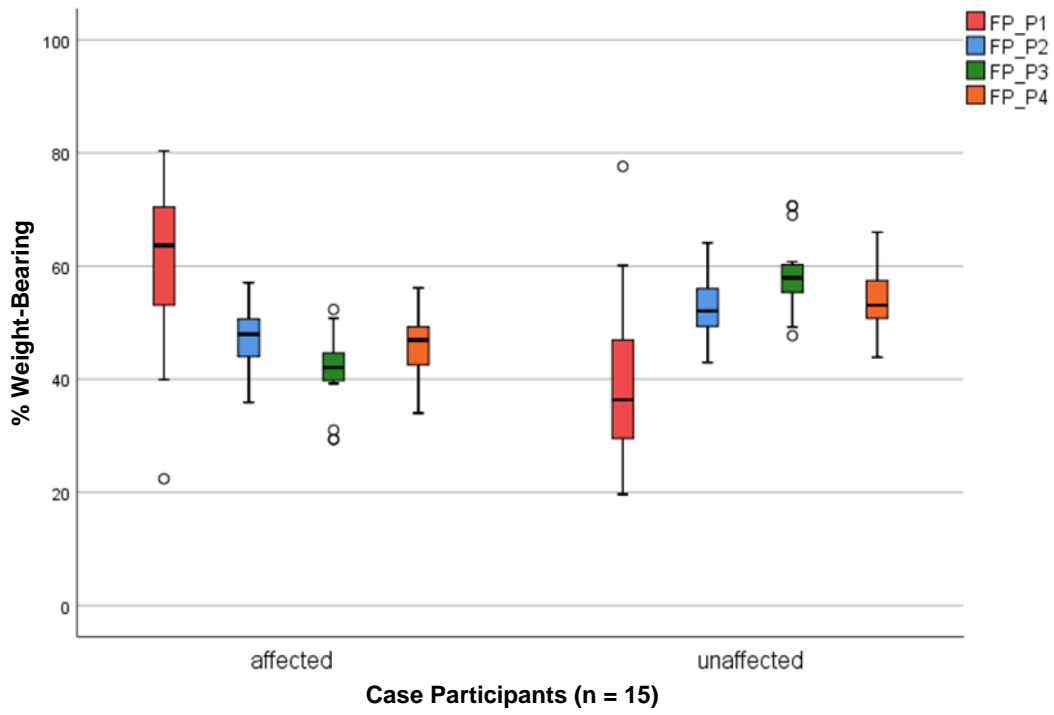


Figure 4.3: Weight-Bearing distribution of the case participants during the four phases of STS

### 4.3.2. Total force generated during Sit-to-Stand

Addendum J illustrates the comparison of force generated between the case and control participants. No statistically significant difference between the case and control groups was found. At the start of the transition, the participants were in a sitting position. A lower force reading is therefore reflected on the MyoPRESSURE during P1. The most force exerted was shown during P2 for the control group, where seat-off takes place and the force transfers from the pelvis and thighs, which were initially on the chair, to the legs and feet on the ground. This maximal force generation was not evident in the case group. For both groups, a decrease in force during the extension in P3 was found. However, even with no statistical difference, it is noteworthy that during P3 ( $p = 0.067$ ) the case group had 675N force compared to the control group's 600N force. Greater force is used by the case group during P3 compared to the control group (Figure 4.4). The case group, in contrast, demonstrated the most force generation during P4 when they were standing upright taking weight through their feet.

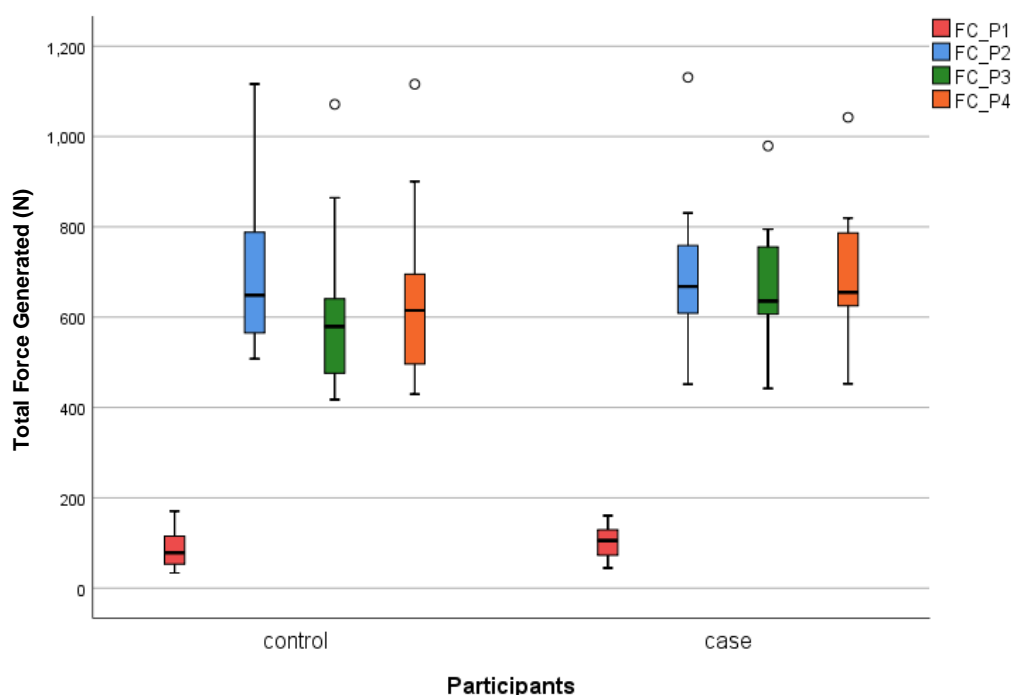


Figure 4.4: Comparison of total force distribution (FC) during STS phases

#### 4.4 Kinematic parameters of Sit-to-Stand

The kinematic parameters of angular displacement, velocity, and acceleration of the trunk were summarised using means and standard deviations for each participant. Non-parametric tests were applied to test the null hypothesis. The significance level was set at  $p < 0.05$  for all comparisons.

Addendum K illustrates the differences in angular displacement of the trunk between the case and control group for all the phases of STS in all planes of movement. Each phase will be reported on individually in this section with relevant data depicted in tables. Table 4.5 gives a guide to the interpretation of the movement direction. In the sagittal plane, the movement takes place in the AP direction producing a forward and backwards movement known as flexion and extension. The maximum direction of movement in the sagittal plane is trunk extension while the minimum direction is trunk flexion. The frontal plane moves in the ML direction known as side-flexion, which could be to the left or right side. The transverse plane produces a rotation movement in the combined AP and ML direction. The maximum direction in the frontal and transverse plane is displacement towards the right side. Thus the minimal direction in the frontal and transverse plane would be displacement towards the left side.

Table 4.5: Guide to biomechanical movement planes and correlation to human movements

Plane of Movement	Human Movement	Max Direction	Min Direction
Sagittal Plane	Flexion/Extension	Extension	Flexion
Frontal Plane	Side-Flexion	to the Right	to the Left
Transverse Plane	Rotation	to the Right	to the Left

The angular velocity of the trunk during all the phases is displayed in Addendum L. Angular velocity refers to how fast the trunk moved within the different planes of movement. Table 4.6 gives a guide to the interpretation of the movement direction. The peak positive and negative values were tabulated to show the direction of the velocity of the trunk. Peak positive in the sagittal plane is trunk extension velocity while peak negative refers to trunk flexion velocity. As peak positive in the frontal and transverse planes indicate velocity towards the right side; the peak negative would denote velocity towards the left side. Again the relevant and significant differences between case and control groups for individual phases are tabulated below.

Table 4.6: Guide to biomechanical movement planes and correlation to the direction of velocity

Plane of Movement	Human Movement	Peak Positive	Peak Negative
Sagittal Plane	Flexion/Extension	Extension	Flexion
Frontal Plane	Side-Flexion	to the Right	to the Left
Transverse Plane	Rotation	to the Right	to the Left

#### 4.4.1. Phase 1 – Initiation of movement

The trunk (as per the thoracic and lumbar IMU sensors) moved more in the frontal and transverse planes in the case group. This resulted in a significant increased thoracic rotation and side-flexion range, from left to right, compared to the control group ( $p=0.001$ ), Table 4.7. The large thoracic side-flexion to the left found in the case group may be linked with the increased left-sided weight-bearing symmetry during P1 as reported under 4.3.1. The left hemiparetic group had 67% of the weight-bearing on the left lower limb (Table 4.9). It may also explain the increased velocity found in the frontal plane for the case group towards the left side. The control group demonstrated a faster velocity of the thoracic segment in the sagittal plane than the case group. The control group initiated P1 with a faster forward thoracic flexion velocity even though the forward flexion range was the same between groups.

Table 4.7: Kinematic parameters of the thoracic segment of the trunk during P1

<b>Thoracic</b>			
	<b>Case Group</b>	<b>Control Group</b>	<b>P-Value</b>
	<b>Mean (SD)</b>	<b>Mean (SD)</b>	
<b>Angular Displacement (°)</b>			
Frontal Plane ROM	6.11 (2.25)	2.81 (1.78)	0.001**
Frontal Plane Min – Side-flexion to the left	-4.45 (3.67)	-1.75 (2.23)	0.037*
Sagittal Plane ROM	30.06 (6.43)	30.13 (9.75)	0.744
Transverse Plane ROM	6.69 (3.83)	2.71 (1.18)	0.001**

	<b>Case Group</b> <b>Mean (SD)</b>	<b>Control Group</b> <b>Mean (SD)</b>	<b>P-Value</b>
<b>Angular Velocity (°/s)</b>			
Frontal Plane Peak Negative - Side-flexion to the Left	-15.64 (12.22)	-5.87 (5.16)	0.013*
Sagittal Plane Peak Negative - Forward Flexion	-65.70 (12.38)	-81.74 (20.93)	0.016*

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

Upon further scrutiny, the left hemiparetic group had an increase weight-bearing through the affected side. This was because 5/8 left hemiparetic participants shifted the balanced foot position to place the unaffected foot backwards. This corresponds with the increased thoracic side-flexion to the left displacement and the increased thoracic side-flexion to the left velocity.

The lumbar segment demonstrated no difference in displacement during this phase of the movement (Table 4.8). Both the case and control groups had an equal amount of forward flexion range in the lumbar segment. The control group had a higher forward flexion velocity than the case group in the sagittal plane.

Table 4.8: Kinematic parameters of the lumbar segment of the trunk during P1

<b>Lumbar</b>			
	<b>Case Group</b> <b>Mean (SD)</b>	<b>Control Group</b> <b>Mean (SD)</b>	<b>P-Value</b>
<b>Angular Displacement (°)</b>			
Sagittal Plane ROM	36.45 (8.98)	37.70 (8.65)	0.902
<b>Angular Velocity (°/s)</b>			
Sagittal Plane Peak Negative - Forward Flexion	-91.14 (14.43)	-114.81 (23.82)	0.002*

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$



Table 4.9: Weight-bearing symmetry between the case and control group during P1

Weight-bearing Symmetry (%)		Left	Right
Case Group	Left Hemiparesis (n=8)	67	33
	Right Hemiparesis (n=7)	49	51
Control Group	Left Dominant (n=4)	51	49
	Right Dominant (n=11)	49	51

#### 4.4.2. Phase 2 – Seat-off

The thoracic segment of the case group had a larger displacement in the frontal and transverse planes. The thorax for the case group was more rotated and side-flexed than the control group during this phase ( $p=0.001$ ). This corresponds to an increased velocity by side-flexing towards the right and rotating towards the left. The velocity was seen in the frontal and transverse plane for the case group. This may be due to the majority of the case group ( $n=9$ ) triggering P2 with the right side leaving the chair/supporting surface last (Table 4.13).

Table 4.10: Kinematic parameters of the thoracic segment during P2

Thoracic			
	Case Group Mean (SD)	Control Group Mean (SD)	P-Value
<b>Angular Displacement (°)</b>			
Frontal Plane ROM	5.20 (1.62)	1.70 (1.36)	0.001**
Transverse Plane ROM	5.07 (2.48)	2.41 (2.12)	0.001**
<b>Angular Velocity (°/s)</b>			
Frontal Plane Peak Positive – Side-flexion to the right	18.09 (13.13)	7.85 (7.23)	0.041*
Sagittal Plane Peak Negative - Forward Flexion	-51.53 (17.00)	-62.29 (21.63)	0.217
Transverse Plane Peak Negative - Rotation to the left	-19.20 (15.79)	-10.14 (9.43)	0.023*

\*Significance at  $p<0.05$

\*\*Significance at  $p<0.001$

The case group showed a decrease in lumbar displacement in the frontal and transverse planes compared to the control group. The lumbar segment in the control group showed an increased range of side-flexion ( $p=0.033$ ). Although the lumbar rotation was not statistically significant ( $p=0.089$ ), a substantial difference in rotation displacement for the control group is seen. The control group ( $n=15$ ) had a larger rotation to the right and correlated to the right thigh ( $n=9$ ) triggering the seat-off (Table 4.13) as well as favouring the right lower limb for weight-distribution (Table 4.12). The lumbar segment in the control group, however, showed an increased forward velocity during seat-off (P2) in the sagittal plane compared to the case group. Overall the velocity moving forward into flexion decreased during P2 compared to P1 as expected in order to prepare for extension during P3.

Table 4.11: Kinematic parameters of the lumbar segment during P2

<b>Lumbar</b>			
	<b>Case Group</b>	<b>Control Group</b>	<b>P-Value</b>
	<b>Mean (SD)</b>	<b>Mean (SD)</b>	
<b>Angular Displacement (°)</b>			
Frontal Plane ROM (°)	3.05 (1.70)	7.64 (22.59)	0.033*
Transverse Plane ROM (°)	3.16 (1.56)	8.22 (24.22)	0.089
Transverse Plane Max (°) – Rotation to the right	1.67 (5.45)	7.02 (24.69)	0.806
<b>Angular Velocity (°/s)</b>			
Sagittal Plane Peak Negative - Forward Flexion	-72.11 (20.50)	-93.77 (27.91)	0.026*
Transverse Plane Peak Positive – Rotation to the right	7.18 (7.64)	36.26 (111.83)	0.624

\*Significance at  $p<0.05$

\*\*Significance at  $p<0.001$

Table 4.12: Weight-bearing symmetry between the case and control group during P2

Weight-bearing Symmetry (%)		Left	Right
<b>Case Group</b>	Left Hemiparesis (n=8)	47	53
	Right Hemiparesis (n=7)	53	47
<b>Control Group</b>	Left Dominant (n=4)	46	54
	Right Dominant (n=11)	50	50

Table 4.13: Differences in the side that triggered seat-off

	Left	Right	Both
<b>Case Group</b>			
Left Hemiparesis (n=8)	2	5	1
Right Hemiparesis (n=7)	3	4	0
<b>Control Group</b>			
Left Dominant (n=4)	2	2	0
Right Dominant (n=11)	3	7	1

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$ 

#### 4.4.3. Phase 3 – Extension

The range of motion of the thorax and lumbar segments in the frontal and transverse planes were significantly different between the groups. The thoracic segment of the case group had a broader range of side-flexion and rotation than the control group. The percentage weight-distribution (Table 4.16) between the hemiparetic sides was equal to each other with a ratio of 41:59 (affected:unaffected). This distribution links well with the increased range of upper trunk rotation and side-flexion as mentioned previously. The case group continued having a considerable right sided velocity in the frontal plane (side-flexion) compared to the control group (Table 4.14). A more considerable thoracic rotation velocity was found towards both left and right for the case group in the transverse plane. A slower thoracic velocity in extension was found in the case group when compared to the control group even though the displacement was similar. This correlates with the longer P3 duration for the case group ( $p=0.002$ ).

Table 4.14: Kinematic parameters of the thoracic segment during P3

<b>Thoracic</b>			
	<b>Case Group</b>	<b>Control Group</b>	<b>P-Value</b>
	<b>Mean (SD)</b>	<b>Mean (SD)</b>	
<b>Angular Displacement (°)</b>			
Frontal Plane ROM	9.09 (3.92)	4.16 (2.63)	0.001**
Frontal Plane Min – Side-flexion to the left	-5.54 (4.24)	-2.50 (2.26)	0.045*
Sagittal Plane ROM	49.53 (9.40)	43.82 (12.99)	0.116
Transverse Plane ROM	9.84 (4.62)	5.15 (3.89)	0.001**
<b>Angular Velocity (°/s)</b>			
Frontal Plane Peak Positive – Side-flexion to the right	15.35 (11.58)	7.48 (5.52)	0.016*
Frontal Plane Peak Negative – Side-flexion to the left	-14.96 (9.58)	-9.28 (9.21)	0.074
Sagittal Plane Peak Positive – backwards Extension	69.92 (24.75)	81.71 (17.79)	0.050*
Transverse Plane Peak Positive – Rotation to the right	17.83 (7.81)	10.68 (9.59)	0.003*
Transverse Plane Peak Negative – Rotation to the left	-17.30 (9.27)	-10.62 (6.85)	0.023*

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$ 

The lumbar segment, in contrast, showed that the control group had larger trunk displacement in the frontal and transverse planes (Table 4.15). The control group showed displacement more into rotation and side-flexion than the case group. The control group also had a faster lumbar rotation to the left shown in the transverse plane. This velocity links to the increased weight-bearing by the control group through the right lower limb, even though not statistically significant (Table 4.16). The range of lumbar displacement

between the two groups in the sagittal plane was similar. However, the velocity of the lumbar segment in the sagittal plane (extending upwards) was slower in the case group ( $p=0.011$ ). This correlates with the slower P3 duration seen in the case group.

Table 4.15: Kinematic parameters of the lumbar segment during P3

<b>Lumbar</b>			
	<b>Case Group</b>	<b>Control Group</b>	<b>P-Value</b>
	<b>Mean (SD)</b>	<b>Mean (SD)</b>	
<b>Angular Displacement (°)</b>			
Frontal Plane ROM	6.17 (2.88)	10.49 (26.07)	0.045*
Sagittal Plane ROM	40.08 (9.09)	40.34 (16.62)	0.775
Transverse Plane ROM	9.28 (3.35)	11.82 (26.70)	0.001**
<b>Angular Velocity (°/s)</b>			
Sagittal Plane Peak Positive – backwards Extension	55.34 (18.28)	74.24 (19.32)	0.011*
Transverse Plane Peak Positive – Rotation to the right	13.56 (8.14)	20.99 (36.64)	0.967
Transverse Plane Peak Negative – Rotation to the left	-14.56 (7.14)	-39.80 (122.69)	0.033*

\*Significance at  $p<0.05$

\*\*Significance at  $p<0.001$

Table 4.16: Weight-bearing symmetry between the case and control group during P3

<b>Weight-bearing Symmetry (%)</b>		<b>Left</b>	<b>Right</b>
<b>Case Group</b>	Left Hemiparesis (n=8)	41	59
	Right Hemiparesis (n=7)	59	41
<b>Control Group</b>	Left Dominant (n=4)	47	53
	Right Dominant (n=11)	49	51

#### 4.4.4. Phase 4 – Stabilisation

The thoracic segment showed significant displacement in the frontal plane (Table 4.17). The case group had a broader range of displacement towards the left and right side. No statistical difference was found for angular velocity of the thoracic segment between the case and control participants during this final phase of STS. The weight-bearing symmetry of the hemiparetic groups favoured the unaffected side during P4 (Table 4.18).

Table 4.17: Kinematic parameters of the thoracic segment during P4

<b>Thoracic</b>			
	<b>Case Group</b>	<b>Control Group</b>	<b>P-Value</b>
	<b>Mean (SD)</b>	<b>Mean (SD)</b>	
<b>Angular Displacement (°)</b>			
Frontal Plane ROM	2.72 (0.92)	1.89 (0.58)	0.008*

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

Table 4.18: Weight-bearing symmetry between the case and control group during P4

<b>Weight-Bearing Symmetry (%)</b>		<b>Left</b>	<b>Right</b>
<b>Case Group</b>	Left Hemiparesis (n=8)	45	55
	Right Hemiparesis (n=7)	52	48
<b>Control Group</b>	Left Dominant (n=4)	50	50
	Right Dominant (n=11)	51	49

#### 4.4.5. Acceleration of the trunk

Addendum M illustrates the differences in the acceleration of the trunk between the case and control groups for all the phases of STS in all planes of movement. This data was derived from the IMU sensors placed over the sternum and lumbar spine; i.e. thoracic and lumbar segments. Each phase will be reported on individually in this section with relevant data depicted in tables again.

Prior to the scaling of the acceleration data to calculate the average intensity for all the participants tested, the vertical acceleration was statistically significant between the two groups ( $p=0.001$ ) for the thoracic and lumbar segment. The control group had a higher acceleration upwards during standing than the case group, see Table 4.19.

Table 4.19: Unscaled Vertical Translation Acceleration

	Case Group Mean (SD)	Control Group Mean (SD)	P-Value
Thoracic Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.41 (0.13)	0.75 (0.26)	0.001**
Lumbar Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.35 (0.17)	0.56 (0.15)	0.001**

\*Significance at  $p<0.05$

\*\*Significance at  $p<0.001$

##### 4.4.5.1. Thoracic acceleration

The sway of the thoracic segment in the Medio-Lateral (ML) direction was significantly increased when compared to the control group, see Table 4.20. The case group, however, had less sway in the Antero-Posterior (AP) direction when compared to the control group. This showed that the case group had an increase of sway in the ML direction while the control group had an increased sway in the AP direction. This simply means that the thoracic segment swayed from left to right predominantly in the case group while the control group swayed mainly forwards and backwards. The control group also had a smoother movement, i.e. JERK, when compared to the case group. The magnitude of the sway velocity, depicted as the area under the curve in the following tables (AUC), was higher for the case group compared to the controls even though no significance was noted ( $p=0.056$ ). The case group had a larger amplitude of thoracic displacement decreasing the smoothness of movement, specifically in the transverse plane.

Table 4.20: Thoracic acceleration

	Case Group Mean (SD)	Control Group Mean (SD)	P-Value
ML Sway Acceleration (m/s <sup>2</sup> )	0.40 (0.10)	0.28 (0.07)	0.001**
AP Sway Acceleration (m/s <sup>2</sup> )	0.83 (0.15)	1.07 (0.16)	0.001**
JERK Sum Transverse Plane (m/s <sup>2</sup> )	13.71 (3.16)	11.43 (2.37)	0.050*
AUC Transverse Plane (m/s)	1.6 (0.4)	1.31 (0.31)	0.056

*Abbreviations:* ML: Mediolateral; AP: Anteroposterior; JERK: Jerkiness of sway; AUC: Area under the curve

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

#### 4.4.5.2. Lumbar acceleration

An increase in ML sway acceleration for the lumbar segment was found for the case group when compared to the control group. This corresponds with the findings in the thoracic segment. Both the case and control group had approximately the same AP sway of the lumbar segment. The control group produced a smoother movement, JERK, compared to the case group, see Table 4.21. The magnitude of the sway velocity, AUC, for the lumbar segment was also higher for the case group compared to the controls. The case group had a larger amplitude of lumbar displacement decreasing the smoothness of movement in the transverse plane compared to the community control group.

Table 4.21: Lumbar acceleration

	Case Group Mean (SD)	Control Group Mean (SD)	P-Value
ML Sway Acceleration (m/s <sup>2</sup> )	0.34 (0.11)	0.25 (0.08)	0.004*
AP Sway Acceleration (m/s <sup>2</sup> )	0.59 (0.20)	0.57 (0.12)	0.902
Jerk Sum Transverse Plane (m/s <sup>2</sup> )	8.71 (2.21)	6.09 (1.67)	0.002*
AUC Transverse Plane (m/s)	1.15 (0.32)	0.74 (0.25)	0.002*

*Abbreviations:* ML: Mediolateral; AP: Anteroposterior; JERK: Jerkiness of sway; AUC: Area under the curve

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$



## 4.5 Correlation with the Trunk Impairment Scale

Spearman's Rho, a non-parametric test, was used to measure the strength of association between the total score of the TIS and the subscales of the TIS with the various kinetic and kinematic parameters tested during the STS transition. All correlations were done in the case group (n=15).

### 4.5.1 Comparison between Temporal parameters of the trunk and TIS

#### Total score

Addendum N illustrates the comparison of the duration of STS with the total TIS score. No association was found with the total score of the TIS and duration of any of the phases of the STS.

### 4.5.2 Correlation between kinetic and kinematic parameters of the trunk and TIS total score

#### 4.5.2.1 Comparison between Kinetic parameters of the trunk and TIS total score

Addenda O and P illustrate the comparison between the various kinetic parameters with the total TIS score. Relevant findings in relation to these comparisons are provided individually in tables in this section of the results chapter. A decrease in total force generated during P1 is positively associated with a decrease in the total TIS score, see Table 4.22. Less force generated over the lower limbs correlates to a lower TIS score. No comparison was found with the total TIS score and WBA in the case group.

Table 4.22: TIS score correlation with total force distribution of the case group

<b>Kinetic Parameter – Total Force Distribution</b>	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
P1 Total Force	-.554	0.032*

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

#### 4.5.2.2 Comparison between the angular displacement of the trunk and TIS total score

Addendum Q illustrates all the comparisons between the angular displacement of the trunk and the total TIS score. Relevant findings in relation to these comparisons are provided here, see Table 4.23. No correlation was found with the lumbar segment displacement. A decrease in thoracic rotation during P1 coincided with a decrease in the total TIS score. During P2 (seat-off), an increase in the sagittal plane range of motion (forward-backwards movement), was associated with an increased total TIS score. During P3 (extension phase), an increase of thoracic range in the sagittal plane was associated with an increased TIS score. A larger extension movement and end extension value correlated with an increase in total TIS score. During P4 when stabilising in quiet stance should happen, a more upright thoracic segment into extension in the sagittal plane corresponded with an increase in total TIS score (Figure 4.5).

Table 4.23: Correlation of total TIS score with the angular displacement of the trunk

<b>Angular Displacement</b>	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
P1 – Thoracic - Transverse Plane Range	-0.559	0.030*
P2 – Thoracic - Sagittal Plane Range	0.595	0.019*
P3 – Thoracic - Sagittal Plane Range	0.655	0.008*
P3 – Thoracic - Sagittal Plane Max (Extension)	0.649	0.009*
P4 – Thoracic - Sagittal Plane Min (Flexion)	0.730	0.002*
P4 – Thoracic - Sagittal Plane Max (Extension)	0.633	0.011*

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

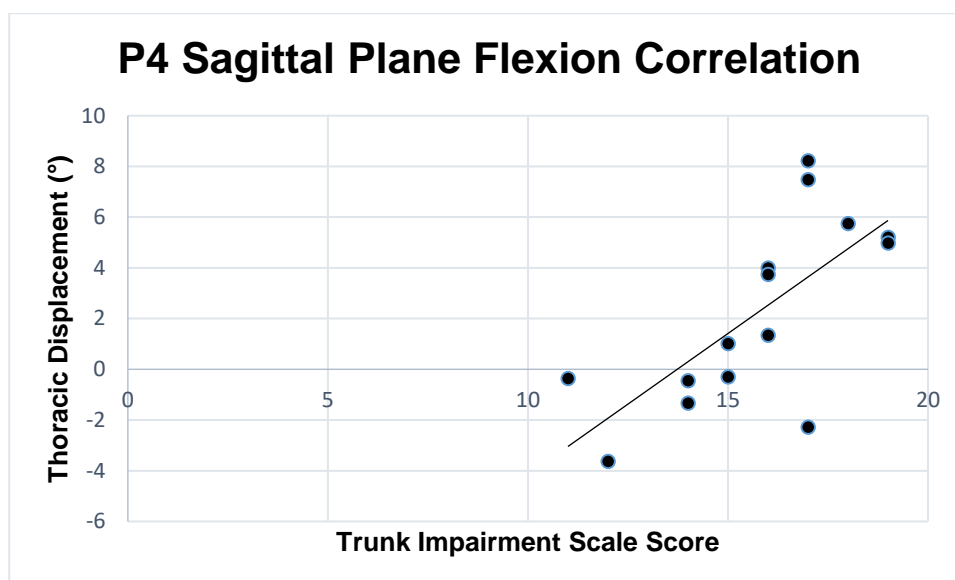


Figure 4.5: Positive correlation of thoracic flexion displacement during P4 with the Total TIS score

#### 4.5.2.3 Comparison between the Angular velocity of the trunk and TIS Total score

Addendum R illustrates the comparison between the angular velocity of the trunk and total TIS score in the case group. The only correlation for velocity was found during P2 of STS (seat-off), see Table 4.24. A decrease in TIS scores correlated with a decrease in velocity of the thoracic and lumbar segments in the sagittal plane. This suggests that a decrease in trunk forward flexion velocity will accompany a decrease in total TIS score (Figure 4.6). An increase of thoracic rotation to the left in the transverse plane also correlated with an increase in total TIS.

