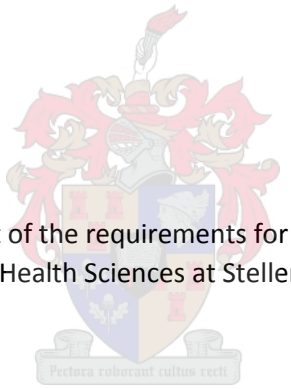
Prefrontal cortical activation during single- and dual-task transitional movements in chronic stroke survivors

By

Taylia Storm Webber



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DECLARATION

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ABSTRACT

Background: Stroke is a leading cause of morbidity in South Africa, and globally. Stroke survivors are often left with motor and cognitive impairments, affecting functional independence, and ability to perform daily activities. Many day-to-day tasks require people to transition between positions (such as sit-to-stand, stand-to-sit, and turning) while engaging in a concurrent cognitive or motor task (i.e. dual-tasking; DT). Dual-tasks are challenging for chronic stroke survivors, however, the neural basis underlying dual-task performance during sit-to-stand, stand-to-sit, and turning tasks in this population has not been explored.

Research aims: To investigate the effects of prefrontal cortical (PFC) activation during single-task (ST), dual-task motor-motor (DTMM) and dual-task cognitive-motor (DTCM) conditions in chronic stroke survivors while performing select transitional movements (i.e. turning, sit-to-stand and stand-to-sit). The secondary aims of the study were to assess DT interference (DTi) during DTCM and DTMM transitional movements; as well as to describe any differences in PFC activation between the four PFC sites (i.e. dorsolateral (DLPF), ventrolateral (VLPF), frontopolar (FPPF) and orbitofrontal (OFPF)), while comparing affected and unaffected sides in chronic stroke survivors.

Methods: This cross-sectional within-participant experimental study design included 17 chronic stroke survivors (≥ 6 months onset of stroke) (11 men: 6 women; age 65.6 ± 11.8 years) who acted as their own control. Participants performed the 360° turn test, and the five times sit-to-stand test (5TSTS) in randomized order under ST, DTCM and DTMM conditions.

Cerebral hemodynamics (i.e. oxygenated haemoglobin (ΔHbO_2), deoxygenated haemoglobin (ΔHbR), and haemoglobin difference (HbDiff)) of the PFC was collected with Near-infrared spectral tomography (NIRSIT). Spatiotemporal and kinematic parameters measured for the 5TSTS test: total duration, and lean angle, and for 360° turn test: duration, velocity, and angle of turn.

Results: For the 5TSTS, adding a cognitive task resulted in 68.1% slower duration ($p \leq 0.01$; $g = 0.51^{M}$), whereas adding a motor task resulted in 19.7% slower 5TSTS duration (19.7%; $p = <0.01$; $g = 0.09^{N}$). The difference in DTi between CM and MM conditions for the sit-to-stand and stand-to-sit durations were significant ($p = \leq 0.01$). For in-phase 360° turning, the DTCM and DTMM condition's lead to reduced turn velocity, slowing down by 10.3% ($p \leq 0.01$; $g = 0.44^{M}$) and 9.5% ($p = <0.01$; $g = 0.43^{M}$). During the 5TSTS test, DTCM displayed increases in ΔHbO_2, in the OFPF,

when compared to VLPF (129.2%; p = 0.04; *d* = 0.35^{M}), decreases in ΔHbR in the VLPF when compared to OFPF of the affected side (88.9%; p = 0.02; d = 0.72^{M}). Increases in ΔHbDiff within the DLPF from ST to DTCM (695.2%; p = 0.03; *d* = 0.69^{M}) were evident. Adding a motor task resulted in decreases in ΔHbR of the affected side, within the DLPF compared to the OFPF (156%; p = 0.03; *d* = 1.05^{L}) and between VLPF and OFPF, where VLPF showed significantly reduced ΔHbR (156%; p = 0.03; *d* = 0.57^{M}). Turning displayed a similar pattern, ΔHbO_2 increased in the OFPF between DTMM and DTCM conditions (266.7%; p = 0.02; g = 0.55^{M}), and ΔHbR decreased in the FPPF compared to the OFPF (103.3%; p = 0.04; g = 0.68^{M}).

Conclusion: Stroke survivors displayed increased PFC activation during dual-task transitional movements. The DTCM condition resulted in more PFC activation, compared to the DTMM. Furthermore, CM dual-tasking resulted in deteriorated motor performance indicated by slower 5TSTS durations and reduced velocity for 360° in-phase turning. This suggests that stroke survivors display reduced attentional capacity and reduced postural control which is further disrupted by CM tasks. This has implications for the assessment and rehabilitation approaches of chronic stroke survivors, where DTCM can be used in conjunction with motor tasks, to enhance task complexity in a safe environment in the presence of health professionals. Furthermore, the behavioural data and neural correlates related to dual-tasking could assist in the instigation of postural control deficits during 5TSTS and 360°turn, which is useful for quantifying one's independent mobility, at home.

OPSOMMING

Agtergrond: Beroerte is een van die hoofoorsake van siektes in Suid-Afrika en wêreldwyd. Beroerte-oorlewendes word dikwels met motoriese en kognitiewe gestremdhede agtergelaat, wat funksionele onafhanklikheid en die vermoë om daaglikse aktiwiteite uit te voer beïnvloed. Baie van hierdie daaglikse take vereis dat mense moet oorgaan tussen posisies (soos sit-na-staan, staan-na-te sit en draai) terwyl hulle besig is met kognitiewe of motoriese take (d.w.s. dubbeltaakwerk). Dubbele take is 'n uitdaging vir oorlewendes van kroniese beroerte, maar die neurale basis onderliggend aan dubbele taakverrigting tydens sit-na-staan, staan-na-sit en draai-take in hierdie populasie is nie ondersoek nie.

Doelstellings: om die effek van prefrontale kortikale (PFC) aktivering tydens enkeltaak (ST), dubbeltaak-motor-motor (DTMM) en dubbeltaak kognitiewe-motoriese (DTCM) toestande van kroniese beroerte-oorlewendes te ondersoek tydens die uitvoering van oorgangsbewegings (d.w.s. draai, sit-na-staan en staan-na-sit). Die sekondêre doelstellings van die studie was om dubbeltaakinterferensie (DTi) tydens DTCM- en DTMM-oorgangsbewegings te beoordeel; asook om enige verskille in PFC-aktivering tussen die vier PFC-webwerwe (d.w.s. dorsolateraal (DLPF), ventrolateraal (VLPF), frontopolêr (FPPF) en orbitofrontaal (OFPF)) te beskryf, terwyl geaffekteerde en ongeaffekteerde kante in oorlewendes van kroniese beroerte vergelyk word.

Metodes: Hierdie eksperimentele binne-deelnemer studie-ontwerp het 17 oorlewendes van kroniese beroerte bevat (≥ 6 maande aanvang van beroerte) (11 mans: 6 vroue; ouderdom 65,6 ± 11,8 jaar) wat as hul eie kontrole opgetree het. Deelnemers het die 360°-draai-toets gedoen en die vyf keer sit-na-staan-toets (5TSTS) in ewekansige volgorde onder ST-, DTCM- en DTMM-toestande. Serebrale hemodinamika (d.w.s. suurstofhoudende hemoglobien (ΔHbO_2), ontoksigineerde hemoglobien (ΔHbR) en hemoglobienverskil (HbDiff)) van die PFC is versamel met Near-infrared spectral tomography (NIRSIT). Spatiotemporale en kinematiese parameters vir die 5TSTS-toets: totale duur en leunhoek, en vir 360° draai-toets: duur, snelheid en draaihoek grade.

Resultate: Vir die 5TSTS het die toevoeging van 'n kognitiewe taak tot 68,1% stadiger duur gelei ($p \leq 0,01$; $g = 0,51^{M}$), terwyl die toevoeging van 'n motoriese taak gelei het tot 19,7% stadiger 5TSTS-duur (19,7%; $p = <0,01$; $g = 0,09^{N}$). Die verskil in DTi tussen CM en MM toestande vir die sit-na-staan en staan-na-sit duur was beduidend ($p = \leq 0.01$). Vir in-fase 360 ° draai het die

DTCM- en DTMM-toestand tot 'n afname in die draaisnelheid gelei, wat vertraag was met 10,3% ($p \leq 0,01$; $g = 0,44^{M}$) en 9,5% ($p = <0,01$; $g = 0,43^{M}$), onderskeidelik. Gedurende die 5TSTS-toets vertoon DTCM toenames in ΔHbO_2 in die OFPF, in vergelyking met VLPF (129, 2%; $p = 0,04$; $d = 0,35^{M}$), asook ‘n afname in ΔHbR in die VLPF in vergelyking met OFPF van die geaffekteerde kant (88,9%; $p = 0,02$; $d = 0,72^{M}$). Toenames in ΔHbDiff binne die DLPF van ST na DTCM (695,2%; $p = 0,03$; $d = 0,69^{M}$) was duidelik. Die toevoeging van 'n motoriese taak het gelei tot afname in ΔHbR van die geaffekteerde kant, binne die DLPF in vergelyking met die OFPF (156%; $p = 0,03$; $d = 1,05^{L}$) en tussen VLPF en OFPF, waar VLPF 'n beduidende verminderde HbR (156%; $p = 0.03$; $d = 0.57^{M}$) getoon het. Draai het 'n soortgelyke patroon getoon; ΔHbO_2 het in die OFPF toegeneem tussen DTMM en DTCM-toestande (266,7%; $p = 0,02$; $g = 0,55^{M}$), en ΔHbR het in die FPPF afgeneem in vergelyking met die OFPF (103,3%; $p = 0,04$; $g = 0,68^{M}$).

Gevolgtrekking: Beroerte-oorlewendes vertoon verhoogde PFC-aktivering tydens oorgangsbewegings met ‘n dubbele taak. Die DTCM-toestand het gelei tot meer PFCaktivering, in vergelyking met die DTMM. Verder het CM-dubbeltaakwerk gelei tot verswakte motorverrigting, aangedui deur stadiger 5TSTS-duur en verminderde snelheid vir 360° in-fasedraai. Dit dui daarop dat oorlewendes van beroerte 'n verminderde aandagvermoë en 'n verminderde postuurbeheer het wat verder deur CM-take onderbreek word. Dit het gevolge vir die assesserings- en rehabilitasiebenaderings van oorlewendes van kroniese beroerte, waar DTCM saam met motoriese take gebruik kan word om die kompleksiteit van take in 'n veilige omgewing en in die teenwoordigheid van gesondheidswerkers te verbeter. Verder kan die gedragsdata en neurale korrelate wat verband hou met dubbele taakwerk help met die aansporing van posturale beheertekorte tydens 5TSTS en 360°-draai, wat nuttig is om hul onafhanklike mobiliteit tuis te kwantifiseer.

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DEDICATIONS

I would like to dedicate this thesis in loving memory of my grandmother, Gillian Bostock who suffered strokes and passed away in 2015 as a result. She had a significant impact on my research.

Additionally, to my Grandfather, Alan Webber who is a former teacher and headmaster. He lives with Parkinson's disease and is my hero.

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LIST OF ABBREVIATIONS

%	:	Percentage
2MWT	:	Two-Minute Walk Test
5TSTS	:	Five Times Sit-To-Stand
ΔHbO_2	:	Relative change in oxygenated haemoglobin
ΔHbR	:	Relative change in deoxygenated haemoglobin
ANOVA	:	Analysis of variance
BBS	:	Berg balance scale
BMI	:	Body Mass Index
BOS	:	Base of support
BP	:	Blood Pressure
Cm	:	Centimetres
CM	:	Cognitive-Motor
CMI	:	Cognitive-motor interference
COM	:	Centre of Mass
COP	:	Centre of pressure
CRR	:	Correct Response Rate
CVA	:	Cerebrovascular accident
d	:	Effect Sizes; Cohens *d*
DLPF	:	Dorsolateral prefrontal Cortex
DSM-IV	:	Diagnostic and Statistical Manual of Mental Disorders
DT	:	Dual-Task
DTCM	:	Dual-Task Cognitive-Motor
DTg	:	Dual-Task Gain
DTi	:	Dual-Task Interference
DTMM	:	Dual-Task Motor-Motor

DTTM	:	Dual-Task Transitional Movements
EEG	:	Electroencephalogram
EMG	:	Electromyography
EF	:	Executive Function
FAC	:	Functional Ambulation Category
FES-I	:	Falls Efficacy Scale-International
fMRI	:	Functional Magnetic Resonance Imaging
fNIRS	:	Functional Near-Infrared Spectroscopy
FPPF	:	Frontopolar prefrontal Cortex
g	:	Effect Sizes, Hedges g
HbO_2	:	Oxygenated Haemoglobin
HbR	:	Deoxygenated Haemoglobin
HbDiff	:	Difference in Haemoglobin
HR	:	Heart Rate
HRQoL	:	Health Related Quality of Life
ICF	:	Informed Consent Form
Kg	:	Kilograms
LSD	:	Least significant difference
m/s	:	Metre Per Second
MCA	:	Middle Cerebral Artery
MCI	:	Mild Cognitive Impairment
mmHg	:	Millimetre of Mercury
MMSE	:	Mini mental state exam
MoCA	:	Montreal Cognitive Assessment
Ms	:	Milliseconds
M1 Area	:	Motor area 1
N	:	Sample Size

NCD's	:	Non-Communicable Disease
NIRSIT	:	Near-Infrared Spectroscopy System
°/s	:	Degrees Per Second
°	:	Degrees
OFPF	:	Orbitofrontal prefrontal cortex
PA	:	Physical Activity
PET	:	Positron Emission Tomography
PFC	:	Prefrontal Cortex
PH-FRAT	:	Peninsula Health Fall Risk Assessment Tool
PHQ-9	:	Patient Health Questionnaire -9
QoL	:	Quality of Life
RAPA	:	Rapid Assessment of Physical Activity
s	:	Seconds
SA	:	South Africa
SD	:	Standard Deviation
SE	:	Standard Error
SSQOL	:	Stroke Specific Quality of Life
ST	:	Single-task
STD	:	Standard deviation
STS	:	Sit-to-stand
TBI	:	Traumatic Brain Injury
TIA	:	Transient Ischemic attack
TM	:	Transitional Movements
TMT	:	Trail Maker Test
TUG	:	Timed Up and Go
USA	:	United States of America
VLPF	:	Ventrolateral prefrontal cortex

WHO	:	World health organisation
WM	:	Working Memory
Y	:	Years
$\bar{x}$	:	Average

CHAPTER ONE

Introduction

1.1 Background

Background

According to the World Health Organization (WHO), globally 15 million individuals suffer stroke every single year, and this number is increasing. Furthermore, in South Africa alone, stroke is responsible for twenty-five thousand deaths each year (Maredza et al., 2015). According to the heart and stroke foundation of South Africa, every day 240 persons suffer a stroke, of which 70 lose their lives. This data indicates that with increasing stroke numbers, 71% of stroke survivors will survive, and require effective rehabilitation and assessment methods to assist with the debilitating after-effects of the stroke burden.

Following stroke, individuals are faced with various problems. One of the main concerns in chronic stroke survivors relates to impairments in cognitive processes (Cumming et al., 2012). Executive function (EF) refers to one's higher order cognitive ability that controls the underlying cognitive functions for goal-directed behaviour, which has been associated with prefrontal cortical activity (Diamond, 2013). It is evident that cognitive decline is a major contributing factor to stroke-related disability as one's ability to accomplish activities of daily living (ADL) is largely dependent on one's executive functions (EF) (Cumming et al., 2012).

Of particular interest to this study is the fact that there are many daily tasks which require people to transition between positions or postures (for example sit-to-stand, stand-to-sit, and turning). Furthermore, many of these tasks are often performed in conjunction with a secondary cognitive or motor task. For example, standing up from a seat while answering a phone call, or standing in the kitchen cooking (e.g. turning towards the oven) while engaging in a conversation. Thus, dual-tasking is crucial for independent mobility, and is not automatic, which means it requires cognitive control. However, despite the regular involvement of dual-task transitional movements in our everyday life, research on such movements is lacking.

The area of the brain primarily responsible for effective use of EF, and thus dual-tasking, is the prefrontal cortex (PFC) (Wagner et al., 2011). Most studies have assessed activation patterns in the PFC during various walking tasks, under cognitive-motor (Al-Yahya et al., 2016; Mori et al., 2018; Lui et al., 2018) and motor-motor (Goh et al., 2017) dual-task conditions. Due to impaired executive and motor function resulting from neurological injury such as stroke, researchers have been interested in the attentional demands of performing single-tasks in comparison to dual-tasks (Mori et al., 2018; Al-Yaha et al., 2016; Montero-Odasso et al.,2012; Mirelman et al., 2014; Tsang et al., 2016; Plummer et al., 2014; Plummer-D'Amato et al., 2012; Pitchierri et al., 2012; Lin and Lin, 2016; Leone et al., 2017; Hollands et al., 2014; Hall et al., 2011). The dual-task paradigm refers to a behavioural procedure which requires individuals to perform two tasks simultaneously (Watanabe & Funahashi, 2017). It is supported that during dual-tasking, neuronal activation in the PFC is increased, which plays a key role in executive functions such as walking and multitasking (Mori, Takeuchi & Izumi, 2018; Mirelman et al., 2014; Al-Yaha et al., 2016). Furthermore, one's ability to dual-task post-stroke is often impaired. From this information, it has been established that when a person is asked to perform a motor task simultaneously with an added cognitive or motor demand, the person's performance on one or both tasks is affected; a term referred to as dual-task interference (Leona et al., 2017; Liu et al., 2017).

Thus, due to the increasing prevalence of stroke in South Africa, it seems reasonable that there will be additional chronic stroke survivors living with physical and cognitive impairments requiring treatment from healthcare professionals. Consequently, research investigating the effects that cognitive and motor tasks have on motor performance and cerebral hemodynamics might assist health professionals with valuable information. More specifically, in determining how stroke survivors react in attention demanding situation's, which tasks stroke survivors find challenging, and how they compensate to effectively complete both tasks. This has implications for the treatment methods used to challenge stroke survivors in therapy, and to assess postural control deficits which may affect independent mobility.

Therefore, this study primarily aimed to investigate the effects on prefrontal cortical (PFC) activation during single-task (ST), dual-task motor-motor (DTMM) as well as dual-task cognitive-motor (DTCM) conditions of chronic stroke survivors while carrying out select transitional movements (i.e. turning, sit-to-stand and stand-to sit).

CHAPTER TWO

Narrative literature review

2.1. Introduction

The number of individuals affected by stroke globally has been increasing by 30 000 per year, since 1990 (Maredza et al., 2015; Pillay-van Wyk et al., 2017). This makes stroke one of the leading causes of disability worldwide, affecting 13 million people every year (Lindsay et al., 2019). Furthermore, stroke occurrence is declining in developed countries, and increasing in developing countries; mainly due to the lack of health care within the latter (Markus, 2016). In line with this, more than eighty percent of strokes occur in low and middle-income countries, and in South Africa alone, stroke is responsible for twenty-five thousand deaths every year (Maredza et al., 2015).

Following stroke, individuals are faced with many cognitive and motor impairments affecting their independence (Cumming et al., 2013). For instance, research has shown that loss of both motor and cognitive function is closely associated with one's functional recovery in activities of daily living (ADL) such as walking and standing (Mercier et al., 2001). This emphasizes the importance of establishing effective rehabilitation modalities to assist individuals living with the debilitating after-effects of the stroke burden. This also draws attention to the need to understand the brain-body connection of stroke survivors within the movement context.

The type of rehabilitation deemed most beneficial are those which are supported by scientific evidence (Platz, 2019), mimics the requirements of everyday life and which enhances the restoration of pathways in the brain through neuroplasticity (Alia et al., 2017). This suggests that motor rehabilitation interventions should consider integrating cognitive components and multiple tasks (e.g. another motor tasks concurrently) to add to the ecological validity of the intervention. In addition, apart from rehabilitation, information regarding assessment methodology of cognitive-motor impairment is also essential for health professionals to effectively plan goals and outcomes of physical activity interventions. Therefore, more research is needed to understand the cognitive-motor connection, in particular during

complex everyday tasks before more effective rehabilitation interventions and assessments can be developed. To date, the most common method to investigate the reciprocal effect of cognitive and motor tasks (i.e. cognitive-motor interference) is the dual-task paradigm.

2.2. Overview of Stroke

Stroke or cerebrovascular accident (CVA) is a clinical syndrome which occurs when there is a sudden disruption of blood supply to a particular part of the brain. It is characterized by focal neurological signs, lasting more than twenty-four hours, or leading to death (Hankey et al., 2016). It must be noted that a transient ischemic attack (TIA) has the same definition as stroke but lasts less than twenty-four hours (Hankey et al., 2016). Strokes result from ischemia or haemorrhage in the vascular system. Each of these stroke types (Figure 2.1) have risk factors which increase the probability of stroke occurrence (Markus, 2016).

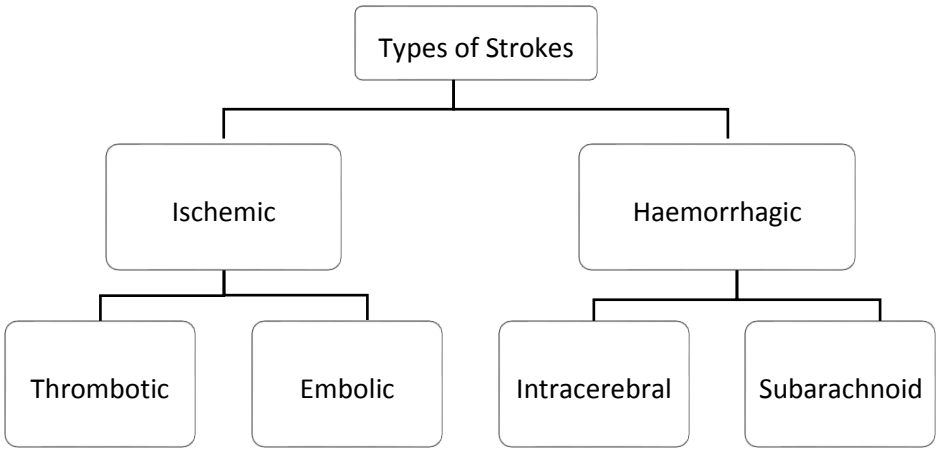

Figure 2.1 A diagram to show the various types and subtypes of strokes.

Ischemic Stroke

Cerebral ischemia is responsible for 85% of stroke occurrence (Musuka et al., 2015). It results from the blockage of a cerebral vessel caused by either a thrombosis or an embolism. Thrombotic strokes are caused by a blood clot, forming in an artery which is either inside the brain, or leading to the brain. The main cause of thrombotic stroke is arteriosclerosis (Hisham

et al., 2013). Embolic strokes occur when a piece of object within the brain breaks loose and transfers through the bloodstream, until it reaches a particular part of the brain that is too narrow for it to pass through, resulting in the blocking of a small cerebral artery, cutting off the blood supply to the brain (Hisham et al., 2013). The main possible causes of an embolic stroke are atrial fibrillation, endocarditis, mitral stenosis, or atherosclerosis (Hisham et al., 2013). Furthermore, sub-types of ischemic strokes are classified within the TOAST classification, otherwise known as the ASCOD phenotyping. This classifies stroke as; A - Atherosclerosis, S- Small vessel disease, C- Cardiac pathology, O- Other cause, D- Dissection.

Haemorrhage Strokes

Twenty percent of stroke occurrences result due to cerebral haemorrhage (Markus, 2016). This type of stroke involves bleeding within the brain from a ruptured, weakened blood vessel. The causes of the ruptured blood vessel can be due to a range of conditions, including uncontrolled hypertension as well as aneurysms (Hisham *et al.,* 2013). There are two different subtypes of haemorrhage strokes, which can be classified as: intracerebral or subarachnoid. These terms describe the bleeding either into the brain itself (intracerebral), or bleeding into the area surrounding the brain (subarachnoid). However, both result in damage to the brain (Musuka et al., 2015).

Haemorrhage strokes are sometimes caused by an aneurysm (Macdonald & Weizer, 2017). Aneurysms can be described as the abnormal bursting of a blood vessel, caused by weakened blood vessel walls. These weakened walls become stretched over time, often by excessive blood pressure, which causes it to rupture, consequently leading to a stroke. Furthermore, haemorrhagic stroke is classified according to its anatomical site or assumed cause. The most common site for intracerebral haemorrhage to occur is the supratentorial region of the brain.

Stroke survivors are also classified according to the time since their stroke event.

- Acute stroke: <6 months following stroke event.

- Chronic stroke: Either >12 months following stroke occurrence, or > or ≥6 months following from the stroke event. The latter is used to define chronic stroke in this study (Mori et al., 2018; Al-Yahya et al., 2016; Liu et al., 201

2.2.1 Epidemiology of Stroke

Stroke is the second leading cause of death worldwide after ischemic heart disease (Feigin et al., 2010). In the year of 2010, stroke was responsible for 5.3 million deaths, or one in ten deaths world-wide (Taylor & Ntisu, 2019). It is estimated that if these trends (i.e. yearly increase in stroke incidents) continue, by the year 2030 there will be 20 million annual stroke deaths and 70 million stroke survivors worldwide (Maredza *et al.,* 2015).

Furthermore, research suggests that more than eighty percent of the stroke burden occurs in low and middle-income countries (Maredza et al., 2016). In South Africa alone, research indicates that 75 000 stroke's occur per year (Bertram *et al*., 2013), being responsible for 25 000 annual deaths. The incidence of stroke in South Africa could indicate that rural South Africa is in a health transition due to a higher level of lifestyle risk factor exposure (Maredza et al., 2015).

Markus (2016) reported that the incidence of stroke rises exponentially with age, stating that 25% of men and 20% of women who live to 85 years of age can expect to suffer a stroke. It is also stated that the incidence of stroke is falling in some developed countries (by 19% from 1990 to 2010 in the United Kingdom) but is rising in less developed countries, such as South Africa. Consequently, a study on the global burden of stroke between 1990 and 2010 reported a 25% increase in stroke in individuals aged between 20 and 64 years old (Feigin et al., 2013). Additionally, there was a 113% rise in the prevalence of stroke survivors, 70% increase in the total number of strokes and a 36% increase in the number of deaths caused by stroke. Over 60% of global stroke occurs in individuals <75 years old.

Thus, it is clear that a large proportion of the population is affected by stroke every single year, meaning that every year there is an increase in the amount of stroke survivors requiring rehabilitation due to the debilitating impairments resulting from stoke.

2.2.2 Aetiology of Stroke

There are various risk factors that contribute to the likelihood of one experiencing a stroke. A considerable amount of these is modifiable through lifestyle behaviours and appropriate intervention. These include: hypertension (Hankey, 2016; Hisham *et al*., 2013; Markus., 2016; Moorley et al., 2015), diabetes mellitus (Hankey, 2016;), alcohol consumption (Markus., 2016;), tobacco use (Markus., 2016;), lack of physical activity (Markus., 2016; Moorley et al., 2015), age (Markus., 2016), gender (Markus., 2016), high cholesterol (Markus., 2016), greater body mass index (BMI) (Moorley et al., 2015), ethnicity (Markus., 2016), homocysteine levels (Markus., 2016), and poor diet (Moorley et al., 2015).

A study performed by Maredza *et al.* (2015) highlight the complexity of stroke in countries where health systems are not adequate. In South Africa, health care and related resources are scarce, which may provide an explanation for the high occurrence of stroke, as a result of noncommunicable diseases (NCD's).

The main reason for stroke occurrence within South Africa has been attributed to other NCD's (Maredza et al., 2015). Specifically, high blood pressure (BP) and excess weight are said to be accountable for the stroke burden in rural South Africa, contributing to 38 % (BP) and 20% (excess weight) of strokes caused (Maredza et al., 2015; Mensah et al., 2008). When compared to Sub-Saharan Africa, SA's stroke incidences as well as the incidence of NCD's, are substantially higher. Additional research supports that NCD's as well as risk factors for NCD's have increased within rural South Africa (Kabudula et al., 2014; Clark SJ et al., 2015). This reiterates the seriousness of the stroke burden, and the impact it is having upon the population.

A study performed by Biggs et al. (2008), to assess health risk behaviours of stroke survivors in the Western Cape region of South Africa found that 40.3% of the stroke survivors did not take part in any form of physical activity or exercise. Furthermore, 30.2% of the participants

smoked and 13.2% consumed alcohol. This highlights the serious need for intervention within the stroke population in South Africa.

2.2.3. Cognitive Impairment in Stroke

In a neurotypical human brain (i.e. the brain of a person with typical developmental, as well as intellectual and cognitive abilities), individuals are able to perform complex tasks that rely on various cognitive processes. These processes incorporate multiple cognitive domains, which do not function in isolation (Cummings et al., 2013). According to Cummings et al. (2013), the general domains include attention and executive function (EF) (both to be discussed in the next section), visuospatial ability (i.e. visual search, drawing, construction), memory (i.e. recall and recognition of visual and verbal information), and language (expressive and receptive).

However, following a stroke, some of these cognitive processes are often impaired, resulting in cognitive deficits (Cumming et al., 2013; VanGilder et al., 2020). The most prevalent cognitive deficits associated with stroke survivors include impairments in attention, memory, processing speed and EF (Tatemichi et al., 1994; Nys et al. 2007; Cumming et al., 2013; Teasell et al., 2018; VanGilder et al., 2020). A study by Lipskaya-Velikovsky et al. (2018), found that varying degrees of EF deficits are still present in chronic stroke survivors (>6 months since stroke onset).

Intriguingly, all of these cognitive deficits listed are particularly relevant to goal-directed movement (VanGilder et al., 2020; Einstad et al., 2021). Recently, Einstad and collegues. (2021), set out to describe the prevalence of concurrent motor and cognitive impairments 3 months post-stroke. The results showed that 30–40% of the (minor) stroke survivors had motor or cognitive impairments, whereas 20% had concurrent (cognitive and motor) impairments. Additionally, they concurred that motor performance in stroke survivors was associated with memory, EF and global cognition. These findings allude to an interplay between cognitive and motor functioning.

It is evident that cognitive decline is a major contributing factor to stroke-related disability as one's ability to accomplish activities of daily living (ADL) is largely dependent on EFs for instance (Cumming et al., 2013). A review by VanGilder et al. (2020), substantiates that deficits in cognitive and motor functioning of stroke survivors may obstruct gait and postural control, increase fall risk, and affect the degree of improvement during exercise or physical therapeutic interventions. In addition, more and more research is confirming that cognitive impairments influences motor recovery and rehabilitation due to the impact it has on motor learning (i.e. to learn or regain motor skills post-stroke) (Mullick et al., 2015; VanGilder et al., 2020).

Therefore, cognition is an important concept to consider in physical rehabilitation of stroke survivors, as cognition and perceived cognitive self-efficacy have been shown to be an important predictor of quality of life (QoL) (Cumming et al., 2013), mobility and responsiveness to motor rehabilitation in stroke survivors (VanGilder et al., 2020). This highlights the importance of considering cognitive activities when designing and implementing physical rehabilitation programmes. However, due to the scope of this thesis the following sections will only elaborate on the cognitive functions needed during dual-task activities, in particular EF and attention (Yogev-Seligmann et al., 2008).

2.2.4 Executive Functions, Attention and the Prefrontal Cortex

Both executive function (EF) and attention are involved in the acquisition of motor skills (Mullick et al., 2015). Executive function (EF) refers to higher order cognitive abilities (like planning, problem solving, multitasking, organising thoughts, inhibition, self-control) that regulates the underlying cognitive functions for goal-directed behaviour, which are essential for performing complex and novel tasks (Diamond, 2013). Executive functioning is typically divided into three subdomains, (1) working memory (which involves holding information and mentally working with it), (2) inhibitory control (which involves being able to control one's attention, thoughts, behaviour and emotions to select an appropriate response for that specific situation), and (3) cognitive flexibility (which involves adapting to the changing

demands required for successful outcomes in a specific situation) (Diamond, 2013). The frontal lobe, and in particular prefrontal cortical activity, has been associated with EF (Yogev-Seligmann et al., 2008; Diamond, 2013).

Attention (or attentional control) is the process of selectively focusing on specific information in the environment (i.e. focusing, shifting, dividing, or sustaining attention on a particular stimulus or task) (Cummings et al., 2013). Again, the prefrontal cortex (PFC) specifically plays an important role in the ability to switch attentional control base on the changing demands of everyday tasks (Rossi et al., 2009).

Day-to-day activities incorporates the interaction among multiple functions (i.e. sensory, cognitive, and motor), and it is this sensory-cognitive-motor network that scale actions to achieve safe and goal-directed movements (Yu et al., 2021). It has been suggested that motor and cognitive behaviours may share neural substrates, potentially in the PFC, that facilitate the flow of information between the cognitive and motor networks in the brain (Hanakawa, 2011). However, uncertainty remains regarding the exact brain regions (anatomical or functional network connections) involved in the integration between sensory, cognition and motor behaviour.

The PFC forms the anterior part of the frontal lobes of the cerebrum, located in front of the motor and premotor areas (Figure 2.2), and it is associated with the primary motor cortex, motor area cortex (M1 area), subcortical structures, and cerebellum (Blahak et al., 2009). From existing evidence, it seems as if the PFC might be involved in the integration between sensory, cognitive and motor information. It is generally understood that the PFC plays an important role in cognitive function (particularly EF and attention) and makes use of sensory information to adjust planned responses, by integrating with other areas of the brain to guide various functions from attention to movement. A resting-state functional magnetic resonance imaging (fMRI) study by Yuan and colleagues. (2015), which included single- and dual-task activities, found that the sensory-cognitive-motor neural circuits involve the frontal cortex,

subcortex, basal ganglia (caudate nucleus, globus pallidus, and thalamus), brainstem, and cerebellum. While Yu et al. (2021), confirmed that executive dysfunction is the most common type of cognitive impairment in stroke survivors, and is controlled by a network of areas within the PFC. Additionally, dual-task (DT) paradigms (see Section 2.2.16) hypothesize that the PFC plays a critical role in EF, attention as well as gait control. Consequently, based on this assumption, changes in EF and attention should be reflected in a person's gait, particularly when having to devote attentional resources to a concurrent secondary task (Pugh & Lipsitz, 2002). Hence, activation of the PFC may provide insight into this cognitive-motor connection during functional movements.

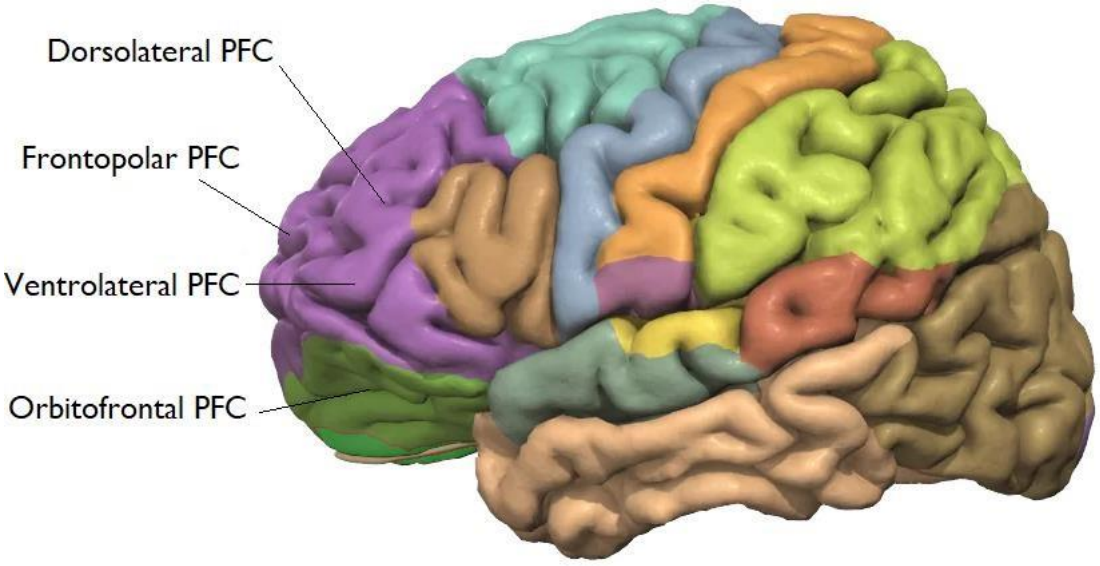

Figure 2.2 An illustration of the lateral surface of the human brain of the prefrontal cortex (PFC) (adapted with permission from Primal pictures©).

The brain sites of the PFC include frontopolar (FPPF) cortex, the dorsolateral (DLPF) cortex the ventrolateral (VLPF) cortex and the Orbitofrontal (OFPF) cortex. These various brain sites form an integrate network of collective functions, especially for EF and attention.

More specifically, the FPPF cortex and DLPF cortex, although distinct regions, are said to both be involved in evaluation, monitoring and manipulation of information held in working

memory (Christoff et al., 2000). The DLPF cortex is said to be involved in the processing of externally generated information, whereas the FPPF cortex is recruited when one must process internally generated information. Research states that the recruitment of the DLPF cortex is enough under circumstances where the internally represented information being processed is present or has recently been present in the environment (Christoff et al., 2000). However, the FPPF cortex is recruited alongside the DLPF cortex when internally represented information being acted on is not present in the environment, having already been internally generated (Christoff et al., 2000). Studies have confirmed the involvement of the both the FPPF cortex (Christoff et al., 2000) and DLPF cortex (Walshe et al.,2015) in complex cognitive tasks. This contrasts with the OFPF cortex, which plays a crucial role in human's ability to make decisions (Rudebeck & Rich, 2018), in particular when inhibiting certain behaviour (Bryden & Roesch, 2015) to produce desirable responses. Research suggests that the OFPF cortex is involved in the EF's that control response selectivity when unwanted movements are redirected by suppression (Bryden & Roesch, 2015), thus playing a vital role in conflict-induced executive control (Mansouri et al., 2014). Lastly, the VLPF cortex is largely associated with cognitive control, and is said to play a critical role in motor inhibition, when control is required to either override or stop motor responses (Aron et al., 2004; Levy and Wagner, 2011). Additionally, researchers have found activation in this brain region during encoding tasks involving long term memory (Buckner et al., 1996).

Executive dysfunctions and disinhibition are typically associated with frontal-subcortical circuit impairments (Bonelli et al., 2007). The functional networks of the frontal-subcortical circuitry connect cognition and motor processes, enabling one to adapt with the environment (Obeso et al., 2017) during gait and turning (Verlinden et al., 2016). Three of these circuits are implicated in high-order human behaviours i.e., the 1). DLPF cortex circuit, OFPF cortex circuit and the anterior cingulate (AC) cortex circuit (Bonelli et al., 2007). The DLPF circuit is required for the organization of information to enable a response (Bonelli et al., 2007). More specifically, the DLPF cortex connects with the striatum, basal ganglia, and thalamus through white matter tracts (Obeso et al., 2017). This is important for motor control, cognition, and

motor learning (Popa et al., 2019). While the OFPF circuit permits the integration of limbic and emotional information into behavioural responses, and the AC circuit allows for motivated behaviour (Bonelli et al., 2007).

Mihara et al. (2008), found that the PFC, but specifically the DLPF cortex, activated during perturbation tasks in healthy adults. This suggest that the DLPF not only plays a part in EF but also in the maintenance of postural control. And one's postural control system is particularly challenged during transitional movements.

2.2.5 Executive Functioning and Postural Control

Postural control includes the organisation of one's body position in space, specifically for orientation and stability (Horak, 2006). Postural orientation refers to the ability to maintain appropriate alignment between the different body segments (i.e. the trunk and head) in relation to the context/environment (i.e. gravity, support surfaces, the visual surroundings) as well as internal references (Horak, 2006). Postural orientation is accomplished through the vestibular, somatosensory and the visual system. Whereas postural stability or balance is the ability to coordinate movement and sensory strategies that stabilise the centre of mass (COM) in relation to the base of support (BOS) during self-initiated and external perturbations (Horak, 2006).

Stroke survivors often demonstrate a wide range of sensory and motor deficits, consequently, the severity of postural control deficits is varied among stroke survivors (VanGilder et al., 2020). These postural control deficits, such as asymmetric and increased sway, a reduced limit of stability as well as poor reactive postural control and weight transfer, are common among stroke survivors, and associated with poor mobility, increased fall risk, as well as reduced independence and QoL (Mackintosh et al., 2005; Cumming et al., 2013; Schmid et al., 2013; de Kam et al., 2017; Choi et al., 2020; VanGilder et al., 2020).

As a consequence of these motor and sensory deficits, stroke survivors require greater cognitive and attentional resources to maintain their postural control (Påhlman et al., 2011; Mori et al., 2018; VanGilder et al., 2020; Yu et al., 2021). This is due to the integrated sensory-

cognitive-motor network system which determines the accuracy of movement (Yu et al., 2021). In other words, for the postural control system to be adaptable in complex environments, it requires perception, spatial orientation, and paying attention to changing surroundings (Horak, 2006).

Stroke-specific research to date suggest that these postural control deficits may predominantly be linked to EF impairments i.e. working memory, cognitive flexibility and inhibition (Påhlman et al., 2011; VanGilder et al., 2020). Furthermore, this executive dysfunction is particularly prominent when stroke survivors perform two tasks simultaneously; they tend to demonstrate more DT interference (i.e. the relative cost of dual-tasking) compared with healthy age-matched counterparts (Mori et al., 2018; VanGilder et al., 2020).

A study by Yu et al. (2021) compared balance and fall risk between stroke survivors (≤ 3 months) with and without cognitive impairment, during walking and complex motor tasks such as standing up, turning, and sitting down. They found that the participants with poor cognitive function (Montreal Cognitive Assessment (MoCA) score between 15–25 A.U.) demonstrated worse balance and a higher fall risk than stroke survivors without cognitive deficits. Additionally, the stroke survivors with poor cognition required more time to turn around and to sit down during the Timed-up-and-go test. Consequently, the authors concluded that postural control during turning around and sitting down required more cognitive resources (especially EF), which has a significant impact on daily life.

However, the exact relationship between of cognition and posture control networks remains still ambiguous (Yu et al., 2021). This is predominantly due to fact that one's postural control system needs to be dynamic and effectively adapt postures when navigating ever-changing, complex environments in day-to-day life.

2.2.6 Executive Functioning and the Risk of Falling

A fall can be defined as an event, resulting in a person coming to rest unintentionally on the ground or other lower level (Hyndman et al., 2002). Research shows that stroke survivors

have a higher risk of falling than age-match healthy counterparts, and that falls are common following stroke (Weerdesteyn et al., 2008; *Persson et al., 2011;* Kerse et al., 2008*;* VanGilder et al., 2020; Yu et al., 2021), especially among chronic survivors (Manaf et al.,2012). For instance, up to about 73% of stroke survivors experience a fall during the first 6 months of their return to their community (Forster & Young, 1995; Batchelor et al., 2012). Whereas about 20% are multiple falls in chronic stroke survivors specifically (Belgen et al., 2006). In a study by Jorgenson et al. (2002), the risk of falling on at least one occasion, was more than twice as high for stroke survivors in comparison to controls.

Falls reported by stroke survivors mostly occurred during dynamic movements such as gait (Dean & Kautz, 2015; Mansfield et al., 2015), and turning (Simpson et al., 2011). Impaired postural control is one of the reasons why stroke survivors have a high fall risk (*Renfro et al., 2016)*.

As stated in the previous section (Section 2.2.5), various studies have demonstrated the relationship between cognition and gait and some on postural control. Therefore, contemporary research has shifted the focus on the role cognition plays in fall risk. For instance, Saverino et al. (2016), assessed the role of different cognitive functions to predict balance and fall risk in various neurological conditions (including stroke survivors). The authors found that specific subcomponents of executive function (specifically inhibitory control and cognitive flexibility) were significantly associated with fall risk i.e. the Stroop Colour Word Test and the number of errors on part B of the Trail Making Test, while a global cognitive dysfunction was associated with poorer balance. In 2007, Liu-Ambrose et al. found that the subcomponents of executive function i.e. cognitive flexibility was independently associated with balance and mobility in stroke survivors (>1 year), regardless of age, quadriceps strength of the paretic side and physical activity status. Another stroke-specific study by Yu et al. (2021) found that poor cognition in stroke survivors increased the risk of falling during transitional movements such as turning around and sitting down.

Pang et al. (2018) found during the 6-month follow-up period that a dual-task training program over 8-weeks for chronic stroke survivors (75 ± 65 months post-stroke onset) reduced the risk of falls and injurious falls by 25% and 22%, respectively, compared to a stroke

control group which did not receive the intervention. This study suggests that better dual-task abilities (including EF and attention) that simulate the cognitive load of everyday activities reduced falls and fall-related injuries in chronic stroke survivors.

This information could provide useful input regarding the types of exercises that should be included in rehabilitation programmes of chronic stroke survivors, in order to combat fall-related events, as well as cognition deficits that result from stroke. It also highlights that an intervention programme including dual-task activities can enhance one's ability to navigate attention demanding situations more independently in day-to-day life.

2.2.7 Assessing Prefrontal Cortical Activation

Various neuroimaging approaches are available to date to evaluate PFC activation. Specifically, functional magnetic resonance imaging (fMRI)(Al-Yahya et al., 2016), electroencephalogram (EEG)(Wu et al., 2016), positron emission tomography (PET), and functional near-infrared spectroscopy (fNIRS) (Mori et al., 2018; Al-Yahya et al., 2016; Lui et al., 2018; Hermand et al., 2019). The gold standard for detecting cortical activity has long since been fMRI, however it has downfalls, such as excessive costs (Agbangla et al., 2017), high signal-to-noise ratio's (Agbangla et al., 2017), as well as requiring individuals to be fully immobilized (Lloyd-Fox et al., 2010), which Is not effective in movement sciences. More recently, studies in movement science have found fNIRS to be beneficial as it allows participants to move around freely, providing opportunity to explore movements without restriction (Herold et al., 2017). Furthermore, fNIRS is non-invasive (Leff et al., 2011; Perrey et al., 2008), and can be used in a neurorehabilitation setting (Cutini & S Brigadoi, 2014; Obrig, 2014).

Functional near-infrared spectroscopy (fNIRS) measures the relative changes in haemoglobin concentration through near infrared light attenuation, which then allows for the quantification of cortical activity changes during movements (Herold et al., 2017). Previous research on stroke has used fNIRS to detect cortical activity in stroke survivors during walking (Al-Yahya et al., 2016; Mori et al., 2018; Lui et al., 2018; Hermand et al., 2019; Hawkins et al., 2019) and balance tasks (Fujimoto et al., 2014; Mihara et al., 2012). Furthermore, studies on Parkinson's disease have utilized fNIRS during in place 360° turning (Stuart et al., 2019;

Belluscio et al., 2019). Considering the beneficial use of fNIRS in previous research on transitional movements, it seems a promising tool in the present study assessing sit-to-stand/stand-to-sit and turning, allowing participants to move around without restriction. In this study, fNIRS was used to quantify changes in oxygenated haemoglobin (HbO_2), deoxygenated haemoglobin (HbR), as well as the difference in haemoglobin (HbDiff).

2.2.8. Movement Impairments in Stroke

The following section will predominantly focus on common motor impairments in stroke survivors. The term motor impairment can be used to describe the various difficulties experienced by stroke survivors, which affect their ability to effectively perform motor skills (Hatem et al., 2016). However, considering that the motor system does not function in isolation, the sensorimotor control deficits contributing to movement impairments are also briefly referred to. Especially, since the sensorimotor deficits are considered to be the foremost causes of physical and activity limitations in stroke survivors (Manaf et al., 2012).

The extent of motor and sensory impairment seems to be present in various degrees in stroke survivors. Consequently, resulting in individual differences between the levels of disability in this population. The differences may be attributed to the severity (i.e. mild, acute, severe), the different brain regions affected and the different body segments affected (face, neck, trunk, upper limb, and/or lower limbs). The most widespread sensory and motor impairments in stroke include spasticity, muscle weakness, distorted movement selection and loss of sensation as well as integration of proprioceptive information (VanGilder et al., 2020).

Motor impairment following stroke has led to research focusing on hemiparesis and motor recovery (Aqueveque et al., 2017). Hemiparesis refers to muscular weakness or partial paralysis, which restricts one side of the body. This is said to be experienced by 88% of stroke survivors, providing challenges for independent mobility (Aqueveque et al., 2017).

