University of Southampton

Faculty of Health Sciences

Whole-body coordination when turning on-the-spot in people with stroke and Parkinson's disease: a comparison with healthy controls

by

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Abstract

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Turning around to interact with the environment is a common activity of daily living. The location of a target for interaction may be known or unknown prior to turning and the angle of a turn may vary depending on the task to be carried out. Stroke and Parkinson's disease could compromise coordination of body movement during turning which may pose a risk for instability and subsequent falls. The sequence of onset latency, peak velocity and timing of peak velocity of body segments (eye, head, shoulder, pelvis and foot) while turning on-the-spot were investigated in people with stroke and age-matched healthy controls (study 1) and in people with Parkinson's disease and age-matched healthy controls (study 2). The effect of target predictability, turn angle and turn direction on the sequence of the movement of the body segments were also investigated. Participants were asked to stand in front of a light and either turn to a specific light (predictable condition) or locate and turn to a random light (unpredictable condition) placed at 45°, 90° or 135° to the right or left when the light in front extinguished.

The results showed that the people with stroke and Parkinson's disease (PD) initiated the movement of the segments later, had lower peak velocities and attained the peak velocities later than their control counterparts. People with PD showed more simultaneous onset of rotation of body segments as compared to their age-matched control when turning to 135°. The sequence of onset of rotation of the body segments was similar between the people with PD and their age-matched controls for all the other turning tasks. People with stroke also had comparable sequence of onset of rotation of body segments with their age-matched controls for all the turning tasks. While people with stroke presented with consistent pattern of peak velocity of the body segments for all the turning tasks, their control counterparts showed differences in the pattern of the peak velocities when turning to dominant and non-dominant sides. People with PD showed similar peak velocities of pelvis and foot when turning 45° to initially affected side as compared to separate peak velocities of the pelvis and foot in the stroke and control groups. The peak velocities of the segments (head, shoulder, pelvis and foot) occurred at more or less the same time for most of the turning tasks.

Impairment of the relative movement of body segments during functional tasks could challenge the balance of an individual. The sequence of movement of body segments in the different tasks could therefore be related to balance during turning to identify which of the strategies of turning could present with risk of falls. Predictability of a target, turn angle and turn direction should be considered when developing interventions to avoid falls during turning and strategies for improving speed of reacting to perturbations should be developed for people with stroke and Parkinson's disease.

Table of contents Page

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6: General discussions

List of figures

List of Tables

Appendices

DECLARATION OF AUTHORSHIP

I **Rufai Yusuf Ahmad**

declare that the thesis entitled:

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and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
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- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- parts of this work have been presented as:
  - Ahmad, RY, Verheyden G, & Ashburn, A (2010) Sequence of head and upper trunk rotations during head turns in people with stroke while sitting: A pilot study. Poster presented at the 29th Scientific meeting of the Physiotherapy Research Society, Middlesbrough, 6 June.
  - Ahmad, RY, Verheyden, G, Burnett, M, Samuel, D, Ashburn, A (2011) Whole-body coordination when turning on the spot in people with stroke and healthy controls. Poster presented at the scientific meeting of the Society for Research in Rehabilitation, Cardiff, 22 February.

- Ahmad, RY, Verheyden, G, Burnett, M, Samuel, D, Ashburn, A. Whole-body coordination when turning on the spot in people with stroke and healthy controls. Abstract accepted for presentation at the International Society for Posture and Gait Research conference. Trondheim, 24-28 June, 2012.

The abstracts are presented in appendix i.

Signed: …………………………………………………………………..

Date:……………………………………………………………………….

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Glossary of terms

- Eye saccades: quick, simultaneous movements of both eyes in the same direction
- Motor coordination: the combination of movement of body segments created with the kinematic and kinetic parameters that result in intended actions
- Centre of mass (COM): the location of the resultant of the weights of the individual parts making up the body
- Base of support (BOS): the region bounded by body parts in contact with a support surface
- Cue: a trigger for an action to be carried out at a specific time
- Onset latency: amount of time it takes for a movement to start after receiving a trigger for the movement

List of abbreviations

- ADL: Activities of daily living
- BBS: Berg Balance Scale
- BI: Barthel Index
- CODA: Cartesian Optoelectronic Dynamic Anthropometer
- FRT: Functional Reach Test
- H & Y: Hoen and Yahr
- MCA: Montreal Cognitive Assessment
- MMSE: Mini-Mental State Examination
- UPDRS: Unified Parkinson’s Disease Rating Scale
- VNG: Videonystagmography
- WHO: World Health Organization

Chapter 1

1. Introduction

1.1. Background

Turning from one point to another to interact with the environment is a common activity of daily living. Orientation of body segments to align with objects in the environment could be carried out in many positions such as lying, sitting, standing and walking. The narrower the base of support, the more the risk of losing stability (Horak, 2006) especially when it involves steps that cause large movement of the centre of mass with respect to the base of support. Thus, turning the whole body in standing and walking may provide a great challenge to the central nervous system (CNS) in coordinating the segments involved while turning to avoid losing stability.

Body orientations that involve coordinated interaction of body segments and environmental factors are controlled by the CNS through interaction of a series of structures (sensory receptors, afferent pathways, brain, efferent pathways and effectors). Apart from the sensory-motor interactions, the cognitive system plays an important role by making sense of the information provided by the sensory system which is forwarded to the motor system to act upon (Montgomery and Connolly, 2003). An intact functioning of these systems ensures that the goal at hand is achieved successfully. Impairment or damage of one or more of the above mentioned motor control components may result from disease. Stroke and Parkinson's disease are examples of diseases which impair the motor, sensory and/or cognitive systems.

People with stroke and Parkinson's disease have been reported to have high incidences of falls especially when turning around (Ashburn et al., 2001b, Hyndman et al., 2002). It is not completely understood why they fall; however, there are suggestions that the relative movement of body segments during functional movements play a role in controlling the centre of mass within the base of support (Alexandrov et al., 1998a, Alexandrov et al., 1998b). This means that impairment of the normal sequence of movement of body segments during turning may affect the balance of an individual and may explain why people with stroke and Parkinson's disease often fall during turning.

The main aim of rehabilitation of people with stroke and Parkinson's disease is to assess and manage the impairments in order to return the individual to the highest functional level. To achieve this, rehabilitation practitioners are faced with two questions; firstly, how does the sensory-motor control mechanism work in normal individuals? This is reflected in the statement of Carr and Shepherd (1987) that "the unique contribution of physiotherapy to the rehabilitation of stroke lies potentially, in the training of motor control based on an understanding of the kinematics and kinetics of normal movement, motor control processes and motor learning" Secondly, how is it affected by impairment of the structures that interact to keep the mechanism in order? Various studies have approached the first question with regards to the interaction of body segments during turning and have provided answers to many questions raised. On the other hand, the second question has been scarcely studied.

This study sets to answer the second question by investigating the sequence of rotation of body segments during turning on-the-spot in people with stroke and people with Parkinson's disease as compared to age-matched healthy controls. **Chapter one** defines turning in the context of this study and gives an overview of how sensory and motor components of motor control interact to produce coordinated movement to achieve desired goals with emphasis on turning. **Chapter two** reviews the literature on whole-body coordination when turning in healthy individuals. In **Chapter three** the aspects of the methodology that are common to both studies (whole-body coordination when turning in people with stroke and age-matched healthy controls and whole-body coordination when turning in people with Parkinson's disease and age-matched healthy controls) are presented. **Chapter four** highlights impairments in people with stroke and how they may affect their ability to turn around, reviews the literature on whole-body coordination during turning in people with stroke and finally presents the results and discussions of the comparisons of the sequence of rotation of body segments during turning on-the-spot between people with stroke and age-matched healthy controls. **Chapter five** highlights impairments in people with Parkinson's disease and how they may affect their ability to turn around, reviews the literature on whole-body coordination during turning in people with Parkinson's disease and finally presents the results and discussions of the comparisons of the sequence of rotation of body segments during turning on-the-spot between people with Parkinson's disease and age-matched healthy controls. Finally, **chapter six** presents the general discussions where the two studies are compared, the relevance of the findings to clinical practice are highlighted and recommendations for further studies given.

1.2. Definition and prevalence of turning

Turning could be defined as a motion in a new direction that involves movement around an axis or centre (rotation). In the context of this study, turning will be defined as rotation of the body or its part in the horizontal plane around the vertical axis (Figure 1.1). Although the main direction of movement occurs in the horizontal plane, movement is not limited to that plane as some degree of translation could take place in either the frontal or sagittal plane at individual joint level. For example, the foot may dorsiflex while at the same time undergo horizontal displacement or the head may flex or extend while rotating during change of direction.

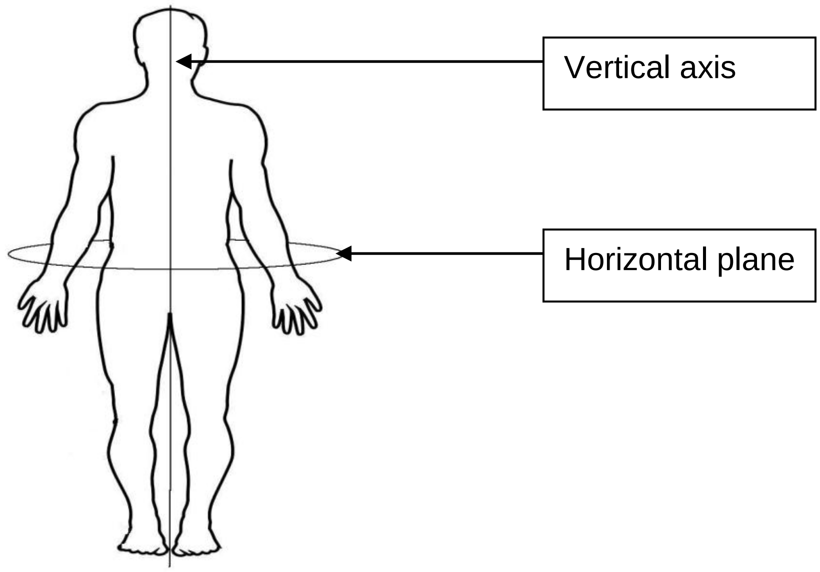


Figure1.1. Diagram showing the plane and axis around which turning occur

Turning has been recognized as an important component of activities of daily living (Sedgeman et al., 1994, Land, 2004, Glaister et al., 2007). Land (2004) reported about 800 eye saccades out of which 54 were accompanied by head and trunk rotations while three healthy subjects were making tea in the kitchen. Turns of 90° or larger were usually produced by two to four foot movements, and many smaller turns involved two foot movements. Turning makes up a large portion of steps taken during activities of daily living. Glaister et al. (2007) filmed 11 subjects from the waist down as they walked from one office to another, from an office to a parking lot, through a convenience store and through a cafeteria. The results showed that out of all the steps taken during each task, the steps involving turning constituted 8%, 35%, 45% and 50% for the four tasks respectively.

Sedgeman et al. (1994) reported a high proportion of turns performed by normal older adults during daily activities in the home setting. Four participants were filmed while performing eight simulated activities including tea making in the kitchen, washing hands in the toilet, letter retrieval from a letter box, telephone call, toileting, laundry cleaning, putting on socks and shoes and opening and closing a door. Steps that involved turning represented 18% of all steps taken during the activities. These involved turns performed while walking or in a stationary position such as turning to flush the toilet. This shows that turning is very prevalent during activities of daily living, though individuals are not always conscious of the fact.

Turning is controlled by the central nervous system just like many other purposeful movements. The next section will explore motor control of goal directed movement and where appropriate explanations will be given specifically on the control of turning.

1.3. Motor control

Goal directed movement occurs through the interaction of three factors; the individual, the task to be carried out and the environment in which the task takes place (Shumway-Cook and Woollacott, 2007). To carry out a task, an individual gathers information from the relevant environmental features through sensory systems; this information is used to plan appropriate movement strategies required to achieve the task. Sensory systems provide information about the state of the body (relation of body parts to each other and position of the body in space) and relationship of the body to objects in the environment that are required for the execution of the task. Integration of the sensory information into meaningful information is essential for planning the movement strategy needed to perform the desired action (Montgomery and Connolly, 2003), cognitive input is therefore essential at this stage of movement planning. The brain utilizes the processed information to issue commands for the activation of specific movement components which, when linked together in the appropriate spatial and temporal sequence, make up the desired task (Carr and Shepherd, 1987).

1.3.1. Sensory information to the brain

For an individual to turn towards a target, the brain needs to know the alignment of the segments involved in the turn so as to compute when and to what degree each segment needs to rotate to reach the target. Awareness of the position of the body in relation to the target is also valuable as it determines to what direction and angle the body needs to turn. Information on the position of the body and its parts is gathered by way of proprioceptors and by the vestibular system which registers position of the head in space (Brodal, 1998). The visual system provides the brain with information about position of the body in relation to the environment (Brodal, 1998). The information gathered by the sensory systems is important for planning the strategy required to initiate the movement and for feedback on whether the movement is progressing according to the plan.

1.3.1.1. Visual system

Incident light around the visual field stimulates receptors in the retina with the image of the main object of interest falling on the central fovea (Bruce et al., 2003). This information is converted into neuronal signals in the retina and conveyed through visual pathways to the primary visual cortex of the brain where the visual information is sorted before being distributed to other cortical areas (Wurtz and Kandel, 2000). The visual areas are divided into two streams: a ventral stream that identifies the nature of objects and a dorsal stream that identifies the location of objects (James et al., 2003). Information from the ventral stream projects directly to the motor areas of the cerebral cortex while that from the dorsal stream projects through the cerebellum to the cells of the motor cortex from which the descending motor tracts originate (Stein and Glickstein, 1992, Glickstein et al., 1994). These projections are shown in Figure 1.2. There are also cerebellar projections to the red nucleus and brainstem areas that give rise to the descending reticulospinal and vestibulospinal tracts (Nolte, 1999). Thus the visual information is important for both motor and postural purposes.

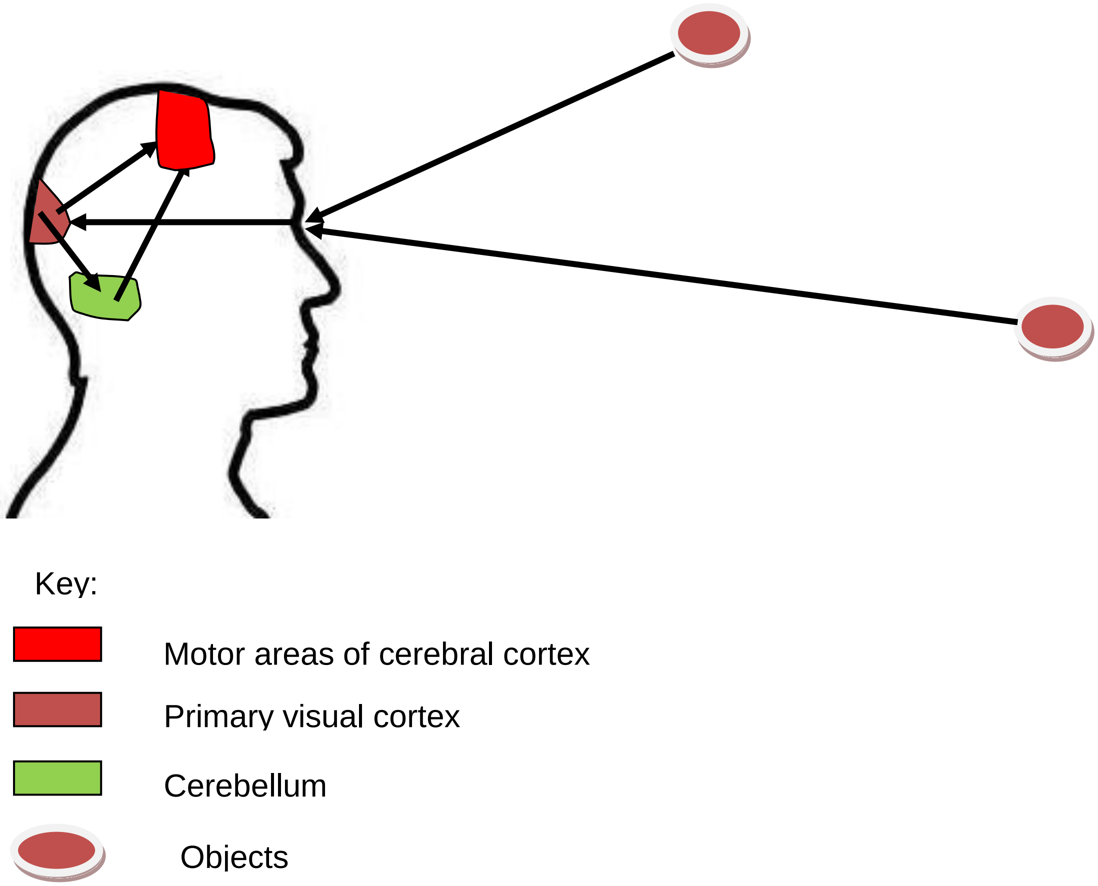


Figure 1.2. Connection of visual and motor system

The location of the target to turn to in relation to the individual is therefore sent to the cerebellum through the pathway described above. The cerebellum utilizes the information to produce the appropriate timing of motor activations that is sent to the motor cortex for execution. The visual information is also important for the maintenance of balance during the turn.

1.3.1.2. Vestibular system

The vestibular system gathers information about the position and movement of the head in space which is used to control eye and head movements and to provide postural adjustments to the body for the maintenance of balance (Baloh and Honrubia, 2001). The vestibular system detects two components of head movement (rotation and translation). Rotational movements such as shaking or nodding the head are detected by three semicircular canals while translational movements such as forward/backward or sideward movement of the head are detected by two otholith receptors (utricle and saccule) (Kemp, 2010). The receptor cells of the semicircular canals and otholiths (vestibular apparatus) send signals to the vestibular nuclei which projects to the eye for fixation of the eye on objects during head motion and to the spinal cord to produce reflexes to stabilize posture (Kemp, 2010). These projections are shown in Figure 1.3.

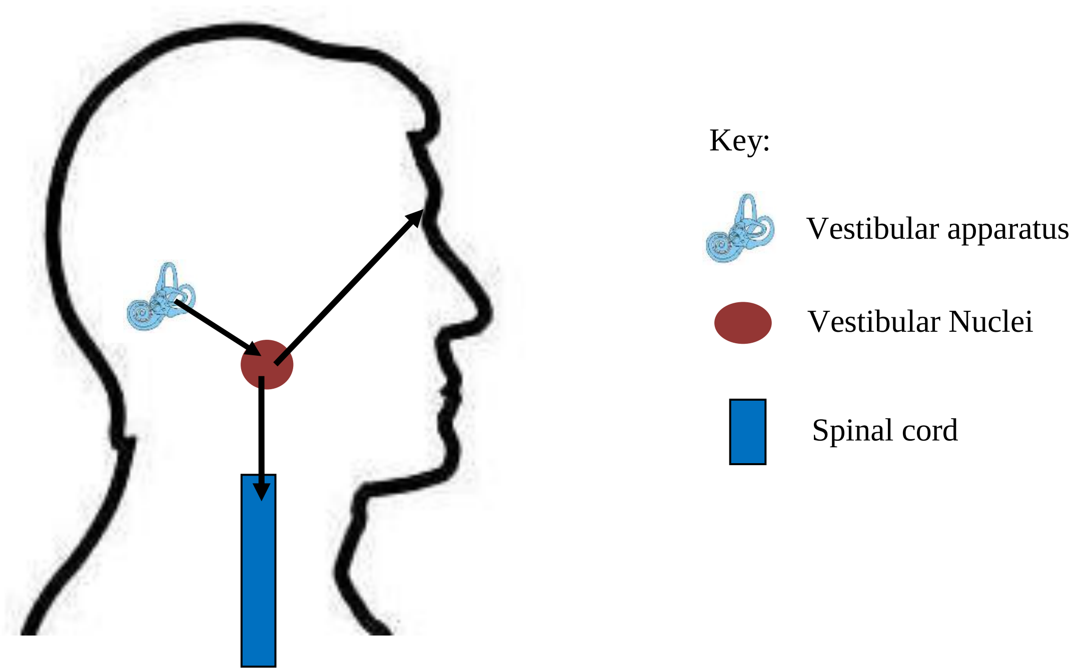


Figure 1.3. Vestibular system

For an individual to turn successfully from one target to another, the eyes need to be properly controlled in relation to movement of the head. During a turn the eye often reaches the object of interest before the head (Land, 2004), probably because of the inertia the head encounters due to its weight. When the eye is fixed on an object, the continuous head movement can alter the stability of the eye on the object. A reflex called the vestibulo-ocular reflex helps in stabilizing the eye on the object by counter-rotating the eye against the movement of the head until the head reaches the object (Laurutis and Robinson, 1986). Another important task for a successful turn from one point to another is the ability to keep vertical orientation with respect to gravity during the turn. If the head and body start to tilt, the vestibular nuclei will automatically compensate by initiating the correct postural adjustments that brings back the body to its vertical position.

1.3.1.3. Proprioceptive system

Proprioception is the information provided to the CNS by sensory receptors in muscles, tendons, joints or skin about the position of the body or its parts; of the force, direction and range of movement of the joints (Mergner et al., 1997, Ropper and Brown, 2005). The information is carried by primary afferent fibres and conveyed, through the thalamus and sensory cortex, to the motor areas of the frontal lobe for the guidance of motor activity (Brodal, 1998). The information is also conveyed to other brainstem areas where it is integrated with information from the visual and vestibular systems for the control of posture (Brodal, 1998). These projections are shown in figure 1.4.

The proprioceptive information to the cerebral cortex helps in updating the central motor system about position of the body segments so that activation of the muscles during the turn is adapted to the actual positions of the segments. On the other hand, the proprioceptive information to the cerebellum is essential for maintaining the body balance while the turn is executed.