Table 4.24: Correlation of total TIS score with the angular velocity of the trunk

Angular Velocity	Correlation Coefficient	Total TIS (p-value)
P2 – Thoracic - Sagittal Plane Peak Negative (Flexion)	-0.525	0.045*
P2 – Thoracic - Transverse Plane Peak Negative (Left)	0.568	0.027*
P2 – Lumbar - Sagittal Plane Peak Negative (Flexion)	-0.548	0.034*

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

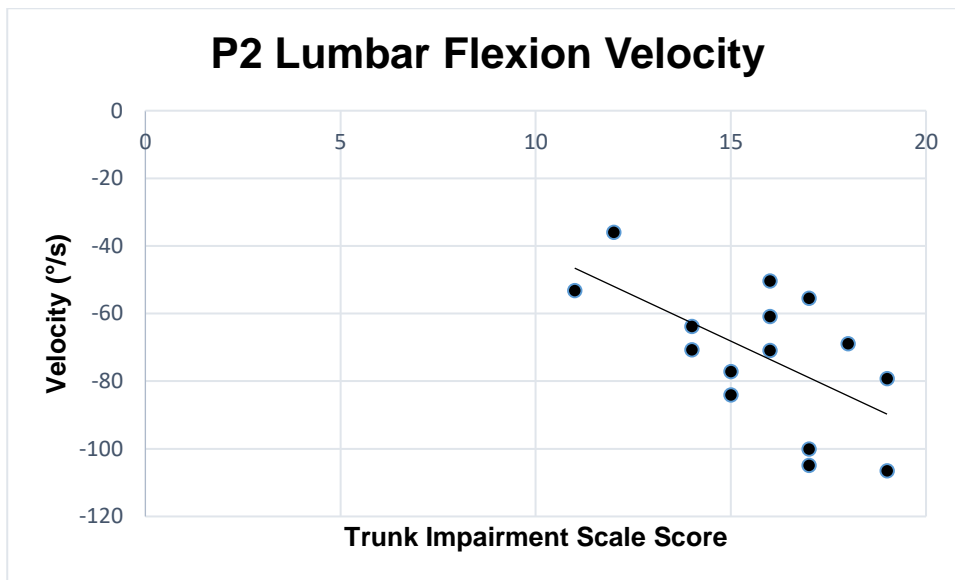


Figure 4.6: Negative correlation between P2 flexion velocity and TIS score

#### 4.5.2.4 Comparison between Acceleration of the trunk and TIS Total score

Addendum S illustrates the comparison between the acceleration of the trunk and total TIS score. No association was found with the total score of the TIS and acceleration of the trunk, irrespective of the segment.

## 4.6 Comparison between Parameters of the trunk and TIS Subscale score

### 4.6.1. Comparison between temporal parameters of the trunk and TIS subscale scores

Addendum N illustrates the comparison of the duration of STS phases with the scores of the subscales of the TIS. No correlation was found with the dynamic subscale of the TIS (Table 4.25). However, an increase in the coordination subscale score correlated positively with a longer P2 duration (Figure 4.7).

Table 4.25: TIS subscale score correlation with phase duration of STS

Temporal Parameter	Correlation Coefficient	Coordination Subscale
P2 Duration	0.520	0.047*

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

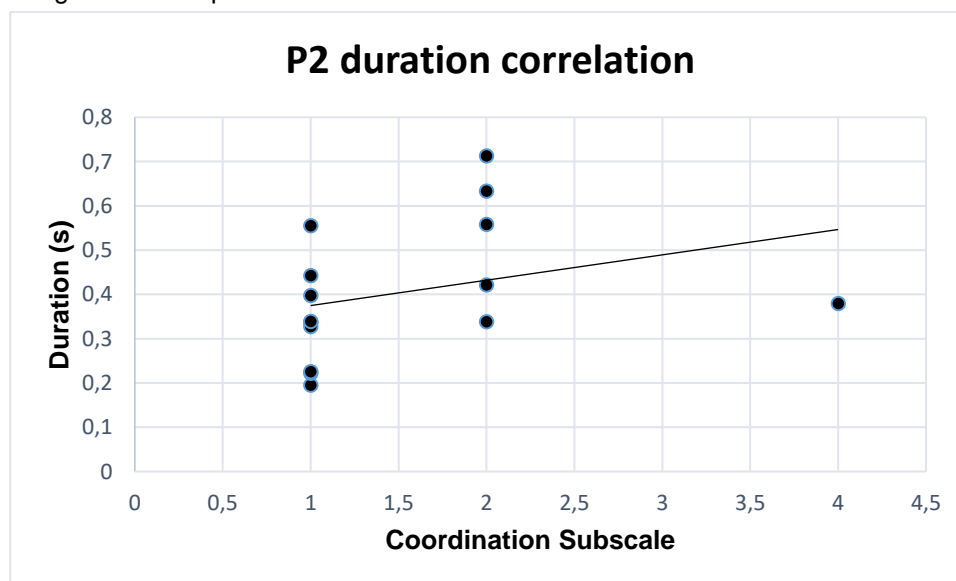


Figure 4.7: The positive correlation between the coordination subscale and P2 duration

## 4.6.2. Correlation between kinetic and kinematic parameters of the trunk and TIS total score

### 4.6.2.1. Comparison between kinetic parameters of the trunk and TIS subscale scores

Addenda O and P illustrates the correlation between the kinetic parameters of the trunk and the TIS subscale scores. No correlation was found between the kinetic parameters (force distribution and weight-bearing symmetry) and the various subscales of the TIS.

### 4.6.2.2. Comparison between angular displacement of the trunk and TIS subscale scores

Addendum Q illustrates the comparison between the angular displacement of the trunk and all TIS subscale scores. The dynamic subscale during P3 correlated with the sagittal plane thoracic range of displacement, see Table 4.26. A larger thoracic flexion/extension range was accompanied by a higher dynamic subscale score. During P4 (stabilisation) a larger displacement in the sagittal plane value is positively correlated with a higher dynamic subscale score. This expresses that at the start of P4 a smaller trunk flexion value, being in extension, correlates to a higher score on the dynamic subscale. An increased lumbar side-flexion displacement in the frontal plane during P4 correlated positively with a higher dynamic subscale. This illustrates a typical standing posture with weight-bearing by the case group mainly on the right lower limb with associated right-sided lumbar flexion during quiet standing.

Table 4.26: Correlation of the dynamic subscale score with the angular displacement of the trunk

Angular Displacement	Correlation Coefficient	Dynamic Subscale
P3 – Thoracic - Sagittal Plane Range	0.576	0.025*
P4 – Thoracic - Sagittal Plane Min (Flexion)	0.578	0.024*
P4 – Lumbar - Frontal Plane Max (Right)	0.521	0.047*

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

During P2 the thoracic segment angular displacement had a positive correlation with the coordination subscale in the sagittal plane, see Table 4.27. A larger thoracic range of forward displacement corresponds to a higher coordination score. Although not significant ( $p=0.051$ ), the same can be said of the lumbar displacement in the sagittal plane during P2. In P3, the maximum thoracic displacement in the sagittal plane correlated positively with the coordination subscale. A larger end range of extension for the thoracic segment during the extension phase corresponded with an increase in the coordination score. In the lumbar segment, the correlation was also found in the sagittal plane of movement. A broader range of lumbar displacement (coming from flexion to extension) corresponded with a higher coordination score. This is also seen in a larger flexion range of the lumbar segment at the start of P3, the higher the coordination subscale (Figure 4.8). During the stabilisation phase for quiet standing, a correlation for the thoracic displacement in the sagittal and transverse planes was also found. The more extended the thoracic segment is during P4, decreased thoracic flexion, the higher the coordination subscale score will be (Figure 4.9). A decrease in the thoracic rotation to the left during P4, standing upright, the higher the coordination subscale will be.

Table 4.27: Correlation of the coordination subscale score with the angular displacement of the trunk

<b>Angular Displacement</b>	<b>Correlation Coefficient</b>	<b>Coordination Subscale</b>
P2 – Thoracic - Sagittal Plane Range	0.569	0.027*
P2 – Lumbar - Sagittal Plane Range	0.511	0.051
P3 – Thoracic - Sagittal Plane Max (Extension)	0.569	0.027*
P3 – Lumbar - Sagittal Plane Range	0.722	0.002*
P3 – Lumbar - Sagittal Plane Min (Flexion)	-0.548	0.034*
P4 – Thoracic - Sagittal Plane Min (Flexion)	0.643	0.010*
P4 – Thoracic - Sagittal Plane Max (Extension)	0.581	0.023*
P4 – Thoracic - Transverse Plane Min (Left)	0.652	0.008*

\*Significance at  $p<0.05$

\*\*Significance at  $p<0.001$

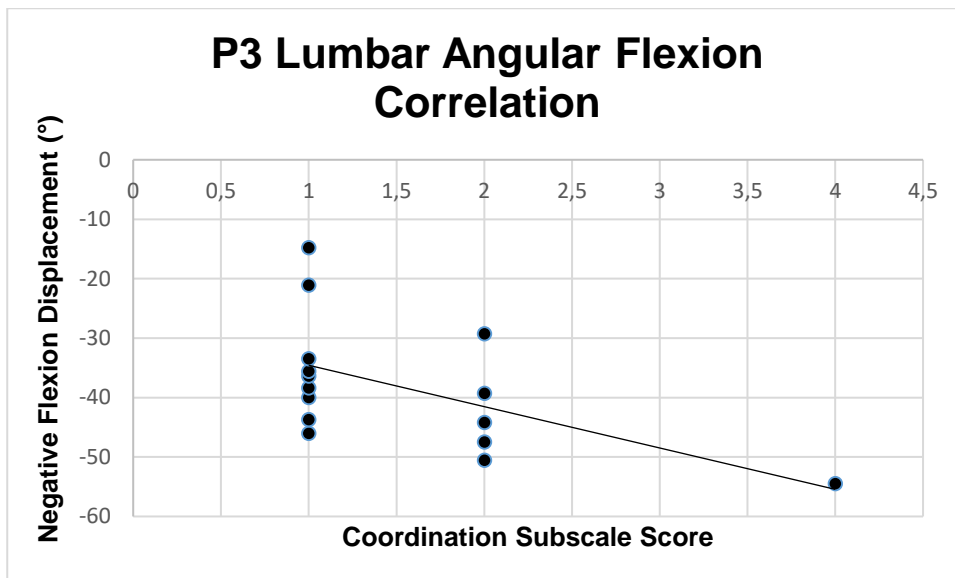


Figure 4.8: Negative correlation between lumbar flexion displacement and the coordination subscale during P3

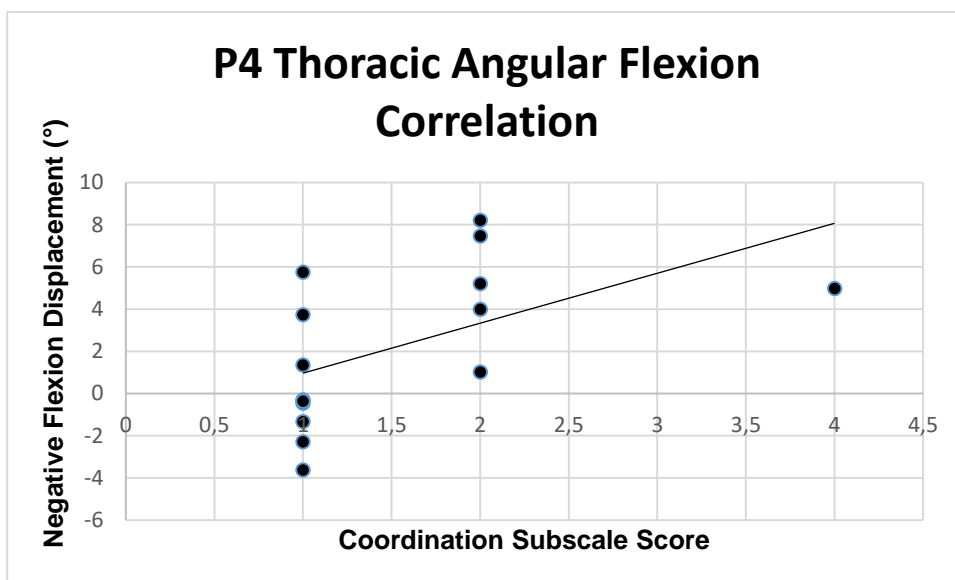


Figure 4.9: Positive correlation between thoracic flexion displacement and the coordination subscale during P4

#### 4.6.2.3. Comparison between the Angular velocity of the trunk and TIS subscale score

Addendum R illustrates the comparison between the angular velocity of the trunk and TIS subscale scores. In P1 a positive correlation in the sagittal plane for the thoracic segment was found with the coordination subscale, see Table 4.28. An increase in velocity of thoracic extension, backwards, was associated with an increase in the coordination subscale. During P2 the velocity of the lumbar segment had a negative correlation with the



dynamic subscale in the sagittal plane (Figure 4.10). The greater the lumbar segment velocity into flexion (forward) during seat-off was the higher the dynamic subscale score.

Table 4.28: Correlation of the dynamic and coordination subscale score with the angular velocity of the trunk

Angular Velocity	Correlation Coefficient	Dynamic Subscale	Coordination Subscale
P1 – Thoracic - Sagittal Plane Peak Positive (Extension)	0.536		0.039*
P2 – Lumbar - Sagittal Plane Peak Negative (Flexion)	-0.521	0.047*	

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

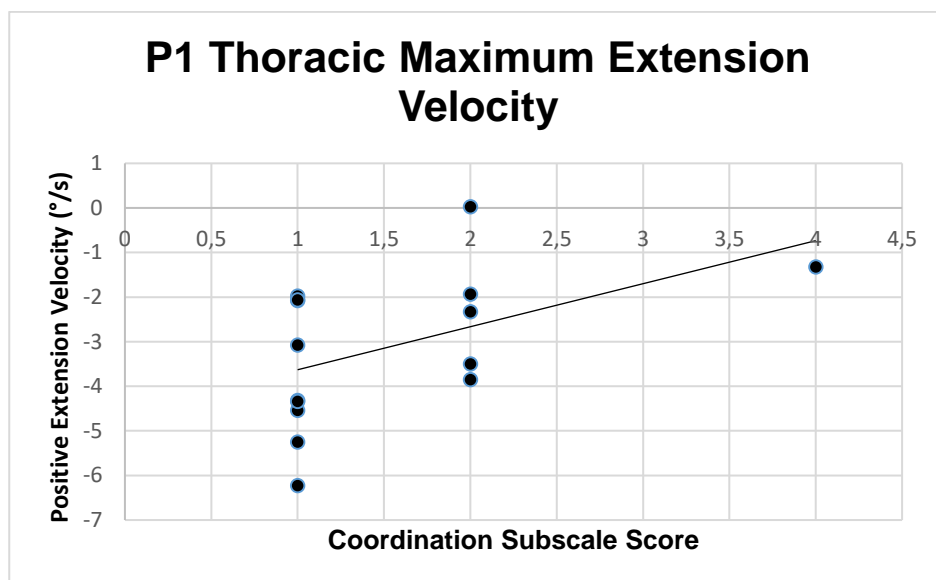


Figure 4.10: P1 thoracic maximum extension velocity during P1

#### 4.6.2.4. Comparison between Acceleration of the trunk and TIS subscale score

Addendum S illustrates the comparison between the acceleration of the trunk and the TIS subscale scores. The dynamic subscale had a negative correlation with thoracic sway in the ML direction (Figure 4.12). Decreased side-ways sway during STS was associated with a decrease in the dynamic subscale score, see Table 4.29.

Table 4.29: Correlation of the dynamic subscale score with the acceleration of the trunk

Acceleration	Correlation Coefficient	Dynamic Subscale
Thoracic ML Sway	-0.523	0.046*

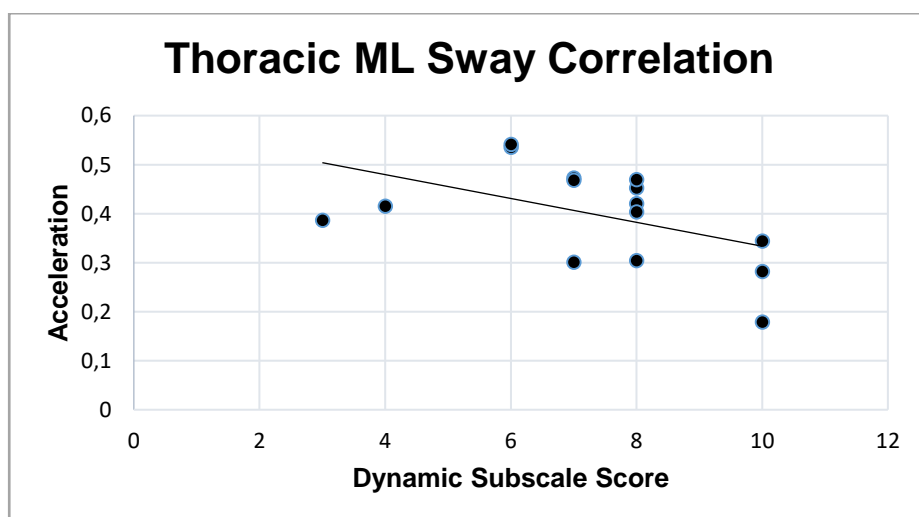
\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$ 

Figure 4.11: Thoracic ML sway correlation with the dynamic subscale

## 4.7 Summary of results

The case group had a longer total STS transition duration and individual phases duration except during P2 ( $p < 0.05$ ). The case group also had a decrease in vertical acceleration during the transition compared to the control group ( $p = 0.001$ ). No difference was found in force distribution through the feet between the case and control group. WBA for the case group was clearly evident for each phase, except P2 ( $p < 0.05$ ). During P1, weight was transferred onto the affected side due to the left hemiparetic group moving their unaffected foot backwards. The thoracic segment moved into side-flexion to the left during the foot shift ( $p = 0.037$ ). From P2 to P4 the weight was transferred to the unaffected side.

During P1 the case group moved the thoracic segment into rotation and side-flexion ( $p = 0.001$ ) while the thoracic segment flexed forward the same distance as the control group. The case group however displaced the thoracic segment forward at a slower velocity than the control group ( $p = 0.016$ ). During P2, the majority participants (9/15) in both groups triggered the start of phase with the right-sided buttock lifting off lastly. The case group moved the thoracic segment at a high velocity into right sided-flexion and rotation to the left for seat-off ( $p < 0.05$ ). The control group moved the lumbar segment into

various side flexion ranges ( $p=0.033$ ) and into higher rotation ranges than the case group ( $p=0.089$ ). The case group during the rest of the phase moved the thoracic segment into various side-flexion and rotation ranges ( $p=0.001$ ). The controls group also had a higher lumbar flexion velocity than the case group ( $p=0.026$ ).

During P3, the case group continued to move the thoracic segment into large ranges of side-flexion and rotation ( $p=0.001$ ). The thoracic velocity was significant ( $p<0.05$ ) for side-flexion and rotation to both sides. The case group had a decrease in extension velocity in both the thoracic and lumbar segments ( $p<0.05$ ). The control group had an increase in lumbar segment side-flexion and rotation ranges compared to the case group ( $p<0.05$ ). During P4, the case group had an increase in thoracic side-flexion range to accompany the unaffected side weight-distribution ( $p=0.008$ ).

The case group had an increase in thoracic and lumbar ML acceleration ( $p=0.001$ ) and Jerk ( $p<0.05$ ) in the transverse plane compared to the control group. The control group had an increase in thoracic AP acceleration ( $p=0.001$ ). The case and control group had the same lumbar AP acceleration ( $p=0.902$ ). These findings will be discussed linked to the literature in the next chapter, Discussion.

The TIS correlated positively with P2 angular velocity for an increased thoracic forward flexion, rotation to the left and lumbar forward flexion. It also correlates to an increased thoracic flexion range during P2. A higher thoracic extension range during P3 correlated with an increase in the TIS, dynamic subscale and coordination subscale scores. A decrease in the ML acceleration was associated with an increase in the dynamic subscale score. An increase in both the dynamic and coordination subscale score correlated positively with an increase of thoracic extension in standing at the end of the transition. These findings will also be discussed linked to the literature in the next chapter, Discussion.

# Chapter 5

## Discussion

The aim of this study was to assess the trunk kinematics and weight-bearing symmetry in the three planes of movement in the four phases of STS. This chapter discusses under various headings the results obtained and how they compare to current literature. PWS use alternative movement strategies during STS due to their asymmetrical deficits caused by hemiparesis (Duclos, Nadeau and Lecours, 2008).

### 5.1. Phase 1 – Initiation of movement

When initiating the transition from sitting to standing (STS), the participants in our study took longer to perform this activity. This is in keeping with various other articles (Mao et al., 2018; Galli et al., 2008) exploring the biomechanical analysis of this activity. In the healthy population, it is expected that body weight-distribution between both feet would be equal (Lecours et al., 2008). This is because the healthy controls generally keep the trunk in a neutral position with minimum asymmetry during STS (Lecours et al., 2008). PWS according to the data of this study presented with asymmetrical body weight distribution since the start of the transition already. PWS would favour their unaffected side with regard to body weight-bearing distribution as the COM undergoes a lateral displacement (Duclos, Nadeau and Lecours, 2008; Lecours et al., 2008). This lateral displacement to the unaffected side was not seen in this data set. There was a preference to favour the affected left side in the left hemiparetic group during the initiation phase of STS. The right hemiparetic group had an equal weight-distribution through the symmetrical foot placement.

This left-sided body weight-distribution by participants with left hemiparesis onto the affected side was accompanied by left thoracic side-flexion displacement and velocity. Upon more in-depth analysis, it was shown that these participants changed their feet positioning during P1 of STS. They started with symmetrical foot placement due to the set-up at the start of data collection but then moved the unaffected right foot behind the left to initiate STS. Changing of the feet position resulted in trunk side-flexion and an increase in body weight to the left affected side. In the study by Roy et al. (2006), the asymmetrical foot positioning of the unaffected foot being placed backwards increased the asymmetrical

force distribution throughout the entire STS. PWS would subsequently favour the unaffected limb during the next phase of the STS transition. Of all the compensatory changes of feet positions, Roy et al. (2006) reported that the backwards placement of the unaffected foot caused the greatest asymmetrical weight-distribution. The placement of the affected foot backwards reduces the asymmetrical weight distribution and a reduction in lateral trunk displacement (Duclos, Nadeau and Lecours, 2008; Lecours et al., 2008).

Normally during this initial phase, we would see the trunk (thoracic and lumbar segments) flexing forward to displace the COM to ensure seat-off during P2 and avoid any anterior instability (Dubost et al., 2005). A decrease in forward velocity of both the thoracic and lumbar segment was found in PWS in earlier literature as well as in this study (Messier et al., 2004). In the current study, potentially to avoid anterior instability by lower limb weakness, participants used a compensatory strategy of displacing the upper trunk into rotation and side-flexion while displacing the COM as far forward as the control group. These findings are supported in previous studies by Lecours et al. (2008) and Mazzà et al. (2006).

A marked decrease in lumbar velocity ( $p=0.002$ ) for PWS is noted compared to the control group during P1. The lumbar velocity was much higher than the thoracic segment in the community control group. Adequate strength and coordination is needed to generate sufficient trunk velocity to accelerate the whole body for a successful seat-off phase but also limited to avoid anterior instability at the end of motion (Dubost et al., 2005). This may suggest that the lumbar segment is used to anticipate for seat-off during P2, as proximal stability for the lower limbs originates in the lumbo-pelvic segment (Davies, 2000). The pelvis provides a BOS for trunk mobility, and limited lumbar mobility is related to a fixed pelvis (Davies, 2000). The need for lumbar mobility could be because 72% of body mass is found in the trunk and thigh segments (Virmavirta and Isolehto, 2014). Pearsall, Reid and Livingston (1996) showed that the average mass of vertebral segments increased the lower down in the spine it was placed (T1-T12 = 2.7%; L1-L5 = 6.3%). PWS may be compensating for the decreased velocity by increasing rotational displacement in the thoracic segment to maintain control. The coordination subscale scores in this study confirmed that thoracic rotation was easier to perform than lumbar rotation post-stroke (Karthikbabu et al., 2012; Davies, 2000). Only four PWS scored 1/3 on the lower trunk rotation, and one PWS scored 2/3. This means 10 of the 15 PWS who took part in this study were unable to rotate the lower trunk at all.

## 5.2. Phase 2 – Seat-Off

During this phase, the COM is still being displaced forward as well as upwards during normal STS transition. Simultaneously the momentum is transferred from a large BOS (hips on chair) to a smaller BOS (feet) (Boukadida et al., 2015). A large degree of control is needed as our COM falls outside, more forward, of our small BOS at the end of P2 (Fujimoto and Chou, 2014).

In this study, the thoracic forward velocity coincided with an increased velocity into right side-flexion and left rotation in PWS. This velocity is in response to PWS triggering seat-off with the right thigh, regardless of the hemiparetic side. This movement corresponds to an adaptive motor strategy to increase weight-bearing through the right lower limb as it is last to leave the seat. After seat-off trigger, the weight-distribution favoured the unaffected side in PWS. This weight-distribution is also confirmed in previous literature (Duclos, Nadeau and Lecours, 2008; Lecours et al., 2008). Weakness of the lower limb muscles affects the seat-off phase as PWS will favour the unaffected side for power-generation around the hips and knees to raise the body off the supporting surface (Mao et al., 2018; Mazzà et al., 2006; Roy et al., 2006). The lateral deviation of the trunk to the unaffected side as seen in this study may also be considered an intuitive strategy due to the lack of reliability and trust of the affected side (Boukadida et al., 2015).

At the lumbar segment in this study, however, fixation may serve as compensation for the lack of stability. This fixation is displayed as a smaller lumbar forward velocity in PWS to bring the COM over the BOS compared to healthy individuals. The thoracic and lumbar segments slowed down with the forward velocity during P2 compared to P1. This decrease in velocity is needed as the next phase will start extending the trunk (Boukadida et al., 2015). Here PWS had the same velocity for the thoracic segment as healthy individuals but slower than the lumbar segment. PWS had a slower lumbar forward flexion velocity than healthy people in this study and in a previous study by Fernanda et al. (2017). Reduced velocity in standing up from a seated position is proportionate to the disability post-stroke (Mao et al., 2018). This is due to the decrease in muscle strength of the affected limb and lack of trunk control needed to maintain stabilisation (Boukadida et al., 2015).

It is noteworthy that the control group also mainly triggered seat-off with the right side regardless of their predetermined dominant side. However, a motor-strategy they used in this study was lumbar side-flexion towards the right. This lumbar side-flexion could be

indicative of a momentary increase weight shift towards the right lower limb to facilitate seat-off. Fotoohabadi, Tully and Galea (2010) state that the thoracic region goes from extension into a quick flexion movement during this phase for healthy participants. This is replicated for the control group as well as PWS in the current study.