Hemiplegia, on the other hand, is a severe or complete loss of strength or paralysis on one side of the body which then result in movement impairment (i.e. difficulties with walking, changing direction, navigating obstacles, and turning) and is associated more with chronic stroke survivors. Stroke survivors with hemiplegia often experience persistent impairments in strength, balance, and coordination of gait (Hollands et al., 2012).

Spasticity is a sensorimotor impairment, especially visible in the elbow flexors, wrist flexors, and quadriceps and calf muscles (Lin et al., 2006). It is defined as a velocity-dependant resistance to stretch specific muscles functions characterized by increase muscle tone with exaggerated tendon jerks (Lin et al., 2006; Winstein et al., 2016). Spasticity is as a result of hyper-excitability of the stretch reflex (Lin et al., 2006) and occurs in about 20% of stroke survivors (Sommerfeld et al., 2004). This affects mobility and ability to perform daily tasks (Manaf et al., 2012), especially spasticity of the affected ankle plantar flexors which may impact gait symmetry in stroke survivors (Lin et al., 2006).

Motor impairments such as gait and upper limb dysfunction also affect mobility of stroke survivors, and are well documented (Hsu et al., 2003; Kollen et al., 2006; Buma et al., 2016; Zambrama et al., 2019). In fact, walking dysfunction is one of the common movement impairments reported among stroke survivors. Consequently, rehabilitation of walking ability is essential post-stroke for independence at home and in the community (Manaf et al., 2012). There is, however, far less post-stroke research focusing on the deficits of lower limb transitional movements (TM) such as turning (Manaf et al., 2014; Manaf et al., 2016; Hollands et al., 2014), as well as sit-to-stand and stand-to-sit (Palanasamy et al., Boukadida et al., 2015) compared to straight-walking gait. These TMs are also important for independence and QoL. Thus, research is required to explore the clinical significance of these TM deficits.

Balance dysfunction (as part of postural control deficits) is often observed post-stroke and contributes significantly to loss in mobility (Holt et al., 2000; Kusoffsky et al., 2001; Cameron et al.,2003; VanGilder et al., 2020). Some of the contributing factors to poor balance include reduce range of motion, muscle weakness, abnormal muscle tone, impaired motor recovery,

poor motor coordination as well as sensory integration, weight shifting abilities and cognition (Mayo et al., 1999; Manaf et al., 2012; Hollands et al., 2014; Liang et al., 2018; Soares et al., 2019). Balance dysfunction also result in turning (Liang et al., 2018) as well as sit-to-stand (Cameron et al.,2003; Ghous et al., 2017) difficulties.

Owing to these movement difficulties, this population is often constrained to perform ADL's within restricted home environments, providing minimal opportunity for engagement within the community; reducing social interaction (Scott et al., 2012), and thus independence as well as QoL. Furthermore, when physical activity opportunities are restricted, movement impairments worsen, and risk of falling is increased.

2.2.9 Transitional Movements in Stroke Survivors

Transitional movements (TM) are defined as an individual's ability to change the position of their body in space and move within the environment (Eschot et al., 2016). As a result, TM involves the complex control of the centre of body mass, while moving from one position to another (Yu et al., 2021), and include activities such as rolling, getting in or out of sitting position or off the floor, getting up into standing position from being seated, getting back down to the floor from standing or sitting, and turning.

These transitional activities are required in everyday life and rely on the postural control system for accurate execution of movements. For instance, moving from sitting to standing requires anticipatory postural control, while turning and sitting down from standing involves spatial orientation (Yu et al., 2021).

Furthermore, Yu et al. (2021), found that TMs such as turning and sitting down placed a higher cognitive as well as postural control load on stroke survivors than straight-walking. Subsequently, these authors suggested that physical or exercise therapists should include the training of turning or sitting task during balance training interventions in stroke survivors with poor cognition.

The following subsections focuses specifically on turning and changing positions between sitting and standing in stroke survivors.

2.2.10 Turning and Stroke Survivors

Turning is considered a series of dynamic foot movements reorienting the body toward a new direction, which requires stability for smooth and safe movements (Liang et al., 2018). Therefore, turning is considered a complex task that requires the integration of muscle coordination with sensory inputs i.e. visual, vestibular, and proprioceptive information. This then allows for the adjustments of postural and gait constraints, as well as the changing the direction of axial body segments (Patla et al., 1999; Imai et al., 2001; Xu et al., 2004; Orendurff et al.,2006; Lamontagne et al., 2007). In the next section, turning ability is explained in relation to common turning strategies, gait parameters (i.e. turn time, the number of steps taken, and the paretic limb) as well as postural control performance in stroke survivors compared to healthy able-body counterparts.

For stroke survivors, the ability to turn is an important component during walking as well as while in-place (i.e. on-the-spot turns), where 'in-place' turning refers to the change in direction and turning while standing (Kobayashi et al., 2015; Soares et al., 2019). This in-place turning is needed when performing daily activities in narrow spaces (e.g. kitchen or bathroom) (Kobayashi et al., 2015). Practically all forms of everyday locomotion or functional movements requires turning (Manaf et al., 2012). For instance, just consider the potential number of turns when making coffee: you turn on the spot to switch on the kettle on the counter, then turn to get the coffee; turn and walk towards the refrigerator to get the milk, turn to the cupboard to get sugar, mug and a spoon before turning towards the kettle again to switch it off and pour the water into the mug and finally turn to sit down and drink the coffee at the kitchen table. Glaister et al. (2007), recorded the turn percentages during selected activities of daily living i.e. walking between offices (45%), from the office to parking lot (8%), and through a supermarket (35%) as well as a cafeteria (50%). Therefore, this study showed that as much as up to 50% of the steps taken each day incorporate turning, and thus highlights to importance of turns in functional mobility. Nevertheless, regardless of how essential turning tasks are in daily activities, to date, there is insufficient knowledge regarding turning ability in stroke survivors, with most gait research focusing on straight-walking (Manaf et al., 2012; Liang et

al., 2018). Interestingly, due to the high demands on postural control and limb coordination, as well as cognitive load, turning is considered more challenging than straight-walking (Courtine et al., 2006; Manaf et al., 2012; Chisholm et al., 2015; Manaf et al., 2012; Yu et al., 2021).

A 2018 study by Liang and colleagues used the four criteria of Thigpen et al. (2000), to delimit turning difficulties during a 180° on-the-spot turn in stroke survivors. Turning difficulty was defined as (1) the presence of staggering during the turn, (2) the absence of pivoting during the turn, (3) the use of five or more steps or shifts in weight to accomplish the turn, and (4) a turn duration of 3 seconds or more (Thigpen et al., 2000). They found that stroke survivors (33 ± 32 months post-stroke; 58 ± 11 years-old) experienced turning difficulties in terms of turn time (53%), number of steps (57%), turn strategy (100%), and balance (70%).

Other stroke research has also found that motor recovery of lower limb physical impairments (i.e. paretic lower limbs), trunk control function, balance and walking ability was associated with turning difficulty post-stroke (Lam & Luttmann,2009; Kobayashi et al., 2015; Shiu et al., 2016; Robinson & Ng, 2018; Liang et al., 2018). In addition, Liang et al. (2018), and Robinson and Ng. (2018), also found that physical turning performances was not associated with perceived concerns about falling during activities of daily living (ADL) or balance confidence, respectively.

More often than not, stroke-related impairments in strength, balance, postural control, gait/walking ability (i.e. hemiparesis) and coordination will affect safe turning ability (Mayo et al., 1999; Hollands et al., 2014; Liang et al., 2018; Soares et al., 2019). When comparing turning ability in stroke survivors to apparently healthy adults, the stroke survivors usually require more time and a greater number of steps to complete turns than age-matched counterparts indicating the presence of turning difficulties after stroke (Faria et al., 2009; Hollands et al., 2010; Ahmad et al., 2014; Shiu et al., 2016; Liang et al., 2018). In addition to these differences, Liang et al. (2018), also reported on ineffective turning strategies used and poorer balance performance/instability of stroke survivors compared to apparently healthy adults. In fact, Liang et al. (2018) consider this poor balance performance to be the reason for

the stroke survivors' turning disabilities, regardless of the compensatory turning strategies implemented.

It is important to mention that most studies discussed here made use of the 180° turns for analyses (Faria et al., 2009; Hollands et al., 2010; Robinson & Ng, 2018; Liang et al., 2018). However other turning angles such as 45°, 90° and 360° confirm most of these findings (Lam et al., 2009; Kobayashi et al., 2015). Though, studies investigating the 360° turn in stroke survivors is still needed, especially since it has been shown to be closely associated with FMA-LE scores, bilateral plantarflexor strength, and dorsiflexor strength of the affected side, functional balance (Berg Balance Scale; BBS), five-times-sit-to-stand; 5TSTS), gait speed, timed up and go (TUG) times (Shiu et al., 2016) and walking ability in chronic stroke survivors (Kobayashi et al., 2015).

2.2.10.1 Types of Turning Strategies:

When changing direction, the turn strategies implemented by a person attempts to maintain safety and stability while reorienting the body. This is because turning results in shifting the center of mass outside the BOS (Orendurff et al., 2006). Turning can generally be classified into two distinct strategies i) step and ii) spin (also known as pivot or cross-over) (Hase & Stein, 1999; Patla et al., 1999) (Figure 2.3). The stepping strategy (outside turn) reorganises the body to the opposite side of the stance limb during a turn task (i.e. a change in direction contralateral to the stance limb (e.g., right turn on the left leg; Figure 2.3 b)), while the spin strategy (inside turn) involves a change in the direction towards the stance limb (i.e. a pivot on the leg ipsilateral to the direction of turn (e.g., right turn on right leg; Figure 2.3 c)) (Manaf et al., 2012; Conradsson et al., 2018; Golyski et al., 2019).

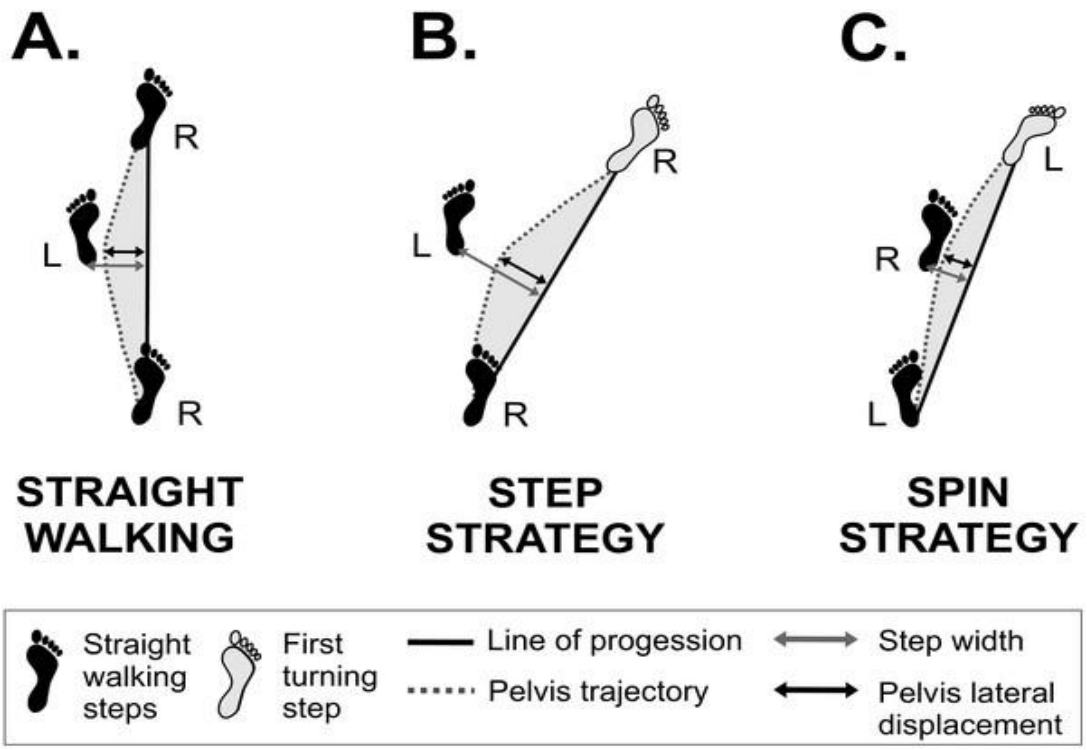

Figure 2.3 Schematic drawing of typical turning strategies during a right turn for (a) straight walking, (b) step strategy and (c) spin strategy (Hase and Stein, 1999; Patla et al., 1999).

Both strategies have advantages in various context, but typically, these turn strategies allow the person to slow down or in some events stop before horizontally rotating the head, trunk (axial body segments) and lower limb into the new direction (Manaf et al., 2012). Consequently, trunk-pelvis coordination during the reorientation of the axial body segments towards a new direction should also be considered a contributing factor to poor turning performance in stroke survivors (Lamontagne et al., 2007; Hollands et al., 2010; Kobayashi et al., 2015).

As discussed earlier in this section, Liang et al. (2018) investigated the differences in 180° in-place turning performance between stroke survivors and healthy controls. They found that during turning stroke survivors predominantly made use of the step strategy, whereas the healthy participants used the spin strategy. The stepping strategy is a slower, closed-looped control movement (i.e. relies more on a feedback approach), while the spin strategy is a quick, open-looped control movement (i.e. relying on feedforward approach). Compared to spin

turning, the step strategy is considered convenient, more stable while changing direction because of a wider BOS and requires less ankle coordination (Hase & Stein, 1999; Taylor et al., 2005). Spin turns are less stable, and Thigpen et al. (2000) suggested that the absence of a spin strategy is a possible early indicator of underlying problems associated with difficulty in turning. Therefore, it seems that the stroke survivors discarded the swift spin turn strategy to achieve greater stability with the step turn which involved less movement coordination (Liang et al., 2018).

2.2.10.2 Gait Parameters during Turning

Generally, turning consists of slowing down walking speed (i.e. deceleration of the body's COM; the equilibrium point of the body's mass), realigning the body, and changing stepping direction (i.e. rotation of the axial body segments) while accelerating the COM and maintain stability (Patla et al., 1991; Hase & Stein, 1999; Xu et al., 2004; Manaf et al., 2012).

Older adults compared to younger adults, with turning difficulties, adapt their gait parameters when turning by relying on more than double the steps of the younger counterparts (≥ 5 steps), and present with tentativeness, pauses, and stops (Thigpen et al., 2000). Similar, stroke survivors maintain stability by increasing the number of steps as well as the time, which is also associated with staggering when turning (Faria et al., 2009; Hollands et al, 2010; Liang et al., 2018). These alterations in gait parameters (number of steps and time) are postural adjustments that decreases momentum by reducing the distance between the COM and the centre of pressure (COP), and in turn decrease the neuromuscular demands places on the stroke survivor (Xu et al., 2004; Taylor et al., 2005). Consequently, taking shorter, slower and simpler steps, are compensatory or adaptive strategies to improve or counteract the loss of motor coordination (Hollands et al., 2010; Liang et al., 2018).

Another contributing factor to the slowing down an instability of gait during turns, may be attributed to the hemiparetic gait (i.e. paretic lower limb). Chen et al. (2014), explains that while turning, the inner leg steadies the posture and the outer leg provide propulsion then swings to readjust the body in the new direction. In spite of this, the paretic leg is ineffective in either roles. Specifically, as the inner leg it demonstrates limited ankle stability (especially

needed to pivot) and alternatively, as the outer leg offered poor ground clearance (Rao & Aruin, 2016). Therefore, asymmetrical motor impairments will affect the ability to execute standing turns (Kobayashi et al., 2015). Chen et al. (2014), also found that stroke survivors had inadequate muscle activation (i.e. tibialis anterior and biceps femoris) of the affected inner leg, along with reduced standing knee flexion, which disturb turning toward the affected side. The slowing down of gait is often used to quantify turning difficulty in stroke survivors. Berg (1989), stated that stroke survivors require more than four seconds to turn 360◦ based on the BBS test and Shui et al. (2016), found that 3.43 to 3.49 seconds for a 360° turn discriminated chronic stroke survivors and healthy older adults (Shiu et al., 2016).

2.2.10.3. Postural Control during Turning.

As explained in the abovementioned sections, turning aims to transport one's body mass in a new direction in three consecutive steps: i) approach, ii) turn, and iii) acceleration in which the person transition from double- to single limb stance before returning to double limb stance again (Crenna et al., 2007). The foot placement is critical from the approach to the turn step and control of the trunk from the turn to acceleration step (Patla et al., 1999). Instability, however, occurs when moving the COM outside the BOS, which is what happens during turning tasks (especially during single limb stance) which aims to transport the body's mass in a new direction (Patla et al., 1999). The resulting momentum (due to the increase in COM and COP distance) that is necessary to turn requires further neuromuscular control to redirect and control the body's mass (Xu et al., 2004; Taylor et al., 2005). It is for these reasons that turning is considered a dynamic and complex task (Manaf et al., 2012), and is often used for various clinical assessments of mobility and balance (Shiu et al., 2016).

Various sensory, motor and biomechanical constraints limits coordination and impairs postural control in stroke survivors. Accordingly, they have difficulty redirecting their body (turning) and also exhibit instability when performing head turns or whole-body rotations (Lamontagne et al., 2007). Subsequently this altered dynamic postural control may also lead to falling if postural equilibrium (or balance) is not re-established by appropriate postural adjustments as discuss in the previous sections (like increasing BOS by widening steps, taking

a greater number of steps or slowing down movements). In short, most compensatory or adaptive strategies during turning is implemented to maintain stability and avoid falls in stroke survivors.

Previous research has found that turning results in dynamic instability more so than straight walking (Segal et al., 2008; Strike and Taylor, 2009). Liang et al. (2018) observed that most of stroke survivors displayed instability during the 180° turns, unlike the healthy counterparts who remained stable. The authors considered poor balance performance as the main reason for turning difficulties experienced by stroke survivors despite having adopted compensatory strategies (Liang et al., 2018). Thus, turning should be an integral part of any rehabilitation programme post-stroke, to enhance the safety of stroke survivors during community ambulation.

2.2.11 Transitioning between Sitting and Standing Postures in Stroke survivors

Both sit-to-stand and stand-to-sit TM are important everyday transfer tasks, which entail weight shifting, transitioning the COM and changing the BOS (Alexander et al., 2000; Faria et al., 2010; Pollock et al., 2014; Frykberg & Häger, 2015; Mohammadi & Mirshoja, 2018). Accordingly, both of these functional activities are challenging to a person's limits of stability. In fact, Riley et al. (1991), stated that both of these activities are two of the most mechanically demanding tasks in day-to-day life. Regrettably, stroke survivors report difficulties in independently transferring from sitting to standing postures and vice versa (Faria et al., 2010; Silva et al., 2014; Frykberg & Häger, 2015).

Being able to stand up and sit down play a significant role in a person's independence, safety and QoL (Nevitt et al., 1989; Kotake et al., 1993; Janssen et al., 2002; Carr et al., 2002; Frykberg & Häger, 2015; Mao et al., 2018). In addition, these tasks are also prerequisite for walking (Nevitt et al., 1989; Kotake et al., 1993; Guralnik et al., 1995; Alexander et al., 2000; Pollock et al., 2014). For instance, the 2021 study by Agustin and colleagues found that stroke survivors that were classified as community ambulators had better performance on the five-times-sit-to-stand task (5TSTS) and faster gait speed, than those classified as household ambulators. Where Chou et al. (2003), investigated the relationship between sit-to-stand and

gait, and reported that better gait performances were associated with a shorter duration of standing up (or less vertical force difference with body weight distribution) during the sit-to-stance task in stroke survivors.

Dubost et al. (2005), however did point out that the trunk performs different roles during these two transfer skills. For instance, while standing up from a seated position the trunk is responsible for momentum generation, and during sitting down from a standing position it controls stability. Hence, these two transfer activities should be investigated distinctly, together, and also contrasted. This will allow the therapist to devise more specific physical and exercise interventions based on the specific task.

Consequently, improving transitional sit-to-stand/stand-to-sit tasks are an important rehabilitation goal for many stroke survivors (Silva et al., 2014; Pollock et al., 2014; Agustín et al., 2021). A review by Pollock et al. (2014) on interventions to improve sit-to-stand performance in stroke survivors, showed that stroke survivors do not easily recover this ability to rise safely from a chair. Therefore, more research is needed to understand the factors that influence sit-to-stand and stand-to-sit activities post-stroke.

The current study included a 5TSTS test, which involves 'sit-to-stand-to-sit' postural transitions. To date, stroke studies do not typically report the sit-to-stand-to-sit transitional movements; instead, most studies focus on analysing single sit-to-stand tasks in isolation, and a limited number of studies have analysed single stand-to-sit tasks in on its own. Thus far, only the study by Ghahramani et al. (2020), have reported on the 'sit-to-stand-to-sit' postural transitions during the 5TSTS. However, this study was on older adults with various degrees of fall risk and not on stroke survivors. Therefore, the following subsections reviews the typical movement patterns, stroke-related adaptations or control strategies and determinants of successful transitions between sitting and standing postures under separate sit-to-stand and stand-to-sit subsections. The purpose is to gain an overview of the transitional movements in stroke survivors.

2.2.11.1 Sit-to-stand:

Yoshioka et al. (2009), describes the sit-to-stand movement (i.e. standing up from a seated position) as the connection (bridge) between static and dynamic positions; a transitional movement into the upright posture.

In able-bodied persons' transition between sitting to standing occurs about 60 times per day (Dall & Kerr, 2010), whereas acute stroke survivors (~45.5 days post-stroke onset) transfer between sitting and standing about 18 times per day (Britton et al., 2008). Depending on age, and the criteria used to define start and end time, the movement time of one single sit-to-stand task in a healthy adult may range between 1.51 to 2.87 seconds (Nuzik et al., 1986; Kotake et al., 1993; Kerr et al., 1997; Hirschfeld et al., 1999).

Previously, it was thought that transitioning from sitting to standing generally involves lower limb muscle strength. However these days it is clear that this functional transfer task is a complex motor skill that can be affected by several factors, including age, sex, muscle strength, coordination, postural control (i.e. postural orientation and stability), chair height and design (i.e. armrests), and foot placement (Rodosky et al., 1989; Janssen et al., 2002; Boukadida et al., 2015; Frykberg & Häger, 2015; Ng et al., 2015). This thesis focuses only on the strokerelated factors.

The Typical Movement Pattern of Sit-to-stand:

Due to the consistent pattern associated with the transitioning from sitting into standing in healthy able-bodied persons, various phases have been used by previous researchers to investigate the sit-to-stand movement. These phases are based on kinematic variables, ground forces and COM movement (Boukadida et al., 2015). Some authors have used a simplified 2 phase model (Hirschfeld et al.,1999) and others have made use of an extended five phase (with six transitional points) model (Moa et al., 2018). However, for the purposes of this thesis, the sit-to-stand task will be discussed by making use of the conventional Schenkman et al. (1990) four phase model (Figure 2.4). The reasons for this is that the four phase model is commonly used in clinical practice by therapist for observational analysis of

the patient's sit-to-stand movement (Hellmers et al., 2019), and the current thesis does not make use of 3D motion analysis or force plates (unlike the two and five phase models).

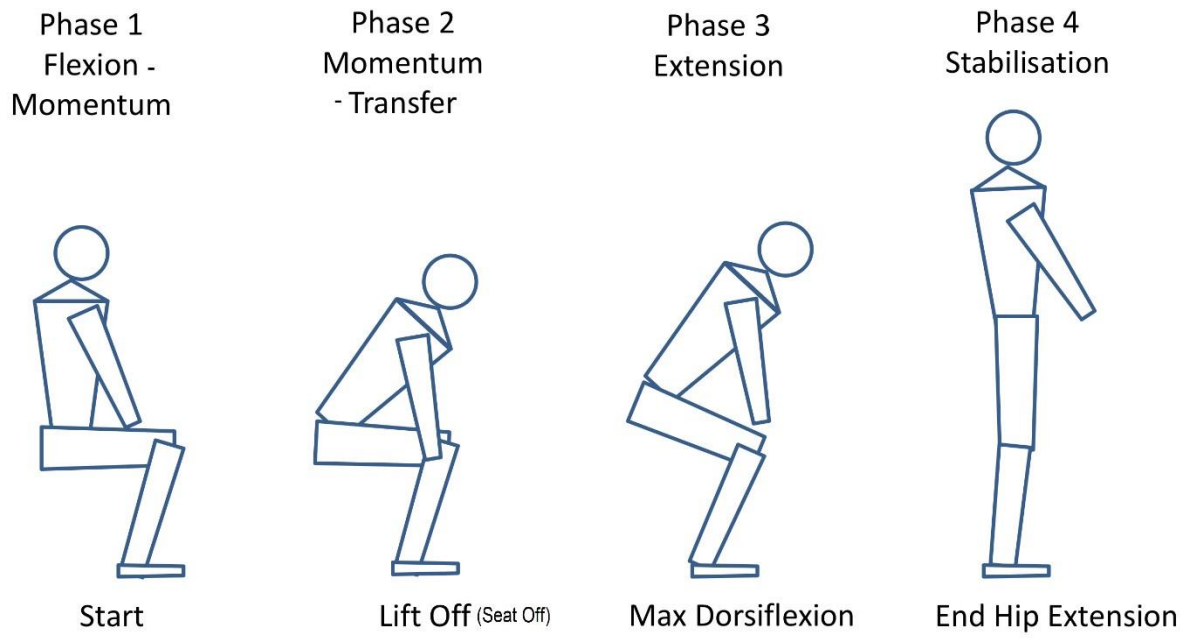

Figure 2.4 The four phases of the sit-to-stand movement as defined by Schenkman et al. (1990) that are differentiated in terms of momentum and stability characteristics.

As shown in Figure 2.4, Phase 1 is referred to as the initial '*Flexion-Momentum*' phase, which is the preparation period for the lift off. Phase 1 starts with the initiation of the movement (i.e. the person bends the trunk and pelvis) until just before the moment that the buttocks /thighs leave the chair (referred to as 'Seat-off'). This phase aims to generate the initial momentum for rising from the chair. Hereafter the person transitions uninterruptedly into Phase 2 (i.e. the '*Momentum-Transfer*' phase). This phase starts with 'Seat-off' (i.e. this is the moment when the person leaves the chair and merely the feet are in contact with the surface; with no force applied on the seat) and continues with the forward momentum of the upper body being transferred (and shifted throughout displacement of COM) to the anterior (forward) and upward momentum of the whole body. The forward COM displacement brings it closer to the COP to reach a quasi-static stability position (Boukadida et al., 2015). This phase stretches from Seat-off to maximum ankle dorsiflexion. Next, the third phase (i.e. the

'*Extension*' phase) during which the body rises to an upright position. This phase is initiated just after maximal ankle dorsiflexion is reached and continues until the hips and knee joints are fully extended. The final phase (i.e. the '*Stabilisation*' phase), starts just after hip extension velocity reaches 0°/s and lasts until all motion associated with stabilization from lifting off the chair is achieved. Therefore, a straight and steady standing posture indicates the end of the transfer in Phase 4, which is necessary for the performance of other tasks. However, the end point of Phase 4 may be challenging to identify (Schenkman et al., 1990; Boukadida et al., 2015; Frykberg & Häger, 2015; Hellmers et al., 2019).

Determinants of sit-to-stand in healthy adults

This section on healthy able-bodied persons is limited to only the concepts that are imperative for the analysis of stroke survivors' sit-to-stand transfers.

Angular displacements of lower limbs and trunk in healthy adults

The hip and the trunk play critical roles transitioning from sitting to standing. During the initial sit-to-stand movement (Figure 2.4) the trunk of healthy adults will moved anterior (forward) in the sagittal plane (i.e. the first 53.3% of the movement; predominantly in Phases 1 and 2), then return to the upright position during Phase 3 (i.e. for 49.8% of the movement) and finally backward for steady standing posture (Phase 4) (Kerr et al., 1997). Hip and trunk flexion is critical for sufficient momentum in order for the person to stand up from the chair (i.e. vertical velocity and displacement). During the initial phases of the movement, the person will go into hip flexion (i.e. the first 40% of the movement) (Nuzik et al., 1986), and then into hip extension in the remaining part of the activity (Phase 3 and 4). In the meanwhile, the knees will continuously move into extension throughout the sit-to-stand movement (Nuzik et al., 1986). Ankle dorsiflexion happens at 20% of the sequence followed by plantar flexion (Nuzik et al., 1986).

Muscular strength and activation pattern of lower limbs in healthy adults

According to Frykberg and Häger (2015), the lower limb muscles and muscle activation patterns are considered important determinants for the sit-to-stand in healthy adults.

Based on the review by Boukadida et al. (2015) the bilateral muscular activation sequence during the sit-to-stand movement in healthy adults include the following: Tibialis anterior [Phase 1] → Iliopsoas [Phase 2] → Quadriceps [Phase 2] → Hamstrings [Phase 3] → Tibialis anterior [Phase 3] → Gastrocnemius and Soleus [Phase 4].

During the sit-to-stand movement, the Tibialis anterior muscles are activated first (Phase 1). The reason for this is that the Tibialis anterior muscles stabilize the feet before starting the forward body movement (Vander Linden et al., 1994; Roebroeck et al., 1994; Goulart et al., 1999; Khemlani et al., 1999). Hereafter knee and hip extensor muscles activate and peak at Seat-off (Phase 2) (Yoshioka et al., 2014). Initial the Iliopsoas initiated hip flexion then Quadriceps continue hip flexion, while stabilizing the knees during extension (Roebroeck et al., 1994; Goulart et al., 1999; Khemlani et al., 1999). After Seat-off, the Hamstrings decelerate the early hip flexion (to stimulate hip extension for the Extension phase (Phase 3) (Goulart et al., 1999). In order to stabilise the forward movement, the Tibialis anterior provide ankle dorsiflexion torques to maintain the COP in a posterior position under the feet (Brunt et al., 2002). At the end of the sit-to-stand movement (Phase 4), the Gastrocnemius and Soleus muscles control of the body's forward shift (Khemlani et al., 1999).

Additionally, 48% of variance in the 5TSTS test and 35% of variance in the 30s chair stand test is explained by lower limb strength for women between the ages of 60 and 69 years (McCarthy et al., 2004). Although, some contradictory evidence exist on which muscles are the strongest predictors on sit-to-stand performance. For instance, Gross et al. (1998) stated that in functional elderly (70 years and older), strength of the hip musculature is more critical than knee extensor strength. While Lord et al. (2002) reported that for elderly (75 years and older) the Quadriceps strength explained 16.5% of the sit-to-stand variance (Lord et al., 2002). These discrepancies are likely attributed to the variability between ages, disabilities, sexes and/or motor strategies involved (Frykberg & Häger, 2015).

Postural control and sit-to-stand in healthy adults

Considering the focus of this thesis, one of the determinants of the sit-to-stand movement to be emphasized is postural control. However, according to Frykberg and Häger (2015) this is

more of a determining factor in elderly as well as persons with disabilities (such as stroke survivors) than younger healthy counterparts who have no postural control deficits. Conversely, Galli et al. (2008) explained the rising from a chair evaluates motor control and stability in healthy (as well as stroke survivors), as it requires coordination between trunk and lower limbs movements, appropriate muscles strength, control of equilibrium.

When a person transitions from a sitting posture to an upright standing posture, this movement involves horizontal (forward) and vertical (upward) displacement of the whole body's COM from a stable position (i.e. sitting) to a less stable position (i.e. standing) without losing their balance, and the COM situated over their extended lower extremities (Roebroeck et al., 1994; Vander Linden et al., 1994; Frykberg & Häger, 2015). Therefore, standing up from a chair really challenges a person's postural stability, as the COM is shifted from a relatively large and stable BOS (i.e. a stable 3-points base), in the sitting position to a much smaller BOS (i.e. a 2-points base), in the standing position (Riley et al., 1997; Galli et al., 2008).

If we explain this within the context of Schenkman et al. (1990)'s four phases (Figure 2.4) then during the sit-to-stand movement, the COM initially moves anterior (forward) in the Flexion Momentum phase (Phase 1). While in Phase 2, the momentum is transferred from the trunk to the lower limbs, which increases the vertical movement of the body. This coordination between the trunk and the lower limbs are an important determinant of sit-to-stand transitions. The COM subsequently reaches peak velocity during Phase 3 (Roebroeck et al., 1994). At Seat-off (Phase 2), COM switches into vertical movement and its velocity continues to accelerate until it reaches a maximum at the middle of the Extension phase (Hirschfeld et al., 1999). The COM is also most posterior relative to the ankle joints in Phase 2. Therefore, COM and COP are here the greatest distance apart, which results in instability, challenging one's postural control system. Vertical momentum is essential for successful sit-to-stand movements. Therefore, if a person produces insufficient vertical velocity in the extension phase, vertical momentum will be too small. Once the person is in the standing position, the COM velocity would decelerate progressively until reaching zero (Hirschfeld et al., 1999). During this steady standing posture (Stabilization Phase 4), the COM is stable over the smaller BOS.

Standing up from a seated position involves changing/scaling body momentum appropriately to successfully perform the task. By observing the forces applied on the ground over time (impulse), researchers report that during the transfer task the ground forces are applied underneath the buttocks (thighs) and feet (Hirschfeld et al., 1999). When rising to stand, the head-, arm- and trunk-segments are the primary contributors to the body's forward propulsion prior to Seat-off (Phase 2), whereas the thighs predominantly contribute to the upward body momentum (Pai & Rogers, 1991). When the person's whole body moves forward it accelerates to a peak prior to decelerating; before standing up (rising). This latter deceleration is referred to as a braking impulse. While the peak horizontal acceleration is evidently fix across various speeds, the velocity of the vertical momentum of COM, on the other hand, varies between successful and unsuccessful sit-to-stand attempts (Pai & Rodgers, 1990; Pai et al., 1994).

Successful attempts are determined by the movement efficiency which improves as postural orientation along with COM stabilisation improves (Da Costa et al., 2013). Bernardi et al. (2004) found that trunk bending momentum and lower limb extensor strength are predictors of successful performance in motor-impaired elderly. In addition, the speed at which the transfer task is performed, with an increase in hip flexion velocity before lifting off the seat (Seat-off) are also considered important for successful sit-to-stands (STS)(Hughes et al., 1996).

As explained by Frykberg and Häger (2015), unsuccessful sit-to-stand attempts (i.e. siting back down or taking a step after rising), in elderly for example, are affected by the control (i.e. scaling and timing) of the horizontal and vertical momenta (Riley et al., 1997). For instance, reduced peak vertical velocity of body's COM have been associated with unsuccessful rising to stand attempts in motor-impaired elderly (Bernardi et al., 2004), traumatic brain injury patients (Zablotny et al., 2003) and Parkinson's disease (Mak et al., 2011). More research is needed to explore the reasons for reduced vertical velocity of COM, however potential explanations may include insufficient momentum transfer, impaired postural orientation and/or poor biomechanics.

Movement strategies may vary from rising with a nearly vertical to a very distinct forward leaning trunk (Coghlin et al., 1994; Doorenbosch et al., 1994; Hughes et al., 1994). The

prominent forward leaning trunk is typically associated with prioritizing stability and safety (Frykberg & Häger, 2015). One possible determined that has received attention is the peak COM acceleration before the Seat-off (Figure 2.4) (Fujimoto & Chou, 2013).

Weight-bearing distribution and foot placement in healthy adults

When seated, the sitting posture assists body stability, requires less energy expenditure and reduces the load on the lower limbs. This is because weight is distributed between support points (e.g. the floor, chair seat and backrest, or if applicable, armrest (Chaffin et al., 2006)). When transitioning from this stable seated posture into standing, weight gets redistributes between the feet and thighs. According to Hirschfeld et al. (1999), before the Seat-off (Phase 2) about 85% and 15% of a healthy person's weight is distributed under their thighs and feet, respectively. Then as the body rises to an upright position during the Extension phase (Phase 3), force under the feet increase from 52% of body weight to total body weight at the end of sit-to-stand (Phase 4).

During a typical sit-to-stand movement a slight posterior foot placement facilitates momentum transfer from the trunk to the lower extremities to produce vertical movement. By placing a foot posteriorly, the distance between the COM and COP is reduced, which provides more stability. Therefore this 'placing the feet posterior' before the start of the rising to stand is a potential movement strategy which may lead to temporal and kinetic advantages (i.e. efficiency, stability and better muscle activation) (Kawagoe et al., 2000).

Lecours et al. (2008), investigated the interaction of three different foot placements, trunk frontal position, weight-bearing and knee moment asymmetry at when rising from a chair in stroke survivors with hemiparesis and healthy adults. They found that when the feet of healthy adults were positioned spontaneously (in other words, no instructions given on the initial foot placing) and symmetrically (i.e. both feet position at 15° dorsiflexion), then the trunk was near the neutral position (frontal plane) at Seat off (Phase 2), and almost identical loading on both lower limbs. However, when the feet were placed asymmetrically (i.e. one foot to the back), healthy subjects stood up from the chair with the trunk displaced towards the posterior foot, which then resulted in asymmetrical weight-bearing.

Determinants of sit-to-stand in stroke survivor's

After a stroke, persons experience a number of problems (i.e. muscle weakness, impaired motor control and balance (Galli et al., 2008; Ng et al., 2010; Boukadida et al., 2015; Moa et al., 2018; Mohammadi & Mirshoja, 2018), which may impede the ability to rise from a seated position independently. These aspects will be discussed in the following subsection.

Angular displacements of lower limbs and trunk in stroke survivors

The velocity and amplitude of trunk and hip joint flexion early in sit-to-stand activities are important (Silva et al., 2017; Moa et al., 2018). Stroke survivors demonstrate uncoordinated movements in the lower limbs and also in the trunk compared to their healthy counterparts. In the study by Silva et al. (2017), the chronic stroke survivors (144.8 ± 73.5 months post-stroke) demonstrated deficits in the generation and transfer of the trunk flexor momentum. This reduced the sit-to-stand performances significantly.

For instance, Ada and Westwood. (1992), investigated the kinematic change of standing up post-stroke, and found that stroke survivors with hemiparesis had poor coordination between hip and knee displacements when they tried to stand up (for example the knee was extended completely by Phase 4, while the hip extension was incomplete). However, as they improved in the sit-to-stand task the kinematic characteristics that changed notably related more to velocity than to angular displacement i.e. as movement time improved so did peak angular velocities and the velocity profiles shifted more towards normal.

As explained previously, trunk displacement plays an important role in achieving both sit-to-stand transfers. Lecours et al. (2008), analyzed the interaction between three different foot placement (see section 2.2.11.1a. 'Weight-bearing distribution and foot placement in healthy adults'), trunk frontal position, weight-bearing and knee moment asymmetry before and after Seat-off (Phase 2) when rising from a chair in chronic stroke survivors (3.2 ± 2.3 years poststroke) compared to healthy controls. The authors reported that stroke survivors typically tilted their trunk towards the less affected side during a sit-to-stand task during spontaneous and symmetrical foot positions, unlike their healthy counterparts that showed a near neutral trunk position in the frontal plane. However, when the stroke survivors placed the paretic

foot behind the no-paretic, the asymmetrical trunk was corrected. Thus weight-bearing are to some extend associated with the frontal trunk position, and foot placement manipulations can be used to modify weight-bearing distribution.

Meisier and colleagues. (2004), performed a dynamic analysis of anterior trunk flexion in stroke survivors (≥3 months post-stroke) compared to healthy counterparts. The stroke survivors had less COP displacement compared to healthy controls (33.7±6.9 vs. 40.5±9.2, respectively); despite similar trunk movement amplitude. The decrease COP displacement resulted in a lower weight-bearing on the feet (i.e. paretic foot: 2.3 ± 3.6%; non-paretic foot: 2.2 ±2.9% vs. Healthy control: non-dominant foot: 5.4 ± 3.4%; dominant foot: 5.2 ± 4.0%). The findings suggest that trunk movements in persons with hemiparesis was executed by flexing the upper trunk along with small anterior pelvis tilt.

Galli et al. (2008) emphasized that efficient sit-to-stand performance requires coordination between trunk and lower limb movements, and this is clearly problematic in stroke survivors. Frykberg and Häger (2015) also pointed out that scaling and timing characteristics of the trunk movements as well as foot position, which influence lower limb muscle activation are important.

Muscular strength and activation changes of lower limbs after stroke

Following a stroke, an asymmetry exists between paretic and non-paretic lower limbs' muscle activation and force production. More specifically, the paretic lower limb shows a reduction in muscle activation, and conversely the non-paretic limb shows excessive activation during sit-to-stand transfers (Galli et al., 2008; Cheng et al., 2004; Prudente et al., 2013). The reduction in force production associated with post-stroke result in the duration of the sit-to-stand movement to slow down (Cameron et al., 2003; Lomaglio et al., 2005).

Furthermore, the timing or onset of muscular activation patterns are greatly impaired in the paretic limb, specifically Tibialis anterior and Soleus muscles, in stroke survivors compared to the non-paretic limb and healthy counterparts (Silva et al., 2013; Kwong et al.,2014). Also, the non-paretic lower limb tends to overcompensate for the paretic limb. Hence muscle coordination and activity on both sides are impaired in the sit-to-stand tasks. These findings

are support by an electromyography (EMG) study by Prudente et al. (2013) of the lower limb muscles during sit-to-stand tasks, comparing the paretic and non-paretic sides of hemiplegic chronic stroke survivors (≥ 6 months post-stroke). Both sides of the lower limb muscles were active, yet impaired, during sit-to-stand tasks. The Hamstring muscle in non-paretic side showed a faster and longer activation compared to the paretic side, with more activity in the Tibialis anterior, Soleus and Quadriceps muscles compared to the paretic side. The onset of activity in all of the lower limb muscles of the non-paretic side was similar, while the Tibialis anterior muscle was activated earlier than the Hamstring and Soleus muscles on the paretic side. Similar results were reported for other muscles i.e. transverse and lateral abdominal muscles of the paretic side of chronic stroke survivors who showed a delay in the sit-to-stand task (Lee et al., 2015). These are possibly compensatory strategies for the weakness of the paretic lower limb and might be related to the increased weight-bearing on the less affected side (Boukadida et al., 2015).

These differences in muscle activation of the lower limb and the resulting compensatory strategies suggest that paretic muscle strength and the ability to load the paretic limb are important factors underlying the ability to rise from a chair. Lomaglio and collegues (2005) supports these findings in their study that investigated the relationship of lower extremity joint torques and weight-bearing symmetry to sit-to-stand performance in chronic stroke survivors.

Therefore, the timing as well as the amount of muscular force and activation will influence the efficiency and speed at which a stroke survivor can complete a sit-to-stand task. Frykberg and Häger (2015) highlighted that the speed at which a stroke survivor can perform the sit-to-stand movement is a critical determinant for the successful transition between sitting and standing.

Postural Control and Sit-to-stand in stroke survivor's

Impaired mobility and balance difficulties may be attributed to poor weight-bearing and weight transfer abilities in stroke survivors, as the the COP and the COM of the body will tend shift towards the non-paretic limb.

Following stroke, survivors typically exhibit a reduced peak vertical reaction force and a larger medio-lateral COP displacement compared with healthy counterparts (Cheng et al., 1998). Galli and co-workers. (2008), supports this, as these researchers also found prolonged sit-to-stand duration in Phase 2 and 3, as well as different vertical forces in stroke survivors in comparison with healthy controls. Moa et al. (2018) found similar findings, when they analysed the various phases (and transitional points) of the sit-to-stand task with 3D motion analysis in subacute stroke survivors (43.6 ± 23.7 days post-stroke) compared to healthy counterparts. The authors found that the stroke survivors took overall longer to complete the sit-to-stand task and all the transitional points were delayed compared with the healthy control. The increase in total duration of the sit-to-stand task was attributed to the delay from the initial point of trunk flexion to the point of maximal hip flexion (Phase I; Figure 2.4), as well as from between the point of maximal ankle dorsiflexion to just standing with full extension of hip and knee (Phase 3 and 4; Figure 2.4). Most of the time was spent on trunk flexion before the hip left the seat (Seat-off), and before hip and knee joints reached full extension (Moa et al., 2018). They explained that longer duration detected throughout Phase I means that slow velocity of standing up from a seated position derives from the initial stage. The authors suggest that poor trunk control and weak muscle strength contribute to these delays and poor postural control (Moa et al., 2018).

Improving postural control (i.e. orientation and stability), bring about steadying a person's COM, which improves control over sit-to-stand performances. Due to the sit-to-stand task challenging the postural control system, various intervention studies often use sit-to-stand activities as balance and proprioceptive specific exercises for chronic stroke populations (Pollock et al., 2014; Kannan et al.; 2021).

Galli et al. (2008) found that control of equilibrium and stability are critical for successful sitto-stand transitions in stroke survivors. Consequently, the optimal timing and scaling of momentum during the sit-to-stand transition is another determinant factor for better performance during this transfer task (Frykberg & Häger, 2015). For example, Duclos et al. (2008) observed the COM of chronic stroke survivors, and found that participants tilted their trunk towards the less affected side in the frontal plane, and showed significant medio-lateral

postural instability early during the sit-to-stand task (i.e. before Seat-off) compared to healthy controls. This instability is attributed to the altered COP placement from the weight-bearing asymmetry. In the same study the researchers also manipulated foot positions to correct the trunk tilt, however this did not affect the postural instability. The researchers stated that the degree of stability of hemiparetic stroke survivors in part depended on their level of motor impairment of the paretic limb, not just by correcting trunk displacement (by altering foot positions), or the strength of the trunk muscles.

Cheng et al. (1998) made use of kinetic assessment during the sit-to-stand task to determine the association with risk for falling in chronic stroke survivors (1 – 2 years post-stroke). They supported previous findings that stroke survivors shifted their weight towards the unaffected side, and that stroke survivors who have had experienced one or more falls demonstrated more increased COP sway in both medio-lateral and antero-posterior directions when compared to non-fallers. Consequently, to reduce the risk of falling stroke survivors have adapted a compensatory strategy such as exaggerating the anterior projection of COM before getting up from the chair. This compensatory strategy positions the COM closer to COP for better postural stability.

Asymmetry, foot placement and weight-bearing distribution in stroke survivors

As mentioned in the preceding sections, stroke survivors with hemiparesis characteristically demonstrate asymmetrical weight-bearing during the sit-to-stand transfer, with reduce weight support on the paretic lower limb, and increased weight-bearing on the unaffected side (Engardt & Olsson; 1992; Durward, 1994; Cheng et al., 1998; Frykberg & Häger, 2015). Asymmetry has been described as the ratio between a person's sides (Lecours et al., 2008). Engardt and Olsson (1992) reported that stroke survivors were only able to maintain 37.5% of their weight instead of the typical 50% when rising and sitting down.

Interestingly, asymmetrical foot positions (specifically positioning the non-paretic foot behind the paretic foot) in stroke survivors may contribute to longer sit-to-stand subphases (Brunt et al., 2002) as well as total movement time (Camargos et al., 2009; Kwong et al., 2014). Conversely, by placing the paretic foot posteriorly have resulted in less asymmetrical trunk

positions and COP displacement (Lecours et al., 2008; Duclos et al., 2008), better weightbearing symmetry (Roy et al., 2006; Lecours et al., 2008) as well as knee moment symmetry (Lecours et al., 2008), improved vertical force production (Brunt et al.,2002) and improved medio-lateral stability (Duclos et al., 2008).

Recently, Noh et al. (2020), found increases in the muscle activation, peak and mean vertical ground reaction force, and weight-bearing symmetry ratio of the lower limbs by placing the less affected foot to the side (by about the width of the person's foot). Which supports the earlier findings of Brunt et al. (2002), who also found that foot placing altered muscle activation in stroke survivors. The researchers reported that when the less affected foot was placed in an extended position, the activity for the Tibialis anterior and the Quadriceps was improved by 29% and 34%, respectively in the paretic limb. Similar, when the less affected foot was placed in an elevated position, activation in paretic limb for Tibialis anterior and Quadriceps improved by 51% and 41%, respectively.

2.2.11.2 Stand-to-sit:

Unlike its inverse counterpart, discussed in the preceding section, there is a dearth of research on the stand-to-sit movement of stroke survivors, which have received relatively little attention (Roy et al., 2006; Faria et al., 2010; Frykberg & Häger, 2015; Vaughan-Graham et al., 2019). It's only since recent advantages in technology that the stand-to-sit task has started to feature slightly more in the literature. Nonetheless, gait-related research for clinical movement analysis still dominates the academic databases, as the number of gait analysis publications in 2017 was over 9 times more than sit-to-stand or stand-to-sit publications (van Lummel, 2017). Undoubtedly more research is needed on stand-to-sit transitional movement, especially if one considers that sitting down from a standing position, as mentioned before, is a common functional everyday activity (Faria et al., 2010; Vaughan-Graham et al., 2019).

