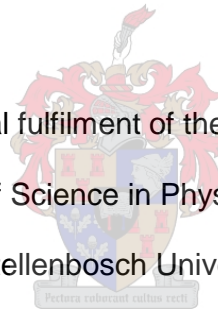


# **An Investigation into the Trunk Kinematics of People with Stroke during Gait**

by  
**Adnil W Titus**

Thesis presented in partial fulfilment of the requirements for the degree  
Master of Science in Physiotherapy at  
Stellenbosch University



Supervisors: Mrs G Inglis-Jassiem and Prof. S Hillier

December 2015

## **Declaration**

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Date: December 2015

## **Abstract**

### **Introduction**

The trunk plays an important role in the symmetry, balance and stability of the lower and upper body during gait. Approximately two out of three people with stroke experience gait restrictions.

### **Objective**

To describe the three dimensional kinematics of the trunk during gait in people with stroke.

### **Methods**

Seventeen subjects that met the following inclusion criteria: males and females 18 years and older; a single cardiovascular incident; ability to follow simple instructions and to walk 10 metres without assistive devices; were recruited by means of convenience sampling for this observational pilot study.

The eight-camera T-10 Vicon system with Nexus 1.8 software and the Plug-in-Gait (PiG) model (Vicon Motion System Limited, Oxford, UK) were used to capture the participants during walking at a self-selected speed. Thorax kinematics and temperospatial parameters were analysed in MATLAB (The Mathworks, Natrick, MA) using custom built scripts. The differences between the two sides of the trunk (affected and less-affected) were calculated using the Sign test (statistical significance level  $p < 0.05$ ) (Stata software).

### **Results**

During the full gait cycle there were statistically significant differences of thorax motion between the affected and the less-affected side in the coronal plane ( $p = 0.049$ ) and pelvic motion in the sagittal plane ( $p = 0.049$ ). At initial contact and foot off there were statistically significant differences of thorax motion between the affected and the less-affected side in all three planes, whereas the pelvic motion was only significantly different in the sagittal plane ( $p = 0.000$ ). In terms of temperospatial parameters, the participants showed symmetry in step/stride length and step/stride time. They managed functional gait speeds although they presented with asymmetrical thorax kinematics.

## **Conclusion**

This pilot study found significant asymmetry in thorax motion between the affected and less-affected sides of people with stroke.

## **Key Words**

Gait, stroke, three dimensional, kinematics, thorax, trunk.

## Opsomming

### Inleiding

Die romp speel 'n belangrike rol in die simmetrie, balans en stabiliteit van die bo- en onderlyf gedurende loopgang. Ongeveer twee uit drie mense met beroerte ondervind ingekorte loopgang

### Oogmerk

Om die drie dimensionele kinematika van die romp gedurende loopgang in mense met beroerte te beskryf.

### Metodologie

Sewentien deelnemers wat aan die in- en uitsluit vereistes voldoen (mans en vroue 18 jaar en ouer, 'n enkele kardiovaskulêre insident, die vermoë om 'n eenvoudige opdrag te kan volg en om 'n 10m afstand sonder hulpmiddels te kan loop) was deur middel van gerieflikheidsteekproefneming vir hierdie waarnemings loodstudie gewarf.

Die agt-kamera T10 Vicon sisteem met Nexus 1.8 sagteware en die "Plug-in Gait" model (Vicon Motion System Limited, Oxford, UK) was gebruik om die deelnemers se loopgang gedurende die selfgekoose spoed op te neem. Torakal kinematika en tempero-ruimtelike parameters was in *MATLAB* (The Mathworks, Natick, MA) geanaliseer deur middel van spesiaal vervaardigde programme. Die verskille tussen die twee sye van die romp (geaffekteerd en minder-geaffekteerd) was bereken deur die *Sign* toets (statistiese beduidende verskille vlak  $p < 0.05$ ) (Stata sagteware).

### Resultate

Gedurende die volledige loopgang siklus was daar statistiese beduidende verskille van die toraks beweging tussen die geaffekteerde en minder-geaffekteerde kante in die koronale vlak ( $p=0.049$ ) en pelvis beweging in die sagitale vlak ( $p=0.049$ ). By aanvanklike kontak en die voorswaai was daar statisties beduidende verskille van die toraks tussen die geaffekteerde en die minder geaffekteerde sye, in al drie vlakke, waar die pelvis beweging slegs in die sagitale vlak beduidend verskillend was ( $p=0.000$ ). In terme van tempero-ruimtelik parameters het die deelnemers simmetrie in tree/ aftree lengte en tree/ aftree tyd getoon. Hulle het funksionele loopspoed handhaaf alhoewel hulle met asimmetriese torakale kinematika getoon het.

## **Gevolgtrekking**

Hierdie loodstudie het bevind dat beduidende asimmetrie in torakale beweging tussen die geaffekteerde en minder-geaffekteerde sye in mense met beroerte voorkom.

## **Sleutel woorde**

Loopgang, beroerte, drie dimensioneel, kinematika, toraks, romp.

## Acknowledgements

I would like to sincerely thank the following people:

- Funding – Divisional funds, Prof Q Louw, Mrs L Crous.
- My family and friends for unwavering support during this process.
- My colleagues for the support and interest shown.
- The staff of the 3D Vicon Motion Analysis laboratory at Stellenbosch University for their guidance and assistance.
- My supervisors, Prof. Susan Hillier and Mrs Gakeemah Inglis-Jassiem for their patience and perseverance while supervising this study.

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## List of Abbreviations

3D	Three dimensional
ADL	Activities of daily living
ASIS	Anterior superior iliac spine
BMI	Body Mass Index
DOH	Department of Health
HREC	Health Research Ethics Committee
LPD	Lateral pelvis displacement
MATLAB	The Matworks Natick, MA
NCD	Non-communicable disease
PiG	Plug-in-Gait
PSIS	Posterior superior iliac spine
ROM	Range of motion
WHO	World Health Organisation

## Chapter 1: Introduction

Stroke is one of the most devastating conditions worldwide. It accounts for approximately 5.5 million deaths annually and for 44 million disability-adjusted life-years lost (Mukherjee & Patil 2011). Hemiparesis is seen as the most common impairment after stroke and has a direct negative influence on the ability of the person to walk (Belda-Lois, Mena-del Horno, Bermejo-Bosch et al., 2011). Chen, Patten, Kothari and Zajac (2005) reported that hemiparetic gait is characterised by reduced walking speed, cadence, stride length, asymmetry in temporal and spatial parameters, as well as increased energy cost. Impairments that can have an effect on gait post stroke include muscle weakness, spasticity, altered selective motor control and proprioceptive changes (Balaban & Tok, 2014). Jang (2010) reported that although there is an overall improvement in gait throughout the first year post stroke, most of the motor recovery will occur within the first three to six months post stroke. Gait recovery is a major objective in the rehabilitation programme for people with stroke (Huitema, Hof, Mulder, Bouwer, Dekker, Postema, 2004) and this is reflected in a large body of literature developing methods to analyse and rehabilitate gait (Jang et al., 2010, Olney & Richards, 1996).

Schaechter (2004) reports that up to 50% of stroke survivors are at least partly dependent in activities of daily living (ADL) as a result of the stroke. Approximately two out of three people with stroke experience gait restrictions (Stanhope et al., 2014). Walking speed decreases post stroke and people with stroke perform significantly worse on most gait parameters than their age matched counterparts without stroke (Hacmon et al., 2012) with reports of walking speed being 36% slower than age-matched peers. Speed is commonly used as a yardstick for performance of gait in the post stroke population.

There are varying degrees of asymmetry in gait post stroke (Balaban & Tok, 2014). Symmetry is linked to the control of the gait pattern, by specifically referring to the step length, stance time and swing time (Patterson et al., 2010). The lack of sufficient motor control, disturbed postural control and decreased weight bearing of the affected lower limb leads to an asymmetrical gait pattern (Balaban & Tok, 2014). Chen et al. (2005) reported that step length asymmetry was prominent in people with stroke and was due to limited hip extension on the paretic side, leading to the body

not being sufficiently propelled forward (Chen et al., 2005). A wider step width was also noted to compensate for the poor balance.

A further contribution to the reported gait restrictions post stroke, is the decreased ability of the hip flexors to initiate the swing phase and plantar flexors during terminal stance to propel the paretic leg forward. The paretic leg has a reduced ability to swing through and needs the trunk to assist by lifting the leg or by circumduction. People with stroke make use of circumduction to counteract the deficits created by the reduced knee flexion and ankle dorsiflexion when increasing their walking speed (Stanhope et al., 2014). These serve as compensation, but are not mechanically energy efficient. The non-paretic leg also has a reduced swing time because of the difficulties with balance during the stance phase of the paretic leg (Chen et al., 2005). Karthikbabu et al. (2011) reported that there is a close link between trunk control, balance, gait and functional ability in people with stroke.

Trunk control is defined as the ability of the muscles of the trunk to maintain an upright position, to weight shift and to selectively move to maintain the centre of gravity over the base of support (Karthikbabu et al., 2011). In 1996 De Leva defined the area between the mid-point of the hip joint centres caudally, and the mid-point between the shoulder joint centres cranially as the thorax segment.

Trunk stability is defined by Butcher et al. (2007) as the ability to maintain active control of the spinal and pelvic posture during movement. Trunk stability is often overlooked as an integral component of balance and coordinated extremity use as needed to perform daily functional activities (Ryerson et al., 2008). The muscles of the trunk are designed to actively contribute to trunk balance during functional activities (Ceccato, 2009). Karthikbabu et al. in 2011 defined trunk control as the ability of the muscles of the trunk to ensure upright alignment and ensuring that the weight is shifted during activities so that the body's centre of mass is maintained over the base of support both during dynamic and static postures. Trunk control is needed to maintain symmetry and balance in walking (Karthikbabu et al., 2011). The trunk plays an important part in stability in both the lower and upper portion of the body during gait (Cromwell, 2001; Carmo et al., 2012).

Kinematics is the science of describing the motion of body segments in the three planes of movement (Shumway-Cook & Woollacott, 2010). It is important to describe

the kinematics of normal as well as abnormal movements and particularly for the activity of gait (Shumway-Cook & Woollacott, 2010). Such information will be useful for both researchers and clinicians to better understand pathomechanics in people with altered movement such as those who have suffered stroke. Kinematic studies in normal individuals report a forward inclination of the trunk in the sagittal plane, a lateral flexion in the coronal plane and a counter rotation between upper and lower trunk segments in the horizontal plane (Hacmon et al., 2012) throughout the gait cycle. In-phase rotation was defined as the pelvis and the trunk moving in the same direction, with anti-phase or counter rotation being the opposite (Seay et al., 2011).

During gait it was found that joint kinematics are different for people with hemiparesis compared to people who are considered healthy (Balaban & Tok, 2014). Earlier kinematic research placed emphasis on the pelvis and its role in gait and not the trunk segments above the pelvis. Tyson (1999) reported on trunk movement, but her findings focussed mainly on lateral movement and did not report on movements in the remaining two movement planes. The inference from the predominant trunk motion described is that during gait the upper limbs swing forward and backward as the contra lateral leg moves forward and backward. A contralateral rotation of the upper torso relative to the pelvis is thus observed (Hacmon et al., 2012).

Whilst hemiparetic gait post stroke has received a lot of interest in the literature, one aspect that has not been characterised well is the action of the trunk during gait. Frigo and Crenna (2009) have also identified a need for in-depth evaluation and biomechanical analysis of the thorax and limbs during different motor tasks. This study aims to investigate the three dimensional kinematics of the trunk during gait in people with stroke.

## Chapter 2: Literature Review

### 2.1 Stroke

Stroke is emerging as a major global health concern. This is in terms of both mortality and even more so with regard to ongoing major disability (Wissel, Olver & Sunnerhagen, 2013). Stroke has been defined by the World Health Organisation (WHO) (Aarli et al. 2006) as a “clinical syndrome of rapid onset of focal (or global, as in subarachnoid haemorrhage) cerebral deficit, lasting more than 24 hours (unless interrupted by surgery or death), with no apparent cause other than a vascular one”. Risk factors for stroke are those that underpin other cardiovascular disease and include modifiable and non-modifiable factors. The non-modifiable risk factors include age and gender, whereas the modifiable risk factors include hypertension, hypercholesterolaemia, diabetes mellitus (type II), tobacco smoking, physical inactivity and obesity (O’Donnell et al. 2010).

Global statistics indicate a mortality rate for stroke of 5.5 million annually. Furthermore, stroke results in 44 million disability-adjusted life-years lost (Mukherjee & Patil 2011). Due to a global increase in the ageing population, and stroke being a disease of ageing, it is expected that there will be an increase in the incidence of stroke (Mukherjee & Patil 2011). In South Africa non-communicable diseases (NCDs) account for 37% of all-cause mortality with ischaemic heart disease and stroke responsible for 6.6% and 6.5% of all deaths respectively (Gray et al. 2013).

Feigin and Krishnamurthi (2011) report a marked increase in stroke incidence in developing countries. This is in contrast to a decline in the incidence of stroke in developed countries. In 2005, 16 million people suffered from a first-ever stroke globally, with an estimated prevalence of 62 million stroke survivors (Mukherjee & Patil 2011). Worldwide the number of people with incident ischaemic and haemorrhagic stroke increased by 37% and 47% respectively (Krishnamurthi, Feigin, Forouzanfar et al., 2013). In the past 20 years the largest increase in incidence of ischaemic stroke occurred in North and Sub-Saharan Africa (73-101 per 100000), the Middle East and Central and East Asia (Krishnamurthi et al., 2013).

According to the WHO, the burden of disease of non-communicable diseases is up to three times higher in South Africa than in developed countries. In Cape Town, for



example, a mortality rate study was done and showed that in Khayelitsha, a low socio-economic community, almost double the number of people died due to NCDs compared to the more affluent Northern and Southern Suburbs (856.4 per 100000 vs. 450-500 per 100000) (Mayosi et al. 2009).

Should the trend noted in these studies persist not only will the mortality rate of stroke in the developing countries (10% of all world deaths) increase, but the burden of disease will be detrimental to the health and economies of these countries (Feigin & Krishnamurthi, 2011).

## **2.2 Burden of disease**

Mortality associated with stroke is decreasing. This however leads to improved survival rates with residual disability. This increase in disability can be translated into placing an increasing strain on economy. (Mukherjee & Patil 2011). Opara and Jaracz (2010) also highlight that with many advances in medicine more people survive stroke.

In South Africa the burden of disease of NCDs seems to be affecting the poorer urban population more than the affluent population (Mayosi, 2009). This is linked to an increase in diseases of lifestyle such as hypertension and diabetes (Mayosi, 2009). One of the reasons predicted by Connor and Bryer in 2005 is a trend of urbanisation. This leads to lifestyle changes in the population which in turn leads to the population becoming more prone to developing modifiable risk factors like vascular disease which could lead to an increase in stroke. Historically the more prominent diseases in developing countries were linked to poverty and poor nutrition. This has been noted in the Indian population where, due to economic growth, the more prominent diseases have shifted from being diseases associated with poverty (more so being infectious diseases) towards an increase in NCDs of lifestyle (Pandian, 2007).

A suggestion from Pandian et al. (2007) is that stroke care should become a priority in India. All developing countries can aim towards this as it has been shown that, as in high income countries, with sustained intervention better results can be obtained and mortality reduced.

### **2.3 Stroke impact of function**

Fifty percent of stroke survivors are at least partly dependent in activities-of-daily-living (ADL) (Schaechter, 2004). Damasceno et al. (2010) reported that up to 70% of stroke survivors in Mozambique, have moderate to severe disability which affect function. Common functional deficits experienced by people with stroke include communication difficulties, visual spatial disorders, cognitive deficits, and hemiparesis. Hemiparesis specifically has a negative influence on the person's ability to walk functionally (Belda-Lois, 2011) with approximately two out of three people with stroke experiencing gait restrictions (Stanhope et al., 2014). The impairments leading to gait restrictions include spasticity and residual muscle weakness due to hemiparesis (Woolley, 2001) which results in a reduced walking speed (Verma, 2012). Balance and lower limb strength required for functional walking is also affected due to a decreased postural control of stroke survivors (Bale and Strand 2008; Kluding and Gajewski 2009 as cited by Verma 2012).

People with stroke who have gait disturbances, decreased balance and a reduced walking speed are therefore at a greater risk of falling. . Verma et al. (2012) reported that people with stroke have a four times higher risk of falling to the hemiparetic side and a ten times higher risk of sustaining a hip fracture than the normal population. Gait recovery is therefore a major objective in the rehabilitation programme for people with stroke and this is reflected in a large body of literature developing methods to analyse and rehabilitate gait (Olney & Richards, 1996).

### **2.4 The trunk in normal and post stroke gait**

In 1996 De Leva defined the trunk as the area between the mid-point of the hip joint centres caudally, and the mid-point between the shoulder joint centres cranially as the trunk segment. The trunk represents 60% of the total body mass. It allows for participation in various motor activities, while maintaining trunk balance (Ceccato et al., 2009). Trunk stability is defined by Butcher et al. (2007) as the ability to maintain active control of the spinal and pelvic posture during movement. Trunk stability is often overlooked as an integral component of balance and coordinated extremity use as needed to perform daily functional activities (Ryerson et al., 2008). Specific functional activities such as walking require the trunk to play a major role in providing stability not just for the lower body but, as demonstrated in the study by Cromwell et

al. (2001), as a stable base for the head and neck. Head movements also provide for body stability (Carmo et al., 2012).

Trunk control is defined as the ability of the muscles of the trunk to maintain an upright position, to shift weight and to selectively move to maintain the centre of gravity over the base of support (Karthikbabu et al., 2014). Proximal trunk control is a prerequisite for functional activities, limb activities and, more importantly, balance. The muscles of the trunk are designed to actively contribute to assist with balance during functional activities (Ceccato, 2009). Trunk control is needed to maintain balance and symmetry in walking (Kathikbabu et al., 2011). Post stroke there is an inability to activate muscle contractions on the affected side, which leads to reduced stability. This muscle weakness is not only due to a reduced central drive to use the muscles, but also potentially due to spasticity and the imbalance between the agonist and antagonists and hence asymmetry (Verma et al., 2012).

According to Perry (cited in Shumway-Cook and Woollacott, 2010) the components of gait related to the pelvis and hip movement occur in all three planes and around all three axes in the following ways: flexion and extension of the hip as well as pelvic tilt occurs in the sagittal plane; pelvic rotation occurs in the transverse plane and allows for an increase in stride lengths. The lateral shift or pelvic obliquity is identified during the stance phase of individual limbs as weight is shifted from one leg to another.

During normal gait there is a forward movement of the pelvis and counter-movement of the trunk or indirectly by the shoulder girdle by means of arm-swing (Bruijn et al., 2008; Lamoth et al., 2002). After stroke, the adaptation of timing between the trunk and the pelvis can lead to failure in this counter mechanism (Bruijn et al., 2008.). Wagenaar (1992) claimed that walking speed had an influence on the amount of rotation of the trunk. Lamoth (2002) found that at lower velocities (1.4 – 2.2 km/h) there was minimal counter-rotation between the trunk and the pelvis, but this increased as speed increased. Wagenaar (1992) also highlighted a higher thoracic rotation in people with stroke during higher speed but with no significant difference between pelvic rotation of people with stroke and normal subjects.

In 2010 Goutier et al. analysed the normal population during gait. Normal gait was defined in this study as participants able to walk unaided with no orthopaedic,

cognitive or rheumatologic condition likely to influence balance. A variable highlighting a decrease in overall stability, i.e. less likely to fall during gait, was trunk sway measured in degrees in the sagittal and coronal planes. This study included 40 participants: two groups of 20 with ten males and ten females in each group. In the younger group (mean age 23) instability occurred as the participants walked faster as well as slower than their preferred normal speeds. An increase in sway was equated to a decrease in overall stability during gait. In the older population (mean age 71) this increased sway occurred only when they walked faster than their normal speed, making them more stable at their normal and slower speeds. Gender differences were highlighted only in the younger population where young men were found to walk with greater movements in the sagittal plane than young women at faster than normal speeds. No gender differences were noted in the older population (Goutier et al., 2010).

## **2.5 Changes in temperospatial parameters post stroke**

The reason behind many of the temperospatial changes that occur post stroke could be ascribed to limited sensori-motor recovery post stroke, decreased balance and weak muscles (Balaban & Tok, 2014). Post stroke gait is characterised by asymmetry, decreased cadence, stride length and speed (Chen et al., 2005). Speed is commonly used as a yardstick for performance of gait in the post stroke population. Symmetry is linked to the control of the gait pattern, by specifically referring to the step length, stance time and swing time (Patterson et al., 2010). The lack of sufficient motor control, disturbed postural control and decreased weight bearing on the affected lower limb leads to an asymmetrical gait pattern (Balaban & Tok, 2014). Symmetry and smooth movements seen in normal gait, are replaced with mass pattern usage, leading to asymmetrical movements on the hemiparetic side. It has been reported that the temperospatial characteristic leading to this asymmetry, is the increased stance time on the unaffected limb. This was also interpreted as a prolonged swing time on the hemiparetic side (Balaban et al., 2014; Verma, 2012; Woolley, 2001). Karthikbabu et al. (2011) also reported that a decrease is noted in the cadence and walking speed post-stroke. People with stroke perform significantly worse during gait and balance activities than their age matched counterparts without stroke (Hacmon et al., 2012; Woolley, 2001). Karthikbabu et al. (2011) reported that there is a close link between trunk control, balance, gait and

functional ability in people with stroke. They suggested that the trunk is the segment maintaining an upright posture of the body, and plays an integral part in the static and dynamic stability of the body. This is achieved by means of active selective movements of the trunk to maintain the centre of gravity within the base of support (Karthikbabu et al., 2011).

In addition Stanhope et al. (2014) reported that these problems are also related to varying gait speeds and altered kinematics. Davies (2001) reported that people with stroke walk with an asymmetrical gait, and walk more slowly and carefully which requires more balance and energy (Olney et al., 1986, 1988 cited in Wagenaar 1992). This slower walking speed adopted by people with stroke has been shown to lead to significant decreased walking stability particularly in the mediolateral directions of the trunk (Kao et al., 2014). These authors used the body marker placed on the 7<sup>th</sup> cervical vertebra to measure trunk movement.

## **2.6 Kinematics**

Kinematics is the science of describing the motion of body segments in the three planes of movement (Shumway-Cook & Woollacott, 2010). It is also described as the branch of physics that deals with the characteristics of motion without regard for the effects of forces or mass. It is important to describe the kinematics of normal as well as abnormal movement and particularly for the activity of gait (Shumway-Cook & Woollacott, 2010). Such information will be useful for both researchers and clinicians to better understand pathomechanics in people with severely altered movement such as those after stroke.

In 1998 Dodd et al. identified the need to assess the gait patterns of people with hemiparesis. People with stroke presented with a need to be more functionally independent and had a normal gait pattern as a goal. Dodd et al. (2003) assessed the reliability of a three dimensional (3D) system on normal subjects' lateral pelvic displacement (LPD) during gait. They found that there was a relationship between LPD and walking speed in people with stroke. Their findings suggested that the faster the person walks, the more normal the LPD amplitude is, whereas when they walk slower, the larger the LPD amplitude is. The authors therefore recommend that clinicians evaluate LPD during clinical gait analysis. Tyson (1999) found by using another 3D motion analysis system (CODA) that the trunk showed larger lateral

movements during gait post stroke, with a marked decrease in movement towards the hemiparetic side.