### **5.3. Phase 3 – Extension**

During this phase, the body starts to extend from the forward position and aims to maintain the COM within the small BOS (Boukadida et al., 2015). Forward momentum is now changed into a backwards and vertical momentum. Lower limb strength is vital as the hip and knee extend from a maximal flexed state (Boukadida et al., 2015). Most of the STS duration also takes place during this phase as control is vital changing from one dynamic flexed state into upright extension. This is as postural stability must first be gained by controlling the COM in relation to foot support prior to attempting to rise (Fotoohabadi, Tully and Galea, 2010). Chou et al. (2003) found that a shorter duration during P3 and symmetrical weight-distribution was associated with better gait performance. If PWS instead placed the affected foot behind the unaffected during rehabilitation, they would be forced to use the affected lower limb. The increased use of the affected lower limb leads to a more symmetrical STS as seen with healthy controls using a symmetrical foot position (Duclos, Nadeau and Lecours, 2008; Roy et al., 2006). This signifies the link between safe and controlled STS transition and other higher order mobility.

During P3 PWS showed the most substantial weight shift to the unaffected side. This could be to compensate for the weak muscle strength of the affected lower limb (Prudente, Rodrigues-de-Paula and Faria, 2013; Mazzà et al., 2006; Roy et al., 2006). In this study, compensation in the thoracic segment with rotation and side-flexion is at its highest displacement to control the COM. The thoracic displacement is also associated with compensatory rotation and side-flexion velocity. Roy et al. (2006) stated that during the extension phase, PWS rely the most on the unaffected limb. This lateral trunk deviation is correlated to the weight-distribution shift to the unaffected side (Lecours et al., 2008; Mazzà et al., 2006).

PWS had the same trunk extension displacement, but at a significantly decreased extension velocity for both the thoracic and lumbar segments in the current study. This is supported by Gharib (2017) who found that the trunk extensors' peak torque was lower in PWS even though there was an increase in spine extension. The increase in extension range was to shift the COM posteriorly as to decrease the load on the back muscles due to



weakening post stroke (Karatas et al., 2004). Quoted in Cirstea (2000), among some of the strategies employed by PWS is the use of fixation of the pelvis on the lumbar segment in an attempt to stabilise themselves. This may be a strategy to decrease the number of motor elements the nervous system has to control to accomplish a motor task (Vereijken et al., 1992; Bernstein, 1967). Fixation patterns such as this one may be a spontaneous response to the inability to maintain balance during more dynamic postural movements. Davies (1990) believes the continual practice of compensatory strategies may be a critical limiting factor for recovery post-stroke. This could explain why some PWS took longer to complete P3 than the community controls. This may also be why compensation takes place in the thoracic segment in PWS owing to the lack of lumbar stability. The control group's lumbar segment had an increased velocity with rotation to the left. This is probably to equalise the velocity from the P2 rotation to the right for seat-off and to then focus on maintaining the COM centrally within the BOS. The control group also had an increase in lumbar side-flexion and rotation range compared to PWS. This could show that healthy people use the lumbar spine to maintain the COM between the feet as far as possible. This may be as most body mass is found in the lumbar segment (Virmavirta and Isolehto, 2014).

#### **5.4. Phase 4 – Stabilisation**

Overall, postural control should be achieved during P4 of STS. The velocity of the COM coming back into the BOS determines the stability of the stance and whether a step needs to be taken to regain stability (Boukadida et al., 2015). None of the participants needed to take a step after completing STS. Interestingly PWS demonstrated the most force generation through the feet during this phase. This could signify compensation in an attempt to maintain an erect position. The holding of the erect position is determined by the contraction of the lower limb muscles for postural stability (Le Mouel and Brette 2017). Again most weight is taken onto the stronger unaffected lower limb, and the fixation is confirmed with the thoracic side-flexing towards the unaffected sides (Genthon et al., 2007). This compensation may be an attempt to keep their postural sway to a minimum, essentially balancing out the weight-bearing of the lower limb on the unaffected side and the thoracic segment towards the affected side.

#### **5.5. Trunk acceleration**

As PWS have a longer STS duration, a decrease in vertical acceleration (VT) during STS in PWS was found. Na et al. (2016) support this finding by also having a decrease in VT



acceleration in PWS. During STS the COM needs to undergo vertical acceleration (VT) as STS is performed against gravity (Zijlstra et al., 2010). In healthy people, vertical acceleration is more significant at the sternum, thoracic segment, compared to the lower sensors at the pelvis and above the greater trochanter, lumbar segment, as these are closer to the body's COM (Zijlstra et al., 2010). In the current study, it was also found that the control group had a much larger VT acceleration in the thoracic segment than the lumbar segment. For PWS, with lower VT acceleration compared to the control group, the thoracic segment VT acceleration was higher than the lumbar segment. This could be due to the fixation of the pelvis found in PWS (Davies, 2000). PWS in this study also had significantly lower lumbar displacement than the community control group for the lumbar spine during the entire transition. This also corresponded with a decreased velocity of the trunk segment in forward flexion and extension. The decrease in VT acceleration in PWS is seen during P3, where the weakness of the paretic quadriceps muscle post stroke often affects the ability to extend the hip and the knee effectively (Lomaglio and Janice, 2005).

Acceleration was measured from seat-off to the point of stabilisation. Minimum acceleration of the trunk occurred in the stable sitting position. In the average population, dynamic postural control is found in the AP plane as it involves the ankle (Fujisawa et al., 2015; Mancini et al., 2012). In PWS we would expect to see the weakest control in the trunk and hips displayed in the ML direction of movement (Cheng et al., 1998). STS is an AP plane transition or movement, where the forward placement of the COM occurs followed by the COM being maintained over the feet upon completion of the transition. It has been reported that even mild weakening of the trunk musculature affects balance and stability hence trunk control being of utmost importance during rehabilitation to decrease acceleration in the ML plane (Karthikbabu et al., 2011).

The direction of postural sway in this study was seen by the direction of acceleration. Healthy people (control group) had an increased sway in the AP direction while PWS had an increased sway in the ML direction. Krebs, McGibbon and Goldvasser (2001) found that PWS widen their BOS in the ML direction to increase postural stability. The smoothness of movement (JERK) in the transverse plane of PWS illustrates the compensation that took place to increase the available BOS. JERK reflects the corrections of the nervous system to control the postural sway (Mancini et al., 2012). Healthy people have a much smoother movement of STS than those with stroke (Krebs, McGibbon and Goldvasser, 2001). This correlates with the increase in the magnitude of sway (AUC) found in PWS in this study.

The magnitude of sway, relating how difficult it was for PWS to come into standing successfully, was higher for the lumbar segment in the transverse plane compared to community controls. This could be as PWS possibly tried to maintain a fixed pelvis during the transition of STS due to a lack of control. Janssen et al. (2008b) found the magnitude of the thoracic sway velocity correlated to the Berg Balance Scale outcome measure. PWS with poor balance have an increase in the magnitude of sway (AUC), and those with good balance have a decrease in sway velocity (Janssen et al., 2008b).

## **5.6. Correlation of Trunk kinematics with the Trunk Impairment Scale**

Kim et al. (2015) found a strong relationship between trunk performance, tested by the TIS, and functional outcomes in PWS emphasising the importance of the incorporation of targeted trunk rehabilitation post stroke.

### **5.6.1. Correlation with the total TIS score**

The TIS observes the quality of trunk movement and can be used as a guide for planning targeted trunk treatment (Verheyden et al., 2004). Kim et al. (2015) found that improvement of the TIS score by trunk intervention correlated positively with better balance and gait. The TIS measures the ability to selectively control the upper and lower trunk during static sitting, dynamic trunk side-flexion and coordinated trunk rotation (Verheyden et al., 2004). The TIS as it is at the moment does not measure flexion/extension of the upper trunk or flexion/extension of the lower trunk. It is important to take note that STS is an AP and vertical directional functional activity (Boukadida et al., 2015). However, in this study, a positive correlation in the upper and lower trunk flexion/extension was found with the TIS.

Prior to seat-off in healthy people, 85% of weight is distributed over the thighs and 15% under the feet (Hirschfeld, Thorsteinsdottir and Olsson, 1999). Anterior displacement of the COM takes place with trunk forward flexion leading to the shifting of body weight onto the feet. In this study, it was found that a decrease in the total TIS directly correlated with a decrease in this anterior displacement, needed to initiate a successful STS. A decrease in the rate of force generated is confirmed by Cheng et al. (1998) who found it linked with PWS who is a fall risk.

A decrease in the thoracic rotation in P1 translates to a decrease in TIS score. Rotation is one of the most challenging trunk movements to selectively execute in PWS (Verheyden et al., 2005). What is interesting is that during P1, PWS had a significant thoracic side-flexion

displacement compared to the controls, but this observation demonstrated no correlation with TIS scores. Whilst testing the static balance of the TIS by picking up the unaffected limb in sitting, compensation is demarcated if the trunk is displaced 10cm or more backwards. This is possibly why no correlation was found with the TIS and frontal plane displacement during P1 as it did not displace 10cm, but approximately 6° to the side compared to the control group. This 6° displacement in sitting roughly translates to 5.2cm displacement laterally as the thoracic sensor is 0.5m above the seat. Therefore the possibility of the TIS static balance subscales compensatory movement, 10cm backwards or use of hands, when lifting the unaffected lower limb may not be sensitive enough. Verheyden and Kersten (2010) and Gjelsvik et al. (2012) found that the static balance subscale demonstrated a ceiling effect in subacute and chronic PWS. Due to this limitation, TIS 2.0 was developed with the exclusion of the static sub-scale.

As STS is an AP transition, it is plausible that the trunk flexion/extension ranges would mainly correlate with the TIS. An increase in forward flexion velocity during seat-off was associated with an increase in TIS score and an increase in trunk movement. This correlates with the control needed to translate the COM over the BOS during seat-off and the need for selective trunk activity (Fujimoto and Chou, 2012).

The goal at the end of P3 and during P4 for healthy individuals is to remain in an upright position. During P3, the trunk starts extending, and maximum trunk extension velocity is reached prior to maximum hip extension (Kuo, Tully and Galea, 2010). The findings of the current study found that an increase in trunk selective activity in PWS correlated with an increased end trunk extension position at the start of P4. Thus the less the trunk is flexed forward in P4 on the extended hip to maintain balance, the more trunk control PWS have maintaining the COM within the BOS (Karthikbabu et al., 2017).

### **5.6.2. Correlation with the Dynamic subscale of the TIS**

The dynamic subscale of the TIS is more comfortable to perform for the person being tested than the coordination subscale (Verheyden et al., 2005). This is seen in clinical practice where side-flexion of the thoracic and lumbar areas is easier to perform than the rotation of these areas. Trunk control for selective side-flexion and rotation in PWS is essential for isolated movements to maintain balance (Karthikbabu et al., 2011). Unlike hemiparetic limb muscles, the trunk muscles are impaired multi-directionally leading to the non-hemiparetic side of the trunk also being affected following a stroke (Messier et al., 2004). Therefore the dynamic and coordination subscales of the TIS provide a useful

qualitative examination tool for trunk control and assists clinicians in identifying the compensatory movements in the trunk PWS may use. It has excellent psychometric properties without reported ceiling effects (Lee, An and Lee, 2018).

The dynamic subscale tests side-flexion between the thoracic and lumbar segments differently (Verheyden et al., 2004). This is done on the affected and unaffected side. Compensatory mechanisms are scored as well as lengthening/shortening of the trunk. The thoracic segment side-flexion is tested by sitting and leaning over onto the elbow and bringing the body back into upright sitting. The lumbar segment is tested by lifting the pelvis off the bed, shortening the lumbar trunk segment on the one side and lengthening on the other. The primary objective is to keep the shoulders and head level while transferring weight from the unaffected to the affected side and vice-versa.

Lateral balance is more affected in PWS than forward/backwards balance (Van Nes et al., 2009; de Haart et al., 2004). This is confirmed in the current study during the transition of STS. A direct link was found between a decreased thoracic ML acceleration during STS and an increase in the score of the dynamic subscale of the TIS. This relates to the study by Krebs, McGibbon and Goldvasser (2001) that an increase in ML sway direction is a compensatory technique to increase the BOS for postural stability.

During P2, an increase in flexion velocity was associated with an increase in side-flexion of the lumbar segment. This means that PWS in this study who were able to shift the COM over the BOS during seat-off, had more selective side-flexion of the lumbar segment and higher velocity to perform the COM shift. This is a positive momentum-transfer that needs to take place to dynamically control the COM displacement within the BOS (Fujimoto and Chou, 2012). This can be argued as the PWS can maintain the neutral, forward position of the COM due to the increase in selective activation of the trunk. During P3, the extension displacement range of the thoracic segment also shows an increase in selective lateral flexion of the trunk. In the fourth phase, PWS had the most weight transferred onto the unaffected side while standing still. To maintain a neutral posture, selective trunk activity needs to take place. The lumbar segment needs to side-flex towards the unaffected limb to maintain an upright position. An increased side-flexion to the unaffected limb of the lumbar segment was found to correlate with the dynamic subscale in this study. The less trunk flexion movement occurred at the end of the transition to maintain balance, the more selective and control of side-flexion could be accomplished.

### 5.6.3. Correlation with the Coordination subscale of the TIS

As rotation of the trunk is more difficult to attain and control after stroke than lateral flexion, it is positive to note that an increase in the rotation ability corresponds to an increased duration during P2 in-order to control the dynamic momentum transfer. The thoracic and lumbar segment flexion range correlated positively with an increase in coordination control. During P1, the higher the coordination subscale score (increased rotational control) for PWS, the higher the extension velocity of the trunk. The thoracic extension is vital to keep the gaze horizontal while accompanied by forward flexion of the lumbar spine and hip (Kuo, Tully and Galea, 2010). The gaze stability is a normal postural movement and forms part of the main goals in stroke rehabilitation. During P3 we saw the effects of an increased coordination subscale score in the increased thoracic extension values associated with the lumbar segments' range of displacement. The start of P3 showed an association between the maximum lumbar flexion position of the trunk and higher coordination scores. In P4 we saw again that an increase in rotational control was associated with an increase in thoracic extension at the end of the transition. In the fourth phase, PWS had the most weight transferred onto the unaffected side while standing still. This means that PWS in this study who were able to rotate the thoracic segment towards the affected side, due to WBA, had an increase in trunk rotation control and a reduction in abnormal standing posture.

## 5.7. Summary

During the phases of sitting to standing PWS in the current study presented with none to minimal movement of the lumbar segment of the trunk. This lack of movement may serve as a compensatory strategy for poor trunk control and is referred to in clinical terms as fixation or keeping the body area more rigid. In contrast, the thoracic segment moved into rotation and side-flexion during the STS transition. Postural sway was more prominent in the ML plane for PWS and also with increased trunk rotation. PWS in the current study also preferred taking more weight on the unaffected side. This may once again signal a compensatory strategy employed to maintain as central COM projection as possible.

Even though the TIS only assesses static sitting, side-flexion and rotational components of the trunk, it still correlated well with STS that is a flexion/extension movement. Rotation of the trunk is the most advanced level of selective trunk control (Verheyden et al., 2004). Rotation is also the most difficult to regain post stroke and why higher values correlated the best with the control demanded during P3 of STS.

The next chapter will discuss the conclusion of the study, clinical relevance and recommendations for further studies.

# Chapter 6

## *Conclusion & Recommendations*

This chapter gives an overall conclusion to the current study. This chapter also discusses the limitations of the current study, recommendations for future studies and the clinical relevance of the findings.

### **6.1. Introduction**

The initial research question inquired “What is the difference in trunk kinematics and weight-bearing symmetry between people with stroke and a community control group in the three planes of movement during the four phases of Sit-To-Stand (STS)?” To answer this question, the introduction and scoping review contained current literature pertaining to STS and its four phases as well as the trunk kinematics in the three planes of movement in PWS and healthy people. After evaluation of the methodology of these previous studies, the aims, objectives and methodology of the current study were developed. All of the aims and objectives were addressed and completed. These findings were presented in the results chapter and the implications of these results were further discussed in Chapter 5.

### **6.2. Objectives**

#### **6.2.1. Primary Objectives**

The trunk kinematics and weight-bearing symmetry in the three planes of movement within the four phases of STS were described in this study. STS places extra strain on dynamic postural stability as the COM translates from a wide BOS (chair) to a small BOS (feet) (Shumway-Cook and Woollacott, 2010). This sample presented with asymmetrical weight-bearing distribution as is expected in people with stroke. As the COM follows the weight-bearing asymmetry to the unaffected side, anticipatory postural adjustments of the trunk took place to counteract the COM deviation to maintain balance.

PWS showed more movement in the thoracic segment of the trunk by rotating and side-flexing during the entire STS transition. The control group demonstrated more movement in the lumbar segment by rotating and side-flexing during STS compared to PWS. The velocity of the thoracic and lumbar segments of the control group forward and backwards was also higher in the flexion/extension phases of the transition. The pelvis generally



provides a stable proximal base for trunk mobility and limited lumbar mobility is related to a fixed pelvis (Davies, 2000). PWS may be compensating for the decreased lumbar segment movement by increasing the movement of the thoracic segment to maintain equilibrium (Asai, 2017). The control group demonstrated smoother acceleration of the thoracic and lumbar segments in the transverse plane and were able to stand up with less sway magnitude, hence a decrease in postural sway corrections (Mancini et al., 2012). The control group appeared to have more postural stability during STS in the AP direction as the trunk moved as reported in previous studies and did not display significant WBA. PWS stabilised in the ML direction as the trunk moved more towards the unaffected side with constant thoracic rotational displacement during STS. An increase in ML acceleration of the trunk can be seen as widening of the BOS needed to maintain balance and increased stability during the transition (Krebs, McGibbon and Goldvasse, 2001). This confirms previous literature indicating that the whole trunk is affected post-stroke and that the trunk can be seen as the proximal anchor of stability.

### **6.2.2. Secondary Objectives**

Overall an increase in TIS score is associated with an improvement in dynamic postural control of the COM displacement during STS. As PWS use the ML direction to maintain postural control during STS, it is understood why an increase in the dynamic subscale, trunk side-flexion, would lead to a decrease in ML sway. With more control of the trunk selective activity, more control of the COM displacement in the AP direction was found. It is also highlighted that it is more difficult for PWS to selectively control the lower trunk compared to the upper trunk. This in turn affected the STS ability of PWS and limited the lumbar segment movement. Rotation of the trunk is the most difficult selective trunk control to regain post-stroke and why higher values in the coordination subscale correlated best with the difficult P3 of STS.

### **6.3. Clinical significance of the findings**

The TIS is a clinical outcome measure to assess the movement and control of the trunk in PWS and assists in formulating a treatment plan (Verheyden et al., 2004). As clinicians we rehabilitate STS within the phases as set out in Davies (2000) for selective retraining of the trunk. As the TIS correlates to the various phases of STS, clinicians can adapt rehabilitation to focus on the lacking components with more conviction and specific or targeted treatment of the affected trunk segment and its control. Davies (2000) advocates for a series of facilitation techniques that correlates to the relearning of the normal



movement pattern of STS. Also, knowing the healthy compensatory mechanisms of the upper and lower trunk deepens our clinical knowledge on what is the normal pattern. It is recommended that the TIS be used to evaluate PWS and due to having no-ceiling effect, it can also mark improvement over time with rehabilitation.

#### **6.4. Limitations of this study**

The sample size was small and recruited from only two settings within the Tygerberg Hospital catchment area. The majority of the participants were ambulatory and all had to be able to independently transition between sitting and standing. This was a limitation as a correlation or relationship could not be established between those ambulatory and those who are not ambulating but wheelchair bound. The majority of the stroke group scored slight dependence on the mBI. This is a limitation in clinical functional ability of the various participants. It is possible to clinically deduct that those who are dependent and those who need assistance will have different STS strategies. These factors could also possibly implicate different postural strategies used to complete STS. The testing was also done in people who suffered a stroke within six months from stroke onset only. The results of this study are therefore not generalisable to the broader population of people with stroke and those with different/varying levels of function. All the participants completed STS at a self-selected speed and with spontaneous feet positioning. It could be possible that the slower the STS transition, the more postural control may be needed to ensure a successful transition. Only the group data has been reported on, with an indication of individual variation provided by the standard deviations. It may be that with the expected heterogeneity in a stroke population further individual analysis would yield more clinically meaningful information.

#### **6.5. Recommendations for future research**

The current study showed differences between the left and right affected hemiparetic groups, but a larger sample size is needed for further comparative analysis. As STS can be performed without being ambulatory, it is recommended for future researchers to study the difference between the postural adaptations of ambulatory and non-ambulatory STS. It is recommended that studies be performed on a larger sample to allow for additional subgroup analysis such as determining the impact of the; site and severity of lesion, different age groups, time since incident, comorbidities, varying functional levels, gender and BMI of PWS. The influence of different chair heights, speed of STS and foot positioning on the kinematics of the upper and lower trunk within the four phases of STS

and three planes of motion, should also be explored. It would be interesting to see how the various foot placements may correlate with the TIS. Further the static balance subscale of the TIS should maybe be reviewed with regards to the permissible and scored trunk displacement, 10cm, before it may be seen as compensation due to the results of the current study.

## **6.6. Summary**

The aim of this study was to describe the trunk kinematics within the three planes of movement and within the four phases of STS in PWS as well as how it correlates to the TIS. In summary, it was found that PWS move their thoracic segment, upper trunk, much more during STS with fixation of the lower trunk. This may serve as a compensatory strategy for diminished postural control in PWS. Compensation was seen in thoracic rotation and side-flexion to maintain as close a central position and movement of COM as possible. In this study it would appear that in contrast the community group used their lumbar segment, lower trunk, to maintain postural control during STS as it is closest to the COM. This strategy by people without stroke one may argue is more biomechanically and energy efficient.

The TIS, specifically the dynamic and coordination subscales which highlight the distinct impairments of the upper and lower trunk, also correlated well with the altered trunk kinematics during STS found in this study. Anecdotally, therapists tend to facilitate STS retraining differentiating between the control of these two trunk segments which is now mirrored in the current study's results. The TIS is a valid outcome tool to use in clinical practice and can be used to mark progress through the rehabilitation process.

## References

- Adame, M.R., Al-Jawad, A., Romanovas, M., Hobert, M., Maetzler, W., Moeller, K. and Manoli, Y. (2012). TUG Test Instrumentation for Parkinson's disease patients using Inertial Sensors and Dynamic Time Warping. *Biomedical Engineering*, 57(1), pp. 1071-1074.
- Aissaoui, R., Ganea, R. and Aminian, K. (2011). Conjugate momentum estimate using non-linear dynamic model of the sit-to-stand correlates well with accelerometric surface data. *Journal of Biomechanics*, 44(6), pp. 1073-1077.
- Anon, *Plug-In-Gait*, (Vicon Motion System Limited, Oxford, UK)
- Asai, H. (2017). Pelvic Movement in Aging Individuals and Stroke Patients. *IntechOpen*, [online]. Available at: <https://www.intechopen.com/books/clinical-physical-therapy/pelvic-movement-in-aging-individuals-and-stroke-patients>.
- Bagala, F., Klenk, J., Cappello, A., Chiari, L., Becker, C. and Lindemann, U. (2013). Quantitative description of the lie-to-sit-to-stand-to-walk transfer by a single body-fixed sensor. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 21(4), pp. 624-633.
- Bauer, C., Rast, F., Ernst, M., Kool, J., Oetiker, S., Rissanen, S., Suni, J. and Kankaanpää, M. (2015). Concurrent validity and reliability of a novel wireless inertial measurement system to assess trunk movement. *Journal of Electromyography and Kinesiology*, 25(5), pp. 782-790.
- Behnke, R. (2012). Kinetic anatomy. 3rd ed. Champaign, Ill.: Human Kinetics.
- Berstein, N. (1967). The coordination and regulation of movements. *Oxford: Pergamon Press*, 1967.
- Bertram, M.Y., Katzenellenbogen, J., Vos, T., Bradshaw, D. and Hofman, K.J. (2013). The disability adjusted life years due to stroke in South Africa in 2008. *International Journal of Stroke*, 8(A100), pp. 76-80.
- Bohannon, R.W., Cassidy, D. and Walsh, S. (1995). Trunk muscle strength is impaired multidirectionally after stroke. *Clinical Rehabilitation*, 9(1), pp. 47-51.
- Bolink, S., Naisas, H., Senden, R., Essers, H., Heyligers, I., Meijer, K. and Grimm, B. (2015). Validity of an inertial measurement unit to assess pelvic orientation angles

during gait, sit–stand transfers and step-up transfers: Comparison with an optoelectronic motion capture system\*. *Medical Engineering & Physics*, 13(5), pp. 1-7.

- Boukadida, A., Piotte, F., Dehail, P. and Nadeau, S. (2015). Determinants of sit-to-stand tasks in individuals with hemiparesis post stroke: A review. *Annals of Physical and Rehabilitation Medicine*, 58(3), pp. 167-172.
- Brenton-Rule, A., Mattock, J., Carroll, M., Dalbeth, N., Bassett, S., Menz, H. and Rome, K. (2012). Reliability of the TekScan MatScan® system for the measurement of postural stability in older people with rheumatoid arthritis. *Journal of Foot and Ankle Research*, 5(21), pp. 1-7.
- Bryer, A., Connor, MD., Haug, P., Cheyip, B., Staub, H., Tipping, B., Duim, W. and Oinkney-Atkinson, V. (2010). South African guideline for management of ischaemic Stroke and transient ischaemic attack 2010: a guideline from the South African Stroke Society (SASS) and the SASS Writing Committee. *SAMJ: South African Medical Journal*, 100(11), pp. 750-778.
- Cheng, P., Liaw, M., Wong, M., Tang, F., Lee, M. and Lin, P. (1998). The sit-to-stand movement in stroke patients and its correlation with falling. *Archives of Physical Medicine and Rehabilitation*, 79, pp. 1043-1046.
- Chern, J., Lo, C., Wu, C., Chen, C., Yang, S. and Tang, F. (2010). Dynamic postural control during trunk bending and reaching in healthy adults and stroke patients. *American Journal of Physical Medicine & Rehabilitation*, 89(3), pp186-197.
- Chong, A. and Al-Baghdadi, J. (2014). Matching 3D Plantar Model with the Force and Pressure Data of the Loading Phase of Gait. Proceedings - 2014 7th International Congress on Image and Signal Processing, *CISP 2014*, pp. 704-708.
- Chou, S., Wong, A., Leong, C., Hong, W., Tang, F. and Lin, T. (2003) Postural control during sit-to-stand and gait in stroke patients. *American Journal of Physical Medicine and Rehabilitation*, 82(1), pp. 42–47.
- Chung, E., Kim, J. and Lee, B. (2013). The effects of core stabilization exercise on dynamic balance and gait function in stroke patients. *Journal of Physical Therapy Science*, 25(7), pp. 803-806.
- Cirstea, M.C. and Levin, M.F. (2000). Compensatory strategies for reaching in stroke. *Brain*, 123, pp. 940-953.