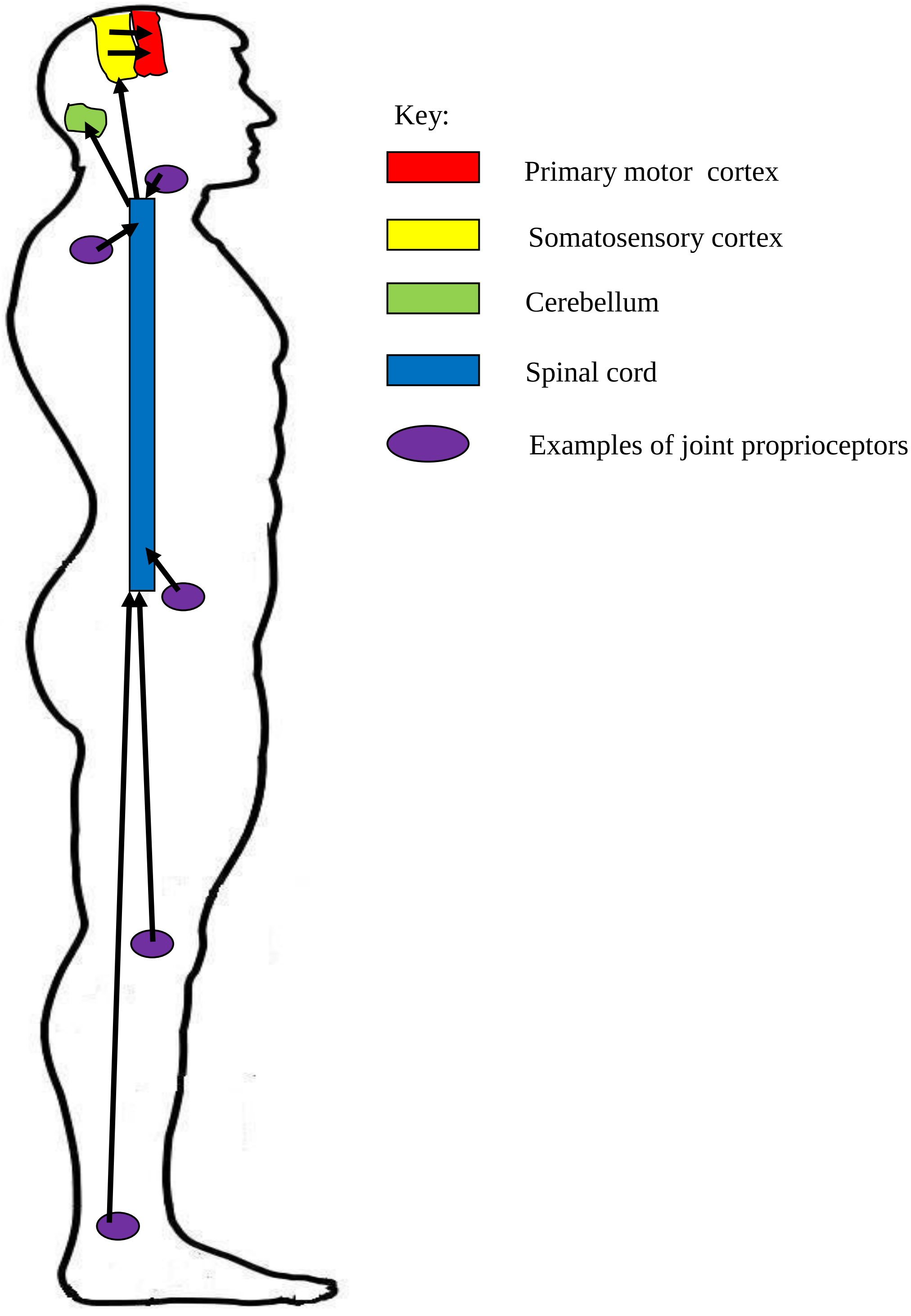
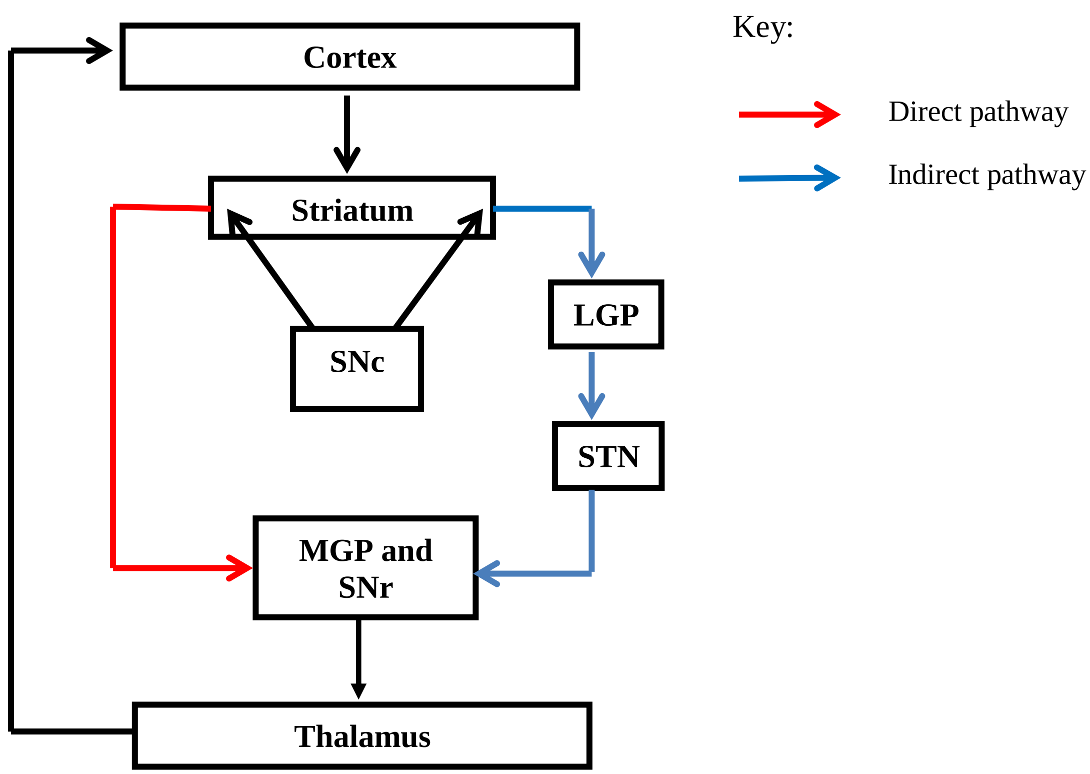


Figure 1.4. Proprioceptive system

1.3.2. Central control of movement

The parietal lobes that gather the sensory information explained in section 1.3.1 are closely interconnected with the prefrontal areas (Figure 1.6), and together these two regions represent the highest level of the motor control hierarchy (Bear et al., 2001). It is at this level that the decisions are made about what action to take to achieve the task at hand. The prefrontal cortex is central in the integration of the sensory information into meaningful information by providing the background for synthesizing a diverse range of information that lays the foundation for deciding what action to take to achieve a task (Miller, 2000). This is termed information processing and forms the core of the cognitive system. Stored memory is also essential for the guidance of purposeful movement (Smyth et al., 1988). The memory structures are necessary in recognizing signals in the environment and for recalling prior movement plans. The prefrontal area sends its axons to the premotor cortex (Area 6) which, having been informed of the kind of action to take, helps to determine the basic components of the movement for this purpose (Bear et al., 2001). This area of the cortex devises a plan for the movement and passes this information on to the motor cortex (M1) for implementation (Bear et al., 2001).

After setting a strategic movement plan for the desired goal by the premotor cortex, it is necessary to ensure that only the required movements are executed. The basal ganglia act as a filter, blocking the execution of movements that are not required to achieve the task. Inputs from the cortex reach the striatum and the output of the striatum are sent to the globus pallidus (GPi) and the substantia nigra pars reticulate (SNr) through direct and indirect pathways (Blandini et al., 2000). Dopamine from the substantia nigra pars compacta (SNc) facilitates striatal neurons in the direct pathway and inhibits those in the indirect pathway (Rodriguez-Oroz et al., 2009). Activation of the direct pathway leads to reduced neuronal firing in the GPi and SNr and movement facilitation, while activation of the indirect pathway increases neuronal firing in the GPi and SNr and suppresses movements (Rodriguez-Oroz et al., 2009). In this way the required components of the movement are facilitated while the unwanted movement components are inhibited. The GPi and SNr give descending outputs to certain brainstem nuclei such as superior colliculus which are probably of importance for the control of coordinated head and eye movements (Hikosaka et al., 2000) as well as outputs to the thalamus. The outputs to the thalamus have widespread ascending projections to the motor cortex, completing a complex cortico-striato-thalamo-cortical loop (McAuley, 2003) as shown in figure 1.5.



SNc = Substantia nigra pars compacta; MGP = Medial globus pallidus; SNr = Substantia nigra pars reticulata; LGP = Lateral globus pallidus; STN = Subthalamic nuclues

Figure 1.5. cortico-striato-thalamo-cortical loop

The appropriate movement components selected by the basal ganglia are executed by the primary motor cortex (M1). However, the arrangement of muscle contractions in space and time need to be specified by the cerebellum. The M1 and cerebellum make up the middle level of the motor control hierarchy (Bear et al., 2001). The cerebellum regulates the duration and sequence of the movements of body segments. It first receives information from the sensory and motor areas then sends information to M1 (Figure 1.6) about the required timing of each movement (Brodal, 1998). M1 sends the information to the relevant parts of the body for implementation (Figure 1.6). Within a particular region of M1, a pyramidal tract neuron innervates more than one muscle and therefore could control more than one joint at a time (Brodal, 1998). A particular movement is achieved by the activity of many neurons each innervating a number of muscles across joints, thus initiation of purposeful movement involves several joints, rather than isolated, single-joint movements (Brodal, 1998). In other words, the motor cortex is organized to ensure the performance of tasks rather than controlling individual joints. M1 issues commands to lower motor neurons by way of nuclei and interneurons of the brainstem and spinal cord.

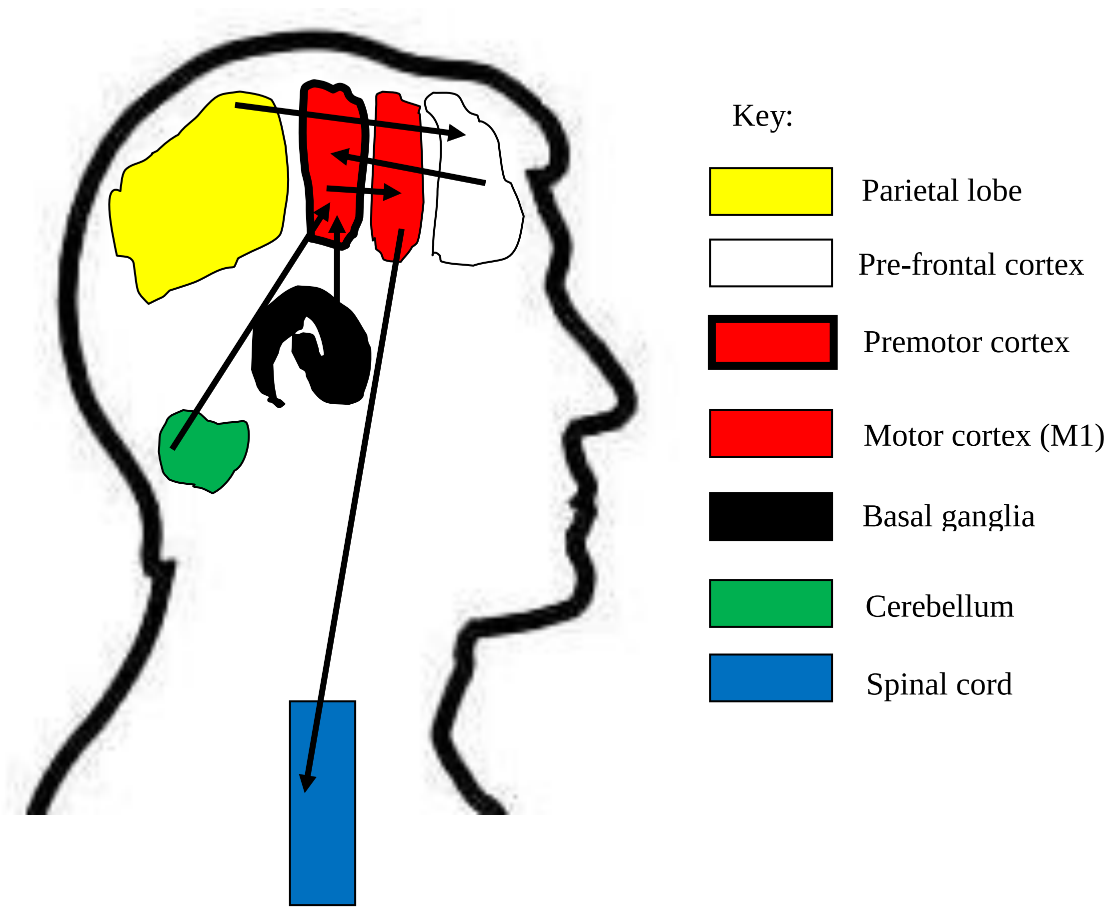


Figure 1.6. Central control of movement

1.3.3. Command to lower level of motor system

The central nervous system gathers information needed for constructing a blueprint required for achieving a particular task. This blueprint is sent to the muscles for implementation through various tracts in the brainstem and spinal cord (Brodal, 1998). Each tract conveys specific information that is required for initiating and maintaining the movement or for stabilizing the body during the movement. This represents the lowest level of the motor control hierarchy (Bear et al., 2001), which is concerned with execution, i.e. activation of the motor neuron and interneuron pools that generate the goal-directed movement and make any necessary adjustments of posture.

The corticospinal tract is the main pathway through which execution of voluntary movement occurs. The reticulospinal, tectospinal and vestibulospinal tracts serve as alternative pathways for the activation of voluntary movement in addition to providing postural adjustments during tasks. However, these are mostly automatic, reflex movements that are relatively independent of descending connections from the cerebral cortex such as movements that orient the body toward external stimuli (Brodal, 1998).

1.3.4. Peripheral control of movement

The axons of lower motor neurons leave the CNS in ventral roots and divide into terminal branches that are distributed to muscles (Bear et al., 2001). Each branch ends at the neuromuscular junction of a muscle fibre. Each motor neuron and the muscle fibres it innervates form a motor unit, which is the smallest functional unit in motor control. The force produced by a normal muscle contraction depends on the number and type of motor units recruited and the characteristics of the motor unit discharge (Clamann, 1993). Muscle force or tension is increased when the absolute number of active motor units is increased and/or the firing rates of already active motor units are increased (Kanosue et al., 1979).

In many situations individual segments that control separate groups of muscles need to be coordinated to smoothly achieve a task. Coordination is defined as “the ability of a given subject to activate appropriate muscles for the execution of a purposeful movement in an accurate and effective manner” (Bourbonnais et al., 1992). A coordinated movement is the net result of activity in several muscles, including agonist, antagonist and synergist, that share a precise temporal (i.e. when a muscle turns on) and spatial (i.e. which muscle turns on) pattern of onset (Bourbonnais et al., 1992). Interneurons (propriospinal neurons) enhance cooperation of the various spinal segments. They establish synaptic contacts between many neurons in the cord, within the segment in which the cell body is located, and in segments above and below (Brodal, 1998).

1.3.5. Coordination of movement and posture

It is very important to maintain a stable body position while at the same time allowing body parts to move freely during functional activities. Failure to achieve any of the two could lead to either instability or inefficiency in carrying out functional tasks. Postural control is organised to build up and update body orientation and ensure that balance is maintained (Massion, 1994) during movement. Pollock et al. (2000) described postural control as ‘‘the act of maintaining, achieving or restoring a state of balance during any posture or activity’’.

Postural control occurs simultaneously with functional tasks and plays a role in controlling the movement of the centre of mass within the base of support of an individual to allow safe and efficient performance of movement. Frank and Earl (1990) postulated that there are three strategies that could be adopted to maintain upright stance during voluntary movement. Firstly, preserving upright stance during movement may involve postural preparations engaged well before movement (Frank and Earl, 1990). An individual preparing to turn around may increase the base of support by widening the distance of the feet and/or stiffening the joints through muscle contractions to set a more stable posture.

Secondly, maintaining upright posture can be achieved by postural adjustments that occur simultaneously with, or just before, the initiation of voluntary movement (Frank and Earl, 1990) in a strategy referred to as the postural accompaniment. The general mechanism of postural accompaniments involves anticipating the effect of the movement on posture and coordinating the activation of both the postural adjustments and the intended movement to minimize the postural disturbance (Frank and Earl, 1990) in a feed-forward control. Alexandrov et al. (1998a) showed that forward bending was performed by flexion in the hip and extension in the knee and ankle joints, a movement synergy that maintained equilibrium during the movement by stabilizing the centre of mass (COM) within the base of support. They argued that the coordinated movement of the joints was centrally controlled in a feed-forward manner as supported by the findings of Massion et al. (1997) that a similar interjoint coordination is preserved even in microgravity. This implies that if there is a problem with central control of movement, the coordination of posture and movement during bending tasks may be jeopardized. This was indeed shown in the study of Alexandrov et al. (1998b) that people with Parkinson's disease present with increased centre of mass shift due to incoordination of joint angles.

The coordination of posture and movement using the postural accompaniment strategy has also been shown during changing direction (turning) while walking in healthy adults. Young healthy adults reoriented their head followed by the trunk, then movement of the COM in the medio-lateral plane which was accompanied by trunk roll (movement of the trunk in the frontal plane) and finally foot displacement in the medio-lateral plane (Paquette et al., 2008). The control of the COM towards the new direction is shown to be affected by the predictability of the target to turn to (Patla et al., 1999). Participants used medio-lateral foot displacement when position of target was predictable (cue for direction of turn given early) while they used trunk roll motion when the position of the target was unpredictable (cue for direction of turn given one stride before the turn). The effect of damage to the CNS in the coordination of movement and posture during turning has not been investigated; however, older adults have been shown to have different sequence of movement and posture parameters as manifested in a delay in the medio-lateral displacement of the COM (Paquette et al., 2008).

Finally, postural disturbances imposed by movement can be counteracted by sensory-based feedback strategies called postural reactions (Frank and Earl, 1990). The general mechanism of feedback strategies consists of excitation of sensory receptors that trigger automatic postural adjustments. This strategy is the primary defence against unexpected external perturbations. An individual may select one or another of these strategies, depending on the perceived need for safe regulation of the body's centre of mass and timing of the movement. Postural preparations arrive well before movement initiation; postural accompaniments arrive within about 100ms of movement initiation and postural reactions arriving about 100ms or more after movement initiation (Frank and Earl, 1990).

It is now clear that performance of efficient goal-directed movements occur through the coordination of posture and movement. When the mechanism that controls the movement is intact but the postural adjustments that ensure stability during the movement is faulty, the balance of an individual could be compromised and vice versa. Many questions could therefore be raised with regards to the consequences of the disruption of the CNS's control of movement and posture during goal directed movement. Firstly, does damage to the CNS lead to in-coordination of the movement itself? Does it affect the development of the appropriate postural adjustments that keep the body upright during the movement? Could these changes lead into instability and subsequent falls? This thesis is set to answer the first question by investigating the coordination of body segments during turning on the spot in people with stroke and Parkinson's disease as compared to age-matched healthy adults.

1.3.6. Summary of motor control

Goal-directed movement depends on information about where the body is in space, where it intends to go, and the selection of a plan to get it there. Once a plan has been selected, instructions to implement the plan must be issued. To some extent, these different aspects of motor control are carried out by different regions of the brain.

To appreciate the different contributions of the three hierarchical levels of motor control to movement, consider the actions of an individual standing preparing to turn the whole body on-the-spot towards a light placed in a particular location. The parietal cortex has information about precisely where the body is in space and its position in relation to the light based on vision, vestibular information and proprioception. Strategies must be devised to move the body from the current state to one in which the body is facing the target light. The set of muscles required to execute the turn are selected in the premotor areas, and the possible alternatives are filtered through the basal ganglia and back to the cortex until a decision is made, based in large part on experience. The motor areas of cortex and the cerebellum then make the decision about sequences of contraction of the muscles and issue instructions to the brain stem and spinal cord. Activation of neurons in the brainstem and spinal cord then causes the movement to be executed. Properly timed activation of motor neurons in the brainstem and spinal cord generates a coordinated movement of the eye, head, shoulders, pelvis and feet. Simultaneously, brain stem input to the thoracic and lumbar spinal cord command the appropriate postural adjustments that keep the person from falling over during the turn. These processes have been outlined in Figure 1. 7.