More recently it has been confirmed that during gait joint kinematics are different for people with hemiparesis compared to people who are considered healthy (Balaban, et al., 2014). They suggested that there is an increase in lateral trunk sway and elevation of the hip to allow for improved foot clearance in people with stroke. In healthy individuals it was noted that in normal gait the trunk and pelvis kinematics remain in-phase, but change to anti-phase as the speed increases. In-phase was defined as the pelvis and the trunk moving in the same direction, with anti-phase being the opposite (Seay, et al., 2011). Boudarham et al. (2013) only reported on hip movement in the sagittal kinematic plane to identify deviations in hemiparetic gait. Their results indicated a link between gait velocity, hip extension range of motion in the stance phase and hip flexion range of motion in the swing phase. They suggest that an increase in the various ranges are associated with an increase in velocity. Their sample exhibited slow and cautious gait during the first trial, which the authors attributed to the sample attempting to maintain balance and stability.

To date literature searches have revealed that the majority of the studies related to kinematics during gait place a primary emphasis on the pelvis and its role and not on the trunk segments above the pelvis. As mentioned, Dodd et al. (2003) specifically assessed the lateral pelvic displacement during gait of people with hemiparesis. Tyson (1999) also reported on trunk movement, but her findings reported mainly on lateral movement and did not report on movements in the remaining two movement planes. The inference from the predominant trunk motion described is that during gait the upper limbs swing forward and backward as the contra lateral leg moves forward and backward, and it is assumed clinically that this is supported by a contralateral rotation of the upper torso relative to the pelvis (Hacmon et al., 2012). These researchers found that the stroke group's walking speed was 36% slower than the control group, and they used more thoracic motion (rotation) than pelvic transverse motion (rotation) than the age matched counterparts. People with stroke had weaker trunk muscles compared to their age counterparts, leading to an inability to move the trunk (Karatat M, Cetin N, Bayramoglu M, Dilek A., 2004). (Hacmon et al., 2012) suggested that the trunk can be seen as a predictor of post stroke

functional rehabilitation, but the thoracic/pelvic segmental range of motion and quality of movement are rarely assessed in the clinical setting.

Although gait post stroke has been described in the literature, one aspect that has not been characterised well is the action of the trunk during gait. Frigo and Crenna (2009) have also identified a need for in-depth evaluation and biomechanical analysis of the trunk and limbs during different motor tasks.

## **2.7 Summary**

In summary, stroke is a highly prevalent disease that results in a high residual burden of disease. One of the ways this burden manifests for the stroke survivor is in reduced ability to walk independently and effectively. Whilst hemiparetic gait post stroke has received a lot of interest in the clinical research literature, one aspect that has not been characterised well is the action of the trunk during gait and how it is impacted by stroke. Our study aims to address this lack of descriptive information of the three dimensional kinematics of the trunk during gait in people with stroke.

## **Chapter 3: The Manuscript**

Manuscript to be submitted to the Archives of Physical medicine and Rehabilitation

Author Guidelines are included as Appendix 10.



## **An Investigation into the Trunk Kinematics of People with Stroke during Gait**

Authors: Titus A W, Inglis-Jassiem G, Hillier S

Institution affiliations of authors:

A W Titus: Physiotherapy Division, Stellenbosch University

G Inglis-Jassiem: Physiotherapy Division, Stellenbosch University

S Hillier: University of South Australia

Corresponding Author:

A W Titus

Physiotherapy Division

Stellenbosch University

PO Box 241

Cape Town

8000

+27 21 938 9083

## **Abstract**

### **Introduction**

The trunk plays an important role in the symmetry, balance and stability of the lower and upper body during gait. Approximately two out of three people with stroke experience gait restrictions.

### **Objective**

To describe the three dimensional kinematics of the trunk during gait in people with stroke.

### **Methods**

Seventeen subjects that met the following inclusion criteria: males and females 18 years and older; a single cardiovascular incident; ability to follow simple instructions and to walk 10 metres without assistive devices; were recruited by means of convenience sampling for this cross-sectional pilot study.

The eight-camera T-10 Vicon (Ltd) (Oxford, UK) system with Nexus 1.8 software and the Plug-in-Gait (PIG) model (Vicon Motion System Limited, Oxford, UK) were used to capture the participants during self-selected speed walking. Thorax kinematics and temperospatial parameters were performed in MATLAB (The Mathworks, Natrick, MA) using custom-built scripts. The differences between the two sides (affected and unaffected) were calculated using the Sign test (statistical significance level  $p < 0.05$ ) (Stata software).

### **Results**

During the full gait cycle there were statistically significant differences of thorax motion between the affected and the unaffected side in the coronal plane ( $p = 0.049$ ) and pelvic motion in the sagittal plane ( $p = 0.049$ ). At initial contact and foot off there were statistically significant differences of thorax motion between the affected and the less-affected side in all three planes, whereas the pelvic motion was only significantly different in the sagittal plane ( $p = 0.000$ ). In terms of temperospatial parameters, the participants showed symmetry in step/stride length and step/stride

time. They managed functional gait speeds although they presented with asymmetrical thorax kinematics.

### **Conclusion**

This pilot study found significant asymmetry in thorax motion between the affected and less-affected sides.

### **Key Words**

Gait, stroke, three dimensional, kinematics, thorax, trunk.

### 3.1 Introduction

Stroke is as an increasingly major global health concern in terms of mortality and even more so with regard to chronic disability (Wissel et al. 2013). Approximately two out of three people with stroke experience gait restrictions (Stanhope et al. 2014). Karthikbabu et al. (2011) reported that there is a close link between trunk control, balance, gait and functional ability in people with stroke. Trunk stability is often overlooked as an integral component of balance and coordinated extremity use as needed to perform daily functional activities (Ryerson et al. 2008).

In 1996 De Leva et al. defined the area between the mid-point of the hip joint centres caudally, and the mid-point between the shoulder joint centres cranially as the thorax segment. The thorax, also known as the trunk, represents 60% of the total body mass. Trunk control is defined as the ability of the muscles of the trunk to maintain an upright position, to weight shift and to selectively move to maintain the centre of gravity over the base of support (Karthikbabu et al. 2011). The muscles of the trunk are designed to actively contribute to balance during functional activities (Ceccato et al. 2009). Trunk control is needed to maintain symmetry and balance in walking (Karthikbabu et al. 2011); (Cromwell et al. 2001; Carmo et al. 2012). Kinematic studies of normal gait report a forward inclination of the trunk in the sagittal plane, lateral flexion in the coronal plane and a counter rotation between upper and lower trunk segments in the horizontal plane (Lamoth et al. 2002) throughout the gait cycle.

It has been reported that joint kinematics during gait are different for people with hemiparesis compared to people who are considered healthy (Balaban & Tok 2014). Earlier kinematic research placed emphasis on the pelvis and its role in gait and not on the trunk segments above the pelvis. Dodd and Morris (2003) specifically assessed the lateral pelvic displacement during gait of people with hemiparesis. Tyson (1999) also reported on trunk movement, but her findings focussed mainly on lateral movement and did not report on movements in the remaining two movement planes. The inference from the predominant trunk motion described is that during gait the upper limbs swing forward and backward as the contra lateral leg moves forward and backward (Hacmon et al., 2012). A contralateral rotation of the upper torso relative to the pelvis is thus observed. Dodd and Morris (2003) reported that participants with stroke used more thoracic motion (rotation) than pelvic transverse motion (rotation) compared with their age matched counterparts. People with stroke

had weaker trunk muscles compared to their age counterparts, leading to an inability to move the trunk (Karactas M, Cetin N, Bayramoglu M, Dilek A., 2004). (Hacmon et al., 2012) suggested that the trunk can be seen as a predictor of post stroke functional rehabilitation, but the thoracic/pelvic segmental range of motion and quality of movement are rarely assessed in the clinical setting

Whilst hemiparetic gait post stroke has received a lot of interest in the literature, one aspect that has not been characterised well is the action of the trunk during gait. Frigo and Crenna (2009) have also identified a need for in-depth evaluation and biomechanical analysis of the trunk and limbs during different motor tasks. This study aims to address this lack of descriptive information of the three dimensional kinematics of the thorax during gait in people with stroke.

### **3.2 Methods**

Ethical approval was granted by the Human Research Ethics Committee (HREC) of Stellenbosch University (reference number: S13/03/056) to conduct this observational descriptive study. Permission was granted by the Department of Health (DOH) of the Western Cape to recruit subjects from a community based rehabilitation centre. All subjects provided written, informed consent.

### **3.3 Sample**

Seventeen subjects were recruited by means of convenience sampling. They met the following inclusion criteria: males and females 18 years and older; a single cardiovascular incident resulting in stroke; ability to follow simple instructions and the ability to walk 10 metres without assistive devices. Subjects with bilateral signs, orthopaedic or neurological pathologies that influence gait, and any known allergies to the adhesive tape used during testing procedures were excluded.

### **3.4 Procedures**

The study was conducted at the Stellenbosch University 3D Movement Analysis Laboratory which uses an eight-camera T-10 Vicon (Ltd) (Oxford, UK) system with Nexus 1.8 software. The Plug-in-Gait (PiG) model (Vicon Motion System Limited, Oxford, UK) was used to capture the three dimensional motion of the participants during walking at a self-selected comfortable speed. The Vicon Motion Analysis

system is regarded as the gold standard in 3D movement analysis due to its good reliability and validity (McGinley et al. 2009).

### **3.4.1 Subject preparation**

The PiG model offers a standardised procedure for the identification and placement of 22 body markers. A physical evaluation was performed by the researcher prior to the participants' gait analysis (Appendix 11). Anthropometric measurements, including height, weight, leg length, knee and ankle width were taken by an experienced laboratory technician, a qualified physiotherapist, specifically trained on the Vicon System.

### **3.4.2 Definition of trunk**

The PiG model refers to the trunk as the thorax and defines it in three dimensions using cardan angles. The Z axis points downwards (longitudinal axis) and is perpendicular to the transverse plane, calculated from the midpoint between cervical spinous process 7 (C7) and the sternal notch (CLAV) to the midpoint of thoracic spinous process 10 (T10) and xiphoid process of the sternum (STRN). The X axis points forward (sagittal axis) and is calculated from the midpoint between C7 and T10 to the midpoint between CLAV and STRN; this axis is perpendicular to the coronal plane. The Y axis (coronal/transverse axis) points right, perpendicular to the X and Z axes, and runs perpendicular to the sagittal plane (Vicon Plug-in Gait Product Guide, 2010).

Anterior and posterior movement of the thorax (sagittal plane) refers to the thorax rotating latero-laterally, resulting in the anterior and posterior movements or tilting (Struyf et al. 2011). In the coronal plane during normal gait, Ceccato et al. (2009) describe the lateral movement of the trunk as a sideways curvature to the last swinging leg. The assumption is that this curvature is concave to the leg that is now in the stance phase. Thorax rotation (transverse plane) is anti-phase to the motion of the pelvis (Bruijn et al. 2008).

Pelvic tilt (sagittal plane) is established by drawing a line between the posterior superior iliac spine (PSIS) and the anterior superior iliac spine (ASIS) and the horizontal plane. Anterior tilt is defined as the increased angle between the line drawn and the horizontal plane. This is due to the ASIS moving inferiorly and the PSIS moving superiorly (Alviso et al. 1988). Lateral pelvic displacement (coronal

plane) is described as a side to side motion of the pelvis during walking. This is often measured as a symmetry score where 0 indicates equal length in the lateral displacement of the pelvis from the midline. During normal forward movement the pelvis rotates in the horizontal plane, and as discussed earlier, there is a normal forward motion in the horizontal plane of the thorax on the contra lateral side (Lamoth et al. 2002).

### **3.4.3 Calibration**

System calibration was performed as per the standard Vicon guidelines (Vicon Plug-in-Gait Product Guide, 2010). Subject calibration was performed for each participant, before they commenced walking using a static pose trial.

### **3.4.4 Gait capturing**

Participants were instructed to walk at a self-selected, comfortable speed along a 10 metre length for a total of 12 trials, six shod and six unshod. An average of all the shod trials were analysed and described in this study. The participants were not specifically instructed on the type of shoes to wear, except that they were not allowed to wear boots. A stool was placed at either end of the walkway length for participants to rest if needed.

### **3.4.5 Data processing**

Preliminary marker reconstruction and labelling were performed using standard Vicon Nexus operations. Gap filling was performed using the standard Wolt-ring filter supplied by Vicon. Specific points during the gait cycle were calculated using marker trajectories that correlated with gait phases. Trunk kinematics in the three different planes and temperospatial parameters were performed in MATLAB (The Mathworks, Natick, MA) using custom-built scripts.

## **3.5 Statistical analysis**

Descriptive statistics were calculated for temperospatial gait parameters and for trunk and pelvis kinematics with mean and standard deviations in the three different planes. The mean and standard deviations were produced for the sample as a group as well as individually for each of the participants. The differences between the two sides (affected and less-affected) were calculated using the Sign test (statistical significance level  $p < 0.05$ ) (Stata software).

## **3.6 Results**

### **3.6.1 Sample description**

Seventeen participants, nine female and eight male, consented to be in this study. Five males and five females had right hemiparesis and three males and four females had left hemiparesis. The average age at stroke incident in the male group was 56.9 years with ages ranging between 48 and 67 years, whereas in the female group the mean age was 47.3 years (range between 27 and 58). Fifteen of the participants were right hand dominant and the mean BMI for the group was 25.66 (See Table 3.1 for group data).



**Table 3.1: Demographic profile of the sample**

	<b>Age (years)</b>	<b>Age at incidence (years)</b>	<b>Time since stroke (months)</b>	<b>BMI</b>
<b>All subjects M=8; F=9</b>				
<b>Mean</b>	56.3	51.8	21.9	25.66
<b>Min</b>	30.0	27.0	2.0	17.10
<b>Max</b>	67.0	67.0	51.0	33.52
<b>SD</b>	± 9.5	± 9.8	± 18.0	± 4.24
<b>Left Hemiparesis M=3; F=4</b>				
<b>Mean</b>	57.0	55.0	24.7	25.1
<b>Min</b>	52.0	52.0	2.0	17.1
<b>Max</b>	61.0	58.0	42.0	33.6
<b>SD</b>	± 2.8	± 2.6	± 16.9	± 5.0
<b>Right Hemiparesis M=5; F=5</b>				
<b>Mean</b>	51.3	49.6	19.7	26.05
<b>Min</b>	30.0	27.0	2.0	20.19
<b>Max</b>	67.0	67.0	51.0	31.78
<b>SD</b>	± 11.8	± 12.4	± 19.9	± 3.9

### 3.6.1 Temperospatial gait parameters

Table 3.2 summarises the averages of the temperospatial parameters including walking speed, cadence, step length, stride length, step time and stride time.

**Table 3.2: Group temperospatial parameters**

	<b>Mean</b>	<b>SD</b>	<b>Max</b>	<b>Min</b>	<b>Range</b>
<b>Walking Speed (m/s)</b>					
<b>Group Combined</b>	0.91	0.24	1.47	0.40	1.07
<b>Left Hemiparetic</b>	0.75	0.04	0.80	0.70	0.10
<b>Right Hemiparetic</b>	1.02	0.05	1.09	0.94	0.15
<b>Cadence (steps/ minutes)</b>					
<b>Group Combined</b>	101.63	16.21	130.00	67.00	63.00
<b>Left Hemiparetic</b>	97.54	7.95	108.71	86.85	21.85
<b>Right Hemiparetic</b>	104.49	9.40	117.50	92.50	25.00
<b>Step Length (m)</b>					
<b>Group Combined</b>	0.55	0.09	0.73	0.33	0.14
<b>Left Hemiparetic</b>	0.47	0.03	0.53	0.43	0.10
<b>Right Hemiparetic</b>	0.61	0.03	0.66	0.56	0.10
<b>Stride Length (m)</b>					
<b>Group Combined</b>	1.07	0.19	1.38	0.65	0.73
<b>Left Hemiparetic</b>	0.91	0.04	0.97	0.85	0.12
<b>Right Hemiparetic</b>	1.18	0.04	1.24	1.13	0.11
<b>Step Time(s)</b>					
<b>Group Combined</b>	0.61	0.10	0.90	0.46	0.44
<b>Left Hemiparetic</b>	0.63	0.05	0.71	0.60	0.15
<b>Right Hemiparetic</b>	0.59	0.06	0.67	0.51	0.16
<b>Stride Time(s)</b>					
<b>Group Combined</b>	1.21	0.17	1.70	0.94	0.76
<b>Left Hemiparetic</b>	1.26	0.04	1.32	1.19	0.13
<b>Right Hemiparetic</b>	1.18	0.04	1.26	1.13	0.13

Twelve of the subjects could be classified as community walkers as they fell within the community category with mean speeds of 1.03m/s (Schmid et al., 2007). In this group the right side affected individuals had higher walking speeds compared to the left.

Table 3.3 summarises the symmetry of temporal and spatial gait parameters respectively. The group did not exhibit asymmetry as indicated by the indices.

**Table 3.3: Comparison of affected and less-affected parameters including symmetry index\***

	Affected	Less-affected	Symmetry Index*
<b>Temporal Symmetry</b>			
<b>Step Time(s)</b>			
<b>Group Combined</b>	0.65	0.57	1.14
<b>Right Hemiparetic</b>	0.63	0.55	1.15
<b>Left Hemiparetic</b>	0.67	0.59	1.14
<b>Stride Time(s)</b>			
<b>Group Combined</b>	1.22	1.22	1.00
<b>Right Hemiparetic</b>	1.18	1.17	1.01
<b>Left Hemiparetic</b>	1.26	1.26	1.00
<b>Spatial Symmetry</b>			
<b>Step Length (m)</b>			
<b>Group Combined</b>	0.56	0.53	1.06
<b>Right Hemiparetic</b>	0.63	0.60	1.05
<b>Left Hemiparetic</b>	0.49	0.46	1.07
<b>Stride Length (m)</b>			
<b>Group Combined</b>	1.11	1.05	1.10
<b>Right Hemiparetic</b>	1.18	1.18	1.00
<b>Left Hemiparetic</b>	0.92	0.91	1.01

\*symmetry index = affected side/ less-affected side (Balaban & Tok, 2014)

### 3.6.3 Thorax and pelvis kinematics during gait of people with stroke

#### *Sagittal plane motion of the thorax*

There was minimal thorax motion noted in the sagittal plane during the gait cycle (Figure 3.1 and Table 3.4). The thorax largely remained anterior to neutral (mean  $4.05^\circ$ , SD 0.86). Anterior movement of the thorax refers to motion in the sagittal plane about the coronal axis, which relates to the sternal and C7 markers moving forward and downward. The maximum anterior motion was approximately  $6^\circ$  while the minimum was approximately  $2^\circ$ . The mean total range of motion (ROM) of the thorax in the sagittal plane was  $4^\circ$  for this sample.

The maximum anterior motion at initial contact was approximately  $6^\circ$  while the mean total range of motion (ROM) was  $4.5^\circ$ . At foot off a difference of  $2^\circ$  was noted between the mean of the affected and less-affected sides (Table 3.4).

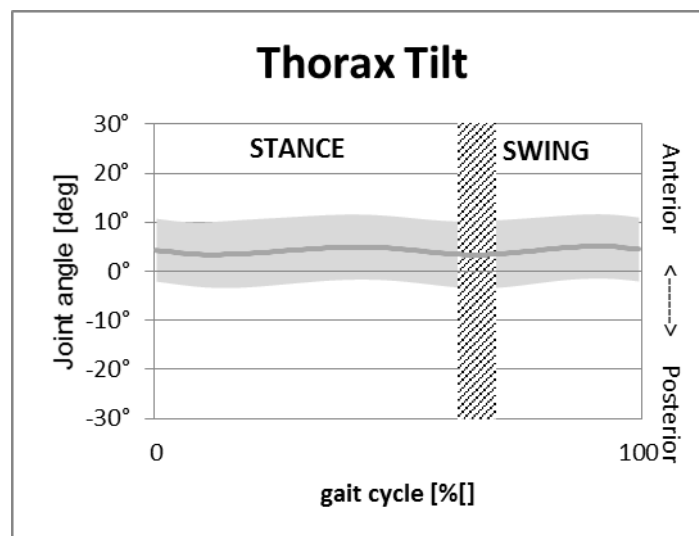


Figure 3.1: Thorax kinematics in the sagittal plane

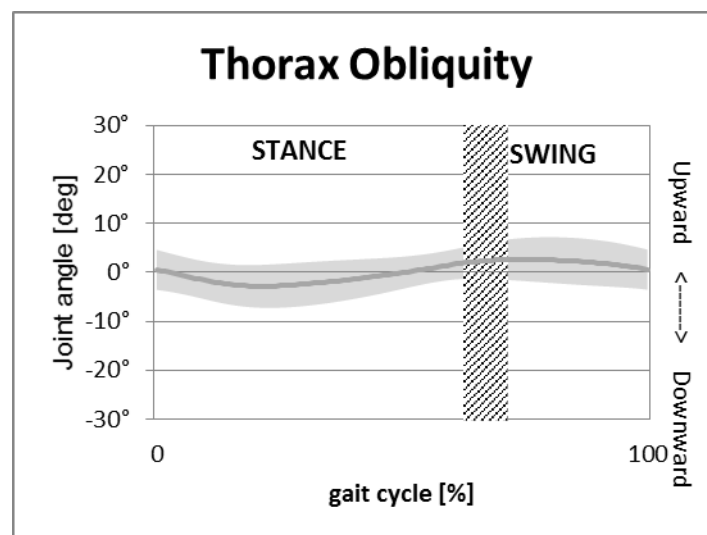
**Table 3.4: Thorax kinematics comparing affected and less-affected sides in all three planes**

	<b>Mean (degrees)</b>	<b>SD</b>	<b>Max Mean (degrees)</b>	<b>Min Mean (degrees)</b>	<b>Total ROM</b>
<b>Sagittal plane - Full gait cycle</b>					
<b>Affected side</b>	4.02	± 0.87	6.10	1.72	4.38
<b>Less-affected side</b>	4.08	± 0.84	6.21	1.91	4.49
<b>Sagittal plane - Initial contact</b>					
<b>Affected Side</b>	3.59	1.23	6.03	1.71	4.41
<b>Less-affected Side</b>	5.39	1.28	6.69	2.17	4.52
<b>Sagittal plane – Foot off</b>					
<b>Affected Side</b>	4.35	1.29	5.83	2.88	3.14
<b>Less-affected Side</b>	2.58	1.41	4.44	0.89	3.55
<b>Coronal plane - Full gait cycle</b>					
<b>Affected Side</b>	-2.27	1.06	0.76	-5.75	6.51
<b>Less-affected Side</b>	2.24	1.30	5.68	-0.79	6.47
<b>Coronal plane – Initial contact</b>					
<b>Affected Side</b>	-1.85	1.86	0.76	-5.75	6.52
<b>Less-affected Side</b>	2.53	1.42	5.68	0.79	6.47
<b>Coronal plane – Foot off</b>					
<b>Affected Side</b>	0.26	1.42	2.07	-1.38	3.46
<b>Less-affected Side</b>	4.82	1.35	6.35	3.15	3.21
<b>Transverse plane - Full gait cycle</b>					
<b>Affected Side</b>	1.81	1.24	6.26	-2.85	9.55
<b>Less-affected Side</b>	-1.00	1.38	3.94	-6.03	9.98
<b>Transverse plane – Initial contact</b>					
<b>Affected Side</b>	-6.57	2.42	1.38	-8.50	9.89
<b>Less-affected Side</b>	0.78	3.47	8.38	-1.58	10.00
<b>Transverse plane – Foot off</b>					
<b>Affected Side</b>	-2.45	2.00	-0.05	-4.99	5.02
<b>Less-affected Side</b>	4.86	1.57	6.95	2.95	4.01

### *Coronal plane motion of the thorax*

Figure 3.2 illustrates the thorax kinematics of the sample in the coronal plane. The thorax remained very central with minimal sideways motion during the full gait cycle. This motion is derived from the lateral movement of the sternal marker. When the marker moves away from the midline, this is considered a downward thoracic motion.