- Coulthard, J., Treen, T., Oates, A. and Lanovaz, J. (2015). Evaluation of an inertial sensor system for analysis of timed-up-and-go under dual-task demands. *Gait and Posture*, 41(4), pp. 882-887.
- Crétual, A. (2015). Which biomechanical models are currently used in standing posture analysis? *Clinical Neurophysiology*, 45(4-5), pp. 285-295.
- Cromwell, R., Aadland-Monahan, T., Nelson, A., Stern-Sylvestre, S. and Seder, B. (2001). Sagittal plane analysis of head, neck, and trunk kinematics and electromyographic activity during locomotion. *Journal of Orthopaedic & Sports Physical Therapy*, 31(5), pp. 255-262.
- Cuesta-Vargas, A., Galán-Mercant, A. and Williams, J. (2010). The use of inertial sensors system for human motion analysis. *Physical Therapy Reviews*, 15(6), pp. 462-473.
- Davies, P. (1990). *Right in the middle: Selective trunk activity in the treatment of adult Hemiplegia*. Germany: Springer-Verlag Berlin and Heidelberg GmbH & Co. K.
- Davies, P. (2000). *Steps to follow: The comprehensive treatment of patients with hemiplegia*. Berlin: Springer.
- De Haart, M., Geurts, A., Huidekoper, S., Fasotti, L. and van Limbeek, J. (2004). Recovery of standing balance in post-acute stroke patients: a rehabilitation cohort study. *Archives of Physical Medicine and Rehabilitation*, 85(6), pp. 886-895.
- De Oliveira, C., de Modeiros, R., Frota, N., Greters, M. and Conforto, A. (2008). Balance control in hemiparetic patients: Main tools for evaluation. *Journal of Rehabilitation Research and Development*, 45(8), pp.1215-1226.
- De Villiers, L., Badri, M., Ferreira, M. and Bryer, A. (2011). Stroke outcomes in a socio-economically disadvantaged urban community. *South African Medical Journal*, 101(5), pp. 345-348.
- Di Monaco, M., Trucco, M., Di Monaco, R., Tappero, R. and Cavanna, A. (2010). The relationship between initial trunk control or postural balance and inpatient rehabilitation outcome after stroke: a prospective comparative study. *Clinical Rehabilitation*, 24(6), pp. 543-554.
- Dubost, V., Beauchet, O., Manckoundia, P., Herrmann, F. and Mourey, F. (2005). Decreased trunk angular displacement during sitting down: an early feature of aging. *Physical Therapy*, 85(5), pp. 404-412.

- Duclos, C., Nadeau, S. and Lecours, J. (2008). Lateral trunk displacement and stability during sit-to-stand transfer in relation to foot placement in patients with hemiparesis. *Neurorehabilitation and Neural Repair*, 22(6), pp. 715-722.
- Fernanda, P., Silva, D., Quintino, L. and Franco, J. (2017). Trunk kinematics related to generation and transfer of the trunk flexor momentum are associated with sit-to-stand performance in chronic stroke survivors. *NeuroRehabilitation – IOS Press*, 40, pp. 57-67.
- Fotoohabadi, M., Tully, E. and Galea, M. (2010). Kinematics of rising from a chair: Image-based analysis of the sagittal hip-spine movement pattern in elderly people who are healthy. *American Physical Therapy*, 90(4), pp. 561-571.
- Fujimoto, M. and Chou, L. (2012). Dynamic balance control during sit-to-stand movement: An examination with the center of mass acceleration. *Journal of Biomechanics*, 45(3), pp. 543-548.
- Fujimoto, M. and Chou, L. (2014). Region of stability derived by center of mass acceleration better identifies individuals with difficulty in sit-to-stand movement. *Annals of Biomedical Engineering*, 42(2), pp. 733-741.
- Fujisawa, H., Suzuki, H., Murakami, K., Kawakami, S. and Suzuki, M. (2015). The relationship between energy cost and the center of gravity trajectory during sit-to-stand motion. *Journal of Physical Therapy Science*, 27(12), pp. 3883-3886.
- Galli, M., Cimolin, V., Crivellini, M. and Campanini, I. (2008). Quantitative analysis of sit to stand movement: Experimental set-up definition and application to healthy and hemiplegic adults. *Gait and Posture*, 28(1), pp. 80-85.
- Ganea, R., Paraschiv-Ionescu, A., Büla, C., Rochat, S. and Aminian, K. (2011). Multi-parametric evaluation of sit-to-stand and stand-to-sit transitions in elderly people. *Medical Engineering and Physics*, 33(9), pp. 1086-1093.
- Geurts, A., De Haart, M., Van Nes, I. and Duysens, J. (2005). A review of standing balance recovery from stroke. *Gait and Posture*, 22(3), pp. 267-281.
- Gentton, N., Vuillerme, N., Monnet, J., Petit, C. and Rougier, P. (2007). Biomechanical assessment of sitting posture maintenance in patients with stroke. *Clinical Biomechanics*, 22(9), pp.1024-1029.

- Gharib, N., Rehab, N. and Rezk-Allah, S. (2017). Sagittal lumbar motion during sit-to-stand task and its relation to balance in chronic stroke patients. *Bulletin of Faculty of Physical Therapy*, 22(1), pp. 59-65.
- Giansanti, D., Maccioni, G., Benvenuti, F. and Macellari, V. (2007). Inertial measurement units furnish accurate trunk trajectory reconstruction of the sit-to-stand manoeuvre in healthy subjects. *Medical and Biological Engineering and Computing*, 45(10), pp. 969-976.
- Gjelsvik, B., Breivik, K., Verheyden, G., Smedal, T., Hofstad, H. and Strand, L. (2012). The Trunk Impairment Scale – modified to ordinal scales in the Norwegian version. *Disability and Rehabilitation*, 34(16), pp. 1385-1395.
- Godfrey, A., Bourke, A., Ólaighin, G., van de Ven, P. and Nelson, J. (2011). Activity classification using a single chest mounted tri-axial accelerometer. *Medical Engineering and Physics*, 33(9), pp. 1127-1135
- Hintze, J. (2013). Power Analysis Statistical Software (PASS). [online] PASS 12. Available at: [www.ncss.com](http://www.ncss.com) [Accessed 30 May 2017]
- Hirschfeld, H., Thorsteinsdottir, M. and Olsson, E. (1999). Coordinated ground forces exerted by buttocks and feet are adequately programmed for weight transfer during sit-to-stand. *Journal of Neurophysiology*, 82(6), pp. 3021-3029.
- Janssen, W., Bussmann, H., Horemans, H. and Stam, H. (2008a). Validity of accelerometry in assessing the duration of the sit-to-stand movement. *Medical and Biological Engineering and Computing*, 46(9), pp. 879-887.
- Janssen, W., Külcü, D., Horemans, H., Stam, H. and Bussmann, J. (2008b). Sensitivity of accelerometry to assess balance control during sit-to-stand movement. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 16(5), pp. 479-484.
- Jeon, S., Lee, S. and Kim, J. (2015). Therapeutic effects of reaching with forward bending of trunk on postural stability, dynamic balance, and gait in individuals with chronic hemiparetic stroke. *Journal of Physical Therapy Science*, 27(8), pp. 2447-2451.
- Jijimol, G., Fayaz, R. and Vijesh, P. (2013). Correlation of trunk impairment with balance in patients with chronic stroke. *NeuroRehabilitation*, 32(2), pp. 323-325.
- Jung, K., Kim, Y., Chung, Y. and Hwang, S. (2014). Weight-Shift training improves trunk control, proprioception and balance in patients with chronic hemiparetic stroke. *The Tohoku Journal of Experimental Medicine*, 232(3), pp.195-199.



- Karatas, M., Cetin, N., Baymramoglu, M. and Dilek, A. (2004). Trunk muscle strength in relation to balance and functional disability in unihemispheric stroke patients. *American Journal of Physical Medicine & Rehabilitation*, 83(2), pp.81–87.
- Karthikbabu, S., Chakrapani, M., Ganeshan, S., Rakshith, K., Nafeez, S. and Prem, V. (2012). A review on assessment and treatment of the trunk in stroke. *Neural Regeneration Research*, 7(25), pp.1974-1977.
- Karthikbabu, S., Rao, B., Manikandan, N., Solomon, J. and Chakrapani, M. (2011). Role of trunk rehabilitation on trunk control, balance and gait in patients with chronic stroke: A pre-post design. *Neuroscience and Medicine*, 2(2), pp.61–67.
- Karthikbabu, S., Chakrapani, M., Ganeshan, S. and Ellajosyla, R. (2017). Pelvic alignment in standing, and its relationship with trunk control and motor recovery of lower limb after stroke. *Neurology and Clinical Neuroscience*, 5(1), pp. 22-28.
- Kim, T., Seo, K., Kim, D. and Kang, S. (2015). The relationship between initial trunk performances and functional prognosis in patients with stroke. *Annals of Rehabilitation Medicine*, 39(1), pp. 66-73.
- Kong, W., Sessa, S., Zecca, M. and Takanishi, A. (2016). Anatomical calibration through post-processing of standard motion tests data. *Sensors*, 16(12), pp. 1-21.
- Krebs, D., McGibbon, C. and Goldvasser, D. (2001). Analysis of postural perturbation responses. *IEEE Engineering in Medicine and Biology Society*, 9(1), pp. 76-80.
- Kuo, Y., Tully, E. and Galea, M. (2010). Kinematics of sagittal spine and lower limb movement in healthy older adults during sit-to-stand from two seat heights. *Spine*, 35(1), pp. 1-7.
- Kuluski, K., Dow, C., Locock, L., Lyons, R. and Lasserson, D. (2014). Life interrupted and life regained? Coping with stroke at a young age. *International Journal of Qualitative Studies on Health and Well-Being*, 9(1), pp. 1-12.
- Kwakkel, G. and Kollen, B. (2013). Predicting activities after stroke: What is clinically relevant? *International Journal of Stroke*, 8(1), pp. 25-32.
- Kwong, P., Ng, S. and Chung, R. (2014). Foot placement and arm position affect the five times sit-to-stand test time of individuals with chronic stroke. *BioMed Research International*, 2014(1), pp. 1-5.
- Lecours, J., Nadeau, S., Gravel, D. and Teixeira-Salmela, L. (2008). Interactions between foot placement, trunk frontal position, weight-bearing and knee moment asymmetry



- at seat-off during rising from a chair in healthy controls and persons with hemiparesis. *Journal of Rehabilitation Medicine*, 40(3), pp. 200-207.
- Lee, T., Choi, J. and Lee, N. (2015). Activation timing patterns of the abdominal and leg muscles during sit-to-stand movement in individuals with chronic hemiparetic stroke. *Journal of Physical Therapy Science*, 27(11), pp. 3593-3595.
- Lee, Y., An, S. and Lee, G. (2018). Clinical utility of the modified trunk impairment scale for stroke survivors. *Disability and Rehabilitation*, 40(10), pp. 1200-1205.
- Le Mouel, C. and Brette, R. (2017). Mobility as the purpose of postural control. *Frontiers in Computational Neuroscience*, 11(July), pp. 1-11.
- Lewallen, S. and Courtright, P. (1998). Epidemiology in practice: Case-control studies. *Community Eye Health Journal*, 11(28), pp. 57-58.
- Liao, C., Liaw, L., Wang, R., Su, F. and Hsu, A. (2015). Relationship between trunk stability during voluntary limb and trunk movements and clinical measurements of patients with chronic stroke. *Journal of Physical Therapy Science*, 27(7), pp. 2201-2206.
- Likhi, M., Jidesh, VV., Kanagaraj, R. and George, JK. (2013). Does trunk, arm, or leg control correlate best with overall function in stroke subjects? *Top Stroke Rehabilitation*, 20(1), pp. 62-67.
- Lomaglio, M. and Janice, J. (2005). Muscle strength and weight-bearing symmetry relate to sit-to-stand performance in Individuals with stroke. *Gait and Posture*, 22(2), pp. 126-131.
- Mao, Y., Wu, X., Li Zhao, J., Lo, W., Chen, L., Ding, M., Xu, Z., Bian, R., Huang, D. and Li, L. (2018). The crucial changes of sit-to-stand phases in subacute stroke survivors identified by movement decomposition analysis. *Frontiers in Neurology*, 9(March), pp. 1-8.
- Mancini, M., Carlson-Kuhta, P., Zampieri, C., Nutt, J., Chiari, L. and Horak, F. (2012). Postural sway as a marker of progression in Parkinson's disease: A pilot longitudinal study. *Gait and Posture*, 36(3), pp. 471-476.
- Maredza, M., Bertram, M. and Tollman, S. (2015). Disease burden of stroke in rural South Africa: an estimate of incidence, mortality and disability adjusted life years. *BMC Neurology*, 15(54), pp. 1-7.

- Masi, A., Nair, K., Evans, T. and Ghandour, Y. (2010). Clinical, biomechanical, and physiological translational interpretations of human resting myofascial tone or tension. *International Journal of Therapeutic Massage & Bodywork*, 3(4), pp. 16-28.
- Mayosi, B., Flisher, A.J., Lalloo, U.G., Sitas, F., Tollman, S.M. And Bradshaw, D. (2009). The burden of non-communicable diseases in South Africa. *Lancet*, 374(9693), pp.934–47.
- Mazzà, C., Stanhope, A., Taviani, A. and Cappozzo, A. (2006). Biomechanic modeling of sit-to-stand to upright posture for mobility assessment of persons with chronic stroke. *Archives of Physical Medicine and Rehabilitation*, 87(5), pp. 635-641.
- Messier, S., Bourbonnais, D., Desrosiers, J. and Roy, Y. (2004). Dynamic analysis of trunk flexion after stroke. *Archives of Physical Medicine and Rehabilitation*, 85(10), pp. 1619-1624.
- Millor, N., Lecumberri, P., Gómez, M., Martínez-Ramírez, A. and Izquierdo, M. (2014). Drift-free position estimation for periodic movements using inertial units. *IEEE Journal of Biomedical and Health Informatics*, 18(4), pp. 1131-1137.
- Mukherjee, D. and Patil, C. (2011). Epidemiology and the global burden of stroke. *World Neurosurgery*, 76(6), pp. 85-90.
- Na, E., Hwang, H. and Woo, Y. (2016). Study of acceleration of center of mass during sit-to-stand and stand-to-sit in patients with stroke. *The Journal of Physical Therapy Science*, 28, pp. 2457-2460.
- Najafi, B., Aminian, K., Paraschiv-Ionescu, A., Loew, F., Büla, C. and Robert, P. (2003). Ambulatory system for human motion analysis using a kinematic sensor: Monitoring of daily physical activity in the elderly. *IEEE Transactions on Biomedical Engineering*, 50(6), pp. 711-723.
- Noraxon., 2015. MyoMOTION System User Manual. [online] Scottsdale: Noraxon U.S.A Inc., pp. 2. Available at: [http://www.noraxon.com/wp-content/uploads/2015/05/P-6808-Rev-C-MyoMotion\\_Hardware\\_New-format.pdf](http://www.noraxon.com/wp-content/uploads/2015/05/P-6808-Rev-C-MyoMotion_Hardware_New-format.pdf) [Accessed 28 February. 2016].
- Oberländer, K. (2015). Inverse Kinematics: Joint considerations and the maths for deriving anatomical angles. Inertial Measurement Unit (IMU) Technology.
- Pearsall, D., Reid, J. and Livingston, L. (1996). Segmental inertial parameters of the human trunk as determined from computed tomography. *Annals of Biomedical Engineering*, 24, pp. 198-210.

- Pendleton, H. and Schultz-Krohn, W. (2013). *Pedretti's Occupational Therapy*. St. Louis, Missouri: Elsevier/Mosby.
- Pillay-van Wyk, V., Msemburi, W., Laubscher, R., Dorrington, RE., Groenewald, P., Glass, T., Nojilana, B., Joubert, JD., Matzopoulos, R., Prinsloo, M., Nannan, N., Gwebushe, N., Vos, T., Somdyala, N., Sithole, N., Neethling, I., Nicol, E., Rossouw, A. and Bradshaw, D. (2016). Mortality trends and differentials in South Africa from 1997 to 2012: second National Burden of Disease Study. *Lancet Global Health*, 2016(4), pp. 42-53.
- Prudente, C., Rodrigues-de-Paula, F. and Faria, C. (2013). Lower limb muscle activation during the sit-to-stand task in subjects who have had a stroke. *American Journal of Physical Medicine & Rehabilitation*, 92(8), pp. 666-675.
- Rabuffetti, M., Bovi, G., Quadri, P., Cattaneo, D., Benvenuti, F. and Ferrarin, M. (2011). An Experimental Paradigm to Assess Postural Stabilization: No More Movement and Not Yet Posture. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 19(4), pp. 420-426.
- Razak, A., Zayegh, A., Begg, R. and Wahab, Y. (2012). Foot Plantar Pressure Measurement System: A Review. *Sensors*, 12(7), pp. 9884-9912.
- Rosário, J. (2014). Biomechanical assessment of human posture: a literature review. *Journal of Bodywork & Movement Therapies*, 18(3), pp. 368-373.
- Roy, G., Nadeau, S., Gravel, D., Malouin, F., McFadyen, B. and Pottie, F. (2006). The effect of foot position and chair height on the asymmetry of vertical forces during sit-to-stand and stand-to-sit tasks in individuals with hemiparesis. *Clinical Biomechanics*, 21(6), pp. 585-593.
- Ryerson, S., Byl, N., Brown, D., Wong, R. and Hidler, J. (2008). Altered trunk position sense and its relation to balance functions in people post-stroke. *Journal of Neurologic Physical Therapy*, 32(1), pp.14–20.
- Salter, K., Campbell, N., Richardson, M. and Mehta, S. (2013). Outcome measures in stroke rehabilitation. *The Evidence-Based Review of Stroke Rehabilitation*, 21, pp. 1-144.
- Shah, S., Vanclay, F. and Cooper, B. (1989). Improving the sensitivity of the Barthel Index for stroke rehabilitation. *Journal of Clinical Epidemiology*, 42(8), pp. 703-709.

- Schenkman, M., Berger, RA., Riley, PO., Mann, RW. and Hodge, WA. (1990). Whole-body movements during rising to standing from sitting. *Physical Therapy*, 70(10), pp. 638-651
- Shumway-Cook, A. and Woollacott, M. (2010). *Motor Control- Translating Research into Practice*. 3rd ed. Philadelphia: Lippincott, Williams & Wilkins.
- Simcox, S., Parker, S., Davis, G., Smith, R. and Middleton, J. (2005). Performance of orientation sensors for use with a functional electrical stimulation mobility system. *Journal of Biomechanics*, 38(5), pp. 1185-1190.
- Sirois-Leclerc, G., Remaud, A. and Bilodeau, M. (2017). Dynamic postural control and associated attentional demands in contemporary dancers versus non-dancers. *PLoS ONE*, 12(3), pp. 4-7.
- Soangra, R. and Lockhart, T. (2012). A comparative study for performance evaluation of sit-to-stand task with body worn sensor and existing laboratory methods. *Biomedical Sciences Instrumentation*, 48, pp. 407-414.
- Stevermer, C. and Gillette, J.C. (2016). Kinematic and kinetic indicators of sit-to-stand. *Journal of Applied Biomechanics*, 32(1), pp. 7-15
- Tanaka, S., Hachisuka, K. and Ogata, H. (1998). Muscle strength of trunk flexion-extension in post-stroke hemiplegic patients. *American Journal of Physical Medicine and Rehabilitation*, 77(4), pp. 288-290.
- Taraldsen, K., Askim, T., Sletvold, O., Einarsen, E., Bjåstad, G., Indredavik, B. and Helbostad., J. (2011). Evaluation of a body-worn sensor system to measure physical activity in older people with impaired function. *Physical Therapy*, 91(2), pp. 277-285.
- Tasseel-Ponche, S., Yelnik, A. and Bonan, I. (2015). Motor strategies of postural control after hemispheric stroke. *Clinical Neurophysiology*, 45, pp. 327-333.
- Thorogood, M., Connor, M., Lewando-Hundt, G., Tollman, S. and Ngoma, B. (2004). Secondary prevention of stroke - results from the Southern Africa Stroke Prevention Initiative (SASPI) study. *Bulletin of the World Health Organization*, 82(7), pp. 503-508.
- Van Lummel, R., Ainsworth, E., Hausdorff, J., Lindemann, U., Beek, P. and van Dieën, J. (2012). Validation of seat-off and seat-on in repeated sit-to-stand movements using a single-body-fixed sensor. *Physiological Measurement*, 33(2012), pp. 1855-1867.

- Van Lummel, R., Ainsworth, E., Lindemann, U., Zijlstra, W., Chiari, L., Van Campen, P. and Hausdorff, J. (2013). Automated approach for quantifying the repeated sit-to-stand using one body fixed sensor in young and older adults. *Gait and Posture*, 38(1), pp. 153-156.
- Van Lummel, R., Walgaard, S., Maier, A., Ainsworth, E., Beek, P. and van Dieën, J. (2016). The instrumented sit-to-stand (iSTS) has greater clinical relevance than the manually recorded sit-to-stand test in older adults. *PLoS ONE*, 11(7), pp. 1-17.
- Van Lummel, R., Evers, J., Niessen, M., Beek, P. and van Dieën, J. (2018). Older adults with weaker muscle strength stand up from a sitting position with more dynamic trunk use. *Sensors*, 18(4), pp. 1-12.
- Van Nes, I., van Kessel, M., Schils, F., Fasotti, L., Geurts, A. and Kwakkel, G. (2009). Is visuospatial hemineglect longitudinally associated with postural imbalance in the postacute phase of stroke? *Neurorehabilitation and Neural Repair*, 23(8), pp. 819-824.
- Vereijken, B., van Emmerik, R., Whiting, H. and Newell, K. (1992). Freezing degrees of freedom in skill acquisition. *Journal of Motor Behaviour*, 24, pp. 133-142.
- Verheyden, G. and Kersten, P. (2010). Investigating the internal validity of the Trunk Impairment Scale (TIS) using Rasch analysis: the TIS 2.0. *Disability and Rehabilitation*, 32(25), pp. 2127-2137.
- Verheyden, G., Nieuwboer, L., De Wit, L., Feys, H., Schuback, B., Baert, I., Jenni, W., Schupp, W., Thijs, V. and De Weerd, W. (2007). Trunk performance after stroke: an eye catching predictor of functional outcome. *Journal of Neurology, Neurosurgery, and Psychiatry*, 78(7), pp. 694-698.
- Verheyden, G., Nieuwboer, A., Mertin, J., Preger, R., Kiekens, C. and De Weerd, W. (2004). The Trunk Impairment Scale: a new tool to measure motor impairment of the trunk after stroke. *Clinical Rehabilitation*, 18(3), pp. 326-334.
- Verheyden, G., Nieuwboer, A., Feys, H., Thijs, V., Vaes, K. and De Weerd, W. (2005). Discriminant ability of the trunk impairment scale: A comparison between stroke patients and healthy individuals. *Disability and Rehabilitation*, 27(17), pp.1023-1028.
- Verheyden, G., Vereeck, L., Truijen, S., Troch, M., Herregodts, I., Lafosse, C. and De Weerd, W. (2006). Trunk performance after stroke and the relationship with balance, gait and functional ability. *Clinical Rehabilitation*, 20(5), pp. 451-458.

- Verheyden, G., van Duijnhoven, H., Burnett, M., Littlewood, J., Kunkel, D. and Ashburn, A. (2011). Kinematic analysis of head, trunk and pelvis movement when people early after stroke reach sideways. *Neurorehabilitation and Neural Repair*, 25(7), pp. 656-663.
- Vette, A., Masani, K., Wu, N. and Popovic, M. (2014). Multidirectional quantification of trunk stiffness and damping during unloaded neutral sitting. *Medical Engineering & Physics*, 36(1), pp.102-109.
- Virmavirta, M. and Isolehto, J. (2014). Determining the location of the body's center of mass for different groups of physically active people. *Journal of Biomechanics*, 47(8), pp. 1909-1913.
- Walgaard, S., Faber, G., van Lummel, R., van Dieën, J. and Kingma, I. (2016). The validity of assessing temporal events, sub-phases and trunk kinematics of the sit-to-walk movement in older adults using a single inertial sensor. *Journal of Biomechanics*, 49(9), pp. 1933-1937.
- Yamamoto, T., Smith, C., Suzuki, Y., Kiyono, K., Tanahashi, T., Sakoda, S., Morasso, P. and Nomura, T. (2015). Universal and individual characteristics of postural sway during quiet standing in healthy young adults. *Physiological Reports*, 3(3), pp. 1-24.
- Young, J. and Tolentino, M. (2009). Stroke evaluation and treatment. *Top Stroke Rehabilitation*, 16(6), pp. 389-410.
- Zakaria, Y., Rashad, U. and Mohammed, R. (2010). Assessment of malalignment of trunk and pelvis in stroke patients. *Egyptian Journal of Neurology, Psychiatry and Neurosurgery*, 47, pp. 599-604.
- Zammit, G., Menz, H. and Munteanu, S. (2010). Reliability of the TekScan MatScan® system for the measurement of plantar forces and pressures during barefoot level walking in healthy adults. *Journal of Foot and Ankle Research*, 3, pp. 11-19.
- Zijlstra, W., Bisseling, R., Schlumbohm, S. and Baldus, H. (2010). A body-fixed-sensor-based analysis of power during sit-to-stand movements. *Gait and Posture*, 31(2), pp. 272-278.

## *List of Addendums*

Addendum A: Ethics Approval Letters	104
Addendum B: Western Cape Department of Health Research Approval Letters	109
Addendum C: Participant Information Leaflet and Consent Form (English/Afrikaans/IsiXhosa)	115
Addendum D: Case Participant Information Form	132
Addendum E: Control Participant Information Form	134
Addendum F: Trunk Impairment Scale – Physiotherapy Outcome Measure	136
Addendum G: Modified Barthel Index – Physiotherapy Outcome Measures	138
Addendum H: Temporal Parameters of Case and Control Participants	142
Addendum I: Kinetic Parameter – Weight-Bearing Symmetry of Case and Control Participants during STS	143
Addendum J: Kinetic Parameter – Comparison of total force distribution of case and control participants during STS	144
Addendum K: Kinematic Parameter - Angular Displacement of Case and Control Participants during STS	145
Addendum L: Kinematic Parameter - Angular Velocity of Case and Control Participants during STS	149
Addendum M: Kinematic Parameter – Acceleration of Case and Control Participants during STS	153
Addendum N: Temporal Parameter: Comparison with Physiotherapy Outcome Measure	155
Addendum O: Kinetic Parameter – Weight-Bearing Symmetry: Comparison with Physiotherapy Outcome Measure	156
Addendum P: Kinetic Parameter – Total Force Distribution: Comparison with Physiotherapy Outcome Measure	157
Addendum Q: Kinematic Parameter – Angular Displacement and Comparison with Physiotherapy Outcome Measure	158
	102

Addendum R: Kinematic Parameter – Angular Velocity and Comparison with Physiotherapy Outcome Measure	170
Addendum S: Kinematic Parameter – Acceleration and Comparison with Physiotherapy Outcome Measure	182



## Addendum A: Ethics Approval Letters



UNIVERSITEIT-STELLENBOSCH-UNIVERSITY  
jou kennisvenoot • your knowledge partner

### Approval Notice Response to Modifications- (New Application)

29-Aug-2016  
Steyn, Hesti H

Ethics Reference #: S16/05/095

Title: THE KINEMATIC ANALYSIS OF THE TRUNK AND WEIGHT-BEARING SYMMETRY IN THE THREE PLANES OF MOVEMENT DURING THE FOUR PHASES OF SIT-TO-STAND IN ADULTS WITH STROKE AND A COMMUNITY CONTROL GROUP – CASE-CONTROL STUDY

Dear Miss Hesti Steyn,

The Response to Modifications - (*New Application*) received on 11-Aug-2016, was reviewed by members of Health Research Ethics Committee 2 via Expedited review procedures on 19-Aug-2016 and was approved.

Please note the following information about your approved research protocol:

Protocol Approval Period: 19-Aug-2016 -18-Aug-2017

Please remember to use your protocol number (S16/05/095) on any documents or correspondence with the HREC concerning your research protocol.

Please note that the HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

#### After Ethical Review:

Please note a template of the progress report is obtainable on [www.sun.ac.za/vids](http://www.sun.ac.za/vids) and should be submitted to the Committee before the year has expired. The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.

Translation of the consent document to the language applicable to the study participants should be submitted.