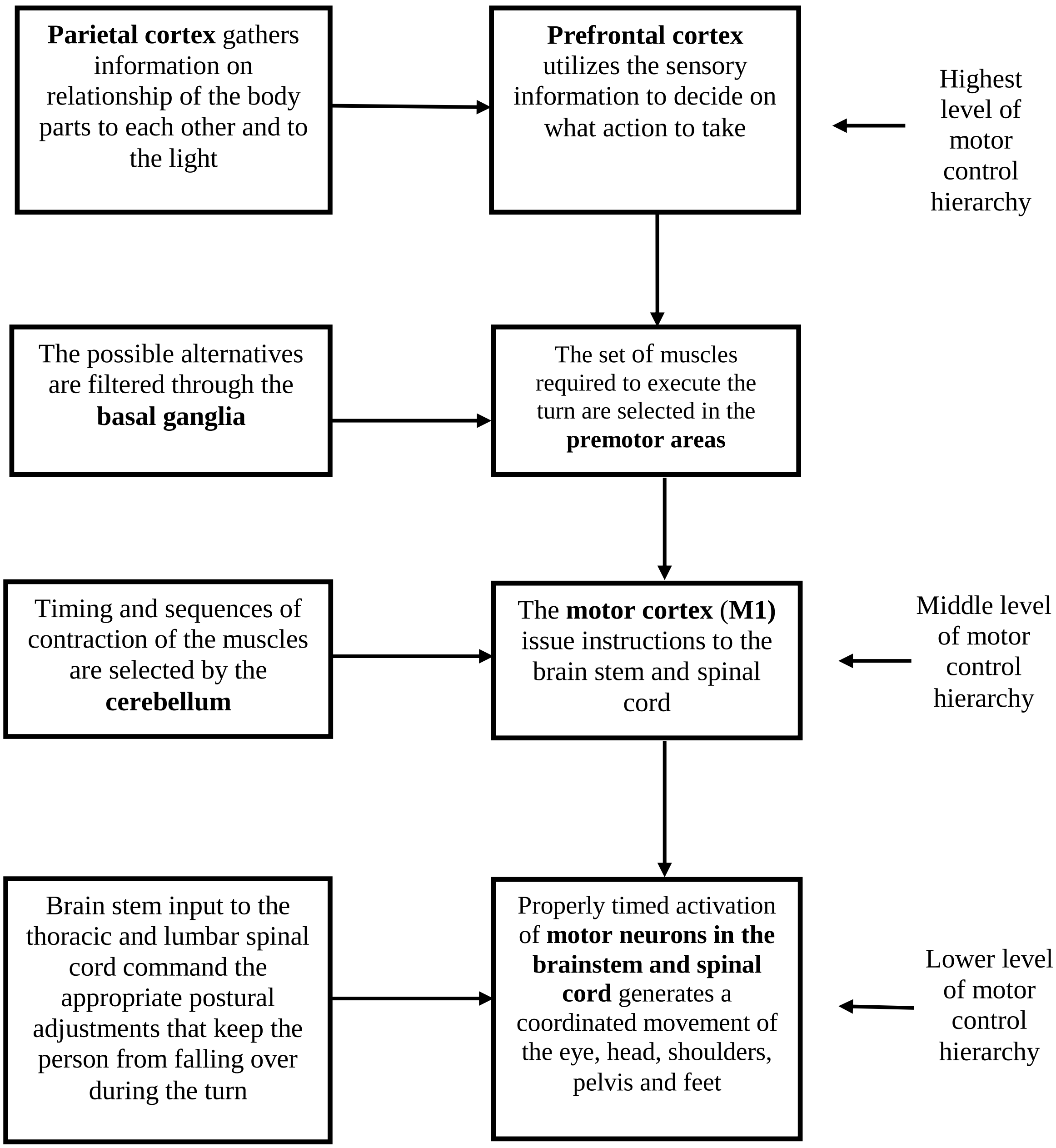


Figure 1.7. Summary of motor control during turning.

Chapter 2

2.0. Literature review

This chapter reviews the literature on whole-body coordination when turning in healthy adults.

2.1. whole-body coordination during turning in healthy adults

Integrated movements of the eyes, head, trunk, and limbs are frequently used to achieve goal directed movements such as orienting the body to face targets in the environment. Researchers have investigated how the segments involved in several activities of daily living are coordinated. Studies on the relationship of the eye and head during gaze shifts in sitting have been carried out by many authors (Guitton and Volle, 1987, Tweed et al., 1995, Goossens and Opstal, 1997, Stahl, 1999, Corneil and Elsley, 2005, Cecala and Freedman, 2008). The contribution of the trunk to the movement is restricted due to the fixation of the lower part of the trunk by the sitting surface. This limits the degree to which the eyes and head can rotate to align with targets.

Information on segmental coordination during body orientations that involve eye and head movement are important in explaining the mechanisms involved in many activities of daily living. However, orientation that extend beyond the range of motion of the eye and head may engage other segments for its accomplishment. Furthermore, due to the relatively wide base of support in sitting, turning the head while sitting may not be very challenging to the body's stability during the task. Turning the whole body is an example of such a task which engages segments other than the eye and head and which may challenge the upright stance during a task and has been reported as a common activity of daily living (Land, 2004, Glaister et al., 2007).

There are many factors that are associated with turning the body during activities of daily living. Turns could be made towards many different directions and positions. When individuals are responding to stimuli in their environment, they first of all identify where the stimulus is located such as in front, beside or behind them and whether it is to their right or left side and then turn to the stimulus. In some instances they could be aware of the position of the stimulus, which means they just need to turn and face it while in other circumstances they need to locate the stimulus. Various studies have looked into inter-segmental coordination during whole-body turns during walking and standing in healthy adults and a number of them have shown how the factors mentioned above affect the coordination of the segments during the turn.

2.2. Sequence of rotation of body segments during turning while walking

Turns are frequently superimposed on straight-ahead walking to change direction or avoid obstacles. There are many studies that have investigated the coordination of body segments during turning while walking and they have consistently shown a top-to-bottom sequence of initiation of rotation of the segments (Patla et al., 1999, Hollands et al., 2001, Fuller et al., 2007, Paquette et al., 2008b, Akram et al., 2010). This means that the head started to rotate followed by the trunk and finally the feet. The visual cue for the turn was given at the beginning of the walking pathway in a predictable manner (Patla et al., 1999) or one step length before the midpoint of the walking pathway in an unpredictable manner (Patla et al., 1999, Hollands et al., 2001). In some instances the participants were told which direction to turn prior to start of walking and were given a verbal instruction to start the walk (Fuller et al., 2007, Paquette et al., 2008, Akram et al., 2010). None of these conditions affected the sequence of rotation of the segments. The sequence was also consistent for the turn angles (20°, 30°, 40°, 45°, 60° and 90°) and turn directions (left and right) investigated in the studies. The details of the studies are outlined in table 2.1.

Table 2.1. Literature review of sequence of onset latency of body segments when turning while walking

Author	Task	Measurements	Results
Patla et al. (1999)	Six healthy adults (age: 22.5±2.1 years) walked along a 9m straight path and were visually cued to alter their direction of travel at the midpoint of the travel path to either 20°, 40° or 60° to the right. Visual cue triggered at beginning of pathway (predictable) and one step length before the midpoint of pathway (unpredictable)	Onset of rotation of the segments was referenced to right foot contact before direction change. Movement was measured using Optotrak motion analysis system	Head started to rotate followed by trunk and finally foot (for both predictability conditions)
Hollands et al. (2001)	Five healthy adults (age: 24.8±2.6 years) walked along a 9m straight path. At	Onset of rotation of the body segments were referenced to the instant of cue delivery.	Head started to rotate followed by trunk and finally foot

	one step length before the midpoint of the path they were visually cued to either continue walking straight or turn either 30° or 60° to the left or right.	Movement measured using Optotrak motion analysis system	
Fuller et al. (2007)	Thirteen older adults (age: 81.5±1.8 years) were instructed to walk along a 3m path and either continue walking straight ahead or turn 40° to the left or right for an additional 2m. Travel path direction specified prior to the start of the trial.	Onset of rotation of the body segments were referenced to when the trunk (marker placed at xiphoid process) crossed the designated turn point. An analogue video camera was used to monitor whole body kinematics.	Head started to rotate followed by trunk and finally foot
Paquette et al. (2008)	Six healthy young adults (age: 20.7±2.9 years) and six healthy older adults (age:	Onset of rotation of the body segments was referenced to the time of heel contact just	Young adults – Head started to rotate followed by trunk and finally

	83.5±5.8 years) were required to walk along a 3m travel path and continue to walk straight ahead or turn 40° to the left or right for an additional 2m. Travel path direction specified prior to the start of each trial.	before the direction change. Movements were measured using Optotrak motion analysis system	foot Older adults – Head started to rotate followed by trunk and finally foot
Akram et al. (2010)	Nineteen healthy older adults (age: 66±4.2 years) were instructed to walk about 4m and turn to 45° or 90° to the right or left for an additional 3m. Participants were told which direction to turn prior to start of walking.	Turn to right was only used for analysis. The onset of head reorientation towards the new direction of travel path was considered as the reference time (time=0). Movement measured using Optotrak 3D imaging system cameras.	Head started to rotate followed by shoulder then pelvis and finally foot

2.3. Sequence of onset latency of body segments during turning on-the-spot

Not all activities of daily living involve changing direction while walking. Some tasks could involve turning on-the-spot. These tasks include turning around to respond to a call, turning to flush the toilet after use and turning from one surface to another that are placed close to each other. Kinematics of turning in-place has been investigated during both natural tasks and laboratory based simulations of activities of daily living. Land et al. (1999) and Land (2004) reported sequence of rotation of eyes, head and trunk during turns produced while three participants where making a cup of tea in a kitchen. Land (2004) presented the sequence of eye and head rotations in a representative turn from one work surface to another for each participant. Each turn was about 130° and involved rotation of the trunk in which the feet made two to four steps. The results showed that the head began to move about 200 ms earlier than the eye.

Land further analysed the sequence of the eye, head and trunk in each participant for three different turn angle while picking objects from one point to another. The head began to move about 100-200 ms earlier than the eye in all cases while the relationship between the head and trunk was variable; the head lagged the trunk in some turns while it led in others. Land et al. (1999) examined all turns that were "object related" (those in which the participant manipulated an object during the tea making) in the three participants (137 in total excluding those in which two actions were occurring simultaneously). They reported that on average, the beginning of the trunk movement preceded the eye movement by 0.61s.

The eyes may have lagged behind the head and trunk in all situations due to the fact that objects where moved from one point to another, the eyes could have been fixed on the object that was picked in the initial stage of the turn. However, the variable relationship of the head and trunk is suggestive of the influence of some factors that determine the sequence of the segments. Factors such as baseline position of the segments, angle of the turn and nature of the task (turning on-the-spot or while walking) could have influenced the sequence. This is a reflection of the statement of Shumway-Cook and Woollacott (2007) that Goal directed movement occurs through the interaction of three factors; the individual, the task to be carried out and the environment in which the task takes place. Land reported that the head started rotating in a position that was out of line (not facing the same direction) with the trunk in some turns (e.g. while picking a cup from the right side to turn toward a kettle on the left side, the head may turn to locate the cup and thus may be out of line with the trunk by the time the body start to turn towards the kettle) and not all turns ended with the head in line with the trunk. This may have caused the variable relationship of the onset of head and trunk. Furthermore, the sequence of the onset of the segments was not categorized according to the angle of the turns; therefore it could not be determined whether the turn angle played a role in the variability of the sequence. Since no variable was controlled, the difference in the sequence could not be attributed to any particular factor.

Whole-body turns to targets involve horizontal displacement of the feet which are important in maintaining balance as they determine the base of support of an individual during activities in standing. The reports of Land et al. (1999) and Land (2004) therefore failed to provide information on this important aspect of turning. Furthermore, the number of participants was considerably small to allow any statistical relevance to be yielded, thus the use of descriptive presentation of the data. Laboratory based investigations of coordination of body segments during turning on-the-spot have included data on horizontal displacement of the feet which provides more detail into the investigations of whole-body coordination during the turn; they have also recruited more participants which gave the opportunity of carrying out inferential statistics on the data collected. More importantly, they have attempted controlling some variables such as target predictability, turn angle and turn direction which could explain the variability of the sequence of the segments during turning on-the-spot.

2.3.1. Effect of target predictability on sequence of rotation of segments during turning on-the-spot

The predictability of a target is important in the planning of movement. The brain utilizes sensory information to decide on the action to take and the components of the action to achieve a particular task. The cerebellum also needs the sensory information to give instructions about the timing of each of the components of the action. When the location of a target is predictable, the brain is equipped with the information required to plan the movement prior to the start of the movement, however when the location of the target is unpredictable, the brain depends on the sensory information provided to it at the point just before the start of the turn. This is in line with the findings that there is increased activation of motor areas of the brain with an unpredictable behaviour compared to a predictable one (Dassonville et al., 1998, Thickbroom et al., 2000). The studies that have investigated the effect of predictability of a target on coordination of body segments during turning used visual cues, therefore the brain depends on the visual system gathering information on the location of the target and reporting to it before planning the movement.

If the eyes are closed and a person is asked to turn towards a light that comes up in an unknown location, there would be no meaningful movement. Even proprioceptive and the vestibular system would not help in directing the movement to the target. This may explain why the CNS defaults to response dominated by vision when a conflict exists between vision and proprioceptive or vestibular input in the guidance of movement (Lee and Lishman 1977). To further emphasize the dominance of visual afferent information over other sources of afferent information, Proteau and Carnahan (2001) showed that the withdrawal of vision of the arm and /or target during a manual aiming task increased aiming error regardless of the amount of practice in normal vision. While the three sensory systems (visual, vestibular and proprioceptive systems) provide information about position of the moving body, the visual system goes further to specify the target position and providing error information regarding the discrepancy between the target and body position. This underscores the importance of vision in goal-directed movement.

When advance information of the position of a visual target was provided (predictable target), the reaction time of segments was shown to be reduced (Anastasopoulous et al. 2009). Visual stimuli from the target are first registered in a short term memory system where they are stored before some are selected for further processing in working memory. The minimum time required to process the visual information has been estimated to be about 100ms (Carlton 1992). This means that when the target is predictable, there is enough time to process the visual information for the guidance of the actual movement even before the cue for the movement appears. In other words, there is an advanced motor planning which specifies the components of the muscle activity required for the movement even before illumination of the visual target. This is in line with a model of movement preparation in which the spatial goal of the movement is first known before visual feedback is used to guide the movement (Hansen et al. 2006).

The visual system has been shown to serve more purpose than that of obtaining a visual picture of the environment (Grasso et al., 1998; Reed-Jones et al., 2009). Grasso et al. (1998) noted that the reorientation of gaze preceded that of other body segments even in darkness. Reed-Jones et al. (2009) showed that visual cues from virtual motion generated gaze movements that triggered orientation of body segments. These indicate that vision plays a role in central programming of movement. However, Land (2004) and Land et al. (1999) have shown that when an object was manipulated during a turn, the movement of the eye occurred later than that of the head and upper trunk implying that the start time of the movement of the eye is not a robust one but depends on the goal at hand and environmental situations. The role of vision in programming movement sequence during turns to predictable and unpredictable targets is still not fully understood due to the discrepancies noted as a result of some factors such as age of participants and situation of the turn (turning on-the-spot or during walking).

Most studies investigating sequence of rotation of segments during turning while walking have shown a clear top to bottom sequence of rotation of body segments with the eyes and head leading (Grasso et al. 1998, Patla et al. 1999, Hollands et al. 2002, Fuller et al. 2007, Akram et al. 2010). This was shown with turns towards predictable and unpredictable targets for different age groups. On the other hand, the sequence of rotation of body segments was shown to be different when turning on-the-spot to predictable and unpredictable targets and among people of different ages. Hollands et al. (2004) showed a clear top to bottom sequence of rotation of segments (with eyes starting to rotate followed by the head, then trunk and finally the feet) when young adults (23±2.6 years) turned on-the-spot towards unpredictable targets (participants were required to locate and turn to targets in response to a visual cue). On the other hand, Akram et al. (2010) showed more simultaneous rotation of body segments (head, shoulder and pelvis turning simultaneously while feet followed) when older adults (66±4 years) were turning towards predictable targets (participants were aware of the direction and location of the target to turn to prior to the turn). Contrary to the results of Akram et al. (2010), Earhart and Hong (2006) reported a separate onset of rotation of head, trunk and feet when young adults (28.2±4.3 years) were instructed to turn towards a known (predictable) location starting with left foot and stepping to the beat of a metronome with their eyes closed. The differences in the instructions, type of cue used and the number of segments investigated in the three studies may have contributed to the differences observed in the sequence of rotation of the segments.

Anastasopoulos et al. (2009) observed the effect of the predictability of the target in a study in which they instructed healthy adults (52 ± 2.6 years) to fixate and align with unpredictably appearing targets and return back to the initial central position under spatially predictable conditions. The result showed that during trials to unpredictable targets, there was a top to bottom spread in latencies (from eye to feet). However, during trials to predictive targets there was more overlap of latencies, resulting in more en bloc rotation of the segments. The eye initiated the rotation when target presentation was unpredictable. With predictive target presentation, the head sometimes initiated the rotation. While the trunk lagged the eye and head in unpredictable trials, it sometimes led them in predictable trials. The onset latency of the feet lagged those of the other segments in both conditions (predictable and unpredictable); however it was reduced during the predictable trials.

The movement of the eye before that of other body segments may serve the purpose of scanning the environment so that movement of the other segments could be programmed based on the information acquired. If there are obstacles that need to be avoided, the visual feedback may send information back to the brain for re-programming of the movement. The environment keeps changing dynamically while walking, explaining why the eyes and head consistently lead other segments when turning during walking. When turning on-the-spot, individuals are aware through memory of their immediate environment and therefore may not need to scan the environment at the start of the movement. However, the fact that the eyes lead the other segments when turning to unpredictable targets serves probably the purpose of locating the target.

2.3.2. Effect of turn angle and direction on sequence of rotation of segments during turning on-the-spot

Turn angle and direction are other factors that are associated with turning from one point to another. To successfully turn from one point to another, the brain needs to acquire information on the direction and angle of the turn through sensory systems; this information is utilized by the brain to plan the muscle activations that will take the body to the appropriate position. Activation in the primary sensorimotor area, supplementary motor area, premotor cortex and cerebellum were found to be more with larger movement amplitude (Waldvogel et al., 1999). The duration of the initial agonist burst that forms part of the triphasic pattern of muscular activation has been shown to increase with increase in movement amplitude (Cooke et al., 1985). This implies that the onset of movement of body parts could be slower with smaller amplitudes. Indeed this has been shown in studies of whole-body coordination during turning that the onset latency of the body segments was slower when turning to smaller angles (Hollands et al., 2004). However, will the sequence of the onset latencies of the segments be different during the turns? Studies investigating coordination of body segments during turning on-the-spot have not reported differences in the sequence of rotation of segments when turning to different angles (Hollands et al., 2004, Anastasopoulos et al., 2009).

Turning behaviour appears to be related to motoric dominance (handedness) due to the positive relationship that exists between the two measures (Mohr et al., 2004). A right sided motoric dominance and a left-sided turning preference (Mohr et al., 2004, Taylor et al., 2007) have been shown in healthy subjects. This means that healthy individuals prefer to turn away from their dominant side. However, the side an individual prefer to turn may not have clinical implications unless it affects the kinematics or kinetics of the movement during turning. Since the left hemisphere has been shown to be dominant in mediating cerebral activation (Dassonville et al., 1998, Schluter et al., 2001), it will be anticipated that differences will exist in the kinematics of turning to the two different sides. However, studies that have investigated kinematics of turning have not reported differences in sequence of rotation of segments when turning to left and right (dominant and non-dominant) sides (Hollands et al., 2004, Anastasopoulos et al., 2009, Akram et al., 2010). Table 2.2 shows the details of the studies on sequence of onset latency of body segments when turning on-the-spot.

Table 2.2. Literature review of sequence of onset latency of body segments during turning on the spot

Author	Task	Measurements	Results
Land et al. (1999) and Land (2004)	Three healthy adults (ages: 28, 46 and 55 years) were asked to make a cup of tea in a small kitchen	Eye and head rotations were recorded by a light-weight head-mounted eye camera while trunk rotation was recorded by a tripod-mounted video camera	The head and trunk precede the eye movement in all cases while the relationship between the head and trunk was variable; the head lagged the trunk in some turns while it led in others
Hollands et al. (2004)	Five healthy adults (age: 23±2.6 years) were required to locate and rotate (location of target unpredictable) their whole bodies to face lights placed at 45°, 90° and 135° to the right and left when a light they were facing went off	Onset of segments' rotation calculated with respect to appearance of central cue. Rotation of eye measured by electro-oculography. Rotation of other body segments measured by Fastrack motion analysis system	Eye started to rotate followed by the head then upper trunk and finally the foot

Akram et al. (2010)	19 elderly adults (66±4 years) were asked to turn to 90º to the right and left on the word “go” with their eyes open or closed. Participants were told what direction to turn to prior to the turn	Turn to right was only used for analysis. The onset of head reorientation towards the new direction of travel path was considered as the reference time (time=0). Movement measured using Optotrak 3D imaging system cameras	Head, shoulder and pelvis moved simultaneously followed by the foot
Earhart and Hong (2006)	Eleven healthy adults (age: 28.2±4.3 years) were instructed to turn in place to the left starting with the left foot and stepping to the beat of a metronome (120 beats per minute)	Onsets of rotations were determined relative to the first toe off. Rotation of segments was measured by 3-D motion analysis system equipped with eight hawk digital cameras	The head started to turn first followed by the trunk and finally the foot

Anastasopoulos et al (2009)	Ten healthy participants (age: 52 ± 2.6 years) were asked to fixate and align with unpredictably appearing targets (placed at 45°, 90° and 135° to the left and right and 180°) and return back to the initial central position under spatially predictable conditions	Onset of segments' rotation calculated with respect to appearance of central cue. Rotations of head, trunk and feet were measured with a Fastrak motion analysis system while the eye displacement was measured with electro-oculography	During trials to unpredictable targets, there was a top to bottom spread in latencies (from eye to feet). However, during trials to predictive targets there was more overlap of latencies, resulting in more en bloc rotation of the segments

The parameter that has been more widely investigated in studies looking at coordination of body segments during turning is the onset latency (reaction time). This is an important parameter for the description of motor coordination as explained by Bourbonnais et al. (1992) that a coordinated movement “is the net result of activity in several muscles that share a precise temporal and spatial pattern of onset”. The onset latency relates the movement of the segments at the start of the turn. Other important parameters that have been used to describe the relationship of movement of the segments during the turn in healthy participants are the peak velocity and time at which the peak velocity occurs.

2.4. Peak velocity/timing of peak velocity of body segments during turning on the spot

The sequence of peak velocity of body segments has been investigated during voluntary turns to predictable targets placed at 90° (Akram et al., 2010) and during step turns to 90° triggered by a verbal cue (Solomon et al., 2006). The peak velocity of the head was shown to be significantly higher than that of shoulder and pelvis (Solomon et al., 2006, Akram et al., 2010). However, the peak velocity of the shoulder and pelvis were not found to be significantly different (Akram et al., 2010). A similar result was obtained by Land (2004) during turns produced in natural situations (tea making in the kitchen) where the peak velocity of the head (250-350°/s) was found to be higher than the peak velocity of the trunk (100-250°/s). However, there were only three participants in the study of Land (2004) and therefore the results were reported descriptively. Both the studies of Akram et al. (2010) and that of Solomon et al. (2006) investigated turns to predictable targets placed at 90° only. It is therefore not known if predictability and angle of the target affect the sequence of rotation of the segments. Meinhart-Shibata et al. (2005) reported no age or direction effect on peak velocity of the pelvis when young and older women turned towards the left and right to an unpredictable target placed at 180°. However, the sequence of rotation of the segments involved in the turn was not reported as the data presented was for the pelvis only.