The thorax moved in a downward direction ( $-1.85^\circ$ ) at initial contact on the affected side (see Table 3.4). In contrast, at initial contact of the less-affected side the thorax tended to move upwards. At foot off on the affected side, the thorax hardly moved, whereas on the less-affected side, the thorax moved upwards (mean =  $4.82^\circ$ ).

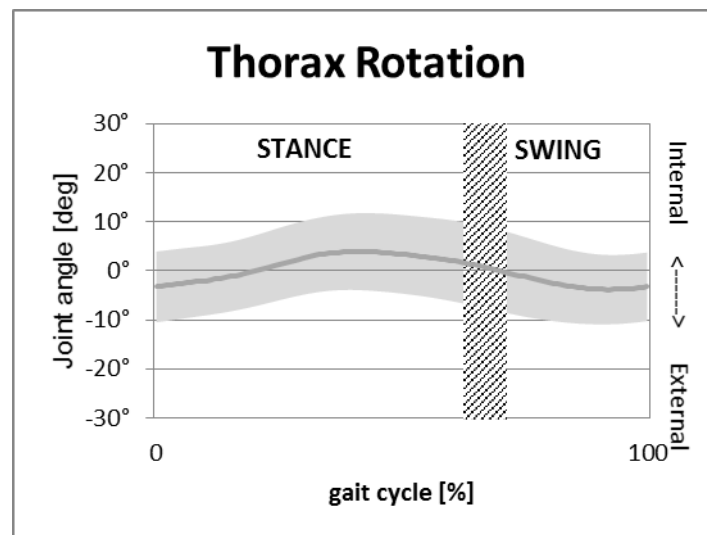


**Figure 3.2: Thorax kinematics in the coronal plane**

### *Transverse plane motion of the thorax*

Figure 3.3 illustrates the rotation motion of the thorax. The term internal refers to a forward rotation of the thorax, and external refers to a backward rotation on the stride side. During the full gait cycle there was an average of 10° range of motion of the thorax in the transverse plane.

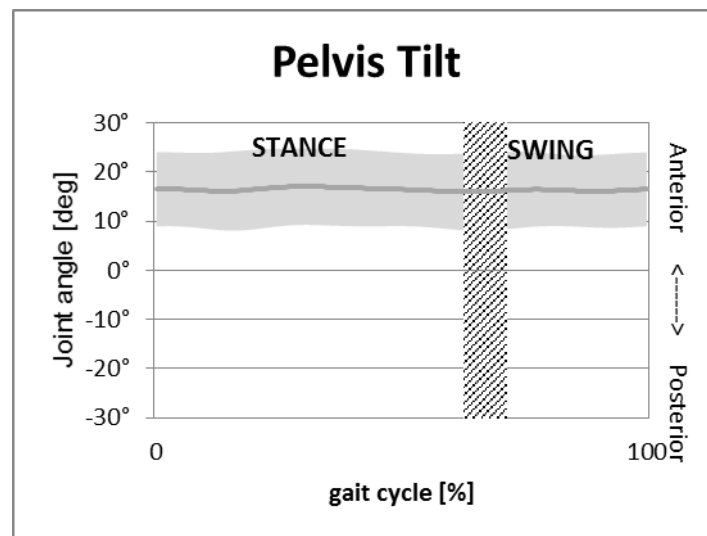
Table 3.4 illustrates that during the gait cycle and at initial contact there was a total range of motion of 10° during the stride of both the affected and the less-affected sides. At initial contact of the affected side the thorax rotated 7° degrees backwards and at foot off the trend of backwards rotation continued.



**Figure 3.3: Thorax kinematics in the transverse plane**

### *Sagittal plane motion of the pelvis*

There was marked anterior pelvic motion noted in the sagittal plane throughout the gait cycle (Figure 3.4), initial contact and foot off (Table 3.5). This is due to the ASIS moving inferiorly and the PSIS moving superiorly. The pelvis remained approximately 16° in an anterior position throughout the gait cycle. The range through which the pelvis moved was between 13° and 19°.



**Figure 3.4: Pelvis kinematics in the sagittal plane**

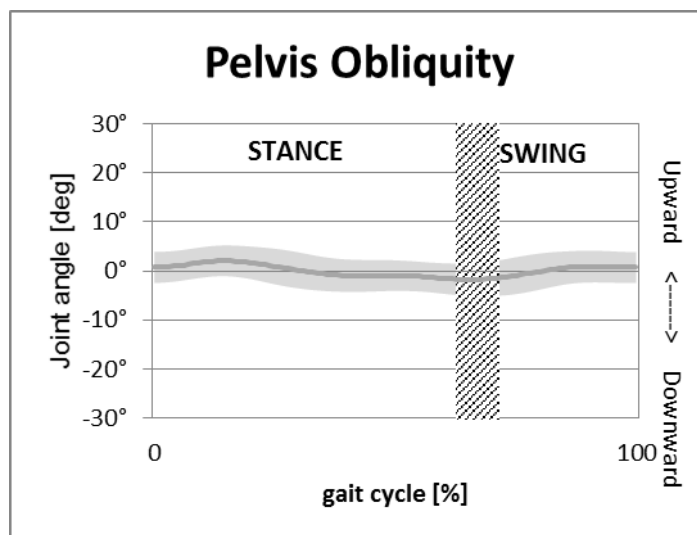


**Table 3.5: Pelvis kinematics comparing affected and less-affected sides in all three planes**

	<b>Mean (degrees)</b>	<b>SD</b>	<b>Max Mean (degrees)</b>	<b>Min Mean (degrees)</b>	<b>Total ROM</b>
<b>Sagittal plane - Full gait cycle</b>					
<b>Affected Side</b>	16.55	0.60	19.43	13.21	6.22
<b>Less-affected Side</b>	16.26	0.52	19.13	13.26	5.87
<b>Sagittal plane - Initial contact</b>					
<b>Affected Side</b>	14.51	0.92	18.94	13.28	5.66
<b>Less-affected Side</b>	17.93	1.01	19.16	13.35	5.64
<b>Sagittal plane – Foot off</b>					
<b>Affected Side</b>	16.96	1.11	18.30	15.74	3.64
<b>Less-affected Side</b>	14.70	1.01	15.94	13.46	2.48
<b>Coronal plane - Full gait cycle</b>					
<b>Affected Side</b>	0.49	0.86	4.08	-3.27	7.35
<b>Less-affected Side</b>	-0.51	0.84	3.27	-4.15	7.42
<b>Coronal plane – Initial contact</b>					
<b>Affected Side</b>	0.94	1.20	4.04	-3.15	7.19
<b>Less-affected Side</b>	0.33	1.20	3.19	-4.10	7.29
<b>Coronal plane – Foot off</b>					
<b>Affected Side</b>	-2.09	0.85	-0.80	-3.34	2.31
<b>Less-affected Side</b>	-2.52	1.06	-1.26	-3.83	2.60
<b>Transverse plane - Full gait cycle</b>					
<b>Affected Side</b>	-2.25	1.26	3.17	-7.53	9.55
<b>Less-affected Side</b>	2.21	1.11	7.70	-3.36	11.06
<b>Transverse plane – Initial contact</b>					
<b>Affected Side</b>	0.14	2.31	3.07	-7.35	10.42
<b>Less-affected Side</b>	3.85	1.93	7.49	-3.26	10.78
<b>Transverse plane – Foot off</b>					
<b>Affected Side</b>	-5.27	1.62	-3.22	-7.24	4.07
<b>Less-affected Side</b>	0.03	1.71	2.14	-2.06	4.21

### *Coronal plane motion of the pelvis*

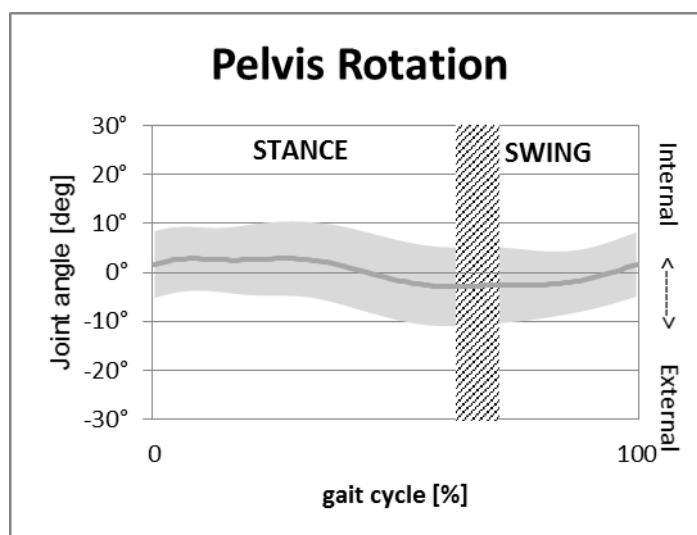
The pelvis remained in a relatively central ( $0^\circ$ ) position (Figure 3.5) during the full gait cycle and at initial contact (Table 3.5). At foot off on the affected and less-affected sides, the pelvis moved slightly downwards.



**Figure 3.5: Pelvis kinematics in the coronal plane**

*Transverse plane motion of the pelvis*

Figure 3.6 illustrates pelvic rotation throughout the gait cycle. During the gait cycle and at foot off, the pelvis is rotated backwards on the affected side. At foot off, the pelvis on the affected side was 5° backwards in contrast with the pelvis at the same point in the gait cycle on the less-affected side.



**Figure 3.6: Pelvis kinematics in the transverse plane**

*Comparison of kinematics for the affected and less-affected sides*

During the full gait cycle there were statistically significant differences of thorax motion between the affected and the less-affected side in the coronal plane ( $p=0.049$ ) and pelvic motion in the sagittal plane ( $p=0.049$ ) (Table 3.6).

At both initial contact ( $p$  value: sagittal = 0.002; coronal = 0.049; transverse = 0.002) and foot off ( $p$  value: sagittal = 0.000; coronal = 0.049; transverse = 0.013) there were statistically significant differences of thorax motion between the affected and the less-affected side in all three planes respectively. Pelvic motion was statistically significant in the sagittal plane throughout the gait cycle, at initial contact and foot off (Table 3.6).

**Table 3.6: Kinematics of the thorax and pelvis in the sagittal, coronal and transverse planes during the full gait cycle, initial contact and foot off**

Kinematics		Affected Mean $\pm$ SD (degrees)	Less-affected Mean $\pm$ SD (degrees)	Mean difference (degrees)	Significance ( $p < 0.05$ )
<b>Full Cycle</b>	Thorax Sag	4.02 $\pm$ 0.87	4.08 $\pm$ 0.84	-0.06	0.144
	Pelvis Sag	16.55 $\pm$ 0.60	16.26 $\pm$ 0.52	0.29	0.049*
	Thorax Cor	-2.27 $\pm$ 1.06	2.24 $\pm$ 1.30	-4.51	0.049*
	Pelvis Cor	0.49 $\pm$ 0.86	-0.51 $\pm$ 0.84	-0.02	1.000
	Thorax Trans	1.81 $\pm$ 1.24	-1.00 $\pm$ 1.38	2.81	0.332
	Pelvis Trans	-2.25 $\pm$ 1.26	2.21 $\pm$ 1.11	-4.46	0.144
<b>Initial Contact</b>	Thorax Sag	3.59 $\pm$ 1.23	5.39 $\pm$ 1.28	-1.8	0.002*
	Pelvis Sag	14.51 $\pm$ 0.92	17.93 $\pm$ 1.01	-3.42	0.000*
	Thorax Cor	-1.85 $\pm$ 1.86	2.53 $\pm$ 1.42	-4.38	0.049*
	Pelvis Cor	0.94 $\pm$ 1.20	0.33 $\pm$ 3.19	0.61	1.000
	Thorax Trans	-6.57 $\pm$ 2.42	0.78 $\pm$ 3.47	-7.35	0.002*
	Pelvis Trans	0.14 $\pm$ 2.31	3.83 $\pm$ 1.71	-5.3	0.143
<b>Foot off</b>	Thorax Sag	4.35 $\pm$ 1.29	2.58 $\pm$ 1.41	1.77	0.000*
	Pelvis Sag	16.96 $\pm$ 1.11	14.70 $\pm$ 1.01	2.26	0.002*
	Thorax Cor	0.26 $\pm$ 1.42	4.82 $\pm$ 1.35	-4.56	0.049*
	Pelvis Cor	-2.09 $\pm$ 0.85	-2.52 $\pm$ 1.06	0.43	1.000
	Thorax Trans	-2.45 $\pm$ 2.00	4.86 $\pm$ 1.57	7.31	0.013*
	Pelvis Trans	-5.27 $\pm$ 1.62	0.03 $\pm$ 1.71	5.3	0.143

\*Statistical Significance ( $p \leq 0.05$ ); Sag = Sagittal Plane; Cor = Coronal Plane; Trans = Transverse Plane

### **3.7 Discussion**

This study aimed to characterise thoracic motion during the gait cycle of people with stroke. The aim was to describe the three dimensional kinematics of the thorax during the gait cycle of people with stroke and compare this for the affected and less-affected sides. Anecdotally pelvic motion during gait of normal people as well as in individuals with stroke is better characterised in the literature.

This sample presented with some of the characteristics seen in the gait patterns of people with stroke, i.e. reduced cadence and walking speed. Five of the 17 participants in this study walked at the 'limited' community speed (mean = 0.63m/s) as per Schmid et al. 2007, and the remaining 12 at community speeds (1.03m/s). Hemiparetic individuals tend to take shorter and wider steps at a slower gait speed compared to normal individuals (Hacmon et al. 2012). The participants in this study had a wide range (67.00 to 130.00 steps) in their cadence. The mean steps per minute for the group was 101.58 steps per minute, compared to 112.5 steps per minute for normal gait in adults (Shumway-Cook & Woollacott, 2012).

A symmetry index provides potential insight regarding asymmetry present in the temporospatial parameters in people with stroke. The participants in the study did not show asymmetry in step/stride length or in step/stride time. Asymmetry was evident in the thorax kinematics between the affected and less-affected sides, as discussed later.

#### **3.7.1 Thorax kinematics**

Overall the thorax did not move through a large range of motion in the sagittal plane (anterior-posterior motion) and would be observed clinically as the thorax being relatively still in a more anterior or forward tilted posture. There was a statistically significant difference between the motion of the thorax during the stride of the affected and less-affected sides at initial contact as well as at foot off in this plane. The difference was not significant throughout the gait cycle in the sagittal plane.

During the stride on the affected side the mean movement of the thorax was slightly downwards upon initial contact as compared to initial contact on the less-affected side, which moved upwards in the coronal plane to peak at mid-stance (Whittle, 2007). Normally the trunk moves side to side in the gait cycle and aligns over each leg during its stance phase. This might be expected due to the need for support. In

1992 Krebs et al. reported that the thorax moves towards the weight bearing leg in normal gait at initial contact and then away from that side at foot off. In our study there was significant coronal asymmetry between the affected and less-affected sides during the full gait cycle, at initial contact, and at foot off. Throughout the gait cycle the thorax markers indicating a downward movement during the affected side stride. At foot off on the affected side the thorax markers were lower than the markers on the less-affected side at foot off.

During gait the rotation (transverse plane) of the thorax of the participants of the study showed statistically significant differences between the affected and the less-affected sides at initial contact and foot off. The thorax rotated backwards at both these points in the gait cycle of the affected side, even more so at initial contact ( $-7^\circ$ ). During normal gait there is a forward swing of the pelvis on the side of the swinging leg, with either a counter rotation of the thorax or the contralateral arm swing forward leads to a thoracic rotation (Lamoth et al. 2002). With an increase in walking speed, these reciprocal thoracic and pelvic rotations become more anti-phase from being in-phase at slower speeds. However, it was recorded that on the affected side the pelvis was backwards during the gait cycle while the thorax was in a slightly forward position. On the less-affected side, however, the pelvis was in a more forward position with the thorax in a backwards position. This is more in line with what was found by Lamoth et al. in their 2002 study. During initial contact and foot off, the thorax was in a more backwards position on the affected side than when weight-bearing on the less-affected side. At initial contact the pelvis was forward during weight-bearing on both the affected and less-affected sides. At initial contact on the less-affected side, the thorax moves very minimally forwards ( $0.78^\circ$ ) on the less-affected side. At initial contact the pelvis too moves in a forward direction ( $0.14^\circ$ ).

### **3.7.2 Pelvis kinematics**

All the participants in this study walked with an anterior pelvic tilt. There was a statistically significant difference noted between pelvic motion in the sagittal plane comparing the affected and the less-affected sides throughout the gait cycle, at initial contact and at foot off. The participants in the study demonstrated between  $14^\circ$  and  $17^\circ$  anterior pelvic tilt at these two points in the gait cycle. Karthikbabu et al. (2011) reported that the anterior muscles are affected on both sides of the trunk post stroke, and may lead to an excessive anterior pelvic tilt (Whittle 2007). This could explain

the phenomenon seen in this sample, where all of the participants demonstrated anterior pelvic tilt during gait.

No difference of pelvic motion was found between the affected and less-affected sides in the coronal plane during gait; in the sample the pelvis remained relatively central.

In a 2014 study, Bruening et al. reported on normal kinematic values of the pelvis during gait in adults. They found that males had an average of  $14.1^\circ$  and females had  $12^\circ$  of pelvic rotation. In this study there was minimal movement noted. There was no statistically significant difference noted between the affected and less-affected sides during pelvic rotation during gait, although there was a slight difference in degrees noted. Due to hemiparesis there may be a disruption between the timing of pelvic and thoracic rotations that is normally present during gait (Bruijn et al. 2008). Pelvic rotation that occurs with the swinging leg (Lamoth 2002), together with thoracic rotation constitutes the relative phases during gait. This changes from in-phase at slower speeds to anti-phase during higher speeds. Throughout the gait cycle the thorax and the pelvis moved in opposite directions in both affected and less-affected strides. On the less-affected side the thorax moves backwards and the pelvis forwards during the stride, whereas the opposite occurred during stride on the affected side.

Gait asymmetry has been an objective as well as a measurement of success in gait re-education in people with stroke (Olney & Richards, 1996). To date no relationship has been found between gait speed and symmetry (Dodd & Morris 2003). The participants in the study did not exhibit temporospatial asymmetry and were all classified as limited or community walkers. However, they presented with asymmetrical thorax and pelvic gait kinematics

Balaban & Tok (2014) reported that the normalisation of gait asymmetry is a common goal in post stroke rehabilitation, but that this asymmetry may be an adaptation or compensation mechanism that allows the person to walk. Balaban & Tok (2014) further reported that symmetry should not be the goal of rehabilitation during the chronic phase after stroke. In Griffin et al. (1995) they suggested that aiming for symmetry in a stable body system (chronic stage of stroke) is not likely to have optimal performance as a consequence. According to the study, an increase in

the contribution of the affected side leads to asymmetry. They linked an increase in speed to optimal performance, but an increase in speed in people with stroke will most likely lead to asymmetry. It is understandable to see asymmetry in a person with limbs that have unequal capabilities (Griffin et al, 1995). People with stroke in the chronic stage may have manifested a habitual gait pattern. This could be due to the incorrect pathways formed post stroke. Neuroplasticity allows the re-education of movement patterns. Neuroplasticity is defined by Cramer et al. (2011) as the ability of the nervous system to reorganise itself by reacting to intrinsic and extrinsic stimuli. Depending on the individual patient and their cognitive level and level of motivation may allow for further improvement in symmetry, provided by further rehabilitation (extrinsic stimuli).

Sixty five percent of the participants in this study were in the chronic phase post stroke. This may be the reason that the participants were able to walk at “limited” community as well as community speeds, although significant asymmetry was found in the kinematics of some of the aspects during their gait.

### **3.8 Limitations of this study**

The sample people were relatively young, recruited from only one setting and were all able to walk without the use of assistive devices. They were, therefore, community level ambulators, the majority of which were in the chronic phase of stroke. This could have influenced the results in terms of the symmetry of temporospatial parameters as well as thorax kinematics. The results of this study are therefore not generalisable to the wider population of people with stroke and those with different/varying levels of function. This report focuses on the group data only, 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. The laboratory setting may have influenced the participants’ gait pattern as this does not emulate their natural environment. It may be argued that the participants could have been self-conscious of their gait patterns due to being observed.



### 3.9 Clinical implications

Gait asymmetry is not uncommon in people with stroke, and may lead to potential negative gait implications e.g. loss of balance and increased energy expenditure (Patterson, Gage, Brooks, Black & McIlroy, 2010). This sample presented with asymmetrical gait as is expected in people with stroke. In the sagittal plane the sample walked with a forward flexed thorax and did not move backwards beyond neutral. The pelvis of the sample remained in an anterior tilt throughout, with no movement towards neutral during the gait cycle. At initial contact the pelvic tilt on the less-affected side is significantly more than during the same point on the less-affected side. Foot off on the affected side resulted in more anterior pelvic tilt than on the less-affected side. This difference in sagittal plane motion of the pelvis may be ascribed to the centre of mass shift that occurs due to the change from double support to single leg weight bearing (Whittle, 2007). The sample's abdominal muscles are assumed to be weak therefore they may have difficulty in maintaining a neutral pelvis.

There was a downward motion of the thorax noted with weight bearing on the affected side, which clinically could be described as a lack of elongation in the thorax that should occur towards the side of the weight bearing leg. The pelvis did not display significant difference between the two sides in this plane. The pelvis remained in a fairly central ( $0^\circ$ ) position during the full gait cycle and at initial contact. At foot off on the affected and less-affected side, the pelvis moved slightly downwards. This could possibly be indicative of the sample fixating around the pelvis, while the pelvis remains in an anterior pelvic tilt as noted in the sagittal plane.

Larger rotation motion is associated with impairment, but it is said that this may be a compensatory mechanism for the paretic arm that is often unable to swing forward (Hacmon et al., 2012). This rotation of the thorax is then used to generate the normal anti-phase motion present during gait. Although there was not a great deal of movement throughout the cycle in this plane the participants did attempt anti phase motion by rotating the thorax forward during the cycle.

Although there were asymmetries found in the participants of this study, most of the participants in this study could be classified as independent community walkers who function at home and in their community. The investigator did not specifically note the interventions the sample received prior to taking part in this study. It is therefore unclear to what degree the focus was on achieving thoracic symmetry. Could further intervention aimed at thorax symmetry perhaps influence the gait speeds of the five participants walking at limited community speeds to the extent that they too are able to walk at community speeds? An assumption would be that by improving the thorax symmetry the balance and quality of gait would improve to allow for them to function as community ambulators.

### **3.10 Recommendations for future research**

As this was a pilot study, it is recommended that it be performed on a larger sample to identify if the trends noted will be replicated. A larger cohort will allow for 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 Body Mass Index (BMI). Having a sample at various stages post stroke and that require the use of assistive devices could provide different results when referring to temperospatial parameters and thorax kinematics. The influence between temperospatial parameters and thorax kinematics should be explored further.

### **3.11 Conclusion**

The aim of this study was to describe the kinematics of the thorax during gait of people with stroke. In summary, we found that the thorax in the sample remained relatively still during gait. However, there were significant asymmetries found in thoracic motion during the stride between the affected and less-affected sides in the sagittal plane. Significant differences were also noted in the in all three planes at initial contact and foot off. Even with this asymmetry, the participants were all functional walkers at community level.

## **Acknowledgments**

Funding:

Harry Crossly Foundation funding was received for this project.

Declaration of interest:

The authors declare that they have no conflicts of interest.

Author's contributions:

All authors were part of the original project team and drafted this manuscript. All authors contributed, read and approved the final version of the manuscript.

Acknowledgements:

We would like to thank all participants for their active participation in this study and to the Harry Crossly Foundation for financial support.

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## Chapter 4: Discussion

### 4.1 Introduction

The aim of this study was to characterise thorax motion during the gait cycle of people with stroke. The study aimed to describe the three dimensional (3D) kinematics of the thorax during the gait cycle of people with stroke. Pelvic motion during gait of normal as well as in individuals with stroke is better characterised in the literature.