Similar to the sit-to-stand, moving from a standing position to take a seat on a chair is a mechanically demanding task (Riley et al., 1991; Faria et al., 2010) that requires the body to transition from one BOS to another. Unlike the sit-to-stand movement, the person now moves form a smaller BOS to a larger BOS (as explained in the previous sections). In addition, one of

the main concerns for this transfer task is controlling the descent or load impact on the body, which requires eccentric muscle actions instead of concentric muscle actions like during the sit-to-stand. Potential reasons for this impact can be attributed to the downward COM velocity, COP and COM relationship, angular momentum modulation and/or poor lower extremity muscle strength (Chen et al., 2010). Thus minimizing impact with the seating surface are important goals for practical and safe mobility as well.

The Movement Pattern of Stand-to-sit:

The movement pattern of the stand-to-sit task or sitting from the standing position is considered the mirror of the sit-to-stand movement in the sagittal plane (Shum et al., 2005; Watkins, 2014; Frykberg & Häger, 2015). Unlike the sit-to-stand, there is no standardised model with specific phases for the stand-to-sit. Regardless, a stand-to-sit transfer could also be separated into four phases (Figure 2.5), specifically, the Standing phase (Phase 1), then the Stand-to-sit transfer or Transition phase (Phase 2), the Sit-down or Seat-on (Phase 3) and finally the Sitting-back or Stabilisation (Phase 4).

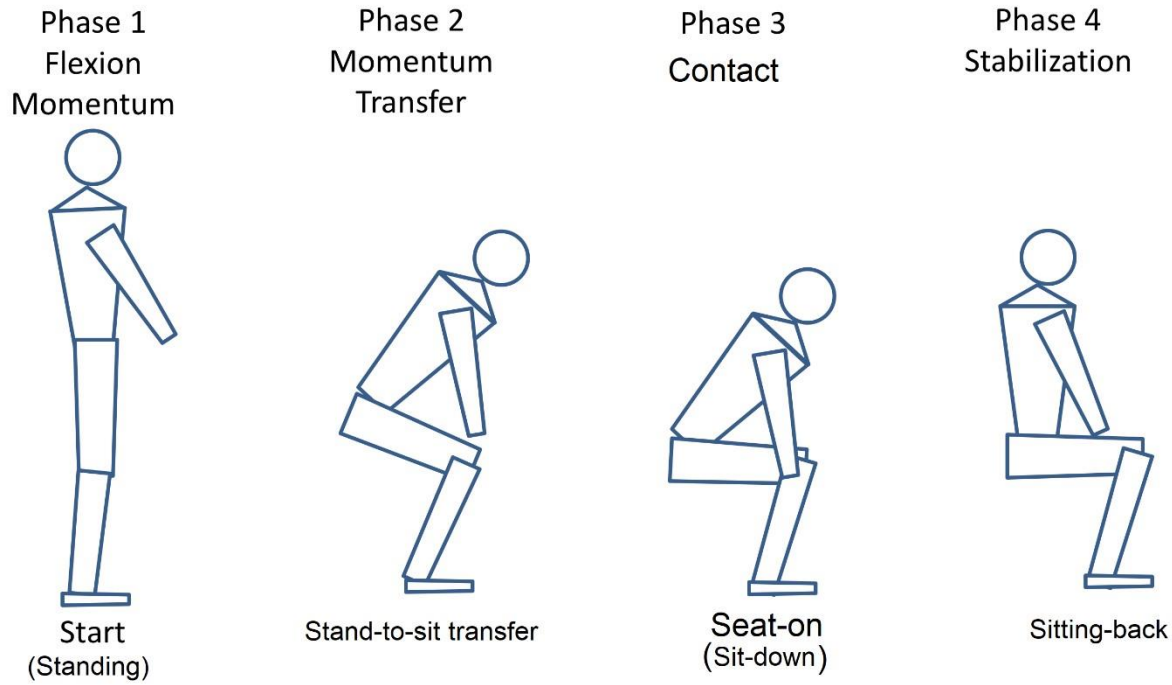

Figure 2.5 The proposed four phases of the stand-to-sit movement that are differentiated in terms of momentum and stability characteristics according to Schenkmann et al. (1990).

When a person transfers from standing upright to sit on a chair, the person moves the feet close to the front of the chair (Phase 1), and then lowers the body by flexing the knees as well as bending the trunk anterior (forward) without changing the BOS (Phase 2). As the buttocks/thighs lowers down towards the seat (Seat-on; Phase 3), the trunk slightly rocks backwards (trunk extension), which transfers the body weight from over the feet to over the seat of the chair; the new BOS (Phase 4) (Ashford, & De Souza, 2000; Watkins, 2014). Therefore, the joints initially go into flexion until the buttocks/ thigh makes contact with the seat (Seat-on) and then the trunk and hips extend until the healthy adult sits upright.

Determinants of sitting down from a standing position in healthy adults & stroke survivors

Owing to the scarcity of information during stand-to-sit in healthy adults and stroke survivors, the following subsection discuss both populations together**.**

Postural control during stand-to-sit

Researchers have stated that the successful completion of this stand-to-sit movement in healthy adults requires postural control which allows for the redistribution of body weight (due to asymmetrical weight distribution) to maintain postural stability during this transfer task (Faria et al., 2010; Watkins, 2014). Stroke survivors usually show more medio-lateral and antero-posterior postural sway than their healthy counterparts during stand-to-sit tasks (Yoshida et al., 1983; Cheng et al., 1998). Respectively, this might be due to poorer dynamic postural stability and/or excessive momentum with the forward body displacement during sitting down. However more research is needed to confirm this (Faria et al., 2010).

Conversely, as mentioned in the previous section, unlike the sit-to-stand movement, uncoordinated weight/load transfer during the stand-to-sit could result in potential injuries or falls, due to poor modulation of the downward velocity (i.e. the sitting impact). Possible reasons for this poor control could be attributes to either due to poor muscle strength, motor coordination or angular momentum modulation (Chen et al., 2010). This may then result in postural instability in stroke survivors. Concluding that the postural instability is caused by the inability of the non-paretic leg to compensate for the postural impairment of the paretic leg,

rather than by asymmetrical load transferring (Genthon et al., 2008; Chen et al., 2010). Therefore, with a smooth weight-transfer the risk of falling is reduced.

Muscular strength and activation pattern of lower limbs during stand-to-sit

As previously stated, the sitting down requires eccentric muscle actions for deceleration (Roy et al., 2006). Chen et al. (2010), explains that the affected paretic muscles in stroke survivors are not strong enough to maintain these eccentric muscle actions. Consequently, making it difficult for the stroke survivor to modulate the sitting down from a standing position more so than in healthy adults. Additionally, movement time for the stand- to-sit may not be an exact reflection of efficient transfer abilities in stroke survivors. Since poor muscle strength may accelerate the stand-to–sit time (i.e. when the stroke survivor just drops they body down towards the chair, instead of controlling the deceleration). Thus, unlike the sit-to-stand, interpretation of the stand-to-sit time should be approached cautiously.

When initiating the movement from standing to sitting requires the adjustment of plantar flexors i.e. Soleus muscle. This then allows the forward (anterior) translation of the tibia in relation to the foot (Silva et al., 2012). Silva et al. (2012), compared the Soleus muscle activation patterns in healthy adults and chronic stroke survivors (28.6 ± 14.9 months poststroke). Their findings showed a decreased Soleus muscle activation in affected paretic lower limb of the stroke survivors, and less activation than in healthy adults.

Angular displacements of lower limbs and trunk during stand-to-sit

Additionally, sitting down from a standing position is influenced by restriction in trunk motion (similar to sit-to-stand) (Shepherd & Gentile, 1994; Shum et al., 2005). According to Hsieh and Pringle. (1994), the lumbar spine in healthy adults contributed approximately 56% to 66% of the trunk flexion during sit-to-stand and stand-to-sit movements. In addition, able-bodied adults have shown a maximum flexion of left hip, right hip and lumbar spine to be 86°, 87°, and 37°, respectively (Shum et al., 2005). Consequently, the hip and the trunk still play a critical role during the stand-to-sit tasks for healthy and stroke survivors (Faria et al., 2010).

Age seems to influence the stand-to-sit movements. Mourey et al. (1998), analysed the sitto-stand and stand-to-sit movements of older and younger adults. The researchers found that the thigh trajectories differed depending on direction. More specifically the thigh was displaced further back during the sitting down movement. Additionally, all the age groups took longer to sit down compared to standing up, however, the older adults still required more time than the younger age group. Another study comparing older to younger adults, found that older adults had less forward displacement of the trunk during sitting down than younger adults. The authors suggested that this was a strategy applied to avoid falling in the older adults (Dubost et al., 2005). Therefore, as mentioned before, the trunk act as is a stability controller when sitting down (Dubost et al., 2005).

Roy and colleagues (2007), investigated hip and knee joint moments on paretic and non-paretic sides of chronic stroke survivors (6 months to 6 years) with four-foot positions during stand up and sit down tasks at a self-paced speed. Additionally, the association between muscle weakness and the asymmetry in the joint moments was determined as well. They found that both transfer tasks are revealed asymmetry in the knee extensor moments (specifically higher for unaffected than affected side; accept when the paretic foot was placed backwards). During the transition (Phase 2) and Seat-off (Phase 3) of the stand-to-sit (Figure 2.5), when the affected paretic foot was placed backwards, it showed the lowest values of net knee joint moment asymmetry. Additional, when the unaffected non-paretic foot was positioned backwards during the stand-to-sit task a higher level of knee joint asymmetry than in the spontaneous and symmetrical foot conditions were reported. The researchers stated that this asymmetry in the knee extensor moments were also associated with knee extensor weakness. No differences were reported for the hip.

Foot placement and weight-bearing during stand-to-sit

Whilst performing a sit-to-stand and stand-to-sit movement, healthy adults tend to load their lower extremities relatively symmetrically (Engardt & Olsson, 1992). Conversely, stroke survivors commonly display asymmetrical weight-bearing during these transitional movements (Cheng et al., 1998). The reports amount of load placed on the affected paretic lower limb differ slightly in existing literature. For instance, Cheng et al. (1998), reports that

stroke survivors are likely to put between 24 to 29% of the load on the affected lower limb, whereas Chou et al. (2003), found that stroke survivors place roughly 41.5% less load on the affected lower limb. These discrepancies might be due to assessment techniques or the descriptive characteristics of the sample included.

Similar to the sit-to-stand, this asymmetrical limb loading (weight-bearing) due to hemiparesis contributes to anterior/posterior and lateral displacement of the COM and poor movement control during sitting down from standing positions (Briere et al., 2010; Chen et al., 2010; Roy et al., 2007). Although higher loads when going down to sit, along for poor control will also result in increased impact and instability.

For instance, Chen et al. (2010), set out to determine chronic hemiplegic stroke survivor's (13.9 ± 11.2 months post-stroke) stand-to-sit lower and upper limb load-sharing strategies and sitting impact forces. The researchers included four different postural configurations of arm and foot placements i.e. two arm placements - symmetrical (relaxed) and/or grasped (90 degrees shoulder with interlaced fingers) and the two leg placements: non-paretic leg posterior and/or paretic leg posterior. The results showed that with the stroke survivors, no differences were found between the two arm placements. The authors attributed this to the high functional abilities of the participants or that the assessment methods are insufficient to pick up discrepancies. More interestingly, the study found leg placement influences leg load sharing strategies and sitting impact forces. When placing the non-paretic leg anterior, the less affected leg is unable to compensate for the poor control of the posterior paretic leg during the eccentric muscle actions going down to sit. Consequently, when placing the paretic leg at the back result in greater sitting impact and more postural instability compared with positioning the non-paretic leg posterior. Thus, for a safer transitioning, more effort-efficient and lower impact, it is best to place the non-paretic at the back, but this will not address the asymmetric weight-bearing. Conversely for more symmetrical weight-bearing and strength training purposes, placing the non-paretic leg in the front would increase the resistance that of the paretic leg will experience when positioned in the back. However, this strategy has higher sitting loads and results in more postural instability.

Foot alignment may influence weight-bearing, postural control (i.e. orientation and stability) in stroke survivors during stand-to-sit activities. Two studies by the same laboratory (Roy et al., 2006; Roy et al., 2007) examined the effects of various foot positioning on the performance of the sit-to-stand and stand-to-sit activities of chronic stroke survivors (6 months to 6 years post-stroke) with hemiplegia. Placing the affected paretic foot in the backward position improved the loading of the affected side. Therefore, addressing the typical asymmetrical alignment associated with hemiplegia, similar to the sit-to-stand transfer tasks discussed in the previous section. However, as explain by Chen et al. (2010), the positioning of the affected foot backwards may assist with weight bearing symmetry but the impact load when sitting down is exacerbated.

A preliminary study by Vaughan-Graham and colleagues. (2019), on nine stroke survivors (16.6 months post-stroke) set out to describe the pelvic and limb loading simultaneously with the path of the COM and the contribution made by the less affected compared to the more affected paretic lower limb during sit-to-stand and stand-to-sit movements. The results revealed two, four and five different movement patterns for pelvic loading, limb loading and COM deviations, respectively. Interestingly, unlike most previous studies a few of the participants did not load or shift the COM towards the less affected side. In addition, some participants show higher loading on the more affected limb in the static phases (sitting & standing) but the loading shifted again towards the less affected limb during the more dynamic or transitional phases (Figure 2.4, Phase 2 & 3). These inconsistencies in movement and COM patterns are likely attributed to the variability between participants and their motor impairments, motor strategies or even limits of the available measurement techniques.

Even though the weight-bearing on the lower limbs of stroke survivors during transitional movements such as sit-to-stand and stand-to-sit is most often studied in stroke survivors, these findings suggest that symmetrical weight-bearing may not always be warranted, and depends on the outcomes of the rehabilitation.

Conclusion for sit-to-stand and stand-to-sit

Chronic stroke survivors need adequate lower extremity function (motor coordination, muscle strength and activation), movement strategies (i.e. the scaling and timing of

momentum generation throughout action) and postural control (i.e. orientation and balance) to be able to perform these functional activities every day (Faria et al., 2010; Frykberg & Häger, 2015; Mohammadi & Mirshoja, 2018). Additionally, factors such as foot position influence sit-to-stand as well as stand-to-sit performances (Faria et al., 2010; Frykberg & Häger, 2015; Mohammadi & Mirshoja, 2018).

In conclusion, forces and movements are generated and controlled by the brain (Frykberg & Häger, 2015), therefore investigating the PFC during these transitional movements may provide a better understanding of the brain-body connection during these complex transitional movements that are essential to every-day life.

2.2.12 Transitional Movements and Cognitive Functioning

It has been proposed that control of turning may be more cognitively demanding than walking in a straight line (Takei & Amorim, 1995; Takei *et al.,* 1996; Malouin *et al.,* 2003), and that older adults and stroke survivors have limited cognitive capacity (Seligmann *et al.,* 2008). Thus, it has been hypothesized (Hollands et al., 2010) that falls during turning after stroke might not be due to the inability to produce movement patterns necessary to achieve the turn but rather due to cognitive-motor interference (Plummer D'Amato *et al.,* 2008). Hence, it is thought that falls during turning occur as a result of the inappropriate utilization of one's limited cognitive resources, leading to exacerbations in motor impairments, when concurrent (i.e. cognitive or motor) demands are added to the primary task.

In agreement with this, Yu and colleagues (2021), compared straight-walking, turning around as well as getting up and sitting down in stroke survivors (≤3 months post-stroke) with and without cognitive impairment. The findings showed that turning around and sitting down required more cognitive resources than straight-walking and getting up. Yu et al. (2021), explained that in contrast to straight-walking, the control of equilibrium during changing postures such as turning around, and sitting down requires a multifaceted control of the COM.

The section under dual-tasking and transitional movements (Section 2.2.18) will delve more into the cognitive load of these complex transitional movements.

2.2.13 Transitional Movements and the Risk of Falling

For stroke survivors the importance of being able to stand up from a seated position or to turn around becomes more apparent when the ability deteriorates and manifests as decreased mobility-related QoL and increased risk of falls (Cheng et al., 2000; Weerdesteyn et al., 2008). Several studies have demonstrated that falls in stroke survivors often occur during ambulation (Weerdesteyn et al., 2008; Nyberg et al., 1995; Forster & Young, 1995; Soyuer and Ozturk, 2007; Baetens et al., 2011). Others have found that the risk of falling in stroke survivors is even higher during transitional movements like turning and transfering between sitting and standing postures (Cumming et al., 1994; Nyberg et al., 1995; Hyndman et al., 2002; Yu et al., 2021 Simpson et al., 2011; Soares et al., 2019). This suggests that movements that require balance, especially dynamic postural control, are associated with a higher fall risk (Simpson et al., 2011).

One other explanation for the higher fall risk during transitional movements are that these transfer tasks have greater attentional demands or cognitive loads due to the complexity of the movement. It is stated that one reason why people often fall is when they are placed in situations that require more or divided attention (Hofheinz et al., 2016; Beauchet et al., 2009; Faulkner et al., 2007; Montero-Odasso et al., 2012; Quinn and Horgan, 2013; Plummer D'Amato et al., 2010). Accordingly, falls are more likely to occur when one is moving between positions, or while executing an additional cognitive or motor task concurrently with another motor task, like dual-task conditions, which occurs in everyday life (Plummer-D'Amato et al., 2010; Hollands et al., 2014; Muir-Hunter & Wittwer, 2016).

When considering turning, specifically, research shows that turning-related falls are common in stroke survivors (Hollands et al., 2010; Simpson et al., 2011; Manaf et al., 2012) especially among community-dwelling chronic survivors (Hyndman et al., 2002; Roerdink et al., 2007; Manaf et al., 2012). In addition, falls during turning are also eight times more prevalent as well as likely to cause injury than during straight-walking activities (Chan et al., 2017; Hyndman et al., 2002). Some researchers have found that turning towards the affected paretic side always results in more falls compared to the unaffected side (Mackintosh et al.,

2005), while others have found that the turning side has no bearing on the fall risk (Soares et al. 2019)

Since stroke survivors are at a high risk of injury from falling, studies have assessed the components of turning, which influence fall risk following stroke (Hollands et al., 2010; Lam et al., 2009). Possible theories to explain the mechanism of falling during turning movements has been attributed to the delayed initiation of turns that has been linked to attentional demands (Hollands et al., 2014). Other stroke-related studies have supported the high attentional load and complexity of turning tasks. For instance, Yu et al. (2021) found that hemiplegic stroke survivors with poor cognition had a greater risk of fall during turning or stand-to-sit movements then those without cognitive impairment. The risk of fall is increased due to the complexity of the transitional movements and then compounded by the cognitive impairment (Hollands et al., 2014).

More specifically, Cheng et al. (1998), investigated factors that contributed to fall risk during rising and sitting tasks. The researchers showed that rate of rise in force was lower in stroke fallers compared to stroke non-fallers and that stroke fallers demonstrated more in mediolateral postural sway during rising (sit-to-stand) and during sitting down (stand-to-sit) compared to stroke non-fallers or healthy adults.

Therefore, in addition to the complexity of transitional movements which adds to the risk of falling, these change in direction and transfer movements are likely attributed to impairments in postural control (orientation and stability, reduced strength, motor coordination in survivors (Simpson et al., 2011; Manaf et al., 2012; Soares et al., 2019).

2.2.14 Assessing Transitional Movements

2.2.14.1 Five times sit-to-stand test (5TSTS)

The sit-to-stand test is used as a measure of lower limb strength (Mentiplay et al., 2020), and is commonly included in fall risk assessment scales (Belgen et al., 2006; LeBrasseur et al.,

2006). The time taken to perform a single sit-to-stand task has also been used in assessment scales (Berg et al., 1989; Judge et al., 1996) as a measure of functional mobility, balance (Whitney et al., 2005) and lower limb strength. Since the abovementioned measurements are affected in post-stroke individuals; showing deficits in performance of such tasks when compared to healthy controls, supports the use of the 5TSTS as a multi-dimensional tool.

2.2.14.2 360-degree turn test

The 360-degree (°) turn test is a measure of dynamic balance and transitional movement. Since postural control and balance are impaired following stroke, this is an area which requires attention within the stroke population. Common testing of turning ability has been done using 180° turns in tests such as the timed up and go test. However, considering that certain daily tasks require one to turn 360° such as manoeuvring around the kitchen or turning in the shops when placing items in the trolley, the 360° turn test has recently been a topic of interest amongst research on transitional movements, particularly among the elderly, and those with neurological injury, who have a higher risk of falling. A study performed by Shui et al. (2016), confirmed that the timed 360° turn test demonstrated excellent inter-rater, interrater, and test-retest reliability for turning toward the affected side and the unaffected sides. The cut off times discriminated well between healthy older adults and stroke survivors for turning toward the unaffected side and the affected side. Furthermore, turn times correlated significantly with Fugl-Meyer assessment of the lower extremity (FMA-LE) scores, five times sit-to-stand times, gait speed, and TUG times.

2.2.15 Dual-task Paradigm

The dual-task paradigm refers to a procedure used to assess one's behaviour, as they perform two separate tasks simultaneously (Watanabe and Funahashi, 2018). These models explain the possible mechanisms underlying attention and the performance of individuals as they engage in dual-tasks. It is important to note two concepts which are used within dual-task research, to explain whether performance deteriorated, or was enhanced due to the addition

of either a motor or cognitive secondary task. These refer to dual-task interference (DTi) and dual-task gain (DTg).

Dual-task interference (DTi)

This term is used to describe the phenomenon where the addition of a secondary task to the primary motor task causes a deterioration in one or both tasks (i.e reduced performance) compared to the primary task being performed alone (Plummer et al., 2016). This is due to competing demands for attentional resources (Yogev-Seligmann et al., 2008), especially when both tasks exceed the person's total attentional capacity.

Dual-task gain (DTg)

In contrast to DTi, DTg refers to an improvement in performance, when a secondary task is added to the primary motor task.

Types of DT's

- DTCM: Cognitive-motor DT's refer to the performance of a motor task with an added cognitive task. Research on stroke survivors investigating CM conditions have included a variety of CM tasks such as walking or balance exercises with added cognitive tasks such as: serial subtraction in 3's (Hollands et al., 2013; Mori et al., 2018; Lui et al., 2018), serial subtractions in 7's (Ohzuno and Usada, 2019; Yang et al., 2018; Al-Yahya et al., 2016), Naming items on a shopping list (Kizony et al., 2010), reaction time tasks (Patel, 2014), a stroop test (Smulders et al., 2012).
- DTMM: motor-motor DT's include the performance of two motor tasks at the same time, with separate goals such as walking while carrying a cup of water (chan et al., 2017), walking while holding a tray (Negahbaan et al., 2017), or carrying a tray of glasses (Yang et al., 2007).

2.2.16 Dual-task models

There are three main models used to explain dual-task related behaviour (Table 2.1)

Table 2.1 Various Dual-task models explained.

Name of Model	Model description
Central capacity sharing theory	Maintains the idea that dual-task interference is due to an individual's limited attentional capacity. For example, when a person engages in dual-tasks, attentional resources will be distributed between tasks in a systematic order (Friedman et al., 1982) i.e., task 1 and task 2 must share the available processing capacity, based on a parallel mediator. Thus, the amount of attention paid to each individual task is reduced, causing deterioration in one or both tasks (Bayot et al., 2018). Furthermore, this theory suggests that when the presentation of the two stimuli is reduced, the processing period is increased (whereby the capacity is shared between two tasks), and this results in an increase in the time required to process the DT. Lastly, this theory believes that there is one mental, central resource responsible for performance decrements, where an extension of this theory believes that task processing requires multiple types of resources (known as the multiple resources theory; see below).
Multiple resources theory	This theory suggests that humans have a distinct number of attentional resources available to complete a task. Thus, there is a communal pool of resources which is used for various types of task processing. Furthermore, this theory explains that if two tasks require the same resources (i.e., two similar tasks are performed) to complete them, excess required resources will occur, thus resulting in an interference (Wickens et al., 2002).
The bottleneck theory	States that task performance on one or both tasks is deteriorated due to serial processing deficits (Bayot et al., 2018). Thus, when two tasks require the same neural processors or if the networks overlap in completion of both tasks, the specific neural processor can only work on one task at a time. This results in a bottleneck effect (Bayot et al., 2018; Leone et al., 2017), displayed by deterioration in one or both tasks.

2.2.17 Prefrontal Cortex and Dual-tasking

Dual-tasks often result in deteriorated performance as each task competes for attentional resources in the brain. Looking more specifically at the areas of the brain involved in DT performance, functional imaging research has reported mixed results, however, a number of studies have reported that dual-task performance results in the recruitment of the prefrontal region of the brain (Desposito et al., 1995; Colette et al., 2005; Dux et al., 2006; Tombu et al., 2011; Szameitaz et al,. 2016).

The PFC is associated with EF, attention, memory, and emotion, along with various other complex cognitive functions (Gray et al., 2002; Miyake et al., 2000; West, 1996). Furthermore, research suggests that these cognitive aspects decline with increasing age. This decline with aging has largely been associated with the disuse of specific cognitive functions, as well as reduced brain activity (Scarmeas et al., 2004). Thus, research has suggested that enhancing the activity in the PFC could help control these age-related adaptations that occur in the brain.

An area of interest, when looking at the PFC, is the adaptations that occur while persons engage in DT activities. With reference to research on stroke survivors, 5 studies have looked at brain activation during dual-tasking; all of which assessed cerebral hemodynamics during gait (AlYahya et al., 2016; Mori et al., 2018; Liu et al., 2018; Hawkins et al., 2018; Hermand et al., 2019).

Al-Yahya et al. (2016), found that during DT gait (with a cognitive task), PFC activation increased, shown by increased HbO_2 and decreased HbR. This contrasts with Hermand et al. (2019), who indicated an increase in HbO_2 during walking, which was not further increased with an added cognitive task. Furthermore, Liu et al. (2018), assessed brain activation during single-task (ST), DTCM and DTMM task walking by means of HbDiff. In his study, it was found that during the DTCM walking task, the affected side of the PFC showed significantly greater increases when compared to ST walking. Furthermore, Mori et al. (2018), compared PFC activation between healthy adults and chronic stroke survivors, and found decreased PFC activity in the latter. This is the opposite to Hawkins et al. (2019), who reported the greatest increase in HbO_2 in chronic stroke survivors during DT walking, when compared to healthy elderly.

Thus, there is evidence that DT gait related activities result in altered PFC activation in stroke survivors. However, the abovementioned differences further highlight the need for the current study exploring DT, and the effects of DT on PFC activation, particularly in a population who find DT activities challenging.

2.2.18. Dual-tasking and Transitional Movements

A study performed by Hollands et al. (2014), aimed to determine the effects of increased cognitive demands on stepping patterns while turning in stroke survivors and healthy, age-matched older-adults. More specifically, to observe the effects of cognitive-motor interference (CMI) on the stepping patterns during turning to identify possible biomechanical mechanisms for falls during turning. The results indicated that both groups took longer, were more variable, tended to widen the second step and, increased single support time on the leg ipsilateral to the turn when distracted. This supports the hypothesis that control needed for turning certainly requires cognitive resources (Takei & Amorim, 1995; Takei *et al.,* 1996), and can identify changes to stepping patterns which may underlie increased falls risk during turning in older-adults and stroke survivors.

Moreover, this is similar to Chan et al. (2017), who also assessed single and dual-task turning in chronic stroke survivors, with an added cognitive task (the stroop test) and found similar results. Specifically, this study reported that during the performance of both the single- and dual-task, stroke survivors displayed substantially longer reaction time and lower accuracy. This, while taking more steps, longer to turn, and requiring more time to complete the turning- while-walking task, under both ST and DT conditions. Again, this highlights the involvement of cognitive control in turning transitions (Takei & Amorim, 1995; Takei et al., 1996).

Furthermore, Manaf et al. (2016), assessed dual-task turning in stroke survivors to define difficulty in turning characteristics employed by this population when placed in attention demanding situations. Results indicated staggering during turning, increased number of steps

in stroke survivors (taking more than 5 steps to turn), longer time to turn, and a mixed turn strategy used by stroke survivors. The variables assessed in the above-mentioned studies indicate that turning is challenging for stroke survivors, leading to deterioration in performance shown by increased number of steps used, altering of turn strategies, as well as taking longer time to turn, when compared to controls.

Focusing on the sit-to-stand movement, Palanisamy et al. (2019), assessed the sit-to-stand performance of stroke survivor's using ST and both a cognitive, and motor DT. This was done to investigate whether performance during DT's correlates with one's trunk impairment. The results showed a significant difference across the three conditions, with evidence to suggest that during the 5TSTS, there is a deterioration in the performance of stroke survivors when placed under DT conditions. Furthermore, associations between performance and trunk impairment were evident, highlighting that those who took longer times to perform the 5TSTS, also required more time to prevent excessive sway and stabilize their centre of mass. Consequently, this study confirmed that both the addition of cognitive and motor tasks lead to task distraction in individuals, resulting in a decline in performance.

It is evident that dual-tasking results in deterioration of performance in chronic stroke survivors, which results in destabilized performance of transitional tasks. Thus, these tests are effective in outlining the compensations that are employed under attention demanding situations, or during task with which a person has limited attentional capacity.

2.2.17 Summary

Therefore, in summary, the abovementioned chapter has outlined that the occurrence of stroke is on the rise, particularly in developing countries like South Africa. Moreover, due to this increase, there will be additional stroke survivors living with long-term motor and cognitive impairments, into the chronic stroke phase. These individuals will require treatment from various health professionals, particularly regarding the regaining of functional independence to effectively engage in ADL's.

It is evident that when placed in attention demanding situations, this population struggle to maintain postural control, which destabilizes their performance during transitional tasks. Thus, research on the types of dual-tasks that cause this deterioration in performance might be beneficial in the development of effective treatment and assessment strategies that are supported by scientific evidence. Furthermore, studies have focused on the effects of dual-task walking and turning on cognitive-motor interference and have neglected the performance of motor tasks with secondary motor tasks (i.e, motor-motor interference). This highlights the necessity for research assessing both cognitive and motor dual-tasks during the performance of transitional movements such as turning, sit-to-stand and stand-to-sit.

Lastly, research has focused on the PFC during DT gait and balance related activities in chronic stroke patients, however, have neglected assessing brain activity during sit-to-stand, stand-to-sit and in-place turning. Considering the importance of such movements in daily life, as well as stroke survivors' struggles with performing DT, assessing cortical activation simultaneously while measuring spatiotemporal parameters could provide valuable information regarding the neural basis underlying complex tasks. As mentioned previously, this information is important for goal-directed rehabilitation.

CHAPTER THREE

Problem statement

3.1 The problem in context

Throughout day-to-day living, people perform a variety of transitional movements (TM) (e.g. turning, sitting down, or standing up) as they navigate their environments. On average, 35% to 45% of our daily steps occur while turning (Glaister et al., 2007). Furthermore, on average, people perform 45 sit-to-stands per day (Bohannon et al., 2015). However, despite the regular involvement of TM in everyday life, these specific transitional positions have not been extensively studied when compared to straight walking (Bayot et al., 2018; Palanisamy & Regan, 2019). Additionally, TM are complex and require greater cognitive and attentional demands in stroke survivors (Chan et al., 2017; Palanisamy & Regan, 2019), i.e., requiring sufficient executive functioning (EF). Executive functioning includes high-level cognitive abilities essential for performing complex and novel tasks, which mainly refers to attention, planning, problem-solving, multitasking, and behavioural control (Lipskaya-Velikovsky et al., 2018). Transitional movements are not automatic and have been associated with greater postural instability in stroke survivors (Chan et al., 2017; Palanisamy & Regan, 2019). This makes these movements even more challenging, since one of the major consequences following stroke relates to deficits in EF (Poulin et al., 2012; L.A et al., 2007; Park & Lee, 2018). Thus, EF is required to successfully perform activities of daily and independent living, especially with regards to allocating the applicable attentional resources required to perform motor tasks effectively and accurately.

This is relevant to daily life, particularly when attention must be allocated towards completing more than one task simultaneously (Chan et al., 2017) (referred to as dual-tasking (DT). Moreover, the performance of DT often occurs while people move between positions, for example, walking while simultaneously performing another task such as carrying something (Chan et al, 2017), taking money out of a wallet or talking on the phone. In general, stroke survivors show deficits in divided attention and DT, due to the additional demand on their

already impaired walking ability (Lui et al., 2018). Furthermore, deficits in DT ability are linked to deficits in functional mobility in stroke survivors (Yang et al., 2007). Thus, adding a cognitive or motor task to a primary task leads to a deterioration of one or both tasks, measured as dual-task interference (DTi). Therefore, considering the importance of dual-task transitional movements (DTTM) in everyday life, and the deficits resulting from stroke, one's performance during DTTM can provide useful information with regards to one's capability of maintaining postural control when faced with attention demanding situations. Performing two attention-demanding tasks simultaneously not only results in attentional resources competing, but it also challenges the brain to prioritize between the two tasks.

The area of the brain involved in controlling one's EF (Doi et al., 2014; Borges et al., 2018; Liu et al., 2018), and consequently complex movements such as DT, is the prefrontal cortex (PFC) (Yr et al., 2007; Ohzuno et al., 2019; Cheng et al., 1998; Herold et al., 2017). Consequently, research has focused on neuronal activity within the PFC during DT balance and gait activities to explain the neuronal mechanisms underlying DT performance. Nevertheless, conflicting evidence displays the complexity of understanding neuronal activation in the PFC during DT. One view is that DT requires a higher cognitive load compared to when you perform each task separately. This refers to increased attentional demand, which require more cognitive function to successfully allocate attention to the various tasks at hand. This view supports that there is a separate brain region that is activated in the performance of DT, but not during each task alone (Doi et al., 2014). In contrast, other studies have reported that performing DT's does not activate additional brain areas relative to those activated during ST performance (Doi et al., 2014). Despite years of investigation on this topic, there is still limited understanding of the neurobiological basis underlying DT performance. This is further limited in stroke survivors and TM. Furthermore, research on motor-motor DT is limited to a greater extent than cognitive-motor DT.

Up to now, no study has investigated the PFC activity during complex TM in stroke survivors. However, twelve studies have been done to detect DT-related brain activity during lower limb

movements, seven using Near-infrared spectroscopy (NIRS) (Watanabe and Funahashi, 2017;D'Esposito et al., 2000; Tachibana et al., 2012; Kondo et al., 2004; Jaeggo et al., 2003; Szameitat et al., 2002; Holtzer et al., 2011; Poulin et al., 2012), two using fMRI (Ohsugi et al., 2013; Meester et al., 2014), and three using electroencephalogram (EEG) (Beurskens et al., 2014; Mirelman et al., 2014; Lamers et al., 2008). These studies included healthy participants with no neurological impairment and did not consist of TM as they only looked at gait. Furthermore, five studies have used NIRS to detect brain activity during single - and dual-task lower limb movements in stroke survivors (Johannsen et al., 2013; Poulin et al., 2012; Blumen et al., 2014). However, similar to before, the abovementioned studies focused only on DTi during gait.

There are different types of DT, namely cognitive-motor (CM) and motor-motor (MM) DT. The former refers to the addition of a cognitive task to the primary motor task (for example serial subtractions in 3's (Baetens et al.,2013; Lui et al., 2018; Chaikeeree et al., 2018), verbal fluency, such as listing animals (Baetens et al., 2013), or walking while shopping for items (Kizony et al., 2010)). The latter refers to the incorporation of a motor task to the primary motor task (for example carrying a glass of water (Chan et al., (2017), or a tray with glasses (Yang et al., 2007)). However, to date, limited studies on stroke survivors have compared the effects of both CM and MM DT conditions. Liu et al. (2018), compared the two DT during straight walking, and Manaf et al. (2016), compared CM and MM during the timed up and go (TUG) test. To date, a few studies have focused on DT turning in stroke survivors. These studies included chronic stroke survivors, most of which focused on the effects of DT on turning ability. However, a few studies (Manaf et al., 2016; Chan et al., 2017) explored turning using the TUG and other straight walking while turning tasks (Chan et al., 2017), which included the assessment of a 180-degree turn. Additionally, some studies assessed turning at a 90-degree angle (Hollands et al., 2002; Hollands et al., 2014). From the above-mentioned studies, only one explored DT turning comparing both a MM and CM DT (Manaf et al.,2016), which included turning with a glass of water (MM task) and turning with serial 3 subtraction task (CM task). However, as mentioned before, this study assessed a 180-degree turn. Thus, although research has to some degree explored DT turning in stroke survivors, there is a lack

of research comparing the two DT conditions during a 360-degree turn. Furthermore, these studies did not assess PFC activation during TM.

Therefore, this study endeavoured to determine the PFC activation during two types of DT conditions in chronic stroke survivors.

3.2 The Purpose of the Study

One may consider that DTTM, such as turning (Manaf et al., 2012) and sit-to-stand (Palanisamy et al., 2019) are important components of a person's everyday life, and are therefore essential for independent mobility. Hence, assessing neuronal activity during TM seems plausible for our understanding of the neural basis underlying the recovery of motor and cognitive abilities following stroke. Furthermore, this comprehensive understanding can be used in rehabilitation practices to optimize performance outcomes.

In general, rehabilitation for chronic stroke survivors needs to promote neuroplasticity to improve motor function (Pin-Barre & Jerome, 2015). As a result, research that aims to develop innovative therapies that enhance neuroplasticity is conducted to allow rehabilitation of these patients (Dimyan & Cohen, 2011). Furthermore, designing programmes that optimize movement patterns may benefit stroke survivors in the activities of daily living. Therefore, the advancement of our understanding of the neuroplastic changes that occur with post-stroke motor impairments, as well as a better understanding regarding instructions that affect task complexity and DTi, are aspects to consider for stroke rehabilitation. Since DT have been shown to destabilize motor performance in stroke survivors, and increase PFC activation during DT gait, assessing this phenomenon during TM used daily in this population may provide useful information regarding one's capabilities with everyday DTTM tasks. This information could guide future research on therapeutic interventions for chronic stroke survivors and enhance the understanding of the neural basis underlying DT performance in everyday life.

Therefore, the purpose of this cross-sectional study was to determine the effects of two types of DT conditions (i.e. CM and MM) on PFC activity during select transitional movements (i.e. turning, sit-to-stand, and stand-to-sit) in chronic stroke survivors. Considering that previous gait research indicated that DT walking elicits greater neuronal activation in the PFC than single-tasks, assessing this relationship during both turning and sit-to-stand movements may enhance current knowledge of the neural mechanisms of DT performances. This is especially of interest within a population who show deficits in EF and motor function. Consequently, understanding these neural mechanisms will provide insights into the designing of future intervention studies regarding DT complexity, as well as be used as potential assessment methods for postural control deficits and functional mobility.

3.3 Hypothesis statement

It is hypothesized that if chronic stroke survivors engage in DT activities, then there will be an increase in CM and MM DTi, as well as an increase in relative oxygenated haemoglobin (ΔHbO_2) and reduced deoxygenated haemoglobin (ΔHbR) in the PFC. The latter, because of the increased cognitive demand of DTTM requiring greater attentional resources, that leads to the activation of brain regions involved with EF; including the PFC. It is expected that motor performance outcomes during DTTM will show decrements (i.e. take longer time to complete, and display reduced efficiency), in response to attention demanding tasks.

3.4 Research Aims and Objectives

3.4.1 Aims

Primary aim:

The main aim was to investigate the effects of prefrontal cortical activation (via cerebral hemodynamics) during the single-task (ST), dual-task motor-motor (DTMM), and dual-task cognitive-motor (DTCM) conditions of chronic stroke survivors while carrying out select transitional movements (i.e., turning, sit-to-stand and stand-to sit).

Secondary aims:

Furthermore, the secondary aims of the study were to assess DTi during DTCM and DTMM TM; as well as to describe any differences in PFC activation between the four PFC sites (i.e., Dorsolateral prefrontal cortex, Ventrolateral prefrontal cortex, Frontopolar prefrontal cortex, and Orbitofrontal prefrontal cortex), while comparing affected and unaffected sides in chronic stroke survivors.

3.4.2 Research objectives

To answer these research aims, the study collected the following information:

1. Prior to the STTM and DTTM protocols:
    - 1.1 Screen for global cognitive functioning (Montreal cognitive assessment), medication use and medical history, severe depressive moods (9-item participant health questionnaire), and physical activity status (rapid assessment of physical activity) as confounding variables.
    - 1.2 Collect descriptive information about participants, i.e., age, sex, height, weight, time since stroke, number of strokes, affected side, lower extremity functional performance (Fugl-Meyer assessment of lower extremity), functional capacity (2-minute walk test), fear of falling (fall efficacy scale international) and fall risk (Peninsula health fall risk assessment tool), perceived health-related quality of life, Trail maker test (TMT) and classify functional ambulation level.
    - 1.3 Collect resting (baseline) oxygenated and deoxygenated haemoglobin levels.
2. During transitional tasks performed under ST and both DT conditions, i.e., sit-to-stand, stand-to-sit, and turning:
    - 2.1 PFC activation via cerebral oxygenation measures:
        - Calculate relative concentrations of oxygenated and deoxygenated haemoglobin (Δ HbO_2 and Δ HbR)
        - Calculate relative haemoglobin difference (cerebral oxygenation index i.e., Δ HbDiff)

2.2 Kinematic behavioural measures of transitional movements During the five times sit-to-stand test:

- Time to complete the test (seconds)
- Lean angle (degrees)

During the 360-degree turn test:

- Time to complete the test (seconds)
- Turn velocity (degrees/s)
- Turn angle (degrees)

2.3 Correct response rate (CRR) during DTCM trials

2.4 Water spills during the DTMM trials 2.5 Calculate % DTi for TM.

Independent variables

- Single- and both DT conditions during the five times sit-to-stand and 360-degree turn tests, respectively.

Dependent variables

Outcome variables include:

Primary:

1. The PFC activation during sit-to-stand, and turning movements:
    - Relative changes in concentrations of oxygenated (ΔHbO_2)
    - Relative changes in deoxygenated haemoglobin (ΔHbR)
    - Relative differences in haemoglobin (ΔHbDiff)

Secondary:

2. Kinematic behavioural transitional movement measures
    - Time to complete the test (s)
    - Lean angle (degrees)
    - Turn velocity (degree/s)
3. Dual-task interference (DTi)

4. Performance during the CM tasks measured by correct response rate (CRR) and measured by water spillage for the MM tasks.

Confounding Variables

- Severe cognitive impairment (Li et al., 2019)
- On unstable medications (change in medications within the previous 4 weeks) (Hammash et al., 2013)
- Depressive moods (Lui et al., 2014; Zhu et al., 2017)
- Stroke lesion (Site of lesion and number of lesions) (Goodin et al., 2018)
- Socio-economic status (Hackman et al., 2015)
- Physical activity status (Talamonti et al., 2021)

CHAPTER FOUR

Methodology

4.1. Study Design

This is a cross-sectional randomised within-subject quasi-experimental study design (Figure 4.1), whereby participants' prefrontal cortical (PFC) activity was observed while performing transitional movements (TM) (specifically (in-place) turning, sitting to standing, and standing to sit), during single-task (ST) and two types of dual-task (DT) conditions (i.e., motor-motor DTMM) and cognitive-motor (DTCM)) in a randomise order. Participants acted as their own control.

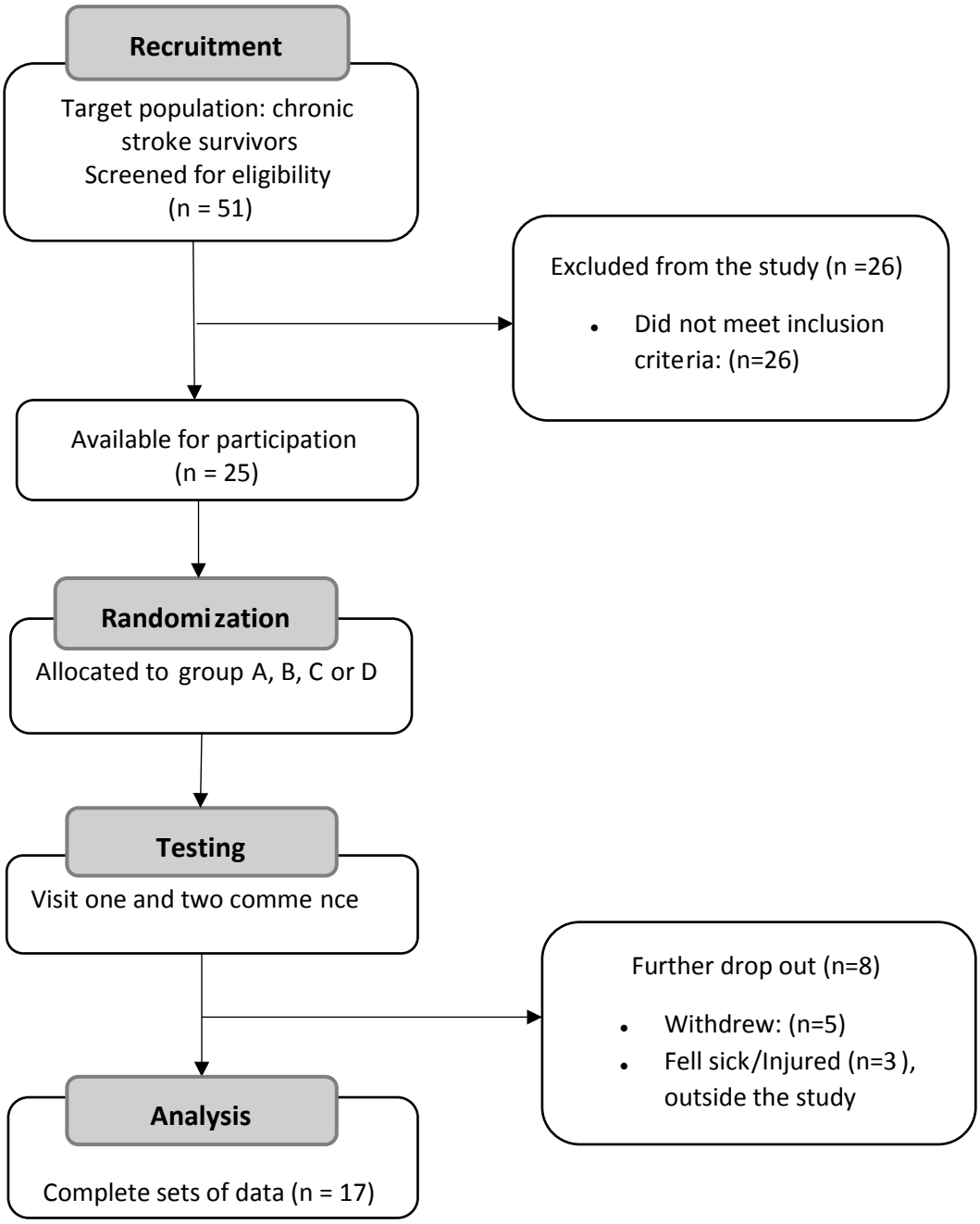

Figure 4.1. Illustration of the study design.

4.2. Ethics

Ethical clearance for this study was received from Stellenbosch University's Health Research Ethics Committee (HREC) (ethics number S18/06/122) (Addendum A: approval letter). Only once approval was received, recruitment of potential participants commenced. The

researcher adhered to the ethical principles as stipulated by the Declaration of Helsinki as well as the South African National Health Act. (No. 61 of 2003).

4.3 Participants

In accordance with previous DT studies that included chronic stroke survivors, the participants recruited were men and women who had experienced at least one stroke event, six or more months (Pang et al., 2018; Yang et al., 2018; Liu et al., 2018) prior to recruitment. Additionally, participants were required to reside within the Western Cape, within a 70-kilometer radius of Stellenbosch University.

4.4. Inclusion and Exclusion criteria

To participate in this study, it was required that individuals:

- Were older than 18 years of age.
- Experienced a stroke ≥ 6 months ago (Pang et al., 2018; Yang et al., 2018; Liu et al., 2018)
- Were cleared for exercise by primary physician or neurologist.
- Were able to ambulate (with or without assistive devices) for at least two minutes at a self-selected pace.
- Were able to stand up from a chair and sit back down again without assistance from another human being.
- Were able to communicate, understand and respond to instructions.