Federal Wide Assurance Number: 00001372

Institutional Review Board (IRB) Number: IRB0005239

The Health Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

#### **Provincial and City of Cape Town Approval**

Please note that for research at a primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western

Cape Department of Health ([healthres@pgwc.gov.za](mailto:healthres@pgwc.gov.za) Tel: +27 21 483 9907) and Dr Helene Visser at City Health ([Helene.Visser@capetown.gov.za](mailto:Helene.Visser@capetown.gov.za) Tel: +27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.  
For standard HREC forms and documents please visit: [www.sun.ac.za/ids](http://www.sun.ac.za/ids)

If you have any questions or need further assistance, please contact the HREC office at .

**Included Documents:**

Application Form.pdf  
20160816 MOD Application Form  
20160816 MOD Protocol Synopsis  
20160816 MOD Appendix C - Control Participant Info  
20160816 MOD Appendix B - Case Participant Info  
Protocol.pdf  
Investigator Declaration G Inglis-Jassiem.pdf  
CV A Titus.pdf  
20160816 MOD Cover Letter  
CV H Steyn.pdf  
20160816 MOD Protocol  
Investigator Declaration A Titus.pdf  
20160816 MOD Appendix A (Informed Consent English)  
HREC PaymentInstruction\_Health research.pdf  
Investigator Declaration H Steyn.pdf  
General Checklist.pdf  
Protocol Synopsis.pdf  
20160816 MOD Payment Instruction form  
CV G Inglis-Jassiem.pdf

Sincerely,

Francis Masiye  
HREC Coordinator  
Health Research Ethics Committee 2



UNIVERSITEIT STELLENBOSCH UNIVERSITY  
an international research partner

## Ethics Letter

15-Aug-2017

**Ethics Reference #: S16/05/095**

**Title: The kinematic analysis of the trunk and weight-bearing symmetry in the three planes of movement during the four phases of sit-to-stand in adults with stroke and a community control group – case control study**

Dear Ms Hesti Steyn,

Your request for extension/annual renewal of ethics approval dated 11 August 2017 refers.

The Health Research Ethics Committee reviewed and approved the annual progress report you submitted through an expedited review process.

The approval of the research project is extended for a further year.

**Approval Date: 15 August 2017**

**Expiry Date: 14 August 2018**

Kindly be reminded to submit progress reports two (2) months before expiry date.

**Where to submit any documentation**

Kindly submit **ONE HARD COPY** to Elvira Rohland, RDSD, Room 5007, Teaching Building, and **ONE ELECTRONIC COPY** to [ethics@sun.ac.za](mailto:ethics@sun.ac.za).

Please remember to use your **protocol number (S16/05/095)** on any documents or correspondence with the HREC concerning your research protocol.

Federal Wide Assurance Number: 00001372

Institutional Review Board (IRB) Number: IRB0006240 for HREC1

Institutional Review Board (IRB) Number: IRB0006239 for HREC2



Fakulteit Geneeskunde en Gesondheidswetenskappe  
Faculty of Medicine and Health Sciences



Afdeling Navorsingtoewijding en -Sous • Research Development and Support Division

Postbus/PO Box 241 • Cape Town 8000 • Suid-Afrika/South Africa  
Tel: +27 (0) 21 938 9677



UNIVERSITEIT STELLENBOSCH-UNIVERSITY  
see tomorrow's world - your knowledge partner

The Health Research Ethics Committee complies with the SA National Health Act No. 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki and the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles, Structures and Processes 2015 (Department of Health).

Yours sincerely,



Francis Masiye,  
HREC Coordinator,  
Health Research Ethics Committee



Fakulteit Geneeskunde en Gesondheidswetenskappe  
Faculty of Medicine and Health Sciences



Afdeling Neurologiese Reëkollegie en -Scans • Research Development and Support Division

Postbus/PO Box 241 • Cape Town 8008 • Suid-Afrika/South Africa  
Tel: +27 (0) 21 538 5677



31/07/2018

**Project ID:** 3642

**Ethics Reference #:** S16/05/095

**Title:** THE KINEMATIC ANALYSIS OF THE TRUNK AND WEIGHT-BEARING SYMMETRY IN THE THREE PLANES OF MOVEMENT DURING THE FOUR PHASES OF SIT-TO-STAND IN ADULTS WITH STROKE AND A COMMUNITY CONTROL GROUP – CASE-CONTROL STUDY

Dear Miss Hestl Steyn ,

Your request for extension/annual renewal of ethics approval dated 31/07/2018 09:46 refers.

The Health Research Ethics Committee reviewed and approved the annual progress report you submitted through an expedited review process. The approval of this project is extended for a further year.

**Approval date:** 31 July 2018

**Expiry date:** 30 July 2019

Kindly be reminded to submit progress reports two (2) months before expiry date.

**Where to submit any documentation**

Kindly note that the HREC uses an electronic ethics review management system, *Infonetica*, to manage ethics applications and ethics review process. To submit any documentation to HREC, please click on the following link: <https://www.ethics.sun.ac.za>.

Please remember to use your Project ID [3642] and Ethics Reference Number on any documents or correspondence with the HREC concerning your research protocol.

National Health Research Ethics Council (NHREC) Registration Numbers: REC-130408-012 for HREC1 and REC-230208-010 for HREC2

Federal Wide Assurance Number: 00001372

Institutional Review Board (IRB) Number: IRB0005240 for HREC1

Institutional Review Board (IRB) Number: IRB0005239 for HREC2

The Health Research Ethics Committee complies with the SA National Health Act No. 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki and the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles, Structures and Processes 2015 (Department of Health).

Yours sincerely,

Francis Mashe,

## Addendum B: Western Cape Department of Health Research Approval Letters



**STRATEGY & HEALTH SUPPORT**  
HealthResearch@westerncape.gov.za  
Tel: +27 21 483 6857; Fax: +27 21 483 9896  
9<sup>th</sup> Floor, Norton Rose House, 8 Ribbeck Street, Cape Town, 8001  
[www.westerncape.gov.za](http://www.westerncape.gov.za)

REFERENCE: WC\_2016RP35\_432  
ENQUIRIES: Ms Charlene Roderick

**Stellenbosch University**

**Matieland**

**Private Bag X1**

**Stellenbosch**

**7602**

For attention: Ms Hestl Steyn, Mrs Gakeemah Inglis-Jassiem, Mr Adnii Titus

Re: **The kinematic analysis of the trunk and weight-bearing symmetry in the three planes of movement during the four phases of sit-to-stand in adults with stroke and a community control group – Case-Control Study.**

Thank you for submitting your proposal to undertake the above-mentioned study. We are pleased to inform you that the department has granted you approval for your research.

Please contact following people to assist you with any further enquiries in accessing the following sites:

**Bishop Lavis CDC**

**Rachel Carelse**

**021 934 6129**

**Karl Bremer Hospital**

**Dr Linda Naude**

**021 918 1222**

Kindly ensure that the following are adhered to:

1. Arrangements can be made with managers, providing that normal activities at requested facilities are not interrupted.
2. Researchers, in accessing provincial health facilities, are expressing consent to provide the department with an electronic copy of the final feedback (**annexure 9**) within six months of

completion of research. This can be submitted to the provincial Research Co-ordinator ([Health.Research@westerncape.gov.za](mailto:Health.Research@westerncape.gov.za)).

3. In the event where the research project goes beyond the estimated completion date which was submitted, researchers are expected to complete and submit a progress report (**Annexure 8**) to the provincial Research Co-ordinator ([Health.Research@westerncape.gov.za](mailto:Health.Research@westerncape.gov.za)).
4. The reference number above should be quoted in all future correspondence.

Yours sincerely



MS A VAN DEN BERG

ACTING DIRECTOR: HEALTH IMPACT ASSESSMENT

DATE: 23/12/2016

CC:

J ARENDESE

DIRECTOR: NORTHERN/ TYGERBERG



Western Cape  
Government

Health

**STRATEGY & HEALTH SUPPORT**

[Health.Research@westerncape.gov.za](mailto:Health.Research@westerncape.gov.za)

tel: +27 21 463 6857; fax: +27 21 463 9895

5<sup>th</sup> Floor, Norton Rose House, 8 Kloof Street, Cape Town, 8001  
[www.westerncape.gov.za](http://www.westerncape.gov.za)

REFERENCE: WC\_2016RP35\_432  
ENQUIRIES: Ms Charlene Roderick

**Stellenbosch University**

**Matieland**

**Private Bag X1**

**Stellenbosch**

**7602**

For attention: Ms Hesti Steyn, Mrs Gokeemah Ingils-Jassiem, Mr Adhil Titus

Re: The kinematic analysis of the trunk and weight-bearing symmetry in the three planes of movement during the four phases of sit-to-stand in adults with stroke and a community control group – Case-Control Study.

Thank you for submitting your proposal to undertake the above-mentioned study. We are pleased to inform you that the department has granted you approval for your research.

Please contact following people to assist you with any further enquiries in accessing the following sites:

**Delft CHC**

**Sheron T Forgas**

**021 954 2237**

Kindly ensure that the following are adhered to:

1. Arrangements can be made with managers, providing that normal activities at requested facilities are not interrupted.
2. Researchers, in accessing provincial health facilities, are expressing consent to provide the department with an electronic copy of the final feedback (**annexure 5**) within six months of completion of research. This can be submitted to the provincial Research Co-ordinator ([Health.Research@westerncape.gov.za](mailto:Health.Research@westerncape.gov.za)).



3. In the event where the research project goes beyond the estimated completion date which was submitted, researchers are expected to complete and submit a progress report (Annexure B) to the provincial Research Co-ordinator ([Health.Research@westerncape.gov.za](mailto:Health.Research@westerncape.gov.za)).
4. The reference number above should be quoted in all future correspondence.

Yours sincerely



Dr Hawkrige

DR A HAWKRIGE

DIRECTOR: HEALTH IMPACT ASSESSMENT

DATE: 10/2/2017,

CC:

J ARENDSE

DIRECTOR: NORTHERN/ TYGERBERG



**Western Cape  
Government**

Health

**STRATEGY & HEALTH SUPPORT**

[Health.Research@westerncape.gov.za](mailto:Health.Research@westerncape.gov.za)

tel: +27 21 483 6857; fax: +27 21 483 9895

3<sup>rd</sup> Floor, Norton Rose House, 8 Beibek Street, Cape Town, 8001

[www.westerncape.gov.za](http://www.westerncape.gov.za)

REFERENCE: WC\_2016RP35\_432

ENQUIRIES: Ms Charlene Roderick

**Stellenbosch University**

**Mafieland**

**Private Bag X1**

**Stellenbosch**

**7602**

For attention: Ms Hestl Steyn, Mrs Gakeemah Ingib-Jassem, Mr Adnill Titus

**Re: The kinematic analysis of the trunk and weight-bearing symmetry in the three planes of movement during the four phases of sit-to-stand in adults with stroke and a community control group – Case-Control Study.**

Thank you for submitting your proposal to undertake the above-mentioned study. We are pleased to inform you that the department has granted you approval for your research.

Please contact following people to assist you with any further enquiries in accessing the following sites:

**Elsies River CHC**

**Rona M Kasker**

**021 931 0211**

Kindly ensure that the following are adhered to:

1. Arrangements can be made with managers, providing that normal activities of requested facilities are not interrupted.
2. Researchers, in accessing provincial health facilities, are expressing consent to provide the department with an electronic copy of the final feedback (**annexure 9**) within six months of completion of research. This can be submitted to the provincial Research Co-ordinator ([Health.Research@westerncape.gov.za](mailto:Health.Research@westerncape.gov.za)).

3. In the event where the research project goes beyond the estimated completion date which was submitted, researchers are expected to complete and submit a progress report (Annexure 8) to the provincial Research Co-ordinator ([Health.Research@westerncape.gov.za](mailto:Health.Research@westerncape.gov.za)).
4. The reference number above should be quoted in all future correspondence.

Yours sincerely

 AT HAWKRIDGE.

DR A HAWKRIDGE

DIRECTOR: HEALTH IMPACT ASSESSMENT

DATE: 21 / 2 / 2017.

CC: J ARENDSE

DIRECTOR: NORTHERN/ TYGERBERG

Addendum C: Participant Information Leaflet and Consent Form  
(English/Afrikaans/IsiXhosa)

## **PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM**

### **TITLE OF THE RESEARCH PROJECT:**

The Kinematic analysis of the trunk and weight-bearing symmetry in the three planes of movement during the four phases of sit-to-stand in adults with stroke and a community control group – Case-Control Study

**REFERENCE NUMBER: S16/05/095**

**PRINCIPAL INVESTIGATOR:** Hesti Steyn

**ADDRESS:** Physiotherapy Division

Department of Interdisciplinary Health Sciences

Faculty of Medicine and Health Sciences (Tygerberg Campus)

Francie Van Zijl Drive

Parow

**CONTACT NUMBER:** 0827395472

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee of Stellenbosch University** (reference number to be inserted here) and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

## **What is this research study all about?**

- This study is about understanding how people with stroke move, specifically how their trunk muscles (abdominal and back muscles) work during the movement from sitting to a standing position. We would like to understand how it differs from people without stroke. It is not always easy standing after a stroke, but understanding what muscles work and how your body moves will help improve future treatment for people who are struggling to stand up.
- For people with stroke, an assessment of the movements of your trunk will be done first. This assessment is done in sitting only and measures how strong and moveable your trunk (abdominal and back muscles) is.
- After this assessment you will be asked to stand up from sitting five times. The people without a stroke will only do the five times sit-to-stand evaluation.
- A few electronic devices will be attached to your body. This device will measure how your body moves; if you lean forward the device will be able to give us that information and also how far you leaned forward.
- The devices will be put onto your stomach area, lower back and legs.
- You will be asked a couple of questions regarding your medical history. People with stroke will also be asked what you could do before the stroke and what you are unable to do now.

## **Why have you been invited to participate?**

You have been invited to participate in this study because you have either had a stroke within the past three months or you are a community member who has never suffered a stroke. This study is specifically for people older than 18 who can stand up from a sitting position by themselves.

## **What will your responsibilities be?**

Person with stroke:

- To arrive an hour and a half before your treatment appointment at the out-patient department.
- We do not expect you to attend this early should you have an appointment for 8h00. Further arrangements will be made with the physiotherapist at the community health centre/ hospital to accommodate you.

- To wear a vest/T-shirt and a shorts underneath your clothing for the ease of application of the electronic devices onto the body. The vest/T-shirt will cover the electronic devices during testing and the stomach area will only be exposed during the application of devices.
- To most importantly be yourself and remember there is no wrong movement. You just stand up as you normally do at home.

Person without a stroke:

- If accompanying a family member for treatment, to instead of waiting for their treatment to end, be willing to participate in this study.
- To wear a vest/T-shirt and a short underneath your clothing for the ease of application of the electronic devices onto the body. The vest/T-shirt will cover the electronic devices during testing and the stomach area will only be exposed during the application of devices.
- To most importantly be yourself and remember there is no wrong movement. You just stand up as you normally do at home.

### **Will you benefit from taking part in this research?**

- People with stroke, if willing, the outcome measures assessed will be given to your physiotherapist – it will be helpful in deciding what exercises you further need to strengthen your trunk (abdominal and back muscles).
- This study will also help physiotherapists to understand how the trunk works during sitting-to-standing and what exercises will be best to help achieve the goal of sitting-to-standing independently.
- People without stroke will benefit by knowing they helped in the understanding of how sit-to-stand differs in people with stroke.

### **Are there in risks involved in your taking part in this research?**

- There are no foreseeable risks to this study.
- In the event that you feel tired and unable to perform this task five times, you will be allowed rest periods in-between.

### **Who will have access to your medical records?**

Only the principle investigator and the two supervisors will have access to your medical records. During the study you will be given a number and so no data will be published with

your name next to it. Only the three people mentioned above will have access to the file with your name and corresponding number.

### **What will happen in the unlikely event of injury occurring as a direct result of your taking part in this research study?**

You will be taken to the nearest doctor for an assessment. However, if you fit the criteria for the study, being able to stand up from sitting by yourself, the chance of being injured by falling is very small. You, the participant, are also covered by Stellenbosch University “no fault” insurance policy. This means should any unforeseeable injury or emotional trauma occur as a result of the study, all medical costs will be compensated in full.

### **Will you be paid to take part in this study and are there any costs involved?**

No you will not be paid to take part in the study and we also do not want you to have any extra expenses. That is why we plan to do the study on the same day you have a treatment appointment. Shopping vouchers (R40) will be given after participation in study as well as refreshments during assessment.

### **Is there anything else that you should know or do?**

- You can contact the **Health Research Ethics Committee** at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your study doctor.
- You will receive a copy of this information and consent form for your own records.
- We appreciate the time and effort for coming early and spending an additional hour and a half at the clinic.

## Declaration by participant

By signing below, I ..... agree to take part in a research study entitled The Kinematic analysis of the trunk and weight-bearing symmetry in the three planes of movement during the four phases of sit-to-stand in adults with stroke and a community control group – case-control study

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ..... on (*date*) .....

.....

.....

**Signature of participant**

**Signature of witness**

## Declaration by investigator

I, **Hesti Steyn**

declare that:

- I explained the information in this document to .....
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter.

Signed at (*place*) ..... on (*date*) .....

.....

.....

**Signature of investigator**

**Signature of witness**



## DEELNEMERINLIGTINGSBLAD EN -TOESTEMMINGSVORM

### TITEL VAN DIE NAVORSINGSPROJEK:

Die kinematiese analise van die romp en gewigdraende simmetrie in die drie vlakke van beweging gedurende die vier fases van sit-tot-staan in volwassenes met 'n beroerte asook 'n kontrole groep – Gevalle-Kontrole Studie

### VERWYSINGSNOMMER: S16/05/095

**HOOFNAVORSER:** Hesti Steyn

**ADRES:** Fisioterapie Afdeling

Departement van Interdissiplinêre Gesondheidswetenskappe

Fakulteit van Geneeskunde en Gesondheids Wetenskappe (Tygerberg  
Kampus)

Francie Van Zijlrylaan

Parow

**KONTAKNOMMER:** 0827395472

U word genooi om deel te neem aan 'n navorsingsprojek. Lees asseblief hierdie inligtingsblad op u tyd deur aangesien die detail van die navorsingsprojek daarin verduidelik word. Indien daar enige deel van die navorsingsprojek is wat u nie ten volle verstaan nie, is u welkom om die navorsingspersoneel daarvoor uit te vra. Dit is baie belangrik dat u ten volle moet verstaan wat die navorsingsprojek behels en hoe u daarby betrokke kan wees. U deelname is ook **volkome vrywillig** en dit staan u vry om deelname te weier. U sal op geen wyse hoegenaamd negatief beïnvloed word indien u sou weier om deel te neem nie. U mag ook te enige tyd aan die navorsingsprojek onttrek, selfs al het u ingestem om deel te neem.

Hierdie navorsingsprojek is deur die **Gesondheidsnavorsingsetiekkomitee (GNEK) van die Universiteit Stellenbosch** (verwysings nommer sal hier bygevoeg word) goedgekeur en sal uitgevoer word volgens die etiese riglyne en beginsels van die Internasionale Verklaring van Helsinki en die Etiese Riglyne vir Navorsing van die Mediese Navorsingsraad (MNR).

## **Wat behels hierdie navorsingsprojek?**

- Hierdie studie is om te verstaan hoe persone wat 'n beroerte gehad het beweeg en spesifiek hoe hul romp (buik- en rugspiere) funksioneer gedurende die sit-tot- staan beweging. Ons wil begryp hoe hierdie beweging verskil van persone wat nog nooit 'n beroerte gehad het nie. Dit is nie altyd maklik om weer te staan na 'n beroerte nie, maar begrip van hoe hierdie spiere funksioneer en hoe die bolyf beweeg sal die toekomstige behandeling van persone met beroerte wat probleme ervaar met staan, verbeter.
- Eerstens sal 'n evaluering van die beweging van die romp van persone met beroerte gedoen word. Hierdie evaluering word slegs in die sittende posisie gedoen en meet hoe sterk en beweeglik jou romp (buik- en rugspiere) is.
- Na die aanvanklike evaluering, sal jy gevra word om vyf keer op te staan vanaf 'n sittende posisie. Persone wat nog nooit 'n beroerte gehad het nie sal slegs geëvalueer word deur die sit-tot-staan beweging vyf keer uit te voer.
- 'n Paar elektroniese toestelle sal aan jou liggaam geheg word. Hierdie toestel sal meet hoe jou liggaam beweeg. Wanneer jy vorentoe beweeg sal die toestel die inligting aan ons verskaf asook hoe ver jy vorentoe beweeg het.
- Hierdie toestelle sal op jou buik, laer rug en bene geplaas word.
- Daar sal aan jou vrae gevra word met betrekking tot jou mediese geskiedenis. Persone met beroerte sal ook gevra word oor watter bewegings hulle voor die beroerte kon doen en wat hul nou nie meer kan doen nie.

## **Waarom is u genooi om deel te neem?**

U word genooi om deel te neem aan hierdie studie omdat u die afgelope drie maande 'n beroerte gehad het of omdat u 'n lid van die gemeenskap is wat nog nooit 'n beroerte gehad het nie. Hierdie studie is spesifiek vir persone ouer as 18 wat op hul eie vanaf 'n sittende posisie kan staan.

## **Wat sal u verantwoordelikhede wees?**

Persoon met beroerte:

- Arriveer 'n uur en 'n half voor jou behandeling afspraak by die buitepasiënt afdeling.
- Indien u 'n 8h00 afspraak het, word daar nie van u verwag om alreeds so vroeg daar te wees nie. Reëlins sal getref word met die fisioterapeut by die gemeenskapsgesondheids sentrum/hospitaal om u tegemoet te kom.

- Dra 'n frokkie/T-hemp en kortbroek onder u klere om die hegting van die elektroniese toestelle aan jou liggaam te vergemaklik. Die frokkie/T-hemp sal die elektroniese toestelle gedurende die toetse bedek en u maag area sal net sigbaar wees tydens die hegting van die toestelle.
- Die belangrikste is om net uself te wees en te onthou dat daar geen verkeerde beweging bestaan nie. U staan net op soos wat u normaalweg by die huis sou doen.

Persoon sonder beroerte:

- Om deel te neem aan die studie terwyl u wag vir die persoon wat u vergesel het se behandelingssessie om te eindig.
- Dra 'n frokkie/T-hemp en kortbroek onder u klere om die hegting van die elektroniese toestelle aan jou liggaam te vergemaklik. Die frokkie/T-hemp sal die elektroniese toestelle gedurende die toetse bedek en u maag area sal net sigbaar wees tydens die hegting van die toestelle.
- Die belangrikste is om net uself te wees en te onthou dat daar geen verkeerde beweging bestaan nie. U staan net op soos wat u normaalweg by die huis sou doen.

### **Sal u voordeel trek deur deel te neem aan hierdie navorsingsprojek?**

- Indien persone met beroerte deel naam aan die projek, sal die uitkomstegemeet aan hul fisioterapeut gegee word. Hierdie evaluasie sal help met die keuse en beplanning van toekomstige oefeninge wat die romp (buik- en rugspiere) sal versterk.
- Hierdie studie sal fisioterapeute help om te verstaan hoe die romp funksioneer tydens die sit-tot-staan beweging en watter oefeninge die beste sal wees om hierdie doelwit onafhanklik te bereik.
- Persone sonder beroerte sal voordeel trek uit die wete dat hulle gehelp het met die begrip van hoe sit-tot-staan verskil in persone met beroerte.

### **Is daar enige risiko's verbonde aan u deelname aan hierdie navorsingsprojek?**

- Daar is geen voorsienbare risiko's verbonde aan hierdie studie nie.
- Indien u moeg word en nie die taak vyf keer kan uitvoer nie, sal u toegelaat word om tussen-in te rus.

### **Wie sal toegang hê tot u mediese rekords?**

Slegs die hoofnavorsers en die twee studieleiers sal toegang hê tot u mediese rekords. Gedurende die studie sal daar 'n nommer aan u toegeken word en geen data sal gepubliseer word met u naam daarnaas nie. Slegs bogenoemde drie persone sal toegang hê tot die lêer met u naam en toegekende nommer.

### **Wat sal gebeur in die onwaarskynlike geval van 'n besering wat mag voorkom as gevolg van u deelname aan hierdie navorsingsprojek?**

U sal na die naaste dokter geneem word vir 'n ondersoek. Indien u egter voldoen aan die kriteria vir die studie, om onafhanklik en op u eie te kan staan vanaf sit, is die waarskynlikheid dat u kan val baie klein. U, die deelnemer, word ook gedek deur die Universiteit van Stellenbosch se "no fault" versekeringspolis. Dit beteken dat indien enige onvoorsienbare besering as gevolg van die studie mag voorkom, alle mediese uitgawes ten volle gedek sal wees.

### **Sal u betaal word vir deelname aan die navorsingsprojek en is daar enige koste verbonde aan deelname?**

Nee, u sal nie betaal word vir deelname aan die studie nie en daar word ook nie van u verwag om enige ekstra uitgawes aan te gaan nie. Dit is waarom ons beplan om die studie te doen op dieselfde dag wat u behandeling plaasvind. Koopbewyse (R40) sal na deelname aan die studie gegee word asook verversings tydens die evaluasie.

### **Is daar enigiets anders wat u moet weet of doen?**

- U kan die **Gesondheidsnavorsingsetiek Administrasie** kontak by 021-938 9207 indien u enige bekommernis of klagte het wat nie bevredigend deur u studiedokter hanteer is nie.
- U sal 'n afskrif van hierdie inligtings- en toestemmingsvorm ontvang vir u eie rekords.
- Ons waardeer u tyd en moeite om vroeg te kom en 'n ekstra uur en 'n half by die kliniek deur te bring.

## Verklaring deur deelnemer

Met die ondertekening van hierdie dokument onderneem ek, ....., om deel te neem aan 'n navorsingsprojek getiteld Die kinematiese analise van die romp en gewigdraende simmetrie in die drie vlakke van beweging gedurende die vier fases van sit-tot-staan in volwassenes met 'n beroerte asook 'n kontrole groep – Gevalle-Kontrole Studie

### Ek verklaar dat:

- Ek hierdie inligtings- en toestemmingsvorm gelees het of aan my laat voorlees het en dat dit in 'n taal geskryf is waarin ek vaardig en gemaklik mee is.
- Ek geleentheid gehad het om vrae te stel en dat al my vrae bevredigend beantwoord is.
- Ek verstaan dat deelname aan hierdie navorsingsprojek **vrywillig** is en dat daar geen druk op my geplaas is om deel te neem nie.
- Ek te eniger tyd aan die navorsingsprojek mag onttrek en dat ek nie op enige wyse daardeur benadeel sal word nie.
- Ek gevra mag word om van die navorsingsprojek te onttrek voordat dit afgehandel is indien die studiedokter of navorser van oordeel is dat dit in my beste belang is, of indien ek nie die ooreengekome navorsingsplan volg nie.

Geteken te (*plek*) ..... op (*datum*) .....

.....

Handtekening van deelnemer

.....

Handtekening van getuie

## Verklaring deur navorser

Ek Hesti Steyn verklaar dat:

- Ek die inligting in hierdie dokument verduidelik het aan .....
- Ek hom/haar aangemoedig het om vrae te vra en voldoende tyd gebruik het om dit te beantwoord.
- Ek tevrede is dat hy/sy al die aspekte van die navorsingsprojek soos hierbo bespreek, voldoende verstaan.
- Ek 'n tolk gebruik het/nie 'n tolk gebruik het nie. (*Indien 'n tolk gebruik is, moet die tolk die onderstaande verklaring teken.*)

Geteken te (plek) ..... op (datum) .....

.....

.....