In keeping with what has been found in the literature, this sample presented with the characteristics seen in the gait patterns of people with stroke: reduced cadence and walking speed. Symmetry index (e.g. Temporal stance symmetry = paretic stance time/non-paretic stance time) provides potential insight regarding asymmetry present in the temporospatial parameters in people with stroke. Between 0.9 and 1.1 is considered to be symmetrical. Values higher indicate asymmetry, with >1.5 indicating severe asymmetry (Patterson et al. 2008). Clinically asymmetry has a negative effect on post stroke gait. It can influence balance, energy expenditure and potential risk of musculoskeletal injury on the less-affected side (Patterson et al. 2010).

Walking at a sufficient speed allows for people with stroke to be more mobile in their environment (Jang 2010). Speeds between 0.4m/s and 0.8m/s are categorised as 'limited' community walkers and higher than 0.8m/s as community walkers. Five of the 17 participants in this study walked at the 'limited' community speed (mean = 0.63m/s) as per Schmid et al. (2007), and the remaining 12 at community speeds (1.03m/s). When comparing the gait speed values found in this study, it was noted that the group mean fell within the range associated with maximum speed of walking in people in the chronic phase after stroke (Balaban & Tok 2014).

Cadence is another parameter affected in gait post stroke (Woolley 2001). Hemiparetic individuals tend to take shorter and wider steps at a slower gait speed compared to normal individuals (Hacmon et al. 2012). The mean steps per minute for adults during normal gait is 112.5 steps per minute (Shumway-Cook & Woollacott, 2012). The participants of this study had a wide range (67.00 to 130.00). The mean steps per minute for the group was 101.58. Cadence according to



Karthikbabu et al. (2011) improves with rehabilitation focussing on the trunk. A high level of variation is expected and the fact that the range was closer to the normal end of the spectrum also suggests that this sample was relatively high functioning. As there had been no measure of initial stroke severity it was not possible to say if this was due to sampling, a bias towards people with milder stroke, or whether they had received excellent rehabilitation.

## 4.2 Thorax kinematics

Overall the thorax did not move through a wide range of motion in the sagittal plane (anterior-posterior motion) and would be observed clinically as the thorax being relatively still. There was wide variation in the amount the individual participants moved as well as their general position from neutral ( $0^\circ$ ).

In this group of 17 participants, there was a statistically significant difference between the motion of the thorax during the stride of the affected and less-affected sides. This occurred at initial contact as well as at foot off, but the difference was not significant throughout the gait cycle in the sagittal plane. This translates to significant asymmetry of the thorax during these two points in the gait cycle. During initial contact there was less anterior movement during affected side stride, than during less-affected side. This could be ascribed to fixation of the thorax at the moment in gait cycle. At foot off, however, there was more sagittal plane thoracic movement during affected side compared to less-affected side.

Hacmon et al. (2012) reported that the forward rotation movement of the thorax during gait was used to assist with the forward swinging of the arm. This occurred automatically in people without stroke. This forward swinging of the arms not only facilitated the normal anti-phase movement (thoracic rotation) that occurs during higher gait speeds, but it also assists with anterior shift of the centre of mass to aid in gait progression.

Gait asymmetry in what is considered independent community ambulators is a very common phenomenon in people with stroke (Alexander et al. 2009). In this study this asymmetry referred to in the literature was evident. Balaban and Tok (2014) report that the normalisation of gait asymmetry is a common goal in post stroke rehabilitation, but that this asymmetry may be an adaptation or compensation mechanism that allows the person to walk. Balaban and Tok (2014) further reported

that symmetry should not be the goal of rehabilitation during the chronic phase after stroke. Balaban and Tok (2014) argued that gait asymmetry is an adaptation to the neurological deficits caused by stroke, to provide the person with stroke with a degree of gait functioning. Griffin et al. (1995) suggested that aiming for symmetry in a stable body system (chronic stage of stroke) is not likely to have optimal performance as a consequence. According to the study, an increase in the contribution of the affected side leads to asymmetry. They linked an increase in speed to optimal performance, but an increase in speed in people with stroke will most likely lead to asymmetry. It is understandable to see asymmetry in a person with limbs that have unequal capabilities (Griffin et al., 1995). People with stroke in the chronic stage may have manifested a habitual gait pattern. This could be due to the incorrect pathways formed post stroke. Neuroplasticity allows the re-education of movement patterns. Neuroplasticity is defined by Cramer et al. (2011) as the ability of the nervous system to reorganise itself by reacting to intrinsic and extrinsic stimuli. Depending on the individual patient and their cognitive level, as well as their level of motivation, may allow for further improvement in symmetry provided by further rehabilitation (extrinsic stimuli). Sixty five percent of the participants in the study were in the chronic phase post stroke and were able to walk, however they presented with asymmetry in tempo-spatial parameters and thorax kinematics.

During the full gait cycle, at initial contact and foot off, there was a statistically significant difference noted between the less-affected and affected sides in the coronal plane. During the stride on the affected side, the mean movement of the thorax for the group was slightly downwards upon initial contact as compared to initial contact on the less-affected side, which moved upwards.

Hacmon et al. (2012) used the Vicon system to illustrate thoracic motion in people with stroke and his control group, using a different marker system than the PiG in this study. Their markers were placed on the acromion processes on either side, and mid sternum. This study reported no differences in the coronal plane between the affected and the less-affected sides. Krebs et al. in 1992 reported that the thorax moves towards the weight bearing leg in normal gait at initial contact and then away from that side at foot off. In this study there was downward movement of the thorax at initial contact (towards the weight bearing leg) during stride of the affected leg and the thorax moved upwards at initial contact on the less-affected side. The direction of

trunk movement in this study correlated with that of the Krebs (1992) study. However it is unclear whether the exact trunk movement from the Krebs (1992) study and this study was the same. Tyson (1999) reported that there is a significant relationship between the lateral displacement (side to side motion) in walking and “good” walking quality. In this study there was significant coronal asymmetry between the affected and less-affected sides during the full gait cycle, at initial contact, and at foot off. The participants in this study were all classified as limited or community walkers, yet they presented with asymmetrical gait. “Good” gait was defined as and related to increased gait speeds in the study by Tyson (1999).

Wagenaar and Beek (1992) used 2D gait analysis with video feedback and mathematical equations to determine the amount of thoracic rotation during gait. Their findings were related to the differences that exist between a group with stroke and one without; the stroke group having a larger thoracic rotation than the healthy control group. During gait the rotation of the thorax of the participants of this study showed statistically significant differences between the affected and the less-affected sides at initial contact and foot off. The thorax rotated backwards at both these points in the gait cycle of the affected side, even more so at initial contact ( $-7^\circ$ ). During normal gait there is a forward swing of the pelvis on the side of the swinging leg, with either a counter rotation of the thorax or the contralateral arm swing forward leads to a thoracic rotation (Lamoth et al. 2002). With an increase in walking speed, these reciprocal thorax and pelvis rotations become more anti-phase from being in-phase at slower speeds.

Hacmon et al. (2012) correlated kinematics of the thorax and pelvis of people with stroke to a control group and mainly reported on the differences between the two groups. They linked large thoracic movement with impairment. They concluded that a reduction in the excessive rotation may improve functional outcomes. They also found that the stroke group in their study was more in-phase than out of phase walking at comfortable speeds. The stroke participants who had more anti-phase motion during gait had better balance and gait functioning scores. The participants in this study walked with an anti-phase motion, even though they did not present with large or excessive rotation.

### 4.3 Pelvis kinematics

All the participants in the study walked with an anterior pelvic tilt. Karthikbabu et al. (2011) reported that the anterior muscles are affected on both sides of the trunk post stroke, and may lead to an excessive anterior pelvic tilt (Whittle 2007). This could explain the phenomenon seen in the sample. During normal gait the trunk has a forward inclination towards the floor during the gait cycle, which is ascribed to the pelvis oscillating in the sagittal plane with an increase in lumbar lordosis (Ceccato et al. 2009). These authors highlight that the anterior pelvic tilt is more at the end of the swing phase and less at the beginning of the swing phase (Ceccato et al. 2009). Prince et al. (1994) state that the motion of the head arms and trunk (HAT) segment is controlled by an extension moment generated by the hip and back extensor muscles at initial contact. The hip extensors in particular play a stabilising role of the pelvis during normal gait (Prince et al. 1994). There was a statistically significant difference noted between pelvic motion in the sagittal plane comparing the affected and the less-affected sides throughout the gait cycle, at initial contact and at foot off. Although the sample's pelvis was in anterior pelvic tilt throughout the gait cycle, they also presented with a significant difference between the position of the pelvis on the affected and the less-affected sides.

The study found no difference between the affected and less-affected sides for pelvic motion in the coronal plane during gait. Dodd and Morris (2003) found that there were no statistically significant differences between stroke and control groups in terms of lateral displacement of the pelvis and that the stroke group had fairly symmetrical pelvic lateral displacement. This study showed that the sample's pelvis remained relatively central. Tyson (1999) found that less lateral movement was directly linked to being a "good" walker. This study, however, had no control group, and compared the less-affected to the affected side, unlike the 2003 Dodd and Morris study. The authors of this 2003 study commented that their results were in contrast with the traditional approaches to gait rehabilitation (Bobath 1990, Carr & Shepherd 1998 and Davies 2000) which suggest that displacement should be encouraged to the paretic side to therefore improve gait symmetry. As a compensatory mechanism the pelvis also elevates to allow for the affected leg to swing through during the gait cycle (Balaban & Tok 2014). This study did not show any consistent evidence of this "hitching" mechanism.

There was no statistically significant difference noted between the affected and less-affected sides during pelvic rotation of this sample. Due to hemiparesis there may be a disruption between the timing of pelvic and thoracic rotations that is normally present during gait (Bruijn et al. 2008). The pelvis rotates forward with the swinging leg during gait (Lamoth et al. 2002). This pelvis rotation together with thoracic rotation constitutes the relative phases during gait. During their gait cycles this sample walked with an anti-phase motion, even though they did not present with excessive rotation motion.

Essentially there were differences found in all three planes in the kinematics of the thorax and the pelvis during gait. Statistically significant differences in the kinematics in the sagittal plane were noted between the affected and less-affected sides of the thorax at initial swing and foot off. For the pelvis this was true throughout the gait cycle, at initial contact and foot off. In the coronal plane a significant difference was noted throughout the cycle (full cycle), at initial contact and at foot off of the thorax. In the transverse plane there were significant differences found in thorax motion at initial contact and foot off, but not for the pelvis at these two points in the gait cycle.

Gait recovery is a main goal for people with stroke (Jang 2010). Hsu et al. (2003) reported that improved gait speed is perceived to be a major goal for the rehabilitation of people with stroke. Gait recovery is linked to activities of daily living that specifically include walking, and that these can be performed as normally and independently as possible (Goldie et al. 2001). Gait symmetry has been an objective in gait re-education in people with stroke, and is often used to measure the success of gait rehabilitation (Olney & Richards 1996). To date no relationship has been found between gait speed and symmetry (Dodd & Morris 2003). The participants in this study did not exhibit temperospatial asymmetry and were all classified as limited or community walkers. However, they presented with asymmetrical thorax and pelvis gait kinematics. Although normalisation of gait asymmetry is a common goal in gait post stroke, this asymmetry may be a compensatory mechanism that allows the person to walk (Balaban & Tok, 2014). Achieving symmetry during gait during the chronic stage of stroke is not likely to improve performance (Griffin et al., 1995.) It should therefore not be a goal of rehabilitation during the chronic stage (Balaban et al., 2014). This may be the reason that in the study sample the participants walked at

“limited” community and community speeds, although significant asymmetry was found in the kinematics of certain aspects during gait.

The conclusions, limitations, clinical significance and recommendations of the study will be discussed in the following section.

## **Chapter 5: Conclusions, Limitations and Recommendations for Future Studies**

### **5.1 Introduction**

Normal movements of the trunk in the three kinematic planes are essential and allow for normal, efficient gait. Gait recovery is a primary goal for most people with stroke. The thorax of the sample as a group was relatively still during gait. However, there was significant asymmetry found in the thorax motion during the stride between the affected and less-affected sides. Gait asymmetry is not uncommon in people with stroke, and may lead to potential negative gait implications e.g. loss of balance and increased energy expenditure. The sample presented with asymmetrical gait as is expected in people with stroke although they were all functional walkers at community level. The aim of this study was to describe the kinematics of the trunk (defined as the thorax in biomechanics studies) during gait of people with stroke.

### **5.2 Clinical significance of the findings**

Gait asymmetry is not uncommon in people with stroke, and may lead to potential negative gait implications e.g. loss of balance and increased energy expenditure (Patterson, Gage, Brooks, Black & McIlroy, 2010). This sample presented with asymmetrical gait as is expected in people with stroke. In the sagittal plane the sample walked with a forward flexed thorax and did not move backwards beyond neutral. The pelvis of the sample remained in an anterior tilt throughout, with no movement towards neutral during the gait cycle. At initial contact the pelvic tilt on the less-affected side is significantly more than during the same point on the less-affected side. Foot off on the affected side resulted in more anterior pelvic tilt than on the less-affected side. This difference in sagittal plane motion of the pelvis may be ascribed to the centre of mass shift that occurs due to the change from double support to single leg weight bearing (Whittle, 2007). The sample's abdominal muscles are assumed to be weak therefore they may have difficulty in maintaining a neutral pelvis.

There was a downward motion of the thorax noted with weight bearing on the affected side, which clinically could be described as a lack of elongation in the thorax that should occur towards the side of the weight bearing leg. The pelvis did not

display significant difference between the two sides in this plane. The pelvis remained in a fairly central ( $0^\circ$ ) position during the full gait cycle and at initial contact. At foot off on the affected and less-affected side, the pelvis moved slightly downwards. This could possibly be indicative of the sample fixating around the pelvis, while the pelvis remains in an anterior pelvic tilt as noted in the sagittal plane.

Larger rotation motion is associated with impairment, but it is said that this may be a compensatory mechanism for the paretic arm that is often unable to swing forward (Hacmon et al., 2012). This rotation of the thorax is then used to generate the normal anti-phase motion present during gait. Although there was not a great deal of movement throughout the cycle in this plane the participants did attempt anti phase motion by rotating the thorax forward during the cycle.

Although there were asymmetries found in the participants of this study, most of the participants in this study could be classified as independent community walkers who function at home and in their community. The investigator did not specifically note the interventions the sample received prior to taking part in this study. It is therefore unclear to what degree the focus was on achieving thoracic symmetry. Could further intervention aimed at thorax symmetry perhaps influence the gait speeds of the five participants walking at limited community speeds to the extent that they too are able to walk at community speeds? An assumption would be that by improving the thorax symmetry the balance and quality of gait would improve to allow for them to function as community ambulators.

In terms of temporospatial parameters, the participants in the study did not show asymmetry in step/stride length or in step/stride time when using a symmetry index. There was a difference noticed in cadence when comparing left hemiparetics (97.54 steps/m) with right hemiparetics (104.49 steps/m). There was a wide range (67.00 – 130.00 steps/m) and a mean cadence of 101.63. Twelve of the seventeen participants walked at community speeds and five at limited community speeds. This sample managed functional gait speeds although they presented with asymmetrical thorax kinematics.



### **5.3 Limitations of this study**

The sample was fairly young, recruited from only one setting and were all able to walk without the use of assistive devices. The majority of the participants were community level ambulators in the chronic phase of stroke. This could have influenced the results in terms of the symmetry of temperospatial parameters as well as thorax kinematics. The results of this study are therefore not generalizable to the broader population of people with stroke and those with different/varying levels of function. 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.

### **5.4 Recommendations**

As this was a pilot study, it is recommended that it be performed on a larger sample to identify if the trends noted will be replicated. A larger cohort will allow for 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. Having a sample at various stages post stroke and that require the use of assistive devices, could provide different results when referring to temperospatial parameters and thorax kinematics. The influence between temperospatial parameters and thorax kinematics should be explored further.

### **5.5 Summary**

The aim of this study was to describe the kinematics of the thorax during gait of people with stroke. In summary, it was found in this pilot study that the thorax in the sample remained relatively still during gait. There were, however, significant asymmetries found in thorax motion during the stride between the affected and less-affected sides. Even with this asymmetry, the participants were all functional walkers at community level. Further research is required to determine the contribution of the trunk to gait and whether it should in fact be the target of rehabilitation.

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## Appendices

### Appendix 1: Temperospatial Parameters: Individual Subjects

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**Table A1.1: Individual Subject Temperospatial Parameters: Walking Speed measured during left stride of gait the cycle in metres per second**

			Walking Speed m/s					
			Mean	SD	Max	Min	Range	Median
<b>Affected Side</b>	<b>Subject 1</b>	S01	0.95	0.06	1.03	0.87	0.16	0.96
	<b>Subject 2</b>	S02	0.46	0.04	0.52	0.40	0.12	0.47
	<b>Subject 3</b>	S03	0.98	0.04	1.03	0.90	0.13	0.99
	<b>Subject 5</b>	S05	0.55	0.03	0.60	0.51	0.09	0.55
	<b>Subject 8</b>	S08	0.90	0.03	0.94	0.86	0.08	0.91
	<b>Subject 12</b>	S12	0.61	0.02	0.63	0.58	0.05	0.61
	<b>Subject 16</b>	S16	0.79	0.03	0.83	0.75	0.08	0.80
<b>Less-affected Side</b>	<b>Subject 4</b>	S04	0.98	0.04	1.06	0.91	0.15	0.99
	<b>Subject 6</b>	S06	1.07	0.04	1.15	1.03	0.12	1.06
	<b>Subject 7</b>	S07	0.92	0.03	0.96	0.88	0.08	0.92
	<b>Subject 9</b>	S09	0.83	0.12	0.94	0.62	0.32	0.88
	<b>Subject 10</b>	S10	0.76	0.07	0.85	0.65	0.20	0.78
	<b>Subject 11</b>	S11	1.11	0.03	1.16	1.07	0.09	1.12
	<b>Subject 13</b>	S13	1.27	0.04	1.31	1.19	0.12	1.30
	<b>Subject 14</b>	S14	0.83	0.03	0.87	0.79	0.08	0.83
	<b>Subject 15</b>	S15	1.08	0.03	1.14	1.02	0.12	1.08
	<b>Subject 17</b>	S17	1.39	0.06	1.47	1.28	0.19	1.40

**Table A1.2: Individual Subject Temperospatial Parameters: Cadence measured during Left stride of gait the cycle in steps per minute**

			Cadence steps/minute					Median
			Mean	SD	Max	Min	Range	
<b>Affected side</b>	<b>Subject 1</b>	S01	114.40	5.90	120.00	106.00	14.00	114.00
	<b>Subject 2</b>	S02	77.40	2.07	80.00	75.00	5.00	77.00
	<b>Subject 3</b>	S03	102.00	3.16	105.00	97.00	8.00	103.00
	<b>Subject 5</b>	S05	79.00	2.34	83.00	77.00	5.99	78.00
	<b>Subject 8</b>	S08	99.20	2.28	103.00	97.00	5.99	99.00
	<b>Subject 12</b>	S12	82.20	1.09	83.00	81.00	2.00	83.00
	<b>Subject 16</b>	S16	86.80	3.11	90.00	83.00	7.00	86.00
<b>Less-affected side</b>	<b>Subject 4</b>	S04	100.80	3.56	106.00	97.00	8.99	101.00
	<b>Subject 6</b>	S06	125.40	0.55	126.00	125.00	1.00	125.00
	<b>Subject 7</b>	S07	110.40	1.81	112.00	108.00	4.00	111.00
	<b>Subject 9</b>	S09	114.40	17.91	126.00	83.00	43.00	121.00
	<b>Subject 10</b>	S10	108.00	12.20	125.00	92.00	33.00	107.00
	<b>Subject 11</b>	S11	113.00	3.31	117.00	108.00	8.99	114.00
	<b>Subject 13</b>	S13	124.00	1.87	126.00	121.00	5.00	124.00
	<b>Subject 14</b>	S14	90.80	4.15	98.00	88.00	10.00	90.00
	<b>Subject 15</b>	S15	103.00	2.34	107.00	101.00	6.00	102.00
<b>Subject 17</b>	S17	124.60	3.58	130.00	121.00	8.99	124.00	

**Table A1.3: Individual Subject Temperospatial Parameters: Step Length measured during Left stride of gait the cycle in metres**

			Step Length m					
			Mean	SD	Max	Min	Range	Median
<b>Affected Side</b>	<b>Subject 1</b>	S01	0.47	0.03	0.55	0.46	0.09	0.48
	<b>Subject 2</b>	S02	0.42	0.05	0.45	0.33	0.12	0.37
	<b>Subject 3</b>	S03	0.58	0.04	0.60	0.48	0.12	0.54
	<b>Subject 5</b>	S05	0.40	0.03	0.45	0.36	0.09	0.39
	<b>Subject 8</b>	S08	0.54	0.02	0.57	0.50	0.07	0.55
	<b>Subject 12</b>	S12	0.44	0.03	0.46	0.36	0.10	0.42
	<b>Subject 16</b>	S16	0.55	0.02	0.60	0.51	0.09	0.56
<b>Less-affected Side</b>	<b>Subject 4</b>	S04	0.60	0.02	0.64	0.55	0.09	0.60
	<b>Subject 6</b>	S06	0.58	0.06	0.68	0.53	0.15	0.63
	<b>Subject 7</b>	S07	0.54	0.02	0.58	0.53	0.05	0.56
	<b>Subject 9</b>	S09	0.52	0.05	0.65	0.50	0.15	0.56
	<b>Subject 10</b>	S10	0.58	0.03	0.61	0.55	0.06	0.59
	<b>Subject 11</b>	S11	0.63	0.03	0.65	0.56	0.09	0.61
	<b>Subject 13</b>	S13	0.62	0.02	0.65	0.59	0.06	0.63
	<b>Subject 14</b>	S14	0.57	0.07	0.73	0.55	0.18	0.64
	<b>Subject 15</b>	S15	0.63	0.02	0.67	0.59	0.08	0.62
	<b>Subject 17</b>	S17	0.68	0.02	0.72	0.66	0.06	0.69

**Table A1.4: Individual Subject Temperospatial Parameters: Stride Length measured during left stride of gait the cycle in metres**

			Stride Length m					
			Mean	SD	Max	Min	Range	Median
<b>Affected Side</b>	<b>Subject 1</b>	S01	0.96	0.03	0.99	0.93	0.06	0.95
	<b>Subject 2</b>	S02	0.70	0.04	0.76	0.66	0.10	0.70
	<b>Subject 3</b>	S03	1.08	0.09	1.19	0.99	0.20	1.08
	<b>Subject 5</b>	S05	0.75	0.04	0.81	0.71	0.10	0.72
	<b>Subject 8</b>	S08	1.07	0.04	1.11	1.01	0.10	1.08
	<b>Subject 12</b>	S12	0.77	0.03	0.81	0.73	0.08	0.78
	<b>Subject 16</b>	S16	1.09	0.04	1.13	1.03	0.10	1.11
<b>Less-affected Side</b>	<b>Subject 4</b>	S04	1.16	0.03	1.20	1.13	0.07	1.15
	<b>Subject 6</b>	S06	1.24	0.06	1.31	1.16	0.15	1.26
	<b>Subject 7</b>	S07	1.06	0.03	1.10	1.02	0.08	1.08
	<b>Subject 9</b>	S09	1.03	0.09	1.15	0.92	0.23	1.05
	<b>Subject 10</b>	S10	1.02	0.09	1.12	0.92	0.20	1.02
	<b>Subject 11</b>	S11	1.20	0.02	1.24	1.18	0.06	1.19
	<b>Subject 13</b>	S13	1.25	0.02	1.27	1.22	0.05	1.26
	<b>Subject 14</b>	S14	1.23	0.02	1.26	1.21	0.05	1.23
	<b>Subject 15</b>	S15	1.23	0.03	1.28	1.20	0.08	1.21
	<b>Subject 17</b>	S17	1.36	0.03	1.38	1.31	0.07	1.37