Participants were excluded from the study under the following circumstances:

- Severe global cognitive impairment (<18 on the Montreal Cognitive Assessment; MoCA). A study including stroke survivors (Salvadori et al., 2013), found a cut-off score of 18 to have 77.1% sensitivity, 87.9% specificity, and 87.1% positive predictive value. Thus, by this, participants had to obtain a total MoCA score of ≥18 to participate in the study.
- Individuals with a history of epilepsy and/or seizures. Poor frontal lobe functioning has been noted in children and adolescents with temporal lobe epilepsy (Igarashi et al.,

2002; Rzezak et al., 2007), as well as in adults (Takaya et al., 2006; Braakman et al., 2011). Furthermore, impaired executive function and structural changes in the frontal lobes and thalami have been demonstrated during the initial stages of epilepsy onset (Pulsipher et al., 2009).

- Current smokers, and individuals who had smoked within the last six months. Studies confirm altered neural activation in smokers when compared to non-smokers. (McClernon et al., 2004; Brody et al., 2006; Sutherland et al., 2011; Janes et al., 2012; Froeliger et al., 2013; Wang et al., 2017). Furthermore, studies have established that components of executive functioning (EF), including working memory (WM) performance is reduced in smokers, when compared to non-smokers (Ernst et al., 2001; Jacobsen et al., 2005; Jacobsen et al., 2007; Greenstein & Kassel, 2009). Based on previous studies' definitions of non-smokers in the field of brain research, it was decided to exclude any individual who had smoked a cigarette within 6 months before recruitment (Froeliger et al., 2013).
- Individuals on unstable medication (defined as changes in medication in the last four weeks). Previous literature (Hammash et al., 2013) defined stable medication as those being taken for at least four weeks.
- Diagnosed with depressive moods or scoring ≥ 10 on the 9 item Patient Health Questionnaire (PHQ-9). According to previous research (De Man-Van Ginkel et al., 2012), the cut-off score for this assessment is 10, with 100% sensitivity and 86% specificity. Furthermore, various studies have used a score of ≥ 10 to distinguish those with major depression (Kroenke et al., 2001; Watnick et al., 2005; Martin et al., 2006), including those with stroke (De Man-Van Ginkel et al., 2012; Janes et al., 2012). Moreover, previous research on stroke survivors has made use of the PHQ-9 as an assessment tool to screen for post-stroke depressive moods (Williams et al., 2005; Kandiah et al., 2011; De Man-Van Ginkel et al., 2012). The importance of screening for depressive moods can be attributed to literature confirming that individuals with major depressive disorders display decreased functional activity and disrupted neural networks in the PFC measured by the functional near-infrared spectroscopy (fNIRS) (Liu et al., 2014; Zhu et al., 2017).

- Individuals who experience aphasia, or who were unable to understand and/or correspond to instructions. It was acknowledged that such individuals would be unable to successfully complete the DT transitional tests, which required verbal response under the cognitive-motor (CM) DT test condition. Furthermore, this is in accordance with previous DT studies utilizing verbal serial subtractions as the cognitive task, whereby persons who experience aphasia were excluded from participating. (Bensoussan et al., 2007; Smulders et al., 2012; Sasaki et al., 2014; Ohzuno et al., 2019).

4.5. Sampling

This study followed a convenience sampling method. Participants were recruited from stroke support groups, retirement villages, as well as medical facilities within the Western Cape.
A priori sample size estimation was determined using G*Power software version 3.1.9.4 (Faul et al., 2007), based on the HBO_2 and trunk linear acceleration results of Mori et al. (2018). The power analysis indicated a total of 9 participants were needed per condition (alpha = 0.05, power 95%, Effect size η2 = 0.34); however, to maximize power for the secondary analyses, the sample size was doubled to 18 participants. Staying mindful that Mori et al. (2018) investigated PFC with fNIRS in chronic stroke survivors during a cognitive-motor DT gait activity. At the time of this sample size estimation there was no study that has looked at dual-task and PFC during TMs. Following recruitment and assessment of participant's eligibility for the study, a total of seventeen participants' data was analysed (Figure 4.1).

4.6. Randomisation

Randomisation was performed using a balloting process. Group A, B, C, and D were printed onto rectangle pieces of paper 15 cm x 10 cm and placed inside of a box (Figure 4.2). For each participant, a piece of paper was randomly balloted from the box, determining which sequence of conditions the participant was assigned to. Additionally, the starting numbers used for the DTCM followed the same procedure, whereby for each participant numbers were randomly

drawn from the box (Figure 4.3) to determine the sequence of numbers used for the DTCM condition (3 for the five times sit-to-stand and 3 for the 360° degree in-place turn test).

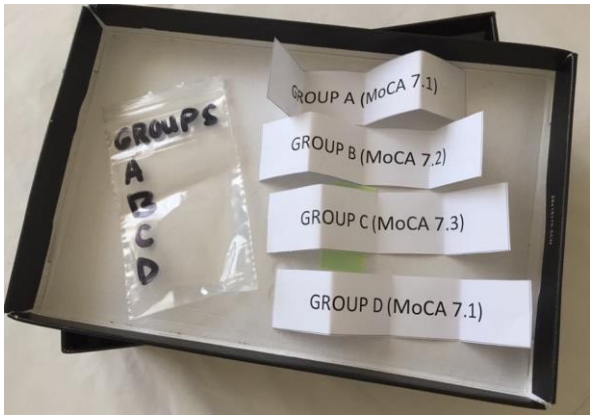

Figure 4.2 Randomisation of Sequence Photos by Taylia Webber (with permission to use)

Figure 4.3 Randomisation of numbers.

4.7. Research protocols and procedures

All assessments used for both the screening and the testing protocols were conducted within similar testing environments by the same researchers. All researchers involved in screening and data collection were competent in the administration of these screening and testing measures and completed all necessary training required for the successful administration of tests. Researchers conducting each test, as well as the controlling of equipment remained consistent throughout the testing of all participants. All researchers involved in screening and collecting data had sufficient experience within their field of duties. This study consisted of a screening visit (Visit 0) and an additional three visits (Figure 4.4, 4.5, and 4.6). Visit zero (screening).

The screening visit entailed a telephone call or communication via email to determine whether the participant met the necessary inclusion or exclusion criteria for the study (Figure 4.5). In certain instances, screening also took place at various stroke support groups within the Western Cape. Following a conversation with the potential participant, it was determined whether the individual met the inclusion criteria for the study and whether they were interested in participating. Hereafter, the researcher either set up an appointment for visit 1

(via telephone or email) or obtained the contact details of the participant (at stroke support group) to later finalize a time that would suit both the researcher and the participant for visit one.

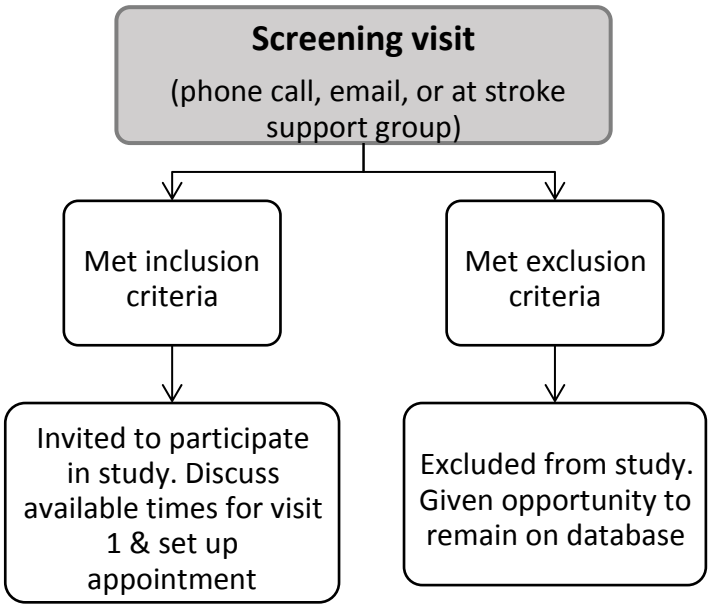

Figure 4.4 Screening visit illustration.

Visit one

Visit one commenced with the explanation of the informed consent form (ICF) (Addendum B), and by obtaining consent. Thereafter, personal, stroke-specific as well as fall history information was collected through an interview format. This was followed by the rapid assessment of the physical activity questionnaire (RAPA) and the PHQ-9 (to screen for physical activity status and depressive moods, respectively). Following this, the researcher randomly balloted a piece of paper (Marked A, B, C, or D) from a box, to determine which sequence the participant was assigned to, and consequently which version of the Montreal cognitive assessment (MoCA) was to be performed. Thereafter, screening for global cognition was performed using the MoCA, as either version one, two, or three, depending on which paper was randomly balloted out of the box. The group letter also determined the order of test conditions (Table 4.1) for visit three (providing that they met the cut-off score for the MoCA to progress to visit 3). Study participants received the MoCA in their home language. Lastly,

the stroke-specific quality of life (SSQOL) questionnaire was completed to determine participant's perceived quality of life.

Table 4.1 Respective sequence of conditions for visit 3.

Group	**A**	**B**	**C**	**D**
MoCA version	7.1	7.2	7.3	7.1
The sequence of tests (visit three)	ST DTCM DTMM	ST DTMM DTCM	DTMM DTCM ST	DTCM ST DTMM

ST: Single-task; DTMM: Dual-task motor-motor; DTCM: Dual-task cognitive-motor

The information and values obtained from the various assessments performed during visit one were used to screen individuals who met the inclusion criteria for the study. Only individuals who meet the cut-off score for the MoCA ($\geq$ 18) were invited to the second visit of testing.

Information collected during the first visit included the following:

- Personal information and medical history (Addendum C). This included age, date of birth, sex, level of education, home language, and previous rehabilitation.
- Stroke specific information included the number of strokes experienced, the time since stroke/s (in months), the affected side, and type of stroke (if known).
- Questions regarding the person's medical history were collected during this session and included any pre-existing medical conditions, previous admissions to the hospital and details thereof, the current use of medication, as well as any changes in medication use or dosage within the 4 weeks prior to visit one, and details of smoking history.
- A name and number of either a close family member or friend was obtained, for use in an emergency during testing sessions.

Visit two

This second visit started with the fall efficacy scale international (FES-I) questionnaire (Yardley et al., 2005) and the abbreviated mental test score questions which form part of the Peninsula health fall risk assessment tool (PH-FRAT) (Stapleton et al., 2009). Thereafter, the trail maker tests (TMT) part A and B (Gaudino et al., 1995) were performed to assess cognitive flexibility. Functional capacity was assessed through the two-minute walk test (Brooks et al., 2004), the Fugle-Meyer assessment (Park et al., 2014) of the lower extremity (FMA-LE), as well as the functional ambulation classification (FAC) (Viosca et al., 2005). Lastly, height and weight were measured to calculate the BMI score for each participant.

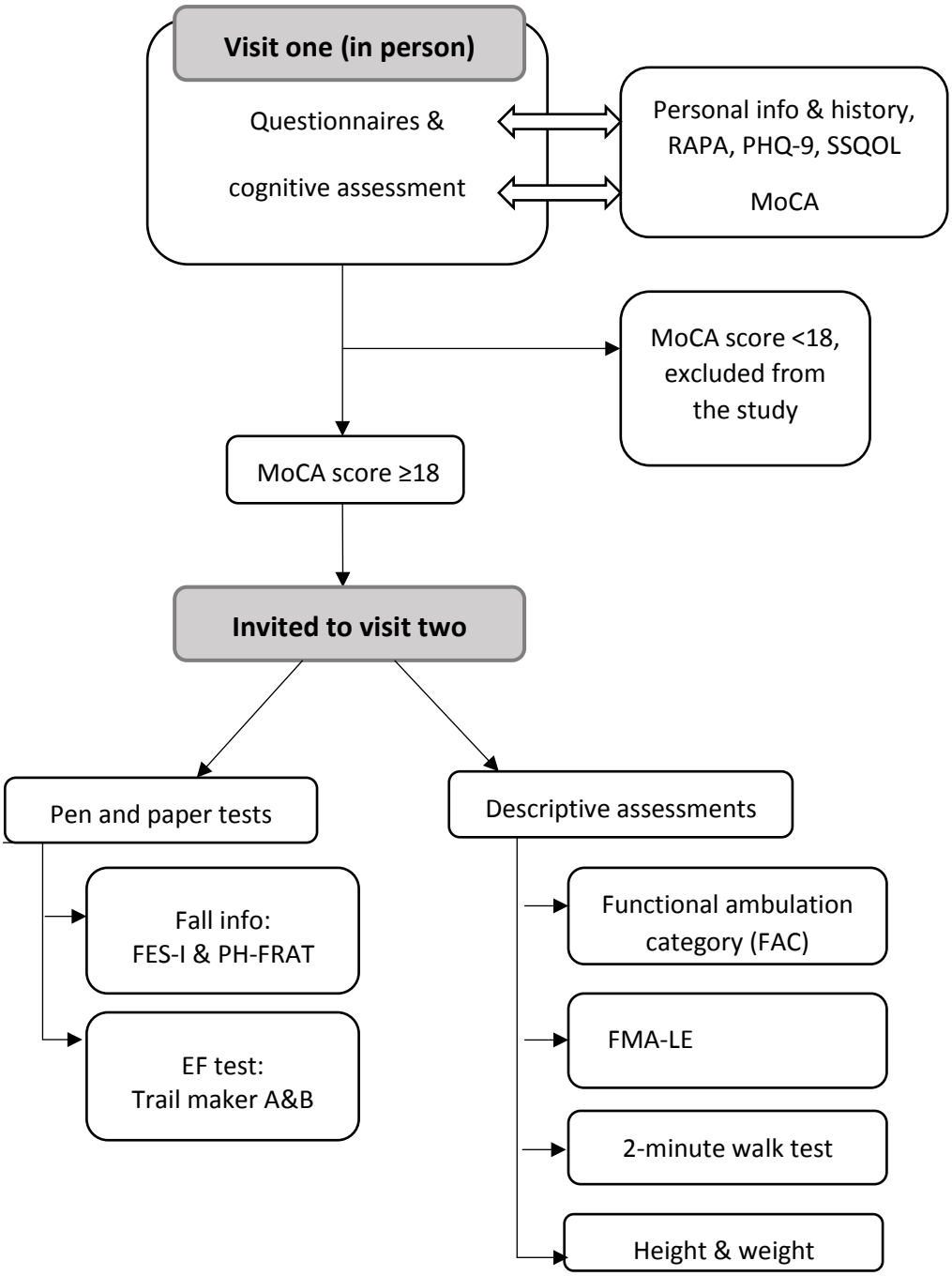

Figure 4.5. Testing procedures of visits one and two, which were conducted following the screening visit (visit 0).

MoCA: Montreal cognitive assessment
RAPA: Rapid assessment of physical activity
PHQ-9: Participant health questionnaire
SSQOL: Stroke specific quality of life scale
EF: Executive function
FES-I: Fall efficacy scale international
PH-FRAT: Peninsula health fall risk assessment tool
FAC: Functional ambulation classification
FMA-LE: Fugl Meyer assessment of the lower

Visit three

Prior to the testing, each participant was asked to sit quietly for 5 minutes. Thereafter, two blood pressure (BP) readings were taken, and the accelerometer and fNIRS equipment were applied to the participant (Mobility lab and Near-infrared spectroscopy system; NIRSIT), see Section 4.10). Testing commenced with baseline PFC activation being measured for 5 minutes. The participant was asked to sit quietly, with their eyes closed, and with as little movement as possible. Thereafter, this testing session comprised of testing the five times sit-to-stand (5TSTS) test and the 360degree in-place turn test, under single-task and two DT conditions: namely cognitive-motor (CM) and motor-motor (MM) DT conditions. Throughout the transitional movements (TM), PFC activation, as well as spatial-temporal gait variables, were measured.

Each TM consisted of three trials, under each condition. Thus, a total of 12 tests were performed by each person. For condition one (single-task), participants completed the 5TSTS test and the 360-degree in-place turn test, respectively. For condition two (DTCM), participants were given a random number between 50 and 100 and were required to verbally perform serial subtractions of 3's from that number, while completing the primary task. Lastly, condition three (DTMM) required participants to perform both the 360-degree turn, and 5TSTS test's respectively, while holding a plastic cup of water. An iPad was used to record the DTCM trials, whereby the footage was later reviewed, and correct and incorrect responses were documented, to determine the correct response rate.

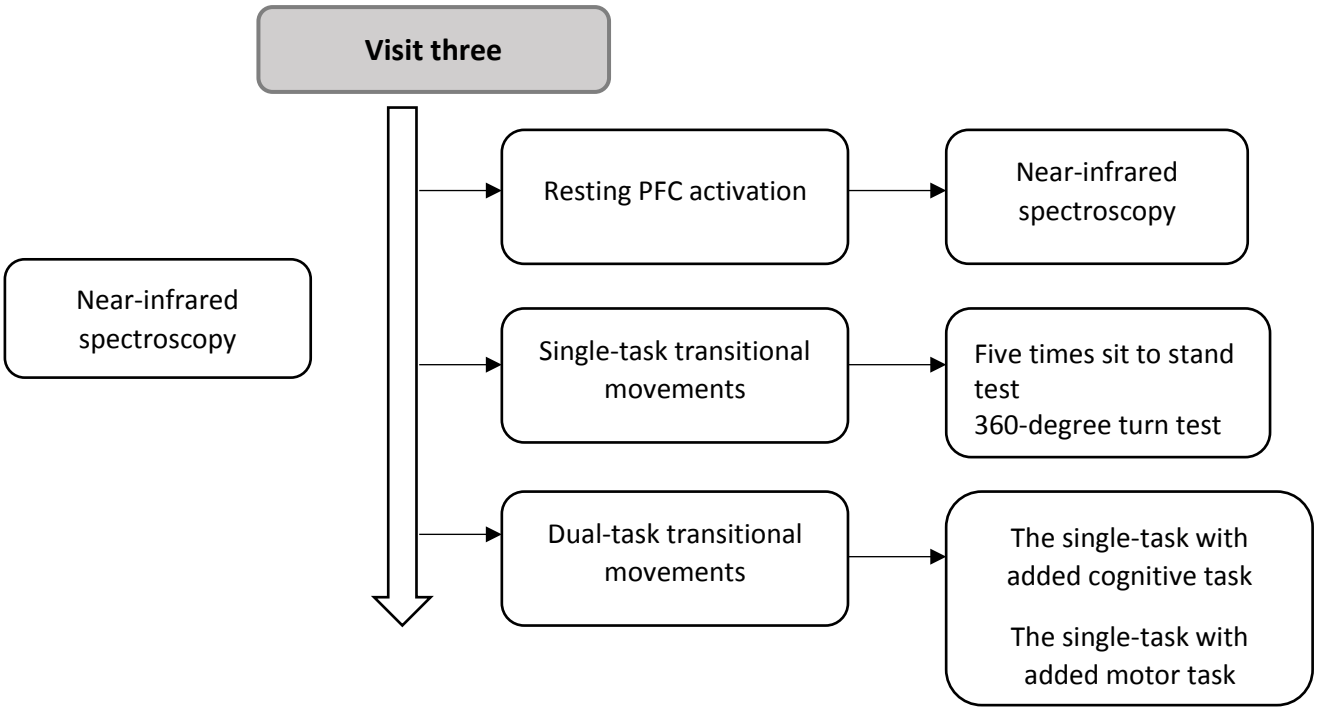

Figure 4.6 Illustration of visit three.

4.8. Tests and measurements

Screening Protocols & Tests:

Montreal Cognitive Assessment (MoCA)

The MoCA (Addendum D: 3 versions) is a simple screening tool first designed to identify mild cognitive impairment (MCI) among elderly persons in a memory clinic (Wong et al., 2015). It is now commonly used within research, particularly amongst neurological populations. The test is scored out of a total of 30 points, taking only 10 minutes to complete. The MoCA comprises sub-sections, evaluating various abilities, namely visuospatial abilities, executive function (EF), short-term memory recall, attention, concentration, working memory, language, and orientation to time and space (Chiti & Pantoni, 2014). Permission to administer the test was obtained from MoCA via email (See Addendum E). A systematic review conducted (Burton & Tyson, 2015) found that, when compared to other cognitive measurements, the MoCA was the most valid screening tool in the identification of stroke

survivors with cognitive impairments requiring further assessment. The MoCA is a reliable (r = 0.92) tool in the identification of MCI among stroke survivors (Nasreddine et al., 2005).

Furthermore, a study by Pendlebury *et al.* (2009) compared the MoCA with other forms of cognitive assessment and found that at both six months and 5 years following a stroke, the MoCA portrayed a better indication of cognitive impairment than the MMSE. The test shows good correlation, high sensitivity, and specificity in predicting post-stroke cognitive impairment (Chiti & Pantoni, 2014). Furthermore, previous studies including those with chronic stroke survivors (≥6 months post-stroke) have used the MoCA as an assessment tool to identify those with MCI (Hwang et al., 2013; Yang et al., 2016; Liu-Ambrose et al., 2015; Chiti & Pantoni, 2014; Pang et al., 2018; Yang et al., 2018; Pinter et al., 2016; Pendlebury *et al*.,2009; Wong *et al.,* 2013 & 2016). The MoCA was adjusted for age and education (Table 4.2) according to normative data from previous research (Malek-Ahmadi et al., 2015).

Table 4.2 MoCA age and education adjusted normative data.

	≤ 12 years	13 – 15 years	≥ 16 years
70 - 79	25.25 (4.11)	27.78 (2.24)	27.59 (2.04)
80 - 89	23.47 (2.97)	25.08 (3.13)	25.82 (2.75)
90 - 99	23.00 (2.63)	23.35 (3.43)	24.61 (2.59)

The Stroke specific quality of life scale (SSQOL)

It is well known that post-stroke impairments can lead to reduced health-related quality of life (HRQoL). Thus, the SSQOL (Addendum F) was developed and validated in 1999 (Wong et al., 2013) to provide health professionals with an instrument to assess the concerns which more specifically relate to those who have experienced a stroke. The test shows excellent test-re-test reliability (r = 0.92) (Williams et al., 2000), excellent inter rater reliability (r = 0.92) and significant predictive validity (Williams et al., 1999b).

The SSQOL scale is a 49-item questionnaire, consisting of questions that relate to 12 different domains including energy, family roles, language, mobility, mood, personality, self-care, social roles, thinking, upper extremity function, vision, and worker productivity. Participants are required to rate each question based on a 1-5-point Likert scale, answering based on their reflection of the previous week. Participants are to select the number that most closely resembles how they felt about various aspects of daily life (Table 4.3). Furthermore, participants have the option to respond from three different views: (1) the amount of help required to do specific tasks, (2) the amount of trouble experienced when attempting tasks, and (3) the degree of agreement with statements regarding their functioning. The results include scores for individual domains, as well as a total score out of 49, where higher scores indicate a greater quality of life.

Table 4.3. 5-point Likert scale used to score the SSQOL questionnaire.

Total help/Couldn't do it at all - **Strongly agree**	1
A lot of help - A lot of trouble - **Moderately agree**	2
Some help - Some trouble **- Neither agree nor disagree**	3
A little help - A little trouble - **Moderately disagree**	4
No help needed - No trouble at all **- Strongly disagree**	5

Patient Health Questionnaire (PHQ-9)

The PHQ-9 (Addendum G) (Kroenke et al., 2001) is a multipurpose tool used to monitor and measure the severity of one's depressive mood symptoms. It is a 9-item, self-administered questionnaire, based on the Diagnostic and Statistical Manual of mental disorders (DSM-IV) diagnostic criteria for depressive disorders. These include anhedonia (lack of pleasure in normally pleasing activities), depressed moods, trouble sleeping, feeling tired, changes in appetite, feelings of guilt or worthlessness, trouble concentrating, feeling either slow or

restless, and suicidal thoughts. The PHQ-9 measures the frequency of each symptom experienced by the participant over the previous 2 weeks and this is processed into a scoring severity index. A follow-up question indicates the extent to which the depressive tendencies affect the individual's level of daily function. The scores are categorized into five levels (Table 4.4), where higher scores indicate a greater occurrence of depressive mood symptoms.

Table 4.4. Scoring index for the PHQ-9 following Kroenke et al. (2001).

0-4:	Minimal symptoms of depression
5-9:	Mild symptoms of depression
10-14:	Moderate symptoms of depression
15-19:	Moderately severe symptoms of depression
>20:	Severe symptoms of depression

The PHQ-9 is seen as a superior measurement tool, showing excellent diagnostic accuracy (Kroenke et al., 2001), as well as test-retest reliability (r = 0.75). Furthermore, its common use within stroke research confirms its value to determine depressive moods in stroke survivors. (De Man-Van Ginkel et al., 2012; Williams et al., 2005). The cut-off score for this study was 10. This is in accordance with literature confirming that PHQ-9 scores of ≥10 had a sensitivity (91%), specificity (89%) for major depression (Williams et al., 2005). Major depression is known to portray decreased functional activity and disrupted neural networks in the prefrontal cortex measured by the fNIRS (Liu et al., 2014; Zhu et al., 2017).

Functional assessments

Functional capacity can be defined as one's ability to manage activities related to daily living (ADL's) (Haor et al., 2015). It is well known that deficits in functional capacity are common in stroke survivors, which negatively affect one's quality of life and independence. Motor impairment resulting from stroke refers to one's loss of muscle control and mobility. This relates to motor impairment of the lower limbs, affecting one's functional mobility which is in turn vital for everyday ambulation and ADL's. Thus, assessing functional capacity and lower limb motor deficits is an important aspect for health professionals to quantify motor deficits,

monitor progress, assess recovery and set goals for rehabilitation. Since deficits in functional capacity negatively affect one's wellbeing, such tests of functional capacity can also be interpreted in an attempt to gain a better understanding of each stroke survivors' psychological state, influenced by motor deficits. This protocol made use of three measures of functional capacity; the two-minute walk test, the Fugl-Meyer Assessment of the Lower Extremities (FMA-LE), and the functional ambulation categories (FAC).

The two-minute walk test (2MWT)

The 2MWT (Addendum H) is a measurement of endurance that assesses the total distance (in meters) covered by participants over two minutes. It is a test commonly utilized in clinical settings in place of both the six and twelve-minute walk tests, as research found the 2MWT to be most reliable, time-efficient and minimized participant's fatigue effects (Kosak and Smith, 2004). Participants were requested to walk at a comfortable speed for two minutes until the researcher instructed them to "Stop". This instruction has shown high reliability (r = 0.93) in individuals between the ages of 20 and 79 years of age (Bohannon,1997). Furthermore, the 2MWT has shown excellent test-retest reliability (ICC = 0.98), as well as high intrarater (ICC =
0.85) and interrater (ICC = 0.85) reliability in persons with stroke. The 2MWT is commonly used as a functional measure in chronic stroke research (Hiengkaew et al., 2012; Meester et al., 2019)

The Fugl-Meyer Assessment of the Lower Extremities (FMA-LE)

The FMA (Addendum I) is one of the most widely used tools to assess one's motor recovery following stroke (Gladstone et al., 2002). This study made use of the lower extremity subsection due to the use of lower limb TM being explored. The assessment measures lower limb motor function using 17 items, assessing reflexes, movement, and coordination (Chan et al., 2017). Each item is scored on a scale ranging from 0-2 (0 = cannot perform, 1 = can partially perform, 2 = can fully perform). The total possible score is 34 (Fugl-Meyer et al., 2010), whereby higher scores indicate superior motor recovery. This test has been used extensively amongst stroke survivors and shows an excellent inter-rater reliability (ICC = 0.91) and

intrarater reliability (ICC = 0.99) (Duncan et al., 1983; Sullivan et al., 2011). A recent study on chronic stroke survivors proposed that a cut-off score of ≥21 can differentiate those with a high level of mobility function, with a sensitivity of 0.87, and specificity of 0.81 (Kwong et al., 2019).

The Functional ambulation categories (FAC)

The FAC (Addendum J) is a functional walking test that evaluates ambulation ability. This 5point scale assesses ambulation status by determining how much human support the individual requires when walking, regardless of whether they use a personal assistive device (Teasell et al., 2011). This test was used as a descriptive measure of walking ability. The FAC has shown very good inter-rater reliability (r = 0.91) (Mehrholz et al., 2007), and excellent testretest reliability (r = 0.95) (Marvin et al., 2011).

Physical Activity status Rapid assessment of physical activity (RAPA)

The RAPA (Addendum K), is a 9-item questionnaire, used to quickly determined one's physical activity (PA) status through either "yes" or "no" answers. Questions refer to 3 categories of PA: light, moderate and vigorous. The Instructions for the RAPA are substantiated by a brief description of which types of PA fall under each of the three levels, including visual images and text explanations. Questions progress from light PA to vigorous PA questions. Scoring of items 1-7 (Table 4.5) is based on the participant's last "yes" response to the intensity of PA engaged in (for example if the participant answered yes to item 5, the score will be 5 plus the other two categories). Separate to this, are the questions relating to strength and flexibility, which represent a further 1 and 2 points, respectively. Thus, higher scores indicated increased participation in PA.

Table 4.5 Scoring of the 5 physical activity categories in the RAPA.

Score for yes	Physical activity status
1	Sedentary
2	Underactive
3	Underactive regular (light activities)

4	Underactive regular
5	
6	Active
7	
+1	Strength activities (item 8)
+2	Flexibility activities (item 9)

RAPA: Rapid Assessment of Physical Activity

The benefits of the RAPA include that it is one of few questionnaires to evaluate strength and flexibility, which are related to falling reduction and independence in older adults. Furthermore, the RAPA assesses light PA, which is of importance when encouraging those to progress from a sedentary lifestyle to light PA.

When compared to 2 other PA assessment tools, the RAPA showed increased accuracy to discriminate between older adults who did and did not engage in regular, moderate PA (Topolski et al., 2006). In addition to this, the RAPA has shown sensitivity (81%), negative predictive value (75%), and specificity (69%) when compared to other assessment tools measuring PA status.

The RAPA represents a short, self-administered test that is commonly used to detect PA status within the research field.

Fall risk

Previous falls experienced by participants were recorded in the personal information sheet. Fall questions (Table 4.6) required participants to recall how many times they have fallen over the past year. Details around each fall were collected as well as time since each fall, the activity at the time of the fall, as well as the environment in which the fall occurred.

Table 4.6 Details of participants fall history.

# of falls in the past 12 months	
Time since each fall event (months)	
Was medical assistance required (doctor/hospital)	
Were any injuries sustained?	
Activity at time of fall	
What surface was the floor	
Position at the time of fall (e.g. standing)	
Place of fall (inside/outside)	
Cognitive activity at the time of fall (If any)	

Additionally, the fall efficacy scale international (FES-I), as well as the Peninsula health fall risk assessment tool (PH-FRAT), was used to determine participant's fall efficacy and fall risk, respectively.

Falls efficacy scale-international (FES-I)

The Falls Efficacy Scale (FES) was developed to evaluate the self-confidence of individuals as they perform ten basic ADL's without falling (Tinetti et al., 1990), using a question format. However, because this assessment did not measure individual's symptoms of fear of falling in social physical activities, the scale could not be utilized within diverse social settings. Due to this, the fall efficacy scale-international (FES-I) was developed (Yardley et al., 2005), to improve the value of its use within a clinical setting. The FES-I is comprised of 16 items, 10 from the original FES with 6 additional items (Dewan & MacDermid, 2014). Each daily activity has a four-point Likert scale (1= not at all concerned, 4= very concerned). Total scores range from 16 (indicating absolutely no concern regarding falling) to 64 (indicating extreme concern regarding falling). Thus, higher scores indicate a greater fear of falling. Participants were

requested to focus on their concerns regarding fear of falling during activities performed over the past 12-month period. The FES-I (Addendum L) is widely used in research involving elderly populations (Marques-Vieira et al., 2016), showing significantly high validity (0.84), excellent internal reliability (r = 0.96) as well as test-retest reliability (r = 0.96)(Greenberg et al., 2011). Literature has confirmed that the FES-I is effective for use within a clinical setting for stroke survivors, showing adequacy in determining whether clients experience fear of falling. Furthermore, it has been translated into 14 different languages (Ulus et al., 2012; Billis et al., 2011), extending its use among researchers. Accordingly, previous studies with chronic stroke survivors have utilized the FES-I to determined one's perceived fear of falling during various ADL's (Danielli et al., 2009; Schmid et al., 2015; Aydogdu et al., 2018; Zastron et al., 2018).

The Peninsula Health Fall Risk Assessment Tool (PH-FRAT)

The PH-FRAT (Addendum M) (Stapleton et al., 2009) is a measurement tool designed to quantify one's risk of falling (developed by the Peninsula Health Falls Prevention Service for a DH-funded project in 1999). It is made up of sub-sections, including recent falls, current use of medications, a psychological domain, as well as a cognitive status domain. Scoring presents 3 categories; low, medium, and high risk (table 4.7).

Table 4.7 Scoring the PH-FRAT.

Status	**Values**
Low risk	5-11
Medium risk	12-15
High risk	16-20

It must be noted that Individuals were automatically categorized as high-risk fallers if they had experienced a recent change in either their functional status and/or their medications, which are known to affect safe mobility. Additionally, individuals fell within a high-risk category under the circumstance that he/she experienced dizziness or postural hypotension. This assessment tool takes only 2-3 minutes (Stapleton et al., 2009) to complete, making it

quick to administer. Furthermore, its use within an elderly population shows good inter-rater reliability within two studies (Stapleton et al., 2009; Dean et al., 2009) at 0.84 and 0.79, respectively. Additionally, the PH-FRAT is a tool that has been found reliable in both subacute and residential care settings (inter-rater reliability $ICC_{2,1}$ = 0.79), proving adequate to screen individuals at risk of falling. Communication with Peninsula Health confirmed that in the initial development of the PH-FRAT, participants of various medical conditions were included, and among them were those who had suffered a stroke.

Anthropometric measures

Height and weight

Height (cm) was measured using a tape measure which was taped to the wall. The participants retained a standing position with their backs and heels touching the wall. A clipboard was used to find the point that correlated from the height at the top of the head, to the tape measure on the wall. Weight (kg) was measured using a bodyweight scale. Participants were requested to remove their shoes before the abovementioned measurements, and an average of two readings was taken for each measurement.

4.9 Testing Protocols

Transitional movements (TM)

Participants were asked to complete each standardized test wearing comfortable shoes and clothing under ST and DT conditions. Spatial-temporal measures were collected during each test, as well as the number of mistakes made during the DT conditions. The APDM Mobility Lab™ (Oregon, USA) wearable body sensors (accelerometers with a gyroscope) were placed on each participant (according to the standardised manufacturer's guidelines) to collect spatial-temporal data, i.e. duration of sit-to-stand , stand-to-sit and turns, lean angle of sit-to-stand, and velocity and angle of turns. Lastly, the functional Near-Infrared Spectroscopy (fNIRS) device, the NIRSIT ™ (Obelab®, Korea) was used to measure cerebral hemodynamics

utilizing relative changes in concentrations of oxygenated (ΔHbO_2) and deoxygenated (ΔHbR) haemoglobin, as well as haemoglobin difference ($\Delta HbDiff$) from resting/baseline values.

Five times sit-to-stand (5TSTS)

The 5TSTS (Addendum 15) (Mong et al., 2010) required participants to stand up from a chair and sit down again, at a comfortable pace. It is commonly used to assess lower extremity muscular strength and balance among the elderly population (Annweiler et al., 2011). Rising from sitting to standing has been reported as one of the most frequent activities leading to falling events amongst stroke survivors (Boukadida et al., 2015). Furthermore, transitioning from a sitting to a standing position is impaired post-stroke (Boukadidada et al., 2015). Thus, the 5TSTS test is a useful tool for stroke studies, as it is a quick and easy test used to assess a TM performed daily, that quantifies participant's risk of falling (Cheng et al., 1998).

In a study performed to assess the feasibility of sit-to-stand variations in participants with neurological disease (ND), it was found that the 5TSTS test was the most commonly used measure within this population (Silva et al., 2014). The 5TSTS proved to be a valid and reliable assessment tool and has demonstrated good clinical feasibility (Silva et al., 2014) in the elderly. Additionally, a significant association has been found between the 5TSTS test and global cognition amongst the elderly. Thus, the test is valuable as a tool to screen individuals for MCI (Silva et al., 2014).

In this study, the 5TSTS test was demonstrated to each participant prior to the actual ST and DT attempts. Participants began in the seated position, at the back of the seat with their backs in contact with the chair, feet flat on the floor and shoulder-width apart, and arms across their chest. If participants were unable to place their arms across their chest, they were requested to leave their arms at their sides and were instructed to make sure they did not use their arms to assist in pushing off from the chair when rising into a standing position. Participants were instructed to rise from the chair into a standing position until their hips were fully extended, and to sit down again, repeating this movement five times. The test was complete when the person's back made contact with the backrest of the chair following the

fifth stand. Equipment used for the 5TSTS test is further explained in section 4.10. Furthermore, the Mobility lab™ variables assessed can be found in table 4.9.

360° in-place turn test

This is a commonly used tool to assess one's ability to turn (Shiu et al., 2016), which is known to be impaired following stroke. Turning is a movement required to complete many activities of daily living. The variables measured by the Mobility lab™ are presented in table 4.9. The test required the subject to begin by standing one foot away from a line marked with tape on the ground, with their arms at their side and feet comfortably apart, pointing at the tape. Timing began following the countdown "3,2,1 begin." The participant was required to turn in a full 360-degree angle until their feet were facing the line again (Shiu et al., 2016). The mobility lab protocol required participants to turn towards the right-hand side covering 360-degrees, followed by a complete 360-degree turn towards the left-hand side, and timing was stopped when the participant's shoulders and feet were facing forward at the line following the completion of both turns. According to literature (Shiu et al., 2016), this test demonstrates excellent intra-rater, interrater, and test-retest reliability (ICC = 0.824 - 0.993) for discriminating between healthy older adults and individuals with chronic stroke (Shiu et al., 2016). The test was simple to administer, assessing one's turning ability following stroke. Participants were given a demonstration of the test and were allowed to have one practice attempt before the actual ST and the DT trials.

Single- and dual-task assessment protocol

The ST and DT protocol was conducted by two independent researchers. For this section they will be referred to as researcher A, and researcher B.

Before the collection of any data, participants were asked to sit comfortably in a chair for 5 minutes, before researcher A took two blood pressure readings, consecutively. Following this, the APDM Mobility Lab™ was attached to the participant (see figures 4.7a and 4.7b), and the procedure of the testing session was explained, where the participant could ask any questions.

Participants were requested to complete the abovementioned TM (5TSTS and 360° in-place turn test) according to the standard protocols described, referred to in this study as the ST conditions, and then asked to repeat the same TM under both cognitive-motor and motor-motor DT conditions. The instructions were as follows:

5TSTS:

Researcher A explained to the participant while performing the movement. Starting seated in the chair, the researcher instructed the participant to sit comfortably in the chair with their feet slightly apart, facing forward and in contact with the ground. The participant was told to make sure their back was in contact with the chair, and that on the command; researcher A would say "3,2,1, begin" whereby the participant should stand up fully from the chair, without using their arms, and sit back down again, repeating this 5 times. It was iterated to the participant that the 5 sit-to-stands would end when the person's back came into contact with the chair after the 5th stand.

Following from this, the motor-motor DT trials were explained by telling the participant that they would complete the exact same test, while holding a cup of water in the hand of the UA side. This protocol was adapted from Chan et al. (2017), who made use of a motor-motor task using the TUG test in chronic stroke survivors.

Lastly, the Cognitive-motor DT were performed per the DT protocol previously applied with chronic stroke survivors (Mori et al., 2018). In their study, the abovementioned researchers investigated PFC activation during DT walking, but not during the TM used in this current study. In this current study, the participant was instructed to complete the 5TSTS while counting backwards in serial subtractions of 3, beginning with a random number between 50 and 100, which was randomly balloted by the researcher. Before the DT, the condition was explained and demonstrated to the participant, using a number below 50 to avoid the participant anticipating their cue. The following instructions were utilized: "If I say your number is 30. 3, 2, 1 begin" you will perform the task (demonstrates the movement) while counting backward in 3's e.g. 27, 24, 21, 18, and so on." The participant could ask any

questions before the trial began. The trial was initiated with the statement "your number is 40. 3,2,1, begin." Thereafter, the participant performed the DTCM, as one researcher controlled the laptop measuring brain activity, and the other researcher controlled the laptop measuring the kinematics of movement, as well as counting the number of reps completed. The correct and incorrect answers were recorded using an iPad, whereby the footage was later reviewed and reported, following the completion of that day's testing.

Serial subtraction is a mental tracking task that loads cognitive resources of the brain that are also engaged in processing attention and working memory (Al-Yahya et al., 2011). This cognitive task is also known to negatively affect walking performance in the elderly, those with neurological disorders, and healthy young adults (Al-Yahya et al., 2011). This cognitive task has been used extensively in DT studies with a chronic stroke population (Pang et l., 2018; Yang et al., 2018; Yang et al., 2018; Dennis et al., 2009; Mori et al., 2018; Timmermans et al., 2018; Al-Yahya et al., 2016; Ohzuno et al., 2019; Patel et al., 2014).

In-place 360 ° Turning:

For the ST condition, a line of tape 60cm long was placed on the floor. The participant was instructed to stand with their feet one foot away from the line, and when researcher A said “3, 2, 1, begin”, they were told to turn towards the right-hand side in a 360° circle, until their shoulders and feet were fully facing the line, followed by turning towards the left in a 360° circle until their shoulders and feet were parallel to the line.

Additionally, referring to the motor-motor DT condition, participants were instructed to follow the exact same protocol as the ST, however holding a cup of water, which was 3cm from the rim of the cup. Lastly, the cognitive-motor DT condition was performed in line with the instructions of the DTCM condition for the 5TSTS. Participants were instructed to count backwards in 3’s following the instructions “Your number is 60; 3, 2, 1, begin” whereby the participant completed the 360° right and left turns consecutively, while counting backwards from their designated number.

It must be noted that participants were not given any instructions regarding which task to prioritize, instead they were told to "complete both tasks at the same time".

Measuring DTI

Dual-task interference (DTi) was determined using the following formula used previously in a DT study with chronic stroke survivors (Mori et al., 2018):

$$DTi = (\text{single-task} - \text{dual-task})/\text{single-task} \times 100$$

Referring to the abovementioned formula, the ST or DT value above would refer to the specific variable being explored. For example, when exploring the DTi during the CM condition of the 5TSTS, for total test duration, one would take the total duration for the single-task and the total duration for the CM condition and place these in the formula to get a percentage. If the end DTi value (%) was a negative value, this would denotate a deterioration in task performance (when comparing the DT condition performance to the ST condition performance). In contrast to this, a positive value would indicate an improvement in performance from ST to DT conditions, which is referred to as a dual-task gain (DTg) (Plummer and Eskes, 2015).

4.10 Equipment

Measuring Spatial-temporal variables

The Mobility Lab™ (APDM, USA) (version 2) was designed to monitor and quantify the kinematics of movement for individuals with various movement disorders, such as Parkinson's disease, Multiple Sclerosis, and Tremor. The tri-axial accelerometers with a gyroscope have been used extensively to measure variables amongst a variety of populations, including individuals with stroke (Watson et al., 2018; Chaikeeree et al., 2018; Chan et al., 2017). The accelerometers robotically process the input signals, providing objective measures for performance during selected tasks.

Wearable sensor placement

This study made use of 4 wireless opal sensors from Mobility lab™ (Table 4.8)., which were placed on the left and right foot, the lumbar area, as well as on the sternum (Figure 4.7a &b). Each opal sensor weighs 25 g and is 55 mm x 40.2 mm x 12.5 mm in size.

Table 4.8 Placement of opal sensors.

Opal	Placement
Foot	Centered on the top of the foot
Lumbar	Centered on the lower back, at the base of the spine
Sternum	Centered on the flat surface of the chest, just below where the collar bones meet

Figure 4.7a Participant seated with opal sensors Secured. Photo by Taylia Webber.

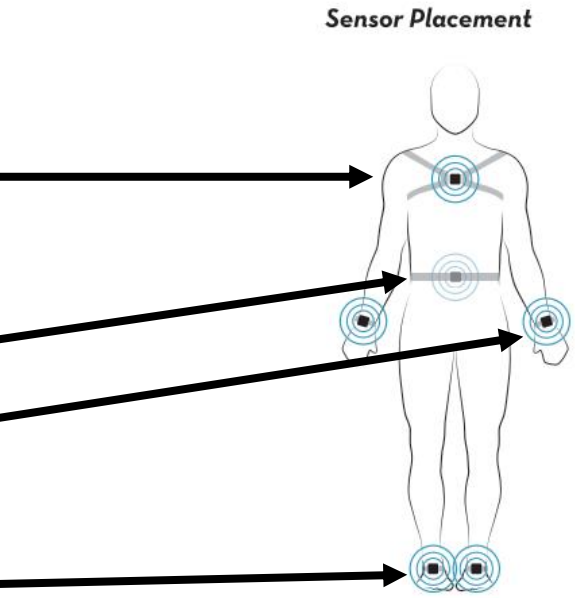

Figure 4.7b Placement of opal sensors, as per APDM Mobility Lab user manual

The Mobility lab™ system consists of a variety of tests, which measure selected kinematic and gait variables. This study utilized the Mobility lab system for the 2MWT, the 5TSTS, as

well as the 360-degree turn test. The kinematic variables analysed in this study are presented in the table below.

Table 4.9. Kinematic variables assessed during transitional movements.

Test	Measures
Five times sit-to-stand test	Sit to stand: duration, lean angle Stand to sit duration, lean angle
360-degree turn test	Turn velocity, turn time, turn angle

Measuring prefrontal cortical activation

A form of fNIRS, specifically the NIRSIT ™ (Near-infrared spectroscopy neuroimaging device) (OBELAB, Korea), was used to measure changes in cerebral oxygenation levels in response to functional stimulation. Studies on neuroergonomics have confirmed that fNIRS-measured PFC activity can be useful for distinguishing changes in participant's cognitive states (Mandrick et al., 2013). In a previous study using fNIRS, oxygenated haemoglobin appeared to be a more sensitive parameter for measuring blood flow (Hoshi et al., 2000; Harada et al., 2009). Thus, this current study used the change in oxygenated haemoglobin along with deoxygenated haemoglobin to indicate changes in PFC activation. This was be done using three measures:

- Oxygenated haemoglobin (HbO_2)
- Deoxygenated haemoglobin (HbR)
- The difference in haemoglobin (Hbdiff)

Methods (Instrumentation and optode placement)

The NIRSIT (Obelab®, Korea), measures PFC activation through a wearable device that reflects light onto the prefrontal lobe of the brain. It differs from other forms of brain imaging tools as it is portable and allowed participants to freely move around. Additionally, it is light

and compact, weighing only 450 g. It has two wavelengths (780nm and 850nm), and a sampling rate of 8.13Hz.

The NIRSIT, comprises 24 sources and 32 detectors (Figure 4.7), used for multi-distance detection. The NIRSIT covers 204 channels, of which 68 channels are based on 3cm, 52 channels are based on 1.5cm, 36 channels are based on 2.12cm, and 48 channels are based on 3.35cm distances (Figure 4.13 under the instrumentation section). All 204 channels are simultaneously detected with a temporal resolution of 122.8msec. The light traveling through the brain channel is detected SiPD, followed by a trans-impedance amplifier (TIA).