Handtekening van navorser

Handtekening van getuie

## **INCWADANA ENGOLWAZI NGOMTHATHI-NXAXHEBA KUNYE NEFOMU YEMVUMELWANO**

### **ISIHLOKO SEPROJEKTHI YOPHANDO:**

Ukuhlahlelwa kweendlela zokushukuma kwesiqu somntu nokulingana kwamacala ngokomzimba kumacala amathathu kwizigaba ezine zokuhlala ukuya ekumeni kubantu abadala abahlaselwe sisifo sokufa icala nophando lokulawula iimeko zoluntu neemeko zamaqela

### **INOMBOLO YONXULUMANO: S16/05/095**

### **UMPHANDI OYINTLOKO: Hesti Steyn**

**IDILESI:** Icandelo lokuNyangwa komzimba ngokuthambisa

Isebe leNzululwazi yezeMpilo kwiinkqubo ezisebenzisanayo

Icandelo leNzululwazi ngaMayeza nezeMpilo (kwiKhampasi eseTygerbery)

EFrancis Van Zijl Drive

Parow

### **INOMBOLO YOQHAGAMSHELWANO: 0827395472**

Uyamenywa ukuba athathe inxaxheba kwiprojekthi yophando. You are being invited to take part in a research project. Nceda thatha ixesha lokufunda ulwazi oluvezwe apha, oluzakuthi luchaze iinkcukacha zale projekthi. Nceda buza nayiphina imibuzo emalunga nayiphina indawo ongayiqondiyo ngokupheleleyo kubasebenzi besi sifundo okanye kugqirha. Kubaluleke kakhulu ukuba waniliseke ngokupheleleyo yinto yokuba ucacelwe kakuhle ukuba yintoni ebangwa sesi sifundo kwaye ungabandakanyeka njani. Kwakhona, ukuthatha kwakho inxaxheba **kungentando yakho ngokupheleleyo** kwaye ukhululekile ukuba ungarhoxa ekuthatheni inxaxheba. Ukuba uthi hayi, oku akusayi kuchaphazela ukungavumi kwakho nangayiphina indlela. Ukwakhululekile ukuba uyeke kwesi sifundo naninina, nkqu nokokuba uyavuma ukuthatha inxaxheba ekuqaleni.

Olu phando luvunywe ziinqobo ezisesikweni **zeKomiti yoPhando Lomntu kwiYunivesithi yaseStellenbosch** kwaye luzakwenziwa ngokwemigaqo esesikweni lophando elamkelekileyo kwiSaziso sehlabathi sika-Helsinki, iMigaqo eLungileyo yoMzantsi Afrika yokuSebenza eKliniki kunye neBhunga lezoPhando ngamaYeza (MRC) iMigaqo yeNqobo yezoPhando.

## **Simalunga nantoni esi sifundo sophando?**

- Olu phando lumalunga nokwazi ukuba abantu abahlaselwe sisifo sokufa icala bahamba njani, imisipha yomzimba wabo (imisipha yesisu neyomqolo) isebenza njani xa behlala naxa besima. Akusoloko kulula ukuma xa uhlaselwe sisifo sokufa icala, kodwa ukuyazi imisipha esebenzayo nokuba ushukuma njani umzimba wakho kuza kunceda ukuphucula unyango lwexesha elizayo kubantu abasokolayo ukuma.
- Kubantu abahlaselwe sisifo sokufa icala, ukuhlolwa kokushukuma komzimba wakho kuza kujongwa kuqala. Olu hlolo lwenziwa xa uhleli kuphela kwaye kuthelekisa kuphela ukomelela nokwazi ukushukuma kwesiqu sakho (imisipha yesisu neyomqolo).
- Emva kolu hlolo uza kucelwa ukuba ume emva kokuhlala phantsi izihlandlo ezintlanu. Abantu abahlaselwe sisifo sokufa icala, baza kukwenza oko kuphela izihlandlo ezintlanu kuhlolwa ukuma nokuhlala kwabo.
- Izixhobo ezimbalwa zombane ziza kufakwa emzimbeni wakho. Esi sixhobo siza kuthelekisa indlela oshukuma ngayo umzimba wakho; xa usiya phambili isixhobo siza kusinika ezo nkukacha kwaye uye kangakanani na phambili.
- Izixhobo ziza kubekwa esiswini sakho, emva emazantsi nasemilenzeni.
- Uza kubuzwa imibuzo embalwa malunga nengxelo yakho yonyango. Abantu abahlaselwe sisifo sokufa icala, baza kubuzwa oko bebekwazi ukukwenza phambi kokuba babahlaselwe sisifo sokufa icala, iyintoni ongakwazi ukuyenza ngoku.

## **Kutheni umenyiwe ukuba uthathe inxaxheba?**

Uye wamenywa ukuba uthathe inxaxheba kolu phando kuba ubuhlaselwe sisifo sokufa icala kwiinyanga ezintathu ezigqithileyo okanye ungumhlali ongazange ahlaselwe sisifo sokufa icala. Olu phando lolwabantu angaphezu kwe-18 ubudala abakwaziyo ukuziphakamela xa bebehleli phantsi.

## **Luyakuba yintoni uxanduva lwakho?**

Umntu ohlaselwe sisifo sokufa icala:

- Fika iyure enesiqingatha phambi kokuba aye kwidinga lakhe lonyango kwicandelo lezigulane ezingalaliswanga.
- Asilindelanga ukuba uvuke kakhulu xa idinga lakho lingentsimbi yesi-8 kusasa. Amanye amalungiselelo aza kwenziwa nengcali enyanga ngokulolonga umzimba kwiziko lempilo elisekuhlaleni/esibhedlele ukukhawulelana nawe.



- Nxiba ivesti/isikipa nebhulukhwe emfutshane phantsi kwempahla yakho ukuze kubelula ukusebenzisa isixhobo emzimbeni wakho. Ivesti/isikipa iza kugquma isixhobo xa uhlolwa nesisu siza kuvela xa kufakwa esi sixhobo.
- Okona kubalulekileyo, yiba nguwe ukhumbule ukuba akukho ntshukumo ichanekileyo nengachanekanga. Phakama ngolu hlobo uqhele ukuphakama ngalo ekhaya.

Umntu ohlaselwe sisifo sokufa icala

- Ukuba ukhapha ilungu losapho eliya kunyango, ndawnei yokulinda unyango luphele, nawe ungathatha inxaxheba kolu phando.
- Nxiba ivesti/isikipa nebhulukhwe emfutshane phantsi kwempahla yakho ukuze kubelula ukusebenzisa isixhobo emzimbeni wakho. Ivesti/isikipa iza kugquma isixhobo xa uhlolwa nesisu siza kuvela xa kufakwa esi sixhobo.
- Okona kubalulekileyo, yiba nguwe ukhumbule ukuba akukho ntshukumo ichanekileyo nengachanekanga. Phakama ngolu hlobo uqhele ukuphakama ngalo ekhaya.

### **Ingaba uza kuzuza ekuthatheni inxaxheba kolu phando?**

- Abantu abahlaselwe sisifo sokufa icala, ukuba banomdla, imiqathango yeziphumo iza kunikwa ingcali enyanga ngokulolongwa komzimba – kuza kuba luncedo ukugqiba ukuba kokuphi ukuzilolonga okudingekayo ukomeleza umzimba wakho (imisipha yesisu neyomqolo).
- Olu phando luza kunceda iingcali ezinyanga ngokulolongwa komzimba ukuze ziqonde indlela osebenza ngayo umzimba womntu xa umntu ehlala ephakama nokuba angazilolonga njani ukumnceda afikelele kqinjongo yokuzimela azihlalele.
- Abantu abangahlaselwanga sisifo sokufa icala baza kuxhamla ngokwazi ukuba ukuba bancedile ekwazini indlela ekwahluke ngayo ukuhlala uphakame kwabantu abahlaselwe sisifo sokufa icala.

### **Ingaba zikho iingozi ezibandakanyekayo ekuthatheni kwakho inxaxheba kolu phando?**

- Awukho umngcipheko ocingelwayo kolu phando.
- Xa uziva udiniwe ungakwazi ukuwenza lo msebenzi izihlandlo ezintlanu, uza kunikwa ithuba lokumane uphumla.

## **Ngubani uza kufumana ingxelo yakho yamayeza?**

Ngumphandi omkhulu kuphela nabaphathi ababini abazokwazi ukufumana iingxelo zakho zonyango. Ngexesha kusenziwa uphando uza kunikwa inombolo ngoko akukho zinkcukacha eziza kupapashwa zinegama lakho ecaleni wkazo. Ngabantu abathathu kuphela abachazwe ngentla abazokwazi ukufumana ifayile enegama lakho nenombolo ehambelana nalo.

## **Kuza kwenzeka ntoni kwimeko yesiganeko esingalindekanga sokwenzakala ngenxa yokuthatha kwakho inxaxheba kwesi sifundo sophando?**

Uza kusiwa kugqirha okufutshane akuhlole. Noxa kunjalo, ukuba ungomnye wabantu abakhethwayo ukuba bangene kolu phando, ukwazi ukuphakama uzimele ngokwakho, lilincinci ithuba lokuba ungonzakaliswa kukuwa. Wena, othatha inxaxheba, uzoncedakala kwi-inshorensi ethi “no fault” (akukho ngxaki) yeyunivesithi yaseStellenbosch. Oku kuthetha ukuba xa kunokubakho umonzakalo ongacingelwanga ngenxa yolu phando, zonke iindleko zonyango ziza kubuyiswa ngokupheleleyo.

## **Ingaba uza kuhlawulwa ngokuthatha inxaxheba kwesi sifundo kwaye ingaba kukho iindleko ezibandakanyekayo?**

Ngoku awuzobhatalwa ngokuthatha kwakho inxaxheba kolu phando kwaye asifuni ubenezinye iindleko. Yiyo loo nto siceba ukulwenza uphando kwangale mini uzela unyango lwakho. Iivawutsha zokuthenga (ze-R40) uza kuzinikwa emva kokuthatha inxaxheba kuphando nokutya uza kufumana xa uhlolwa.

## **Ingaba ikho enye into ekumele uyazi okanye uyenze?**

- Ungaqhagamshelana **neKomiti yeNdlela zokuziphatha kuPhando lwezeMpilo** ku-021-938 9207 ukuba zikhona izinto ezikuxhalabisayo okanye izikhalazo ezingaphendulwanga ngokwanelisayo ngugqirha wakho wophando.
- Uza kufumana ikopi yeenkcukacha uzigcinele.
- Siyabulela ngexesha lakho neenzame ozenzileyo zokuza kwangethuba nokuchitha enye iyure enesiqingatha ekliniki.

## Isifungo somthathi-nxaxheba

Ngokuyityikitya ngezantsi, Mna ..... ndiyavuma ukuthatha inxaxheba kwisifundo sophando semfuzo esibizwa ngokuba (*faka ishloko sesifundo*).

Ndazisa ukuba:

- Ndilufundile okanye ndalufunda olu lwazi kunye nefomu yemvumelwano kwaye ibhalwe ngolwimi endiliciko nendikhululekileyo kulo
- Bendinalo ithuba lokuba ndibuze imibuzo kwaye yonke imibuzo yam iphendulwe ngokwanelisayo.
- Ndiyakuqonda ukuba ukuthatha inxaxheba kolu phando kube **kukuzithandela kwam** kwaye andikhange ndinyanzelwe ukuba ndithathe inxaxheba.
- Ndingakhetha ukusishiya isifundo naninina kwaye andisayi kohlwaywa okanye uqal' ugwetywe nangayiphi indlela.
- Usenokucelwa ukuba usishiye isifundo phambi kokuba siphela, ukuba ugqirha wesifundo okanye umphandi ukubona kuyinzuzo kuwe, okanye ukuba andisilandeli isicwangciso sesifundo, ekuvunyelenwe ngaso.

Kutyikitywe e-(indawo) ..... ngo-(usuku) .....

.....

**Umtyikityo womthathi-nxaxheba**

.....

**Umtyikityo wengqina**

## Isifungo somphandi

Mna **Hesti Steyn** ndiyafunga ukuba:

- Ndilucacisile                    ulwazi                    olu                    kweli                    xwebhu                    ku-  
.....
- Ndimkhuthazile ukuba abuze imibuzo kwaye athathe ixesha elifanelekileyo ukuba ayiphendule.
- Ndiyaneliseka kukuba uyakuqonda ngokwanelisayo konke okumalunga nophando okuxoxwe ngasentla.
- Ndisebenzise/andisebenzisanga toliki. (*Ukuba itoliki isetyenzisiwe kumele ityikitye isaziso ngezantsi.*)

Kutyikitywe                    e-(indawo)                    .....                    ngo-(usuku)

.....

.....

.....

**Umtyikityo womphandi**

**Umtyikityo wengqina**

## Addendum D: Case Participant Information Form

**Case Participant Information Form**

Study Title: The kinematic analysis of the trunk and weight-bearing symmetry in the three planes of movement during the four phases of sit-to-stand in adults with stroke and a community control group – case-control study

Date of interview:

Interview conducted by:

**Personal Information**

Surname	
First name	
Participant Code	
Gender	
Date of Birth	
Date of Injury/ Incident	
Home address	
Telephone number/ Cell phone number	
Additional/alternate contact number	

**Medical Information**

Doctor's name/ institution name	
Doctor's/ Institution contact details	
Out-Patient Centre	
Physiotherapist's name	
Physiotherapist's contact details	
Diagnosis/ Medical conditions	
Co-morbidities	
Current medications	
Allergies	
Side Affected	
Dominance	

Age at Incident	
Height	
Weight	
Brief history of incident and management to date	
Imaging	
Assistive Devices	
Emergency Information	
Emergency contact's name	
Relationship to you	
Address	
Phone number(s)	

### Sample characteristics

The following criteria will be used to determine eligibility of participants for this study:

#### Inclusion Criteria

- Adult (>18years) males & females with first ever stroke
- Between onset & within three months post stroke
- Present with a single incident leading to hemiparesis affecting the right or left side of the body.
- Able to follow simple two-part verbal instruction as assessed by a physiotherapist.
- Sitting independently, without back support.
- Be able to come from sitting to standing without assistance from another person or arm rests.

#### Exclusion Criteria

- No history of cardiac conditions and pacemakers as these devices are a contraindication to the use of the MyoMOTION IMU
- No prior disability due to previous orthopaedic and/ or neurological conditions.
- No bilateral motor signs as the non-paretic side will also be observed for possible compensatory strategies.
- Any allergies to plaster tape as it may be used to attach the MyoMOTION IMU onto the patient.

## Addendum E: Control Participant Information Form

**Control Participant Information Form**

Study Title: The kinematic analysis of the trunk and weight-bearing symmetry in the three planes of movement during the four phases of sit-to-stand in adults with stroke and a community control group – case-control study

Date of interview:

Interview conducted by:

**Personal Information**

Surname	
First name	
Participant Code	
Case Code related to	
Gender	
Date of Birth	
Home address	
Telephone number/ Cell phone number	
Additional/alternate contact number	

**Medical Information**

Doctor's name/ institution name	
Doctor's/ Institution contact details	
Out-Patient Centre	
Diagnosis/ Medical conditions	
Co-morbidities	
Current medications	
Allergies	
Dominance	
Height	

Weight	
Brief medical history and management to date	
Emergency Information	
Emergency contact's name	
Relationship to you	
Address	
Phone number(s)	

## Sample characteristics

The following criteria will be used to determine eligibility of participants for this study:

### Inclusion Criteria

- Adult (>18years) males & females
- No history of previous stroke
- Be able to stand up from sitting independently
- Must live in same catchment area as case group to ensure that participants come from the same socioeconomic environment

### Exclusion Criteria

- No history of cardiac conditions and pacemakers as these devices are a contraindication to the use of the MyoMOTION IMU (Noraxon., 2015).
- No prior disability due to previous orthopaedic and/ or neurological conditions that affects their ability to independently come from sit-to-stand.
- Any allergies to plaster tape as it may be used to attach the MyoMOTION IMU onto the patient.
- No assistive device for ambulatory uses.



## Addendum F: Trunk Impairment Scale – Physiotherapy Outcome Measure

**Appendix – Trunk Impairment Scale (TIS)**

The starting position for each item is the same. The patient is sitting on the edge of a bed or treatment table without back and arm support. The thighs make full contact with the bed or table, the feet are hip width apart and placed flat on the floor. The knee angle is 90°. The arms rest on the legs. If hypertonia is present the position of the hemiplegic arm is taken as the starting position. The head and trunk are in a midline position.

If the patient scores 0 on the first item, the total score for the TIS is 0.

Each item of the test can be performed three times. The highest score counts. No practice session is allowed.

The patient can be corrected between the attempts.

The tests are verbally explained to the patient and can be demonstrated if needed.

Item			
<b>Static sitting balance</b>			
1	Starting position	Patient falls or cannot maintain starting position for 10 seconds without arm support	<input type="checkbox"/> 0
		Patient can maintain starting position for 10 seconds	<input type="checkbox"/> 2
		If score = 0, then TIS total score = 0	
2	Starting position Therapist crosses the unaffected leg over the hemiplegic leg	Patient falls or cannot maintain sitting position for 10 seconds without arm support	<input type="checkbox"/> 0
		Patient can maintain sitting position for 10 seconds	<input type="checkbox"/> 2
3	Starting position Patient crosses the unaffected leg over the hemiplegic leg	Patient falls	<input type="checkbox"/> 0
		Patient cannot cross the legs without arm support on bed or table	<input type="checkbox"/> 1
		Patient crosses the legs but displaces the trunk more than 10 cm backwards or assists crossing with the hand	<input type="checkbox"/> 2
		Patient crosses the legs without trunk displacement or assistance	<input type="checkbox"/> 3
		Total static sitting balance	/7
<b>Dynamic sitting balance</b>			
1	Starting position Patient is instructed to touch the bed or table with the hemiplegic elbow (by shortening the hemiplegic side and lengthening the unaffected side) and return to the starting position	Patient falls, needs support from an upper extremity or the elbow does not touch the bed or table	<input type="checkbox"/> 0
		Patient moves actively without help, elbow touches bed or table	<input type="checkbox"/> 1
		If score = 0, then items 2 and 3 score 0	
2	Repeat item 1	Patient demonstrates no or opposite shortening/lengthening	<input type="checkbox"/> 0
		Patient demonstrates appropriate shortening/lengthening	<input type="checkbox"/> 1
		If score = 0, then item 3 scores 0	
3	Repeat item 1	Patient compensates. Possible compensations are: (1) use of upper extremity, (2) contralateral hip abduction, (3) hip flexion (if elbow touches bed or table further than proximal half of femur), (4) knee flexion, (5) sliding of the feet	<input type="checkbox"/> 0
		Patient moves without compensation	<input type="checkbox"/> 1
4	Starting position Patient is instructed to touch the bed or table with the unaffected elbow (by shortening the unaffected side and lengthening the hemiplegic side) and return to the starting position	Patient falls, needs support from an upper extremity or the elbow does not touch the bed or table	<input type="checkbox"/> 0
		Patient moves actively without help, elbow touches bed or table	<input type="checkbox"/> 1
		If score = 0, then items 5 and 6 score 0	
5	Repeat item 4	Patient demonstrates no or opposite shortening/lengthening	<input type="checkbox"/> 0
		Patient demonstrates appropriate shortening/lengthening	<input type="checkbox"/> 1
		If score = 0, then item 6 scores 0	

Item			
6	Repeat item 4	Patient compensates. Possible compensations are: (1) use of upper extremity, (2) contralateral hip abduction, (3) hip flexion (if elbow touches bed or table further than proximal half of femur), (4) knee flexion, (5) sliding of the feet Patient moves without compensation	<input type="checkbox"/> 0 <input type="checkbox"/> 1
7	Starting position Patient is instructed to lift pelvis from bed or table at the hemiplegic side (by shortening the hemiplegic side and lengthening the unaffected side) and return to the starting position	Patient demonstrates no or opposite shortening/lengthening Patient demonstrates appropriate shortening/lengthening If score = 0, then item 8 scores 0	<input type="checkbox"/> 0 <input type="checkbox"/> 1
8	Repeat item 7	Patient compensates. Possible compensations are: (1) use of upper extremity, (2) pushing off with the ipsilateral foot (heel loses contact with the floor) Patient moves without compensation	<input type="checkbox"/> 0 <input type="checkbox"/> 1
9	Starting position Patient is instructed to lift pelvis from bed or table at the unaffected side (by shortening the unaffected side and lengthening the hemiplegic side) and return to the starting position	Patient demonstrates no or opposite shortening/lengthening Patient demonstrates appropriate shortening/lengthening If score = 0, then item 10 scores 0	<input type="checkbox"/> 0 <input type="checkbox"/> 1
10	Repeat item 9	Patient compensates. Possible compensations are: (1) use of upper extremities, (2) pushing off with the ipsilateral foot (heel loses contact with the floor) Patient moves without compensation Total dynamic sitting balance	<input type="checkbox"/> 0 <input type="checkbox"/> 1 /10
<b>Co-ordination</b>			
1	Starting position Patient is instructed to rotate upper trunk 6 times (every shoulder should be moved forward 3 times), first side that moves must be hemiplegic side, head should be fixated in starting position	Hemiplegic side is not moved three times Rotation is asymmetrical Rotation is symmetrical If score = 0, then item 2 scores 0	<input type="checkbox"/> 0 <input type="checkbox"/> 1 <input type="checkbox"/> 2
2	Repeat item 1 within 6 seconds	Rotation is asymmetrical Rotation is symmetrical	<input type="checkbox"/> 0 <input type="checkbox"/> 1
3	Starting position Patient is instructed to rotate lower trunk 6 times (every knee should be moved forward 3 times), first side that moves must be hemiplegic side, upper trunk should be fixated in starting position	Hemiplegic side is not moved three times Rotation is asymmetrical Rotation is symmetrical If score = 0, then item 4 scores 0	<input type="checkbox"/> 0 <input type="checkbox"/> 1 <input type="checkbox"/> 2
4	Repeat item 3 within 6 seconds	Rotation is asymmetrical Rotation is symmetrical Total co-ordination	<input type="checkbox"/> 0 <input type="checkbox"/> 1 /6
Total Trunk Impairment Scale			/23

## Addendum G: Modified Barthel Index – Physiotherapy Outcome Measures

<i>MODIFIED BARTHEL INDEX (SHAH VERSION): SELF CARE ASSESSMENT</i>		
INDEX ITEM	SCORE	DESCRIPTION
<i>CHAIR/BED TRANSFERS</i>	0	Unable to participate in a transfer. Two attendants are required to transfer the patient with or without a mechanical device.
	3	Able to participate but maximum assistance of one other person is require in <u>all aspects</u> of the transfer.
	8	The transfer requires the assistance of one other person. Assistance may be required in <u>any</u> aspect of the transfer.
	12	The presence of another person is required either as a confidence measure, or to provide supervision for safety.
	15	The patient can safely approach the bed walking or in a wheelchair, lock brakes, lift footrests, or position walking aid, move safely to bed, lie down, come to a sitting position on the side of the bed, change the position of the wheelchair, transfer back into it safely and/or grasp aid and stand. The patient must be independent in all phases of this activity.
<i>AMBULATION</i>	0	Dependent in ambulation.
	3	Constant presence of one or more assistant is required during ambulation.
	8	Assistance is required with reaching aids and/or their manipulation. One person is required to offer assistance.
	12	The patient is independent in ambulation but unable to walk 50 metres without help, or supervision is needed for confidence or safety in hazardous situations.
	15	The patient must be able to wear braces if required, lock and unlock these braces assume standing position, sit down, and place the necessary aids into position for use. The patient must be able to crutches, canes, or a walkerette, and walk 50 metres without help or supervision.
<i>AMBULATION/WHEEL CHAIR</i>  * (If unable to walk)  Only use this item if the patient is rated "0" for Ambulation, and then only if the patient has been trained in wheelchair management.	0	Dependent in wheelchair ambulation.
	1	Patient can propel self short distances on flat surface, but assistance is required for all other steps of wheelchair management.
	3	Presence of one person is necessary and constant assistance is required to manipulate chair to table, bed, etc.
	4	The patient can propel self for a reasonable duration over regularly encountered terrain. Minimal assistance may still be required in "tight corners" or to negotiate a kerb 100mm high.
	5	To propel wheelchair independently, the patient must be able to go around corners, turn around, manoeuvre the chair to a table, bed, toilet, etc. The patient must be able to push a chair at least 50 metres and negotiate a kerb.

INDEX ITEM	SCORE	DESCRIPTION
<i>STAIR CLIMBING</i>	0	The patient is unable to climb stairs.
	2	Assistance is required in all aspects of chair climbing, including assistance with walking aids.
	3	The patient is able to ascend/descend but is unable to carry walking aids and needs supervision and assistance.
	8	Generally no assistance is required. At times supervision is required for safety due to morning stiffness, shortness of breath, etc.
	10	The patient is able to go up and down a flight of stairs safely without help or supervision. The patient is able to use hand rails, cane or crutches when needed and is able to carry these devices as he/she ascends or descends.
<i>TOILET TRANSFERS</i>	0	Fully dependant in toileting.
	2	Assistance required in all aspects of toileting.
	3	Assistance may be required with management of clothing, transferring, or washing hands.
	8	Supervision may be required for safety with normal toilet. A commode may be used at night but assistance is required for emptying and cleaning.
	10	The patient is able to get on/off the toilet, fasten clothing and use toilet paper without help. If necessary, the patient may use a bed pan or commode or urinal at night, but must be able to empty it and clean it.
<i>BOWEL CONTROL</i>	0	The patient is bowel incontinent.
	2	The patient needs help to assume appropriate position, and with bowel movement facilitatory techniques.
	3	The patient can assume appropriate position, but cannot use facilitatory techniques or clean self without assistance and has frequent accidents. Assistance is required with incontinence aids such as pad, etc.
	8	The patient may require supervision with the use of suppository or enema and has occasional accidents.
	10	The patient can control bowels and has no accidents, can use suppository, or take an enema when necessary.
<i>BLADDER CONTROL</i>	0	The patient is dependent in bladder management, is incontinent, or has indwelling catheter.
	2	The patient is incontinent but is able to assist with the application of an internal or external device.
	3	The patient is generally dry by day, but not at night and needs some assistance with the devices.
	8	The patient is generally dry by day and night, but may have an occasional accident or need minimal assistance with internal or external devices.
	10	The patient is able to control bladder day and night, and/or is independent with internal or external devices.

INDEX ITEM	SCORE	DESCRIPTION
<i>BATHING</i>	0	Total dependence in bathing self.
	1	Assistance is required in all aspects of bathing, but patient is able to make some contribution.
	3	Assistance is required with either transfer to shower/bath or with washing or drying; including inability to complete a task because of condition or disease, etc.
	4	Supervision is required for safety in adjusting the water temperature, or in the transfer.
	5	The patient may use a bathtub, a shower, or take a complete sponge bath. The patient must be able to do all the steps of whichever method is employed without another person being present.
<i>DRESSING</i>	0	The patient is dependent in all aspects of dressing and is unable to participate in the activity.
	2	The patient is able to participate to some degree, but is dependant in all aspects of dressing.
	5	Assistance is needed in putting on, and/or removing any clothing.
	8	Only minimal assistance is required with fastening clothing such as buttons, zips, bra, shoes, etc.
	10	The patient is able to put on, remove, corset, braces, as prescribed.
<i>PERSONAL HYGIENE</i> (Grooming)	0	The patient is unable to attend to personal hygiene and is dependent in all aspects.
	1	Assistance is required in all steps of personal hygiene, but patient able to make some contribution.
	3	Some assistance is required in one or more steps of personal hygiene.
	4	Patient is able to conduct his/her own personal hygiene but requires minimal assistance before and/or after the operation.
	5	The patient can wash his/her hands and face, comb hair, clean teeth and shave. A male patient may use any kind of razor but must insert the blade, or plug in the razor without help, as well as retrieve it from the drawer or cabinet. A female patient must apply her own make-up, if used, but need not braid or style her hair.
<i>FEEDING</i>	0	Dependent in all aspects and needs to be fed, nasogastric needs to be administered.
	2	Can manipulate an eating device, usually a spoon, but someone must provide active assistance during the meal.
	3	Able to feed self with supervision. Assistance is required with associated tasks such as putting milk/sugar into tea, salt, pepper, spreading butter, turning a plate or other "set up" activities.
	8	Independence in feeding with prepared tray, except may need meat cut, milk carton opened or jar lid etc. The presence of another person is not required.
	10	The patient can feed self from a tray or table when someone puts the food within reach. The patient must put on an assistive device if needed, cut food, and if desired use salt and pepper, spread butter, etc.