**Table A1.5: Individual Subject Temperospatial Parameters: Stride Time measured during left stride of gait the cycle in seconds**

			Stride Times					
			Mean	SD	Max	Min	Range	Median
<b>Affected Side</b>	<b>Subject 1</b>	S01	1.01	0.04	1.07	0.97	0.10	1.00
	<b>Subject 2</b>	S02	1.53	0.13	1.70	1.36	0.34	1.52
	<b>Subject 3</b>	S03	1.11	0.03	1.16	1.06	0.09	1.10
	<b>Subject 5</b>	S08	1.36	0.02	1.39	1.35	0.04	1.37
	<b>Subject 8</b>	S04	1.18	0.02	1.22	1.17	0.05	1.17
	<b>Subject 12</b>	S10	1.27	0.02	1.30	1.26	0.04	1.26
	<b>Subject 16</b>	S15	1.37	0.01	1.39	1.36	0.03	1.38
<b>Less-affected Side</b>	<b>Subject 4</b>	S05	1.19	0.03	1.22	1.15	0.07	1.20
	<b>Subject 6</b>	S12	1.17	0.03	1.21	1.13	0.08	1.17
	<b>Subject 7</b>	S16	1.15	0.02	1.17	1.13	0.04	1.15
	<b>Subject 9</b>	S06	1.25	0.10	1.42	1.17	0.25	1.23
	<b>Subject 10</b>	S07	1.33	0.06	1.43	1.27	0.16	1.31
	<b>Subject 11</b>	S09	1.08	0.01	1.10	1.07	0.03	1.08
	<b>Subject 13</b>	S11	0.98	0.02	1.02	0.96	0.06	0.99
	<b>Subject 14</b>	S13	1.49	0.04	1.52	1.42	0.09	1.50
	<b>Subject 15</b>	S14	1.15	0.02	1.19	1.13	0.06	1.14
	<b>Subject 17</b>	S17	0.98	0.03	1.02	0.94	0.08	0.98

**Table A1.6: Individual Subject Temperospatial Parameters: Percentage Limp Index**

			Percent Limp Index (R/L)					
			Mean	SD	Max	Min	Range	Median
<b>Affected Side</b>	<b>Subject 1</b>	S01	104.71	1.46	106.04	102.56	3.48	104.88
	<b>Subject 2</b>	S02	117.90	2.37	120.96	114.59	6.36	118.10
	<b>Subject 3</b>	S03	109.36	1.79	110.96	106.75	4.20	109.73
	<b>Subject 5</b>	S05	104.14	2.23	106.01	100.33	5.68	104.49
	<b>Subject 8</b>	S08	105.07	1.32	107.03	103.54	3.49	104.76
	<b>Subject 12</b>	S12	114.32	2.22	116.07	110.50	5.58	114.92
	<b>Subject 16</b>	S16	101.31	2.15	103.93	98.36	5.57	101.60
<b>Less-affected Side</b>	<b>Subject 4</b>	S04	101.08	1.18	102.63	99.89	2.74	100.52
	<b>Subject 6</b>	S06	82.44	1.88	84.43	80.04	4.39	82.94
	<b>Subject 7</b>	S07	93.99	2.68	96.58	89.70	6.88	94.80
	<b>Subject 9</b>	S09	89.51	1.52	91.09	87.06	4.03	89.79
	<b>Subject 10</b>	S10	85.25	3.23	89.60	81.89	7.71	85.18
	<b>Subject 11</b>	S11	95.61	1.32	97.20	93.64	3.56	95.62
	<b>Subject 13</b>	S13	97.53	0.15	97.68	97.32	0.35	97.51
	<b>Subject 14</b>	S14	86.12	1.52	87.87	83.85	4.02	85.89
	<b>Subject 15</b>	S15	101.89	0.54	102.56	101.10	1.47	102.02
	<b>Subject 17</b>	S17	97.10	0.44	97.57	96.41	1.16	97.22

**Table A1.7: Individual Subject Temperospatial Parameters: Walking Speed measured in metres per second during right gait cycle**

			Walking Speed m/s					
			Mean	SD	Max	Min	Range	Median
<b>Affected Side</b>	<b>Subject 4</b>	S04	0.99	0.05	1.06	0.91	0.15	1.00
	<b>Subject 6</b>	S06	1.08	0.04	1.15	1.05	0.10	1.06
	<b>Subject 7</b>	S07	0.92	0.04	0.96	0.88	0.08	0.90
	<b>Subject 9</b>	S09	0.83	0.13	0.93	0.62	0.31	0.86
	<b>Subject 10</b>	S10	0.75	0.07	0.82	0.65	0.17	0.76
	<b>Subject 11</b>	S11	1.11	0.04	1.15	1.07	0.08	1.13
	<b>Subject 13</b>	S13	1.27	0.05	1.31	1.19	0.12	1.30
	<b>Subject 14</b>	S14	0.83	0.03	0.87	0.79	0.08	0.83
	<b>Subject 15</b>	S15	1.08	0.04	1.14	1.05	0.09	1.08
	<b>Subject 17</b>	S17	1.38	0.06	1.46	1.29	0.17	1.38
<b>Less-affected Side</b>	<b>Subject 1</b>	S01	0.95	0.06	1.01	0.88	0.13	0.97
	<b>Subject 2</b>	S02	0.46	0.05	0.52	0.40	0.12	0.47
	<b>Subject 3</b>	S03	0.98	0.03	1.01	0.94	0.07	1.00
	<b>Subject 5</b>	S05	0.55	0.04	0.59	0.51	0.08	0.56
	<b>Subject 8</b>	S08	0.90	0.03	0.94	0.86	0.08	0.91
	<b>Subject 12</b>	S12	0.60	0.02	0.63	0.58	0.05	0.59
	<b>Subject 16</b>	S16	0.79	0.03	0.83	0.75	0.08	0.79



**Table A1.8: Individual Subject Temperospatial Parameters: Cadence measured in steps per minute during right gait cycle**

			Cadence (steps/minute)					
			Mean	SD	Max	Min	Range	Median
<b>Affected Side</b>	<b>Subject 4</b>	S04	101.80	3.63	106.00	98.00	8.00	103.00
	<b>Subject 6</b>	S06	88.40	3.05	93.00	86.00	7.00	87.00
	<b>Subject 7</b>	S07	98.00	2.12	101.00	95.00	6.00	98.00
	<b>Subject 9</b>	S09	83.20	6.41	90.00	73.00	17.00	83.00
	<b>Subject 10</b>	S10	76.60	4.33	81.00	70.00	11.00	76.00
	<b>Subject 11</b>	S11	108.20	1.30	109.00	106.00	3.00	109.00
	<b>Subject 13</b>	S13	119.00	3.16	122.00	114.00	8.00	120.00
	<b>Subject 14</b>	S14	71.80	4.32	79.00	68.00	11.00	71.00
	<b>Subject 15</b>	S15	107.00	2.00	109.00	104.00	5.00	108.00
<b>Less-affected Side</b>	<b>Subject 1</b>	S01	120.80	0.83	122.00	120.00	2.00	121.00
	<b>Subject 2</b>	S02	81.60	11.67	98.00	67.00	31.00	82.00
	<b>Subject 3</b>	S03	117.60	3.28	121.00	114.00	7.00	117.00
	<b>Subject 5</b>	S05	98.00	4.00	102.00	92.00	10.00	100.00
	<b>Subject 8</b>	S08	107.00	2.12	110.00	105.00	5.00	107.00
	<b>Subject 12</b>	S12	111.40	3.50	117.00	108.00	8.99	111.00
	<b>Subject 16</b>	S16	88.20	2.59	91.00	85.00	5.99	89.00

**Table A1.9: Individual Subject Temperospatial Parameters: Step Length measured in metres during right gait cycle**

			Step Length (m)					
			Mean	SD	Max	Min	Range	Median
<b>Affected Side</b>	<b>Subject 4</b>	S04	0.59	0.02	0.61	0.55	0.06	0.60
	<b>Subject 6</b>	S06	0.66	0.03	0.68	0.62	0.06	0.68
	<b>Subject 7</b>	S07	0.57	0.01	0.58	0.56	0.02	0.58
	<b>Subject 9</b>	S09	0.60	0.03	0.65	0.57	0.08	0.61
	<b>Subject 10</b>	S10	0.58	0.03	0.61	0.55	0.06	0.59
	<b>Subject 11</b>	S11	0.59	0.02	0.61	0.56	0.05	0.60
	<b>Subject 13</b>	S13	0.64	0.01	0.65	0.63	0.02	0.64
	<b>Subject 14</b>	S14	0.70	0.02	0.73	0.68	0.05	0.70
	<b>Subject 15</b>	S15	0.63	0.01	0.64	0.62	0.02	0.62
<b>Less-affected Side</b>	<b>Subject 1</b>	S01	0.52	0.03	0.55	0.48	0.07	0.53
	<b>Subject 2</b>	S02	0.34	0.01	0.36	0.33	0.03	0.34
	<b>Subject 3</b>	S03	0.51	0.03	0.54	0.48	0.06	0.52
	<b>Subject 5</b>	S05	0.39	0.03	0.43	0.36	0.07	0.38
	<b>Subject 8</b>	S08	0.54	0.03	0.56	0.50	0.06	0.55
	<b>Subject 12</b>	S12	0.38	0.01	0.40	0.36	0.04	0.38
	<b>Subject 16</b>	S16	0.57	0.02	0.60	0.55	0.05	0.56

**Table A1.10: Individual Subject Temperospatial Parameters: Stride Length measured in metres during right gait cycle**

			Stride Length (m)					
			Mean	SD	Max	Min	Range	Median
<b>Affected Side</b>	<b>Subject 4</b>	S04	1.17	0.04	1.23	1.13	0.10	1.16
	<b>Subject 6</b>	S06	1.25	0.06	1.33	1.18	0.15	1.24
	<b>Subject 7</b>	S07	1.06	0.02	1.09	1.03	0.06	1.05
	<b>Subject 9</b>	S09	1.03	0.07	1.12	0.96	0.16	1.01
	<b>Subject 10</b>	S10	1.01	0.04	1.08	0.97	0.11	1.01
	<b>Subject 11</b>	S11	1.21	0.02	1.24	1.18	0.06	1.21
	<b>Subject 13</b>	S13	1.26	0.02	1.28	1.22	0.06	1.26
	<b>Subject 14</b>	S14	1.25	0.02	1.27	1.22	0.05	1.25
	<b>Subject 15</b>	S15	1.24	0.04	1.30	1.20	0.10	1.22
	<b>Subject 17</b>	S17	1.36	0.03	1.38	1.31	0.07	1.36
<b>Less-affected Side</b>	<b>Subject 1</b>	S01	0.97	0.03	1.00	0.93	0.07	0.97
	<b>Subject 2</b>	S02	0.69	0.02	0.71	0.65	0.06	0.70
	<b>Subject 3</b>	S03	1.07	0.04	1.11	1.01	0.10	1.06
	<b>Subject 5</b>	S05	0.75	0.05	0.82	0.70	0.12	0.74
	<b>Subject 8</b>	S08	1.05	0.05	1.11	1.00	0.11	1.04
	<b>Subject 12</b>	S12	0.76	0.03	0.81	0.74	0.07	0.75
	<b>Subject 16</b>	S16	1.07	0.05	1.10	0.98	0.12	1.10

**Table A1.11: Individual Subject Temperospatial Parameters: Stride Time measured in seconds during right gait cycle**

			Stride Time(s)					
			Mean	SD	Max	Min	Range	Median
<b>Affected Side</b>	<b>Subject 4</b>	S04	1.18	0.03	1.24	1.15	0.09	1.18
	<b>Subject 6</b>	S06	1.16	0.02	1.18	1.13	0.05	1.17
	<b>Subject 7</b>	S07	1.15	0.02	1.17	1.12	0.04	1.17
	<b>Subject 9</b>	S09	1.26	0.16	1.54	1.14	0.40	1.20
	<b>Subject 10</b>	S10	1.35	0.09	1.51	1.27	0.25	1.33
	<b>Subject 11</b>	S11	1.09	0.02	1.12	1.06	0.06	1.08
	<b>Subject 13</b>	S13	0.99	0.02	1.03	0.97	0.05	0.98
	<b>Subject 14</b>	S14	1.51	0.06	1.58	1.43	0.15	1.52
	<b>Subject 15</b>	S15	1.14	0.02	1.17	1.11	0.05	1.15
	<b>Subject 17</b>	S17	0.99	0.03	1.02	0.95	0.07	0.99
<b>Less-affected Side</b>	<b>Subject 1</b>	S01	1.03	0.03	1.06	1.00	0.07	1.02
	<b>Subject 2</b>	S02	1.52	0.11	1.65	1.37	0.27	1.49
	<b>Subject 3</b>	S03	1.09	0.02	1.12	1.07	0.05	1.10
	<b>Subject 5</b>	S05	1.38	0.04	1.43	1.32	0.11	1.37
	<b>Subject 8</b>	S08	1.16	0.02	1.18	1.13	0.05	1.18
	<b>Subject 12</b>	S12	1.27	0.03	1.30	1.23	0.07	1.27
	<b>Subject 16</b>	S16	1.35	0.04	1.39	1.30	0.09	1.36

## Appendix 2: Thorax and Pelvis Kinematics during Gait of People with Stroke

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**Table A2.1: Subject kinematics of the thorax in the sagittal plane on the affected side throughout the gait cycle**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min mean</b>	<b>ROM</b>
<b>Subject 1</b>	-1.45	0.54	-0.18	-3.19	3.01
<b>Subject 2</b>	4.93	0.94	7.85	1.99	5.86
<b>Subject 3</b>	0.07	1.48	2.81	-2.23	5.04
<b>Subject 5</b>	18.51	0.61	21.53	14.10	7.43
<b>Subject 8</b>	-3.13	0.68	-1.90	-4.26	2.36
<b>Subject 12</b>	-1.69	0.66	0.01	-3.75	3.76
<b>Subject 16</b>	13.75	1.35	15.00	12.03	2.97
<b>Subject 4</b>	-0.71	0.53	0.39	-1.80	2.19
<b>Subject 6</b>	11.35	0.90	13.83	7.70	6.13
<b>Subject 7</b>	5.66	0.95	7.06	3.86	3.20
<b>Subject 9</b>	-2.70	0.83	1.03	-6.85	7.88
<b>Subject 10</b>	3.04	0.54	5.42	0.05	5.37
<b>Subject 11</b>	3.88	0.60	6.88	1.65	5.23
<b>Subject 13</b>	-3.16	0.69	-2.12	-4.00	1.88
<b>Subject 14</b>	14.22	1.52	16.79	10.82	5.97
<b>Subject 15</b>	3.65	0.87	6.33	1.89	4.44
<b>Subject 17</b>	2.17	1.04	3.04	1.24	1.80
<b>Affected Mean</b>	4.02	0.87	6.10	1.72	4.38



**Table A2.2: Subject kinematics of the thorax in the sagittal plane on the less-affected side throughout the gait cycle**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>ROM</b>
<b>Subject 1</b>	-1.41	0.54	-0.03	-0.03	3.14
<b>Subject 2</b>	4.98	0.96	7.95	1.95	6.00
<b>Subject 3</b>	0.17	1.20	2.77	-1.97	4.74
<b>Subject 5</b>	18.53	0.67	21.57	14.08	7.49
<b>Subject 8</b>	-3.17	0.63	-1.94	-4.36	2.42
<b>Subject 12</b>	-1.73	0.78	0.00	-3.92	3.92
<b>Subject 16</b>	14.00	1.09	15.67	12.38	3.29
<b>Subject 4</b>	-0.81	0.48	0.26	-1.66	1.91
<b>Subject 6</b>	11.41	0.93	13.76	7.72	6.05
<b>Subject 7</b>	5.70	0.82	7.07	3.94	3.13
<b>Subject 9</b>	-2.73	0.97	1.10	-7.27	8.36
<b>Subject 10</b>	3.27	0.68	5.72	0.06	5.67
<b>Subject 11</b>	3.92	0.64	7.04	1.62	5.42
<b>Subject 13</b>	-3.03	0.62	-2.04	-3.95	1.91
<b>Subject 14</b>	14.34	1.17	17.25	10.91	6.34
<b>Subject 15</b>	3.74	1.08	6.50	1.76	4.74
<b>Subject 17</b>	2.16	1.07	2.90	1.14	1.76
<b>Less-affected Mean</b>	4.08	0.84	6.21	1.91	4.49

**Table A2.3: Subject kinematics of the thorax in the sagittal plane on the affected side at initial contact**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>ROM</b>
<b>Subject 1</b>	-1.37	0.71	-1.77	-3.19	3.01
<b>Subject 2</b>	3.37	1.13	7.85	1.99	5.86
<b>Subject 3</b>	-0.67	2.34	2.81	-2.23	5.04
<b>Subject 5</b>	16.50	1.42	21.53	14.10	7.43
<b>Subject 8</b>	2.69	0.89	-1.90	-4.26	2.36
<b>Subject 12</b>	-2.11	0.88	0.01	-3.75	3.76
<b>Subject 16</b>	13.94	1.34	15.00	12.03	2.97
<b>Subject 4</b>	-1.47	0.83	0.39	-1.80	2.19
<b>Subject 6</b>	9.34	1.43	13.83	7.70	6.13
<b>Subject 7</b>	5.84	1.11	7.06	3.86	3.20
<b>Subject 9</b>	-4.67	1.27	1.03	-6.85	7.88
<b>Subject 10</b>	2.10	1.66	5.42	0.05	5.37
<b>Subject 11</b>	2.68	1.07	6.88	1.65	5.23
<b>Subject 13</b>	-3.10	0.78	-2.12	-4.00	1.88
<b>Subject 14</b>	11.08	1.86	16.79	10.82	5.97
<b>Subject 15</b>	5.38	1.20	6.33	1.89	4.44
<b>Subject 17</b>	1.55	1.01	3.35	1.14	2.21
<b>Affected Mean</b>	3.59	1.23	6.03	1.71	4.41

**Table A2.4: Subject kinematics of the thorax in the sagittal plane on the less-affected side at initial contact**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>ROM</b>
<b>Subject 1</b>	-0.17	0.94	-0.03	-3.17	3.14
<b>Subject 2</b>	7.87	1.25	7.95	1.95	6.00
<b>Subject 3</b>	2.36	2.27	2.77	-1.97	4.74
<b>Subject 5</b>	21.00	1.71	21.57	14.08	7.49
<b>Subject 8</b>	-2.15	0.63	1.94	-4.36	2.42
<b>Subject 12</b>	1.47	1.06	0.00	-3.92	3.92
<b>Subject 16</b>	14.38	1.52	15.67	12.38	3.29
<b>Subject 4</b>	-0.07	0.92	0.26	-1.66	1.91
<b>Subject 6</b>	13.03	0.88	13.67	7.72	6.05
<b>Subject 7</b>	6.04	0.94	7.07	3.94	3.13
<b>Subject 9</b>	0.47	1.70	1.10	-7.27	8.36
<b>Subject 10</b>	2.56	1.29	5.72	0.06	5.67
<b>Subject 11</b>	6.86	1.18	7.04	1.62	5.42
<b>Subject 13</b>	-2.20	0.82	2.04	3.95	1.91
<b>Subject 14</b>	13.60	1.87	17.25	10.91	6.34
<b>Subject 15</b>	3.67	1.26	6.50	1.76	4.74
<b>Subject 17</b>	2.87	1.48	3.16	0.93	2.23
<b>Less-affected Mean</b>	5.39	1.28	6.69	2.17	4.52

**Table A2.5: Subject kinematics of the thorax in the sagittal plane on the affected side at foot off**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-1.20	0.86	-0.40	-2.20	1.80
<b>Subject 2</b>	5.98	1.89	8.50	4.10	4.40
<b>Subject 3</b>	0.32	2.19	3.80	-2.00	5.80
<b>Subject 5</b>	20.86	1.84	22.90	18.00	4.90
<b>Subject 8</b>	-3.66	0.50	-3.20	-4.50	1.30
<b>Subject 12</b>	-1.88	0.50	-1.20	-2.50	1.30
<b>Subject 16</b>	12.84	1.27	14.00	11.10	2.90
<b>Subject 4</b>	-0.62	1.00	0.40	-2.00	2.40
<b>Subject 6</b>	11.02	1.24	12.30	9.50	2.80
<b>Subject 7</b>	4.88	1.09	5.90	3.60	2.30
<b>Subject 9</b>	-0.80	1.85	0.70	-3.90	4.60
<b>Subject 10</b>	3.54	1.41	4.90	1.30	3.60
<b>Subject 11</b>	4.94	0.98	6.50	3.80	2.70
<b>Subject 13</b>	-3.20	0.90	-2.30	-4.30	2.00
<b>Subject 14</b>	15.56	1.63	17.00	13.50	3.50
<b>Subject 15</b>	2.58	1.60	5.30	1.40	3.90
<b>Subject 17</b>	2.73	1.21	4.00	4.00	3.10
<b>Affected Mean</b>	4.35	1.29	5.83	2.88	3.14

**Table A2.6: Subject kinematics of the thorax in the sagittal plane on the less-affected side at foot off**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-2.70	0.72	-1.90	-3.60	1.70
<b>Subject 2</b>	3.90	0.91	5.20	2.80	2.40
<b>Subject 3</b>	-0.24	3.63	5.60	-4.20	9.80
<b>Subject 5</b>	15.18	1.56	17.20	13.20	4.00
<b>Subject 8</b>	-3.90	1.13	-2.40	-5.40	3.00
<b>Subject 12</b>	-3.72	1.11	-2.50	-5.50	3.00
<b>Subject 16</b>	12.36	1.55	14.10	9.90	4.20
<b>Subject 4</b>	-0.98	1.00	0.40	-2.20	2.60
<b>Subject 6</b>	8.12	1.28	10.10	6.90	3.20
<b>Subject 7</b>	4.52	1.35	6.20	2.90	3.30
<b>Subject 9</b>	-6.52	0.75	-5.40	-7.30	1.90
<b>Subject 10</b>	0.26	1.23	2.10	-1.10	3.20
<b>Subject 11</b>	2.24	1.40	3.90	0.50	3.40
<b>Subject 13</b>	-3.68	0.53	-2.90	-4.30	1.40
<b>Subject 14</b>	14.78	3.30	18.00	10.80	7.20
<b>Subject 15</b>	2.70	0.92	4.20	1.70	2.50
<b>Subject 17</b>	1.48	1.52	3.60	0.00	3.60
<b>Less-affected Mean</b>	2.58	1.41	4.44	0.89	3.55

**Table A2.7: Subject kinematics of the thorax in the coronal plane on the affected side throughout the gait cycle**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-1.61	1.54	-0.18	-3.74	3.56
<b>Subject 2</b>	-1.33	1.37	-0.27	-2.27	2.00
<b>Subject 3</b>	-2.69	0.86	-0.31	-5.59	5.28
<b>Subject 5</b>	-1.14	2.28	4.49	-6.50	10.99
<b>Subject 8</b>	1.43	0.94	3.24	-0.27	3.51
<b>Subject 12</b>	0.83	0.77	2.54	-1.60	4.14
<b>Subject 16</b>	-0.92	0.82	0.56	-2.79	3.36
<b>Subject 4</b>	-3.07	1.02	-1.13	-4.88	3.75
<b>Subject 6</b>	-5.27	1.16	-1.08	-8.48	7.40
<b>Subject 7</b>	-4.79	0.74	-0.06	-9.18	9.12
<b>Subject 9</b>	-4.34	1.02	-1.44	-8.98	7.54
<b>Subject 10</b>	-4.75	1.56	1.65	-15.11	16.75
<b>Subject 11</b>	0.34	1.06	4.37	-4.04	8.41
<b>Subject 13</b>	-3.48	0.44	-2.19	-4.90	2.71
<b>Subject 14</b>	-6.10	3.04	-0.86	-12.69	11.83
<b>Subject 15</b>	0.20	0.90	2.57	-2.02	4.58
<b>Subject 17</b>	-1.89	-1.55	1.10	-4.73	5.83
<b>Affected Mean</b>	-2.27	1.06	0.76	-5.75	6.51