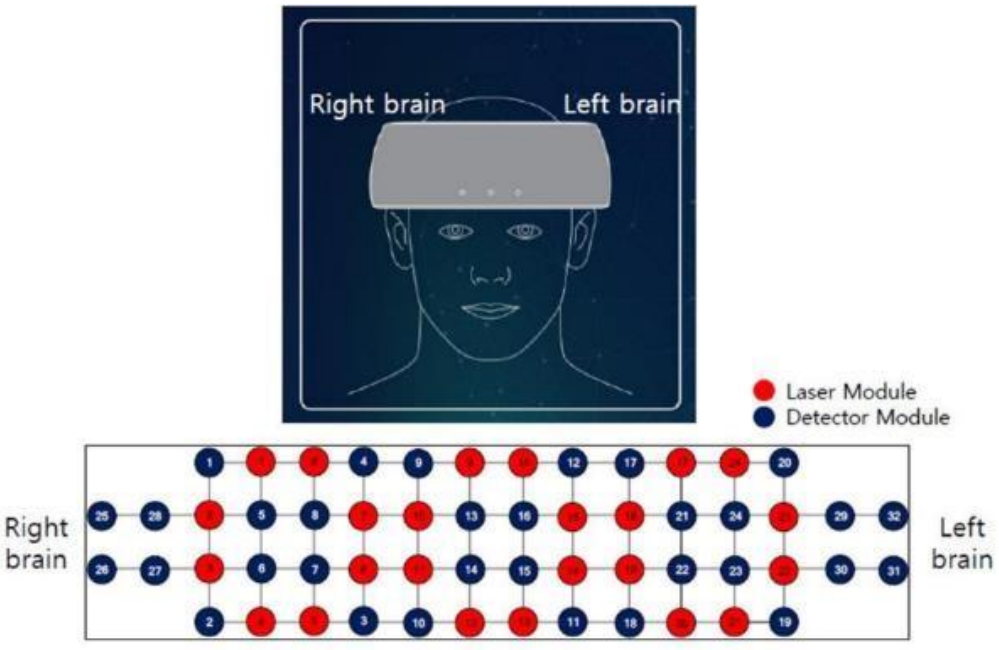

Figure 4.8 An image to show the source and detector arrangement of the NIRSIT©.

Reliability study

The only study to date evaluating the feasibility of the fNIRS device NIRSIT^{TM} (Obelab, Korea) was a white paper review performed by Obelab (Trakoolwilaiwan & Kim, 2016). Thus, to determine the reliability of the NIRSIT in detecting PFC activity, a test-retest reliability study was conducted at the Sports Science department at Stellenbosch University. The study

consisted of two sessions, separated by no more than 10 days. Participants included were 5 healthy individuals, between 21 and 28 years of age.

Reliability study protocol:

The test-retest reliability study included 5 young and healthy participants who completed the entire protocol twice, each on separate days. The protocol was repeated within 10 days of testing day 1. Participants were seated for 5 minutes; whereby baseline PFC activity was measured (See Figure 4.9).

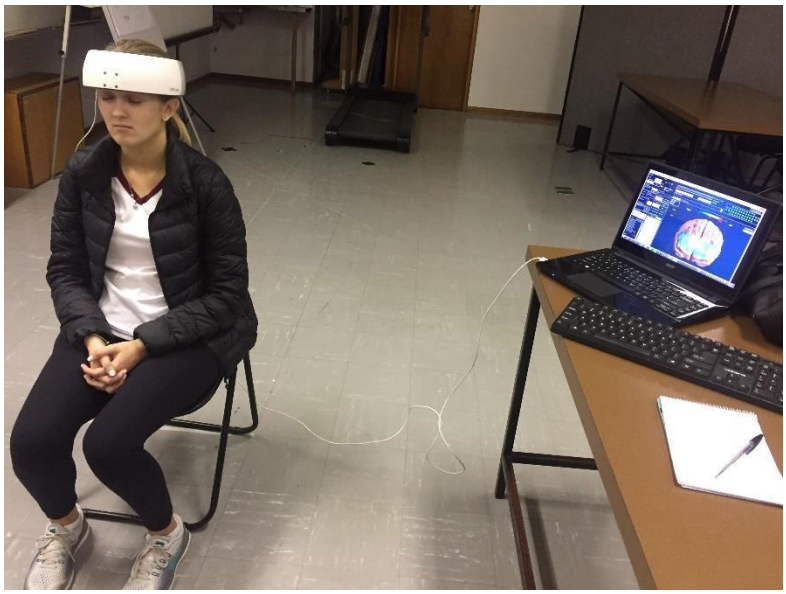

Figure 4.9 An image to show the reliability study setup, in the movement laboratory at Stellenbosch University. Photo by Taylia Webber (with permission).

Following this, each participant performed two sets of the 5TSTS test, and the 360-degree turn test. Each test was separated by a one-minute rest period, allowing time for brain activity to stabilize. Before data processing, it was established that minutes 3 and 4 of the 5-minute baseline period represented the greatest resting state, thus these 2 minutes were used in calculations to distinguish changes in cortical activation from baseline to task.

Table 4.10 ICC's collected from the test-retest reliability study on the NIRSIT.

Variable	ICC	95% CI Lower Limit	95% CI Upper Limit
HBO_2_DLPF	0.86	0.52	0.98
HBO_2_FPPF	0.65	0.14	0.95
HBO_2_OFPF	0.78	0.35	0.97
HbR_DLPF	0.86	0.53	0.98
HbR_FPPF	0.73	0.26	0.96
HbR_OFPF	0.61	0.09	0.94
HBO_2_DLPF	0.58	0.06	0.94
HBO_2_VLPF	0.50	-0.02	0.92
HBO_2_OFPF	0.84	0.47	0.98
HbR_DLPF	0.54	0.01	0.93
HbR_FPPF	0.82	0.43	0.98
HbR_OFPF	0.80	0.38	0.97

DLPF: dorsolateral; FPPF: frontopolar; OFPF: Orbitofrontal; HbR: Deoxygenated haemoglobin; HBO_2: Oxygenated haemoglobin; ICC values less than 0.5 are indicative of poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.90 indicate excellent reliability (Koo et al., 2016).

Protocol

Application of NIRSIT device

Participants sat comfortably in a chair, while the researcher allocated to the NIRSIT^{TM} explained the forthcoming procedures to them. This researcher used alcohol solution and cotton wool to clean the persons forehead and remove hair out the way (Figure 4.10.a). The researcher applied the NIRSIT to the persons forehead, using one hand to hold their hair back, and one hand to secure the NIRSIT onto the person's head. Once the position was adjusted, ensuring that the line on the middle of the NIRSIT device was in line with the participants nose

and in between their eyebrows, the Velcro strap was adjusted to ensure the NIRSIT was sitting firm and tight to the persons head (Figure 4.10.b).

a.

b.

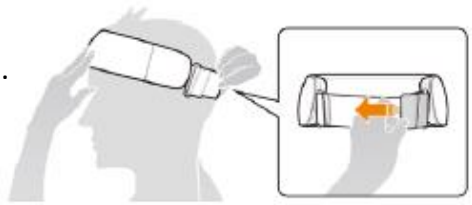

Figure 4.10 a and 4.10b The procedures followed to remove hair and secure the NIRSIT to the participants forehead. Permission obtained from Obelab.

The fNIRS protocol used in this study was adapted from that of a previous DT study assessing brain activity in chronic stroke survivors (Mori et al., 2018). Participants were instructed to complete a 5-minute baseline assessment of brain activity before the collection of any movement data. Participants were asked to sit comfortably for 5 minutes with their eyes closed and instructed: “attempt not to think of anything, try to keep your hands, feet, and body as still as possible, and no talking until the researchers tell you to open your eyes". Following baseline measurement, cerebral oxygenation was assessed during both TM being explored, as a ST, as well as during two DT (i.e. DTCM and a DTMM condition). The NIRS data during the ST and DT are defined for statistical analysis as the mean of the data recorded during the period of the ST trials and DT trials, respectively. Rest periods between each trial consisted of 60 seconds, and rest periods between the 5TSTS block and 360-degree turn block consisted of 2 minutes. All rest periods were instructed under the same conditions previously mentioned for the baseline measurement.

A comparison between the resting condition and the task phase was used to determine the changes occurring to ΔHbO_2 and ΔHbR from rest to task. Furthermore, these values were used to calculated $\Delta HbDiff$. The values obtained during the baseline session were used as the

rest value. Hemodynamic changes refer to the overall change in ΔHbO_2, ΔHbR, and ΔHbDiff from rest to single-task, and from rest to dual-task.

The calculations used to determine PFC hemodynamic changes during both TM explored in this study, for the affected and unaffected brain hemispheres of four separate brain sites included the following (Hermand et al., 2019):

Relative % Change in HBO_2 for the 5TSTS test:

Delta (Δ) = ((average of all 5TSTS_ST – Baseline)/ Baseline) * 100

Delta (Δ) = ((average of all 5TSTS_DTMM – Baseline)/ Baseline) * 100

Delta (Δ) = ((average of all 5TSTS_DTCM – Baseline)/ Baseline) * 100 *Relative %*

Change HBO_2 for the 360° turn test:

Delta (Δ) = ((average of all Turn_ST – Baseline)/ Baseline) * 100

Delta (Δ) = ((average of all Turn_DTMM – Baseline)/ Baseline) * 100

Delta (Δ) = ((average of all Turn_DTCM – Baseline)/ Baseline) * 100 *Relative %*

Change HbR for the 5TSTS test:

Delta (Δ) = ((average of all 5TSTS_ST – Baseline)/ Baseline) * 100

Delta (Δ) = ((average of all 5TSTS_DTMM – Baseline)/ Baseline) * 100

Delta (Δ) = ((average of all 5TSTS_DTCM – Baseline)/ Baseline) * 100

Relative % Change HbR for the 360° turn test:

Delta (Δ) = ((average of all Turn_ST – Baseline)/ Baseline) * 100

Delta (Δ) = ((average of all Turn_DTMM – Baseline)/ Baseline) * 100

Delta (Δ) = ((average of all Turn_DTCM – Baseline)/ Baseline) * 100 *Delta*

(Δ) Hbdiff for the 5TSTS and 360 turn test, respectively:

Delta (Δ) Hbdiff = (Δ HbO_2 - Δ HbR)

The instrumentation required for transitional movements:

- Chair: A chair with a height of 45cm, with no armrests (Figure 4.11) was utilized for all participant's testing sessions. The chair height was determined by previous research assessing sit-to-stands in persons with stroke (Beniato et al., 2009).

Figure 4.11 Chair used for Five times sit-to-stand (5TSTS) test
Photo by Taylia Webber (with permission).

- Plastic cup: This study made use of a plastic cup required for the DTMM condition. The cup was filled with water, 3cm from the rim (Figure 4.12). This was revised from previous research investigating a DTMM among chronic stroke survivors (Chan, Si Tou, Tse, & Ng, 2017).

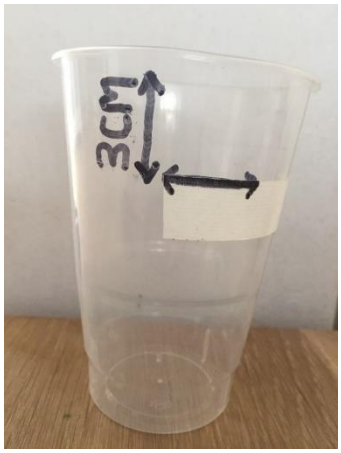

Figure 4.12 The cup of water used for the DTMM condition. Photo by Taylia Webber (with permission).

4.10 Data Analysis

Data was processed using an extension on the Matlab™ program (Mathworks, R2017a, version 9.2, Las Vegas), namely the NIRSIT analysis tool. After eyeballing the 5-minute baseline period, minutes 3 and 4 showed a plateau in baseline activity. Thus, the middle 120 seconds of the allocated 5 minutes were used as baseline values. Following this, the baseline and task data light intensity was filtered using a Low pass filter with a high cut-off of 0.05Hz and a high pass filter with a low cut-off of 0.005Hz. Thereafter, a channel rejection process was performed to identify and reject those channels that were prone to the noise by evaluating the SNR (signal to noise ratio) of each channel. The SNR cut-off was set at 30DB, thus eliminating motion artifacts. The modified Beer-Lambert law (MBLL) was applied to calculate hemodynamic responses from light intensity changes (Delpy et al., 1988). Among the 204 channels, only 3cm channels were used for analysis (Figure 4.13). The 3cm channels are known to optimally detect the hemodynamic response within the human brain.

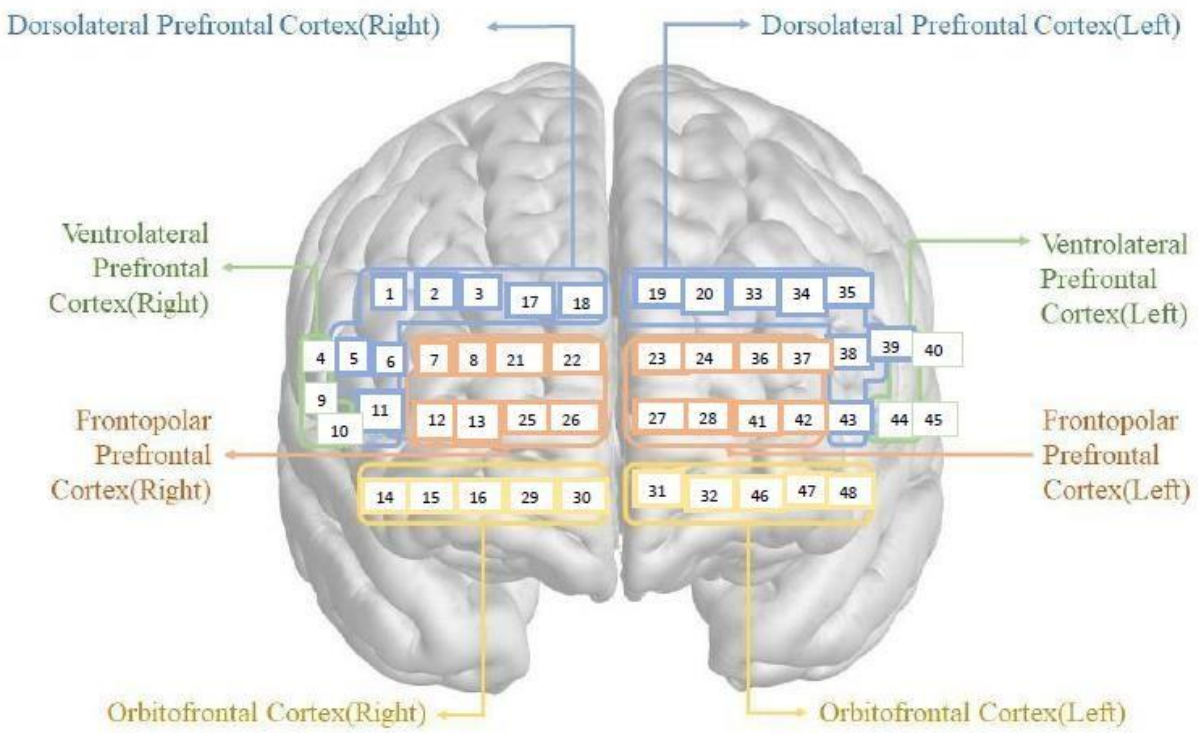

Figure 4.13 An image to show the 3 cm-based channels of the NIRSIT©, used for data analysis per previous research. Similarly, outlined are 8 specific brain sites explored in this study. Picture obtained with permission, from Obelab.

4.11 Statistical analysis

- Data Analysis was performed using the software programmes i.e. Statistica™ statistical package (Version 13.6, Dell, TIBCO®) and Microsoft Excel (Microsoft Office®, USA). Descriptive data were summarized in Excel™, and presented as means ($\bar{x}$) and standard deviations (parametric data) and as median and inter-quartile range (non-parametric data). A significance level 5% was used.
- Mixed model ANOVA was used for analysis of the brain data. Participants were entered into the model as a random effect (to cater for repeated measures nature of the data). The factors “side”, “site” and “condition” were entered as fixed effects.

- For post hoc testing Fisher least Significant Difference (LSD) was used. Normal probability plots were inspected and in cases where it was judged not to support normality assumptions, Box-Cox transformations were used.
- For behavioural data mixed model ANOVA was used with subject as random effect and treatment as fixed effect. The R package "lmer" was used to do the mixed model ANOVA's.
- In addition to this, Cohens d and Hedges g (Weissgerber et al., 2017. were calculated to determined treatment effect sizes. Effect sizes were interpreted as negligible(^{N}) (≥-0.15 and <0.15), small (^{S})(≥0.15 and <0.40), medium (^{M})(≥0.40 and <0.75), and large(^{L}) (≥0.75 and <1.10), respectively.
- Pearson correlations were performed to compare correct response rate with 5TSTS and 360-degree turning, durations, respectively.
- The following variables were transformed using BoxCox: Total 5TSTS duration, ΔHbO_2, ΔHbR, and ΔHbdiff for turning.
- Lastly, dotplot's were created to represent the data sets.

Chapter 5

Results

5.1. Participants

Of the 17 participants, twelve were men, and five were women. Table 5.1 summarizes the descriptive characteristics of the participants.

Table 5.1 Descriptive characteristics of participants (n = 17).

Variables	$\bar{x}$ ± STD/M	Range/IQR
Age (y)	65.6 ± 11.8	44 - 81
Sex (M: F)	12:5	
Height (cm)	170.2 ± 10.5	146-186
Body mass (kg)	86.2 ± 13.0	62.3-115.6
BMI (kg/m²)	30.0 ± 5.2	20.7-38.9
Time since stroke (mts)	59	6-228
Number of strokes (no.)	1.5	1-4
Affected side (R:L)	12:5	
Global cognition (A.U)	23.6 ± 3.6	18-29
Depressive moods (A.U)	3.9 ± 3.1	

y: years; M:F: male/female; cm: centimeters; kg: kilograms; BMI: body mass index; m:meters; mts: months; no.: number of; L:R: left/right; A.U: arbitrary units; IQR: Interquartile range; M: mean; STD: Standard deviation

The subsequent section (Table 5.2) summarizes the functional characteristics of all the participants.

Table 5.2 Functional characteristics of participants (n = 17)

Variables	$\bar{x}$ ± STD/M	Range/IQR
Functional capacity 2min (m)	101.6 ± 25.6	69.31-162
FMA-LE (A.U)	19.9 ± 4.8	7-27
Physical activity status (A.U)	5.8 ± 2.7	1-10
Functional ambulation (A.U) Level 3: 4: 5	4: 7: 5	
Fall efficacy (A.U)	27	16-50
Fall risk (A.U)	9.9 ± 2.8	6-16
Trail maker test (s)	116 ± 78.4	14.95-303
No. chronic medications	5.6 ± 2.4	1-10

No. comorbidities	2.8	1-4
SSQOL Quality of life (A.U)	197.2 ± 30.1	126-242

2min; 2-minute walk test; m: meters, FMA-LE: Fugl-Meyer Assessment – Lower extremities; A.U: arbitrary units; s: seconds; no.: number of; SSQOL: Stroke specific quality of life scale

5.2. Transitional movement variables

5.2.1 Transitioning between sitting and standing positions.

a. Total duration

Figure 5.1 (a to c) illustrates the total duration (seconds) for the single-task (ST) (18.9 ± 6.1s), as well as the cognitive-motor (DTCM: 31.7 ± 34.4s) and motor-motor (DTMM: 19.4 ± 4.3s) dual-task conditions, respectively, during the 5TSTS test.

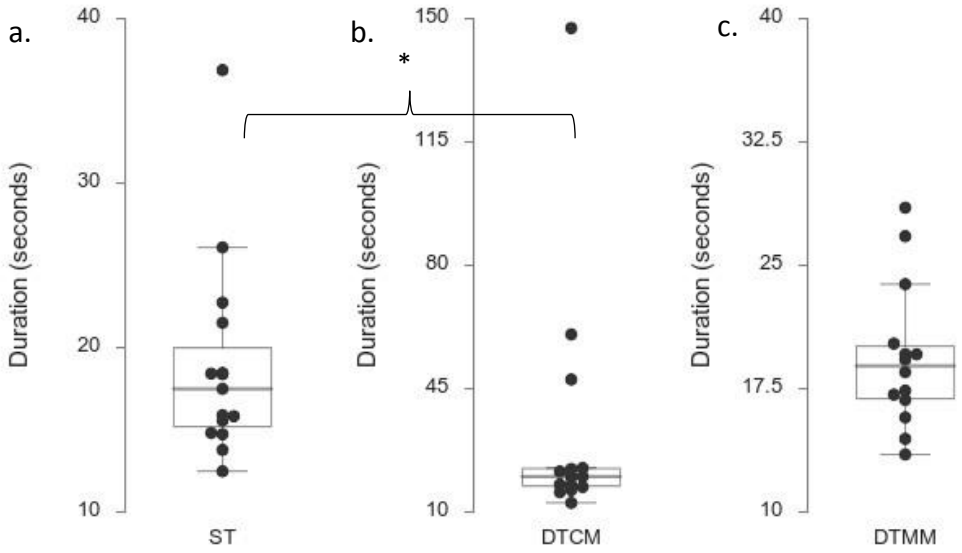

Figure 5.1 The box dot plots (a, b, and c) illustrate the single-task and dual-task durations for the cognitive-motor and motor-motor tasks, respectively. *: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

The analysis of variance (ANOVA) revealed no overall differences between conditions ($F(2,27) = 2.79$, $p = 0.08$). Post-hoc comparisons revealed a 68.1% difference between ST and DTCM conditions ($p \leq 0.01$; $g = 0.51^{M}$), as well as a difference between ST and DTMM conditions,

after Box Cox transformations were performed (19.7%; p ≤ 0.01; *g* = 0.09[N]). However, the differences between DTCM and the DTMM conditions (33.7%; p = 0.12; *g* = 0.48[M]) were not significant.

The dual-task interference (DTi) for the DTCM condition showed a median reduction of -12.5% (IQR = -27.7 to -8.8%). The negative sign indicates a reduction in dual-task ability (in other words more dual-task interference). Whereas the DTi for the DTMM condition had a median of -10.1 (IQR = -15.8 to -6.2%). There was no significant difference in DTi between the two dual-task conditions (p = 0.46).

b. Sit-to-stand duration

Separating the 5TSTS duration (seconds) into the 'sit-to-stand' phase only (Figure 5.2(a – c)) showed that ST duration (1.3 ± 0.3s) did not differ from the DTCM (1.3 ± 0.2s) and DTMM (1.3 ± 0.2s).

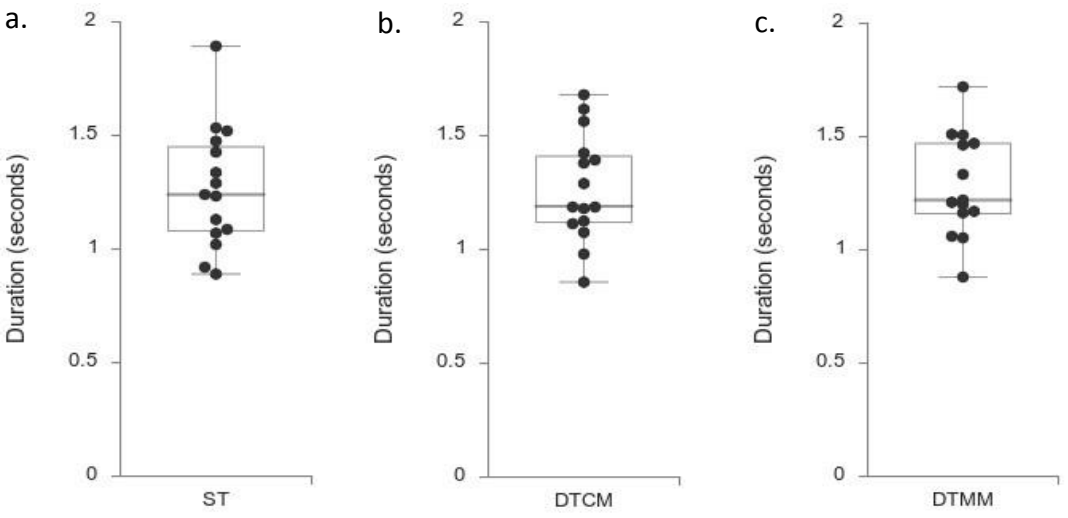

Figure 5.2 The box dot plots (a, b, and c) illustrate the single-task and dual-task sit-to-stand durations for the cognitive-motor and motor-motor tasks, respectively.

ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

The ANOVA revealed no differences between the three conditions ($F(2.27) = 0.24$, $p = 0.79$). Post-hoc comparisons showed no statistically significant difference between ST and DTCM conditions (0.1%; $p = 0.98$; $g = 0.00^{N}$), and between ST and DTMM conditions (2.4%; $p = 0.55$; $g = 0.05^{N}$). Furthermore, no statistically significant difference was found between DTCM and DTMM conditions (-2.4%; $p = 0.54$; $g = 0.05^{N}$).

The DTi for the DTCM condition displayed a median of -5.4% (IQR: -10.3 to 3.8%). Similar, the DTi for the DTMM condition had a median of -5.1% (IQR = -13.2 to 1.6%). There was a significant difference in DTi between the two dual-task conditions ($p \leq 0.01$).

c. *Sit-to-stand lean angle*

Figure 5.3 (a, b, and c) illustrates the 'sit-to-stand' lean angle (°) of the single- (28.4 ± 10.1°) and dual-task conditions, specifically the DTCM (29.8 ± 10.0°) and DTMM (25.7 ± 9.0°), respectively.

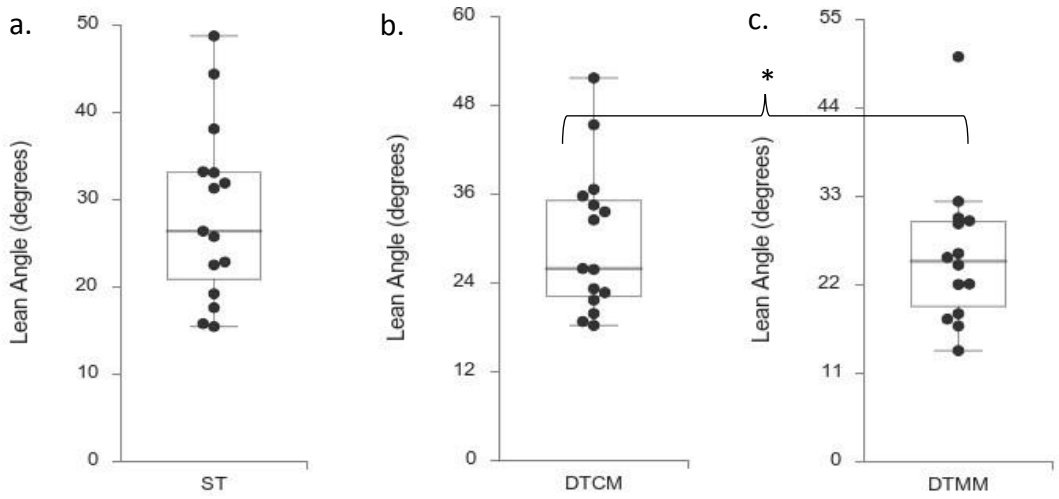

Figure 5.3 The box dot plots (a, b, and c) illustrate the single-task and dual-task sit-to-stand lean angles for the cognitive-motor and motor-motor tasks, respectively. *: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

The ANOVA revealed a difference between the three conditions on average (F (2,27) = 3.94, p = 0.03). Upon further inspection, the post-hoc comparisons revealed no difference between ST and DTCM conditions (4.7%; p = 0.18; *g* =0.13^{N}), nor between ST and DTMM conditions (-5.1%; p = 0.15; *g* = 0.28^{S}). However, there was a difference between the DTCM and DTMM conditions (9.8%; p ≤ 0.01; *g* = 0.42^{M}).

The DTi for the DTCM task demonstrated a median of -1.616. (IQR = -16.4 to 2.3%). Whereas the dual-task gain (DTg) for the DTMM task had a median increase of 7.4% (IQR = 1.4 to 15.1%). There was no difference in dual-task interference between the two dual-task conditions (p = 0.07).

d. Stand-to-sit duration

Figure 5.4 (a to c) illustrates the duration of the 'stand-to-sit' phase only during the 5TSTS for the ST (0.9 ± 0.2s), as well as the DTCM (1.0 ± 0.2s) and DTMM (1.0 ± 0.2s) conditions, respectively.

The ANOVA revealed no difference between conditions (F (2,27) = 0.36, p = 0.70). Post-hoc comparisons revealed no differences between ST and DTCM conditions (2.6%; p = 0.51; *g* = 0.11^{N}), as well as between ST and DTMM conditions (3.1%; p = 0.44; *g* = 0.03^{N}). Furthermore, no statistically significant difference was found between the dual-task conditions (-0.5%; p = 0.90; 0.1^{N}).

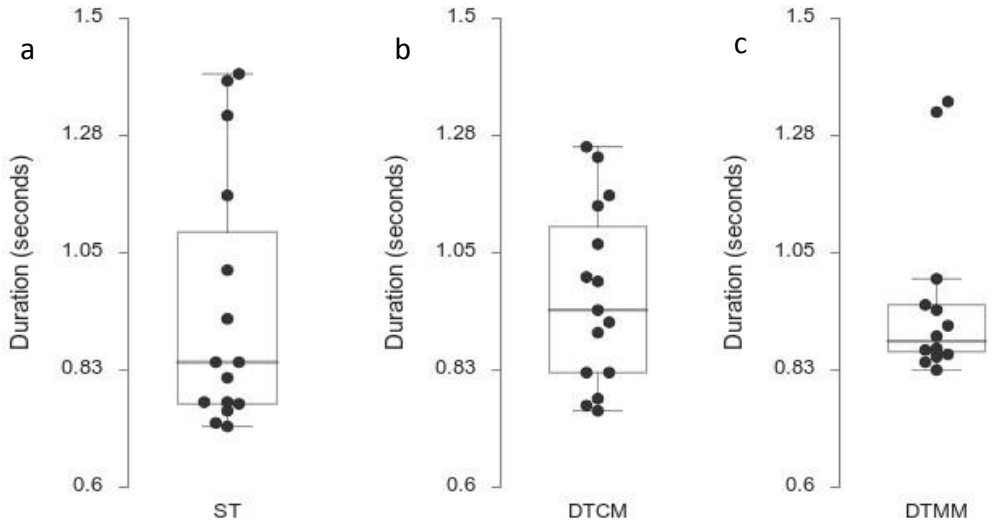

Figure 5.4 The box dot plots (a, b, and c) illustrate the single-task and dual-task stand-to-sit durations for the cognitive-motor and motor-motor tasks, respectively. ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

The DTg for the DTCM condition showed a median of 7.4% (IQR = -4.9 to 23.5%). While the DTi for the DTMM condition was a median of -10.9% (IQR = -15.1 to 1.4%). There was a significant difference in Dti between the two dual-task conditions ($p \leq 0.01$).

e. Stand-to-sit lean angle

Figure 5.5 (a to c) illustrates the stand-to-sit lean angle (°) for the single-task (ST) (25.0 ± 9.9°), as well as the cognitive-motor (27.2 ± 9.2°) and motor-motor (23.1 ± 8.0°) dual-task conditions, respectively, during the 5TSTS test.

The ANOVA revealed a difference between the three conditions on average ($F(2,27) = 4.79$, $p = 0.02$). Additional, post-hoc comparisons revealed differences between ST and DTCM conditions (9.3%; $p = 0.01$; $g = 0.24^{S}$), as well as between the DTCM and DTMM conditions (8.9%; $p = 0.01$; $g = 0.45^{M}$). However, no difference was found between ST and DTMM conditions (-0.1%; $p = 0.98$; $g = 0.19^{S}$).

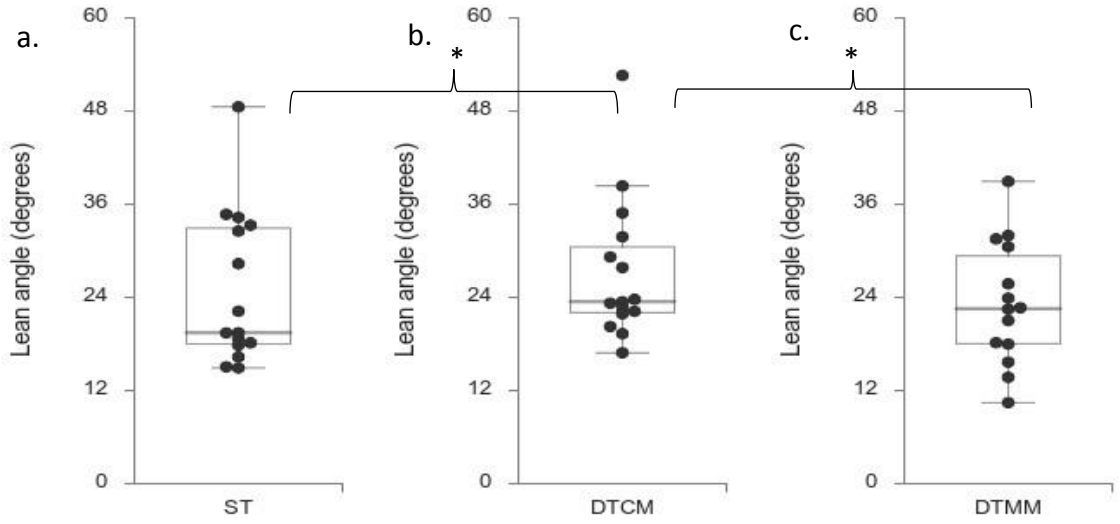

Figure 5.5 The box dot plots (a, b, and c) illustrate the single-task and dual-task a, b, and c stand-to-sit lean angles for the cognitive-motor and motor-motor tasks, respectively. ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

The DTi for the DTCM condition had a median of -10.6% (IQR = -22.2 to -4.7%). The DTi for the DTMM condition had a median of 3.8% (IQR = -10.1 to 9.1%). There was no difference in DTi between the two dual-task conditions (p = 0.72).

5.2.2 Transitioning between turning

a. Turn duration

Figure 5.6 (a, b, and c) illustrates the 360° turning duration (seconds) of the single- (4.5 ± 1.1s) and dual-task conditions, specifically the DTCM (4.6 ± 1.1s) and DTMM (4.9 ± 1.2)s, respectively.

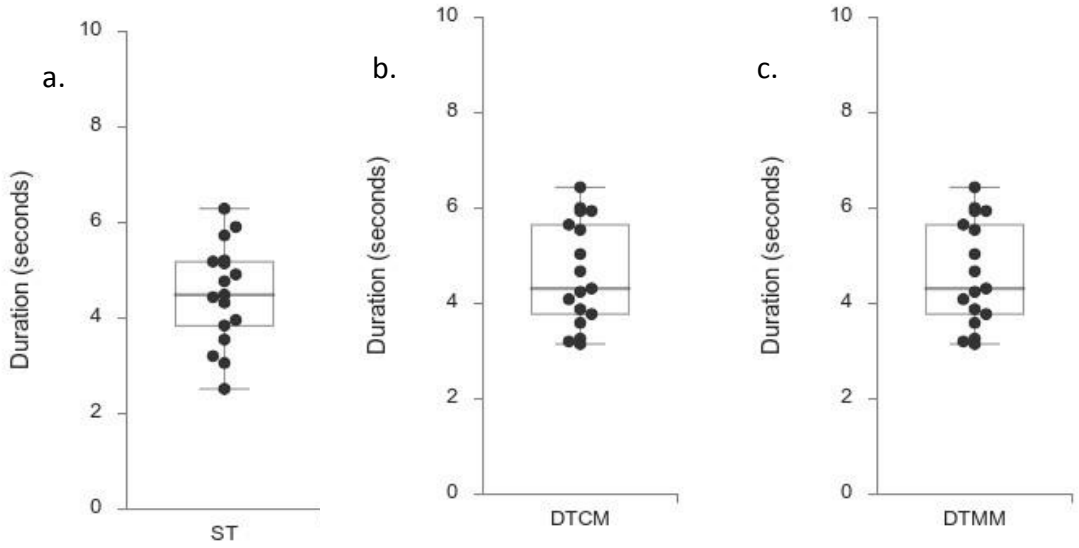

Figure 5.6 The box dot plots (a, b, and c) illustrate the single-task and dual-task turning durations for the cognitive-motor and motor-motor tasks, respectively. ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

The ANOVA revealed no differences between the conditions ($F(2,31) = 0.99$, $p = 0.38$). Similar, post-hoc comparisons revealed no differences between ST and DTCM (2.9%; $p = 0.66$; $g = 0.12^{N}$); nor ST and DTMM conditions (9.1%; $p = 0.18$; $g = 0.31^{S}$). Furthermore, no difference was found between DTCM and DTMM conditions (-5.8%; $p = 0.35$; $g = 0.19^{S}$).

The DTi for the turn duration during the DTCM condition displayed a median of -8.6% (IQR = -16.5 to -1.6%). The DTi of the DTMM task had a median of -4.1% (IQR: -16.9 to 1.0%). There was no difference in DTi between the two dual-task conditions ($p = 0.81$).

b. Turn velocity

Figure 5.7 (a to c) illustrates the turning velocity ($°.s^{-1}$) of the single- ($146.2 \pm 29.8°.s^{-1}$) and dual-task conditions, specifically the DTCM ($132.4 \pm 33.0°.s^{-1}$) and DTMM ($133.1 \pm 28.6°.s^{-1}$), respectively.

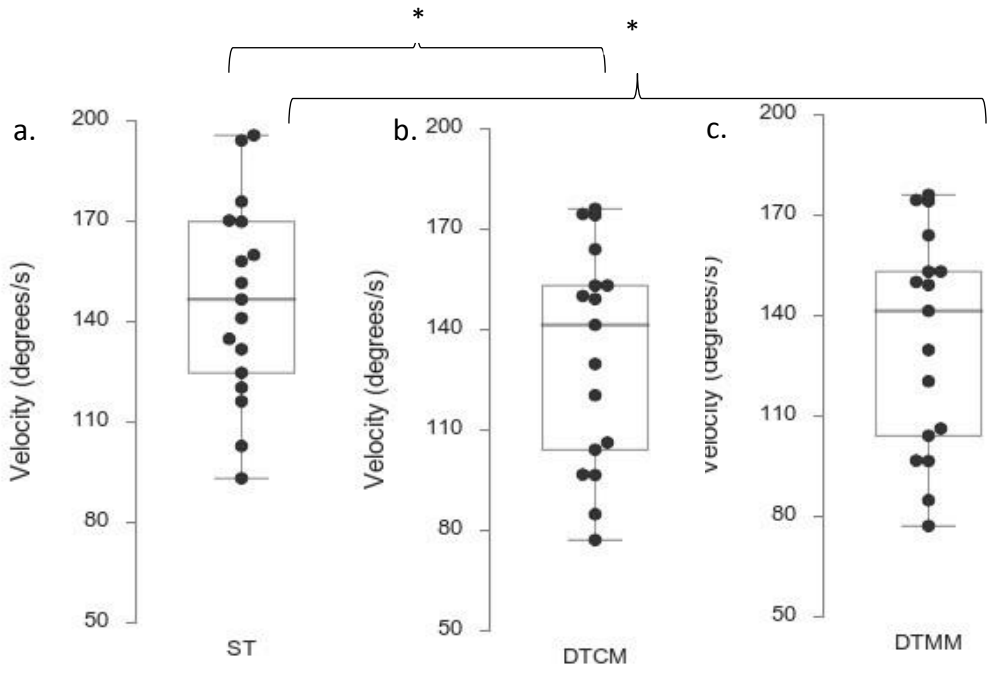

Figure 5.7 The box dot plots (a, b, and c) illustrate the single-task and dual-task turn velocity during the 360-degree turn test for the cognitive* -motor and motor-motor tasks, respectively. *: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

The ANOVA revealed differences between the three conditions on average ($F(2,31) = 6.87$, $p \leq 0.01$). Post-hoc comparisons revealed differences between ST and DTCM conditions (-9.5%; $p \leq 0.01$; $g = 0.43^{M}$), as well as between ST and DTMM conditions (10.3% ; $p \leq 0.01$; $g = 0.44^{M}$). However, there was no difference between DTCM and DTMM conditions (1%; $p = 0.78$; $g = 0.02^{N}$).

The DTg for turn velocity during the cognitive-motor task had a median of 9.8% (IQR = 3.8 to 13.4%. The DTg for the motor-motor task had a median of 8.8% (IQR = 3.8 to 14.1%). There was no difference in DTi between the two dual-task conditions ($p = 0.77$).

c. Turn angle

The turning angle (°) during both the single- (323.3 ± 68.8°) and dual-task conditions, i.e. the DTCM (301.8 ± 85.6°) and DTMM (324.4 ± 53.9°), are illustrated in Figure 5.8 (a to c), respectively.

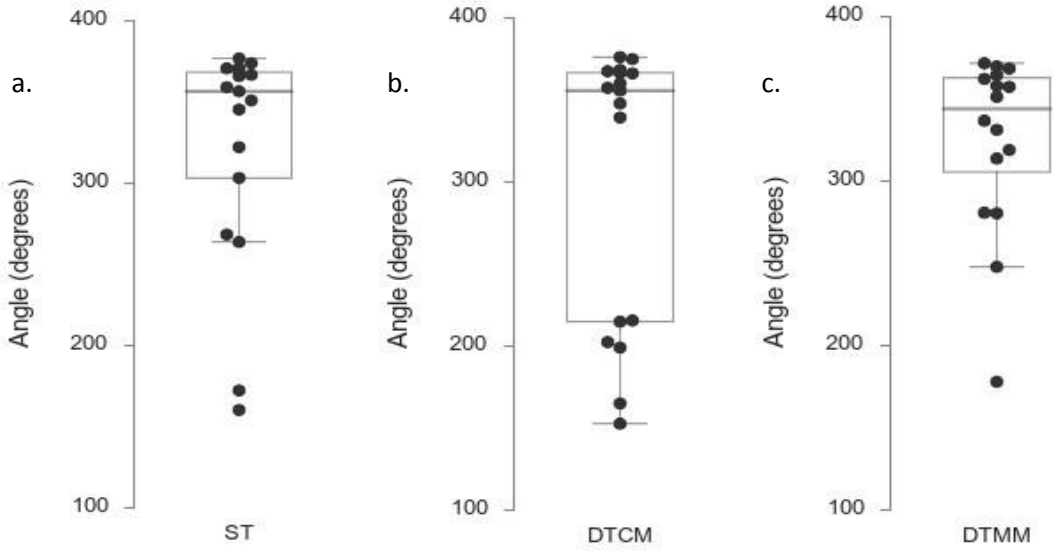

Figure 5.8 The box dot plots (a, b, and c) illustrate the single-task and dual-task turn angle during the 360-degree turn test for the cognitive-motor and motor-motor tasks, respectively. *: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

The ANOVA revealed no difference between the three conditions ($F(2,31) = 1.30$, $p = 0.29$). Similar, post-hoc comparisons revealed no differences between both ST and DTCM (-6.7%; $p = 0.17$; $g = 0.27^{S}$), and between ST and DTMM conditions (-0.1%; $p = 0.98$; $g = 0.02^{N}$). Furthermore, no difference was found between DTCM and DTMM conditions (-6.7%; $p = 0.18$; $g = 0.31^{S}$).

The DTg for the turning angle during the DTCM task had a median of 2.3% (IQR: -2.0 to 4.7%). While the DTg for the turning angle presented during the DTMM task condition had a median of 0.7% (IQ: -3.0 to 4.0%). There was no difference in DTi between the two dual-task conditions ($p = 0.91$).

5.2.3 Correct response rate

DTCM condition: Transitioning during sitting and standing position's

The correct response rate (CRR; %) for the 5TSTS task revealed an average of 20.9 ± 11.9% correct responses. The only significant finding found was between the CRR and the total 5TSTS duration (-0.68; $p \leq 0.01$). The rest of the correlations between CRR and sit-to-stand lean angle (-0.22; $p = 0.43$) and between CRR and stand-to-sit lean angle (-0.36; $p = 0.18$) revealed no statistically significant differences ($p \geq 0.05$).

DTCM condition: Transitioning during turning

The CRR of the cognitive-motor condition during turning was 30.7 ± 23.8%. Correlations between CRR and turn duration (-0.08; $p = 0.76$), CRR and turn angle (-0.02; $p = 0.93$) as well as between CRR and turn velocity (-0.14; $p = 0.6$) revealed no significant differences ($p \geq 0.05$).

DTMM condition: Transitioning during sitting and standing position's and during turning

No single event of water spillage during the dual-task motor-motor condition was reported during any of the 5TSTS tests as well as during the 360-degree turn test.

Table 5.3 Summary of transitional variable results.

Transitional Variable	Sit-to-stand and stand-to-sit positions		
	ST	DTCM	DTMM
Total test duration (s)	18.87	31.71	22.58
Sit-to-stand duration (s)	1.27	1.27	1.30
Stand-to-sit duration (s)	0.94	0.97	0.97
Sit-to-stand lean angle (°)	28.43	29.77	26.98
Stand-to-sit lean angle (°)	24.90	27.21	24.89
Transitional Variable	**ST**	**In phase turning**	**DTMM**
		DTCM	
Turn duration (s)	4.50	4.63	4.91
Turn Velocity (°/s)	146.27	132.44	131.16
Turn angle (°)	323.30	301.77	322.85

ST: Single-task; DTCM Dual-task cognitive-motor; DTMM: Dual-task motor-motor; °: degrees; °/s: degrees per second

5.3 Prefrontal hemodynamic variables

5.3.1 During the sit-to-stand, and stand-to-sit movement's

a. Relative % change (Δ) in oxygenated haemoglobin (HbO_2) from baseline:

Overall comparisons of brain site, side, and the three conditions (Side X Site X Condition) There was no difference between *Side X Site X Condition* (p = 0.81). Post-hoc analyses for ST conditions showed that there were no significant differences in Δ HbO_2 between the four PFC sites. However, there was a significant difference within the DLPF between ST and DTCM conditions for the unaffected side (1000%; p = 0.04; $g = 0.1^{N}$).

Comparing across the three conditions:

When looking at the Δ HbO_2 in the PFC from baseline during the 5TSTS test, irrespective of the A and UA sides, between the three conditions i.e. ST, DTCM and DTMM. There was no difference between ST and DTMM conditions (41.7%; p = 0.22; $d = 0.24^{S}$), nor between the

DTMM and DTCM conditions (27.9%; p = 0.24; *d* = 0.07^{N}). However, there was a difference between the Δ HbO_2 between ST and DTCM conditions (81.3%; p = 0.01; *d* = 0.27^{S}) (Figure 5.9).

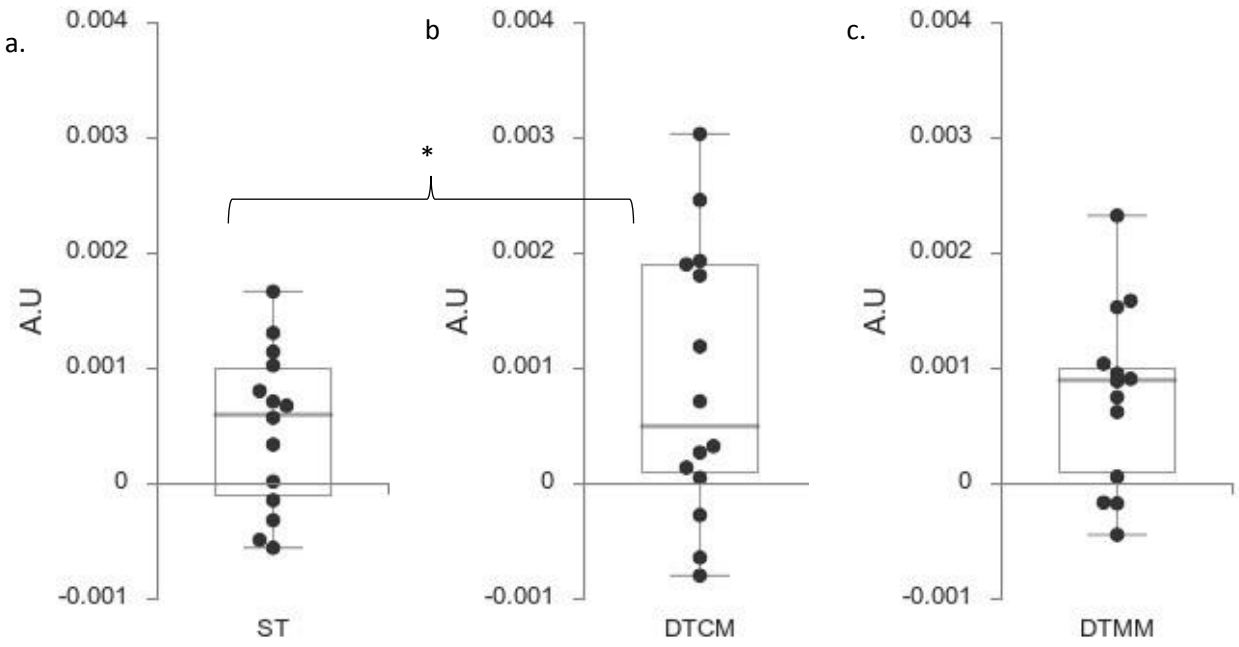

Figure 5.9 Relative change Δ in HbO_2 (A.U) from baseline to the task, during three different conditions (a, b, and c) of the 5TSTS. *: p < 0.05; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor; 5TSTS: Five times sit-to-stand.