Akram et al. (2010) investigated the sequence of rotation of head, shoulder and pelvis when turning to the right side only. On the other hand, Solomon et al. (2006) reported no differences in the sequence of the peak velocity of the head and pelvis when turning to the right and left sides. The sequence of the time the peak velocities of the head, shoulder and pelvis occurred has also been reported by Akram et al. (2010) during turns to predictable targets placed at 90°. The head reached its peak velocity significantly earlier than the shoulder and pelvis (0.51±0.16s, 0.65±0.21s and 0.69±0.25s respectively). As with the results of the peak velocity, there is no report of the effect of predictability and angle of the target, furthermore the participants turn to the right only and therefore there is no report on the effect of the turn direction either.

Table 2.3. Literature review of sequence of peak velocity and time to reach peak velocity of body segments during turning on the spot

Author	Task	Measurements	Results
Akram et al. (2010)	19 participants (66±4 years) were asked to turn to 90º to the right and left on the word "go" with their eyes open or closed. Participants were told what direction to turn to prior to the turn	Turn to right was only used for analysis. Movement measured using Optotrak 3D imaging system cameras	Peak velocity of the head was higher than that of the shoulder and pelvis. The head also reached its peak velocity earlier than the shoulder and pelvis
Solomon et al (2006)	20 young adults (age range: 19 to 62 years) were instructed to make step turns to face targets on either left or right upon an auditory cue (turn to face the target). Participants were aware of which side to turn to prior to the cue	Rotations of head and pelvis were measured using Active marker video system (Optotrak)	Peak head velocity was greater than peak pelvis velocity

Land (2004)	Three healthy adults (ages: 28, 46 and 55) were asked to make a cup of tea in a small kitchen.	Eye and head rotations where recorded by a light-weight head-mounted eye camera while trunk rotation was recorded by a tripod-mounted video camera	Peak head velocity was greater than peak trunk velocity
Meinhart-Shibata et al. (2005)	10 young women (21.8±1.99 years) and 10 older women (72.5±5.82 years) picked up a bowl executed a 180° turn in the direction indicated by an illuminated arrow and placed the bowl on a table 2m behind them.	The pelvic rotational velocity was measured using Optotrak camera system	There was no age or direction effect on maximum pelvic rotational velocity

2.5. Summary of whole body coordination when turning on-the-spot in healthy adults

Predictability of a target, turn amplitude and turn direction have been shown to be associated with the coordination of body segments during turning on-the-spot. Predictability of a target has been reported to affect the sequence of onset latency of body segments during turning on-the-spot in healthy individuals. When turning towards unpredictable targets, body segments started to move more separately and in a top to bottom sequence (starting with eye, followed by head, trunk and finally the feet) while when turning towards predictable targets the body segments started to move more simultaneously. Turn angle and turn direction were not reported to alter the sequence of onset of rotation of body segments during turning on-the-spot. Although, the onset latency is an important indicator of body coordination, it only takes into consideration what happens at the point when the turn is initiated. The peak velocity and the time at which the peak velocity occur are other parameters that describe the coordination of body segments during the turn. The peak velocity of the head has been reported to be higher than that of the shoulder and pelvis when turning on the spot to predictable targets and during turns in natural situations. The head was also shown to reach its peak velocity earlier than the shoulder and pelvis. However, the effect of the predictability of a target, turn angle and turn direction on either the peak velocity or the time to reach the peak velocity have not been reported.

The coordination of body segments during turning on-the-spot as described in this chapter could be impaired in people with stroke and Parkinson’s disease due to the sensory, motor and cognitive impairments they encounter. How these impairments could challenge coordination of body segments during turning on-the-spot in people with stroke and Parkinson’s disease are explained in detail in Chapter 4 and 5.

Chapter 3

3.0. Methodology

The aims of the studies in this thesis were to investigate the effect of target predictability, turn angle and turn direction on the sequence of onset latency, peak velocity and timing of peak velocity of body segments during turning on-the-spot in people with stroke and age-matched healthy controls (first study) and in people with Parkinson's disease (PD) and age-matched healthy controls (second study). This chapter presents aspects of the methodology that are common to both studies that are presented in chapter 4 and chapter 5. The chapter describes the design and materials used for the studies. The process of data collection and extraction is detailed and the analysis carried out on the data is stated.

3.1. Design

Participants were assessed on one occasion in this study making it a *cross-sectional observational design*. The study also observed both between subject and within subject factors giving rise to a *mixed design*. The between subject factor is the group of the participants (people with stroke and age-matched healthy controls in the first study and people with Parkinson's disease and age-matched healthy controls in the second study). The within subject factors are target predictability (predictable and unpredictable), turn angle (45°, 90° and 135°), turn direction (right and left) and segment (eye, head, shoulder, pelvis and foot).

3.2. Materials

The horizontal displacement of the eye was measured by an eye tracking camera called VNG Ulmer (SYNAPSIS SA, Marseille, France) with a sampling rate of 100Hz. The VNG is a high frequency 1-camera system. The video images of the eyes were analysed within a PC-based VNG system to detect onset of horizontal eye movement.

The head, shoulder, pelvis and feet rotations were measured using CODA motion analysis system (Charnwood Dynamics Ltd, Leicestershire, UK) with a sampling rate of 200Hz. It recorded the position of sensory markers in three dimensions. The markers (Figure 3.1) consisted of infrared 1x2cm LED's (light-emitting diodes) which were plugged into light weight battery packs; the LED's were triggered and pulsed sequentially by a computer, permitting automatic identification of each marker, both were attached to the subject's clothing by double sided hypoallergenic sticky tape. The timing, position and angles calculated from the data were displayed by a computer. The CODA motion analysis system has been reported to be a valid and reliable tool for measuring the spatial and temporal parameters of body movements (Maynard et al., 2003, Monaghan et al., 2007).

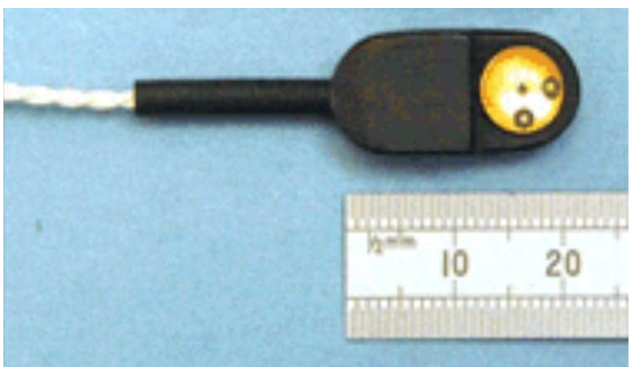


Figure 3.1. Sensory marker (scale is in mm)

3.3. Data collection

Prior to data collection, potential participants were screened for inclusion and those that fulfilled the inclusion criteria were invited to the Movement laboratory for the data collection. Secondary outcome measures were measured to aid in describing the participants' functional, balance and cognitive status. The details of the recruitment of participants and measurement of the secondary outcome measures are detailed in chapter 4 and 5. After collecting the secondary outcome measures, the eye tracking camera and the sensory markers were attached to the body. The eye tracking camera was fixed to a helmet that had adjustable straps that went over the top of the head and around the occiput. The straps were adjusted so that the front surface of the helmet was just above the eyebrow. The camera hanged facing the eyes as shown in Figure 3.2.

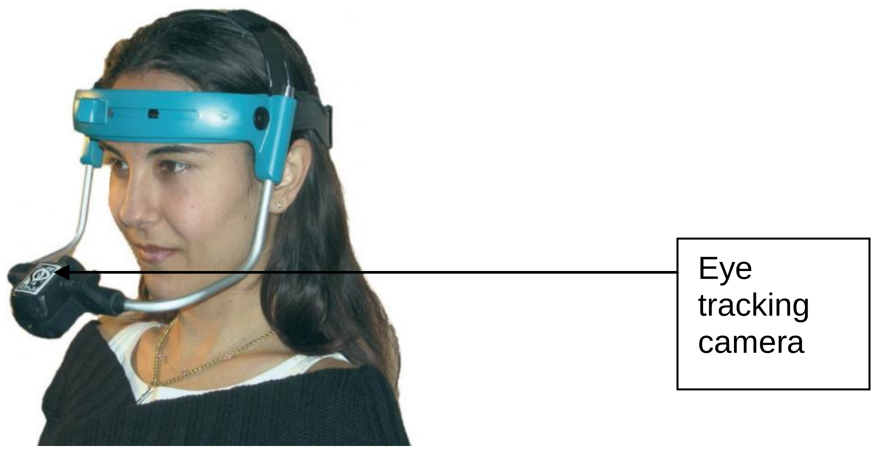


Figure 3.2. Eye tracking camera and its position on the head

The eye tracking camera was capable of capturing the linear displacement of the movement of the eye. The camera therefore needed to be calibrated to be able to transform the linear displacement into angular displacement that would be used to extract the onset of the eye's horizontal displacement. To calibrate the eye tracking camera the participants were asked to look at a dot at the middle of a sighting frame placed at 2m from the participant as shown in figure 3.3. The participants were instructed to follow the dot which would move up and down and to the right and left while keeping the head still and only moving the eyes. Since the distance between the position of the dots and the distance of the participant from the sighting screen were known, the angle covered could be computed. This procedure took approximately 30 seconds. The system was therefore capable of transforming the displacement of the movement of the eye during the turns into angles from which the start time of the eye movements were obtained. The calibration was repeated after every 12 set of turns as the VNG computer was set to save 12 recordings only at a time.

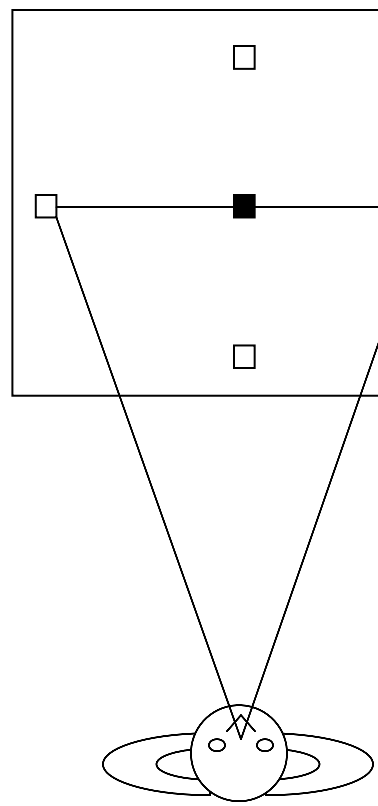


Figure 3.3. Calibration of eye tracking camera set-up (The triangle represent the distance between the dots and the distance between the eyes and the dots)

Fourteen sensory markers were attached to the head, shoulders, pelvis and feet of the participants as described below to ensure markers were visible from start to end of each movement (marker placement is shown in Figure 3.4). The markers were attached to the participants' clothing except were the marker placement area was exposed. In such cases the marker was placed on the participant's skin after confirming that the participant didn't have any allergies to sticky tape.

a. Head: four markers were attached to the helmet of the eye tracking camera, one inch above the lateral end of each eye and on each side of the occiput. The marker placements were horizontal to the floor to allow rotation angles to be easily calculated.

b. Shoulders: markers were placed at the upper surface of the acromion on each side. To ensure that the marker remained stable on the clothing over the shoulder of the participant, a double sided sticky tape was attached to the shoulder over the acromion. The clothing was attached to the upper surface of the sticky tape while the marker was placed over the clothing at the point where the sticky tape was.
c. Pelvis: Four markers were placed on a truncated half pyramid block (Figure 3.5) attached to a belt placed over the posterior superior iliac spine to measure pelvis rotation.
d. Feet: for measurement of feet rotation, a marker was placed over the first toe and on the heel at 45º to the midline of the subject in normal standing. When a participant was wearing a shoe, he/she was asked to raise the first toe and the marker was placed on the shoe over the location of the first toe. In some instances the participants wore sandals; therefore the markers were placed on their first toe and on their skin at the heel. The placement of the heel marker at 45º ensured that it was in view of either of the CODA systems in front and at the back of the participant throughout the turn.

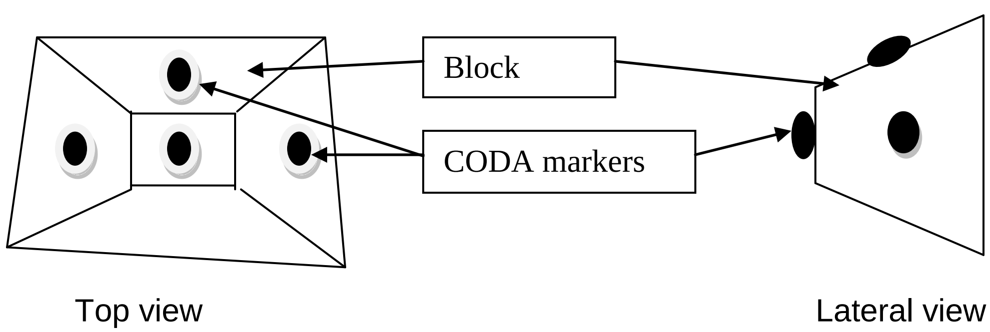


Figure 3.5. Truncated half pyramid block with four CODA markers attached.

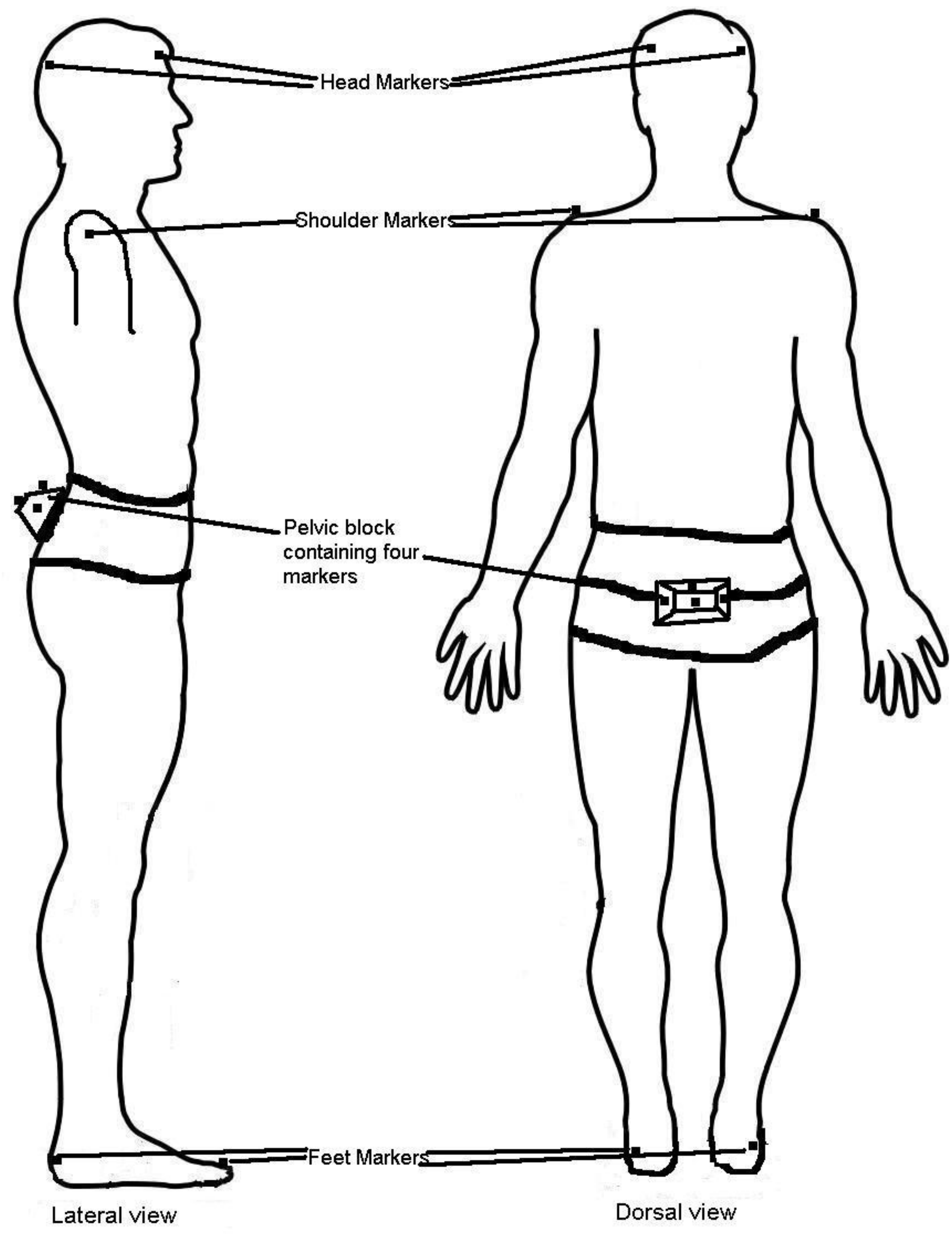


Figure 3.4 Marker placement.

Lights from red bulbs (about 10 mm in diameter) attached to stands were placed in front of the participant and at 45°, 90° and 135° to the right and left (Figure

3.6). The lights were adjusted to the eye level of the participant at approximately 2m distance.

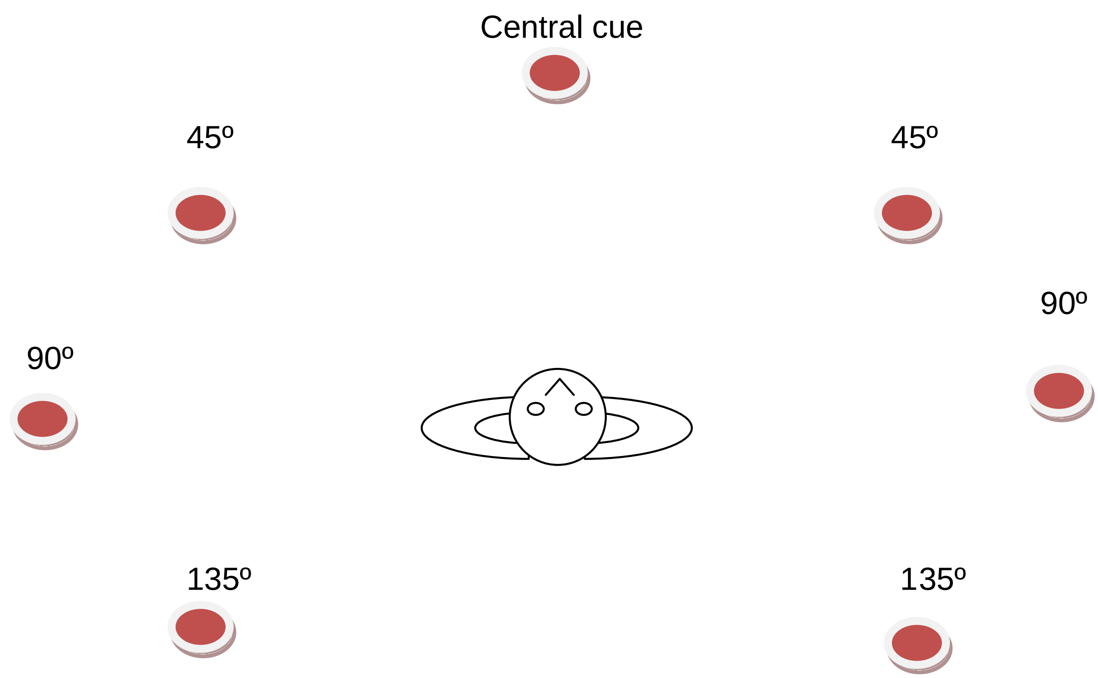


Figure 3.6 Experimental set up showing a participant standing in the middle of the central cue and six target lights.

The set-up gives six positions to turn to, however, participants were required to turn to each position in an unpredictable (participants not aware of which direction and position to turn to prior to cue delivery) and predictable (participants aware of which direction and position to turn to prior to cue delivery) conditions giving rise to 12 tasks as itemized in Figure 3.7. Participants were required to turn five times for each of the 12 tasks. The five trials would be averaged and used for analysis. However, if the 12 tasks were randomized and participants were asked to perform five trials for each task, there would have been bias. Therefore, the 12 tasks were randomized in five sets (as shown in appendix ii) by a software designed for the purpose of randomizing multiple tasks.