SCORE	INTERPRETATION
00 - 20	Total Dependence
21 - 60	Severe Dependence
61 - 90	Moderate Dependence
91 - 99	Slight Dependence
- 100	Independence

SCORE	PREDICTION
Less Than 40	Unlikely to go home - Dependent in Mobility - Dependent in Self Care
60	Pivotal score where patients move from dependency to assisted independence.
60 - 80	If living alone will probably need a number of community services to cope.
More Than 85	Likely to be discharged to community living - Independent in transfers and able to walk or use wheelchair independently.

#### REFERENCES

1. Shah, S., Vancly, F., & Cooper, B. (1989a). Improving the sensitivity of the Barthel Index for stroke rehabilitation. *Journal of Clinical Epidemiology*, 42, 703 - 709.
2. Shah, S., & Cooper, B. (1991). Documentation for measuring stroke rehabilitation outcomes. *Australian Medical Records Journal*, 21, 88 - 95.
3. Shah, S., Cooper, B., & Maas, F. (1992). The Barthel Index and A D L evaluation in stroke rehabilitation in Australia, Japan, the U K and the U S A. *Australian Occupational Therapy Journal*, 39, 5 - 13.
4. Granger, V., Dewis, L., Peters, W., Sherwood, C., & Barrett, J. (1979). Stroke rehabilitation analysis of repeated Barthel Index measures. *Archives of Physical and Medical Rehabilitation*, 60, 14 - 17.
5. Hasselkus, B. (1982). Barthel self-care index and geriatric home care patients. *Physical and Occupational Therapy in Geriatrics*, 1, 11 - 22.
6. Leonard, R., & McGovern, L. (1992). The Barthel Index in an acute geriatric setting. *American Journal of Occupational Therapy*, 39, 41 - 43.

## Addendum H: Temporal Parameters of Case and Control Participants

	Case	Control	P-Value	
			Parametric	Non-parametric
<b>Phase 1 – Initiation (s)</b>	0.86 (0.26)	0.68 (0.24)	0.63	0.026*
<b>Phase 2 – Seat Off (s)</b>	0.41 (0.15)	0.30 (0.13)	0.55	0.067
<b>Phase 3 – Extension (s)</b>	1.79 (0.59)	1.17 (0.40)	0.002*	0.002**
<b>Total duration (s)</b>	3.06 (0.76)	2.15 (0.59)	0.001**	0.002**

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

Addendum I: Kinetic Parameter – Weight-Bearing Symmetry of Case and Control  
Participants during STS

(Mean; SD)	Case	(Mean; SD)	Control	P-Value	
				Parametric	Non-parametric
<b>Phase 1</b>					
<b>Affected (%)</b>	59.68 (15.30)	<b>Non-Dominant (%)</b>	49.05 (9.51)	0.030*	0.011*
<b>Unaffected (%)</b>	40.32 (15.30)	<b>Dominant (%)</b>	50.95 (9.51)	0.030*	0.011*
<b>Phase 2</b>					
<b>Affected (%)</b>	47.17 (6.18)	<b>Non-Dominant (%)</b>	51 (4.10)	0.062	0.126
<b>Unaffected (%)</b>	52.73 (6.18)	<b>Dominant (%)</b>	49 (4.10)	0.062	0.126
<b>Phase 3</b>					
<b>Affected (%)</b>	41.17 (6.95)	<b>Non-Dominant (%)</b>	50.21 (4.86)	0.001**	0.001**
<b>Unaffected (%)</b>	58.83 (6.95)	<b>Dominant (%)</b>	49.79 (4.86)	0.001**	0.001**
<b>Phase 4</b>					
<b>Affected (%)</b>	46.37 (5.95)	<b>Non-Dominant (%)</b>	51.06 (6.41)	0.047*	0.023*
<b>Unaffected (%)</b>	53.63 (5.95)	<b>Dominant (%)</b>	48.94 (6.41)	0.047*	0.023*

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$



Addendum J: Kinetic Parameter – Comparison of total force distribution of case and control participants during STS

<b>(Mean; SD)</b>	<b>Case</b>	<b>Control</b>	<b>P-Value Parametric</b>	<b>Non- parametric</b>
<b>P1 Total Force (N)</b>	100.92 (35.4)	85.88 (39.3)	0.280	0.187
<b>P2 Total Force (N)</b>	688.44 (167.30)	702.22 (172.68)	0.826	0.967
<b>P3 Total Force (N)</b>	674.89 (128.22)	599.62 (179.28)	0.197	0.067
<b>P4 Total Force (N)</b>	703.35 (136.97)	641.03 (187.87)	0.308	0.202

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

## Addendum K: Kinematic Parameter - Angular Displacement of Case and Control

Participants during STS

<b>ANGULAR DISPLACEMENT (°)</b>				
	<b>Case</b>	<b>Control</b>	<b>P - Value</b>	
			<b>Parametric</b>	<b>Non-Parametric</b>
<b>Phase 1</b>				
Upper Trunk (Thoracic)				
Frontal Plane ROM	6.11 (2.25)	2.81 (1.78)	0.001**	0.001**
Frontal Plane Max	1.65 (3.50)	1.06 (2.93)	0.619	0.838
Frontal Plane Min	-4.45 (3.67)	-1.75 (2.23)	0.021*	0.037*
Sagittal Plane ROM	30.06 (6.43)	30.13 (9.75)	0.981	0.744
Sagittal Plane Max	-6.81 (6.02)	-4.56 (5.87)	0.310	0.412
Sagittal Plane Min	-36.87 (7.65)	-34.70 (8.70)	0.473	0.345
Transverse Plane ROM	6.69 (3.83)	2.71 (1.18)	0.001**	0.001**
Transverse Plane Max	3.31 (3.45)	1.71 (1.08)	0.098	0.512
Transverse Plane Min	-3.38 (4.45)	-1.00 (1.20)	0.056	0.106
Lower Trunk (Lumbar)				
Frontal Plane ROM	4.07 (2.32)	3.92 (4.28)	0.904	0.389
Frontal Plane Max	1.08 (3.39)	1.00 (4.16)	0.955	0.744
Frontal Plane Min	-2.99 (2.60)	-2.92 (4.42)	0.957	0.567
Sagittal Plane ROM	36.45 (8.98)	37.70 (8.65)	0.702	0.902
Sagittal Plane Max	8.67 (9.57)	8.16 (11.81)	0.899	0.838
Sagittal Plane Min	-27.79 (13.52)	-29.53 (15.63)	0.746	0.838
Transverse Plane ROM	4.33 (2.74)	3.65 (4.40)	0.616	0.106
Transverse Plane Max	2.25 (2.92)	2.07 (3.11)	0.874	0.967
Transverse Plane Min	-2.08 (2.46)	-1.58 (1.82)	0.530	0.595

Phase 2				
Upper Trunk (Thoracic)				
Frontal Plane ROM	5.20 (1.62)	1.70 (1.36)	0.001**	0.001**
Frontal Plane Max	1.77 (6.31)	0.82 (4.27)	0.633	0.567
Frontal Plane Min	-3.43 (6.11)	-0.88 (3.59)	0.174	0.267
Sagittal Plane ROM	10.40 (6.49)	9.38 (5.59)	0.650	0.624
Sagittal Plane Max	-36.45 (7.84)	-33.11 (9.69)	0.309	0.202
Sagittal Plane Min	-46.85 (7.01)	-42.50 (11.45)	0.220	0.217
Transverse Plane ROM	5.07 (2.48)	2.41 (2.12)	0.004*	0.001**
Transverse Plane Max	1.43 (8.12)	1.67 (2.77)	0.914	0.775
Transverse Plane Min	-3.65 (7.70)	-0.75 (4.18)	0.210	0.325
Lower Trunk (Lumbar)				
Frontal Plane ROM	3.05 (1.70)	7.64 (22.59)	0.439	0.033*
Frontal Plane Max	0.52 (5.60)	3.00 (9.38)	0.387	0.285
Frontal Plane Min	-2.53 (4.76)	-4.64 (15.03)	0.608	0.285
Sagittal Plane ROM	12.31 (7.94)	12.03 (7.32)	0.920	0.838
Sagittal Plane Max	-27.43 (13.23)	-28.95 (15.67)	0.776	0.870
Sagittal Plane Min	-39.74 (10.63)	-40.98 (17.27)	0.814	0.838
Transverse Plane ROM	3.16 (1.56)	8.22 (24.22)	0.426	0.089
Transverse Plane Max	1.67 (5.45)	7.02 (24.69)	0.419	0.806
Transverse Plane Min	-1.49 (6.25)	-1.20 (2.94)	0.872	0.902

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

<b>Phase 3</b>				
Upper Trunk (Thoracic)				
Frontal Plane ROM	9.09 (3.92)	4.16 (2.63)	0.001**	0.001**
Frontal Plane Max	3.55 (4.36)	1.65 (2.92)	0.173	0.202
Frontal Plane Min	-5.54 (4.24)	-2.50 (2.26)	0.021*	0.045*
Sagittal Plane ROM	49.53 (9.40)	43.82 (12.99)	0.179	0.116
Sagittal Plane Max	3.90 (4.22)	4.84 (4.08)	0.541	1.000
Sagittal Plane Min	-45.63 (7.92)	-38.98 (13.24)	0.106	0.098
Transverse Plane ROM	9.84 (4.62)	5.15 (3.89)	0.005*	0.001**
Transverse Plane Max	3.83 (4.53)	2.64 (1.89)	0.356	0.935
Transverse Plane Min	-6.01 (5.90)	-2.51 (4.19)	0.071	0.067
Lower Trunk (Lumbar)				
Frontal Plane ROM	6.17 (2.88)	10.49 (26.07)	0.530	0.045*
Frontal Plane Max	2.70 (4.11)	4.85 (11.23)	0.492	0.653
Frontal Plane Min	-3.48 (3.38)	-5.64 (15.30)	0.598	0.367
Sagittal Plane ROM	40.08 (9.09)	40.34 (16.62)	0.958	0.775
Sagittal Plane Max	1.80 (3.90)	2.37 (3.72)	0.685	0.461
Sagittal Plane Min	-38.28 (10.66)	-37.97 (17.93)	0.955	0.539
Transverse Plane ROM	9.28 (3.35)	11.82 (26.70)	0.717	0.001**
Transverse Plane Max	4.20 (4.14)	8.64 (23.05)	0.469	0.345
Transverse Plane Min	-5.08 (4.40)	-3.19 (4.31)	0.244	0.202

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

<b>Phase 4</b>				
Upper Trunk (Thoracic)				
Frontal Plane ROM	2.72 (0.92)	1.89 (0.58)	0.006*	0.008*
Frontal Plane Max	0.51 (3.61)	0.08 (1.62)	0.674	0.567
Frontal Plane Min	-2.21 (3.63)	-1.81 (1.67)	0.703	0.653
Sagittal Plane ROM	4.29 (1.72)	3.81 (1.47)	0.418	0.325
Sagittal Plane Max	6.52 (3.90)	6.04 (3.45)	0.727	0.567
Sagittal Plane Min	2.23 (3.66)	2.23 (2.89)	0.996	0.838
Transverse Plane ROM	4.31 (1.60)	3.98 (1.28)	0.546	0.512
Transverse Plane Max	2.02 (3.15)	3.19 (2.06)	0.237	0.161
Transverse Plane Min	-2.29 (2.80)	-0.79 (2.06)	0.106	0.137
Lower Trunk (Lumbar)				
Frontal Plane ROM	1.52 (0.60)	1.29 (0.73)	0.348	0.126
Frontal Plane Max	0.51 (1.16)	0.67 (0.71)	0.644	0.806
Frontal Plane Min	-1.01 (1.13)	-0.61 (1.05)	0.327	0.217
Sagittal Plane ROM	3.41 (1.23)	3.01 (1.20)	0.374	0.325
Sagittal Plane Max	4.20 (3.44)	4.08 (3.18)	0.922	0.806
Sagittal Plane Min	0.79 (3.62)	1.07 (3.06)	0.819	0.683
Transverse Plane ROM	3.66 (1.81)	3.76 (1.28)	0.857	0.461
Transverse Plane Max	1.05 (4.42)	2.96 (2.70)	0.165	0.250
Transverse Plane Min	-2.61 (4.45)	-0.81 (3.03)	0.206	0.233

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

Addendum L: Kinematic Parameter - Angular Velocity of Case and Control Participants during STS

<b>ANGULAR VELOCITY (°/s)</b>				
	<b>Case</b>	<b>Control</b>	<b>P - Value</b>	
			<b>Parametric</b>	<b>Non-parametric</b>
<b>Phase 1</b>				
<b>Upper Trunk (Thoracic)</b>				
Frontal Plane Peak Positive	15.31 (12.56)	8.18 (9.02)	0.085	0.098
Frontal Plane Peak Negative	-15.64 (12.22)	-5.87 (5.16)	0.008*	0.013*
Sagittal Plane Peak Positive	-3.11 (1.66)	-3.14 (4.26)	0.985	0.744
Sagittal Plane Peak Negative	-65.70 (12.38)	-81.74 (20.93)	0.016*	0.016*
Transverse Plane Peak Positive	12.58 (11.95)	8.45 (4.91)	0.227	0.624
Transverse Plane Peak Negative	-14.16 (13.41)	-6.84 (7.10)	0.072	0.089
<b>Lower Trunk (Lumbar)</b>				
Frontal Plane Peak Positive	7.13 (6.77)	16.32 (30.11)	0.259	0.367
Frontal Plane Peak Negative	-8.98 (7.42)	-12.83 (35.01)	0.680	0.161
Sagittal Plane Peak Positive	-3.95 (4.24)	-7.97 (14.16)	0.301	0.683
Sagittal Plane Peak Negative	-91.14 (14.43)	-114.81 (23.82)	0.003*	0.002*
Transverse Plane Peak Positive	9.14 (8.26)	18.15 (44.16)	0.444	0.935
Transverse Plane Peak Negative	-8.95 (8.10)	-11.74 (14.72)	0.525	0.838

<b>Phase 2</b>				
<b>Upper Trunk (Thoracic)</b>				
Frontal Plane Peak Positive	18.09 (13.13)	7.85 (7.23)	0.013*	0.041*
Frontal Plane Peak Negative	-14.75 (13.42)	-7.42 (5.03)	0.058	0.187
Sagittal Plane Peak Positive	10.15 (19.10)	28.44 (30.85)	0.061	0.137
Sagittal Plane Peak Negative	-51.53 (17.00)	-62.29 (21.63)	0.141	0.217
Transverse Plane Peak Positive	11.86 (12.84)	4.57 (8.30)	0.075	0.106
Transverse Plane Peak Negative	-19.20 (15.79)	-10.14 (9.43)	0.067	0.023*
<b>Lower Trunk (Lumbar)</b>				
Frontal Plane Peak Positive	8.80 (7.84)	18.66 (40.38)	0.361	0.935
Frontal Plane Peak Negative	-6.80 (8.83)	-22.20 (55.48)	0.297	0.345
Sagittal Plane Peak Positive	10.76 (19.70)	26.53 (30.73)	0.105	0.148
Sagittal Plane Peak Negative	-72.11 (20.50)	-93.77 (27.91)	0.022*	0.026*
Transverse Plane Peak Positive	7.18 (7.64)	36.26 (111.83)	0.324	0.624
Transverse Plane Peak Negative	-11.29 (7.45)	-5.25 (13.30)	0.136	0.148

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

<b>Phase 3</b>				
Upper Trunk (Thoracic)				
Frontal Plane Peak Positive	15.35 (11.58)	7.48 (5.52)	0.024*	0.016*
Frontal Plane Peak Negative	-14.96 (9.58)	-9.28 (9.21)	0.109	0.074
Sagittal Plane Peak Positive	69.92 (24.75)	81.71 (17.79)	0.145	0.050*
Sagittal Plane Peak Negative	-4.09 (7.14)	-3.77 (6.92)	0.900	1.000
Transverse Plane Peak Positive	17.83 (7.81)	10.68 (9.59)	0.033*	0.003*
Transverse Plane Peak Negative	-17.30 (9.27)	-10.62 (6.85)	0.033*	0.023*
Lower Trunk (Lumbar)				
Frontal Plane Peak Positive	10.07 (7.04)	27.62 (82.69)	0.419	0.217
Frontal Plane Peak Negative	-8.81 (5.64)	-22.91 (59.04)	0.365	0.486
Sagittal Plane Peak Positive	55.34 (18.28)	74.24 (19.32)	0.010*	0.011*
Sagittal Plane Peak Negative	-3.92 (6.62)	-3.19 (8.60)	0.795	0.806
Transverse Plane Peak Positive	13.56 (8.14)	20.99 (36.64)	0.450	0.967
Transverse Plane Peak Negative	-14.56 (7.14)	-39.80 (122.69)	0.433	0.033*

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$



Phase 4				
Upper Trunk (Thoracic)				
Frontal Plane Peak Positive	3.86 (1.63)	3.30 (1.41)	0.320	0.325
Frontal Plane Peak Negative	-3.67 (1.95)	-3.26 (1.74)	0.547	0.683
Sagittal Plane Peak Positive	5.61 (3.04)	5.25 (2.25)	0.716	0.902
Sagittal Plane Peak Negative	-4.21 (1.76)	-5.39 (3.85)	0.287	0.775
Transverse Plane Peak Positive	6.43 (3.14)	5.36 (2.63)	0.320	0.267
Transverse Plane Peak Negative	-6.25 (2.90)	-4.83 (2.90)	0.191	0.098
Lower Trunk (Lumbar)				
Frontal Plane Peak Positive	1.76 (1.20)	2.28 (2.46)	0.465	0.567
Frontal Plane Peak Negative	-1.77 (1.49)	-1.76 (0.78)	0.981	0.461
Sagittal Plane Peak Positive	4.67 (3.07)	5.08 (3.16)	0.719	0.838
Sagittal Plane Peak Negative	-3.19 (2.28)	-3.82 (3.10)	0.528	0.512
Transverse Plane Peak Positive	5.01 (3.35)	5.99 (3.04)	0.406	0.389
Transverse Plane Peak Negative	-5.23 (2.96)	-5.24 (2.74)	0.998	1.000

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

Addendum M: Kinematic Parameter – Acceleration of Case and Control Participants during STS

Raw Acceleration Data	Case	Control	P - Value	
			Parametric	Non-Parametric
Thoracic Medio-Lateral Sway Acceleration (m/s <sup>2</sup> )	0.29 (0.09)	0.39 (0.17)	0.051	0.089
Thoracic Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.41 (0.13)	0.75 (0.26)	0.001**	0.001**
Thoracic Antero-Posterior Sway Acceleration (m/s <sup>2</sup> )	0.64 (0.34)	1.57 (0.72)	0.001**	0.001**
Thoracic Jerk Sum Transverse Plane (m/s <sup>2</sup> )	9.72 (2.58)	15.55 (4.63)	0.001**	0.001**
Thoracic AUC Transverse Plane (m/s)	1.11 (0.24)	1.77 (0.54)	0.001**	0.001**
Lumbar Medio-Lateral Sway Acceleration (m/s <sup>2</sup> )	0.25 (0.12)	0.33 (0.12)	0.093	0.026*
Lumbar Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.35 (0.17)	0.56 (0.15)	0.002*	0.001**
Lumbar Antero-Posterior Sway Acceleration (m/s <sup>2</sup> )	0.46 (0.29)	0.80 (0.35)	0.007*	0.003*
Lumbar Jerk Sum Transverse Plane (m/s <sup>2</sup> )	6.07 (1.46)	8.13 (2.48)	0.010*	0.026*
Lumbar AUC Transverse Plane (m/s)	0.79 (0.18)	0.96 (0.27)	0.056	0.098

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

<b>Scaled Acceleration Data</b>						
Thoracic	Medio-Lateral	Sway	0.40 (0.10)	0.28 (0.07)	0.001**	0.001**
Acceleration (m/s <sup>2</sup> )						
Thoracic	Vertical Translation	Sway	0.56 (0.14)	0.55 (0.15)	0.783	0.683
Acceleration (m/s <sup>2</sup> )						
Thoracic	Antero-Posterior	Sway	0.83 (0.15)	1.07 (0.16)	0.001**	0.001**
Acceleration (m/s <sup>2</sup> )						
Thoracic	Jerk Sum Transverse Plane		13.71 (3.16)	11.43 (2.37)	0.034*	0.050*
(m/s <sup>2</sup> )						
Thoracic	AUC Transverse Plane	(m/s)	1.6 (0.4)	1.31 (0.31)	0.038*	0.056
Lumbar	Medio-Lateral	Sway	0.34 (0.11)	0.25 (0.08)	0.008*	0.004*
Acceleration (m/s <sup>2</sup> )						
Lumbar	Vertical Translation	Sway	0.47 (0.14)	0.43 (0.13)	0.368	0.267
Acceleration (m/s <sup>2</sup> )						
Lumbar	Antero-Posterior	Sway	0.59 (0.20)	0.57 (0.12)	0.736	0.902
Acceleration (m/s <sup>2</sup> )						
Lumbar	Jerk Sum Transverse Plane		8.71 (2.21)	6.09 (1.67)	0.001**	0.002*
(m/s <sup>2</sup> )						
Lumbar	AUC Transverse Plane	(m/s)	1.15 (0.32)	0.74 (0.25)	0.001**	0.002*

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

## Addendum N: Temporal Parameter: Comparison with Physiotherapy Outcome Measure

	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
<b>Phase 1 – Initiation Phase</b>	-0.032	0.909
<b>Phase 2 – Seat Off Phase</b>	0.422	0.117
<b>Phase 3 – Extension Phase</b>	-0.085	0.764
<b>Total STS Transition</b>	-0.207	0.754

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$ 

	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>
<b>Phase 1 – Initiation Phase</b>	-0.029	0.917
<b>Phase 2 – Seat Off Phase</b>	0.369	0.176
<b>Phase 3 – Extension Phase</b>	-0.094	0.740
<b>Total STS Transition</b>	0.064	0.820

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$ 

	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
<b>Phase 1 – Initiation Phase</b>	0.198	0.479
<b>Phase 2 – Seat Off Phase</b>	0.520	0.047*
<b>Phase 3 – Extension Phase</b>	0.169	0.547
<b>Total STS Transition</b>	0.400	0.140

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

### Addendum O: Kinetic Parameter – Weight-Bearing Symmetry: Comparison with Physiotherapy Outcome Measure

	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
P1 – Affected	0.032	0.909
P1 - Unaffected	-0.032	0.909
P2 – Affected	0.294	0.288
P2 - Unaffected	-0.294	0.288
P3 – Affected	0.045	0.873
P3 - Unaffected	-0.045	0.873
P4 – Affected	0.252	0.364
P4 - Unaffected	-0.252	0.364

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
P1 – Affected	0.196	0.483	-0.293	0.290
P1 - Unaffected	-0.196	0.483	0.293	0.290
P2 – Affected	0.325	0.238	0.177	0.527
P2 - Unaffected	-0.325	0.238	-0.177	0.527
P3 – Affected	0.092	0.745	-0.103	0.715
P3 - Unaffected	-0.092	0.745	0.103	0.715
P4 – Affected	0.222	0.427	0.091	0.748
P4 - Unaffected	-0.222	0.427	-0.091	0.748

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

Addendum P: Kinetic Parameter – Total Force Distribution: Comparison with  
Physiotherapy Outcome Measure

	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
P1 Total Force	-0.554	0.032*
P2 Total Force	-0.222	0.427
P3 Total Force	0.202	0.470
P4 Total Force	0.180	0.520

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>
P1 Total Force	-0.477	0.072
P2 Total Force	-0.143	0.611
P3 Total Force	0.336	0.221
P4 Total Force	0.321	0.244

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
P1 Total Force	-0.412	0.127
P2 Total Force	-0.334	0.224
P3 Total Force	-0.099	0.726
P4 Total Force	-0.144	0.608

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

Addendum Q: Kinematic Parameter – Angular Displacement and Comparison with  
Physiotherapy Outcome Measure

<b>Phase 1</b>		
<b>Angular Displacement (°)</b>	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk ROM Frontal Plane Range	-0.413	0.126
Trunk ROM Frontal Plane Min	-0.106	0.706
Trunk ROM Frontal Plane Max	-0.294	0.288
Trunk ROM Sagittal Plane Range	-0.211	0.450
Trunk ROM Sagittal Plane Min	0.085	0.764
Trunk ROM Sagittal Plane Max	0.011	0.969
Trunk ROM Transverse Plane Range	-0.559	0.030*
Trunk ROM Transverse Plane Min	0.162	0.563
Trunk ROM Transverse Plane Max	-0.058	0.838
<b>Lower Trunk (Lumbar)</b>		
Trunk ROM Frontal Plane Range	-0.016	0.954
Trunk ROM Frontal Plane Min	-0.114	0.687
Trunk ROM Frontal Plane Max	-0.023	0.934
Trunk ROM Sagittal Plane Range	0.368	0.177
Trunk ROM Sagittal Plane Min	0.157	0.577
Trunk ROM Sagittal Plane Max	0.023	0.934
Trunk ROM Transverse Plane Range	0.188	0.503
Trunk ROM Transverse Plane Min	0.382	0.160
Trunk ROM Transverse Plane Max	0.069	0.808

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

<b>Phase 1</b>		
<b>Angular Displacement (°)</b>	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk ROM Frontal Plane Range	-0.449	0.093
Trunk ROM Frontal Plane Min	-0.101	0.721
Trunk ROM Frontal Plane Max	-0.240	0.388
Trunk ROM Sagittal Plane Range	-0.215	0.443
Trunk ROM Sagittal Plane Min	0.053	0.851
Trunk ROM Sagittal Plane Max	-0.062	0.825
Trunk ROM Transverse Plane Range	-0.512	0.051
Trunk ROM Transverse Plane Min	-0.037	0.897
Trunk ROM Transverse Plane Max	-0.182	0.517
<b>Lower Trunk (Lumbar)</b>		
Trunk ROM Frontal Plane Range	-0.165	0.557
Trunk ROM Frontal Plane Min	-0.167	0.552
Trunk ROM Frontal Plane Max	-0.141	0.616
Trunk ROM Sagittal Plane Range	-0.402	0.138
Trunk ROM Sagittal Plane Min	0.244	0.381
Trunk ROM Sagittal Plane Max	0.139	0.620
Trunk ROM Transverse Plane Range	-0.339	0.216
Trunk ROM Transverse Plane Min	0.290	0.295
Trunk ROM Transverse Plane Max	0.053	0.851

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$



<b>Phase 1</b>		
<b>Angular Displacement (°)</b>	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk ROM Frontal Plane Range	-0.190	0.498
Trunk ROM Frontal Plane Min	0.223	0.425
Trunk ROM Frontal Plane Max	0.054	0.849
Trunk ROM Sagittal Plane Range	-0.177	0.527
Trunk ROM Sagittal Plane Min	0.276	0.319
Trunk ROM Sagittal Plane Max	0.371	0.173
Trunk ROM Transverse Plane Range	-0.177	0.527
Trunk ROM Transverse Plane Min	0.190	0.498
Trunk ROM Transverse Plane Max	-0.016	0.953
<b>Lower Trunk (Lumbar)</b>		
Trunk ROM Frontal Plane Range	0.021	0.942
Trunk ROM Frontal Plane Min	-0.095	0.737
Trunk ROM Frontal Plane Max	-0.041	0.884
Trunk ROM Sagittal Plane Range	-0.111	0.693
Trunk ROM Sagittal Plane Min	-0.049	0.861
Trunk ROM Sagittal Plane Max	-0.235	0.399
Trunk ROM Transverse Plane Range	-0.095	0.737
Trunk ROM Transverse Plane Min	0.293	0.290
Trunk ROM Transverse Plane Max	0.045	0.872