Task condition vs. affected and unaffected side (Side X Condition):

When looking at the UA side, no difference was found between ST and DTMM, and between the two DT conditions. However, there was a difference between ST and DTCM (138.9%; p = 0.02; *d* = 0.35^{S}). No difference was found for the affected sides (p ≥ 0.05).

Means and standard deviations for *side X Condition* can be found in Addendum P

Figure 5.10 shows the UA side of the PFC for the relative change in HbO_2 from baseline, during the ST as well as two DT conditions.

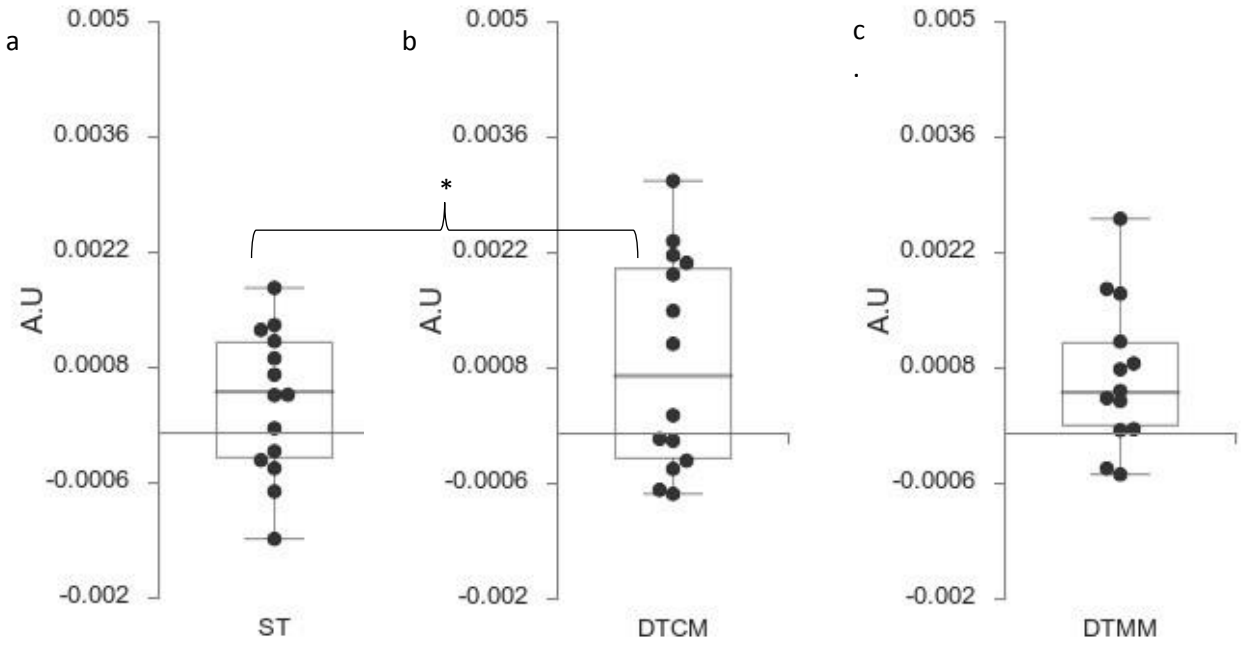

Figure 5.10 Relative change Δ in HbO_2 (A.U) from baseline to the task, during three different conditions (a, b, and c) of the 5TSTS test, for the unaffected side of the PFC. *: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor; 5TSTS Five times sit-to-stand.

Below, Figure 5.11 illustrates the box dot plots of the affected side of the PFC for the relative change in HbO_2 from baseline, during the ST as well as two DT conditions.

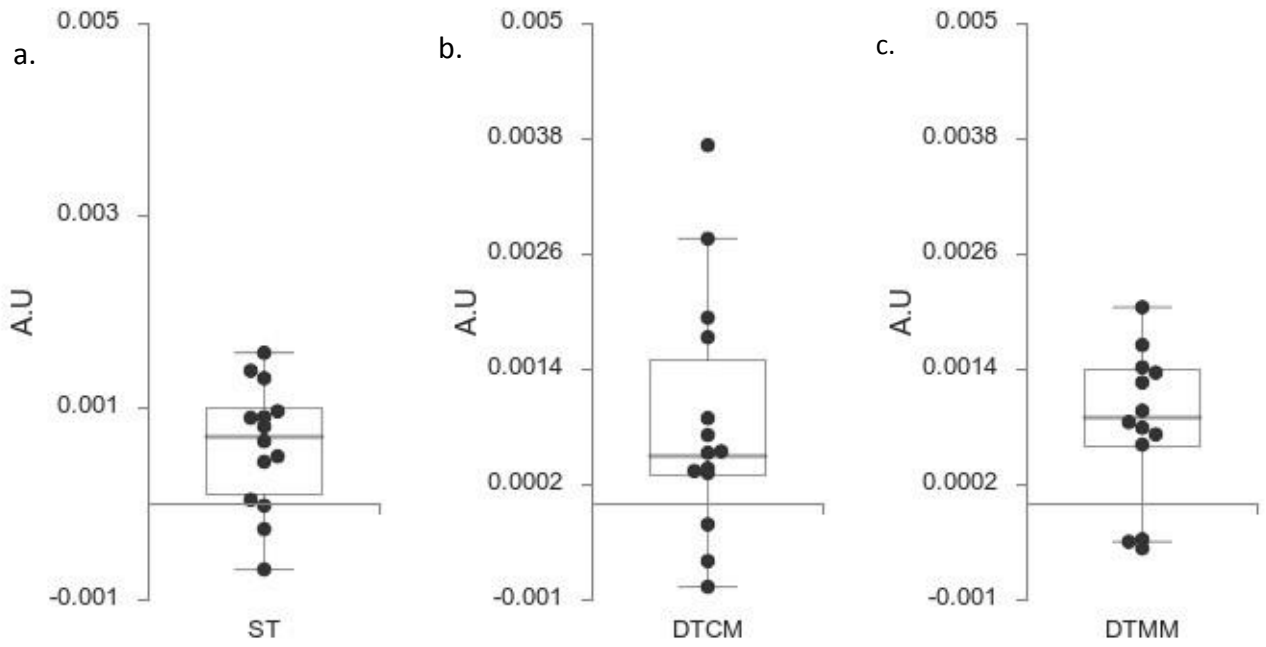

Figure 5.11 Relative change Δ in HbO_2 (A.U) from baseline to the task, during three different conditions (a, b, and c) of the 5TSTS test, representing the affected side of the PFC. *: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor; 5TSTS: Five times sit-to-stand.

Comparing prefrontal cortical sites

Based on the PFC sites (i.e. Ventrolateral (VLPF), Orbitofrontal (OFPF), Frontopolar (FPPF), and Dorsolateral (DLPF)), there were significant main effects, and based on the conditions, there was a trend for a main effect ($p = 0.049$). However, for all other variables, there was no difference during the interactions and main effects ($p \geq 0.05$).

Task condition vs. PFC sites (Site X Condition)

For the change in HbO_2 during the ST conditions, when comparing the four brain sites, the only difference found was between the VLPF cortex, and the OFPF cortex (275%; $p = 0.03$; $d = 0.49^{M}$). There was a tendency for the DLPF cortex to differ from the OFPF (172.7%; $p = 0.07$; $d = 0.50^{M}$). There was no difference between any of the brain sites for the DTMM condition ($p \geq 0.05$). During the DTCM condition, the only difference in

the Δ HbO_2 found was between the VLPF and OFPF, where there was a tendency to differ (129.2%; p = 0.046; *d* = 0.35^{M}).

b. Relative change (Δ) in deoxygenated Haemoglobin (HbR)

Overall comparisons of brain site, side, and the three conditions (Side X Site X Condition)

Based on the PFC sites (i.e. Ventrolateral (VLPF), Orbitofrontal (OFPF), Frontopolar (FPPF), and Dorsolateral (DLPF)), there were significant main effects (p ≤0.01). Specifically, between the DLPF and OFPF, VLPF and OFPF, as well as between the FPPF and OFPF. However, for all other variables, there was no difference during the interactions and main effects (p ≥ 0.05).

For ST conditions, a difference was found between FPPF and OFPF for the unaffected side (-160%; p = 0.03; *d* = 0.75^{L}). In addition to this, there were trends for UA VLPF and FPPF to differ (-140%; p = 0.06; *d* = 0.62^{M}), as well as for UAVLPF and AVLPF to differ (350%%; p = 0.05; *d* = 0.46^{M}).

For DTMM conditions, no differences were found between sides (p ≥ 0.05). However, when looking at the brain sites, there was a significant difference between DLPF and OFPF of the affected side (-156%; p = 0.03; *d* = 1.05^{L}), as well as between VLPF and OFPF of the affected side (-156%; p = 0.03; *d* = 0.57^{M}). Furthermore, there was a tendency for DLPF and OFPF of the UA side to differ (-120%; p = 0.05; *d* = 0.7^{M}), also seen between FPPF and OFPF of the affected side (-170%; p=0.07; *d* = 0.86^{L}).

For the DTCM condition, there was a significant main effect between VLPF and OFPF of the affected side (-88.9%; p = 0.02; *d* = 0.72^{M}). Additionally, there was a tendency for significant main effects between DLPF and OFPF of the unaffected side (-100%; p =

0.07; *d* = 0.68^{M}), as well as between sides for the VLPF (200%; p = 0.08; *d* = 0.56^{M}).

Comparing across the three conditions

No significant differences were found between the three conditions (Graph 5.12 a, b, and c), irrespective of sides. There was, however, a tendency for ST to differ from DTCM conditions (100%; p = 0.08*; d* = 0.22^{S})

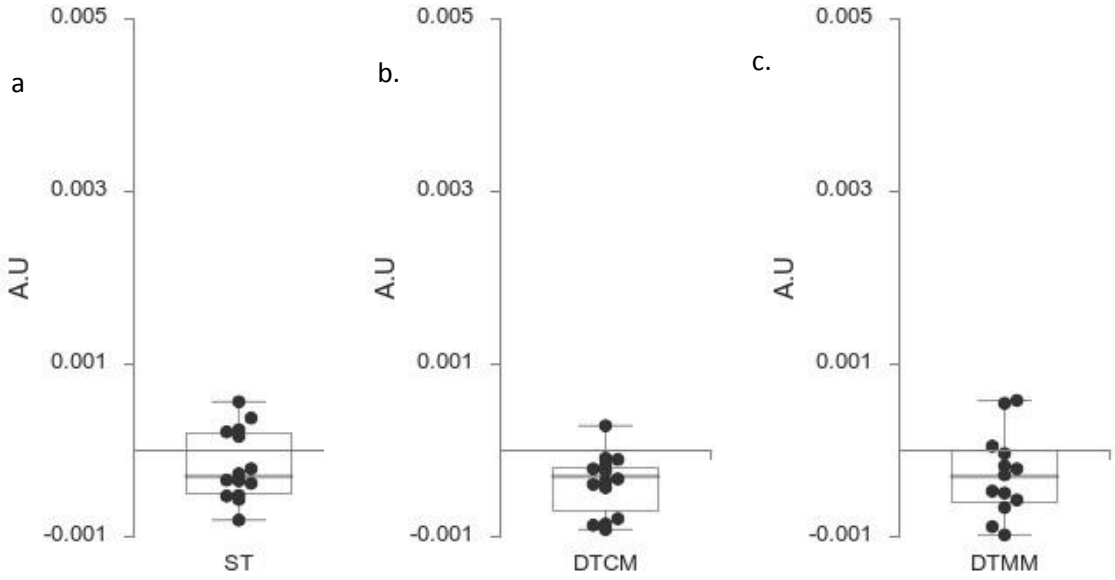

Figure 5.12 A graph to show the relative change Δ in HbR (A.U) under three different conditions (a, b, and c), during the 5TSTS test. *: p < 0.05; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor; 5TSTS: Five times sit-to-stand.

Task condition vs. affected and unaffected side (Side X Condition)

Means and standard deviations for side and condition can be found (Addendum P). Looking at the A and UA sides (shown in graph 5.13 a, b, and c, as well as 5.14 a, b, and c), no significant differences were found between variables. However, there was a tendency for ST and DTCM conditions to differ for the unaffected side (-100%; p = 0.09; *d*= 0.32^{S}).

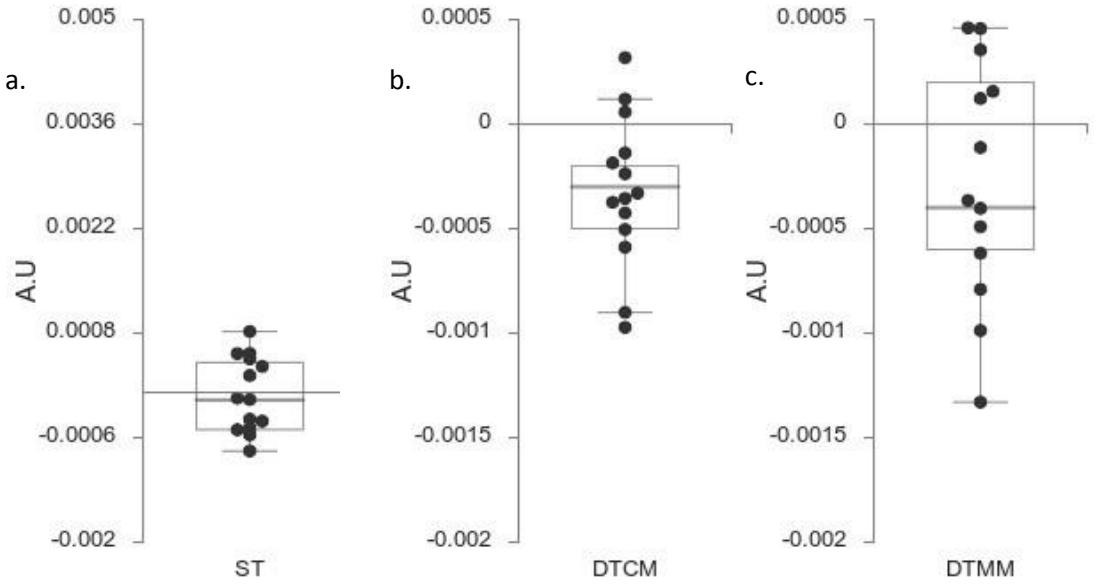

Figure 5.13 Relative change Δ in HbR (A.U) from baseline to the task, during three different conditions (a, b, and c) of the 5TSTS test, representing the unaffected side of the PFC. *: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor; 5TSTS: Five times sit-to-stand.

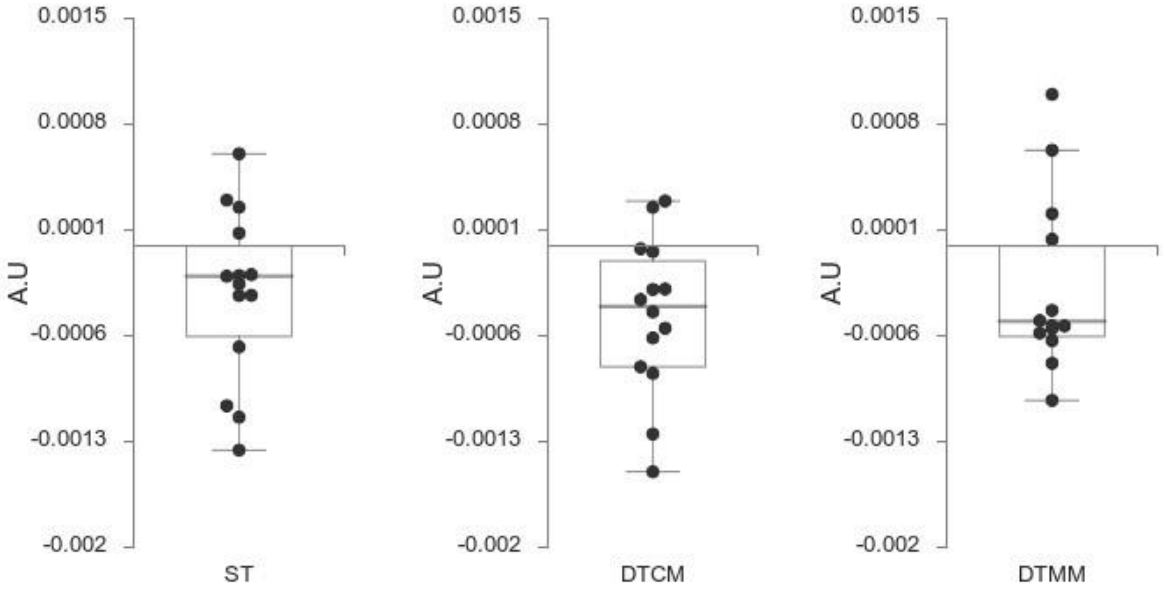

Figure 5.14 Relative change Δ in HbR (A.U) from baseline to the task, during three different conditions of the 5TSTS test, for the affected side of the PFC. *: p < 0.05; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor; 5TSTS: Five times sit-to-stand.

Task condition vs. PFC sites (Site X Condition)

When comparing the different brains sites, significant differences were evident between the DLPF and OFPF for ST (-186.7%; p = 0.02; $d = 0.69^{M}$), DTMM (-133.3%; p ≤0.01; $d = 0.89^{L}$), as well as DTCM (-100%; p = 0.02 ; $d = 0.63^{M}$) conditions. Additionally, differences were found between the VLPF and OFPF for MM (-150%; p = 0.01; $d = 0.53^{M}$) and CM (-100%; p = 0.04; $d = 0.53^{M}$) dual-task conditions. Lastly, comparing FPPF and OFPF, revealed significant differences between ST (-150%; p ≤0.01; $d = 0.85^{L}$) and MM (-166.7%; p = 0.05; $d = 0.67^{M}$) conditions.

c. *Difference in Haemoglobin*

Overall comparisons of brain site, side, and the three conditions (Side X Site X Condition)

The ANOVA showed no difference for interaction effects (p = 0.86). However, post-hoc analyses presented a significant difference in the unaffected side of the DLPF, from ST to DTCM conditions (695.2%; p = 0.03; $d = 0.69^{M}$).

The only other differences revealed were tendencies for HbDiff to differ, between the VLPF and FPPF region of the UA side, during ST conditions (-1180%; p = 0.06; $d = 0.42^{M}$), as well as within the VLPF region of the PFC for UA side, from ST to DTCM conditions (-1050%; p = 0.08; $d = 0.55^{M}$).

Comparing across the three conditions

The ANOVA revealed that for the PFC as a whole, and irrespective of A and UA sides, a significant main effect (p = 0.04) (see graph 5.15 a, b, and c). Further investigation revealed a significant difference between ST and DTCM conditions (90.9%; p = 0.01; *d* = 0.31[S]).

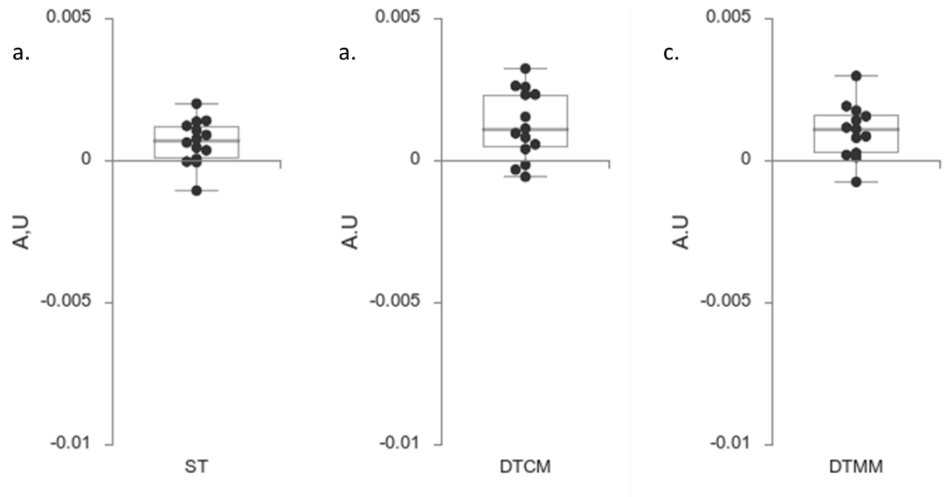

Figure 5.15 A graph to show the relative change in Hbdiff between the three different conditions (a, b, and c) of the 5TSTS test. *: p < 0.05; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor. 5TSTS: Five times sit-to-stand.

Task condition vs. affected and unaffected side (Side X Condition)

Means and standard deviations for side and condition can be found (Addendum P). There was no difference indicated for this interaction effect (p = 0.59). However, post-hoc analysis indicated a significant difference between ST and DTCM conditions for the unaffected side of the PFC (202.6%; p = 0.02; *d* = 0.4[M]). (See Figure 5.16 and 5.17)

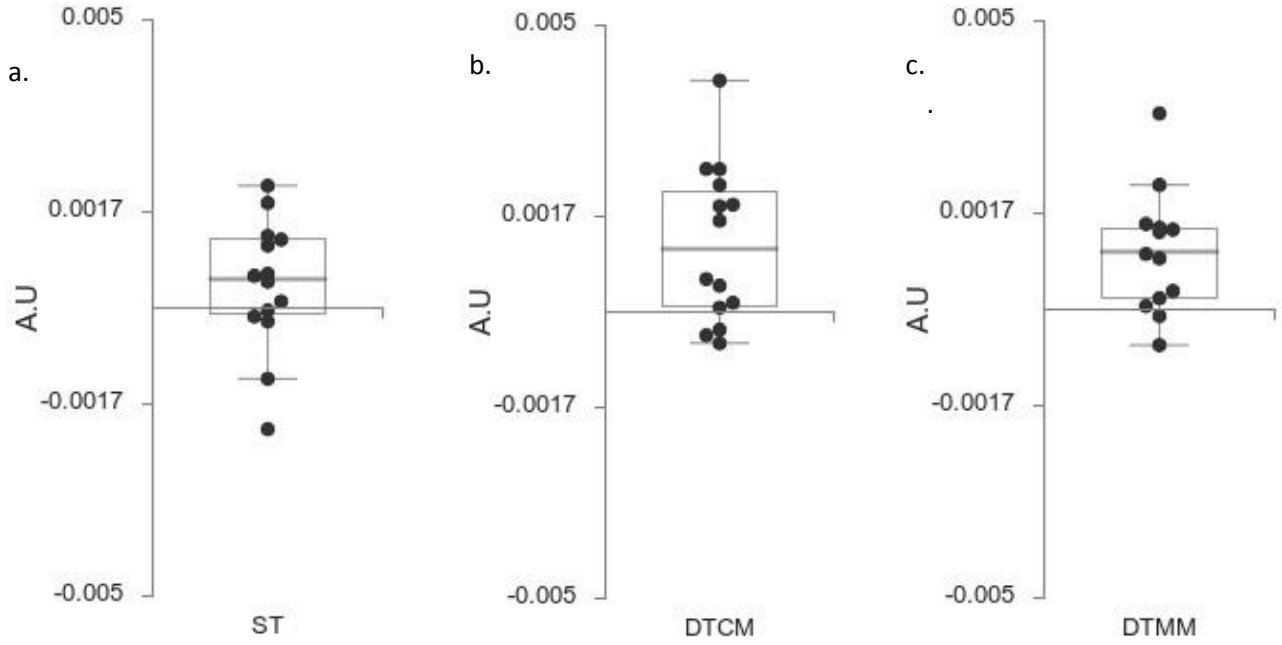

Figure 5.16 Relative change Δ in HbDiff (A.U) from baseline to the task, during three different conditions (a, b, and c) of the 5TSTS test, for the unaffected side of the PFC.

*: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor; 5TSTS: Five times sit-to-stand.

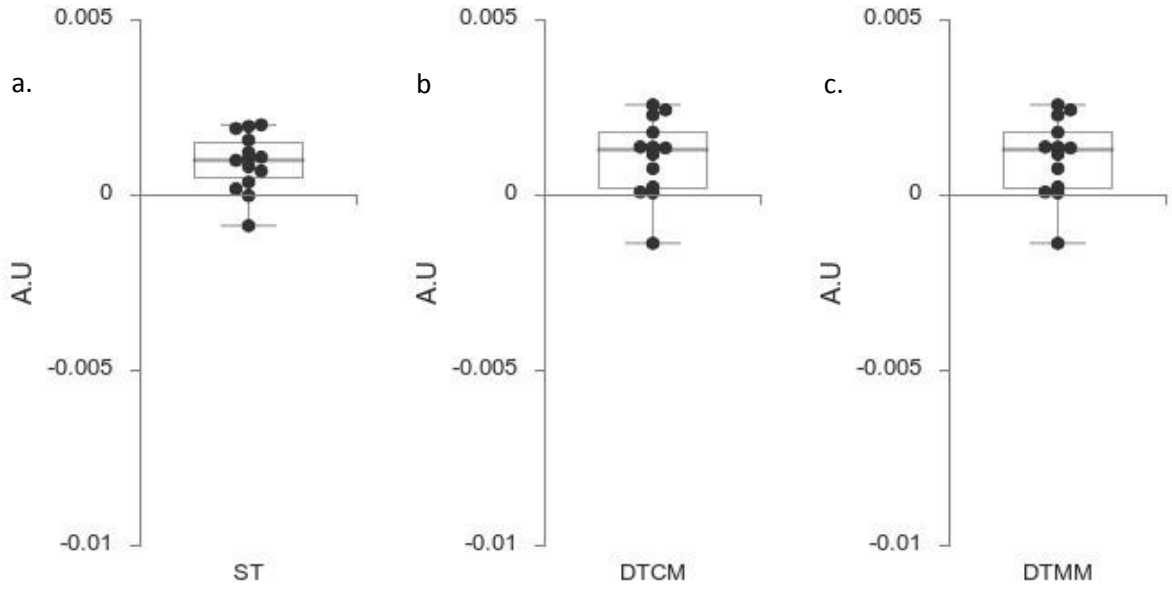

Figure 5.17 Relative change Δ in HbDiff (A.U) from baseline to the task, during three different conditions (a, b, and c) of the 5TSTS test, for the affected side of the PFC.*: p < 0.05; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor; 5TSTS: Five times sit-to-stand.

Task condition vs. PFC sites (Site X Condition)

The ANOVA showed no interaction effect (p = 0.93). Furthermore, additional analyses indicated no differences in HbDiff. There was, however, a tendency for Hbdiff to differ between the ST and the DTCM condition, within the DLPF, irrespective of the brain side (129.9%; p = 0.06; *d* = 0.45^{M})

5.3.2 During the turning movement of 360-degree turn

a. Relative Change (Δ) in Oxygenated Haemoglobin (HbO_2)

Overall comparisons of brain site, side, and the three conditions (Side X Site X Condition)

ANOVA indicated no differences for interaction effect (p = 0.92). However, further analyses revealed that when looking at the unaffected side, there was a difference in ΔHbO_2 within the OFPF region of the PFC, from MM to DTCM conditions (266.7%; p = 0.02; *g* = 0.55^{M}).

Comparing across the three conditions

The ANOVA revealed A trend for HbO_2 to differ (p = 0.06). More specifically, post-hoc analyses indicated a trend for HbO_2 to differ from ST to CM conditions (100%; p = 0.09; *d* = 0.16^{S}), as well as a significant difference between MM and CM conditions (100%;p = 0.02 *d* = 0.21^{S}). Cognitive-motor (CM) conditions lead to the greatest increase in HbO_2, whereas the MM condition resulted in a decrease in HbO_2. Graph 5.18 below displays the three conditions during the 360-degree turn test.

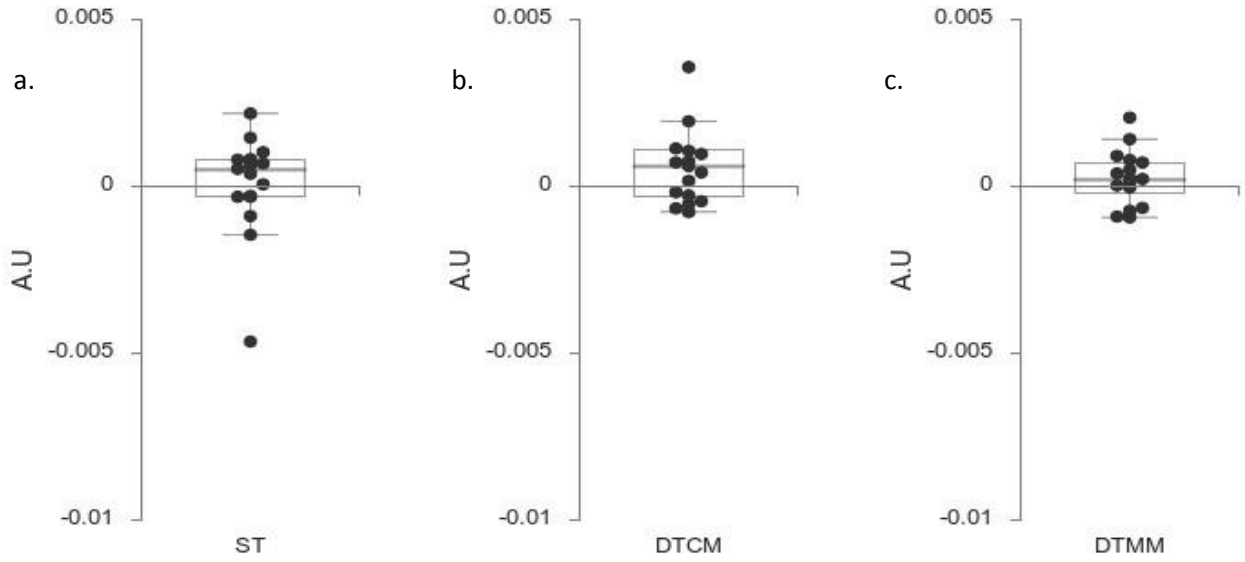

Figure 5.18 Relative change Δ in HbO_2 (A.U) from baseline to the task, during three different conditions (a, b, and c) of turning *: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor; 5TSTS: Five times sit-to-stand.

Task condition vs. affected and unaffected side (Side X Condition)

The ANOVA revealed no interaction effect ($p = 0.93$). Furthermore, Post-hoc showed no difference between conditions, irrespective of brain site, except for a tendency for Δ HbO_2 to differ for the unaffected side from MM to CM conditions. (256.3%; $p = 0.07$; $d = 0.24^S$).

Means and standard deviations for *side X Condition* can be found (Addendum P). Furthermore, figures 5.19 and 5.20 display the relative change Δ HbO_2 (A.U) from baseline to the task, during three different conditions of turning for the affected and unaffected sides, respectively.

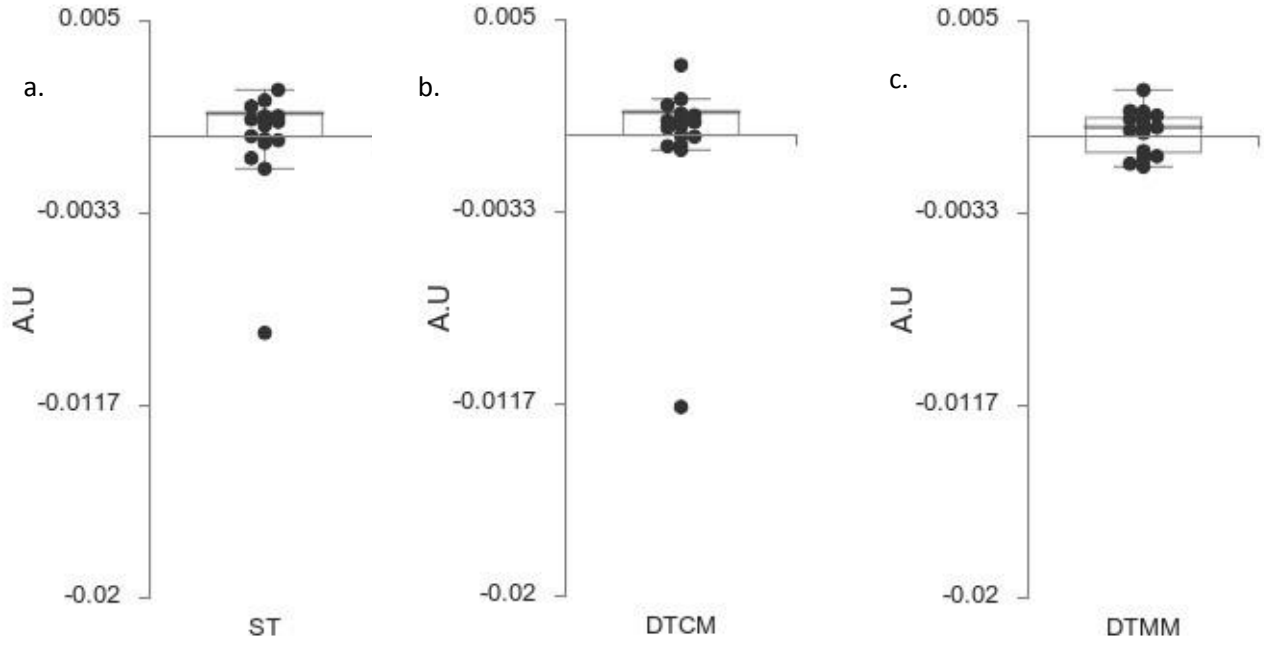

Figure 5.19 Relative change Δ in HbO_2 (A.U) from baseline to the task, during three different conditions (a, b, and c) of turning, for the unaffected side of the PFC.

*: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor; 5TSTS: Five times sit-to-stand

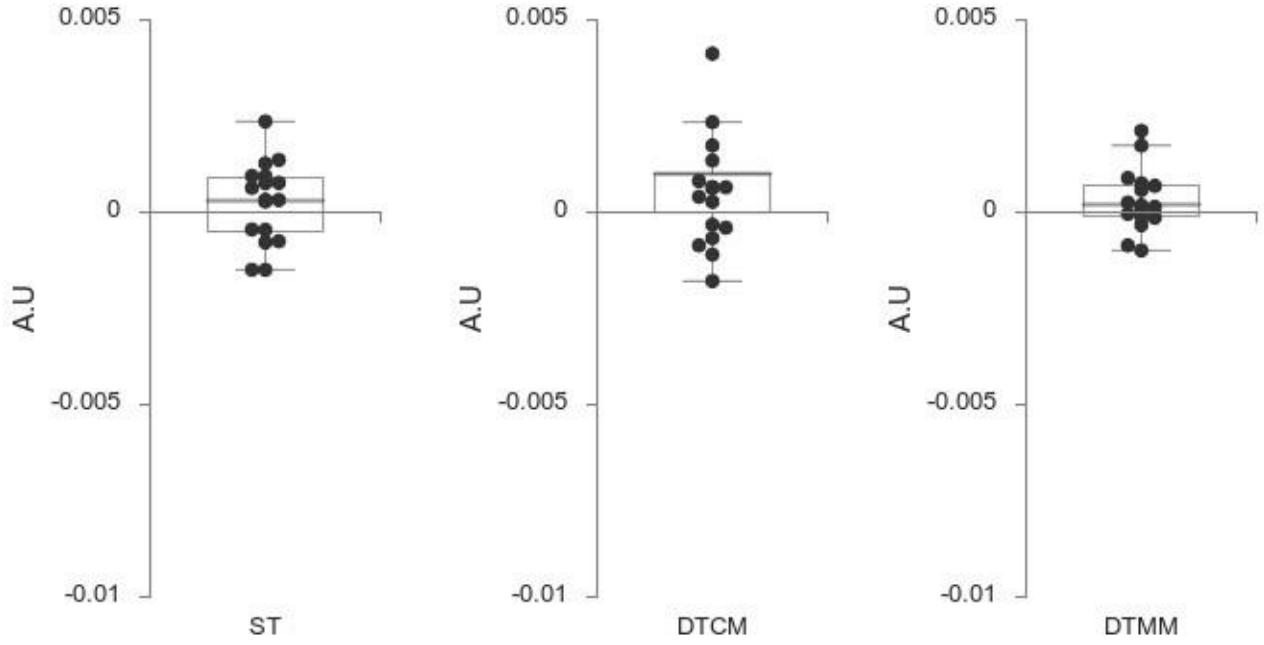

Figure 5.20 Relative change Δ in HbO_2 (A.U) from baseline to the task, during three different conditions (a, b, and c) of turning, for the affected side of the PFC.

*: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

b. Relative change (Δ) in deoxygenated Haemoglobin (HbR)

Overall compassions of brain site, side, and the three conditions (Side X Site X Condition)

ANOVA revealed no significant difference for interaction effect (p = 0.97). However, further investigation indicated that when looking at DTCM conditions, there was a tendency for the FPPF and OFPF to differ for the unaffected side (-104%; p = 0.05; $g = 0.78^{L}$). Similarly, still looking at CM conditions, there was a tendency for VLPF and OFPF to differ (-2600%; p = 0.08; $g = 0.48^{M}$). A significant difference was found in HbR during CM conditions for the affected brain region, between the FPPF and OFPF (-103.3%; p = 0.04; $g = 0.68^{M}$). The only difference found between conditions was a tendency for HbR to differ from ST to CM conditions, in the DLPF region (-257.9%; p = 0.08; $g = 0.65^{M}$).

Comparing across the three conditions

The ANOVA revealed a significant difference between conditions (p = 0.04) (See figure 5.21). Further analyses revealed a significant difference in ΔHbR to differ from ST to DTCM conditions (200%; p = 0.02; $d = 0.24^{S}$), as well as for MM and DTCM conditions to differ (100%; p = 0.04; $d = 0.24^{S}$), irrespective of side, and reflective of the entire PFC.

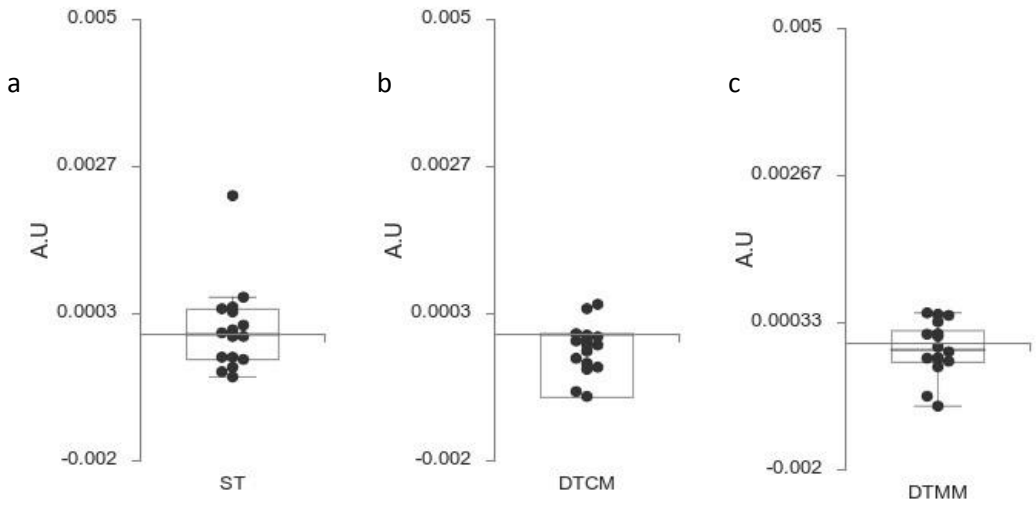

Figure 5.21 Relative change Δ in HbR (A.U) from baseline to the task, during three different conditions (a, b, and c) of turning. *: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

Task condition vs. affected and unaffected side (Side X Condition)

The ANOVA revealed no difference for interaction effects ($p = 0.63$). After further investigation, when looking at the affected side, A significant difference was found between ST and DTCM conditions ($p = 0.03$; $d = 0.35^{S}$).

Means and standard deviations for *side X Condition* can be found (Addendum P).

Task condition vs. PFC sites (Site X Condition)

The ANOVA showed no difference for interaction effects ($p = 0.90$). Post-hoc revealed significant differences for ST, between the DLPF and FPPF (-122.5%; $p = 0.01$; $d = 0.6^{M}$), and between OFPF and FPPF (-300%; $p \leq 0.01$; $d = 0.75^{L}$). The only finding present for the MM condition, were tendencies for VLPF and OFPF to differ (xx%; $p = 0.07$; $d = 0.44^{M}$) and for FPPF and OFPF to differ (-211.11%; $p = 0.06$; $d = 0.53^{M}$). Looking at DTCM conditions,

the only significant difference found was for HbR to differ between FPPF and OFPF brain region.

Furthermore, there was a tendency for HbR to differ between the VLPF and OFPF region (-104%; p = 0.08; d = 0.37^{S}).

Furthermore, Figure 5.22 and 5.23 display the relative change Δ in HbR (A.U) from baseline to the task, during three different conditions of turning, for the A and UA side of the PFC

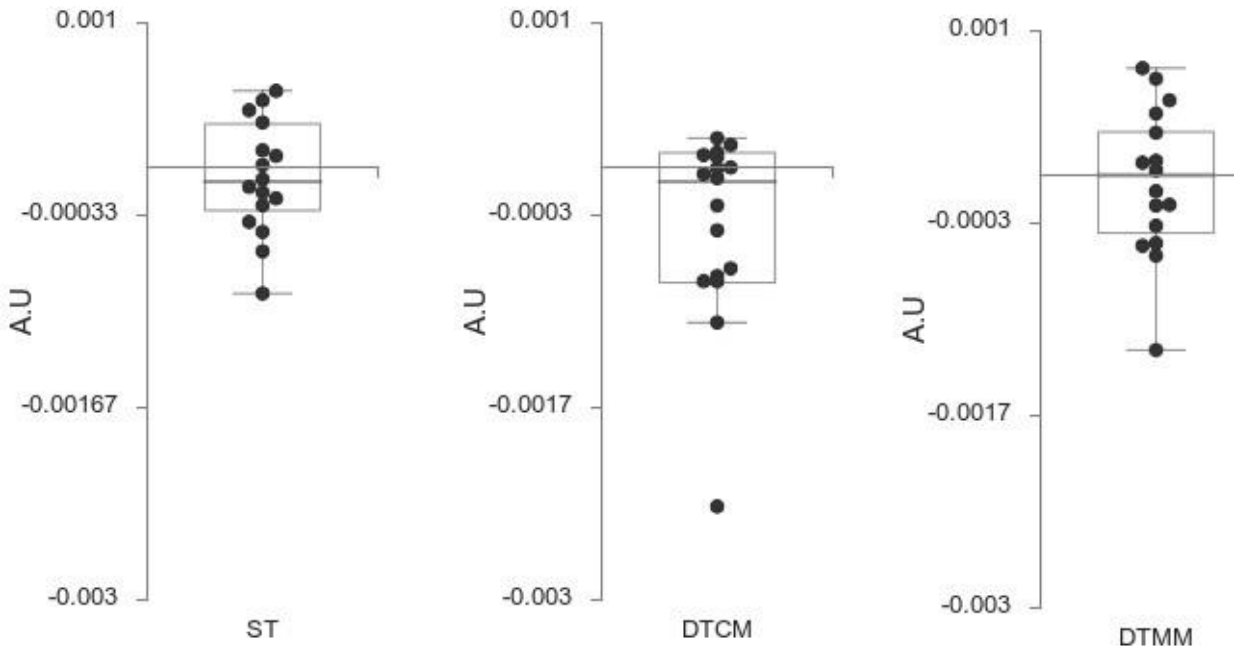

Figure 5.22 Relative change Δ in HbR (A.U) from baseline to the task, during three different conditions (a, b, and c) of turning, for the unaffected side of the PFC.

*: p < 0.05; ST: Single- task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

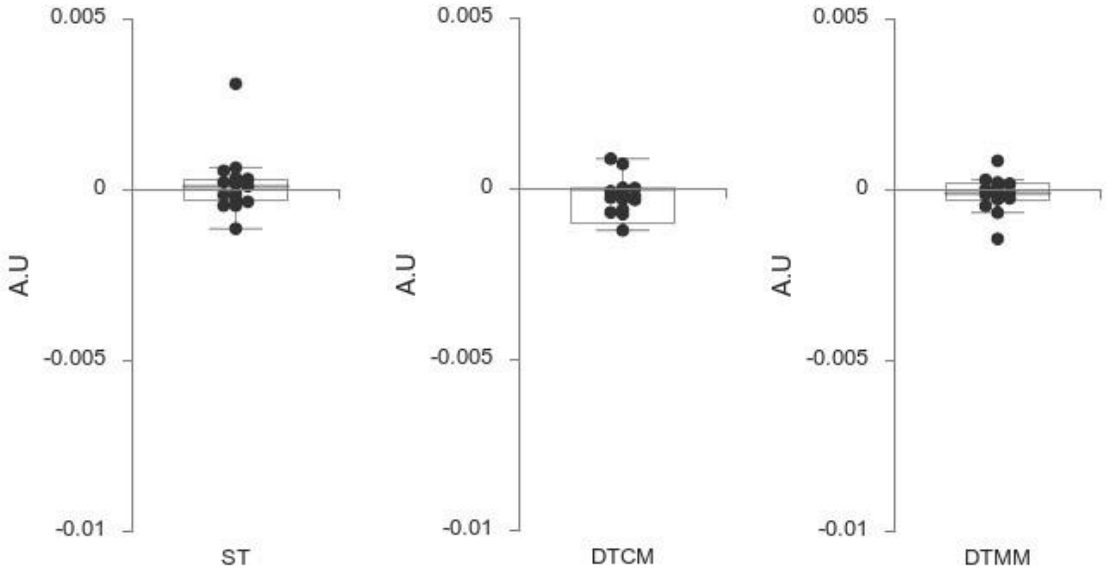

Figure 5.23 Relative change Δ in HbR (A.U) from baseline to the task, during three different conditions (a, b, and c) of turning, for the affected side of the PFC. *: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

c. The difference in Haemoglobin (HbDiff)

Overall compassions of brain site, side, and the three conditions (Side X Site X Condition)

When looking at the unaffected side of the PFC, the only difference found was a tendency for HbDiff to differ, within the OFPF brain region of the unaffected side, between MM and DTCM conditions (390.48%; $p = 0.06$; $g = 0.6^{M}$)

Comparing across the three conditions

The ANOVA revealed significant main effects ($p = 0.01$). Post-hoc analysis showed a significant difference for HbDiff to differ between the ST and CM conditions (152.8%; $p = 0.02$; $d = 0.24^{S}$) as well as between MM and CM conditions (111.11%; $p \leq 0.01$; $d = 0.29^{S}$) (See figure 5.24 below).

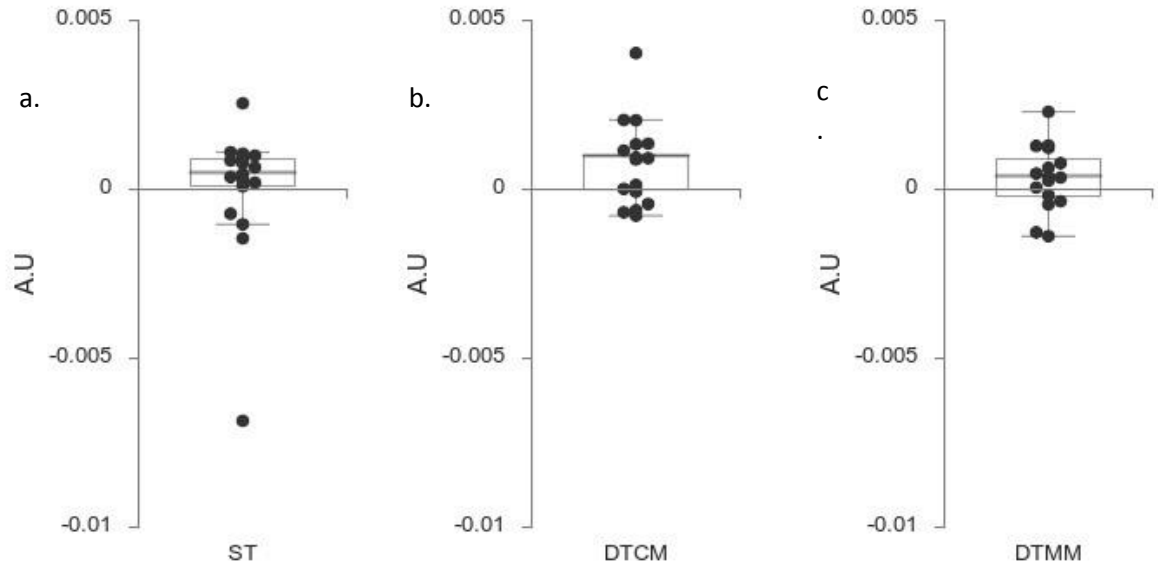

Figure 5.24 Relative change Δ in HbDiff (A.U) from baseline to the task, during three different conditions (a, b, and c) of turning. *: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

Task condition vs. affected and unaffected side (Side X Condition)

The ANOVA revealed no significant difference for interaction effects ($p = 0.95$). However, further analyses revealed tendencies for HbDiff in the PFC to differ. Specifically, when looking at the unaffected side between MM and DTCM conditions (128.7%; $p = 0.06$; $d = 0.28^{S}$). Similarly, when looking at the affected side, there was a tendency for HbDiff to differ from MM to DTCM conditions (98.5%; $p = 0.05$; $d = 0.3^{S}$).