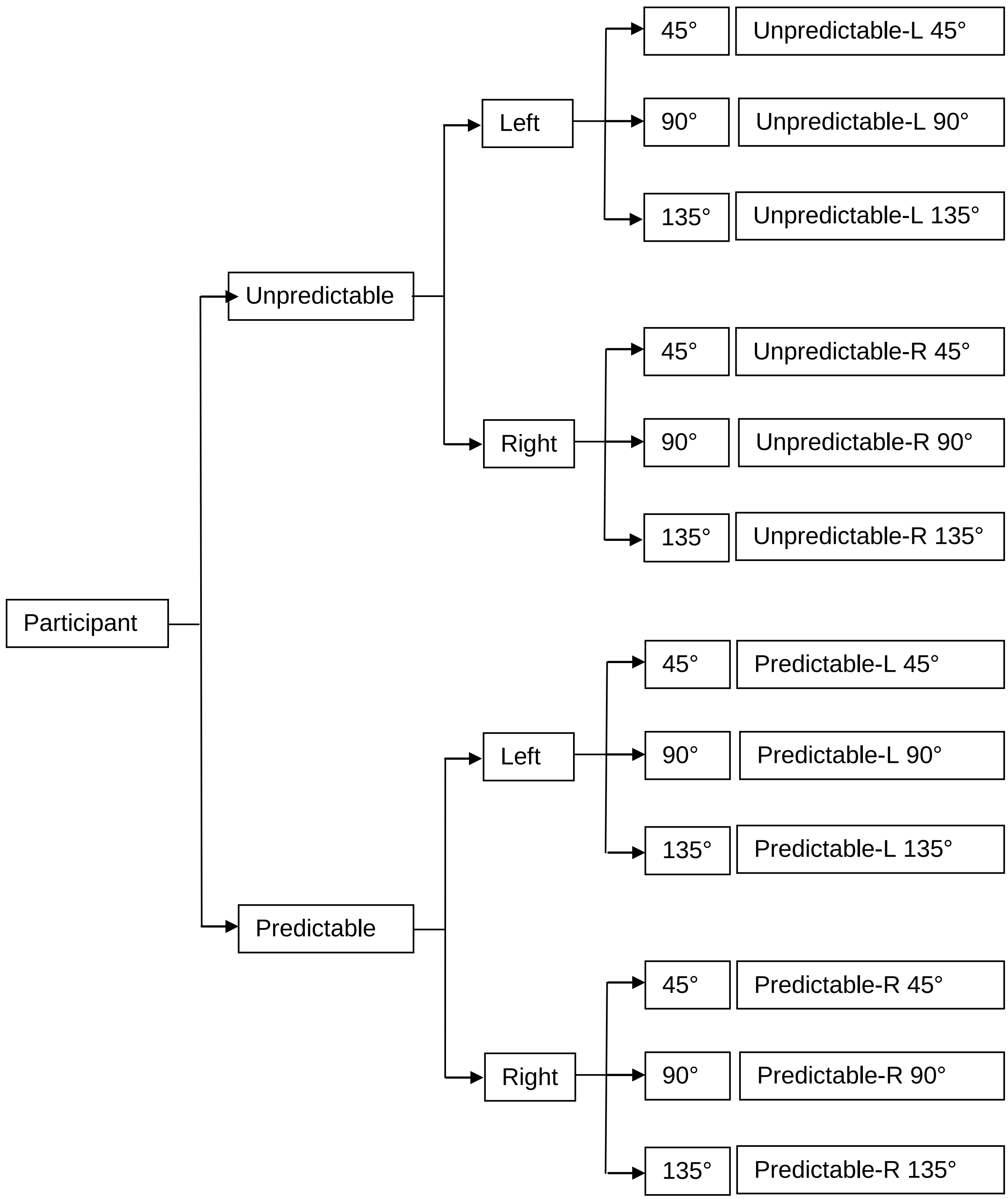


Figure 3.7. Twelve Itemized tasks

Participants were asked to stand and face the central light and were asked to keep looking at the light, when it extinguished they were asked to locate and turn their whole body to face the light that came up in the array of lights in an unpredictable condition or they were told to which light they should turn to in a predictable condition. There was no specific instruction about the speed of turning so the participants were required to turn in a self-paced, natural way. The commands for the unpredictable condition were standardized and itemized as follows:

a. Keep looking at the light at the centre
b. When it goes out, *find the light that comes up and turn your whole body to face it*.
c. Keep looking at the target light
d. When it goes out turn your whole body back to the light in the centre. This allowed the researchers to control whether the participants actually turned towards the target light.

The commands for the predictable condition were standardized and itemized as follows

a. Keep looking at the light at the centre
b. When it goes out, *turn to the light*
    - *in front by your left (45º to the left)*
    - *in front by your right (45º to the right)*
    - *beside you by the left (90º to the left)*
    - *beside you by the right (90º to the right)*
    - *behind you by the left (135º to the left)*
    - *behind you by the right (135º to the right)*
c. Keep looking at the target light
d. When it goes out turn your whole body back to the light in the centre.

It was anticipated that participants may turn towards the wrong light when turning to 135º target in the unpredictable tasks; these attempts were not used for analysis (as in the protocol of Hollands et al. (2004)). The data for the horizontal displacement of the eyes, rotation of head, shoulder and pelvis and horizontal displacement of the feet were extracted for data analysis.

3.4. Data extraction

3.4.1. Setting room coordinates

Room coordinates were set prior to the data collection. Four sensory markers were placed at 90° to each other about a meter apart in the middle of the target lights. The line joining two of the sensory markers that was perpendicular to the line in the direction of the central light was designated as the x-axis while the line joining the other two markers and perpendicular to the x-axis was designated as the y-axis (Figure 3.8). Z-axis was computed from the x and y axes using vector cross product analysis. These procedures were carried out by the experimental officer of the Rehabilitation Research Unit of the University of Southampton. The room coordinates served as the baseline against which rotation of the local axes of the head, shoulder, pelvis and feet were defined.

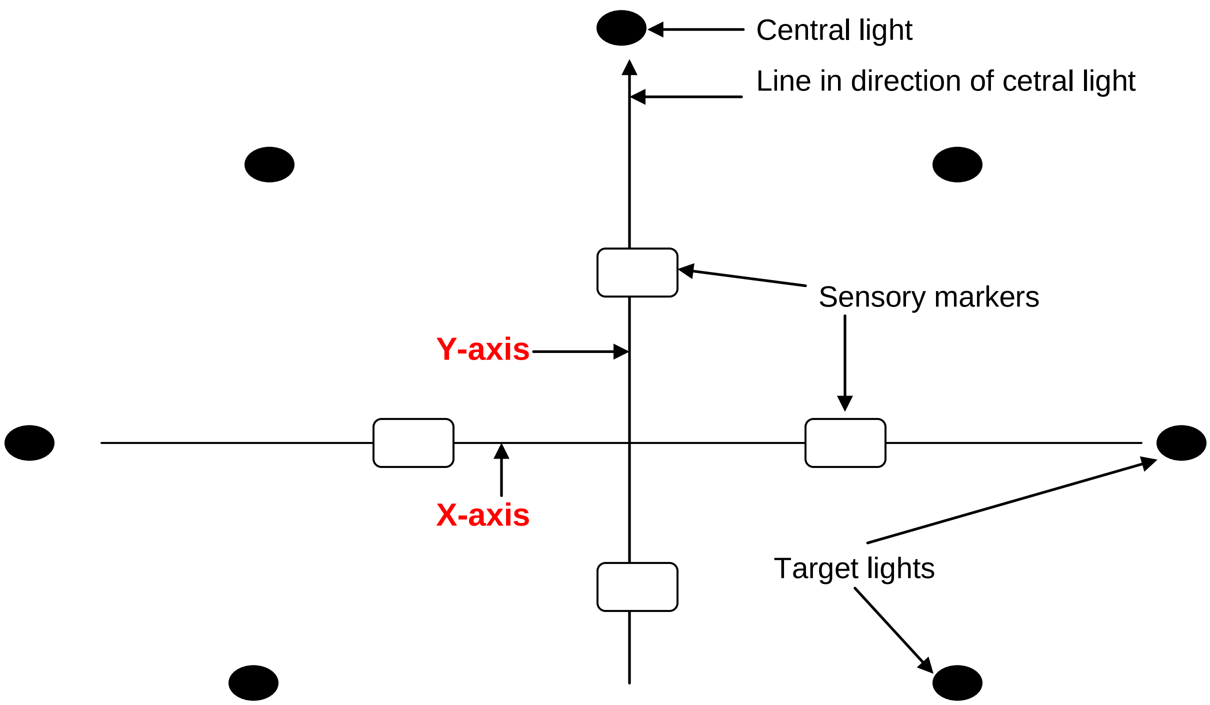
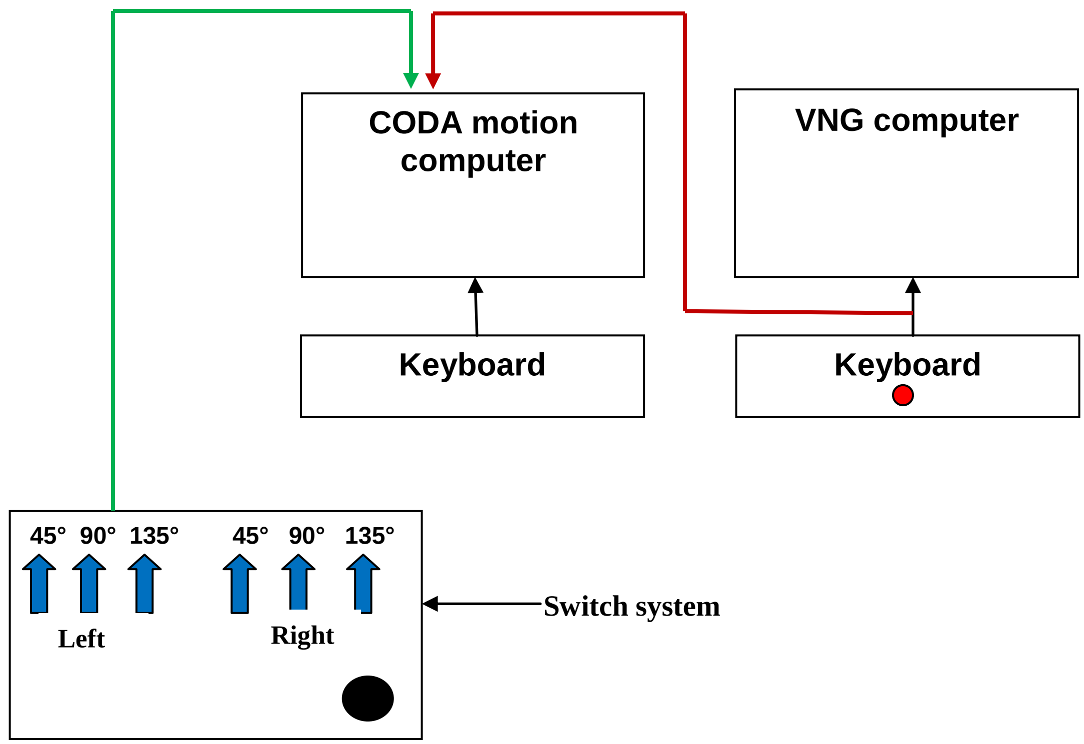


Figure 3.8. Diagram showing room coordinates

3.4.2. Synchronizing CODA motion and VNG systems

The protocol required that participants turned to a selected target light when the central light went out. The lights were controlled through a switch system that was connected to the CODA motion computer (figure 3.9). The switch system consisted of a switch and six buttons controlling each of the six turn angles (45°, 90° and 135° to the left and right). When a button for a particular target light was selected and the switch was pressed, the central light switched off (this indicated the cue for the start of the turn) while the particular target light appeared simultaneously. The switch system then automatically sent a signal to the CODA motion computer by placing a pulse on the graph were the angular displacement of the body during the turn would be presented (figure 3.10). The time at which the pulse occurred would be used to calculate the onset latency and the time at which the peak velocity occurred.

The switch system was connected to the CODA motion computer as shown in figure 3.9, therefore the pulse indicating the time the central light switched off (the time the cue for the turn was given) did not appear on the VNG computer. To obtain the time at which the cue for the turn was given on the VNG computer, a button was constructed on the VNG keyboard which was connected to the VNG computer and the CODA motion computer (figure 3.9). On pressing the button a pulse was placed on both angular displacement graphs on the VNG computer and CODA motion computer and on releasing the button another pulse was also placed on both computers (figure 3.10). These pulses were at a set timing apart, the position of the two pulses and the pulse placed on the CODA graph showing when the central light switched off (cue for the turn) were used to compute the position at which the cue appeared on the VNG computer. This was then used to calculate the onset latency for the horizontal displacement of the eye. The timing errors between placing the pulses on the VNG and CODA were known and were factored into the calculation.



Key:

Buttons that control each target light

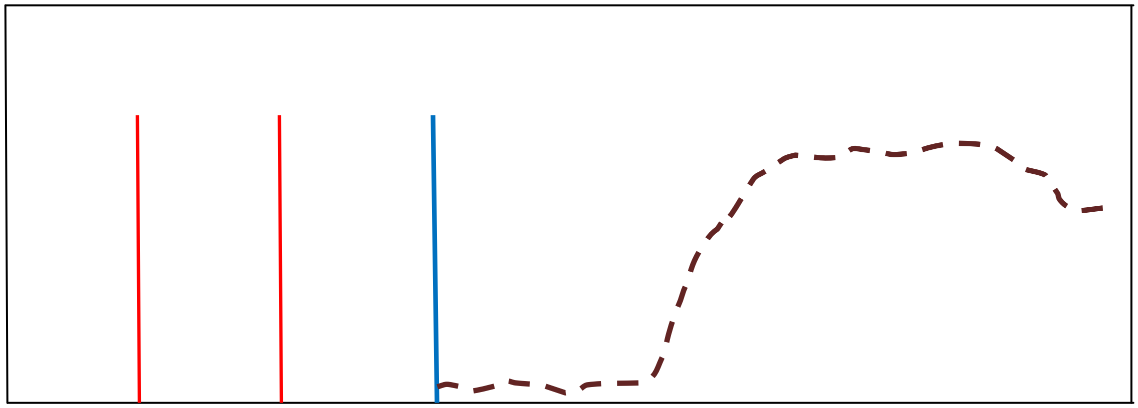
Central switch that switches off the central light
and automatically puts on the selected target light

Button that places pulse on both VNG and CODA computers

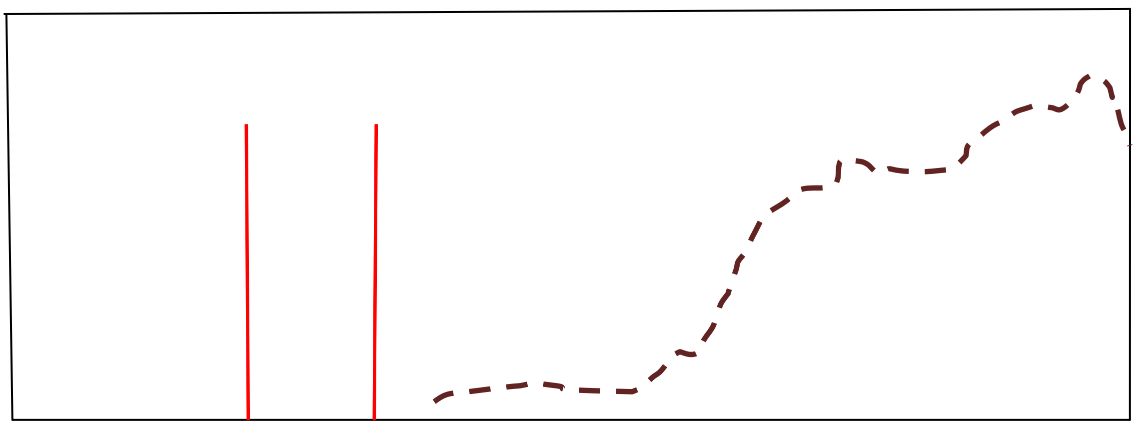
Cord that connects switch system to CODA computer

Cord that connects VNG computer to CODA computer

Figure 3.9. Synchronization of CODA and VNG



a) Graph on CODA motion computer



b) Graph on VNG computer

Key:

Synchronization pulses

Point at which central light went off (cue for turning)

Angular displacement

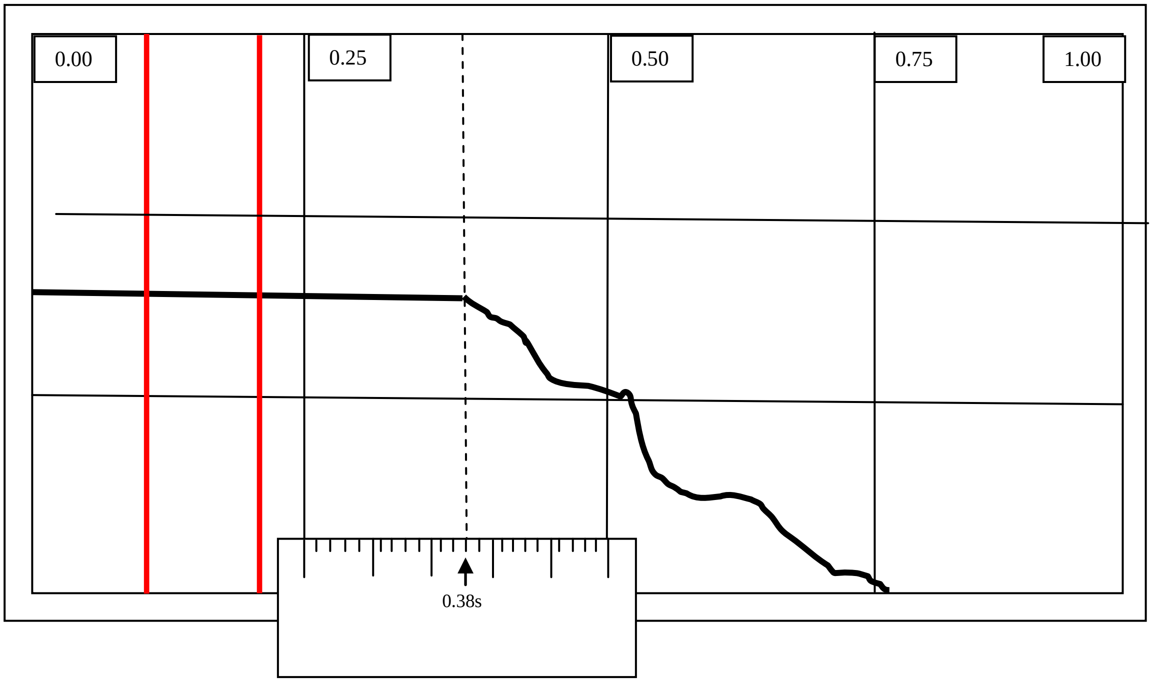
Figure 3.10. Graphs showing synchronization pulses on CODA and VNG computers. The graph shows two synchronization pulses on each of the CODA and VNG computers and a pulse indicating when the light went off on the CODA computer. The positions of these pulses were used to calculate the time at which the light went off on the VNG computer.

In summary, as the participant stood looking at the central light after getting the instructions from the researcher about the particular task to be performed, the operator of the computers (experimental officer):

a. pressed and released the button on the VNG keyboard which placed the two pulses on the VNG and CODA at a set timing apart
b. selected the particular button for the turn angle
c. pressed the switch that automatically switched off the central light, simultaneously switched on the target light and at the same time placed a pulse on the CODA showing the position of the cue triggering the start of the movement.

3.4.3. Extraction of onset latency of eye rotation

The data was captured and presented as an angular displacement graph. The graph contained grid patterns with each grid divided into 25 units (figure 3.11). Each unit represented one hundredth of a second (0.01s). The time at which the two synchronization pulses and the start of the eye rotation occurred were manually recorded by a scale calibrated into 25 units (figure 3.11), each unit representing one hundredth of a second.



Key:

Synchronization bars

Eye angular displacement

Start of eye rotation

Figure 3.11. Extraction of onset latency of eye movement

3.4.4. Extraction of onset latency, peak velocity and time to reach peak velocity for head, shoulder, pelvis and foot

The time at which the two synchronization pulses and the pulse indicating when the cue to turn appeared on the CODA motion were extracted directly by moving the cursor to each pulse and recording the time. The data on the CODA motion has multiple graphs, one presenting angular displacement of each segment and a graph presenting all the segments superimposed. The latter graph was used to export the data (from about one second before the cue appeared to about one second after the end of rotation of the last segment) onto a special excel sheet that had been designed to extract the onset latency, peak velocity and time at which the peak velocity occurred. The special excel sheet was designed by the experimental officer of the Rehabilitation Research Unit of the University of Southampton.

3.4.4.1. Onset latency

The average rotation magnitude of each segment was computed by calculating the mean of rotation of each segment between the visual estimate of the starting point of the segment's rotation and 0.5s before that (figure 3.12). This was defined as the baseline starting position. The onset of each segments' rotation was defined as the time when each segment's rotation exceeded plus or minus three standard deviation (SD) of the baseline starting position (when the turn was to the left direction the SD was added to the mean and when the turn was to the right direction the SD was subtracted from the mean). This procedure ensured that deviation from the baseline was an actual movement. The time obtained from the position of the pulse indicating when the central light switched off was subtracted from the onset of rotation of each segment to give the *onset latency* (the period between the times the turn cue was delivered and when the actual movement of the segment started). For the foot rotation, the onset latency of the first foot to turn was recorded.

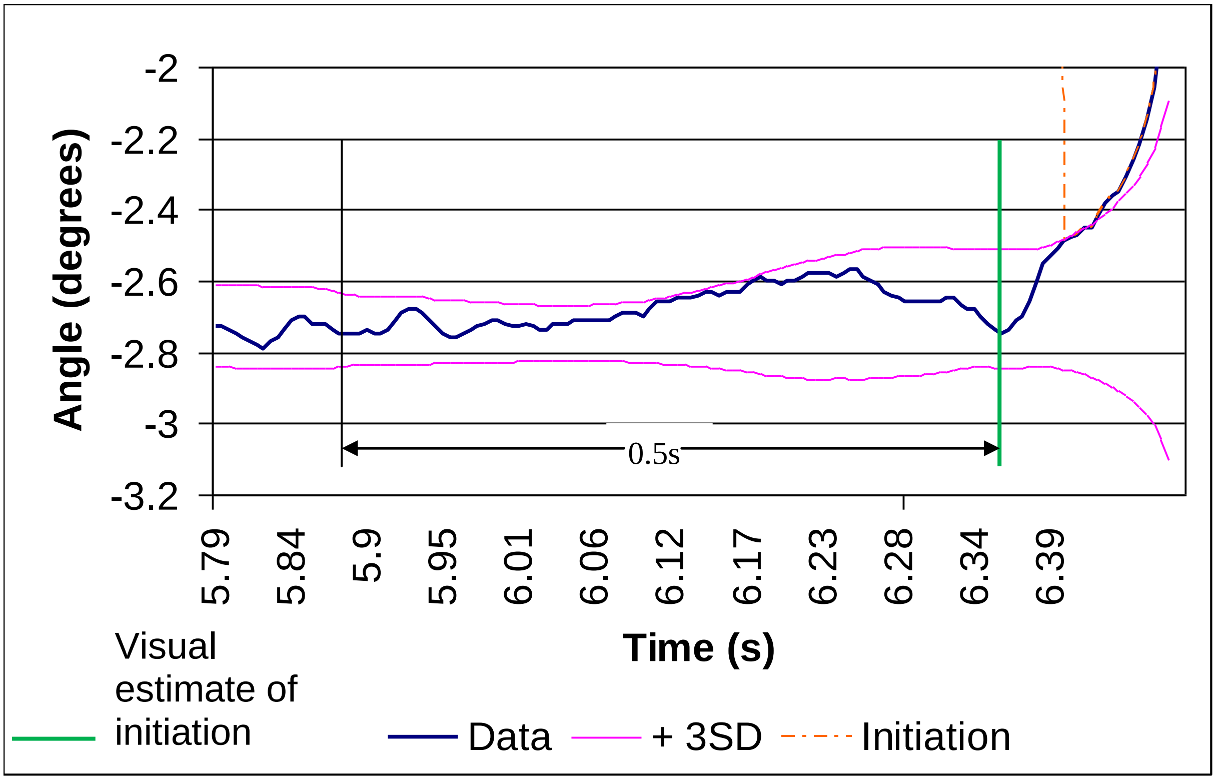


Figure 3.12. Extraction of onset latency of body segments.