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

<b>Phase 2</b>		
<b>Angular Displacement (°)</b>	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk ROM Frontal Plane Range	0.296	0.284
Trunk ROM Frontal Plane Min	-0.041	0.883
Trunk ROM Frontal Plane Max	-0.166	0.555
Trunk ROM Sagittal Plane Range	0.595	0.019*
Trunk ROM Sagittal Plane Min	-0.429	0.110
Trunk ROM Sagittal Plane Max	0.092	0.744
Trunk ROM Transverse Plane Range	0.142	0.612
Trunk ROM Transverse Plane Min	0.142	0.612
Trunk ROM Transverse Plane Max	0.180	0.520
<b>Lower Trunk (Lumbar)</b>		
Trunk ROM Frontal Plane Range	0.225	0.419
Trunk ROM Frontal Plane Min	-0.231	0.408
Trunk ROM Frontal Plane Max	-0.121	0.668
Trunk ROM Sagittal Plane Range	0.451	0.092
Trunk ROM Sagittal Plane Min	-0.186	0.507
Trunk ROM Sagittal Plane Max	0.133	0.635
Trunk ROM Transverse Plane Range	0.211	0.450
Trunk ROM Transverse Plane Min	0.180	0.520
Trunk ROM Transverse Plane Max	0.164	0.559

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

<b>Phase 2</b>		
<b>Angular Displacement (°)</b>	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk ROM Frontal Plane Range	-0.167	0.552
Trunk ROM Frontal Plane Min	0.068	0.810
Trunk ROM Frontal Plane Max	-0.028	0.922
Trunk ROM Sagittal Plane Range	0.506	0.054
Trunk ROM Sagittal Plane Min	-0.402	0.138
Trunk ROM Sagittal Plane Max	0.083	0.770
Trunk ROM Transverse Plane Range	0.237	0.396
Trunk ROM Transverse Plane Min	-0.026	0.928
Trunk ROM Transverse Plane Max	0.073	0.795
<b>Lower Trunk (Lumbar)</b>		
Trunk ROM Frontal Plane Range	0.006	0.984
Trunk ROM Frontal Plane Min	-0.099	0.725
Trunk ROM Frontal Plane Max	-0.094	0.740
Trunk ROM Sagittal Plane Range	0.367	0.179
Trunk ROM Sagittal Plane Min	-0.022	0.938
Trunk ROM Sagittal Plane Max	0.211	0.451
Trunk ROM Transverse Plane Range	0.046	0.871
Trunk ROM Transverse Plane Min	0.112	0.691
Trunk ROM Transverse Plane Max	0.059	0.835

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

<b>Phase 2</b>		
<b>Angular Displacement (°)</b>	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk ROM Frontal Plane Range	-0.404	0.135
Trunk ROM Frontal Plane Min	0.140	0.618
Trunk ROM Frontal Plane Max	0.012	0.965
Trunk ROM Sagittal Plane Range	0.569	0.027*
Trunk ROM Sagittal Plane Min	-0.140	0.618
Trunk ROM Sagittal Plane Max	0.247	0.374
Trunk ROM Transverse Plane Range	-0.148	0.597
Trunk ROM Transverse Plane Min	0.124	0.660
Trunk ROM Transverse Plane Max	0.058	0.838
<b>Lower Trunk (Lumbar)</b>		
Trunk ROM Frontal Plane Range	0.276	0.319
Trunk ROM Frontal Plane Min	-0.235	0.399
Trunk ROM Frontal Plane Max	-0.144	0.608
Trunk ROM Sagittal Plane Range	0.511	0.051
Trunk ROM Sagittal Plane Min	-0.462	0.083
Trunk ROM Sagittal Plane Max	-0.021	0.942
Trunk ROM Transverse Plane Range	0.363	0.184
Trunk ROM Transverse Plane Min	0.045	0.872
Trunk ROM Transverse Plane Max	0.103	0.715

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

<b>Phase 3</b>		
<b>Angular Displacement (°)</b>	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk ROM Frontal Plane Range	0.195	0.487
Trunk ROM Frontal Plane Min	-0.193	0.491
Trunk ROM Frontal Plane Max	-0.018	0.949
Trunk ROM Sagittal Plane Range	0.655	0.008*
Trunk ROM Sagittal Plane Min	-0.415	0.124
Trunk ROM Sagittal Plane Max	0.649	0.009*
Trunk ROM Transverse Plane Range	-0.099	0.725
Trunk ROM Transverse Plane Min	0.296	0.284
Trunk ROM Transverse Plane Max	0.151	0.590
<b>Lower Trunk (Lumbar)</b>		
Trunk ROM Frontal Plane Range	0.307	0.266
Trunk ROM Frontal Plane Min	-0.155	0.581
Trunk ROM Frontal Plane Max	0.142	0.612
Trunk ROM Sagittal Plane Range	0.442	0.099
Trunk ROM Sagittal Plane Min	-0.312	0.258
Trunk ROM Sagittal Plane Max	0.011	0.969
Trunk ROM Transverse Plane Range	0.469	0.078
Trunk ROM Transverse Plane Min	-0.050	0.858
Trunk ROM Transverse Plane Max	0.133	0.635

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

<b>Phase 3</b>		
<b>Angular Displacement (°)</b>	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk ROM Frontal Plane Range	0.167	0.552
Trunk ROM Frontal Plane Min	-0.191	0.496
Trunk ROM Frontal Plane Max	-0.042	0.881
Trunk ROM Sagittal Plane Range	0.576	0.025*
Trunk ROM Sagittal Plane Min	-0.363	0.183
Trunk ROM Sagittal Plane Max	0.501	0.057
Trunk ROM Transverse Plane Range	-0.094	0.740
Trunk ROM Transverse Plane Min	0.194	0.488
Trunk ROM Transverse Plane Max	-0.057	0.841
<b>Lower Trunk (Lumbar)</b>		
Trunk ROM Frontal Plane Range	0.125	0.658
Trunk ROM Frontal Plane Min	-0.055	0.846
Trunk ROM Frontal Plane Max	0.132	0.639
Trunk ROM Sagittal Plane Range	0.207	0.459
Trunk ROM Sagittal Plane Min	-0.125	0.658
Trunk ROM Sagittal Plane Max	0.015	0.959
Trunk ROM Transverse Plane Range	0.319	0.246
Trunk ROM Transverse Plane Min	-0.075	0.790
Trunk ROM Transverse Plane Max	0.029	0.917

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

<b>Phase 3</b>		
<b>Angular Displacement (°)</b>	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk ROM Frontal Plane Range	0.066	0.815
Trunk ROM Frontal Plane Min	0.227	0.416
Trunk ROM Frontal Plane Max	0.276	0.319
Trunk ROM Sagittal Plane Range	0.425	0.115
Trunk ROM Sagittal Plane Min	-0.169	0.547
Trunk ROM Sagittal Plane Max	0.569	0.027*
Trunk ROM Transverse Plane Range	0.128	0.650
Trunk ROM Transverse Plane Min	0.124	0.660
Trunk ROM Transverse Plane Max	0.429	0.111
<b>Lower Trunk (Lumbar)</b>		
Trunk ROM Frontal Plane Range	0.367	0.178
Trunk ROM Frontal Plane Min	-0.165	0.557
Trunk ROM Frontal Plane Max	0.029	0.919
Trunk ROM Sagittal Plane Range	0.722	0.002*
Trunk ROM Sagittal Plane Min	-0.548	0.034*
Trunk ROM Sagittal Plane Max	0.058	0.838
Trunk ROM Transverse Plane Range	0.264	0.342
Trunk ROM Transverse Plane Min	0.037	0.896
Trunk ROM Transverse Plane Max	0.062	0.827

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

<b>Phase 4</b>		
<b>Angular Displacement (°)</b>	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk ROM Frontal Plane Range	0.278	0.316
Trunk ROM Frontal Plane Min	-0.014	0.959
Trunk ROM Frontal Plane Max	0.124	0.659
Trunk ROM Sagittal Plane Range	-0.079	0.779
Trunk ROM Sagittal Plane Min	0.730	0.002*
Trunk ROM Sagittal Plane Max	0.633	0.011*
Trunk ROM Transverse Plane Range	0.424	0.115
Trunk ROM Transverse Plane Min	0.402	0.137
Trunk ROM Transverse Plane Max	0.480	0.070
<b>Lower Trunk (Lumbar)</b>		
Trunk ROM Frontal Plane Range	0.370	0.175
Trunk ROM Frontal Plane Min	0.260	0.350
Trunk ROM Frontal Plane Max	0.491	0.063
Trunk ROM Sagittal Plane Range	0.078	0.784
Trunk ROM Sagittal Plane Min	-0.135	0.631
Trunk ROM Sagittal Plane Max	0.029	0.919
Trunk ROM Transverse Plane Range	0.206	0.462
Trunk ROM Transverse Plane Min	0.094	0.740
Trunk ROM Transverse Plane Max	0.085	0.764

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$



<b>Phase 4</b>		
<b>Angular Displacement (°)</b>	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk ROM Frontal Plane Range	0.299	0.279
Trunk ROM Frontal Plane Min	-0.183	0.513
Trunk ROM Frontal Plane Max	-0.011	0.959
Trunk ROM Sagittal Plane Range	-0.183	0.513
Trunk ROM Sagittal Plane Min	0.578	0.024*
Trunk ROM Sagittal Plane Max	0.438	0.102
Trunk ROM Transverse Plane Range	0.381	0.161
Trunk ROM Transverse Plane Min	0.169	0.548
Trunk ROM Transverse Plane Max	0.306	0.267
<b>Lower Trunk (Lumbar)</b>		
Trunk ROM Frontal Plane Range	0.332	0.227
Trunk ROM Frontal Plane Min	0.328	0.232
Trunk ROM Frontal Plane Max	0.521	0.047*
Trunk ROM Sagittal Plane Range	0.039	0.892
Trunk ROM Sagittal Plane Min	-0.156	0.579
Trunk ROM Sagittal Plane Max	-0.020	0.943
Trunk ROM Transverse Plane Range	0.292	0.292
Trunk ROM Transverse Plane Min	0.141	0.616
Trunk ROM Transverse Plane Max	0.180	0.522

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

<b>Phase 4</b>		
<b>Angular Displacement (°)</b>	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk ROM Frontal Plane Range	-0.074	0.793
Trunk ROM Frontal Plane Min	0.437	0.103
Trunk ROM Frontal Plane Max	0.437	0.103
Trunk ROM Sagittal Plane Range	0.004	0.988
Trunk ROM Sagittal Plane Min	0.643	0.010*
Trunk ROM Sagittal Plane Max	0.581	0.023*
Trunk ROM Transverse Plane Range	0.078	0.781
Trunk ROM Transverse Plane Min	0.652	0.008*
Trunk ROM Transverse Plane Max	0.507	0.054
<b>Lower Trunk (Lumbar)</b>		
Trunk ROM Frontal Plane Range	0.016	0.953
Trunk ROM Frontal Plane Min	0.165	0.557
Trunk ROM Frontal Plane Max	0.214	0.443
Trunk ROM Sagittal Plane Range	-0.054	0.849
Trunk ROM Sagittal Plane Min	0.029	0.919
Trunk ROM Sagittal Plane Max	0.025	0.930
Trunk ROM Transverse Plane Range	-0.194	0.489
Trunk ROM Transverse Plane Min	0.062	0.827
Trunk ROM Transverse Plane Max	-0.124	0.660

\*Significance at  $p < 0.05$ \*\*Significance at  $p < 0.001$

Addendum R: Kinematic Parameter – Angular Velocity and Comparison with  
Physiotherapy Outcome Measure

<b>Phase 1</b>		
<b>Angular Velocity (°/s)</b>	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk Velocity Frontal Plane Peak Negative	0.316	0.252
Trunk Velocity Frontal Plane Peak Positive	-0.263	0.343
Trunk Velocity Sagittal Plane Peak Negative	-0.177	0.529
Trunk Velocity Sagittal Plane Peak Positive	0.180	0.520
Trunk Velocity Transverse Plane Peak Negative	0.267	0.336
Trunk Velocity Transverse Plane Peak Positive	-0.022	0.939
<b>Lower Trunk (Lumbar)</b>		
Trunk Velocity Frontal Plane Peak Negative	-0.016	0.954
Trunk Velocity Frontal Plane Peak Positive	-0.254	0.360
Trunk Velocity Sagittal Plane Peak Negative	-0.110	0.696
Trunk Velocity Sagittal Plane Peak Positive	0.249	0.371
Trunk Velocity Transverse Plane Peak Negative	0.233	0.404
Trunk Velocity Transverse Plane Peak Positive	-0.022	0.939

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

<b>Phase 1</b>		
<b>Angular Velocity (°/s)</b>	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk Velocity Frontal Plane Peak Negative	0.396	0.144
Trunk Velocity Frontal Plane Peak Positive	-0.101	0.721
Trunk Velocity Sagittal Plane Peak Negative	-0.143	0.611
Trunk Velocity Sagittal Plane Peak Positive	0.090	0.750
Trunk Velocity Transverse Plane Peak Negative	0.039	0.892
Trunk Velocity Transverse Plane Peak Positive	-0.119	0.672
<b>Lower Trunk (Lumbar)</b>		
Trunk Velocity Frontal Plane Peak Negative	0.149	0.597
Trunk Velocity Frontal Plane Peak Positive	-0.090	0.750
Trunk Velocity Sagittal Plane Peak Negative	-0.037	0.897
Trunk Velocity Sagittal Plane Peak Positive	0.249	0.370
Trunk Velocity Transverse Plane Peak Negative	0.121	0.667
Trunk Velocity Transverse Plane Peak Positive	-0.092	0.745

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

<b>Phase 1</b>		
<b>Angular Velocity (°/s)</b>	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk Velocity Frontal Plane Peak Negative	0.293	0.290
Trunk Velocity Frontal Plane Peak Positive	-0.219	0.434
Trunk Velocity Sagittal Plane Peak Negative	0.103	0.715
Trunk Velocity Sagittal Plane Peak Positive	0.536	0.039*
Trunk Velocity Transverse Plane Peak Negative	0.276	0.319
Trunk Velocity Transverse Plane Peak Positive	-0.087	0.759
<b>Lower Trunk (Lumbar)</b>		
Trunk Velocity Frontal Plane Peak Negative	-0.029	0.919
Trunk Velocity Frontal Plane Peak Positive	-0.289	0.297
Trunk Velocity Sagittal Plane Peak Negative	-0.087	0.759
Trunk Velocity Sagittal Plane Peak Positive	0.400	0.140
Trunk Velocity Transverse Plane Peak Negative	0.264	0.342
Trunk Velocity Transverse Plane Peak Positive	-0.099	0.726

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

<b>Phase 2</b>		
<b>Angular Velocity (°/s)</b>	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk Velocity Frontal Plane Peak Negative	-0.032	0.909
Trunk Velocity Frontal Plane Peak Positive	-0.358	0.096
Trunk Velocity Sagittal Plane Peak Negative	-0.525	0.045*
Trunk Velocity Sagittal Plane Peak Positive	-0.087	0.759
Trunk Velocity Transverse Plane Peak Negative	0.568	0.027*
Trunk Velocity Transverse Plane Peak Positive	0.141	0.617
<b>Lower Trunk (Lumbar)</b>		
Trunk Velocity Frontal Plane Peak Negative	-0.211	0.450
Trunk Velocity Frontal Plane Peak Positive	-0.092	0.744
Trunk Velocity Sagittal Plane Peak Negative	-0.548	0.034*
Trunk Velocity Sagittal Plane Peak Positive	0.138	0.813
Trunk Velocity Transverse Plane Peak Negative	0.119	0.673
Trunk Velocity Transverse Plane Peak Positive	0.378	0.090

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

<b>Phase 2</b>		
<b>Angular Velocity (°/s)</b>	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk Velocity Frontal Plane Peak Negative	-0.128	0.648
Trunk Velocity Frontal Plane Peak Positive	-0.358	0.191
Trunk Velocity Sagittal Plane Peak Negative	-0.468	0.079
Trunk Velocity Sagittal Plane Peak Positive	-0.017	0.953
Trunk Velocity Transverse Plane Peak Negative	0.504	0.055
Trunk Velocity Transverse Plane Peak Positive	0.167	0.552
<b>Lower Trunk (Lumbar)</b>		
Trunk Velocity Frontal Plane Peak Negative	-0.101	0.721
Trunk Velocity Frontal Plane Peak Positive	-0.106	0.706
Trunk Velocity Sagittal Plane Peak Negative	-0.521	0.047*
Trunk Velocity Sagittal Plane Peak Positive	0.138	0.625
Trunk Velocity Transverse Plane Peak Negative	0.154	0.584
Trunk Velocity Transverse Plane Peak Positive	0.378	0.165

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

<b>Phase 2</b>		
<b>Angular Velocity (°/s)</b>	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk Velocity Frontal Plane Peak Negative	0.289	0.297
Trunk Velocity Frontal Plane Peak Positive	-0.252	0.366
Trunk Velocity Sagittal Plane Peak Negative	-0.264	0.342
Trunk Velocity Sagittal Plane Peak Positive	-0.190	0.498
Trunk Velocity Transverse Plane Peak Negative	0.223	0.425
Trunk Velocity Transverse Plane Peak Positive	0.033	0.907
<b>Lower Trunk (Lumbar)</b>		
Trunk Velocity Frontal Plane Peak Negative	-0.115	0.682
Trunk Velocity Frontal Plane Peak Positive	-0.021	0.942
Trunk Velocity Sagittal Plane Peak Negative	-0.375	0.168
Trunk Velocity Sagittal Plane Peak Positive	-0.132	0.639
Trunk Velocity Transverse Plane Peak Negative	0.029	0.919
Trunk Velocity Transverse Plane Peak Positive	0.115	0.682

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$



<b>Phase 3</b>		
<b>Angular Velocity (°/s)</b>	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk Velocity Frontal Plane Peak Negative	0.202	0.470
Trunk Velocity Frontal Plane Peak Positive	-0.191	0.495
Trunk Velocity Sagittal Plane Peak Negative	-0.220	0.431
Trunk Velocity Sagittal Plane Peak Positive	0.301	0.275
Trunk Velocity Transverse Plane Peak Negative	0.050	0.858
Trunk Velocity Transverse Plane Peak Positive	-0.040	0.888
<b>Lower Trunk (Lumbar)</b>		
Trunk Velocity Frontal Plane Peak Negative	0.480	0.070
Trunk Velocity Frontal Plane Peak Positive	0.018	0.949
Trunk Velocity Sagittal Plane Peak Negative	0.117	0.677
Trunk Velocity Sagittal Plane Peak Positive	0.060	0.833
Trunk Velocity Transverse Plane Peak Negative	-0.056	0.843
Trunk Velocity Transverse Plane Peak Positive	-0.287	0.300

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

<b>Phase 3</b>		
<b>Angular Velocity (°/s)</b>	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk Velocity Frontal Plane Peak Negative	0.002	0.995
Trunk Velocity Frontal Plane Peak Positive	-0.354	0.196
Trunk Velocity Sagittal Plane Peak Negative	-0.224	0.423
Trunk Velocity Sagittal Plane Peak Positive	0.266	0.338
Trunk Velocity Transverse Plane Peak Negative	0.138	0.625
Trunk Velocity Transverse Plane Peak Positive	0.072	0.800
<b>Lower Trunk (Lumbar)</b>		
Trunk Velocity Frontal Plane Peak Negative	0.431	0.109
Trunk Velocity Frontal Plane Peak Positive	-0.123	0.663
Trunk Velocity Sagittal Plane Peak Negative	-0.002	0.995
Trunk Velocity Sagittal Plane Peak Positive	-0.051	0.856
Trunk Velocity Transverse Plane Peak Negative	-0.007	0.979
Trunk Velocity Transverse Plane Peak Positive	-0.222	0.427

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

<b>Phase 3</b>		
<b>Angular Velocity (°/s)</b>	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk Velocity Frontal Plane Peak Negative	0.318	0.249
Trunk Velocity Frontal Plane Peak Positive	-0.037	0.896
Trunk Velocity Sagittal Plane Peak Negative	-0.223	0.425
Trunk Velocity Sagittal Plane Peak Positive	0.120	0.671
Trunk Velocity Transverse Plane Peak Negative	0.157	0.577
Trunk Velocity Transverse Plane Peak Positive	-0.153	0.587
<b>Lower Trunk (Lumbar)</b>		
Trunk Velocity Frontal Plane Peak Negative	0.433	0.107
Trunk Velocity Frontal Plane Peak Positive	0.074	0.793
Trunk Velocity Sagittal Plane Peak Negative	0.190	0.498
Trunk Velocity Sagittal Plane Peak Positive	0.132	0.639
Trunk Velocity Transverse Plane Peak Negative	0.140	0.618
Trunk Velocity Transverse Plane Peak Positive	-0.276	0.319

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

<b>Phase 4</b>		
<b>Angular Velocity (°/s)</b>	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk Velocity Frontal Plane Peak Negative	-0.262	0.346
Trunk Velocity Frontal Plane Peak Positive	0.188	0.503
Trunk Velocity Sagittal Plane Peak Negative	-0.312	0.258
Trunk Velocity Sagittal Plane Peak Positive	0.173	0.537
Trunk Velocity Transverse Plane Peak Negative	-0.162	0.563
Trunk Velocity Transverse Plane Peak Positive	0.393	0.147
<b>Lower Trunk (Lumbar)</b>		
Trunk Velocity Frontal Plane Peak Negative	-0.236	0.397
Trunk Velocity Frontal Plane Peak Positive	0.121	0.668
Trunk Velocity Sagittal Plane Peak Negative	-0.344	0.209
Trunk Velocity Sagittal Plane Peak Positive	0.067	0.813
Trunk Velocity Transverse Plane Peak Negative	0.027	0.924
Trunk Velocity Transverse Plane Peak Positive	0.137	0.626

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

<b>Phase 4</b>		
<b>Angular Velocity (°/s)</b>	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk Velocity Frontal Plane Peak Negative	-0.248	0.374
Trunk Velocity Frontal Plane Peak Positive	0.187	0.504
Trunk Velocity Sagittal Plane Peak Negative	-0.180	0.522
Trunk Velocity Sagittal Plane Peak Positive	0.117	0.677
Trunk Velocity Transverse Plane Peak Negative	-0.198	0.479
Trunk Velocity Transverse Plane Peak Positive	0.435	0.105
<b>Lower Trunk (Lumbar)</b>		
Trunk Velocity Frontal Plane Peak Negative	-0.253	0.363
Trunk Velocity Frontal Plane Peak Positive	0.160	0.570
Trunk Velocity Sagittal Plane Peak Negative	-0.299	0.279
Trunk Velocity Sagittal Plane Peak Positive	0.007	0.979
Trunk Velocity Transverse Plane Peak Negative	0.015	0.959
Trunk Velocity Transverse Plane Peak Positive	0.202	0.471

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

<b>Phase 4</b>		
<b>Angular Velocity (°/s)</b>	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
<b>Upper Trunk (Thoracic)</b>		
Trunk Velocity Frontal Plane Peak Negative	-0.004	0.988
Trunk Velocity Frontal Plane Peak Positive	-0.107	0.704
Trunk Velocity Sagittal Plane Peak Negative	-0.148	0.597
Trunk Velocity Sagittal Plane Peak Positive	-0.144	0.608
Trunk Velocity Transverse Plane Peak Negative	0.177	0.527
Trunk Velocity Transverse Plane Peak Positive	-0.115	0.682
<b>Lower Trunk (Lumbar)</b>		
Trunk Velocity Frontal Plane Peak Negative	0.054	0.849
Trunk Velocity Frontal Plane Peak Positive	-0.264	0.342
Trunk Velocity Sagittal Plane Peak Negative	-0.045	0.872
Trunk Velocity Sagittal Plane Peak Positive	-0.173	0.537
Trunk Velocity Transverse Plane Peak Negative	0.239	0.391
Trunk Velocity Transverse Plane Peak Positive	-0.206	0.461

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$

Addendum S: Kinematic Parameter – Acceleration and Comparison with Physiotherapy Outcome Measure

<b>Raw Acceleration</b>	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
Thoracic Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.280	0.313
Lumbar Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.101	0.720

\*Significance at p<0.05

\*\*Significance at p<0.001

<b>Raw Acceleration</b>	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>
Thoracic Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.341	0.213
Lumbar Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.205	0.463

\*Significance at p<0.05

\*\*Significance at p<0.001

<b>Raw Acceleration</b>	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
Thoracic Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	-0.272	0.326
Lumbar Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	-0.400	0.140

\*Significance at p<0.05

\*\*Significance at p<0.001

<b>Scaled Acceleration</b>	<b>Correlation Coefficient</b>	<b>Total TIS (p-value)</b>
Thoracic Medio-Lateral Sway Acceleration (m/s <sup>2</sup> )	-0.449	0.093
Thoracic Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.240	0.389
Thoracic Antero-Posterior Sway Acceleration (m/s <sup>2</sup> )	-0.096	0.735
Thoracic Jerk Sum Transverse Plane (m/s <sup>2</sup> )	-0.014	0.959
Thoracic AUC Transverse Plane (m/s)	-0.020	0.944
Lumbar Medio-Lateral Sway Acceleration (m/s <sup>2</sup> )	-0.283	0.306
Lumbar Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.124	0.659
Lumbar Antero-Posterior Sway Acceleration (m/s <sup>2</sup> )	-0.454	0.089
Lumbar Jerk Sum Transverse Plane (m/s <sup>2</sup> )	-0.117	0.677
Lumbar AUC Transverse Plane (m/s)	-0.029	0.919

\*Significance at p&lt;0.05

\*\*Significance at p&lt;0.001

<b>Scaled Acceleration</b>	<b>Correlation Coefficient</b>	<b>Dynamic Subscale (p-value)</b>
Thoracic Medio-Lateral Sway Acceleration (m/s <sup>2</sup> )	-0.523	0.046*
Thoracic Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.207	0.459
Thoracic Antero-Posterior Sway Acceleration (m/s <sup>2</sup> )	0.099	0.725
Thoracic Jerk Sum Transverse Plane (m/s <sup>2</sup> )	0.013	0.964
Thoracic AUC Transverse Plane (m/s)	-0.004	0.990
Lumbar Medio-Lateral Sway Acceleration (m/s <sup>2</sup> )	-0.202	0.471
Lumbar Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.271	0.328
Lumbar Antero-Posterior Sway Acceleration (m/s <sup>2</sup> )	-0.367	0.179
Lumbar Jerk Sum Transverse Plane (m/s <sup>2</sup> )	-0.180	0.522
Lumbar AUC Transverse Plane (m/s)	-0.055	0.846

\*Significance at p&lt;0.05

\*\*Significance at p&lt;0.001



<b>Scaled Acceleration</b>	<b>Correlation Coefficient</b>	<b>Coordination Subscale (p-value)</b>
Thoracic Medio-Lateral Sway Acceleration (m/s <sup>2</sup> )	0.045	0.872
Thoracic Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	0.256	0.358
Thoracic Antero-Posterior Sway Acceleration (m/s <sup>2</sup> )	-0.478	0.071
Thoracic Jerk Sum Transverse Plane (m/s <sup>2</sup> )	0.214	0.443
Thoracic AUC Transverse Plane (m/s)	0.186	0.508
Lumbar Medio-Lateral Sway Acceleration (m/s <sup>2</sup> )	-0.190	0.498
Lumbar Vertical Translation Sway Acceleration (m/s <sup>2</sup> )	-0.239	0.391
Lumbar Antero-Posterior Sway Acceleration (m/s <sup>2</sup> )	-0.433	0.107
Lumbar Jerk Sum Transverse Plane (m/s <sup>2</sup> )	0.214	0.443
Lumbar AUC Transverse Plane (m/s)	0.202	0.470

\*Significance at  $p < 0.05$

\*\*Significance at  $p < 0.001$