Means and standard deviations for side and the condition can be found (Addendum P) Furthermore, see Figure 5.25 and 5.26 below.

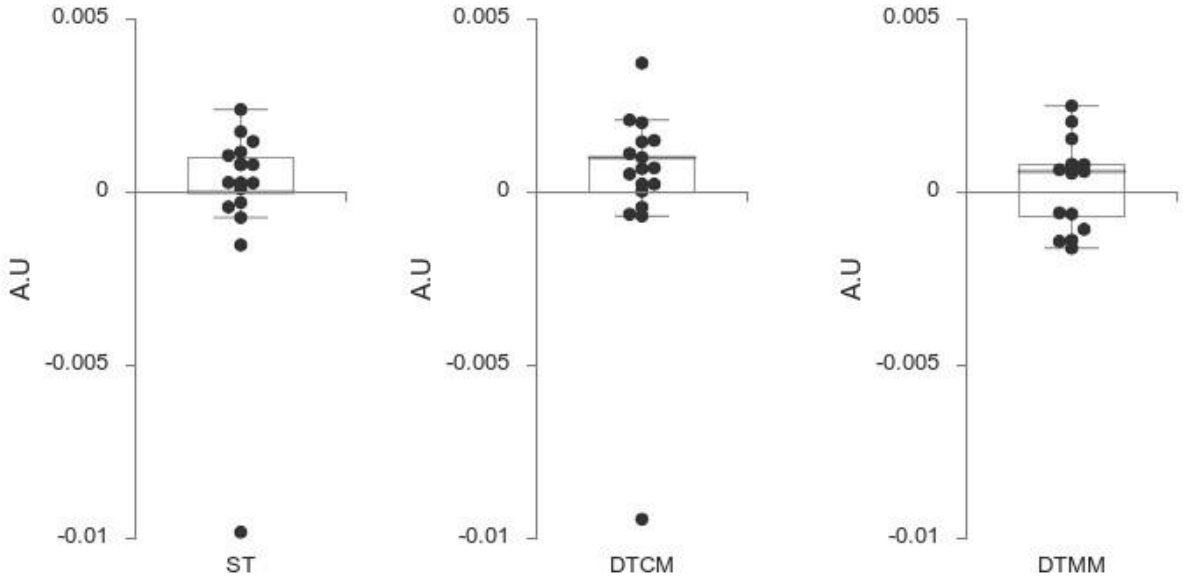

Figure 5.25 Relative change Δ in HbDiff (A.U) from baseline to the task, during three different conditions (a, b, and c) of turning, for the unaffected side of the PFC.

*: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

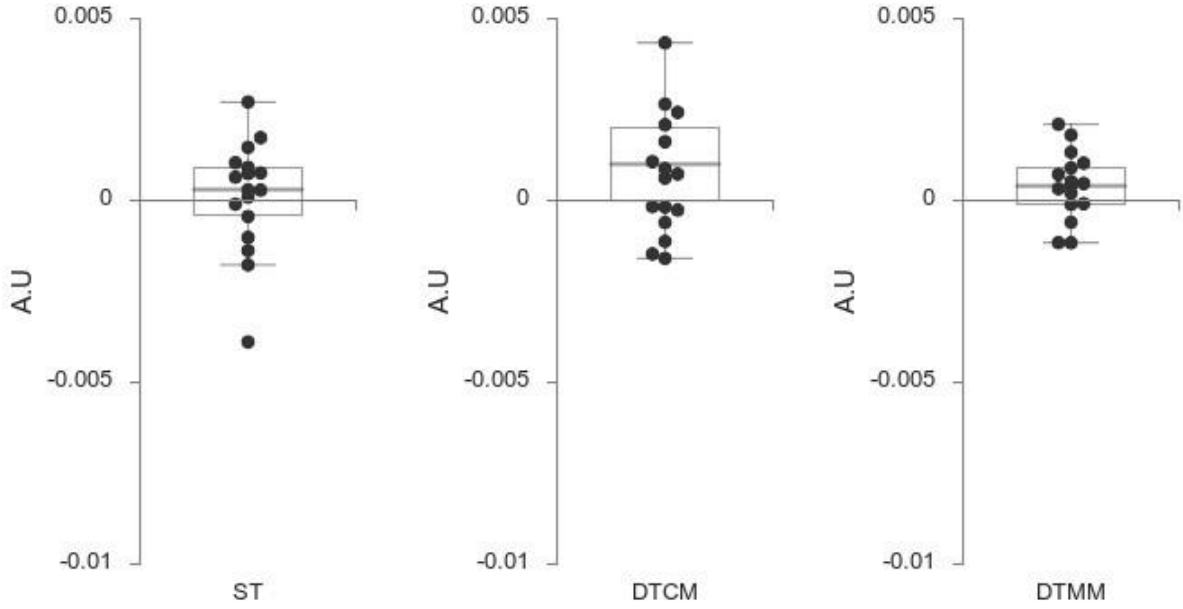

Figure 5.26 Relative change Δ in HbDiff (A.U) from baseline to the task, during three

different conditions (a, b, and c) of turning, for the affected side of the PFC. *: $p < 0.05$; ST: Single-task; DT: Dual-task; CM: cognitive-motor; MM: Motor-motor.

Task condition vs. PFC sites (Site X Condition)

When looking at the OFPF brain region, a significant difference was found in HbDiff between MM and DTCM conditions (350.9%; $p = 0.04$; $d = 0.49^{M}$).

Chapter 6

Discussion

The main aim of this study was to investigate the effects of prefrontal cortical (PFC) activation during single-task (ST), dual-task motor-motor (DTMM) as well as dual-task cognitive-motor (DTCM) conditions of chronic stroke survivors while carrying out select transitional movements (i.e. turning, sit-to-stand and stand-to sit). Furthermore, the secondary aims were to assess dual-task interference (DTi) during DTCM and DTMM transitional movements, as well as to describe any differences in PFC activation between the main PFC sites, while comparing affected and unaffected sides in chronic stroke survivors.

The present chapter will begin by discussing the characteristics of the participants who took part in the study, and how this may have affected the findings. Thereafter, the transitional movements will be addressed for the five times sit-to-stand test (5TSTS), followed by the in-place 360° turn test. Finally, the relative hemodynamic changes in the PFC will be discoursed, for the sit-to-stand-to-sit transitions, and the in-place turning, respectively.

6.1 Participants

The age range of participants was very heterogeneous, varying between 44 and 81 years of age. Previous studies have shown that postural control decrements start at relatively young ages, worsen further from about 60 years of age (Era et al., 2006), and deteriorate yet more from 70 years onwards (Michalska et al., 2021). Therefore, it is expected to find postural control deficits in the participants of the current study, based on their ages. These age-related postural control deficits could be attributed to reduced sensory feedback (i.e. visual, vestibular and somatosensory) (Baltich et al., 2015), poor muscular fitness (in particular muscular strength) (Chen et al., 2013), physical deformities, forward posture (Szot et al., 2008), poor cognition, and/or degenerated motor responses (Hsiao & Cho, 2012). Moreover, age-related deficits are intensified when a person suffers a stroke. For instance, stroke survivors typically demonstrate even more reduced muscle strength compared to their age

match healthy counterparts (Mohammad & Mirshoja, 2018). And in chronic stroke survivors muscle strength is fundamental in rising from a chair (Mohammad & Mirshoja, 2018). Therefore, when interpreting the findings of the current study, it is important to take into consideration the age of the participants, not only the stroke pathology, and that the participants varied a lot in age. Which may explain the variability observed in the findings of this investigation (as illustrated in the distribution of some of the dot-plots in Chapter 5). For instance, the participants in the current study might also show different transitional movement strategies based on their wide ranges in age and cognitive capabilities, regardless of the stroke diagnosis. A study by Weiss et al. (2016), found that older individuals (80.3 ± 7.6 years) tend to use different transitional movement strategies between the turn and stand-to-sit task in a timed-up-and-go (TUG) test based on their varied motor and cognitive abilities. However, regardless of the strategies employed, the longer this time interval between these TM were, the poorer the motor and cognitive functioning of the older adults (Weiss et al.; 2016).

Furthermore, a person's ability to complete dual-tasks are impaired with increasing age, and even more so in older chronic stroke survivors with motor and cognitive deficits (Yang et al., 2007). Furthermore, elderly individuals follow a different strategy when performing DT activities. This difficulty with dual-tasking typically presents itself as reduced postural control (Yang et al., 2007). It is thus expected that the age group in the current study, who show mild cognitive deficits might struggle when required to perform transitional movements (TM) during single- and dual-task conditions.

As mentioned in the previous paragraphs, along with postural control, cognition has an influence on dual-task abilities. The Montreal cognitive assessment (MoCA) scores (which represents global cognition) of the participants were 23.6 ± 3.6 A.U. This is similar to other chronic stroke survivor studies who reported 20.6 ± 6.4 (Schinkel-Ivy et al., 2016), 25.3 ± 2.4 (Yang et al., 2018), and 24.8 ± 2.9 (Yang et al., 2016), respectively. The typical range for MoCA scores in chronic stroke survivors ranges between 20 - 27 A.U (Pendlebury et al., 2012; Wong et al., 2009; Tu et al., 2013). Thus, confirming that the participants of this study are affected

by some degree of mild cognitive impairment, as expected (Chiti & Pantoni, 2014). Trail making test (TMT) scores are a measure of executive functioning (Muir et al., 2015). In the current study, the average difference (i.e. between part B and part A) was 116 ± 78.4 seconds for the participants. This is slightly more than Ohzuno et al. (2019), who reported an average of 95.3 ± 73.4 seconds. Accordingly, the poor executive functions of the participants may have impacted dual-task performance during the TMs.

When considering the sex difference in participants, this study consisted of 12 men, and 5 women. Previous research has indicated that sex does not play a major role in cognitive-motor interference during dual-task gait activities in healthy adults (Almajid & Keshner, 2019), however to date research has not confirmed this during dual-task transitional movements. Furthermore, the transition between turning and moving from sitting to standing and vice versa might be different between sexes, if one considers muscular strength differences (Patrella et al., 2005), as well as height differences (Roldán-Jiménez et al., 2019). Research suggests that the taller a person is, the wider the range of motion needed to get up from a chair, and this may have had an effect on the results. Thus, differences in strength, mobility, and height between sexes is another factor to consider. Furthermore, a study assessing the sit-to-stand movement between sexes of healthy elderly participants found that men showed a higher mean trunk motion mobility (Roldán-Jiménez et al., 2019). Considering the small sample size of the current study, it could not be determined if sex had an influence on the dual-task TM activities.

Research has indicated that the greatest improvements in the performance of the sit-to-stand movement in stroke survivors were displayed during the first 3 months post-stroke, accompanied by a plateau thereafter. Furthermore, it has been suggested that from 2 years post-stroke, disuse atrophy of the lower limbs might affect sit-to-stand performance (Darwish et al., 2019). The participants in this study's time since stroke onset ranged between 6-228 months. Thus, this vast range in time must be considered, in terms of muscle atrophy and the potential effects this has on one's ability to perform transitional movements.

The average body mass index (BMI) of the participants fell in the obese category. Even though this is expected in this population (Hu et al., 2007; Strazzullo et al., 2010), excessive BMI does have implications for a person's movement capabilities. In particular, various researchers have shown that the TM strategy between normal-weight and obese participants differs while performing sit-to-stand movements, with obese individuals displaying a less efficient movement strategy (Galli et al., 2000; Sibella et al., 2003). An increased body weight can be a key factor influencing a person's ability to perform an independent sit-to-stand task (Bohannon, 2007). Furthermore, obesity is known to affect functional capacity (Pataky et al., 2014).

In this study, the 2-minute walk test and the Fugl-Meyer assessment (FMA-LE) for the lower extremities were used to classify participants' functional capacity and motor impairments, respectively. On average, participants were able to walk 101.6 ± 25.6 meters throughout the designated 2 minutes. Previous research has shown that elderly (age 81-90 year) walked 150.4 ± 23.1 meters. This indicates that the participants in this study had less functional capacity compared to healthy and even older persons, which is expected in chronic stroke patients due to walking impairments (Polese et al., 2017). The average FMA-LE score for this study was 19.9 ± 4.8 A.U. When comparing this to previous chronic stroke survivors' studies, this is below the average of other studies that presented values of 28 ± 4 (Chaikeeree et al., 2018), 23.8 ± 6.2 A.U. (Chan et al., 2017), 25.8 ± 4.8 A.U. (Ohzuno et al., 2019), and 24.2 ± 5.3 A.U. (Plumer D'Amato et al., 2012). Additionally, when looking at the physical activity status of the participants, a mean of 5.8 ± 2.7 (A.U) was displayed, categorizing participants as 'under-active regular (light activities)', generally engaging in only light activities. Thus, the chronic stroke survivors in this study presented poor lower limb mobility when considering the below average 2-minute walk test distance, under-active activity status as well as below average FMA-LE scores.

6.2 Transitional movements

The secondary aim of this study was to assess the interference of a secondary concurrent task (dual-task) during transitional movements, and to compare two types of DT conditions i.e. cognitive-motor and motor-motor. Therefore, the following section will review the impact that these two types of DT conditions had on the behavioural variables during sit-to-stand-tosit as well as turning movements.

6.2.1 Transitioning between sitting and standing positions

The five times-sit-to-stand (5TSTS) test assesses muscular endurance, balance and functional mobility and is commonly used as a clinical assessment tool in the rehabilitation of stroke patients (Ghous et al., 2017). Chronic stroke survivors rely on lower extremity function and good postural control to enable them to transition from sit-to-stand and stand-to-sit positions in their everyday lives (Mohammadi & Mirshoja, 2018; Galli et al., 2008; Whitney et al., 2005). On average, the participants were able to complete the 5TSTS test in 18.9 ± 6.2 seconds, which was similar to other stroke survivors. For instance, Chan et al. (2017), reported an average of 23.8 ± 6.2 seconds in chronic stroke survivors. This result is consistent with Mong et al. (2010), who found that taking longer than 12 seconds to complete the 5TSTS test discriminates healthy adults from chronic stroke survivors, while Kwon (2014), found that over 9.9 seconds differentiated between healthy older adults and stroke survivors. Also considering that 15.5 seconds were found to be the cut off between fallers and non-fallers; the chronic stroke survivors in the current study scoring 19 seconds showed poor functional mobility and a higher risk for falling (Kwon, 2014). This is supported by the poor lower limb mobility found in participants as mentioned earlier in this chapter. Looking at the Penninsula health falls risk assessment (PH-FRAT), the participants scores ranged between 6 (low-risk category) and 16 (high risk category). This represents a heterogeneous sample in terms of fall risk. This study also assessed fall efficacy, to investigate participants concern for falling. The mean score of 28.9 ± 10.8 A.U indicated that participants exhibited a high concern for falling. This is relevant considering the time it took for participants to complete the 5TSTS test.

Compared to the single-task (ST) sit-to-stand-to-sit movement, there was a 68% increase (13 seconds) in the time to complete this TM when participants were asked to perform a concurrent cognitive task (DTCM). However, when the participants had to complete a concurrent motor task during the 5TSTS movement, the DTMM attempt took only 1 second longer (19.7% difference). This finding is similar to Palanasamy et al. (2019), who reported a 32% increase in the time to complete the 5TSTS test during the DTCM condition compared to the ST 5TSTS test. Furthermore, Palanasamy et al. (2019), also found that holding a cup of water during the 5TSTS (i.e. DTMM condition similar to the current study), only increased the 5TSTS duration by 2 second from the ST attempt. Palanasamy and colleagues (2019) explained that the poor sit-to-stand-to-sit performance in stroke survivors was due to trunk impairment, related to asymmetrical weight-bearing commonly found in hemiparetic stroke survivors, and that the two DT conditions aggravated the control of the trunk due to the added cognitive load to an already complex transfer task. Therefore, one possible explanation for the vast difference between ST and DTCM in this study, is that the cognitive-motor condition requires a person to divide their attention between both the executive functioning (PFC) and the motor part of the brain, exceeding their attentional capacity. This can be explained by the central capacity sharing theory, which proposes that everyone has limited capacity when it comes to the processing of attentional resources. Thus, dual-tasking is possible in a situation where capacity is not reached, however if the person's capacity is reached, performance in one or both tasks will be negatively affected. This is likely in stroke survivors who show reduced attentional capacity, and can be attributed to the attention demanding situation overwhelming their (already reduced) motor capacity (Liu et al., 2018). Alternatively, looking at the DTMM condition, one must consider that there are different views regarding DT, in terms of difficulty, as well as in terms of how many goals are being directed at once. For example, McIsaac and colleagues (2015), argued that carrying a glass of water while walking is not a dual-task but rather a complex single-task with one single goal (i.e. transporting the water). Consequently, it is possible that the DTMM condition enhanced the complexity of the task but did not challenge the person to divide their attention. Nevertheless, McIsaac and colleagues. (2015), is in contrasts with most other researchers who consider this glass carrying motor-motor task as a DT with separate goals and outcomes

to assess (Bayot et al., 2018). Interestingly, Hunter et al. (2018) explained that concurrent motor tasks (such as holding a cup of water in the current study), probably only enhances the complexity of the DT task and is not hindered by the stroke survivor's language, speech problems or literacy levels, as the cognitive secondary task would have been. This may also explain why the DTCM condition resulted in more dual-task interference (DTi) compared the DTMM.

Another possible explanation why the DTCM and DTMM conditions differed from the ST, could be attributed to the variability in the motor and physical functioning as well as physical activity status of the participants. The Fugl-Meyer lower extremity (FMA-LE) assessment scores range between 7-27 A.U, which portrays a large difference in lower limb physical performance. According to Kwong and Ng (2019), a score higher than 21 on the FMA-LE indicates a high level of mobility in chronic stroke survivors, whereas on average the participants in this study demonstrated mobility scores under this threshold (19.9 ± 4.8 A.U). In terms of the physical activity status, participants displayed an average of 5.8 ± 2.7 A.U indicating that they fell within the '*under-active regular (light activities)'* status, suggesting that they do not engage in regular aerobic or resistance exercise. This poor mobility and heterogeneity is not uncommon in stroke survivors, but could be a possible explanation for the differences found.

When transition from the sitting to the standing position, optimal scaling and timing characteristics of the trunk movements are crucial for successful rising (Frykberg & Hager, 2015). Therefore, participants had to engage in trunk flexion, represented by the anterior lean angle of the trunk, which would consequently provide momentum when lifting off of the seat (Seat-off) (Frykberg & Hager, 2015). This would then shift one's weight over their BOS, finally allowing the person to start extending the trunk to stand upright. On average, the lean angle of the participants in this study from sitting to standing position was 28.4 ± 10.1°. When participants had to perform cognitive task during the 5TSTS, the lean angle increase slightly to 29.8± 10.0°, unlike with the concurrent motor task, where the lean angle was actually reduced to 25.7 ± 9.1°. Although instructions regarding which task to prioritize

were not given, the increase in lean angle seen during CM tasks, could be supported by the idea that the person was largely focused on the counting task, that they jeopardized their postural control, to correctly complete the CM task. Usually when a person struggles to get out of a chair, they either make use of a higher chair, or make use of the arm rests on the chair or change the position of their feet. However, in this study the participants could not make those adjustments, which left them with the option to change their body kinematics to complete both tasks effectively. During the DTMM condition the participant had to hold a cup filled with water as they stood up from the chair. This might explain the lower lean angle observed in this study, as participants may not have wanted to spill the water.

In comparison to a study performed by Boukadida et al. (2015), the average trunk lean angle displayed by the stroke patients was 12.1 ± 6.1°. Thus, the participants in the current study had a greater lean angle (i.e. forward trunk displacement). Furthermore, Silva et al. (2017), reported a trunk lean angle of 42.63 ± 6.54 °, and Roldán-Jiménez et al. (2019), reported a range between 32.16 and 43.23°, this study participants indicating lower lean angle.

Conversely, to successfully control the stand-to-sit movement and move from standing to seated position, it is required that one lowers their centre of mass with certain amount of flexion at the trunk to meet with the chair. However, the more one leans forward, the more the centre of mass is moved towards the limits of stability. Thus, to ensure safety while descending from standing to sitting, the trunk is used as a stability controller to initiate the sit-down action (Frykberg & Hager, 2015). The control of this sit-down movement is important as someone who just drops down to the chair would indicate poor postural control, thus affecting balance, and possibly fall risk.

Previous research compared the movement patterns during sitting down in young and older adults and found that during sitting, the older adults (76 ± 3 years) significantly reduced their forward displacement of the trunk. This is thought to be a strategy used to avoid falling (Dubost et al., 2005). In the current study, the average stand-to-sit lean angle was 24.9 ± 9.8° for the stroke survivors during the single-task condition. When comparing this to the MM-

(23.2 ±7.9°) and CM conditions (27.2 ±9.2°), DTMM showed a similar trunk lean angle to the ST condition, while the trunk lean angle increased by 9% in the CM condition. An increase in lean angle during CM would represent that the addition of a cognitive task resulted in destabilized performance, as excessive lean angle during sit-to-stand would indicate poor trunk control. This is supported by Palanasamy et al. (2019), who highlighted that the addition of a motor or cognitive task diverts the person's attention capacity, thus resulting in a decrease in the task performance. Lastly, it must be acknowledged that trunk control may be impaired following stroke (Tassee-Ponche et al., 2015), depending on the brain lesion, and this study did not assess the brain lesions of participants.

Furthermore, DTi for the 5TSTS showed significance between CM and MM conditions for both the sit-to-stand and stand-to-sit movements ($p = \leq 0.01$). It was found that cognitive-motor tasks resulted in greater dual-task interference, compared to motor-motor tasks. This increase in dual-task interference can be attributed to a higher cognitive load of the task, requiring greater divided attention due to the task complexity. This is interesting, if we look at the correct response rate of stroke survivors during the 5TSTS, which displayed significance for the total 5TSTS duration during the CM, DT condition. It was found that the longer persons took to perform the task, the lower their correct response rate (%), suggesting that the complexity of the task lead to deterioration in both the motor task (indicated by slower test times), as well as the cognitive task (reduced correct response rate).

6.2.2 Transitioning during in-place turning movements

Turning is required for successful completion of many day-to-day activities, and an essential component of clinical assessment. In particular, many of these movements one performs in smaller spaces in the house while cleaning and cooking, thus are essential for daily independance. It is well known that stroke survivors find turning challenging (Manaf et al., 2016), exposing them to an even higher risk for falling (Chan & Tsang, 2017). This is because turning requires cognitive processing while integrating visual, vestibular and somatosensory sensory information with the motor response, and is therefore not an automatic process (Manaf et al., 2016; Chan & Tsang, 2017; Bayot et al., 2018). Previous research on chronic

stroke has indicated that cut-off times of 3.49 and 3.43 seconds discriminated between healthy older adults and stroke survivors (Shiu et al., 2016). In the current study, stroke survivors took on average 4.5 ± 1.1 seconds to complete a 360° in-place turn task during the single-task condition, which was similar to the DTMM and DTCM conditions. As mentioned previously, the participants in this current study had poor functional capacities and scored low on the FMALE, which is suggested that the participants' motor impairments may have contributed to their slower turning duration. Shiu et al. (2016), supports this, as they stated that FMA-LE (affected and unaffected side) was significantly associated with the 360° turn duration in chronic stroke survivors. Thus, lower FMA-LE scores would indicate greater sensorimotor impairment in this population, which could affect their ability to turn, possibly reducing turning performance.

Research has looked at DT turning in stroke survivors, mostly including 90° and 180° turning (Manaf et al.,2015; Chan et al., 2017; Hollands et al., 2014) thus research on a 360-degree turn is lacking. Furthermore, to date, as far as the researcher is aware, only one study has compared the interference of both DTMM and DTC in chronic stroke survivors, however using a 180-degree turn (Manaf et al., 2015). The study performed by Manaf and colleagues (2015), found that additional demands on turning resulted in deterioration in performance (shown by reduced gait speed), indicating that persons with stroke are more vulnerable to dual-task interference during walking and talking. Furthermore, these findings are in line with the present study, which also showed reduced velocity of turns, when cognitive or motor tasks were added to the primary motor task. There are certain daily movements such as maneuvering around the kitchen, turning to place items in a trolley at the shops, and cleaning small spaces in the home that would require one's engagement with 360-degree turning. Additionally, research has confirmed that DT turning in stroke survivors results in deteriorated task performance. However, since limited research exists regarding the specific roles cognitive vs motor tasks play in DT performance, this studies findings are evidence to display differential task complexity between added cognitive vs motor tasks.

During the turning movement, the velocity refers to the speed at which a person moves from stationary position through the whole turn. In the case of a turn test, the speed at which a person is able to complete a task may be indicative of their ability to perform such movements in real life. The peak turn velocity of this study was 146.3 ± 29.8 degrees per second (°/s). When compared to the two dual-task conditions, a similar 9% faster turn velocity was evident between ST and DTMM, as well as DTCM conditions. This could indicate the difficulty of performing this TM with the added cognitive and/or motor secondary task. It is known that stroke survivors find DT's challenging, and since many ADL's require one to move between positions while performing additional cognitive or motor tasks, this finding has implications for the approach therapists employ while working with persons with cognitive and motor deficits, such as in stroke survivors. Furthermore, the significant difference found, indicates that when stroke survivors are placed in attention demanding situations, their efficiency in completing the motor task is reduced, in order to maintain the secondary task. This has practical implications for therapists when exploring one's ability in everyday tasks, and the possibility of loss of postural control (shown by increased test duration) when required to divide their attention. These exercises can be used to assess one's performance during DT, to clarify postural control deficits. Furthermore, when designing rehabilitation programmes, therapists can consider including motor exercises, with added secondary cognitive and motor tasks, to challenge one's postural control. This, for the patient to learn about their limits, how to maintain balance in attention demanding situations at home, when they do have a health-care professional guiding them. Lastly, the practicing of such activities during rehabilitation sessions with a therapist could be useful for individuals to translate into their everyday lives, in a safer manner.

6.3 Prefrontal cortex hemodynamics

The next section explores the main aim of this study, which was to investigate the prefrontal cortical (PFC) activation during single-task, DTMM and DTCM conditions for sit-to-stand-to sit as well as in-place turning transitional movements. In addition, when applicable the

affected and unaffected side, as well as different brain regions will be incorporated into the discussion.

To date, PFC activation during the TM explored in this study, have not been examined in chronic stroke survivors. The average pattern of change from baseline for the hemodynamic variables – indicating prefrontal cortical (PFC) activation - is summarized in Table 6.1 for the TMs (i.e. sit-to-stand, stand-to-sit and in-phase turning) during all the task conditions.

Table 6.1 Summary of the hemodynamic response patterns in the prefrontal cortex during the various conditions.

Hemodynamic variable	**Sit-to-stand and stand-to-sit positions**		
	Single-task	**DTCM**	**DTMM**
Δ HbO_2	↑	↑↑↑	↑↑
Δ HbR	↓	↓↓↓	↓↓
Δ HbDiff	↑	↑↑↑	↑↑
Hemodynamic variable	**In phase turning**		
	Single-task	**DTCM**	**DTMM**
Δ HbO_2	↑↑	↑↑↑	↑
Δ HbR	↓	↓↓↓	↓↓
Δ Hbdiff	↑↑	↑↑↑	↑

DTCM: cognitive-motor dual-task; DTMM: motor-motor dual-task; Δ HbO_2: relative change in oxygenated haemoglobin; Δ HbR: relative change in deoxygenated haemoglobin; HbDiff: The relative difference in haemoglobin; ↑: increase; ↓; decrease;

Functional imaging research has reported mixed results, however, a number of studies have connected DT performance to the recruitment of prefrontal and parietal regions of the brain (Desposito et al., 1995; Colette et al., 2005; Dux et al., 2006; Szameitaz et al,. 2016; Tombu et al., 2011). Looking at research on stroke survivors, 5 studies have looked at brain activation during dual-tasking; all of which assessed cerebral hemodynamics during gait (AlYahya et al.,

2016; Mori et al., 2018; Liu et al., 2018; Hawkins et al., 2018; Hermand et al., 2019). Al-Yahya et al. (2016), found that during DT gait (with a cognitive task), PFC activation increased, shown by increased HbO_2 and decreased HbR. This contrasts with Hermand et al. (2019), who indicated an increase in HbO_2 during walking, which was not further increased with an added cognitive task. Furthermore, Liu et al. (2018), assessed brain activation during ST, CM and MM task walking by means of HbDiff. In his study, it was found that during the CM walking task, the affected side of the PFC showed significantly greater increases when compared to ST walking. Mori et al. (2018), compared PFC activation between healthy adults and chronic stroke survivors, and found decreased PFC activity in the latter. This is the opposite to Hawkins et al. (2019), who reported the greatest increase in HbO_2 in chronic stroke survivors during DT walking, when compared to healthy elderly. The abovementioned differences further highlight the need for the current study exploring DT in the PFC.

6.3.1 During the sit-to-stand, and stand-to-sit movements

Relative change (Δ) in oxygenated haemoglobin (HbO_2)

During the sit-to-stand movement, on average ΔHbO_2 increased. This increase was the greatest for the DTCM, which showed a significant 81% difference from ST, followed by the DTMM (41% difference), where the ST showed the smallest increase. This infers that PFC activation was greatest when a cognitive task was added to the 5TSTS task. Interestingly, looking at the time it took to complete the 5TSTS test, the pattern was similar, where participants performance was slowest during CM (68% longer), followed by MM conditions (20% longer). This is in line with Palanasamy et al. (2019), who found a consistent pattern in the time it took the stroke survivors in the study to perform the test. Interestingly, it has been proposed that stroke survivors who took longer to perform 5TSTS test are the ones requiring additional time to stabilize their body's center of mass, to prevent excessive sway. Looking at the lean angle used between sitting and standing, the CM condition resulted in the greatest forward trunk displacement, indicating that CM task destabilized task performance, leading to a deterioration in the motor task. Thus, the longer time taken for

the 5TSTS test and the increased lean angle displayed during CM conditions, may be a result of competing attentional resources, displayed by increased ΔHbO_2.

Furthermore, looking at sides, the affected side displayed only a slightly higher pattern of ΔHbO_2, however this was not significant. This increase in the affected side could be due to the lesion requiring greater concentration than the unaffected brain hemisphere. More specifically, when looking at the sites explored in this study, a significant interaction effect was revealed, during CM conditions, between the OFPF which was much greater than the VLPF regions. This dominance of the OFPF could be related to the suppression of unwanted behaviour, which Is required in CM conditions, in order to complete both tasks.

The VLPFC is an important structure for motor inhibition (Carrieri et al., 2016), the stopping of a movement, and the OFPFC is also involved in inhibiting responses (Bryden & Roesch, 2015). Thus, since the DTCM requires one to select and inhibit certain information, the activation of these areas seems plausible due to the uses they might provide in enabling the completion of this TM under dual-task conditions.

This finding of ΔHbO_2 increase during DTCM is consistent with those of Al-Yahya et al. (2016), who reported an increase in ΔHbO_2, during DT walking in chronic stroke survivors. Since an increase in ΔHBO_2 reflects superior neuronal activation (Al-Yahya et al., 2019), it may be that the metabolic demands of the brain were enhanced, resulting in the need for more local cerebral blood flow of the brain, by means of increased oxygen delivery, which is known as neurovascular coupling (Fabiani et al., 2014; Perrey, 2008). Additionally, looking at the DLPF brain region, significance was found between ST and DTCM. Since the DLPF is primarily responsible for executive function and motor planning, it seems reasonable that differences would be found due to the increasing complexity of task demands from single-task to DTCM activity. Thus, the DTCM task required both the use of motor planning to plan and perform the sit-to-stand movement, as well as components of executive functioning, to perform counting backwards in 3's.

Relative change (Δ) in deoxygenated haemoglobin (HbR)

Overall, during the 5TSTS test, there was a decrease in HbR, indicating increased PFC activation (Nakamura et al., 2019). Looking at the conditions, this decrease was greatest for the CM condition, followed by the MM condition, where the ST showed the smallest decrease. This indicates that the CM condition resulted in the highest recruitment of the PFC when compared to the ST, although insignificant (100%; p = 0.08*; d* = 0.22^{S}). When exploring the specific sites, the addition of a motor task resulted in differences between the DLPF and OFPF (156%; p = 0.03; *d* = 1.05^{L}), as well as VLPF and OFPF (156%; p = 0.03; *d* = 0.57^{M}) of the affected side, where DLPF and VLPF displayed great reductions in ΔHbR; indicating activation in these areas during the MM task. Considering that research has found the DLPF brain region to activate during the cognitive control of task planning (Schulz et al., 2019), and the VLPF to activate during action inhibition (Schulz et al., 2019), it seems that stroke survivors had to really concentrate on completing the 5TSTS while keeping the cup of water from spilling, by inhibiting some response such as the urge to lose control of the cup.

Furthermore, the addition of serial 3 subtraction task to the 5TSTS test resulted in differences between the VLPF and OFPF (88.9%; p = 0.02; *d* = 0.72^{M}) region for the affected side, where VLPF showed the greatest decrease in ΔHbR. This indicates significant activation of the VLPF region during CM conditions. As previously mentioned, this area accounts for control and motor inhibition (Levy & Wagner, 2011), which is crucial for successful performance of backward counting in 3's, where one must inhibit certain stimuli, and appropriately select correct responses. Interestingly, when looking at the correct response rate (CRR) and total 5TSTS duration, a difference between the two was evident (p =<0.01), where an increased time to complete 5TSTS test was accompanied by worse CRR scores. This suggests that stroke survivors had limited capacity to perform this task, indicated by higher activation in brain areas that control and inhibit responses.

Relative change (Δ) in Hb difference (HbDiff)

Overall, HbDiff increased during all three conditions. This increase was greater for CM conditions (90.9%; p = 0.01; *d* = 0.31^{S}). Specifically, when looking at the site, this difference from ST to CM conditions, was evident within the DLPF brain region of the unaffected side (695.2%; p = 0.03; *d* = 0.69^{M}). This highlights the involvement of cognitive processes in performing sit-to-stand and stand-to-sit transitions, particularly when performed with an added cognitive task. This is relevant to our understanding of the neural basis underlying real world tasks, when one must transition while holding a cup or for example answer a phone call (Palanasamy et al., 2019). Taken into consideration alongside the slower test times for CM tasks, it again suggests that stroke survivors display limited capacity to perform DT, where increased cortical activation is accompanied by reduced task performance.

6.3.2 During Turning

Relative change (Δ) in oxygenated haemoglobin (HbO_2)

During the 360-degree turn test, PFC activation increased significantly for the DTCM, while it decreased for the DTMM. More specifically, when looking at the different sites of the brain, these findings were present within the OFPF brain region. Interestingly, if we compare this finding to the turning duration, the MM task took longer to complete compared to the CM task. A reason for this could be that the CM task has a cognitive component, requiring higher levels of activation in the PFC, whereas the MM does not. Thus, the reason for the MM condition slowing down even more than CM, yet with less activation in the PFC, could be due to the stroke survivors needing more time to concentrate on maintaining balance during the task. Furthermore, the motor-motor trials found no water spillage from the cup held by participants, so it is also possible that individuals slowed down to this extent to prevent the water from spilling during the MM task.

If you consider that the OFPF inhibits unwanted actions in everyday behaviour (Bryden & Roesch, 2015), it means that a component is being suppressed. Since the DTMM condition substantially slowed down in seconds, the assumption is that the participant inhibited the

cognitive task, in order to focus on the MM task, to maintain balance, thus increasing OFPF activity. However, unfortunately, because this study did not include a control task for the cognitive task (i.e serial 3 subtractions individually), we cannot see which task was prioritized, and which response was suppressed. Mori and colleagues. (2018), who did include a control task, and looked at chronic stroke, found that gait slowed down during DT, and suggested that this reduction in acceleration is probably a compensatory mechanism by which the stroke survivor tries to stabilize themselves. Furthermore, turning data for this current study showed that the velocity of the turn during both the CM and MM dual-task conditions slowed down. This is alongside an increase in ΔHbO_2 during CM and MM conditions. Thus, this could represent a protective mechanism employed by chronic stroke survivors to prevent falls.

Relative change (Δ) in deoxygenated haemoglobin (HbR)

Overall, during turning, ΔHbR decreased, thus indicating an increase in cortical activation. ST and MM showed remarkably similar dynamics, however significant decreases were evident from ST to CM, and from DTMM to DTCM conditions, reflecting that DTCM conditions caused the highest PFC activation.

Looking at brain sites, differences were found for the CM condition between the FPPF (ΔHbR decreased substantially) and the OFPF (ΔHbR increased) brain regions. The latter is not what the researcher expected to find, as the OFPF brain region also resulted in an increase in ΔHbO_2. However, research stipulates that in the older population, individuals may show less activity in certain brain regions, as well as overactivation in others, in response to complex tasks (Amiri et al., 2014) thus, these discrepancies could be explained by the elder population explored with further neurological deficits. Furthermore, the FPPF brain region, which had the greatest decrease during DTCM conditions (thus indicating highest PFC activation), is widely involved in multi-tasking behaviour (Dreher et al., 2008). Thus, referring back to the capacity sharing theory, since stroke survivors show reduced attentional capacity during dual-tasking, the recruitment of the FPPF brain region was even more vital, to enable multitasking of the DTCM condition.

Another significant finding during DTCM condition, was between the OFPF region (increased) and the VLPF brain region (decreased). Since the VLPF plays a role in the controlling of motor actions (Carrieri et al., 2016), this could indicate that the turning task was particularly challenging for the stroke survivors under DT conditions. Thus, they might have required increased recruitment of this brain region to enable efficient motor responses.

Relative change (Δ) in haemoglobin difference (HbDiff)

When looking at HbDiff, again, the results indicated the greatest increase in activation of the PFC during the DTCM condition. There was significance between ST and CM (which increased), as well as between MM and CM (increased), highlighting the need for higher recruitment of the brain region known to assist in the function of inhibiting a specific action. These effects were explained under the ΔHbO_2 section, thus these results confirm the recruitment of the OFPF brain region during complex tasks, specifically involving both a motor and cognitive component. The significant difference between MM and CM is interesting, particularly when looking at the turn duration.

6.4 Study limitations and recommendations for future studies

- A limitation of this study is that the stroke participants specific brain lesions were not determined. Thus, some survivors may have had multiple lesions, or lesions involving the PFC or basal ganglia. The latter cause disturbance of the fronto-subcortical circuits in stroke patients, which might have indirectly caused lower PFC activity during the TM explored.
- Furthermore, this study only examined the PFC region of the brain. Although we know that this region is responsible for EF and DT, research has also found involvement in additional brain regions such as the supplementary motor areas, as well as the premotor cortex (Liu et al., 2018). Thus, future research could focus on assessing various brain regions under similar conditions.

- A drawback of the use of functional near-infrared spectroscopy (fNIRS) is the variability in the path length (Chincarini et al., 2020), which depends on individual differences in superficial scalp and the tissue structure of the brain.
- Looking at the specific DT's used in this study, it should be considered that certain tasks may be easier or more difficult for each person to perform. Thus, exploring a variety of cognitive-motor and motor-motor tasks and the effect they have on PFC activation during the tasks used here, could give a better indication of task complexity and cerebral hemodynamics in this population.
- The small sample size of this population should also be considered, as the power analysis revealed a sample size of 40-90 participants would be sufficient.
- Furthermore, this study did not monitor additional physiological measures known to influence fNIRS data such as blood pressure, heart rate and skin blood flow (Herold et al., 2018).
- Another aspect future studies could consider, is filming the participants in view of a full body, so to assess foot positioning during turning and sit-to-stand movements. This would assist in identifying the movement strategies used by stroke survivors.
- For the cognitive-motor condition, this study did not include a control task for the cognitive component, thus we could not compare the performance during DTCM's to a control. The inclusion of a control task would benefit future research, particularly when drawing conclusions about the prioritization of the task under DT conditions.
- Furthermore, the laterality of the stroke lesion would also affect the results, and this was not determined in this study.
- Another aspect this study did not account for is socioeconomic status. This is something that may have affected the results of this study, which should be accounted for in future studies on chronic stroke survivors.
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6.5 Conclusion

To the best of the researcher's knowledge, this is the first comprehensive study to assess patterns of hemodynamic response in the PFC during 5TSTS and 360° in-phase turning in

chronic stroke survivors, while assessing spatiotemporal and kinematic data. This study found increased PFC activation during the 5TSTS and 360° in-phase turning in chronic stroke survivors, which was further increased during MM and CM dual-tasks, the latter showing greatest activation. Furthermore, increases in PFC activation, were accompanied by reduced motor task performance (slower test times and reduced turn velocity) suggesting that stroke survivors have difficulty with completing DT, especially with added cognitive demands. This provides health professionals with evidence to confirm that the addition of secondary tasks may destabilize performance in this population, and the inclusion of these in the assessments of stroke survivors could provide useful information regarding daily independence.

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ADDENDA

Addendum A: ETHICS APPROVAL

Health Research Ethics Committee (HREC)

Approval Notice

New Application

Project ID :7009 11/02/2019

HREC Reference #: S18/06/122

Title: Brain activation during transitional movements in stroke survivors

Dear Miss Taylia Webber,

The **Response to Modifications** received on 01/02/2019 09:31 was reviewed by members of **Health Research Ethics Committee 2 (HREC2)** via **expedited** review procedures on 11/02/2019 and was approved.

Please note the following information about your approved research protocol:

Protocol Approval Period: This project has approval for 12 months from the date of this letter.

Please remember to use your **Project ID [7009]** 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 you can submit your progress report through the online ethics application process, available at: Links Application Form Direct Link and the application should be submitted to the HREC before the year has expired. Please see *Forms and Instructions* on

our HREC website (www.sun.ac.za/healthresearchethics) for guidance on how to submit a progress report.

The HREC 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.

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 Departement of Health and/or City Health) to conduct the research as stated in the protocol. Please consult the Western Cape Government website for access to the online Health Research Approval Process, see: https://www.westerncape.gov.za/general-publication/health-researchapproval-process. 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 instructions, please visit: Forms and Instructions on our HREC website https://applyethics.sun.ac.za/ProjectView/Index/7009

If you have any questions or need further assistance, please contact the HREC office at 021 938 9677.

Yours sincerely,

HREC Coordinator,

Health Research Ethics Committee 2 (HREC2).

National Health Research Ethics Council (NHREC) Registration Number:

REC-130408-012 (HREC1)·REC-230208-010 (HREC2)

Federal Wide Assurance Number: 00001372

Office of Human Research Protections (OHRP) Institutional Review Board (IRB) Number: IRB0005240 (HREC1)·IRB0005239 (HREC2)

The Health Research Ethics Committee (HREC) complies with the SA National Health Act

No. 61 of 2003 as it pertains to health research. The HREC abides by the ethical norms and principles for research, established by the World Medical Association (2013). Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects; the South African Department of Health (2006). Guidelines for Good Practice in the Conduct of Clinical Trials with Human Participants in South Africa (2nd edition); as well as the Department of Health (2015). Ethics in Health Research: Principles, Processes and Structures (2nd edition).

The Health Research Ethics Committee reviews research involving human subjects conducted or supported by the Department of Health and Human Services, or other federal departments or agencies that apply the Federal Policy for the Protection of Human Subjects to such research (United States Code of Federal Regulations Title 45 Part 46); and/or clinical investigations regulated by the Food and Drug Administration (FDA) of the Department of Health and Human Services.

Addendum B: INFORMED CONSENT FORM

Research project title: Prefrontal cortical activation during turning and sit to stand movements in stroke survivors.

Ethics reference: S18/06/122

Principal investigator: Taylia Webber

Address: 000000

Contact number: 000000

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 researcher any questions about any part of the project that you do not fully understand. It is very important that you are satisfied that you clearly understand what this research entails and how you could be involved. Your participation is entirely voluntary, and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part at first.

What is this study all about?

- This study will be conducted at the Department of Sports science, at Stellenbosch University.
- The aim of the project is to see how the brain activates during turning and sit to stand movements. After a person has experienced a stroke, they experience motor and cognitive impairments. There are many daily tasks that require us to use cognitive and motor skills at the same time (multitasking). Studies have found that multitasking results in increased brain activation. Additionally, research has established that falls often occur when people are multitasking. Because many activities of daily living require us to multitask, observing brain activation during tasks like those used daily can provide us with information about one's risk of falling. This information could be very beneficial to the person's team of health professionals. Using this information, they can plan effective rehabilitation sessions with clear goals that promote practicing of movements in a safe environment. Additionally, the information can be used as a screening tool to identify those at risk of falling, and implement necessary changes to the long term plan, adapting the person's environment and educating them on their form during specific tasks used daily.

- Visit one: Partake in a telephonic interview with the primary researcher of this project. This will entail giving informed consent over the phone and answering some questions about you and your health (birth date, occupation, doctor's name, injuries, surgeries, conditions, occupation etc.). Following this, you will also be asked questions about your physical activity status and your moods/emotional health. This will take about 45 minutes. From this, it will be decided whether you meet the inclusion or exclusion criteria for visit two. If you meet the inclusion criteria, you will be invited to the next visit. For the second visit, the primary researcher will either meet you at your residence or at the department of Sports Science at Stellenbosch University (depending on the individual circumstances).

- Visit two: will involve signing of the informed consent, after which you will have the opportunity to ask any questions. Following this, you will do a pen and paper test for cognition. Thereafter, we will assess your functional mobility (a walking test and a test to assess muscle strength & flexibility). This will take +- two hours. From these tests it will be decided whether you meet the inclusion or exclusion criteria. This will determine if you will be invited to partake in the study, visit three.

- Visit three: Department of sports science, Stellenbosch University. At the beginning of the session, your baseline brain activity will be measured. This will be done by placing non-invasive sensors on your forehead. This procedure is not painful and will not cause you any harm. Following this, you will be asked to perform turning and sit to stand movements while your brain activity is being measured by the sensor on your head. You will also be asked to add something to each task (so you will do more than one thing at a time). You will be given a demonstration and a practice trial of each movement before the actual tests. You will be guided through every movement and will not be asked to do anything you are not capable of doing. This will take +- one and a half hours.

- The final visit will be for the primary researcher to provide the subject (you) with feedback, and to provide you with a home-based programme of exercises for strengthening and stretching based on your needs.

Why have you been invited to participate?

- You have been invited to participate in this study because you have experienced a stroke event more than six months ago. Additionally, you live in the Western Cape, are celared for exercise by your physician/neurologist, are able to walk at least eight metres (with or without a crutch/walker/frame), you have been on stable medication for the last 4 weeks, and you do not smoke for at least 6 months).

What will your responsibilities be?

- Partake in a telephonic interview with the primary researcher of this project. Thereafter, you will get transported to the Department of sports science, Stellenbosch University on two separate occasions for testing.

Will you benefit from taking part in this research?

- Personal benefits of this study include education on stroke and a home-based programme that you will receive following the study. This will include exercises based on participants concerns or weaknesses observed during assessments.
- An important benefit of this study is for chronic stroke survivors and health professionals working in rehabilitation settings. The information from this study can be used to guide rehabilitation programmes and include exercises that may enhance recovery post-stroke and provide information about falls and fall-risk in neurologically injured clients.

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

- There may be a potential risk for losing your balance during the tests, and this could result in a fall. If this was to happen, I would assist you with getting back up. I would then call the campus doctor/A doctor of your choice if necessary, to perform further observation; which would be of no cost to you. All researchers and assistants involved are qualified in first aid and will be able to assist you if there is a fall. I will also add chairs to the testing area to prevent serious harm in case of a fall.