3.4.4.2. Peak velocity/time to reach peak velocity

The angular displacement and angular velocity of the movement of one body segment is shown in figure 3.13. The peak velocity (maximum velocity) and the time at which the peak velocity occurred during the turn were identified from the angular velocity traces by the excel sheet. The peak velocity was used directly for analysis while the time obtained from the position of the pulse indicating when the central light switched off was subtracted from the time the peak velocity occurred to give a standardized time for all the trials and participants. For the foot data, the peak velocity of the foot that had the highest peak velocity was recorded.

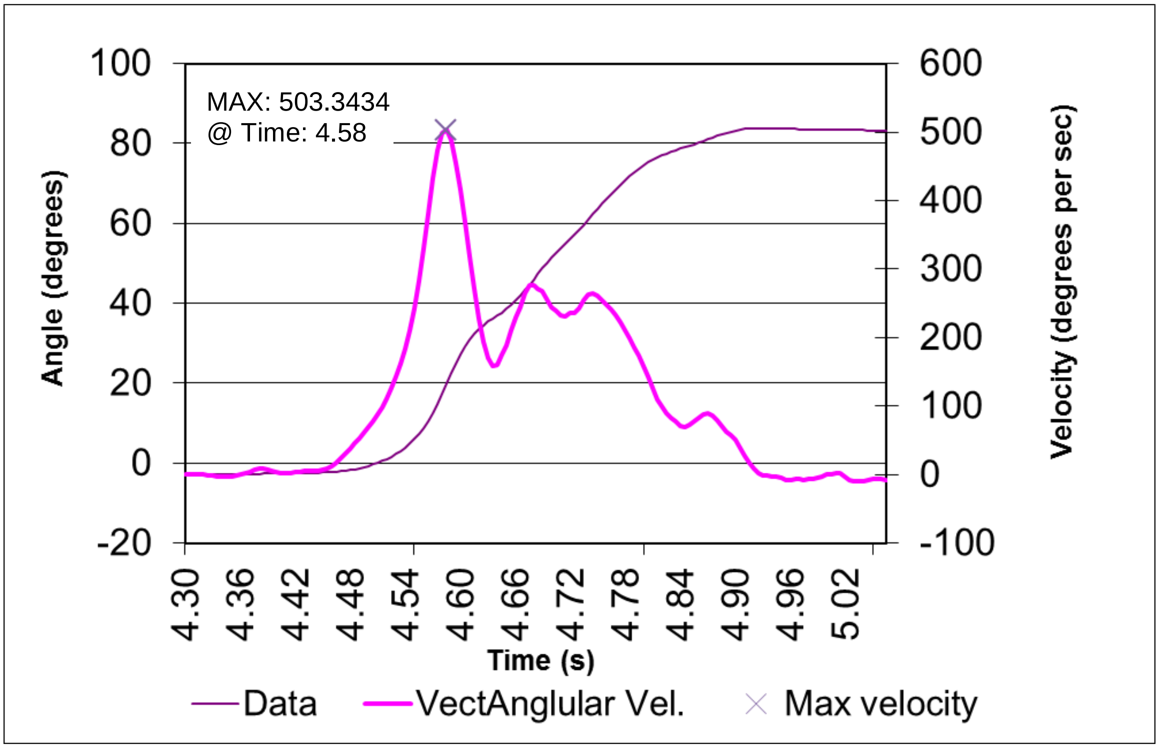


Figure 3.13. Extraction of peak velocity and time to reach peak velocity

3.5. Data analysis

A mixed ANOVA with one between-subject factor (group – people with stroke and age-matched healthy controls in the first study and people with Parkinson's disease and age-matched healthy controls in the second study) and four within subject factors (target predictability, turn direction, turn angle and body segment) was performed on each of the three dependent variables (onset latency, peak velocity and time to reach peak velocity). When main or interaction effects were significant, post hoc comparisons were made with Bonferroni tests. SPSS (version 17) was used for all statistical analyses and the p-value was set as 0.05.

Chapter 4

Whole body coordination when turning on-the-spot in people with stroke and healthy controls

4.0. Introduction

Impairments in people with stroke and how they may affect their ability to turn around will be addressed in this chapter. The literature on whole-body coordination during turning in people with stroke will be reviewed. The results and discussions of the comparisons of the sequence of rotation of body segments during turning on-the-spot between people with stroke and age-matched healthy controls will also be addressed. The aim of the study was to investigate the effect of target predictability, turn angle and turn direction on the sequence of onset latency, peak velocity and timing of peak velocity in people with stroke as compared to age-matched healthy controls.

4.1 Stroke

Stroke is a common condition that limits an individual's ability to perform normal functional activities. According to WHO estimates, 15 million people suffer from a stroke each year and 5 million are left permanently disabled (Mackay et al., 2004). An estimated 110,000 people in the United Kingdom have a stroke every year (Damage, 2005). The reported crude incidence rate per 1000 population per year in the UK is between 1.33 to 4.45 (Du et al., 1997, Stewart et al., 1999, Greenwood et al., 2001, Wolfe et al., 2002, Rothwell et al., 2004). The overall prevalence of stroke in UK ranges from 17.5 to 46.8 per 1000 (O'Mahony et al., 1999, Geddes et al., 1996).These rates are alarming especially considering the significant economic burden placed on society in developed countries (Evers et al., 2004). Stroke cost the UK economy £8 billion in 2004 (Luengo-Fernandez et al., 2006) and has increased to £9 billion a year (Saka et al., 2009). The chronic phase of the disease is the most costly (Saka et al., 2009). Evers et al. (2004)

reported that whereas the percentage of both outpatient and inpatient treatment costs decreases from 44% to 24% on the average, the costs of long term care in Europe and USA (1995-2002) increased from 13% to 49%.

Stroke has been defined as “a syndrome of rapidly developing clinical signs of focal (or global) disturbance of cerebral function, with symptoms lasting 24 hours or longer or leading to death, with no apparent cause other than of vascular origin” (WHO-Monica project principal investigators, 1988). The clinical signs depend on the location of the vascular problem. The brain derives its blood supply from a network of vessels formed by the internal carotid system and the vertebrobasilar system (Nolte, 1999). The internal carotid system supplies most of the cerebrum and part of the diencephalon (thalamus and hypothalamus). The vertebrobasilar system supplies part of the cerebrum, the occipital and temporal lobes, part of the diencephalon, brainstem, cerebellum, and spinal cord. The internal carotid and vertebrobasilar systems form an arterial network called the circle of willis which allows important anastomotic flow when a major vessel becomes occluded (Nolte, 1999). However, decrease in blood flow of about 10ml/100g/min for more than a few minutes may lead to brain tissue damage (Nolte, 1999) that could lead to compromise in the smooth performance of functional tasks.

4.2. Impairments after stroke

This section highlights the impairments in sensory, motor and cognitive systems and references are made to how they may affect the ability of people with stroke to turn around.

4.2.1. Sensory impairments

Sensory impairments often occur after stroke. Bonan et al. (2004) reported that after stroke, visual, vestibular and somatosensory input may be impaired or lost and this may distort the processing and integration of sensory information. Connell et al. (2008) used the Nottingham Sensory Assessment (NSA) to measure sensory impairments on the face, trunk, shoulder, elbow, wrist, hand, hip, knee, ankle and foot of 70 people with stroke. The results showed that proprioception was frequently impaired (34-64% of occurrence). Visual impairments following stroke include eye movement and visual field abnormalities, visual perceptual difficulties, gaze palsies, diplopia, reduced vision and ptosis (Jones and Shinton, 2006, Rowe et al., 2009). Of 323 stroke survivors referred for vision assessment in 14 acute trust hospitals, 68% had eye alignment/movement impairment, 49% had visual field impairment, 26.5% had low vision, and 20.5% had perceptual difficulties status, 54.8% had a combination of two or more visual impairments while only 8% had normal vision status (Rowe and VIS group UK, 2009).

Sensory information from the visual, vestibular and somatosensory systems is necessary for setting the strategy required for the successful execution of a purposeful movement (Brodal, 1998). Since each of the systems supply the brain with unique information about the relationship of body parts and that of the features of the environment necessary for performing a specific task, impairment of any of the systems could compromise achievement of goal directed movement. Although the brain may obtain information on position of the body in relation to targets in the environment through the visual system, defect in proprioception will deprive the brain of adequate information about position of the body's segments in space. This could affect the processing of signals that will be sent to the segments to command them about the timing and range of movement required for each segment.

Apart from controlling the movement itself, the sensory systems are required for maintaining balance while the movement is being carried out. Bonan et al. (2004) reported that people with stroke may lose the ability to choose the appropriate sensory information to prevent falls. Impairment in the sensory systems has been reported to have significant relationship with decrease in balance control. Niam et al. (1999) showed that stroke patients with impaired ankle proprioception had significantly decreased balance scale scores when compared with subjects with intact ankle proprioception.

4.2.2. Motor impairments

Motor deficits seen following stroke include hemiplegia/hemiparesis, spasticity and incoordination during movement. The manifestation of motor disturbances is the result of an abnormal regulation of spatial and temporal characteristics of the motorneurones by the higher centres and/or the result of abnormal changes within the motorneurones and muscles themselves (Bourbonnais et al., 1992). Motor deficits can take various forms, the main concern being the loss of motor function on the side opposite the side of the lesion such as picking up objects to more complex coordinated movements such as turning. Common to these motor tasks is control of muscular force, which is affected by damage to the central nervous system and may manifest as muscle weakness, spasticity and impaired intersegmental coordination.

4.2.2.1. Hemiplegia/hemiparesis

Hemiplegia/hemiparesis are reflected by the inability to generate normal muscle force (Bourbonnais and Noven, 1989, Canning et al., 1999). Reduction in muscle strength decreases the ability of a muscle to produce the force required for initiating movement, controlling the movement, and maintaining stability during the movement (Smidt and Rogers, 1982). The muscular weakness is mainly attributed to the loss of excitation through the descending pathways. The relevant excitatory impulses are interrupted by the lesion of the relevant neurons, or of the fibre pathways as they pass through the basal ganglia or brainstem (Carr and Shepherd, 1998).

Although loss of descending excitation is an important component of the weakness, there are now several reports suggesting that some abnormal changes occur at the segmental level which may also contribute to the muscle weakness. Specific changes in the motorneuron at muscle level can decrease a person’s ability to produce force. Neural aspect of force production depends on the number, type and discharge frequency of the motor units recruited (Bourbonnais and Noven, 1989). Many studies have documented significant reduction in motor unit number (McComas et al., 1973, Hara et al., 2004, Arasaki et al., 2006, Choi et al., 2007), inadequate motor unit recruitment (Gowland et al., 1992) and reduction in mean motor unit discharge rate (Rosenfalck and Andreassen, 1980, Tang and Rymer, 1981, Gemperline et al., 1995) of paretic muscles of hemiparetic stroke patients.

Reductions in strength of paretic muscles have been reported in upper and lower limbs (Chae et al., 2002, Ada et al., 2003) and in axial muscles that move the trunk in different directions (Bohannon et al., 1995, Tanaka et al., 1997, Tanaka et al., 1998). Andrews and Bohannon (2000) showed an irregular distribution of weakness among different muscle groups of hemiparetic stroke patients. This means that some muscle groups are stronger than others. Since muscle strength determines initiation and control of movement of body parts (Shumway-Cook and Woollacott, 2007), differences in the strength of muscle groups involved in turning around could affect the sequence of the movement of the segments. Furthermore, significant decrease in strength of paretic as compared to non-paretic sides in people with stroke (Bohannon et al., 1995, Andrews and Bohannon, 2000) may affect the sequence of the segments when turning towards the paretic and non-paretic side.

4.2.2.2. Abnormalities of muscle tone

Protective mechanisms are in place to prevent injury to muscles during movement and also to ensure balance is maintained. One of these protective measures is the muscle tone which is a partial state of contraction of the muscles (Payndyan et al., 2005). The muscle tone of a particular muscle automatically increases with a sudden stretch to the muscle (a phenomenon referred to as a stretch reflex) in order to avoid over-stretching of the muscle (Payndyan et al., 2005). The muscles that act at a joint in normal individuals maintain a constant tone while at rest to maintain stability. During voluntary movement, the antagonist muscles are inhibited from the constant muscle tension to allow movement in the agonist muscles, a mechanism referred to as reciprocal inhibition. These mechanisms are usually impaired in people with stroke due to loss of descending inhibition from the brain to the spinal cord leading to over-activity in the muscles and increased resistance to passive stretch (Sommerfeld et al., 2004), a mechanism referred to as spasticity.

Although the characteristics of spasticity have been clinically observed as excessive resistance of muscles to passive stretch, the characteristics could also be triggered during voluntary movement. When an agonist muscle contracts to produce a movement, the antagonist muscle may lengthen (stretch) at a particular point to ensure the agonist is not excessively shortened. In people with spasticity, the stretching of the antagonist is not inhibited to allow smooth contraction of the agonists. This results in co-contraction of the agonist and antagonists (Kamper and Rymer, 2001; El-Abd et al., 1993) and may lead to altered initiation and execution of agonist movement. The co-contraction of agonists and antagonists in some segments and not others may affect sequencing of segments rotation during turning.

4.2.2.3. Coordination problems

In the two sections above, the effect of stroke on motor activity was discussed, however, this effect is more or less segmental and functional movements such as turning are multi-segmental which need to be coordinated. Coordinated movement involves multiple joints and muscles that are activated at the appropriate time and with the correct amount of force, so that smooth, efficient and accurate movement occurs (Bourbonnais et al., 1992). Thus, the essence of coordination is the timing and sequencing of the activation of multiple muscle groups. Incoordination in stroke patients could result from a disruption of muscle activation patterns (Bourbonnais et al., 1992) resulting in functional movement abnormalities.

Damage of some of the structures of the CNS due to stroke can produce problems in activating appropriate muscles for functional tasks. This may result in activation of muscles that are not required for a particular task and may lead to the inability to move a single joint without generating movement in other joints. The activation of the muscles follows a similar pattern referred to as abnormal synergy irrespective of the task to be performed or the changing demands of the environment (Shumway-Cook and Woollacott, 2007). This disrupts the coherence in the movement of the joints responsible for giving a smooth movement. During normally coordinated movement, joint angles at synergistic joints change smoothly and at synchronized rates related to one another to produce a smooth movement trajectory (Shumway-Cook and Woollacott, 2007). In patients with spastic hemiparesis due to stroke, movement trajectories are characterized by segmented movements rather than interjoint coordination (Archambault et al., 1999).

Incoordination can also manifest as an inability to appropriately time the activation of muscles and thus the movement itself. There are many facets to timing (reaction time, movement time and time needed to stop a movement). Neuromuscular factors that have been proposed to affect movement timing include inadequate force generation, decreased rate of force generation, insufficient range of motion to allow movement, reduced motivation to move, abnormal postural control, specifically the inability to stabilize the body in anticipation of potentially destabilizing movements (Shumway-Cook and Woollacott, 2007). Studies among stroke survivors have shown significant delay in initiation and termination of muscle contraction (Sahrmann and Norton, 1977, Chae et al., 2006). Dickstein et al. (2004) reported that major impairments in the activity of trunk muscles in hemiparetic subjects were manifested in reduced activity level, in delayed onset, and in reduced synchronization between activation of pertinent muscular pairs. The slow firing and poor synchronization of muscle pairs could result in altered sequencing and timing of movements.

4.2.3. Cognitive impairment

For an individual to react appropriately to environmental stimuli, the information gathered from the environment needs to be processed together with the internal mechanisms that ensure the right responses are executed. This is termed information processing and forms the core of the cognitive system. Memory structures are necessary in recognizing signals in the environment and for recalling prior movement plans. Alterations of any mechanism involved in information processing or memory storage could alter environmentally oriented functional movements (Montgomery and Connolly, 2003).

Tatemichi et al. (1994) examined cognitive function in 227 patients three months after stroke and reported that 35.2% had cognitive impairment which increased the possibility of having functional impairments. The cognitive domains most likely to be affected where reported to be memory, orientation, language and attention. Hauer et al. (2003) reported that cognitive impairment in geriatric patients significantly decreased motor performance and postural stability. The prevalence rate of cognitive impairment was shown to be 39%, 35%, 30% and 32% at three months, 1, 2, and 3 years post stroke respectively indicating that cognitive impairment could persist up to the chronic stage of stroke (Patel et al. 2003).

4.2.4. Summary of impairments after stroke

People with stroke may present with various impairments that could affect normal functional movement. Sensory impairments are a result of the effect of stroke on the sensory systems that gather information about relationship of parts of the body in space and to the environment. Problems in the sensory systems deprives the brain of information that is necessary for planning appropriate movement required for achieving purposeful movement and also for maintaining balance during the movement. On the other hand, motor impairment could lead to inappropriate timing and sequencing of activation of muscles (predominantly on one side) which may compromise coordination of parts of the body during goal directed movements. Turning the body to interact with the environment, requires intact sensory and motor systems that ensures proper timing and sequencing of movement of the body segments required to carry the body to a target. To decide on what action to take to achieve the successful turn to a particular target, placed in either direction in the environment requires information processing of the signals gathered from the environment and the ability to recall prior tasks. Therefore, cognitive impairments may play a role in hindering a coordinated turning task in people with stroke. Sensory, motor and cognitive impairments can compromise the coordination of segments needed to turn the body around and may lead to loss of stability and subsequent falls.

4.2.5. Consequences of stroke

Stroke is one of the leading causes of impairments and disabilities in the UK with a growing number of survivors being dependent in activities of daily living (Wolfe et al., 2002). The most common consequence of stroke is muscle paresis (Gray et al., 1990) which hinders the performance of activities of daily living. Poor sitting and standing balance control is also a significant consequence (Eng and Chu, 2002) because it may lead to limitations in activities of daily living (Hyndman and Ashburn, 2003) and is considered a significant risk factor for the increase in the number of falls after stroke (Nyberg and Gustafson, 1995).

The experience of a fall event is an important issue which needs to be prevented due to its adverse consequences. Falls are associated with increased health care costs (Rizzo et al., 1998). A fall is one of the most frequent complications among stroke patients in rehabilitation (Dromerick and Reding, 1994). Studies have reported 16.3 to 55% of one or more falls in hospitalized stroke patients (Nyberg and Gustafson, 1995, Davenport et al., 1996, Teasell et al., 2002, Ashburn et al., 2008). The number of stroke patients that fall in the community after discharge from hospital is even higher. These are estimated to be around 46 to 73% (Foster and Young, 1995, Mackintosh et al., 2005). In a study observing the consequences of falls in community dwellers, Campbell et al. (1990) reported that individuals who fell had an increased subsequent risk of death compared to those who did not fall. A significant proportion of falls or near falls in a stroke population living in the community occurred while performing a head or whole-body turn in standing or walking (Hyndman et al., 2002, Harris et al., 2005). This makes turning an important area of research that could help in the prevention of fall incidences in people with stroke.

4.3. Whole-body coordination during turning in people with stroke

A small number of studies have reported altered sensorimotor integration during head turns in sitting (Verheyden et al., 2011), standing (Lamontagne et al., 2003) and walking (Lamontagne et al., 2005) in people with stroke with the observation of either axial coordination problems or abnormal postural adjustments. Verheyden et al. (2011) reported an impaired axial coordination during head turns in sitting which manifested as an en bloc rotation of head and shoulder. They showed a non significant difference between start times of head and shoulder rotations in six people with stroke as compared to a significant rotation of head before rotation of shoulders in six healthy participants. Although an impaired axial coordination could compromise stability of an individual during turning in sitting, the risk seems to be less compared to standing and walking due to the wider base of support in sitting and participation of fewer segments during the turn.

Lamontagne et al. (2003) compared postural adjustments to voluntary head turns during standing between eight people with stroke (age: mean±SD=65±9years) and five age-matched healthy participants (age: mean±SD=67±9years). The participants were asked to perform fast head motions (up, down, right, left, or none) in a random sequence in standing. They reported significantly longer reaction times of head rotations in the people with stroke (mean±SD = 407±85ms) as compared to the healthy controls (mean±SD = 324±86ms). The results also showed that the stroke patients moved their head at lower velocities and showed larger differences in displacement of center of pressure (the point where the net pressure force on the body acts) and center of mass (the point where a body behaves as if its mass were concentrated) than the controls. This implies that the stroke participants needed more excursion of the center of pressure in order to stabilize the body center of mass. They concluded that stroke patients manifested altered postural adjustments to voluntary head motions in standing suggesting an impaired sensorimotor integration process for stance and balance after stroke. The study did not present the sequence of axial segments' rotation which is a function of axial coordination during functional activities.