**Table A2.8: Subject kinematics of the thorax in the coronal plane on the less-affected side throughout the gait cycle**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	1.62	1.46	3.76	0.24	3.53
<b>Subject 2</b>	1.30	1.42	2.28	0.16	2.12
<b>Subject 3</b>	2.57	0.75	5.24	0.29	4.95
<b>Subject 5</b>	1.27	2.27	6.56	-4.49	11.05
<b>Subject 8</b>	-1.43	0.99	0.16	-3.14	3.29
<b>Subject 12</b>	-0.81	0.76	1.63	-2.54	4.17
<b>Subject 16</b>	0.70	1.13	2.26	-0.82	3.07
<b>Subject 4</b>	2.96	0.89	4.83	1.09	3.74
<b>Subject 6</b>	5.25	1.20	8.53	1.09	7.43
<b>Subject 7</b>	4.80	0.81	9.28	-0.07	9.35
<b>Subject 9</b>	4.32	1.02	8.98	1.27	7.71
<b>Subject 10</b>	4.75	1.66	14.69	-1.47	16.16
<b>Subject 11</b>	-0.37	0.97	3.90	-4.29	8.19
<b>Subject 13</b>	3.34	0.33	4.92	1.99	2.93
<b>Subject 14</b>	6.14	3.04	12.91	0.93	11.97
<b>Subject 15</b>	-0.16	0.90	2.07	-2.64	4.71
<b>Subject 17</b>	1.91	2.58	4.62	-1.04	5.66
<b>Less-affected Mean</b>	2.24	1.30	5.68	-0.79	6.47

**Table A2.9: Subject kinematics of the thorax in the coronal plane on the affected side at initial contact**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-0.43	1.51	-0.18	-3.74	3.56
<b>Subject 2</b>	1.20	1.30	-0.27	-2.27	2.00
<b>Subject 3</b>	-2.37	1.41	-0.31	-5.59	5.28
<b>Subject 5</b>	-1.84	4.65	4.49	-6.50	10.99
<b>Subject 8</b>	0.98	1.27	3.24	-0.27	3.51
<b>Subject 12</b>	1.10	1.20	2.54	-1.60	4.14
<b>Subject 16</b>	-2.14	1.73	0.56	-2.79	3.36
<b>Subject 4</b>	-3.07	1.37	-1.13	-4.88	3.75
<b>Subject 6</b>	-6.54	1.63	-1.08	-8.48	7.40
<b>Subject 7</b>	-4.45	1.15	-0.06	-9.18	9.12
<b>Subject 9</b>	-3.16	1.75	-1.44	-8.98	7.54
<b>Subject 10</b>	-2.90	3.09	1.65	-15.11	16.75
<b>Subject 11</b>	1.23	1.04	4.37	-4.04	8.41
<b>Subject 13</b>	-4.13	0.66	-2.19	-4.90	2.71
<b>Subject 14</b>	-1.67	1.77	-0.86	-12.69	11.83
<b>Subject 15</b>	-1.92	0.85	2.57	-2.02	4.58
<b>Subject 17</b>	-1.38	5.32	1.10	-4.73	5.83
<b>Affected Mean</b>	-1.85	1.86	0.76	-5.75	6.52



**Table A2.10: Subject kinematics of the thorax in the coronal plane on the less-affected side at initial contact**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	1.90	1.35	3.76	0.24	3.53
<b>Subject 2</b>	1.72	1.84	2.28	0.16	2.12
<b>Subject 3</b>	1.97	1.73	5.24	0.29	4.95
<b>Subject 5</b>	1.96	2.17	6.56	-4.49	11.05
<b>Subject 8</b>	-1.60	1.07	0.16	-3.14	3.29
<b>Subject 12</b>	-2.28	1.15	1.63	-2.54	4.17
<b>Subject 16</b>	-0.17	1.44	2.26	-0.82	3.07
<b>Subject 4</b>	3.01	1.24	4.83	1.09	3.74
<b>Subject 6</b>	4.25	1.25	8.53	1.09	7.43
<b>Subject 7</b>	6.02	1.04	9.28	-0.07	9.35
<b>Subject 9</b>	7.24	1.29	8.98	1.27	7.71
<b>Subject 10</b>	8.61	2.44	14.69	-1.47	16.16
<b>Subject 11</b>	0.75	1.19	3.90	-4.29	8.19
<b>Subject 13</b>	2.35	0.62	4.92	1.99	2.93
<b>Subject 14</b>	7.94	1.75	12.91	0.93	11.97
<b>Subject 15</b>	-2.75	1.19	2.07	-2.64	4.71
<b>Subject 17</b>	2.09	1.40	4.62	-1.04	5.66
<b>Less-affected Mean</b>	2.53	1.42	5.68	-0.79	6.47

**Table A2.11: Subject kinematics of the thorax in the coronal plane on the affected side at foot off**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-0.20	1.74	1.70	-2.20	3.90
<b>Subject 2</b>	-0.88	1.78	0.50	-3.80	4.30
<b>Subject 3</b>	-0.16	2.27	3.20	-2.90	6.10
<b>Subject 5</b>	4.02	1.95	6.70	1.80	4.90
<b>Subject 8</b>	2.78	1.21	4.20	1.30	2.90
<b>Subject 12</b>	1.90	0.75	2.90	1.10	1.80
<b>Subject 16</b>	0.12	0.57	1.00	-0.50	1.50
<b>Subject 4</b>	-1.14	1.81	0.70	-3.50	4.20
<b>Subject 6</b>	-1.18	1.68	0.50	-3.40	3.90
<b>Subject 7</b>	0.12	1.88	2.30	-2.00	4.30
<b>Subject 9</b>	-2.30	1.66	-0.60	-4.60	4.00
<b>Subject 10</b>	1.38	2.14	4.60	-0.80	5.40
<b>Subject 11</b>	3.40	1.79	6.20	1.30	4.90
<b>Subject 13</b>	-2.12	0.58	-1.50	-3.00	1.50
<b>Subject 14</b>	-1.96	1.77	0.90	-3.30	4.20
<b>Subject 15</b>	1.90	0.76	2.50	0.60	1.90
<b>Subject 17</b>	-1.23	-0.23	-0.68	0.36	-0.90
<b>Affected Mean</b>	0.26	1.42	2.07	-1.38	3.46

**Table A2.12: Subject kinematics of the thorax in the coronal plane on the less-affected side at foot off**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	2.62	1.43	4.40	1.20	3.20
<b>Subject 2</b>	1.54	1.75	4.00	-0.20	4.20
<b>Subject 3</b>	5.28	1.80	7.10	2.90	4.20
<b>Subject 5</b>	6.60	3.09	9.30	2.40	6.90
<b>Subject 8</b>	0.58	1.02	1.70	-1.00	2.70
<b>Subject 12</b>	1.28	1.63	3.80	-0.10	3.90
<b>Subject 16</b>	2.58	1.94	4.10	-0.20	4.30
<b>Subject 4</b>	4.46	1.00	5.90	3.40	2.50
<b>Subject 6</b>	8.50	0.84	9.70	7.50	2.20
<b>Subject 7</b>	7.56	1.10	8.80	6.20	2.60
<b>Subject 9</b>	5.70	0.99	7.10	4.50	2.60
<b>Subject 10</b>	10.94	1.91	12.80	8.50	4.30
<b>Subject 11</b>	2.38	0.61	2.80	1.30	1.50
<b>Subject 13</b>	4.90	0.58	5.80	4.30	1.50
<b>Subject 14</b>	10.24	1.19	11.40	8.70	2.70
<b>Subject 15</b>	0.88	1.02	2.30	-0.50	2.80
<b>Subject 17</b>	5.85	0.98	7.00	4.60	2.40
<b>Less-affected Mean</b>	4.82	1.35	6.35	3.15	3.21

**Table A2.13: Subject kinematics of the thorax in the transverse plane on the affected side throughout the gait cycle**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-1.45	0.54	-1.45	-0.18	3.01
<b>Subject 2</b>	5.82	1.27	3.55	3.46	3.20
<b>Subject 3</b>	-3.19	2.06	-0.80	-6.05	5.24
<b>Subject 5</b>	-6.58	1.41	0.69	-15.27	15.96
<b>Subject 8</b>	-2.57	1.07	2.85	-7.80	10.65
<b>Subject 12</b>	0.37	1.97	5.93	-3.83	9.76
<b>Subject 16</b>	1.63	0.73	3.72	-0.35	4.07
<b>Subject 4</b>	-5.29	1.02	-4.06	-6.64	2.58
<b>Subject 6</b>	0.29	1.04	7.57	-5.88	13.45
<b>Subject 7</b>	4.01	2.05	9.67	-2.62	12.29
<b>Subject 9</b>	7.71	1.19	13.05	0.55	12.50
<b>Subject 10</b>	18.69	0.75	29.82	8.21	21.62
<b>Subject 11</b>	-2.37	0.81	-0.27	-4.52	4.25
<b>Subject 13</b>	1.77	0.58	2.93	0.60	2.34
<b>Subject 14</b>	8.86	2.67	14.81	3.20	11.61
<b>Subject 15</b>	1.15	0.88	10.95	-8.31	19.26
<b>Subject 17</b>	1.99	1.09	7.49	-3.10	10.59
<b>Affected Mean</b>	1.81	1.24	6.26	-2.85	9.55

**Table A2.14: Subject kinematics of the thorax in the transverse plane on the less-affected side throughout the gait cycle**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	8.21	1.18	12.72	3.32	9.40
<b>Subject 2</b>	3.43	2.67	5.03	1.55	3.48
<b>Subject 3</b>	3.44	1.62	6.40	0.88	5.51
<b>Subject 5</b>	6.31	1.53	15.41	-0.77	16.18
<b>Subject 8</b>	2.43	0.93	7.64	-3.13	10.78
<b>Subject 12</b>	-0.49	1.93	3.81	-6.23	10.05
<b>Subject 16</b>	-2.16	0.40	-0.52	-4.69	4.17
<b>Subject 4</b>	5.16	1.20	6.84	3.60	3.24
<b>Subject 6</b>	-0.32	1.01	5.79	-7.49	13.28
<b>Subject 7</b>	-4.51	1.98	2.20	-10.24	12.44
<b>Subject 9</b>	-7.88	1.40	-0.79	-13.28	12.49
<b>Subject 10</b>	-18.76	0.95	-8.59	-29.26	20.67
<b>Subject 11</b>	2.47	0.85	4.53	0.27	4.26
<b>Subject 13</b>	-1.78	0.60	-0.74	-2.95	2.21
<b>Subject 14</b>	-9.41	3.23	-4.09	-15.23	11.14
<b>Subject 15</b>	-0.92	0.81	8.49	-11.04	19.53
<b>Subject 17</b>	-2.14	1.18	2.93	-7.87	10.80
<b>Less-affected Mean</b>	-1.00	1.38	3.94	-6.03	9.98

**Table A2.15: Subject kinematics of the thorax in the transverse plane on the affected side at initial contact**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-12.15	2.71	-3.95	-12.35	9.02
<b>Subject 2</b>	-3.33	2.58	-1.48	-4.86	3.38
<b>Subject 3</b>	-3.11	3.35	-0.80	-6.05	5.24
<b>Subject 5</b>	-14.40	2.90	0.69	-15.27	15.96
<b>Subject 8</b>	-7.28	1.45	2.85	-7.80	10.65
<b>Subject 12</b>	-2.66	2.04	5.93	-3.83	9.76
<b>Subject 16</b>	0.04	1.65	3.72	-0.35	4.07
<b>Subject 4</b>	4.25	1.78	6.84	3.60	3.24
<b>Subject 6</b>	-6.55	1.60	5.79	-7.49	13.28
<b>Subject 7</b>	-9.78	2.76	2.20	-10.24	12.44
<b>Subject 9</b>	-11.19	3.59	-0.79	-13.28	12.49
<b>Subject 10</b>	-20.31	3.27	-8.59	-29.26	20.67
<b>Subject 11</b>	1.04	1.43	4.53	-0.27	4.26
<b>Subject 13</b>	-1.72	1.11	-0.74	-2.95	2.21
<b>Subject 14</b>	-6.99	4.53	-4.09	-15.23	11.14
<b>Subject 15</b>	-10.58	1.76	8.49	-11.04	19.53
<b>Subject 17</b>	-7.03	2.60	2.93	-7.78	10.80
<b>Affected Mean</b>	-6.57	2.42	1.38	-8.50	9.89

**Table A2.16: Subject kinematics of the thorax in the transverse plane on the less-affected side at initial contact**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	5.95	26.00	12.72	3.32	9.40
<b>Subject 2</b>	2.50	2.21	5.03	1.55	3.48
<b>Subject 3</b>	3.47	2.76	6.40	0.08	5.51
<b>Subject 5</b>	-0.04	2.07	15.41	0.77	16.18
<b>Subject 8</b>	-2.89	1.50	7.67	-3.13	10.78
<b>Subject 12</b>	-0.58	2.59	3.81	-6.23	10.05
<b>Subject 16</b>	3.22	1.50	-0.52	-4.69	4.17
<b>Subject 4</b>	-6.04	1.59	-4.06	-6.64	2.58
<b>Subject 6</b>	-4.27	2.11	7.57	-5.88	13.45
<b>Subject 7</b>	-0.93	2.78	9.67	-2.62	12.29
<b>Subject 9</b>	5.51	2.44	13.05	0.55	12.50
<b>Subject 10</b>	11.60	2.56	29.82	8.21	21.62
<b>Subject 11</b>	-3.03	1.55	-0.27	-4.52	4.25
<b>Subject 13</b>	2.35	1.14	2.93	0.60	2.34
<b>Subject 14</b>	6.48	1.63	14.81	3.20	11.61
<b>Subject 15</b>	-8.00	2.20	10.95	-8.31	19.26
<b>Subject 17</b>	-2.05	2.35	7.49	-3.10	10.59
<b>Less-affected Mean</b>	0.78	3.47	8.38	-1.58	10.00

**Table A2.17: Subject kinematics of the thorax in the transverse plane on the affected side at foot off**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-10.14	3.52	-7.80	-16.20	8.40
<b>Subject 2</b>	-4.58	1.07	-2.70	-5.20	2.50
<b>Subject 3</b>	-4.18	3.70	1.80	-7.60	9.40
<b>Subject 5</b>	-4.68	2.73	-1.20	-8.20	7.00
<b>Subject 8</b>	1.84	1.46	3.80	0.00	3.80
<b>Subject 12</b>	-0.74	1.71	0.70	-3.50	4.20
<b>Subject 16</b>	1.46	1.83	3.30	-0.50	3.80
<b>Subject 4</b>	4.32	2.31	6.90	0.70	6.20
<b>Subject 6</b>	4.38	1.21	5.30	2.40	2.90
<b>Subject 7</b>	-2.68	1.62	-0.30	-4.80	4.50
<b>Subject 9</b>	-3.22	2.81	-0.30	-6.90	6.60
<b>Subject 10</b>	-22.54	1.68	-20.30	-24.40	4.10
<b>Subject 11</b>	4.56	1.62	6.60	2.70	3.90
<b>Subject 13</b>	-2.80	0.89	-2.10	-4.30	2.20
<b>Subject 14</b>	-9.76	3.32	-5.20	-14.50	9.30
<b>Subject 15</b>	5.64	1.95	9.10	4.40	4.70
<b>Subject 17</b>	1.48	0.50	1.59	1.07	1.76
<b>Affected Mean</b>	-2.45	2.00	-0.05	-4.99	5.02



**Table A2.18: Subject kinematics of the thorax in the transverse plane on the less-affected side at foot off**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	8.00	2.85	12.00	4.60	7.40
<b>Subject 2</b>	4.40	0.94	5.80	3.40	2.40
<b>Subject 3</b>	5.12	2.73	9.00	1.40	7.60
<b>Subject 5</b>	6.58	1.39	7.80	4.50	3.30
<b>Subject 8</b>	7.20	0.52	7.60	6.30	1.30
<b>Subject 12</b>	-0.24	2.22	2.80	-2.50	5.30
<b>Subject 16</b>	-1.30	0.77	-0.40	-2.20	1.80
<b>Subject 4</b>	-8.52	2.08	-6.30	-11.50	5.20
<b>Subject 6</b>	-1.58	2.05	1.40	-4.10	5.50
<b>Subject 7</b>	0.00	1.80	1.90	-2.80	4.70
<b>Subject 9</b>	5.60	1.55	7.90	3.70	4.20
<b>Subject 10</b>	10.14	1.05	11.90	9.10	2.80
<b>Subject 11</b>	-4.90	1.63	-3.60	-7.70	4.10
<b>Subject 13</b>	-0.48	0.72	0.20	-1.30	1.50
<b>Subject 14</b>	-1.52	2.42	0.70	-5.40	6.10
<b>Subject 15</b>	1.60	2.66	5.10	-1.20	6.30
<b>Subject 17</b>	-0.40	1.64	1.60	-2.40	4.00
<b>Less-affected Mean</b>	4.86	1.57	6.95	2.95	4.01

**Table A2.19: Subject kinematics of the pelvis in the sagittal plane on the affected side throughout the gait cycle**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	20.97	0.17	23.23	18.48	4.75
<b>Subject 2</b>	7.14	0.83	11.22	3.12	8.10
<b>Subject 3</b>	14.55	1.02	16.61	12.96	3.66
<b>Subject 5</b>	5.58	0.41	8.01	3.92	4.09
<b>Subject 8</b>	11.73	0.44	13.09	10.36	2.73
<b>Subject 12</b>	23.72	0.27	26.00	21.81	4.19
<b>Subject 16</b>	7.30	1.31	8.55	5.82	2.73
<b>Subject 4</b>	19.03	0.46	21.12	16.77	4.35
<b>Subject 6</b>	20.33	0.79	24.61	15.09	9.51
<b>Subject 7</b>	13.66	0.23	15.31	12.35	2.95
<b>Subject 9</b>	24.82	0.46	28.32	20.99	7.33
<b>Subject 10</b>	27.20	0.72	31.65	19.21	12.45
<b>Subject 11</b>	27.20	0.72	31.65	19.21	12.45
<b>Subject 13</b>	24.40	0.47	25.51	23.40	2.11
<b>Subject 14</b>	13.75	0.47	18.00	8.07	9.94
<b>Subject 15</b>	2.19	0.57	7.18	-2.43	9.61
<b>Subject 17</b>	17.72	0.84	20.21	15.44	4.76
<b>Affected Mean</b>	16.55	0.60	19.43	13.21	6.22

**Table A2.20: Subject kinematics of the pelvis in the sagittal plane on the less-affected side throughout the gait cycle**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	21.06	0.19	23.40	18.59	4.81
<b>Subject 2</b>	7.12	0.82	11.36	3.16	8.20
<b>Subject 3</b>	14.76	0.86	16.66	13.26	3.40
<b>Subject 5</b>	5.63	0.53	8.02	3.95	4.07
<b>Subject 8</b>	11.78	0.35	13.06	10.30	2.76
<b>Subject 12</b>	23.70	0.22	26.00	21.68	4.32
<b>Subject 16</b>	7.40	1.16	8.83	6.10	2.73
<b>Subject 4</b>	19.08	0.19	21.57	17.18	4.39
<b>Subject 6</b>	20.36	0.82	24.61	15.30	9.31
<b>Subject 7</b>	13.59	0.21	15.34	12.23	3.11
<b>Subject 9</b>	24.82	0.46	28.35	20.83	7.52
<b>Subject 10</b>	27.43	0.81	31.60	19.32	12.27
<b>Subject 11</b>	21.32	0.42	24.94	18.78	6.17
<b>Subject 13</b>	24.52	0.30	25.64	23.53	2.11
<b>Subject 14</b>	13.87	0.38	18.08	8.11	9.97
<b>Subject 15</b>	2.28	0.62	7.28	-2.50	9.79
<b>Subject 17</b>	17.75	0.47	20.40	15.58	4.82
<b>Less-affected Mean</b>	16.26	0.52	19.13	13.26	5.87

**Table A2.21: Subject kinematics of the pelvis in the sagittal plane on the affected side at initial contact**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	19.87	0.63	23.22	18.49	4.73
<b>Subject 2</b>	3.28	1.06	11.21	3.28	7.93
<b>Subject 3</b>	14.06	1.19	16.38	13.10	3.28
<b>Subject 5</b>	4.28	1.25	7.99	4.22	3.77
<b>Subject 8</b>	12.05	0.48	13.07	10.45	2.63
<b>Subject 12</b>	23.09	0.66	25.97	21.82	4.14
<b>Subject 16</b>	6.22	1.52	8.44	5.74	2.70
<b>Subject 4</b>	19.46	0.65	21.05	16.80	4.25
<b>Subject 6</b>	15.45	1.22	24.58	15.19	9.39
<b>Subject 7</b>	12.81	0.68	15.27	12.53	2.74
<b>Subject 9</b>	23.26	1.49	27.65	21.15	6.50
<b>Subject 10</b>	20.77	0.99	31.53	19.31	12.23
<b>Subject 11</b>	16.61	0.74	24.91	18.73	6.19
<b>Subject 13</b>	25.25	0.58	25.44	23.47	1.96
<b>Subject 14</b>	8.33	0.81	17.90	8.16	9.74
<b>Subject 15</b>	4.66	1.10	7.08	-2.28	9.36
<b>Subject 17</b>	17.23	0.51	20.22	15.60	4.62
<b>Affected Mean</b>	14.51	0.92	18.94	13.28	5.66

**Table A2.22: Subject kinematics of the pelvis in the sagittal plane on the less-affected side at initial contact**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	23.24	0.53	23.40	18.60	4.80
<b>Subject 2</b>	11.13	1.23	11.13	3.17	7.97
<b>Subject 3</b>	15.16	1.34	16.52	13.29	3.23
<b>Subject 5</b>	5.68	1.28	7.89	4.27	3.72
<b>Subject 8</b>	12.52	0.56	13.05	10.41	2.63
<b>Subject 12</b>	23.79	0.59	25.98	21.70	4.28
<b>Subject 16</b>	8.03	1.36	8.74	6.18	2.56
<b>Subject 4</b>	20.71	1.00	21.38	17.22	4.16
<b>Subject 6</b>	20.46	0.92	24.69	15.40	9.29
<b>Subject 7</b>	14.82	0.58	15.29	12.36	2.93
<b>Subject 9</b>	25.42	1.74	27.61	21.02	6.59
<b>Subject 10</b>	31.38	1.53	31.42	19.34	12.08
<b>Subject 11</b>	24.88	0.71	27.88	18.82	6.06
<b>Subject 13</b>	25.46	0.67	25.52	23.72	1.80
<b>Subject 14</b>	15.01	1.01	17.90	8.14	9.76
<b>Subject 15</b>	6.81	1.21	7.08	-2.30	9.38
<b>Subject 17</b>	20.27	0.89	20.27	15.61	4.66
<b>Less-affected Mean</b>	17.93	1.01	19.16	13.35	5.64