- It is possible that individuals might fear certain movements. Please remember that you may withdrawal at any stage should you wish to, and that the individuals conducting the study are qualified sports scientists and biokineticists with firm medical background and first aid experience. At no stage during testing will you be required to perform a task that you are

unable to, as all movements involved in each task will be discussed in the initial stages of testing.

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

- If you would not like to partake in this study, you are welcome to review alternative studies for participation that are currently taking place at Stellenbosch University with the same population group.

Who will have access to your medical records?

- All information received from be confidential, and only the primary researcher and supervisor will have access to this information. Furthermore, if this information is used in a publication or thesis, the identity of every participant will remain anonymous by using a code such as P01, P02 etc. instead of your name. In no way will your personal information or contact details be shared beyond the abovementioned parties. When we need to give you feedback on your own results (and only your results), the primary researcher and supervisor who have access to the names and the codes will be the only people able to contact you to provide feedback.

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

This study does have insurance cover. If additional information be required, you can approach the primary researcher of this study.

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

No you will not be paid to take part in the study. However, there are no costs involved as your transport and snacks & cool drinks will be covered for each study visit.

Is there anything else that you should know or do?

- You should inform your family practitioner or usual doctor that you are taking part in a research study.
- Please wear comfortable clothing and sports shoes to the testing sessions.
- Please also bring a list of your medications.
- You should also inform your medical insurance company that you are participating in a research study.

- You can contact the researcher of this study should you encounter any problems, and she will recommend a doctor to you.
- You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your study doctor.
- You will receive a copy of this information and consent form for your own records.

Declaration by participant

By signing below, I …….. agree to take part in a research study entitled "prefrontal cortical activation during single-task and dual-task transitional movements in chronic stroke survivors".

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.

- I understand that taking part in this study is voluntary and I have not been pressurised to take part.

- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.

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

Signed at (place) ..... on (date) …….. 2018.

....

Signature of participant 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 understands all aspects of the research, as discussed above
- I did/did not use a interpreter. (If a interpreter is used then the interpreter must sign the declaration below.

Signed at (place) ..... on (date) …….. 2018.

....

Signature of investigator Signature of witness

Declaration by interpreter

I (name) …… declare that:

- I assisted the investigator (name) ……. to explain the information in this document to (name of participant)

…….. using the language medium of

Afrikaans/Xhosa.

We encouraged him/her to ask questions and took adequate time to answer them.

- I conveyed a factually correct version of what was related to me.
- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her question satisfactorily answered.

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

....

Signature of interpreter Signature of witness

Addendum C: GENERAL INFORMATION AND STROKE SPECIFIC QUESTIONNAIRE

Participant information

Sportwetenskap
Sport Science
STELLENBOSCH

Full name: _____

Gender: _____

If you are a female, do you experience menopause? _____

Date of birth: _____

ID number: _____

Home Language: _____

Where do you live? _____ Level of education (years):_____ When last did you visit your doctor for a general check-up?

_____

What is your doctor's name?

_____

Have you been admitted to hospital for any operations or serious illness?

_____

_____

Are you a current smoker? (YES/NO) _____

If you used to smoke, when last did you smoke a cigarette?

_____

Are you currently taking any chronic (long-term) medication? If so, please list all of them:

_____

_____

Have you changed any of your medication in the last four weeks? (YES/NO)

_____

If yes, please explain if you were taken off a medication, prescribed a new medication, or if your medication dose for a specific type was either increased or decreased.

_____

_____

Have you been diagnosed with any other medical conditions?

Arthritis, Epilepsy, Anaemia, TB, Diabetes, Asthma, High blood pressure, Cholesterol

Please provided a name and contact number of a close relative/friend in case of emergency:

Name: _____cell number: _____

Stroke related questions

When did your stroke occur? _____

Have you had more than one stroke? (YES/NO)_____

If yes, how many? _____

Do you know what part of the brain is damaged? _____

What part and side of your body is affected? _____

Have you had any form of physical (rehabilitative) exercise since your stroke? _____ If yes, what type of exercises and for how long?

_____

Do you experience spasticity? _____

Are you able to walk independently for at least 8 meters? _____

Do you make use of an assistive device? Crutch, cane, walker, frame?

_____

Are you able to get up from a chair and sit back down again without assistance?

_____

Can you walk for 2 minutes at your own pace?

_____

Do you require transport to sports science? _____

I am now going to ask you about any possible falls you might have had. A fall is an event where you unintentionally came to rest on the floor or another lower surface, but was not due to a seizure, stroke, heart attack, or external force (eg, earthquake)

1. Have you experienced a fall over the past year? (in the last 12 months). If yes, how many?

   _____

   _____

2. When was the last time you fell?

   _____

3. Did you have to see a Doctor or have to go to the emergency room for any of the falls?

   _____

4. Did any of the falls result in any injuries?

   _____

   _____

5. What were you doing when you fell? Activity (eg, walking, transferring, not moving, reaching, turning or bending) _____

   _____

6. If you were walking, what surface were you walking on when you fell? Surface level ground or up/downstairs, a ramp, uneven surface?

   _____

   _____

7. What position was the person in at the time of fall (sitting, lying, standing walking)

   _____

8. Where were you when you fell? location of fall (indoor, outdoor)

   _____

   _____

9. Cognitive activity at the time of the fall. Were you doing anything that required your concentration at the time when you fell? eg. Were you talking to somebody, were you counting something or thinking?

   _____
   _____

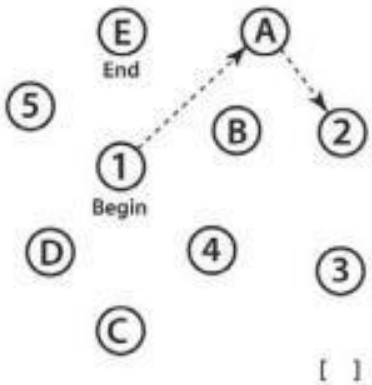
Addendum D: MONTREAL COGNITIVE ASSESSMENT 7.1

NAME :

MONTREAL COGNITIVE ASSESSMENT (MOCA) Education : Date of birth :

Version 7.1 Original Version Sex : DATE :

VISUOSPATIAL / EXECUTIVE — POINTS



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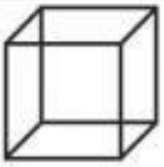


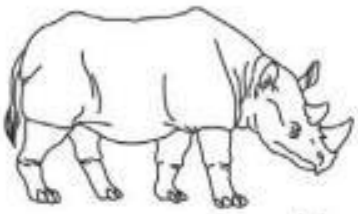
Draw CLOCK (Ten past eleven) (3 points)

[ ] Contour [ ] Numbers [ ] Hands

/5

NAMING

[ ]



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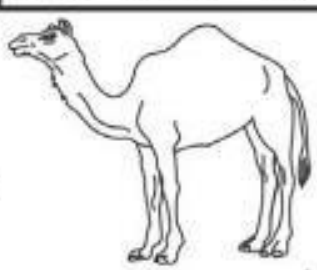


[ ]

/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	FACE	VELVET	CHURCH	DAISY	RED
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).

Subject has to repeat them in the forward order [ ] 2 1 8 5 4

Subject has to repeat them in the backward order [ ] 7 4 2

/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors

[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

/1

Serial 7 subtraction starting at 100 [ ] 93 [ ] 86 [ ] 79 [ ] 72 [ ] 65

4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

/3

LANGUAGE Repeat : I only know that John is the one to help today. [ ]

The cat always hid under the couch when dogs were in the room. [ ]

/2

Fluency / Name maximum number of words in one minute that begin with the letter F [ ] ____ (N ≥ 11 words)

/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] train – bicycle [ ] watch - ruler

/2

DELAYED RECALL

	Has to recall words WITH NO CUE	FACE [ ]	VELVET [ ]	CHURCH [ ]	DAISY [ ]	RED [ ]	Points for UNCUED recall only
Optional	Category cue						
	Multiple choice cue						

/5

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City

/6

© Z.Nasreddine MD www.mocatest.org Normal ≥ 26 / 30

TOTAL /30

Add 1 point if ≤ 12 yr edu

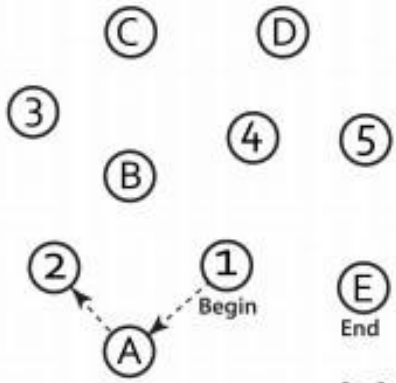
Administered by: _____

MONTREAL COGNITIVE ASSESSMENT 7.2

MONTREAL COGNITIVE ASSESSMENT (MOCA©)
Version 7.2 Alternative Version

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE — POINTS



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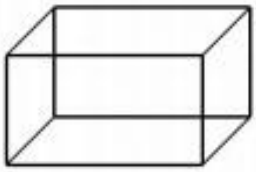
Copy rectangle



Draw CLOCK (Five past four)
(3 points)

[ ] Contour [ ] Numbers [ ] Hands

__/5

NAMING

[ ]

[ ]

[ ]

__/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	TRUCK	BANANA	VIOLIN	DESK	GREEN
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.). Subject has to repeat them in the forward order [ ] 3 2 9 6 5
Subject has to repeat them in the backward order [ ] 8 5 2

__/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors
[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

__/1

Serial 7 subtraction starting at 90 [ ] 83 [ ] 76 [ ] 69 [ ] 62 [ ] 55
4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

__/3

LANGUAGE Repeat : A bird can fly into closed windows when it's dark and windy. [ ]
The caring grandmother sent groceries over a week ago. [ ]

__/2

Fluency / Name maximum number of words in one minute that begin with the letter S [ ] _____ (N ≥ 11 words)

__/1

ABSTRACTION Similarity between e.g. carrot - potato = vegetable. [ ] diamond - ruby [ ] cannon - rifle

__/2

DELAYED RECALL

	Has to recall words WITH NO CUE	TRUCK	BANANA	VIOLIN	DESK	GREEN	Points for UNCUED recall only
		[ ]	[ ]	[ ]	[ ]	[ ]	
Optional	Category cue						
	Multiple choice cue						

__/5

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City

__/6

Adapted by : Z. Nasreddine MD, N. Phillips PhD, H. Chertkow MD
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Administered by: _____

Normal ≥ 26 / 30

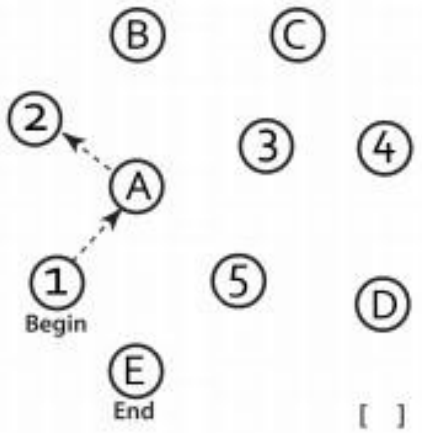
TOTAL __/30
Add 1 point if ≤ 12 yr edu

MONTREAL COGNITIVE ASSESSMENT 7.3

MONTREAL COGNITIVE ASSESSMENT (MOCA)
Version 7.3 Alternative Version

NAME :
Education : Date of birth :
Sex : DATE :

VISUOSPATIAL / EXECUTIVE — POINTS



[ ] [ ]

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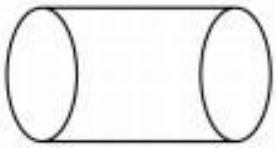
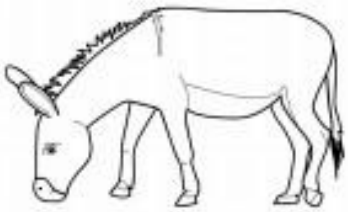


Draw CLOCK (Ten past nine)
(3 points)

[ ] Contour [ ] Numbers [ ] Hands

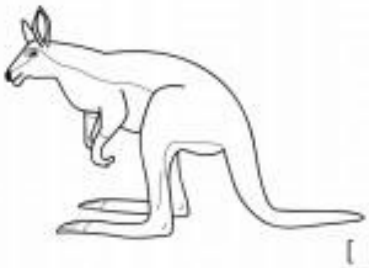
__/5

NAMING



[ ]

[ ]



[ ]

__/3

MEMORY Read list of words, subject must repeat them. Do 2 trials, even if 1st trial is successful. Do a recall after 5 minutes.

	TRAIN	EGG	HAT	CHAIR	BLUE
1st trial					
2nd trial					

No points

ATTENTION Read list of digits (1 digit/ sec.).

Subject has to repeat them in the forward order [ ] 5 4 1 8 7

Subject has to repeat them in the backward order [ ] 1 7 4

__/2

Read list of letters. The subject must tap with his hand at each letter A. No points if ≥ 2 errors

[ ] F B A C M N A A J K L B A F A K D E A A A J A M O F A A B

__/1

Serial 7 subtraction starting at 80 [ ] 73 [ ] 66 [ ] 59 [ ] 52 [ ] 45

4 or 5 correct subtractions: **3 pts**, 2 or 3 correct: **2 pts**, 1 correct: **1 pt**, 0 correct: **0 pt**

__/3

LANGUAGE Repeat : She heard his lawyer was the one to sue after the accident. [ ]

The little girls who were given too much candy got stomach aches. [ ]

__/2

Fluency / Name maximum number of words in one minute that begin with the letter B [ ] _____ (N ≥ 11 words)

__/1

ABSTRACTION Similarity between e.g. banana - orange = fruit [ ] eye – ear [ ] trumpet – piano

__/2

DELAYED RECALL

	Has to recall words WITH NO CUE	TRAIN [ ]	EGG [ ]	HAT [ ]	CHAIR [ ]	BLUE [ ]	Points for UNCUED recall only
Optional	Category cue						
	Multiple choice cue						

__/5

ORIENTATION [ ] Date [ ] Month [ ] Year [ ] Day [ ] Place [ ] City

__/6

Adapted by : Z. Nasreddine MD, N. Phillips PhD, H. Chertkow MD
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Normal ≥ 26 / 30

TOTAL __/30

Add 1 point if ≤ 12 yr edu

Administered by: _____

Addendum E: PERMISSION OBTAINED TO USE MOCA

RE: MoCA© Permission Request Inbox ×

to me

Hello,

Thank you for your interest in the MoCA©.

You are welcome to use the MoCA© Test as you described below with no further permission requirements.

No changes or adaptations to the MoCA© Test and instructions are permitted.

All the best,

MoCA
INSTITUT & CLINIQUE

MSOT
Occupational Therapist/ Psychometrician
On behalf of Dr Neurologist, MoCA© Copyright Owner
MoCA Clinic & Institute

Greenfield Park, Quebec, Canada, J4V 2J2

www.mocatest.org / www.alzheimer.TV

Addendum F: stroke specific quality of life scale

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Sportwetenskap
Sport Science
STELLENBOSCH

Total help/Couldn't do it at all - **Strongly agree**	1
A lot of help - A lot of trouble - **Moderately agree**	2
Some help - Some trouble **- Neither agree nor disagree**	3
A little help - A little trouble - **Moderately disagree**	4
No help needed - No trouble at all **- Strongly disagree**	5

Energy

1. I felt tired most of the time. ____
2. I had to stop and rest during the day. ____
3. I was too tired to do what I wanted to do. ____

Family Roles

1. I didn't join in activities just for fun with my family. ____
2. I felt I was a burden to my family. ____
3. My physical condition interfered with my personal life. ____

Language

1. Did you have trouble speaking? For example, get stuck, stutter, stammer, or slur your words? ____
2. Did you have trouble speaking clearly enough to use the telephone? ____
3. Did other people have trouble in understanding what you said? ____
4. Did you have trouble finding the word you wanted to say? ____
5. Did you have to repeat yourself so others could understand you? ____

Mobility

1. Did you have trouble walking? (If patient can't walk, go to question 4 and score questions 2-3 as 1.) ____
2. Did you lose your balance when bending over to or reaching for something? ____
3. Did you have trouble climbing stairs? ____
4. Did you have to stop, and rest more than you would like when walking or using a wheelchair? ____

5. Did you have trouble with standing? ____
6. Did you have trouble getting out of a chair? ____

Mood

1. I was discouraged about my future. ____
2. I wasn't interested in other people or activities. ____
3. I felt withdrawn from other people. ____
4. I had little confidence in myself. ____
5. I was not interested in food. ____

Personality

1. I was irritable. ____
2. I was inpatient with others. ____
3. My personality has changed. ____

Self-Care

1. Did you need help preparing food? ____
2. Did you need help eating? For example, cutting food or preparing food? ____
3. Did you need help getting dressed? For example, putting on socks or shoes, buttoning buttons, or zipping? ____
4. Did you need help taking a bath or a shower? ____
5. Did you need help to use the toilet? ____

Social Roles

1. I didn't go out as often as I would like. ____
2. I did my hobbies and recreation for shorter periods of time than I would like. ____
3. I didn't see as many of my friends as I would like. ____
4. I had sex less often than I would like. ____
5. My physical condition interfered with my social life. ____

Thinking

1. It was hard for me to concentrate. ____
2. I had trouble remembering things. ____
3. I had to write things down to remember them. ____

Upper Extremity Function

1. Did you have trouble writing or typing? ____
2. Did you have trouble putting on socks? ____
3. Did you have trouble buttoning buttons? ____
4. Did you have trouble zipping a zipper? ____
5. Did you have trouble opening a jar? ____

Vision

1. Did you have trouble seeing the television well enough to enjoy a show? ____

2. Did you have trouble reaching things because of poor eyesight? ____
3. Did you have trouble seeing things off to one side? ____

Work/Productivity

1. Did you have trouble doing daily work around the house? ____
2. Did you have trouble finishing jobs that you started? ____
3. Did you have trouble doing the work you used to do? ____

TOTAL: _____

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STELLENBOSCH UNIVERSITY

Addendum G: Participant health questionnaire

Sportwetenskap Sport Science STELLENBOSCH

(PHQ-9)

Name:_____ Date: _____

Over the last two weeks, how often have you been bothered by any of the following problems? (Use a tick to indicate your answer)

Q		Not at all	Several days	More than half the days	Nearly every day
1.	Little interest or pleasure in doing things	0	1	2	3
2.	Feeling down, depressed, or hopeless	0	1	2	3
3.	Trouble falling or staying asleep, or sleeping too much	0	1	2	3
4.	Feeling tired or having little energy	0	1	2	3
5.	Poor appetite or overeating	0	1	2	3
6.	Feeling bad about yourself- or that you are a failure or have let yourself or your family down	0	1	2	3
7.	Trouble concentrating on things, such as reading the newspaper or watching television	0	1	2	3
8.	Moving or speaking so slowly that people could have noticed. Or the opposite- being so fidgety or restless that you have been moving around a lot more than usual	0	1	2	3
9.	Thoughts that you would be better off dead, or of hurting yourself	0	1	2	3
	Add columns: ( ) + ( ) + ( ) Total = _____				
		Not difficult at all	Somewhat difficult	Very difficult	Extremely difficult
	If you checked off any problems, how difficult have these problems made it for you to do your work, take care of things at home, or get along with other people?				

Addendum H: 2-minute walk test instructions

Movement Laboratories
STELLENBOSCH UNIVERSITY

Sportwetenskap Sport Science STELLENBOSCH

Date: _____ BP1: _____

Participant: _____ BP2: _____

Language: _____ Height: _____

Side affected: _____ Weight: _____

- BP x 2
- Height + weight
- 2-minute walk test

2-minute walk test:

"You are going to start here at this line, when I say START, you are going to walk to the line on the other side, around it and back again. You must keep going for two minutes. I will tell you when to stop. You must walk as far as you can in two minutes, but safely. Do you understand?"

Notes: _____

Distance: _____

Comments:_____

_____

_____

_____

Emergency contact: _____Call:_____

Addendum I: Fugl-meyer assessment of the lower extremity

Participant: _____ Date: _____

E. LOWER EXTREMITY				
I. Reflex activity, supine position		**None**	**Can be elicited**	
Flexors: knee flexors **Extensors:** patellar, Achilles (at least one)		0 0	2 2	
Subtotal I (max 4)				
II. Volitional movement within synergies, supine position		**None**	**Partial**	**Full**
	Hip flexion Knee flexion Ankle dorsiflexion	0 0 0	1 1 1	2 2 2
	Hip extension adduction Knee extension Ankle plantar flexion	0 0 0 0	1 1 1 1	2 2 2 2
Subtotal II (max 14)				
III. Volitional movement mixing synergies Sitting position, knee 10cm from the edge of the plinth		**None**	**Partial**	**Full**
Knee flexion from actively or passively extending knee	No active motion Less than 90® active flexion, palpate tendons of hamstrings' More than 90® active flexion	0	1	2
Ankle dorsiflexion compare with unaffected side	No active motion Limited dorsiflexion Complete dorsiflexion	0	1	2
Subtotal III. (max 4)				
V. Normal reflex activity supine position ,assessed only if full score of 4 points is achieved in part IV, compare with the unaffected side		**0 (IV), hyper**	**Lively**	**normal**
Reflex activity knee flexors, Patellar, Achilles	0 point on part IV or 2 of 3 reflexes markedly hyperactive or at least 2 reflexes lively maximum of 1 reflex lively, none hyperactive	0	1	2

Subtotal V (max 2)	
Total E (max 28)	

Tester: _____ Side Affected: _____

F. COORDINATION/SPEED SUPINE, AFTER ONE TRIAL WITH BOTH LEGS, EYES CLOSED, HEEL TO KNEE CAP OF THE OPPOSITE LEG, 5 TIMES AS FAST AS POSSIBLE				
TREMOR	AT LEAST 1 COMPLETED MOVEMENT	0	1	2
DYSMETRIA	PRONOUNCED OR UNSYSTEMATIC SLIGHT AND SYSTEMATIC NO DYSMETRIA	0	1	2
		≥6s	**2-5s**	**NORMAL**
TIME START AND END WITH THE HAND ON THE KNEE	AT LEAST 6 SECONDS SLOWER THAN UNAFFECTED SIDE 2-5 SECONDS SLOWER THAN UNAFFECTED SIDE LESS THAN 2 SECONDS SLOWER THAN UNAFFECTED SIDE	0	1	2
Total F (max 6)				
H. Sensation, lower extremity eyes closed, compare with unaffected side		**Anaesthesia**	**Hypoesthesia or dysthesia**	**normal**
Light touch	Leg footsole	0 0	1 1	2 2
		Less than ¾ correct or absence	**¾ Correct or considerable difference**	**correct 100% little or no difference**
Position Small alterations in the position	Hip Knee Ankle Great toe (IP-Joint)	0 0 0 0	1 1 1 1	2 2 2 2
			Total H (max 12)	

Passive joint motion, lower extremity supine position, compare with the unaffected side				**J. Joint pain** during passive motion, lower extremity		
	Only few degrees	Decreased	normal	pronounced pain during movement or very marked pain at the end of the movement	some pain	no pain

Hip						
Flexion	0	1	2	0	1	2
Abduction	0	1	2	0	1	2
External rotation	0	1	2	0	1	2
Internal rotation	0	1	2	0	1	2
Knee	0	1	2	0	1	2
Flexion	0	1	2	0	1	2
Extension						
Ankle	0	1	2	0	1	2
Dorsiflexion	0	1	2	0	1	2
Plantar flexion						
Foot	0	1	2	0	1	2
Pronation	0	1	2	0	1	2
Supination						
Total (max 20)				**Total** (max 20)		

Total: / 86

J: New functional ambulation classification (FAC)

Movement Laboratories
STELLENBOSCH UNIVERSITY

Sportwetenskap Sport Science STELLENBOSCH

FAC	Ambulation Description	Definition
0	Nonfunctional ambulation	Subject cannot ambulate, ambulates in parallel bars only, or requires supervision or physical assistance from more than one person to ambulate safely outside of parallel bars
1	Ambulator-Dependent for Physical Assistance Level II	Subject requires manual contacts of no more than one person during ambulation on level surfaces to prevent falling. Manual contacts are continuous and necessary to support body weight as well as maintain balance and/or assist coordination
2	Ambulator-Dependent for Physical Assistance Level I	Subject requires manual contact of no more than one person during ambulation on level surfaces to prevent falling. Manual contact consists of continuous or intermittent light touch to assist balance or coordination
3	Ambulator-Dependent for Supervision	Subject can physically ambulate on level surfaces without manual contact of another person but for safety requires standby guarding on no more than one person because of poor judgment, questionable cardiac status, or the need for verbal cuing to complete the task.
4	Ambulator-Independent Level Surfaces only	Subject can ambulate independently on level surfaces but requires supervision or physical assistance to negotiate any of the following: stairs, inclines, or non-level surfaces.
5	Ambulator-Independent	Subject can ambulate independently on nonlevel and level surfaces, stairs, and inclines.

Addendum K: Rapid assessment of physical activity (RAPA)

NAME: _____ DATE: _____

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Participants are educated on the 3 different levels of physical activity, including examples of each, as seen below.

Light activities Your heart beats slightly faster than normal. You can talk and sing	 Walking Leisurely	 Vacuuming or Light Yard Work	 Stretching	
Moderate activities Your heart beats faster than normal You can talk but not sing	 Fast Walking	 Aerobics Class	 Strength Training	 Swimming Gently
Vigorous activities Your heart rate increases a lot You can't talk or your talking is broken up by large breaths	 Stair Machine	 Jogging or Running	 Tennis, Racquetball or Badminton	

Answer yes or no:

I rarely or never do any physical activities. _____

I do some light or moderate physical activities, but not every week. _____

I do some light physical activity every week. _____

I do moderate physical activities every week, but less than 30 minutes a day or 5 days a week. _____

I do vigorous physical activities every week, but less than 20 minutes a day or 3 days a week. _____

I do 30 minutes or more a day of moderate physical activities, 5 or more days a week. _____

I do 20 minutes or more a day of vigorous physical activities, 3 or more days a week. _____

I do activities to increase muscle strength, eg. weights or calisthenics, once a week or more. _____

I do activities to improve flexibility, such as stretching or yoga, once a week or more. _____

Addendum L: falls efficacy scale – international.

Now we would like to ask some questions about how concerned you are about the possibility of falling. Please reply thinking about how you usually do the activity. If you currently don't do the activity (e.g. if someone does your shopping for you), please answer to show whether you think you would be concerned about falling if you did the activity. For each of the following activities, please tick the box which is closest to your own opinion to show how concerned you are that you might fall if you did this activity.

		Not at all concerned 1	Somewhat concerned 2	Fairly concerned 3	Very concerned 4
1.	*Cleaning the house (eg. Sweep, vacuum or dust)*	*1*	*2*	*3*	*4*
2.	*Getting dressed or undressed*	*1*	*2*	*3*	*4*
3.	*Preparing simple meals*	*1*	*2*	*3*	*4*
4.	*Taking a bath or shower*	*1*	*2*	*3*	*4*
5.	*Going to the shop*	*1*	*2*	*3*	*4*
6.	*Getting in or out of a chair*	*1*	*2*	*3*	*4*
7.	*Going up or down stairs*	*1*	*2*	*3*	*4*
8.	*Walking around in the neighbourhood*	*1*	*2*	*3*	*4*
9.	*Reaching for something above your head or on the ground*	*1*	*2*	*3*	*4*
10.	*Going to answer the telephone before it stops ringing*	*1*	*2*	*3*	*4*
11.	*Walking on a slippery surface (eg. Wet or icy)*	*1*	*2*	*3*	*4*
12.	*Visiting a friend or relative*	*1*	*2*	*3*	*4*
13.	*Walking in a place with crowds*	*1*	*2*	*3*	*4*
14.	*Walking on an uneven surface (eg. Rocky ground, poorly maintained pavement)*	*1*	*2*	*3*	*4*
15.	*Walking up or down a slope*	*1*	*2*	*3*	*4*
16.	*Going out to a social event (eg. Religious service, family gathering or club meeting)*	*1*	*2*	*3*	*4*

Addendum M: Fall Risk Assessment Tool (FRAT)

Fall risk assessment tool (FRAT)

Name: _____

Date of birth: _____

Automatic high risk if person:

Recent change in functional status and/or medications affecting safe mobility

Risk Factor	Level	Risk score
RECENT FALLS *Complete history of falls*	None in the last 12 months One or more between 3 and 12 months ago One or more in the last 3 months One or more in the last 3 months whilst inpatient/resident	2 4 6 8
MEDICATIONS *Sedatives, anti-depressants, anti-Parkinson's, diuretics, anti-hypertensive's, hypnotics*	Not taking any of these Taking one of these Taking two of these Taking more than two	1 2 3 4
PSYCHOLOGICAL Anxiety, depression, ↓cooperation, ↓ insight, ↓judgement esp. RE mobility	Does not appear to have any of these Appears mildly affected by one or more Appears moderately affected by one or more Appears severely affected by one or more	1 2 3 4
COGNITIVE STATUS AMTS: Mental test score	AMTS 9/10 or 10/10 OR intact AMTS 7-8 mildly impaired AMTS 5-6 moderately impaired AMTS 4 or less severely impaired	1 2 3 4

Low risk: 5-11 | Medium risk: 12-15 | High risk: 16-20 **Risk score: _____/ 20**

Abbreviated Mental Test Score (AMTS)

Each question correctly answered scores one point:

1. What is your age? _____
2. What is the time to the nearest hour? _____
3. Give the patient an address, and ask him or her to repeat it at the end of the test _____
4. What is the year? _____
5. What is the name of the hospital or number of the residence where the patient is situated? _____
6. Can the patient recognize two persons (the doctor, nurse, home help, etc.)? _____
7. What is your date of birth? (Day and month sufficient) _____
8. In what year did World War 1 begin? _____
9. Name the present monarch/prime minister/president. _____
10. Count backwards from 20 down to 1. _____ TOTAL: _____

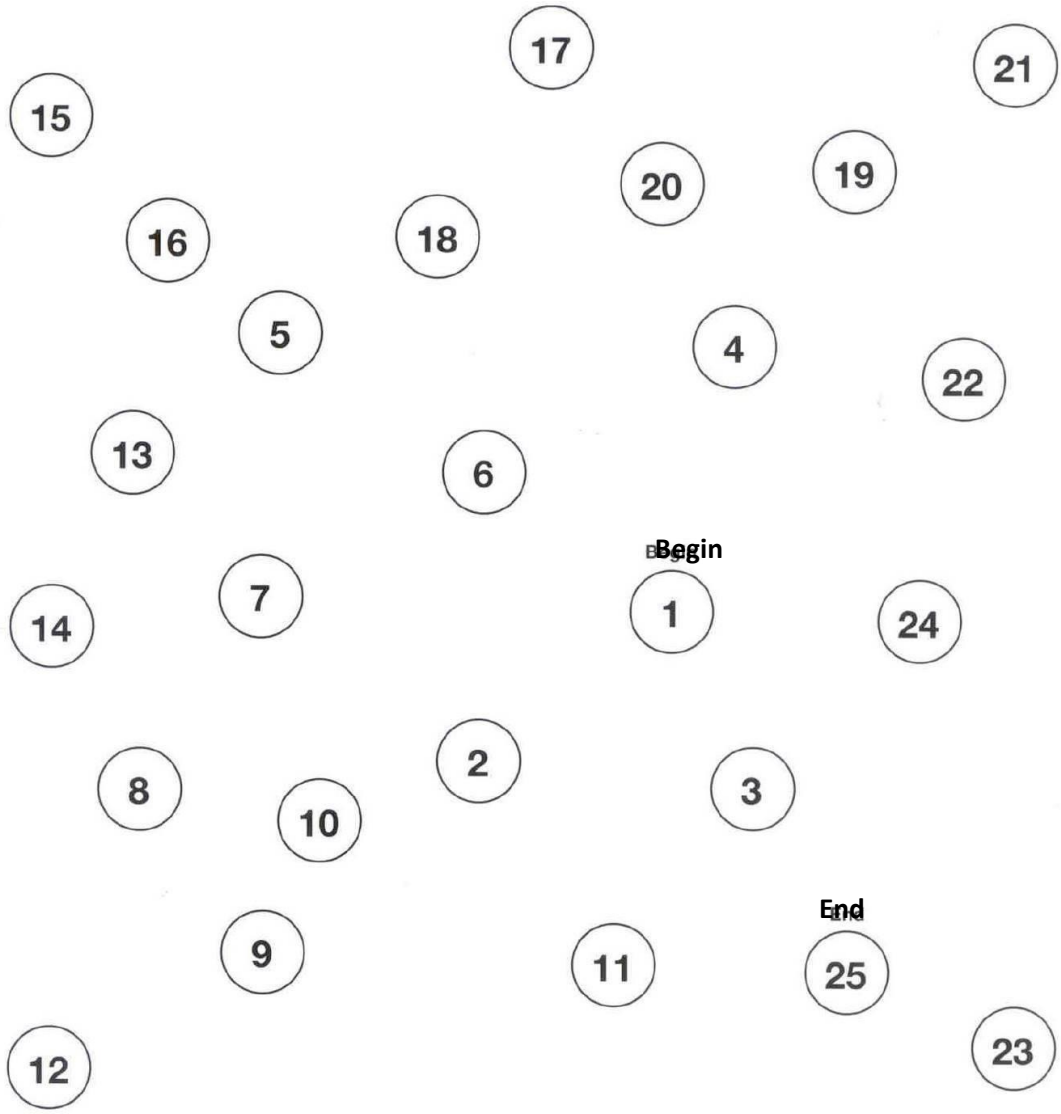
Addendum N: Trail making test A & B

Trail maker Part A

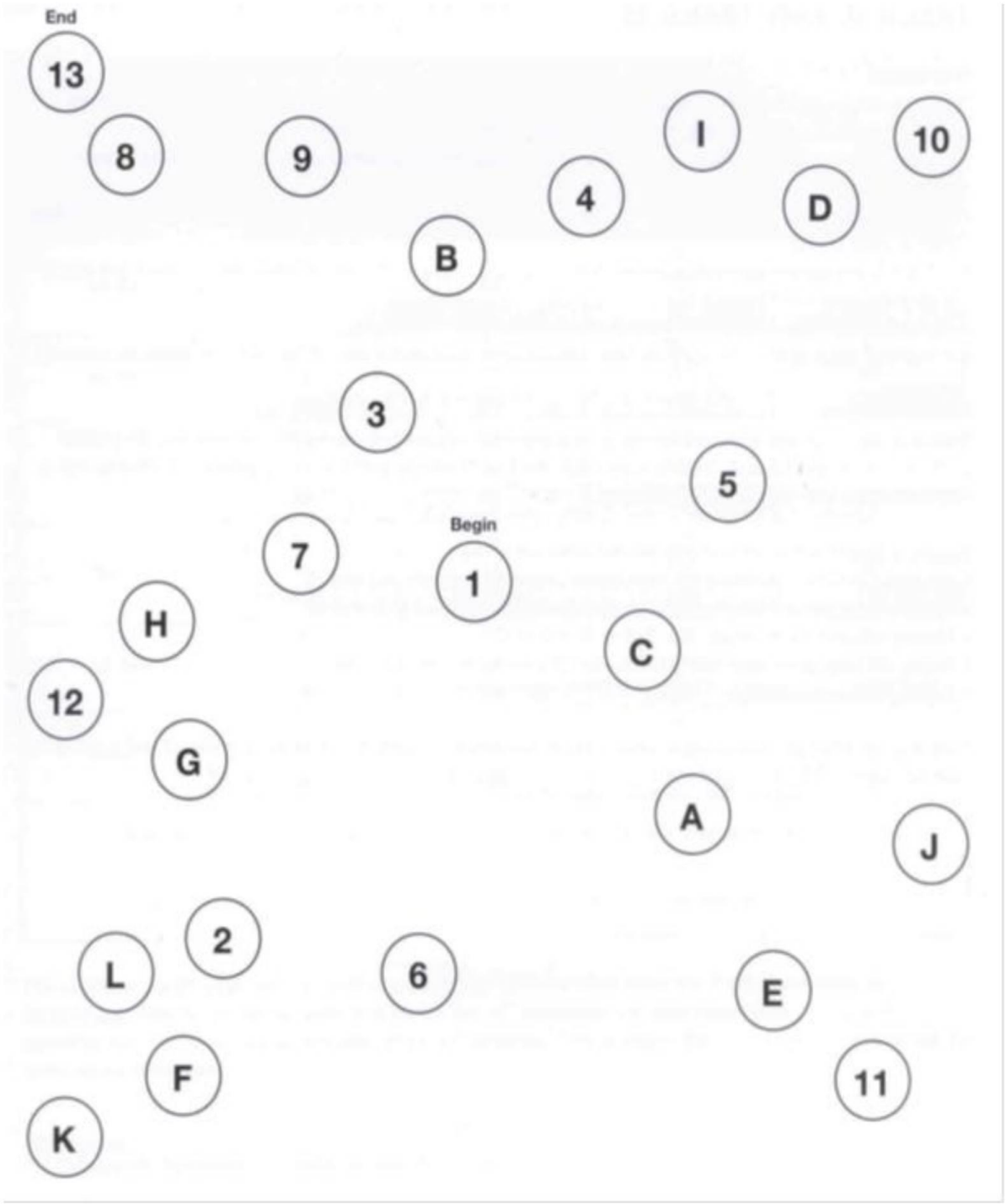
Name: _____ Date: _____

Time: _____

Part A



Part B



Addendum O: Visit three Protocol

Visit three test sheet:

1. Single-task
2. Dual-task cognitive-motor
3. Dual-task motor-motor

Date: _____ BP1: _____

Participant: _____ BP2: _____

Language: _____ Height: _____

Side affected: _____ Weight: _____

- BP x 2
- Height + weight
- 2-minute walk test

2-minute walk test:

"You are going to start here at this line, when I say START, you are going to walk to the line on the other side, around it and back again. You must keep going for two minutes. I will tell you when to stop. You must walk as far as you can in two minutes, but safely. Do you understand?"

Notes: _____

Distance: _____

Comments:_____

_____

_____

Emergency contact: _____Call:_____

"You are going to please listen to the instructions carefully. I am going to explain the first test to you now and then you are going to practice it before we start. However; each time you do

the test, I am going to ask you to do another activity while doing the test. I will explain it to you as we go.

5 Times sit to stand:

Tester demonstrates You are going to be seated comfortably in your chair- bottom at the back of the seat, feet flat on the ground, comfortably spaced apart with your arms across your chest. Try not to use your arms to assist you – like so (show). I am going to say 3, 2, 1, START, you are going to stand up nice and straight as quickly as you can and then sit down again, 5 times. The test will end as your bottom touches the seat after the 5th time. Do you understand? Any questions? Let's practice. Tester to say "3, 2, 1, START" out loud.

Application of NIRSIT

Now I want you to relax, sit back, **close your eyes** and try not to think of anything, try sleeping. We are just measuring the activity of your brain when you are not doing anything at all. This should not hurt. Please let me know if you are uncomfortable. **Please try not to move or speak during this activity.**

BASELINE 5 minutes ○ 5 x sit

to stand_ 1_ST

60 seconds ○ 5 x sit

to stand_ 2_ST

60 seconds ○ 5 x sit

to stand_ 3_ST

Explain next condition

Cognitive-motor

Now, we are still doing the sit to stand test, but I am going to give you a number, and you are going to count backwards from that number in 3's.

For example, I am going say are you ready? Your number is 30. 3,2,1…START, and then you must stand up as quick as possible and start counting; "27, 24, 21" while doing the test. Listen carefully I want you to say the numbers nice and loudly. First let's rest for a minute

60 seconds

Your number is …. + press start on APDM, Ipad, + Student counting errors ○

5 x sit to stand_ 4_DTCM

60 seconds

Your number is …. + press start on APDM, Ipad, + Student counting errors ○

5 x sit to stand_ 5_DTCM

60 seconds

Your number is …. + press start on APDM, Ipad, + Student counting errors ○

5 x sit to stand_ 6_DTCM

Explain next condition

Motor-Motor

For the next one I am going to give you this cup of water and I want you to hold it while you do the 5 times of sitting to standing. Do you have any questions? *First let's rest for a minute before I give you the cup of water*

60 seconds ○ 5 x sit to stand_ 7_DTMM

60 seconds ○ 5 x sit to stand_ 8_DTMM

60 seconds ○ 5 x sit to stand_ 9_DTMM

*J TO MEASURE END

360degree turn

Tester demonstrates

"You are going to stand nice and comfortably feet apart and in contact with the ground. Your toes must be pointing to the tape, arms comfortably at your side".

When you hear me say "3, 2, 1, START" you are going to turn completely around to the right until your shoulders are facing forward, immediately followed by a complete turn to the left.

The test will only end once your body is completely facing the front again and toes are pointing to the tape. Do you understand? Any questions? Please stand up for me. Let's practice. "3, 2, 1, START". Correct person if there are any mistakes.

NIRSIT Setup

First we are going to rest for 2 minutes

2 minutes rest

TURN_ 1_ ST

60 seconds

TURN _ 2_ ST

60 seconds

TURN _ 3_ ST

Explain next condition

Cognitive-motor

Now, for the next 3 trials I am going to give you a number again, and you are going to count backwards from that number in 3's, while you do the turning. Do you understand? First let's rest for a minute

60 seconds

Your number is …. + press start on APDM, Ipad, + Student counting errors

TURN _ 4_DTCM

60 seconds

Your number is …. + press start on APDM, Ipad, + Student counting errors ○

TURN _ 5_DTCM

60 seconds

Your number is …. + press start on APDM, Ipad, + Student counting errors ○

TURN _ 6_DTCM

Explain next condition

Motor-motor

Now, I am going to give you this cup of water and I want you to hold it while you do the turn test. Do you have any questions? *First let's close your eyes and rest for a minute*

60 seconds

- TURN _ 7_ MM

60 seconds

- TURN _ 8_ MM

60 seconds

- TURN _ 9_ MM

Addendum P: Tables 5.3 and 5.4

Table 5.3 The average and standard deviations ($\bar{x} \pm SD$) of the relative % Δ in hemodynamics from baseline to task during three conditions, reflecting the unaffected side of the PFC.

Variable	Δ Single Task [a]	95% CI	Δ DTMM [b]	95% CI	Δ DTCM [c]	95% CI	p-value	Effect size (*d*)
5TSTS								
Δ $HB0_2$	0.0004 ± 0.0012	-0.0002 – 0.0009	0.0007 ± 0.0011	0.0001 – 0.0012	0.0009 ± 0.0016	0.0003 - 0.0014	0.22^{ab}; 0.02_{ac}; 0.32_{bc}	$_{ab}0.31_{S}$ $_{ac}0.35_{S}$ $_{bc}0.10_{N}$
Δ HBR	-0.0000 ± 0.0010	-0.0003 – 0.0003	-0.0003 ± 0.0010	-0.0006 –0.00004	-0.0003 ± 0.0008	-0.0006 – -0.00002	0.17^{ab}; 0.09_{ac}; 0.78_{bc}	$_{ab}$ 0.24$_{S}$ $_{ac}0.32_{S}$ $_{bc}0.06_{N}$
HbDiff	0.0004 ± 0.0019	-0.0002 - 0.0010	0.0010 ± 0.0016	0.0003 –0.0016	0.0012 ± 0.0020	0.0006 – 0.0018	0.12^{ab}; 0.02_{ac}; 0.43^{bc}	$_{ab}$ 0.34$_{S}$ $_{ac}0.40_{M}$ $_{bc}0.11_{N}$
360 Turn								
Δ $HB0_2$	-0.0001 ± 0.0055	-0.0018 – 0.0016	0.0002 ± 0.0012	-0.0016 –0.0020	-0.0002 ± 0.0115	-0.0019 - 0.0016	0.81^{ab}; 0.96_{ac}; 0.78_{bc}	$_{ab}$ 0.08$_{N}$ $_{ac}0.01_{N}$ $_{bc}0.04_{N}$
Δ HBR	0.0000 ± 0.0034	-0.0013 – 0.0013	-0.0000 ± 0.0008	-0.0014 – 0.0013	-0.0004 ± 0.0078	-0.0017 –0.0009	0.96^{ab}; 0.67_{ac}; 0.71_{bc}	$_{ab}$ 0.02$_{N}$ $_{ac}0.07_{N}$ $_{bc}0.06_{N}$
ΔHbDiff	-0.0001 ± 0.0081	-0.0031 –0.0028	0.0003 ± 0.0017	-0.0027 – 0.0032	0.0002 ± 0.0183	-0.0026 –0.0031	0.87^{ab}; 0.87_{ac}; 0.99^{bc}	$_{ab}$ 0.06$_{N}$ $_{ac}0.02_{N}$ $_{bc}0.00_{N}$

DTMM: Dual-task Motor-motor; DTCM: Dual-task Cognitive-motor; 5TSTS: five times sit-to-stand; HBO_2: oxyhaemoglobin; HbR: de-oxyhaemoglobin; Hbdiff : Haemoglobin difference; Δ: Delta; *: $p < 0.05$; ** $p < 0.01$; [a]: Single-task; [b]: Dual-task MM [c]: Dual-task CM; [L]: Large; [M]: Medium; [S]: Small; N: Negligible

Table 5.4 The average and standard deviations ($\bar{x} \pm SD$) of the relative change in hemodynamics from baseline to task during three conditions, reflecting the affected side of the PFC.

MM: Motor-motor Interference; CM: Cognitive- motor Interference; 5TSTS: five times sit-to-stand; HBO: oxyhaemoglobin; HBR: de-oxyhaemoglobin; Hbdiff : Haemoglobin

Variable	Δ Single Task [a]	95% CI	Δ DTMM [b]	95% CI	Δ DTCM [c]	95% CI	p-value	Effect size (*d*)
5TSTS								
Δ HB0	0.0006 ± 0.0011	0.00010 – 0.0011	0.0008 ± 0.0012	0.0002 – 0.0012	0.0009 ± 0.0018	0.0004 – 0.0014	0.60^{ab}; 0.23_{ac}; 0.51_{bc}	$_{ab}0.18_{S}$ $_{ac}0.18_{S}$ $_{bc}0.04_{N}$
Δ HBR	-0.0003 ± 0.0011	-0.0006 — 0.00002	-0.0003 ± 0.0011	-0.0006 – 0.00003	-0.0005 ± 0.0010	-0.0008 – -0.0002	0.83^{ab}; 0.43_{ac}; 0.32_{bc}	$_{ab}0.04_{N}$ $_{ac}0.14_{N}$ $_{bc}0.17_{S}$
Δ HbDiff	0.0009 ± 0.0016	0.0003 – 0.0016	0.0011 ± 0.0018	0.0004 – 0.0017	0.0013 ± 0.0021	0.0007 - 0.0020	0.80^{ab}; 0.22_{ac}; 0.35^{bc}	$_{ab}0.09_{N}$ $_{ac}0.21_{S}$ $_{bc}0.12_{N}$
360 Turn								
Δ HB0	0.0003 ± 0.0061	-0.0015 - 0.0020	0.0003 ± 0.0011	-0.0015 – 0.0021	0.0021 ± 0.0105	0.0003– 0.0038	0.97^{ab}; 0.15_{ac}; 0.17_{bc}	$_{ab}0.01_{N}$ $_{ac}0.21_{S}$ $_{bc}0.23_{S}$
Δ HBR	0.0001 ± 0.0035	-0.0012 – 0.0015	-0.0001 ± 0.0008	-0.0015 – 0.00125	-0.0020 ± 0.0092	-0.0033– -0.0007	0.79^{ab}; 0.02_{ac}; 0.04_{bc}	$_{ab}0.10_{N}$ $_{ac}0.31_{S}$ $_{bc}0.29_{S}$
Δ HbDiff	0.01 ± 0.02	-0.0027– 0.0030	0.03 ± 0.04 0.0015	-0.0025 – 0.0034	0.0041 ± 0.0193	0.0012– 0.0070	0.89^{ab}; 0.05_{ac}; 0.08^{bc}	$_{ab}0.05_{N}$ $_{ac}0.27_{S}$ $_{bc}0.27_{S}$

difference; DTMM: Dual-task Motor-motor; DTCM: Dual-task Cognitive-motor; 5TSTS: five times sit-to-stand; HBO_2: oxyhaemoglobin; HbR: de-oxyhaemoglobin; Hbdiff :

Haemoglobin difference; Δ: Delta; *: $p < 0.05$; ** $p < 0.01$; [a]: Single-task; [b]: Dual-task MM [c]: Dual-task CM; [L]: Large; [M]: Medium; [S]: Small; N: Negligible