Lamontagne et al. (2005) compared the coordination pattern of axial segments when voluntary head motions were carried out during walking in five healthy and 10 people with stroke. Participants were instructed to turn their head as fast and as soon as possible to the right or left as indicated by an illuminated arrow. The arrow was triggered at initial contact of the right foot of the healthy subject or paretic foot of the stroke subject with a force plate located 2.5m ahead of the point of gait initiation. Head, thorax and pelvic rotations were measured by a Vicon512 motion analysis system. In the healthy participants head and thorax started moving at the same time. In hemiparetic participants, the head moved before the thorax with head turns toward the paretic side whereas the thorax moved before the head with head turns toward the non-paretic side. They suggested that the stroke participants had a disruption of the axial segmental coordination observed in the healthy participants which suggests that stroke alters axial segmental coordination which may contribute to balance dysfunctions during locomotion. Since the protocol involved turning the head in response to a visual target, it would be anticipated that movement of the eye would play an important role in the task. However, the analysis was limited to the head, thorax and pelvis. There was no rationale provided for the instructions given to the participants (turn the head as fast and as soon as possible to the target). As the task may not be common to many activities of daily living, generalization of the results may not be plausible.

Although falls are reported to occur during head turns (Hyndman et al., 2002), the challenge offered to the control system may not be as much as turning the whole-body. Furthermore, participation of other segments of the body apart from the head, such as trunk and feet could occur during turning to interact with the environment. A few studies have observed coordination of body segments during turning while walking in people with stroke and healthy controls (Lamontagne et al., 2007, Lamontagne and Fung, 2009, Hollands et al., 2010a, Hollands et al., 2010b). The studies showed that while healthy controls presented with a top to bottom sequence of rotation of eye, head, thorax, pelvis and feet when turning to 90°, their stroke counterparts presented with a more simultaneous and disrupted rotation of the segments which was more obvious when turning to the paretic side (Lamontagne et al., 2007, Lamontagne and Fung, 2009). Studies investigating coordination of body segments during turning while walking in healthy adults have also shown that the onset of rotation of body segments (head, shoulder, pelvis and foot) was in a top to bottom sequence (Paquette et al., 2008b, Akram et al., 2010).

Hollands et al. (2010a) showed a similar sequence of rotation of head, thorax and pelvis in stroke and control groups when turning to 45° while walking. The head started to rotate followed by the thorax and pelvis which started rotating at the same time. The sequence in the controls was similar to that of Lamontagne and Fung (2009) who also reported rotation of head before thorax and pelvis, however, Lamontagne and Fung (2009) reported simultaneous onset of rotation of the head, thorax and pelvis. The difference between the sequences of the segments between the stroke groups in the two studies (head before thorax and pelvis in the study of Hollands et al. (2010a) and synchronous movement of the segments in the study of Lamontagne and Fung (2009) may be attributed to the amplitude of the turn (45° and 90°). Since turning to 90° appear to be more challenging, stroke participants may have more difficulty coordinating the segments and this may explain the en bloc rotation of the segments.

Turning 180° during the Timed-Up and Go test showed no significant difference in rotation of head, thorax and pelvis in both people with stroke and healthy controls, in other words both groups had an en-bloc rotation of the segments (Hollands et al., 2010b). Many factors could explain the difference in the sequence of the segments in the study of Hollands et al. (2010a) and that of Hollands et al. (2010b). First, the experimental set up in the study of Hollands et al. (2010b) required no cuing while the turning in the study of Hollands et al. (2010a) was directed by a visual cue. Secondly, the angle of rotation was very large in the study of Hollands et al. (2010b). Other factors could be baseline characteristics of the participants in the different studies such as time since stroke and equipments used to measure the rotation of the segments.

Other factors that need to be taken into account while determining the sequence of rotation of segments during turning in people with stroke are direction of turning and predictability of the target to turn to. Lamontagne and Fung (2009) showed that while turning to 90°, people with stroke turned their eye and head first when turning towards the paretic side while they turned the pelvis first when turning towards the non-paretic side. An earlier rotation of head, thorax and pelvis was reported by Hollands et al. (2010a) when turning towards the paretic side as compared to non-paretic side.

The only study that compared turning towards predictable and un-predictable targets during turning while walking was that of Hollands et al. (2010a) in which the cue showing the direction of turn was presented at the start of walking (in a predictable condition) or one stride length before the point of turning (in an unpredictable condition). They showed an earlier head rotation in the predictable condition which did not alter the sequence of the rotation of the segments as compared to the unpredictable condition. However, the turns where carried out to

45° only. Could there be difference in the sequence of the segments between the stroke and control groups with turn angles greater than 45°? Furthermore, the result does not include the rotation of the eye and feet which must have participated in the turn. Details of the studies on coordination of rotation of body segments during turning while walking in people with stroke is presented in table 4.1.

It is difficult to synthesize the results of the studies because some of the factors that are thought to influence coordination of body segments during turning (predictability of a target, turn angle and turn direction) have been investigated in different studies with different methodologies. It was therefore unclear from these studies if the differences seen in the sequence of rotation of the body segments were as a result of manipulating the three variables (target predictability, turn angle and turn direction) or as a result of differences in methodologies used since the variables were studied in separate studies. Rotation of body segments during turning involves segments of the body such as the eye and pelvis, both of which are important. The eyes are believed to provide a frame of reference for the other parts of the body involved in turning (Hollands et al., 2001) while the centre of mass is located around the pelvic region and the pelvis is therefore crucial for stability. Not all previous studies measured the movement of the eye and pelvis during the turning tasks. Finally, none of the studies used a power calculation to determine the appropriate number of participants required. It is therefore not certain if non-significant results are actually not significant or as a result of insufficient number of participants to yield significance. To determine the difference in the sequence of rotation of the segments between people with stroke and controls considering the effect of target predictability, turn angle and turn direction, a study that observes the effect of the factors in the same set of participants using the same protocol and equipments is important.

Table 4.1. Literature review of sequence of onset latency of body segments when turning while walking in people with stroke

Author	Task	Measurements	Results
Lamontagne et al. (2007)	Two people with stroke (age: 33 and 43 years) and one healthy control (age: 33 years) walked straight ahead along a 9 m pathway or around a 90° corner (to the right or left) located 5 m from the starting position. Participants had prior knowledge of the walking direction.	Eye movement was measured using an Eyelink – 1 video-based system. Movement of head, thorax and pelvis was measured by a 6-camera Vicon 3D motion analysis system.	Results were presented descriptively due to the small sample size: Stroke group: Eyes and head started to rotate simultaneously followed by thorax and pelvis which started to rotate simultaneously. The movement of the segments was more synchronous when turning towards the paretic side Control group: The eyes started to rotate followed by head then thorax and finally pelvis
Lamontagne et al. (2009)	Eight people with stroke (age: 65±7 years) and	Eye movement was measured by an Eyelink – 11	Stroke group: When turning to paretic side, the eye and head

	Seven healthy controls (age: 62±4 years) walked straight ahead along a 9 m pathway or around a 90° corner (to the right or left) located 5 m from the starting position in response to a visual cue. The cue was triggered 1 m before the intersection in an unpredictable manner.	video-based system. Movement of head, thorax and pelvis was measured by a 6-camera Vicon 3D motion analysis system.	started to rotate followed by the thorax and finally the pelvis. When turning to non-paretic side, the pelvis started to rotate followed by the eye and head and finally the thorax. Control group: The eyes started to rotate followed by head then thorax and finally pelvis
Hollands et al. (2010a)	14 people with stroke (age: 60±11 years) and 14 age-matched healthy controls changed walking direction by 45° to the right or left, at the midpoint of a 6 m path. Participants were provided a visual cue either at the start of the walk (predictable	Rotation of head, thorax and pelvis were measured by 13 VICON cameras.	The head started to rotate followed by simultaneous rotation of trunk and pelvis for both predictable and unpredictable condition in both groups.

	condition) or one stride before they reached the turn point (unpredictable condition).		
Hollands et al. (2010b)	18 people with stroke (age: 60±10 years) and 18 age-matched healthy controls performed the 180° turn around in the timed UP & GO test. The direction of turn was known prior to the turn.	Rotation of head, thorax and pelvis were measured by 13 VICON cameras.	The head, thorax and pelvis started to move simultaneously in both stroke and control groups

4.3.1. Summary

Turning the whole body in standing and walking is thought to present a greater challenge to the motor coordination system than head turns in sitting, standing and walking. Few studies have reported altered body segments coordination during whole-body turns while walking. When turning to 90°, healthy controls presented with separate onset of rotation of body segments (eye, head, thorax and pelvis) in a top to bottom sequence, while people with stroke presented with a more simultaneous onset of rotation of the segments especially when turning to the paretic side. Changing the turn angle to 45° or 180° altered the sequence of onset of rotation of the segments. However, since the effect of the turn angle was observed in different studies, it is not known if other factors apart from the turn angle influenced the sequencing. Factors such as equipment used, instructions given to participants and presence or absence of a cue for the turn were different across the studies. Predictability of a target affected how fast the segments started to rotate but not the sequence of rotation of the segments. However, the effect of the predictability of the target was observed only when turning to 45° but not larger turn angles.

4.4. Gaps in knowledge

Impaired coordination of body segments when changing direction while walking have been reported in people with stroke (Lamontagne et al., 2007, Lamontagne and Fung, 2009, Hollands et al., 2010a). However, some activities of daily living require turning on-the-spot such as turning to flush a toilet after use. There is no known study that has investigated the coordination of body segments during turning on-the-spot in people with stroke. The key point highlighted in the studies on whole-body coordination during turning in healthy adults is that the sequence of rotation of the segments depends on the task to be accomplished which is governed by sensory and environmental factors such as predictability of the target, type of cue triggering the start of the turn, direction of turn and angle of the turn.

The predictability of a target is important in the planning of movement. The brain utilizes sensory information about the environment to plan a functional movement; this information is available to the brain for a longer period with a predictable than an unpredictable condition. This is reflected in the report of Dassonville et al. (1998) and Thickbroom et al. (2000) that there is an increased activation of motor areas of the brain with an unpredictable behaviour compared to a predictable one. Predictability of a visual target has been reported to influence sequence of segmental rotation during turning on-the-spot in healthy adults (Anastasopoulos et al., 2009). Turning to unpredictable visual targets resulted in a top to bottom sequence of onset of segments rotation (Hollands et al., 2004, Anastasopoulos et al., 2009) while turning to predictable visual targets resulted in more simultaneous onset of rotation of the segments (Anastasopoulos et al., 2009). Since stroke patients present with damage to the brain, could the sequence differ between the predictable and unpredictable conditions as compared to healthy controls?

Turn angle does not alter the sequence of onset of segmental rotation during turning on-the-spot in healthy adults (Hollands et al., 2004, Anastasopoulos et al., 2009). However turning to different angles requires attention and cognition (Neville and Lawson, 1987), factors that could be impaired in stroke. Therefore stroke patients may manifest a different sequence of segmental rotation while turning to different angles. People with stroke are characterized by hemiplegia/hemiparesis of one side of the body, postural asymmetries and abnormal reflexes that manifest on turning towards or away from the hemiplegic side (Carr and Kenney, 1992). Although turning to the left and right has not been reported to alter the sequence of onset of segments rotation during turning in healthy individuals, the sequence may be different when turning towards and away from the hemiplegic side in stroke patients.

Although the onset latency is an important indicator of coordination of body segments, it only takes into consideration what happens at the point when the turn is initiated. The peak velocity and the timing of the peak velocity are other parameters that describe the coordination of body segments during the turn. There is no known study that has investigated the effect of target predictability, turn angle and turn direction on the sequence of peak velocity and timing of peak velocity in people with stroke.

Many schools of thought in the field of rehabilitation such as Bobath (1990) and Carr and Shepherd (1998) have used the concept of ‘relearning’ to describe the recovery process. Training activities of daily living (ADLs) require information on specific coordination deficits in functional tasks, “only when one knows precisely what is being relearned, can one begin to come to terms with how relearning takes place” (Wagenaar and van Emmerik, 1996; pg 162). It is therefore crucial to explore the mechanisms that underpin coordination in specific functional tasks to identify the alterations caused by impairment of the structures that control them. Hence, a study investigating the sequence of body segments during whole-body turning may provide new knowledge that could enhance rehabilitation of stroke patients and could form a basis for further research.

The reason for carrying out this study is to investigate how people with stroke move their body during turning as compared to healthy controls by comparing the sequence of horizontal displacement of the eye and rotation of head, shoulders, pelvis and feet when turning to predictable and unpredictable targets placed at three different angles (45°, 90° and 135°) and two directions (right and left). It is hoped that the results will help identify the problems that people with stroke may encounter during turning which may predispose them to losing stability and subsequent falls.

4.5. Methodology

The aim of the study was to compare the sequence of rotation of body segments (eye, head, shoulder, pelvis and foot) during turning on-the-spot between people with stroke and age-matched healthy controls. The effect of target predictability, turn angle and turn direction on the sequence of rotation of the body segments was also investigated. It was hypothesized that people with stroke will present with a different sequence of rotation of body segments during turning on-the-spot as compared to the healthy controls.

4.5.1. Recruitment

The participants targeted for this study were community dwelling individuals who agreed to be contacted by the Faculty of Health Sciences, University of Southampton during previous studies or were members of local stroke clubs. The healthy participants were individuals without any neurological conditions or any other condition that could affect the way they turn and who agreed to be contacted by the Faculty of Health Sciences, University of Southampton or were partners of the participants with stroke. The inclusion and exclusion criteria for the stroke and control groups are listed below:

4.5.1.1. Stroke group

4.5.1.1.1. Inclusion criteria

1. Diagnosis of stroke,
2. First stroke only,
3. 6 months or more after onset of stroke,

4.5.1.1.2. Exclusion criteria

1. Unilateral neglect as measured by star cancellation test (Halligan et al. 1990),
2. Visual field defect as tested by visual field test (Elliot et al. 1997),

3. Other self-reported vision impairments that could not be corrected with glasses,
4. Self-reported vestibular disorders,
5. Vestibular problems as determined by spontaneous nystagmus test,
6. Inability to understand and remember instructions: The instructions for the tasks were explained to the participants and they were asked to say it back in the sequence in which it was said to them. To be included in the study, the participants needed to remember the instructions in the sequence in which it was explained to them,
7. Inability to stand and turn independently,
8. Musculoskeletal disorders such as amputation which could alter the participants' performance while turning,
9. Other neurological conditions because they may serve as confounding variables by affecting the way the participants turn.

4.5.1.2. Control group

4.5.1.2..1. Inclusion criteria

1. Healthy individuals that were age-matched to the participants with stroke.

4.5.1.2.2. Exclusion criteria

Healthy participants with the following characteristics were excluded:

1. Self-reported vision impairments that could not be corrected with glasses,
2. Self-reported vestibular disorders,
3. Inability to stand independently,
4. Presence of self reported musculoskeletal and neurological disorders which would affect turning.

The study was approved by the Faculty of Health Science's ethics committee [ethics number: SoHS-ETHICS-09-033 (appendix iii)] and all participants were informed about the study and asked to sign a consent form (appendix iv) prior to data collection.

4.5.2. Outcome measures

For the stroke participants, clinical measures were taken to aid in describing the participants' level of functional independence, balance and cognition. The clinical measures used were Barthel Index (Mahoney and Barthel, 1965) which assesses functional independence, Berg Balance Scale (Berg et al., 1992) which assesses balance and Mini-Mental State Examination (Folstein et al., 1975) which assesses cognitive status. The measurements were carried out as follows:

1. Barthel Index: The Barthel Index was used to measure the functional status of the participants. It consists of 10 items which include feeding, moving from chair to bed and return, grooming, transferring to and from a toilet, bathing, walking on level surface, dressing, stair climbing and bowel and bladder continence. The items were scored based on whether the participant has received help while doing the tasks (with scores rated as 0, 5, 10 or 15). The scores for each of the items were summed to give a total score with maximum score of 100. A higher score indicated a greater level of independent. The Barthel Index is a valid and reliable tool for measuring functional status of people with stroke (Wade and Collin, 1988).

2. Berg Balance Scale (BBS): The BBS was used to measure the balance status of the participants. The Berg Balance Scale has 14 items which include sitting to standing, standing and standing unsupported, standing to sitting, transfers, standing with eyes closed, standing with feet together, reaching forward with outstretched arm, retrieving object from floor, turning to look behind, placing alternate foot on stool, standing with one foot in front and standing on one foot. The items were measured on a five-point ordinal scale ranging from 0-4 (0 indicates the lowest level of function and 4 the highest level of function). The total score for the test is

56, a higher score indicated a greater balance ability. The equipment needed for the test are a ruler, 2 chairs, footstool or step, stopwatch or wristwatch and 15 feet walkway. The Berg Balance scale is a valid and reliable tool for measuring balance of people with stroke (Mao et al., 2002).

3. Mini Mental State Examination (MMSE): The MMSE was used to measure the participants' cognitive status. The MMSE is a 30-point questionnaire test that provides measures of orientation, registration (immediate memory), short term memory and language functioning. A score of 24 or above is considered normal. The MMSE is a valid and reliable tool for measuring cognitive function in people with stroke (Grace et al., 1995).

The research design and materials used for this study have been stated in chapter 3. The processes of data collection, extraction and analysis have also been detailed in chapter 3.

4.6. Results

4.6.1. Participants

Seventy two people with stroke and 47 healthy individuals were given information sheets with details of the study. Fifteen people with stroke and 11 healthy individuals agreed to take part in the study. One person with stroke later declined to participate on health grounds. Three people with stroke did not fulfil the inclusion criteria and were not included. One participant with stroke asked to leave immediately after data collection started while one healthy individual did not make it to the lab for data collection and no reason was given for that. In total, data was collected from ten people with stroke and ten healthy controls. The details of the recruitment process are shown in a flow chart in appendix v.

4.6.2. Demographic data/baseline measures

The ten people with stroke had mean age of 66 (SD=10) years (8 males) and the ten healthy controls had mean age of 65 (SD=8) years (6 males). Six of the stroke participants had left sided hemiplegia while four had right sided hemiplegia. All healthy controls were right hand/foot dominant. The dominance was collected by asking the participants what hand they would use to write and what leg they would use to kick a football. Since there were more stroke participants with left sided hemiplegia (six), the paretic side of the participants with stroke was compared to the non-dominant side (left) of the controls. The mean number of years since having the stroke was 5 (SD = 3). The demographic data and baseline measures of the control group and the stroke group are presented in table 4.2 and 4.3 respectively. The stroke group had normal cognitive status (mean±SD of MMSE = 29±2), high functional status (mean±SD of barthel index scores = 91±11) and moderate to high balance status (mean±SD of berg balance scale = 47±6) as shown in table 4.3.

Table 4.2. Demographic data of control group

Age (years)	Gender	Dominant side
65	M	R
73	F	R
68	F	R
58	F	R
70	M	R
64	F	R
65	M	R
68	M	R
45	M	R
69	M	R
Mean=64.5 SD=7.96		

Table 4.3. Demographic data/baseline measures of stroke group

Age (yrs)	Gender	BI	BBS	MMSE	PS	TSS(yrs)
46	M	90	54	30	L	2
75	M	60	37	28	R	8
68	M	100	52	30	L	5
62	M	95	49	25	L	7
62	M	95	52	29	R	5
65	M	90	51	30	L	6
60	F	95	45	28	R	12
61	M	95	44	29	L	5
73	M	90	40	27	R	2
84	F	95	41	29	L	1
Mean=65.6 SD=10.28		Mean=90.5 SD=11.17	Mean=46.5 SD=5.91	Mean=28.5 SD=1.58		Mean=5.3 SD=3.27

BI = Barthel Index; BBS = Berg Balance Scale; MMSE = Mini-Mental Score Examination; PS = Paretic Side; TSS = Time since stroke

The data for onset latency, peak velocity and timing of peak velocity of body segments during turning on-the-spot in people with stroke and healthy controls is presented in the following sections. The effect of a number of variables (target predictability, turn angle, turn direction, body segment and group) on the onset latency, peak velocity and timing of peak velocity of body segments was analyzed in this study. Therefore to make the presentation of the data easier to follow, graphs are shown for a particular variable of interest averaged across other variables. Where differences exist across the level of another variable, graphs are presented to show the differences.

4.6.3. Sequence of onset of rotation of body segments

The results showed a difference in sequence of onset of rotation of body segments (eye, head, shoulder, pelvis and foot) when turning to predictable and unpredictable targets (figure 4.1) when the onset latency was averaged across the three turn angles, two turn directions and two groups. This was shown by the significant interaction of predictability vs segment [F (4, 72) = 21.852, p = 0.001] from the results of the ANOVA.

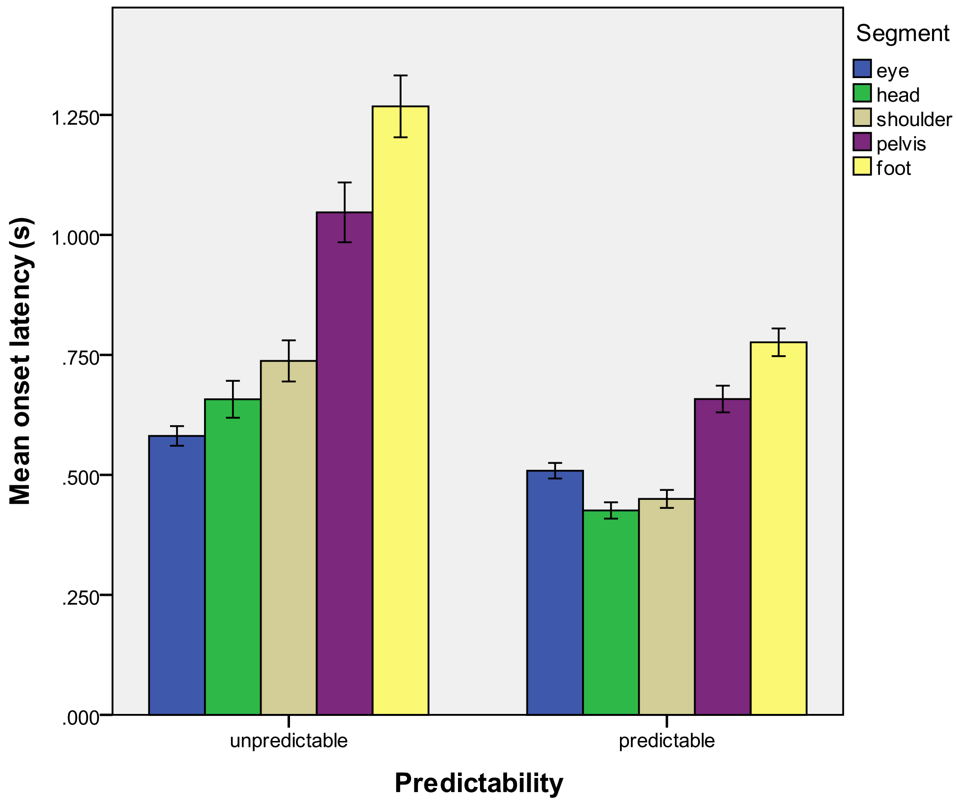


Figure 4.1. Mean and standard error (Error bars: +/- 1 SE) of the onset latency of eye, head, shoulder, pelvis and foot when turning to predictable and unpredictable targets averaged across the three turn angles, two directions and two groups.