**Table A2.23: Subject kinematics of the pelvis in the sagittal plane on the affected side at foot off**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	21.02	0.75	21.50	19.70	1.80
<b>Subject 2</b>	9.28	1.69	11.70	7.80	3.90
<b>Subject 3</b>	15.02	2.06	17.50	12.80	4.70
<b>Subject 5</b>	7.82	1.32	9.50	6.40	3.10
<b>Subject 8</b>	11.00	0.32	11.30	10.50	0.80
<b>Subject 12</b>	26.12	0.90	27.10	24.80	2.30
<b>Subject 16</b>	7.06	1.68	9.30	5.40	3.90
<b>Subject 4</b>	18.62	0.75	19.50	17.70	1.80
<b>Subject 6</b>	23.54	0.78	24.50	22.60	1.90
<b>Subject 7</b>	12.54	0.64	13.20	11.70	1.50
<b>Subject 9</b>	27.78	2.22	31.00	25.70	5.30
<b>Subject 10</b>	29.02	1.50	30.60	26.90	3.70
<b>Subject 11</b>	22.40	0.95	23.90	21.40	2.50
<b>Subject 13</b>	24.08	0.57	24.50	23.20	1.30
<b>Subject 14</b>	16.78	1.18	17.70	15.30	2.40
<b>Subject 15</b>	-1.64	1.17	-0.20	-2.90	2.70
<b>Subject 17</b>	17.88	0.43	18.50	18.50	18.20
<b>Affected Mean</b>	16.96	1.11	18.30	15.74	3.64

**Table A2.24: Subject kinematics of the pelvis in the sagittal plane on the less-affected side at foot off**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	18.84	0.25	19.20	18.50	0.70
<b>Subject 2</b>	6.66	0.82	7.70	5.60	2.10
<b>Subject 3</b>	14.46	2.41	16.90	11.70	5.20
<b>Subject 5</b>	4.50	1.90	6.60	1.80	4.80
<b>Subject 8</b>	10.24	1.06	11.60	9.00	2.60
<b>Subject 12</b>	21.70	0.35	22.00	21.10	0.90
<b>Subject 16</b>	7.20	1.80	9.80	5.00	4.80
<b>Subject 4</b>	16.80	0.72	17.70	15.80	1.90
<b>Subject 6</b>	16.36	1.46	18.60	14.70	3.90
<b>Subject 7</b>	13.28	0.44	13.90	12.70	1.20
<b>Subject 9</b>	21.40	0.85	22.50	20.60	1.90
<b>Subject 10</b>	28.38	0.86	29.20	27.00	2.20
<b>Subject 11</b>	18.68	0.51	19.50	18.20	1.30
<b>Subject 13</b>	23.90	0.35	24.30	23.40	0.90
<b>Subject 14</b>	13.36	1.22	14.70	11.70	3.00
<b>Subject 15</b>	-2.00	1.16	-0.50	-3.00	2.50
<b>Subject 17</b>	16.18	0.97	17.30	15.10	2.20
<b>Less-affected Mean</b>	14.70	1.01	15.94	13.46	2.48

**Table A2.25: Subject kinematics of the pelvis in the coronal plane on the affected side throughout the gait cycle**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-2.95	1.10	-0.87	-5.28	4.41
<b>Subject 2</b>	-0.52	0.71	2.72	-3.05	5.77
<b>Subject 3</b>	-0.90	1.28	2.01	-4.01	6.02
<b>Subject 5</b>	1.07	1.21	1.84	0.37	1.47
<b>Subject 8</b>	3.05	1.13	6.26	-0.41	6.67
<b>Subject 12</b>	2.95	0.49	5.44	-1.06	6.49
<b>Subject 16</b>	-1.36	0.86	1.23	-4.06	5.29
<b>Subject 4</b>	-0.17	0.87	3.71	-4.66	8.37
<b>Subject 6</b>	3.73	0.69	6.76	0.53	6.23
<b>Subject 7</b>	1.27	0.51	5.02	-3.64	8.65
<b>Subject 9</b>	0.03	1.14	3.99	-3.67	7.65
<b>Subject 10</b>	-2.24	1.36	1.49	-6.05	7.54
<b>Subject 11</b>	-1.07	0.87	2.35	-5.05	7.41
<b>Subject 13</b>	2.77	0.19	7.10	-1.58	8.67
<b>Subject 14</b>	0.26	1.06	4.79	-3.45	8.24
<b>Subject 15</b>	4.86	0.74	15.19	-5.10	20.29
<b>Subject 17</b>	-2.41	0.47	0.39	-5.41	5.80
<b>Affected Mean</b>	0.49	0.86	4.08	-3.27	7.35



**Table A2.26: Subject kinematics of the pelvis in the coronal plane on the less-affected side throughout the gait cycle**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	2.93	1.07	5.39	0.79	4.60
<b>Subject 2</b>	0.59	0.80	3.07	-2.68	5.75
<b>Subject 3</b>	0.97	1.21	4.22	-1.86	6.07
<b>Subject 5</b>	-1.07	1.20	-0.31	-1.85	1.53
<b>Subject 8</b>	-3.01	1.10	0.42	-6.28	6.70
<b>Subject 12</b>	-2.89	0.46	1.04	-5.34	6.38
<b>Subject 16</b>	1.08	0.95	4.03	-2.04	6.07
<b>Subject 4</b>	0.15	0.72	4.59	-3.80	8.39
<b>Subject 6</b>	-3.71	0.87	-0.41	-7.01	6.59
<b>Subject 7</b>	-1.20	0.49	3.71	-4.95	8.65
<b>Subject 9</b>	-0.14	0.96	3.51	-4.20	7.71
<b>Subject 10</b>	2.25	1.51	6.13	-1.40	7.54
<b>Subject 11</b>	1.09	0.78	5.10	-2.43	7.53
<b>Subject 13</b>	-2.78	0.21	1.54	-7.07	8.60
<b>Subject 14</b>	-0.38	0.84	3.11	-4.77	7.87
<b>Subject 15</b>	-4.92	0.74	5.14	-15.17	20.31
<b>Subject 17</b>	2.37	0.46	5.38	-0.44	5.83
<b>Less-affected Mean</b>	-0.51	0.84	3.27	-4.15	7.42

**Table A2.27: Subject kinematics of the pelvis in the coronal plane on the affected side at initial contact**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-1.40	1.43	-0.84	-5.16	4.32
<b>Subject 2</b>	0.75	1.24	2.68	-3.01	5.69
<b>Subject 3</b>	0.51	1.28	1.93	-4.09	6.02
<b>Subject 5</b>	0.78	1.28	1.83	0.39	1.44
<b>Subject 8</b>	3.20	0.99	6.28	-0.33	6.60
<b>Subject 12</b>	5.30	0.66	5.30	-1.05	6.36
<b>Subject 16</b>	-2.19	1.38	1.33	-3.99	5.32
<b>Subject 4</b>	1.01	0.72	3.69	-4.55	8.24
<b>Subject 6</b>	4.84	1.04	6.76	0.60	6.16
<b>Subject 7</b>	4.48	0.80	4.92	-3.59	8.51
<b>Subject 9</b>	-2.48	2.90	3.75	-2.76	6.51
<b>Subject 10</b>	-0.65	2.10	1.44	-5.94	7.39
<b>Subject 11</b>	-0.51	1.02	2.29	-5.01	7.31
<b>Subject 13</b>	5.01	0.55	7.09	-1.59	8.68
<b>Subject 14</b>	-0.46	0.72	4.81	-3.01	7.82
<b>Subject 15</b>	0.65	1.60	15.12	-5.03	20.15
<b>Subject 17</b>	-2.90	0.65	0.37	-5.39	5.76
<b>Affected Mean</b>	0.94	1.20	4.04	-3.15	7.19

**Table A2.28: Subject kinematics of the pelvis in the coronal plane on the less-affected side at initial contact**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	4.04	1.52	5.37	0.78	4.58
<b>Subject 2</b>	2.55	1.51	3.06	-2.67	5.72
<b>Subject 3</b>	2.91	1.41	4.13	-1.86	5.99
<b>Subject 5</b>	-1.34	1.22	-0.33	-1.83	1.50
<b>Subject 8</b>	-2.34	1.30	0.41	-6.27	6.68
<b>Subject 12</b>	-0.39	0.71	1.04	-5.27	6.31
<b>Subject 16</b>	0.57	1.03	4.04	-2.06	6.11
<b>Subject 4</b>	1.25	1.44	4.64	-3.68	8.33
<b>Subject 6</b>	-1.86	1.10	-0.34	-6.87	6.53
<b>Subject 7</b>	0.41	0.90	3.71	-4.91	8.62
<b>Subject 9</b>	-3.45	1.76	2.82	-3.90	6.71
<b>Subject 10</b>	5.95	1.74	5.97	-1.29	7.26
<b>Subject 11</b>	2.06	0.91	5.09	-2.41	7.50
<b>Subject 13</b>	-0.15	0.72	1.59	-7.10	8.69
<b>Subject 14</b>	0.86	0.94	2.71	-4.76	7.46
<b>Subject 15</b>	-8.12	1.52	5.02	-15.17	20.19
<b>Subject 17</b>	2.60	0.60	5.34	-0.48	5.82
<b>Less-affected Mean</b>	0.33	1.20	3.19	-4.10	7.29

**Table A2.29: Subject kinematics of the pelvis in the coronal plane on the affected side at foot off**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-5.80	1.59	-3.90	-7.70	3.80
<b>Subject 2</b>	-1.02	0.84	-0.30	-2.40	2.10
<b>Subject 3</b>	-3.94	1.68	-1.90	-5.80	3.90
<b>Subject 5</b>	1.08	1.45	2.80	-0.20	3.00
<b>Subject 8</b>	-0.36	1.17	1.20	-1.50	2.70
<b>Subject 12</b>	0.76	0.65	1.40	-0.10	1.50
<b>Subject 16</b>	-4.28	1.05	-3.10	-5.60	2.50
<b>Subject 4</b>	-4.74	1.46	-3.20	-6.90	3.70
<b>Subject 6</b>	0.26	0.71	1.20	-0.80	2.00
<b>Subject 7</b>	-3.26	0.94	-2.20	-4.70	2.50
<b>Subject 9</b>	0.06	1.64	2.80	-1.50	4.30
<b>Subject 10</b>	-4.04	1.35	-2.50	-5.40	2.90
<b>Subject 11</b>	-4.90	1.60	-2.70	-7.00	4.30
<b>Subject 13</b>	-1.82	0.69	-0.60	-2.20	1.60
<b>Subject 14</b>	1.20	0.98	2.00	-0.10	2.10
<b>Subject 15</b>	-0.68	0.25	-0.50	-1.10	0.60
<b>Subject 17</b>	-3.98	-3.63	-4.04	-3.81	-4.21
<b>Affected Mean</b>	-2.09	0.85	-0.80	-3.34	2.31

**Table A2.30: Subject kinematics of the pelvis in the coronal plane on the less-affected side at foot off**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	1.04	1.75	2.90	-1.40	4.30
<b>Subject 2</b>	1.56	0.97	2.70	0.60	2.10
<b>Subject 3</b>	-0.16	2.04	2.20	-2.60	4.80
<b>Subject 5</b>	-0.78	1.43	0.80	-2.70	3.50
<b>Subject 8</b>	-5.76	0.97	-4.90	-7.00	2.10
<b>Subject 12</b>	-4.52	0.33	-4.20	-5.00	0.80
<b>Subject 16</b>	-1.38	1.33	0.10	-2.80	2.90
<b>Subject 4</b>	-3.74	0.72	-2.70	-4.70	2.00
<b>Subject 6</b>	-5.82	1.21	-4.70	-7.50	2.80
<b>Subject 7</b>	-5.02	1.36	-3.60	-6.90	3.30
<b>Subject 9</b>	1.38	1.40	3.60	0.10	3.50
<b>Subject 10</b>	-1.12	1.61	1.30	-3.20	4.50
<b>Subject 11</b>	-1.60	0.48	-1.00	-2.10	1.10
<b>Subject 13</b>	-6.76	0.38	-6.30	-7.10	0.80
<b>Subject 14</b>	1.14	0.57	1.90	0.60	1.30
<b>Subject 15</b>	-11.80	1.39	-10.00	-13.70	3.70
<b>Subject 17</b>	0.53	0.13	0.46	0.24	0.66
<b>Less-affected Mean</b>	-2.52	1.06	-1.26	-3.83	2.60

**Table A2.31: Subject kinematics of the pelvis in the transverse plane on the affected side throughout the gait cycle**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-4.87	0.96	-1.62	-7.94	6.32
<b>Subject 2</b>	-1.70	1.26	1.75	-4.52	6.27
<b>Subject 3</b>	-1.21	1.85	6.78	-9.53	16.31
<b>Subject 5</b>	-4.79	1.04	0.49	-11.21	11.70
<b>Subject 8</b>	0.33	1.07	3.61	-2.76	6.36
<b>Subject 12</b>	-3.66	1.19	0.29	-7.07	7.36
<b>Subject 16</b>	4.92	0.93	7.19	2.69	4.51
<b>Subject 4</b>	4.29	1.49	9.62	-1.73	11.34
<b>Subject 6</b>	-0.81	0.96	5.30	-7.80	13.10
<b>Subject 7</b>	-3.55	2.16	1.77	-7.05	8.82
<b>Subject 9</b>	-6.95	1.20	-4.77	-9.83	5.06
<b>Subject 10</b>	-19.24	0.72	-5.27	-33.72	28.45
<b>Subject 11</b>	4.32	0.85	6.39	1.49	4.89
<b>Subject 13</b>	-1.10	0.61	4.55	-6.64	11.19
<b>Subject 14</b>	-4.90	3.22	4.28	-12.77	-2.45
<b>Subject 15</b>	0.85	0.97	11.75	-7.64	19.39
<b>Subject 17</b>	-0.18	0.92	1.70	-2.06	3.76
<b>Affected Mean</b>	-2.25	1.26	3.17	-7.53	9.55

**Table A2.32: Subject kinematics of the pelvis in the transverse plane on the less-affected side throughout the gait cycle**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	4.77	1.04	8.09	1.10	6.99
<b>Subject 2</b>	1.83	1.24	4.78	-1.77	6.55
<b>Subject 3</b>	1.67	1.41	10.27	-6.78	17.05
<b>Subject 5</b>	4.64	1.17	11.57	-0.51	12.08
<b>Subject 8</b>	-0.37	0.86	2.69	-3.68	6.38
<b>Subject 12</b>	3.63	1.14	7.06	-0.41	7.47
<b>Subject 16</b>	-5.41	0.68	-2.73	-8.00	5.27
<b>Subject 4</b>	-4.24	1.19	1.87	-10.05	11.93
<b>Subject 6</b>	0.94	0.78	7.86	-4.98	12.84
<b>Subject 7</b>	3.28	2.18	6.68	-1.97	8.64
<b>Subject 9</b>	6.79	1.14	10.06	3.91	6.15
<b>Subject 10</b>	19.17	0.65	34.12	4.87	29.25
<b>Subject 11</b>	-4.19	0.68	-1.24	-6.21	4.97
<b>Subject 13</b>	1.12	0.56	6.81	-4.33	11.14
<b>Subject 14</b>	4.27	2.24	12.56	-4.71	17.27
<b>Subject 15</b>	-0.46	0.98	8.28	-11.90	20.19
<b>Subject 17</b>	0.13	0.93	2.18	-1.63	3.81
<b>Less-affected Mean</b>	2.21	1.11	7.70	-3.36	11.06

**Table A2.33: Subject kinematics of the pelvis in the transverse plane on the affected side at initial contact**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-4.23	1.98	-1.45	-7.80	6.35
<b>Subject 2</b>	0.82	2.44	1.73	-4.47	6.20
<b>Subject 3</b>	5.65	3.56	6.52	-9.46	15.97
<b>Subject 5</b>	-8.84	3.16	0.40	-11.19	11.59
<b>Subject 8</b>	-2.40	1.22	3.56	-2.66	6.22
<b>Subject 12</b>	-4.01	1.48	0.28	-7.03	7.31
<b>Subject 16</b>	4.35	2.25	7.18	2.86	4.32
<b>Subject 4</b>	8.54	1.58	9.63	-1.49	11.12
<b>Subject 6</b>	4.68	1.87	5.17	-7.72	12.89
<b>Subject 7</b>	-3.40	2.81	1.76	-6.93	8.69
<b>Subject 9</b>	-6.14	3.21	-5.25	-9.05	3.80
<b>Subject 10</b>	-17.29	2.87	-5.35	-33.53	28.18
<b>Subject 11</b>	5.76	1.41	5.99	1.66	4.33
<b>Subject 13</b>	4.11	1.11	4.32	-6.69	11.01
<b>Subject 14</b>	3.33	5.20	4.80	-11.80	16.61
<b>Subject 15</b>	10.79	1.64	11.59	-7.72	19.30
<b>Subject 17</b>	0.69	1.42	1.31	-1.88	3.19
<b>Affected Mean</b>	0.14	2.31	3.07	-7.35	10.42



**Table A2.34: Subject kinematics of the pelvis in the transverse plane on the less-affected side at initial contact at initial contact**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	6.55	1.79	8.12	1.11	7.07
<b>Subject 2</b>	3.14	1.93	4.77	-1.71	6.47
<b>Subject 3</b>	7.47	2.37	10.07	-6.78	16.85
<b>Subject 5</b>	0.95	2.17	11.53	-0.41	11.95
<b>Subject 8</b>	-3.52	1.39	2.67	-3.52	6.2
<b>Subject 12</b>	0.85	1.64	7.02	-0.4	7.42
<b>Subject 16</b>	-4.82	2.42	-2.8	-7.9	5.1
<b>Subject 4</b>	0.12	2.33	1.47	-10.03	11.5
<b>Subject 6</b>	6.92	1.94	7.66	-4.96	12.61
<b>Subject 7</b>	4.88	2.6	6.53	-1.92	8.44
<b>Subject 9</b>	6.62	2.41	9.32	4.74	4.58
<b>Subject 10</b>	14.11	1.93	34.06	4.88	29.19
<b>Subject 11</b>	-1.43	1.73	-1.34	-5.79	4.44
<b>Subject 13</b>	6.62	1.02	6.72	-4.17	10.9
<b>Subject 14</b>	7.09	1.95	11.62	-5.36	16.98
<b>Subject 15</b>	7.87	2.03	8.34	-11.86	20.21
<b>Subject 17</b>	2.05	1.12	2.13	-1.28	3.41
<b>Less-affected Mean</b>	3.85	1.93	7.49	-3.26	10.78

**Table A2.35: Subject kinematics of the pelvis in the transverse plane on the affected side foot off**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	-8.14	1.73	-6.90	-11.00	4.10
<b>Subject 2</b>	-4.92	0.76	-3.90	-5.70	1.80
<b>Subject 3</b>	-8.66	3.03	-4.10	-12.10	8.00
<b>Subject 5</b>	-5.14	2.00	-2.50	-7.80	5.30
<b>Subject 8</b>	2.24	1.18	3.60	0.70	2.90
<b>Subject 12</b>	-6.50	0.73	-5.60	-7.20	1.60
<b>Subject 16</b>	3.12	1.93	6.20	1.50	4.70
<b>Subject 4</b>	-0.22	1.95	2.70	-2.60	5.30
<b>Subject 6</b>	-5.42	2.35	-2.90	-8.50	5.60
<b>Subject 7</b>	-6.56	1.53	-4.00	-7.70	3.70
<b>Subject 9</b>	-8.98	1.35	-7.20	-10.40	3.20
<b>Subject 10</b>	-29.22	1.98	-26.60	-31.30	4.70
<b>Subject 11</b>	3.72	2.18	6.20	1.80	4.40
<b>Subject 13</b>	-4.32	1.28	-3.40	-6.50	3.10
<b>Subject 14</b>	-11.60	2.70	-8.80	-14.60	5.80
<b>Subject 15</b>	-0.08	1.49	1.60	-1.80	3.40
<b>Subject 17</b>	1.15	-0.57	0.79	0.11	1.61
<b>Affected Mean</b>	-5.27	1.62	-3.22	-7.24	4.07

**Table A2.36: Subject kinematics of the pelvis in the transverse plane on the less-affected side at foot off**

	<b>Mean</b>	<b>SD</b>	<b>Max Mean</b>	<b>Min Mean</b>	<b>Range</b>
<b>Subject 1</b>	1.44	1.62	3.30	-0.70	4.00
<b>Subject 2</b>	2.66	1.19	4.30	1.20	3.10
<b>Subject 3</b>	-2.18	3.20	3.00	-5.30	8.30
<b>Subject 5</b>	2.52	1.43	4.50	1.10	3.40
<b>Subject 8</b>	0.86	0.85	1.90	-0.20	2.10
<b>Subject 12</b>	1.70	1.57	3.50	0.10	3.40
<b>Subject 16</b>	-6.12	1.45	-4.90	-7.70	2.80
<b>Subject 4</b>	-8.52	2.08	-6.30	-11.50	5.20
<b>Subject 6</b>	-1.58	2.05	1.40	-4.10	5.50
<b>Subject 7</b>	0.00	1.80	1.90	-2.80	4.70
<b>Subject 9</b>	5.60	1.55	7.90	3.70	4.20
<b>Subject 10</b>	10.14	1.05	11.90	9.10	2.80
<b>Subject 11</b>	-4.90	1.63	-3.60	-7.70	4.10
<b>Subject 13</b>	-0.48	0.72	0.20	-1.30	1.50
<b>Subject 14</b>	-1.52	2.42	0.70	-5.40	6.10
<b>Subject 15</b>	1.60	2.66	5.10	-1.20	6.30
<b>Subject 17</b>	-0.65	1.78	1.60	-2.40	4.00
<b>Less-affected Mean</b>	0.03	1.71	2.14	-2.06	4.21

### Appendix 3: Demographic Information

Table A3.1: Individual subject demographic information

	Gender	Side affected	Age (years)	Age at Incident (years)	Time since incident (months)	BMI	Dominance
<b>Subject 1</b>	F	L	56	53	38	24.45	L
<b>Subject 2</b>	F	L	58	56	35	24.84	R
<b>Subject 3</b>	M	L	61	58	35	28.46	R
<b>Subject 4</b>	M	R	61	58	36	27.03	R
<b>Subject 5</b>	M	L	58	56	18	17.10	R
<b>Subject 6</b>	M	R	60	59	11	20.19	R
<b>Subject 7</b>	M	R	59	57	41	26.98	R
<b>Subject 8</b>	M	L	56	52	42	23.70	R
<b>Subject 9</b>	F	R	39	35	51	25.79	R
<b>Subject 10</b>	F	R	30	27	45	23.76	R
<b>Subject 11</b>	M	R	49	48	11	25.42	R
<b>Subject 12</b>	F	L	58	58	2	33.52	R
<b>Subject 13</b>	F	R	41	41	5	27.02	L
<b>Subject 14</b>	M	R	67	67	5	20.90	R
<b>Subject 15</b>	F	R	48	47	2	31.78	R
<b>Subject 16</b>	F	L	52	52	3	23.61	R
<b>Subject 17</b>	F	R	59	57	6	31.64	R
<b>Average</b>			54	52	23	25.66	

Gender: F= Female; M= Male  
Side Affected: L= Left; R= Right

## Appendix 4: Ethics Approval



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Jou kennisvenoot • your knowledge partner

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

23-Jul-2013  
Tinas, Adnil AW

**Ethics Reference #:** 513/03/056

**Title:** An investigation into the trunk kinematics of people with hemiparesis due to stroke.

Dear Mr. Adnil Tinas,

The **Response to Modifications - (New Application)** received on 19-Jul-2013, was reviewed by members of **Health Research Ethics Committee 2** via Expedited review procedures on 22-Jul-2013 and was approved.  
Please note the following information about your approved research protocol:

Protocol Approval Period: 22-Jul-2013 -22-Jul-2014

Please remember to use your protocol number (513/03/056) 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/yds](http://www.sun.ac.za/yds) 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@gpw.gov.za](mailto:healthres@gpw.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/yds](http://www.sun.ac.za/yds)

If you have any questions or need further assistance, please contact the HREC office at 0219389207.

**Included Documents:**

DEC LETTER HILLIER  
PROTOCOL  
DEC LETTER INGLIS  
CV INLGIS  
DEC LETTER TITUS  
APPLIC FORM  
CV TITUS  
CV HILLIER  
CHECKLIST  
SYNOPSIS

Sincerely,

Mertrude Davids  
HREC Coordinator  
Health Research Ethics Committee 2

## Appendix 5: Ethics Approval – Extension



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jou kennisvenoot • your knowledge partner

### Ethics Letter

18-Jul-2014

Ethics Reference #: 513/03/056

Title: An investigation into the trunk kinematics of people with hemiparesis due to stroke.

Dear Mr. Adnil Titus,

At a review panel meeting of the Health Research Ethics Committee that was held on 16 July 2014, the progress report for the abovementioned project has been approved and the study has been granted an extension for a period of one year from this date.

Please remember to submit progress reports in good time for annual renewal in the standard HREC format.

Approval Date: 16 July 2014 Expiry Date: 16 July 2015

If you have any queries or need further help, please contact the REC Office 0219389207.

Sincerely,

REC Coordinator  
Mertrude Davids  
Health Research Ethics Committee 2

## Appendix 6: Provincial Approval



REFERENCE: RP134 /2013  
ENQUIRIES: Ms Charlene Roderick

**STRATEGY & HEALTH SUPPORT**  
Health.Research@westerncape.gov.za  
tel: +27 21 483 6857; fax: +27 21 483 9895  
5th floor, Nathan Rose House, 8 Riebeeck Street, Cape Town, 8001  
[www.capegateway.gov.za](http://www.capegateway.gov.za)

Division of Physiotherapy  
Faculty of Medicine and Health Sciences  
University of Stellenbosch  
PO Box 19063  
Tygerberg  
7505

For attention: **Adnil Titus**

**Re: An investigation into the trunk kinematics of people with hemiparesis due to stroke**

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

<b>Western Cape Rehabilitation Centre</b>	<b>J Hendry</b>	<b>Contact No. 021 3702316</b>
<b>Bishop Lavis Rehabilitation Centre</b>	<b>R Carelse</b>	<b>Contact No. 021 934 5060</b>

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 report 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. The reference number above should be quoted in all future correspondence.

Yours sincerely

  
**DR NT Naledi**  
**DIRECTOR: HEALTH IMPACT ASSESSMENT**

DATE: 8/4/2013  
CC DR L BITALO  
CC MS P OLCKERS

DIRECTOR: NORTHERN / TYGERBERG  
DIRECTOR: MITCHELLS PLAIN / KLIPFONTEIN

**Appendix 7: Indemnity Form****VRYWARING  
GEBRUIK VAN US VOERTUIG DEUR BUIEPERSOON****Besonderhede van voertuig:**

Fabrikaat	Jaar	Model	Registrasienuommer

**Bestuurder:**

<b>Volle naam:</b>													
<b>Identiteitsnommer:</b>													
<b>Adres:</b>													
<b>Telefoonnommer:</b>							<b>Selnommer:</b>						
<b>Bestuurslisensie:</b>	<b>Nommer:</b>	<b>Datum uitgereik:</b>		<b>Plek uitgereik:</b>				<b>Kode:</b>					
<b>Doel waarvoor voertuig gebruik gaan word:</b>													

Ek \_\_\_\_\_ (volle naam) verklaar dat ek onderneem om geen eis van enige aard teen die Universiteit of enige werknemer van die Universiteit in te stel nie en om op geen wyse hoegenaamd die Universiteit of enige werknemer van die Universiteit aanspreeklik te hou vir enige skade of verlies van watter aard ookal wat ek persoonlik of aan eiendom van my mag ly en wat regstreeks of onregstreeks spruit uit die gebruik van bogenoemde voertuig van die Universiteit nie en dat die gebruik daarvan op my eie verantwoordelikheid sal geskied en dat ek die risiko daaraan verbonde vrywillig aanvaar, en dat ek verstaan dat die Universiteit geen versekering vir hierdie doel namens my of vir my voordeel uitneem nie. Ek vrywaar hiermee die US en al sy werknemers gesamentlik en afsonderlik en stel hul skadeloos teen alle aanspreeklikheid wat uit die gebruik van bogenoemde voertuig vir die US mag voortspruit.

**Handtekening****Datum**

--	--	--	--	--	--	--	--	--	--	--	--

--	--	--	--	--	--	--	--

(dd/mm/jjjj)



## **Appendix 8: Consent Form**

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

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

An investigation into the trunk kinematics of people with hemiparesis due to stroke

#### **REFERENCE NUMBER:**

**PRINCIPAL INVESTIGATOR:** Adnil W Titus

#### **ADDRESS:**

Division of Physiotherapy

Department of Interdisciplinary Health Science

Stellenbosch University

PO Box 19063

Tygerberg

7505

**CONTACT NUMBER:** 021 938 9083

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 your choice 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 initially agree to take part.

This study has been approved by the Health Research Ethics Committee at Stellenbosch University and will be conducted according to internationally accepted ethical standards and guidelines 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?**

The aim of the study is to investigate and describe the movement of the trunk in people with stroke when they walk. This research will be conducted at the Physiotherapy Motion Analysis Lab (Stellenbosch University, Tygerberg Campus). You will be asked to walk ten meters barefoot and with shoes. You will be asked to walk six times in each of these conditions. You will be given ample rest during the investigation.

You will not receive any additional treatment during this investigation. The following will be measured by the Vicon Motion Analysis System: movement from 3 different angles; front/back, sides and top/ bottom. The analysis will be done by attaching, reflective, markers (stickers) to specific areas on your body using double sided tape. It is advised to wear clothing that will allow the motion laboratory staff to adjust and tape your clothing in a way that allows the marker to be secured to the skin and ensure that it is visible to the movement analysis cameras throughout the testing procedure.

The most appropriate times for testing will be agreed upon by the principle investigator, administration of the Vicon Motion Analysis Laboratory and according to your treatment schedule. With this study we hope to be able to recommend a more specific treatment plan for people who are learning to walk after suffering a stroke.

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

To conduct a scientific study, a set of inclusion criteria has been set. You fall within these criteria: You are an adult diagnosed with a single onset stroke. Your way of walking was affected by your stroke, but you are able to walk barefoot for ten meters without support, on an even surface.

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

If possible, you may use your own transport to attend the appointment at the Physiotherapy Motion Analysis Lab at (Stellenbosch University, Tygerberg Campus). You will be reimbursed for your transport cost. In case you do not have transport, transport will be provided for you and you will be requested to sign an indemnity form. You will need to provide consent should you agree to participate in the study.

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

There is no risk involved in taking part in this research project. Your participation will help the research team to analyse and then recommend an intervention that may assist your walking rehabilitation.

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

There are no known risks involved in participating in this research project.

### **If you do not agree to take part, what alternatives do you have?**

If you choose not to participate, your therapy will continue with your therapist. You will not suffer any negative consequences.

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

All the information collected for this project will be treated as confidential and will be protected. If this information is used in a thesis or publication, your identity will remain anonymous. Only the researchers will have access to the information. The records will be kept in safe storage in the Physiotherapy Division at Stellenbosch University. All video recordings will be destroyed after the completion of study, except if you agree to have them used for scientific presentations.

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

There is very little risk involved with this method of testing, but in the event that you have a skin reaction to the sticky markers the research team will treat this with a suitable cream.

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

You will not be paid to take part in the study. If you do take part in this study, there will be no cost involved for you.

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

You can contact Adnil Titus at telephone number 021 938 9083 if you have any further queries or encounter any problems.

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 the research team.

You will receive a copy of this information and signed consent form for your own records.

The results of your gait analysis will be available to you as soon as it has been analysed. You will have the opportunity to discuss the results with the principle investigator as well as your physiotherapist.

## Declaration by participant

By signing below, I (Name)..... agree to take part in a research study entitled 'An investigation into the trunk kinematics of People with Hemiplegia due to Stroke'.

I declare that:

I have read or had read to me this information and consent form and that 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 withdraw from the study at any time and will not be punished or discriminated against in any way.

I may be asked to leave the study before it has finished, if the researcher feels it is my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ..... On (*date*) .....  
2013.

**Signature of Participant or family member**

**Signature of witness**

**Declaration by investigator**

I (*name*) ..... 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 understand all aspects of the research, as discussed above

I made use of/ did not make use of a translator (*if a translator is used, then the translator must sign the declaration below*).

Signed at (*place*) ..... On (*date*) ..... 2014.

**Signature of investigator**

**Signature of witness**

## Appendix 9: Marker Placement

Upper extremity markers name and placement

Lt side		Rt side	
Marker	Placement	Marker	Placement
<b>LSHO</b>	<i>Left shoulder</i> On the acromio-clavicular joint.	<b>RSHO</b>	<i>Right shoulder</i> On the acromio-clavicular joint.
<b>LUPA</b>	<i>Left upper arm</i> On the upper lateral 1/3 surface of the left arm (Place asymmetrically with RUPA).	<b>RUPA</b>	<i>Right upper arm</i> On the lower lateral 1/3 surface of the right arm (Place asymmetrically with LUPA).
<b>LELB</b>	<i>Left elbow</i> On the lateral epicondyle approximating the elbow joint axis.	<b>RELB</b>	<i>Right elbow</i> On the lateral epicondyle approximating the elbow joint axis.
<b>LFRM</b>	<i>Left forearm</i> On the lower lateral 1/3 surface of the left forearm (Place asymmetrically with RFRM).	<b>RFRM</b>	<i>Right forearm</i> On the lower lateral 1/3 surface of the right forearm (Place asymmetrically with LFRM).
<b>LWRA</b>	<i>Left wrist marker A</i> At the thumb side of a bar attached to a wristband on the posterior of the left wrist, as close to the wrist joint center as possible. Loose markers can be used but for better tracking of the axial rotations, a bar is recommended.	<b>RWRA</b>	<i>Right wrist marker A</i> At the thumb side of a bar attached symmetrically with a wristband on the posterior of the right wrist, as close to the wrist joint center as possible.
<b>LWRB</b>	<i>Left wrist marker B</i> At the little finger side of a bar attached to a	<b>RWRB</b>	<i>Right wrist marker B</i> At the little finger side of a bar attached

	wristband on the posterior of the left wrist, as close to the wrist joint center as possible. Loose markers can be used but for better tracking of the axial rotations, a bar is recommended.		symmetrically with a wristband on the posterior of the right wrist, as close to the wrist joint center as possible. Loose markers can be used but for better tracking of the axial rotations, a bar is recommended.
<b>LFIN</b>	<i>Left finger</i> Just proximal to the middle knuckle on the left hand.	<b>RFIN</b>	<i>Right finger</i> Just below the middle knuckle on the right hand.

## Pectoral girdle markers name and placement

<b>Marker</b>	<b>Placement</b>
<b>C7</b>	<i>7th cervical vertebra</i> On the spinous process of the 7th cervical vertebra.
<b>T10</b>	<i>10th thoracic vertebra</i> On the spinous process of the 10th thoracic vertebra.
<b>CLAV</b>	<i>Clavicle</i> On the jugular notch where the clavicles meet the sternum.
<b>STRN</b>	<i>Sternum</i> On the xiphoid process of the sternum.
<b>RBAK</b>	<i>Right back</i> Anywhere over the right scapula. (This marker has no equivalent marker on the left side. This asymmetry helps the auto labelling routine determine right from left on the subject. Placement is not critical as it is not included in the Plug-in Gait model calculations)



## Pelvic markers name and placement

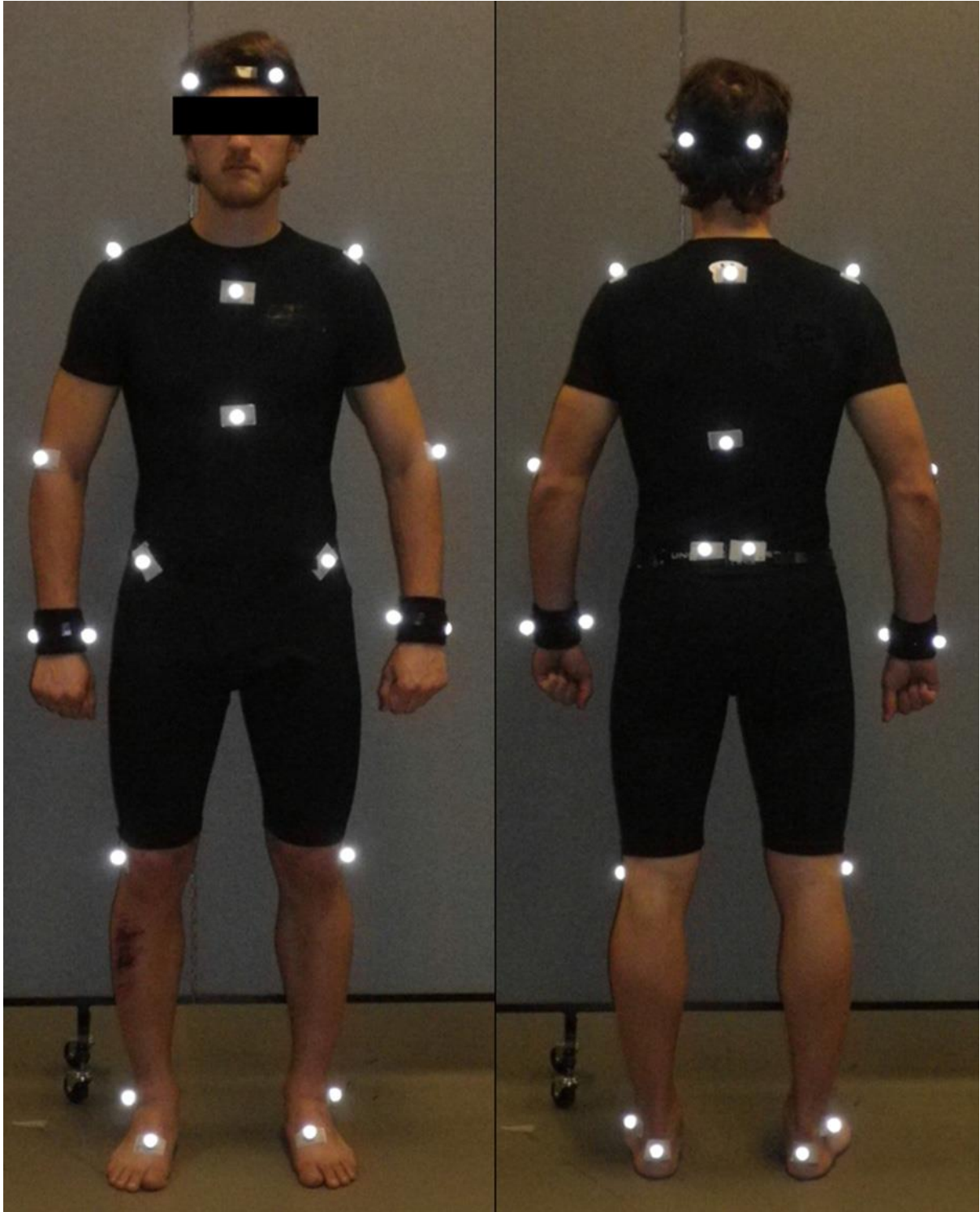
Marker	Placement
<b>SACR</b>	<i>Sacral</i> On the skin mid-way between the posterior superior iliac spines (PSIS) and positioned to lie in the plane formed by the ASIS and PSIS points.
<b>LASI</b>	<i>Left ASIS</i> Left anterior superior iliac spine.
<b>RASI</b>	<i>Right ASIS</i> Right anterior superior iliac spine.
<b>LPSI</b>	<i>Left PSIS</i> Left posterior superior iliac spine (immediately below the sacro-iliac joints, at the point where the spine joins the pelvis) This marker is used with the RPSI marker as an alternative to the single SACR marker.
<b>RPSI</b>	<i>Right PSIS</i> Right posterior superior iliac spine (immediately below the sacro-iliac joints, at the point where the spine joins the pelvis). This marker is used with the LPSI marker as an alternative to the single SACR marker.

## Lower Extremity markers name and placement

Lt Side		Rt Side	
Marker	Placement	Marker	Placement
<b>LTHI</b>	<i>Left thigh</i> Over the lower lateral 1/3 surface of the left thigh.	<b>RTHI</b>	<i>Right thigh</i> Over the lower lateral 1/3 surface of the right thigh.
<b>LKNE</b>	<i>Left knee</i> On the flexion-extension axis of the left knee.	<b>RKNE</b>	<i>Right knee</i> On the flexion-extension axis of the right knee.
<b>LTIB</b>	<i>Left tibia</i> Over the lower 1/3 surface of the left shank.	<b>RTIB</b>	<i>Right tibia</i> Over the lower 1/3 surface of the right shank.
<b>LANK</b>	<i>Left ankle</i> On the lateral malleolus	<b>RANK</b>	<i>Right ankle</i> On the lateral malleolus

	along an imaginary line that passes through the transmalleolar axis.		along an imaginary line that passes through the transmalleolar axis.
<b>LHEE</b>	<i>Left heel</i> On the calcaneus at the same height above the plantar surface of the foot as the toe marker.	<b>RHEE</b>	<i>Right heel</i> On the calcaneus at the same height above the plantar surface of the foot as the toe marker.
<b>LTOE</b>	<i>Left toe</i> Over the second metatarsal head, on the mid-foot side of the equinus break between fore-foot.	<b>RTOE</b>	<i>Right toe</i> Over the second metatarsal head, on the mid-foot side of the equinus break between fore-foot.

## Illustration of Marker Placement



(Federolf et al., 2012)

## Appendix 10: Author Guidelines



# ARCHIVES OF PHYSICAL MEDICINE AND REHABILITATION

Official Journal of the [American Congress of Rehabilitation Medicine](#)

### AUTHOR INFORMATION PACK

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ISSN: 0003-9993

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#### DESCRIPTION

The Archives of Physical Medicine and Rehabilitation publishes original, peer-reviewed research and clinical reports on important trends and developments in physical medicine and rehabilitation and related fields. This international journal brings researchers and clinicians authoritative information on the therapeutic utilization of physical, behavioral and pharmaceutical agents in providing comprehensive care for individuals with chronic illness and disabilities.

Archives began publication in 1920, publishes monthly, and is the official journal of the American Congress of Rehabilitation Medicine. Its papers are cited more often than any other rehabilitation journal.

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#### IMPACT FACTOR

2013: 2.441 © Thomson Reuters Journal Citation Reports 2014

#### ABSTRACTING AND INDEXING

Scopus

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To find out more, please visit the Preparation section below.

## INTRODUCTION

Archives of Physical Medicine and Rehabilitation publishes original articles that report on important trends and developments in physical medicine and rehabilitation and in the wider interdisciplinary field of rehabilitation. Archives of Physical Medicine and Rehabilitation brings readers authoritative information on the therapeutic utilization of physical and pharmaceutical agents in providing comprehensive care for persons with disabilities and for chronically ill individuals. Archives began publication in 1920, publishes monthly, and is the official journal of the ACRM | American Congress of Rehabilitation Medicine. Its content is cited more often than any other rehabilitation journal.

### *Types of papers*

**Brief Reports:** Provide preliminary communications of new data, research methods, brief case studies of interest, new ideas, and techniques. Manuscripts should be limited to 1500 words of text (or 1200 words plus 1-2 figures or tables, Introduction through Conclusions), and no more than 10 references.

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These fact sheets are printed as tear-out pages. They are designed to provide consumer-friendly information on topics relevant to rehabilitation medicine, including basic background or overview, similar to a Wikipedia entry, or brief how-to suggestions. They are targeted toward people with disabilities, their caregivers, or clinicians; and are designed so that a practitioner can tear out and copy, or download the pages, to make them available to patients and caregivers.

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Click on the checklist that applies to your manuscript, download it to your computer, fill it out electronically, "save as," and upload it with your manuscript when you submit.

Links to mandatory flow diagrams also are provided. Randomized Controlled Trials – CONSORT - Consolidated Standards of Reporting Trials Observational Studies – STROBE – Strengthening the Reporting of Observational studies in Epidemiology Systematic Review of Controlled Trials – PRISMA – Preferred Reporting Items for Systematic Reviews and Meta-Analyses Study of Diagnostic accuracy/assessment scale – STARD – Standards for the Reporting of Diagnostic Accuracy Studies Case Reports – CARE – for case reports

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All submissions will be screened by editors to determine their suitability for further review. Manuscripts that are approved for review will be evaluated by at least one recognized expert in the particular subject matter. Biostatistical review may be obtained. Peer reviewers' assessments are referred to a member of the Editorial Board, who may also critique the manuscript. The assigned Editorial Board Member will then make a final decision and communicate with the corresponding author via e-mail. Decisions are typically communicated within 60 days after the manuscript has been approved for peer review. All reviews are conducted in a double-blind fashion.

Letters to the Editors and Editorials are generally evaluated by an editorial committee, however, external reviews may also be sought.

Published annually without peer review are the ACRM | American Congress of Rehabilitation Medicine presidential address and the John Stanley Coulter Lecture. The Editorial Board does not peer review the published abstracts of posters, platform presentations of scientific papers, or audiovisual materials presented at the ACRM annual meeting. Archives also publishes the official documents of ACRM. These documents are not peer reviewed by Archives and include position papers and other materials approved by the ACRM.

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### *References*

ref1 1. International Committee of Medical Journal Editors. Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly Work in Medical Journals. 2013. Available at: <http://www.icmje.org>. Accessed July 16, 2014.

ref2 2. Committee on Publication Ethics. Flowcharts: Changes in Authorship. nd. Available at:

<http://www.publicationethics.org/resources/flowcharts>. Accessed June 16, 2014.

ref3 3. 64th WMA General Assembly. WMA Declaration of Helsinki - Ethical Principles for Medical Research Involving Human Subjects. Available at

<http://www.wma.net/en/30publications/10policies/b3/>. Accessed June 16, 2014.

ref4 4. Ottenbacher KJ. Why rehabilitation research does not work (as well as we think it should). *Arch Phys Med Rehabil* 1995;76:606-9.

*Updated June 2014*

### Appendix 11: Physical Evaluation form

Name:		Date of Birth:		Date assessment:		Assessment by:		DOMNELL	
Movement	Position	Notes	ROM (degrees)		Movement	Strength 0-5		Selectivity 0-2	
			Left	Right		Left	Right	Left	Right
<b>Hips</b>					<b>Hips</b>				
Flexion	Supine				Flexion				
Extension	Side	Knee Ext			Extension				
Abduction	Supine	Hips Ext			Abduction				
Adduction	Supine				Adduction				
External rotation	Prone				<b>Knee</b>				
Internal rotation	Prone				Flexion				
Femoral anteversion	Prone				Extension				
Duncan-Ely test	Prone	Hip flex? (Rec Fem)			<b>Ankle</b>				
Modified Thomas test	Supine	Hip flex? (Psoas)			Dorsiflexion				
		Knee ext? (Rec Fem)			Plantar flexion				
<b>Knee</b>					Tib ant				
Flexion	Prone				Tib post				
Extension	Supine				Peroneus longus				
Popliteal angle	Supine	Unilateral			Peroneus brevis				
	Supine	Bilateral			Extensor hall. longus				
	Supine	HS shift			Flexor hall. longus				
Tibial torsion	Supine	BM axis							
	Prone	TF angle							
	Prone	2 <sup>nd</sup> toe test							
<b>Ankle</b>					<b>Muscles</b>	<b>Muscle tone</b> (Ashworth 1- 5)		<b>Additional</b>	
Dorsiflexion	Supine	Knee Ext			<b>Lower extremities</b>	<b>Left</b>	<b>Right</b>	<b>Strength</b>	
	Supine	Knee Fl			Hip flexors				
Plantar flexion	Supine	Knee Fl			Adductors				
<b>Foot non-weight bearing</b>					Hamstrings			<b>Other comments</b>	
Hindfoot position	Prone				Rec Fem				
Midfoot position	Prone	(Arch)			Plantar flexors				
Forefoot position	Prone				Clonus				