There was also a difference in the sequence of rotation of the segments when turning to 45°, 90° and 135° (figure 4.2.) when the onset latency was averaged across the two predictability conditions, two turn directions and two groups. This was shown by the significant interaction of angle vs segment [F (8, 144) = 10.619, p = 0.001].

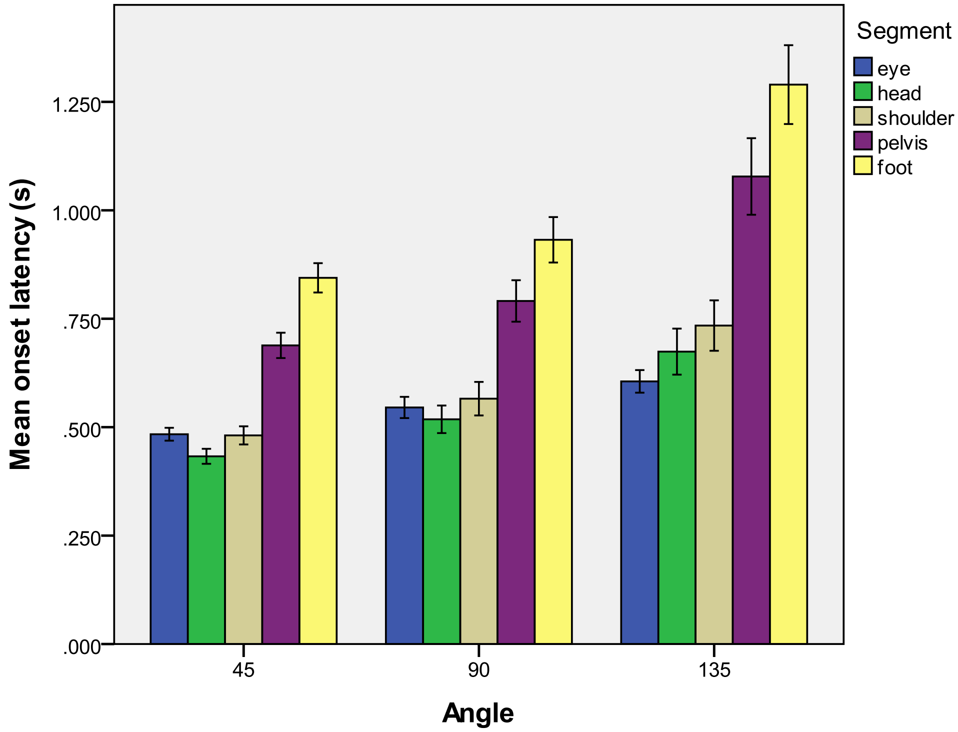


Figure 4.2. Mean and standard error (Error bars: +/- 1 SE) of the onset latency of eye, head, shoulder, pelvis and foot when turning to 45°, 90° and 135° averaged across the two predictability conditions, two directions and two groups.

However, the sequence of the onset latencies of the segments across the three turn angles was different for the two predictability conditions (figure 4.3) when the onset latency of the segments were averaged across the two turn directions and two groups. This was shown by the significant interaction of predictability vs segment vs angle, $F(8, 144) = 18.571$, $p = 0.001$.

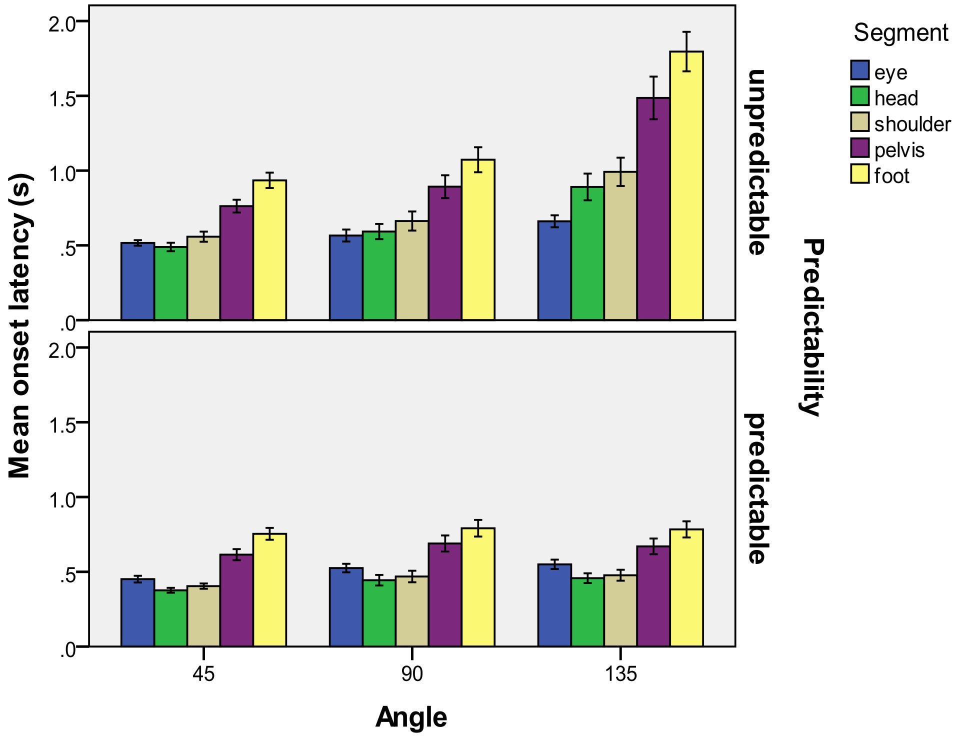


Figure 4.3. Mean and standard error (Error bars: +/- 1 SE) of the onset latency of eye, head, shoulder, pelvis and foot when turning to the three turn anges for each predictability condition, averaged across the two turn directions and two groups.

There was no difference in the sequence of onset of the segments when turning to the paretic/non-dominant side and the non-paretic/dominant side (figure 4.4) when the onset latency was averaged across the two predictability conditions, three turn angles and two groups. This was shown by the non-significant interaction of direction vs segment [F (2.530, 45.539) = 0.991, p = 0.395].

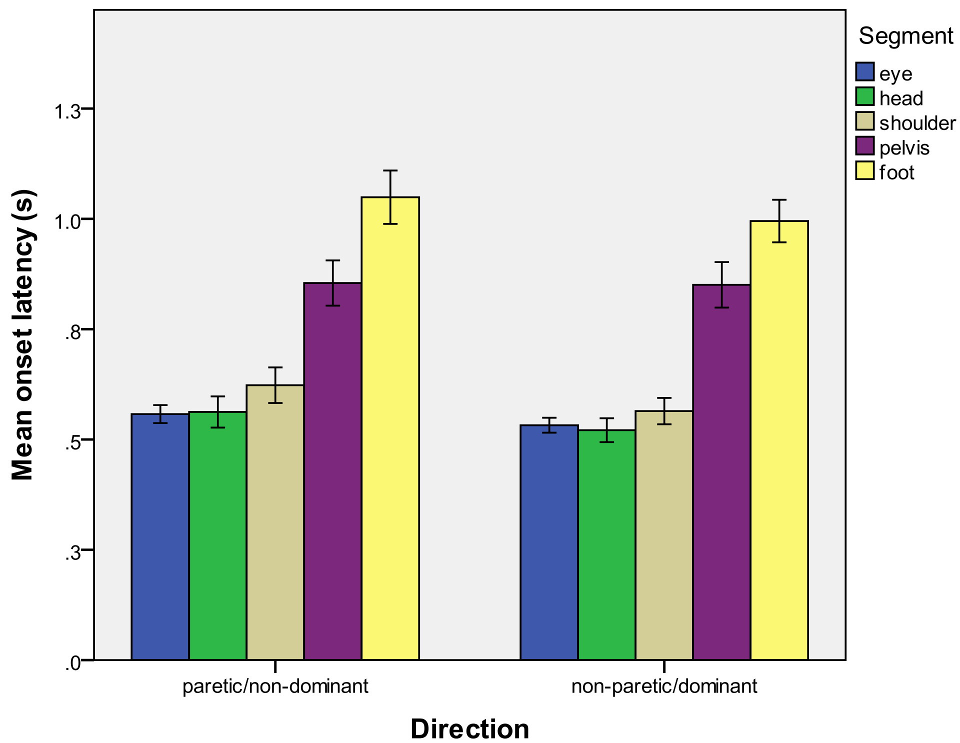


Figure 4.4. Mean and standard error (Error bars: +/- 1 SE) of the onset latency of eye, head, shoulder, pelvis and foot when turning to paretic/non-dominant and non-paretic/dominant sides, averaged across the two predictability conditions, three angles and two groups.

The eye, head and shoulder started to move simultaneously when turning to unpredictable targets placed at all angles and both directions in both groups. This was shown by the non-significant difference in the onset latency of the eye, head and shoulder in the post hoc analysis. The simultaneous movement of the eye, head and shoulder was followed by the pelvis and finally the foot when turning towards 45° and 90°. On the other hand, the pelvis and foot also moved simultaneously when turning to 135°. When turning to predictable targets, either the eye, head and shoulder moved simultaneously or the head and shoulder moved before the eye. The pelvis and foot moved simultaneously when turning to 90° and 135° to both sides (except when turning to 90° towards the dominant side in the control group) while the two segments moved separately (with the pelvis moving first) when turning to 45° to both sides.

The similarities in the sequence of onset of the segments between the two groups observed in the post hoc analysis was confirmed by a non-significant interaction effect of predictability vs angle vs segment vs group, $F(2.749, 49.489) = 2.227$, $p = 0.102$ (figure 4.5 and 4.6). Although there was no difference in the sequence of onset of the segments between the two groups, the stroke group initiated the movement slower than the control group (table 4.4 and 4.5). This was shown by the significant main effect of group, $F(1, 18) = 7.371$, $p = 0.014$. The mean (SE) of the onset latencies of the stroke and control groups when averaged across the two predictability conditions, three turn angles, two directions and five segments were 0.839s (0.066) and 0.583s (0.066) respectively.

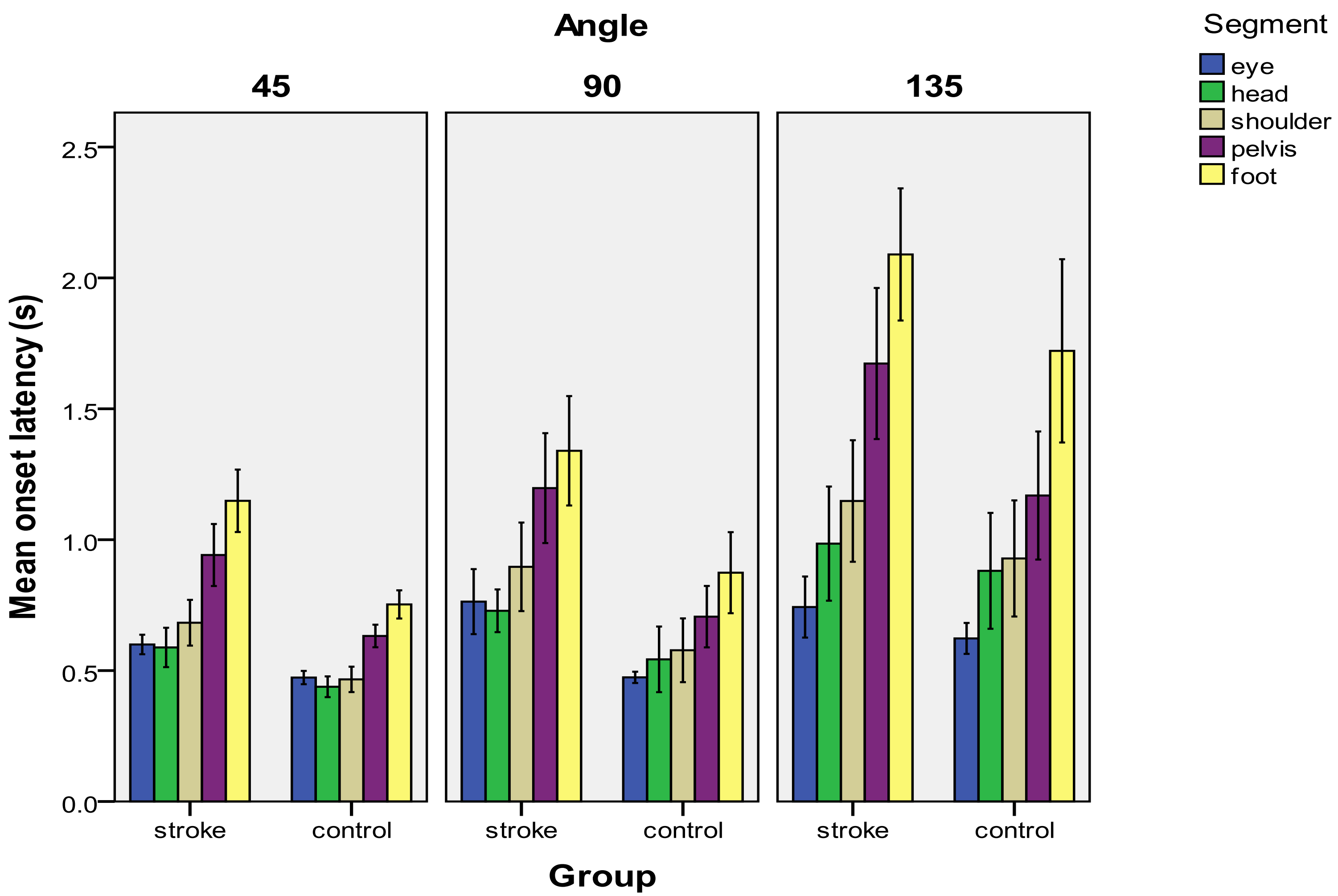


Figure 4.5. Mean and standard error (Error bars: +/- 1 SE) of onset latency of eye, head, shoulder, pelvis and foot when turning towards paretic/non-dominant side - Unpredictable condition.

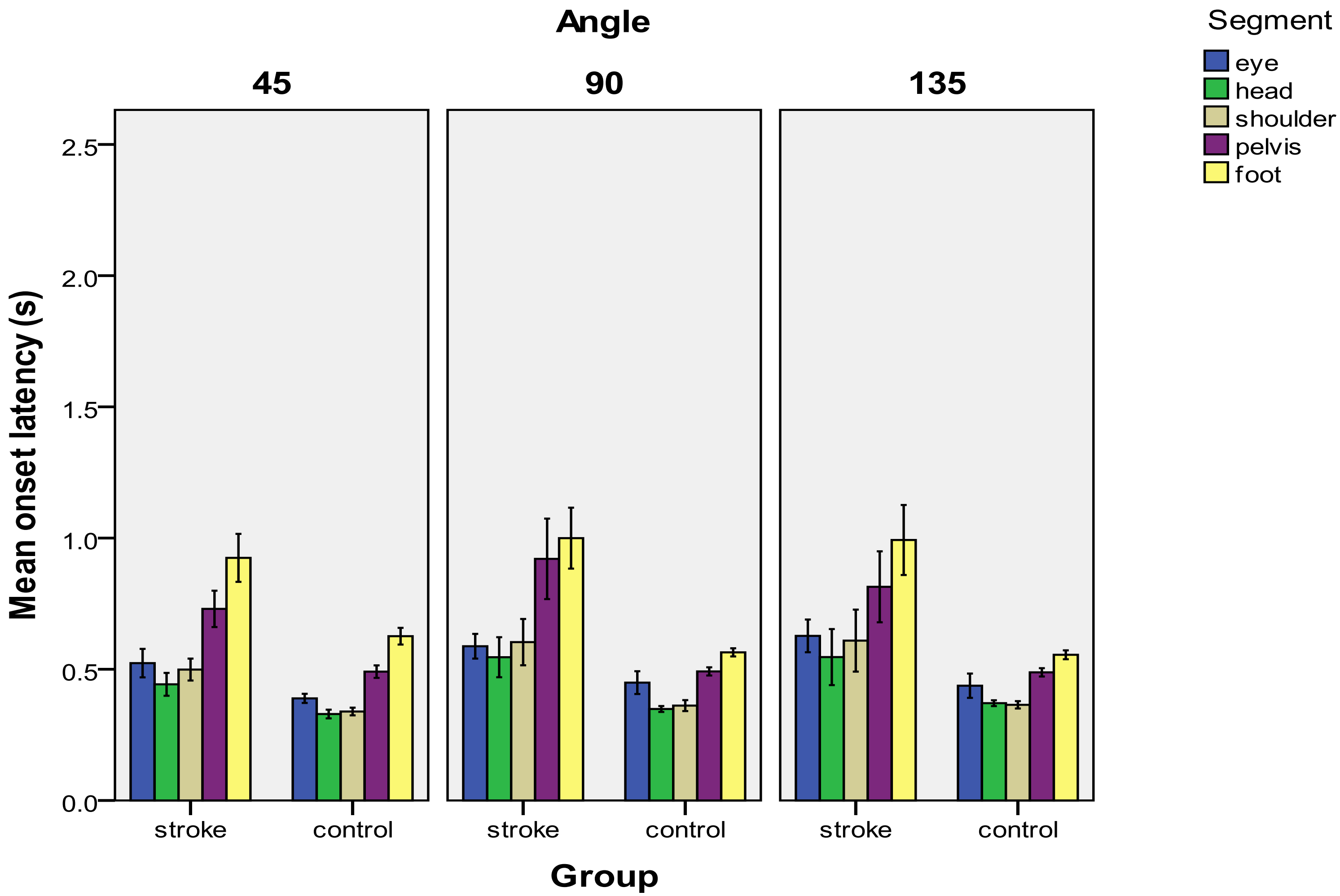


Figure 4.6. Mean and standard error (Error bars: +/- 1 SE) of onset latency of eye, head, shoulder, pelvis and foot when turning towards paretic/non-dominant side - Predictable condition.

Table 4.4. Onset latencies when turning towards paretic/non-dominant side – Unpredictable condition

	45°		90°		135°	
	Stroke [mean(±SE)s]	Control [mean(±SE)s]	Stroke [mean(±SE)s]	Control [mean(±SE)s]	Stroke [mean(±SE)s]	Control [mean(±SE)s]
Eye	0.600(0.037)	0.473(0.025)	0.763(0.124)	0.474(0.022)	0.743(0.117)	0.623(0.059)
Head	0.588(0.075)	0.438(0.040)	0.728(0.082)	0.543(0.125)	0.985(0.218)	0.881(0.221)
Shoulder	0.683(0.087)	0.466(0.049)	0.896(0.169)	0.578(0.122)	1.148(0.232)	0.928(0.222)
Pelvis	0.942(0.118)	0.632(0.043)	1.197(0.210)	0.706(0.117)	1.673(0.289)	1.169(0.245)
Foot	1.149(0.119)	0.753(0.054)	1.340(0.209)	0.874(0.155)	2.090(0.252)	1.721(0.350)

Table 4.5. Onset latencies when turning towards paretic/non-dominant side – Predictable condition

	45°		90°		135°	
	Stroke [mean(±SE)s]	Control [mean(±SE)s]	Stroke [mean(±SE)s]	Control [mean(±SE)s]	Stroke [mean(±SE)s]	Control [mean(±SE)s]
Eye	0.523(0.054)	0.389(0.017)	0.587(0.047)	0.449(0.043)	0.627(0.062)	0.437(0.046)
Head	0.443(0.044)	0.329(0.017)	0.546(0.076)	0.349(0.011)	0.546(0.107)	0.371(0.011)
Shoulder	0.499(0.042)	0.339(0.024)	0.603(0.088)	0.361(0.021)	0.609(0.118)	0.365(0.014)
Pelvis	0.730(0.069)	0.491(0.024)	0.921(0.153)	0.492(0.016)	0.814(0.135)	0.488(0.016)
Foot	0.924(0.091)	0.626(0.032)	1.000(0.116)	0.564(0.016)	0.993(0.133)	0.555(0.017)

The onset of rotation of the segments was significantly faster when turning to predictable targets as compared to turning to unpredictable targets as shown in table 4.4 and 4.5. This was shown by a significant main effect of predictability on the onset latencies of the segments, $F(1, 18) = 32.662$, $p = 0.001$. The mean (SE) of the onset latencies while turning to predictable and unpredictable targets when the onset latencies were averaged across the three turn angles, two directions, five segments and two groups were 0.564s (0.037) and 0.858s (0.066) respectively.

There was a significant increase in the onset of movement with increase in turn angle (table 4.4 and 4.5). This was shown by a significant main effect of turn angle on the onset latencies of the segments, $F(2, 36) = 30.38$, $p = 0.001$. The mean (SE) of the onset latencies for turns to 45°, 90° and 135° when the onset latencies of the segments were averaged across the two predictability conditions, two directions, five segments and two groups were 0.586s (0.032), 0.670s (0.052) and 0.876 (0.066) respectively. The pairwise comparisons between the onset latencies of the three groups showed that there was a significant difference between all the three paired combinations (45° vs 90°, $p = 0.014$, 90° vs 135°, $p = 0.001$ and 45° vs 135°, $p = 0.001$). However, the increase in onset latency with increase in turn angle was found to be more pronounced when turning to unpredictable targets as compared to turning to predictable targets (figure 4.7).

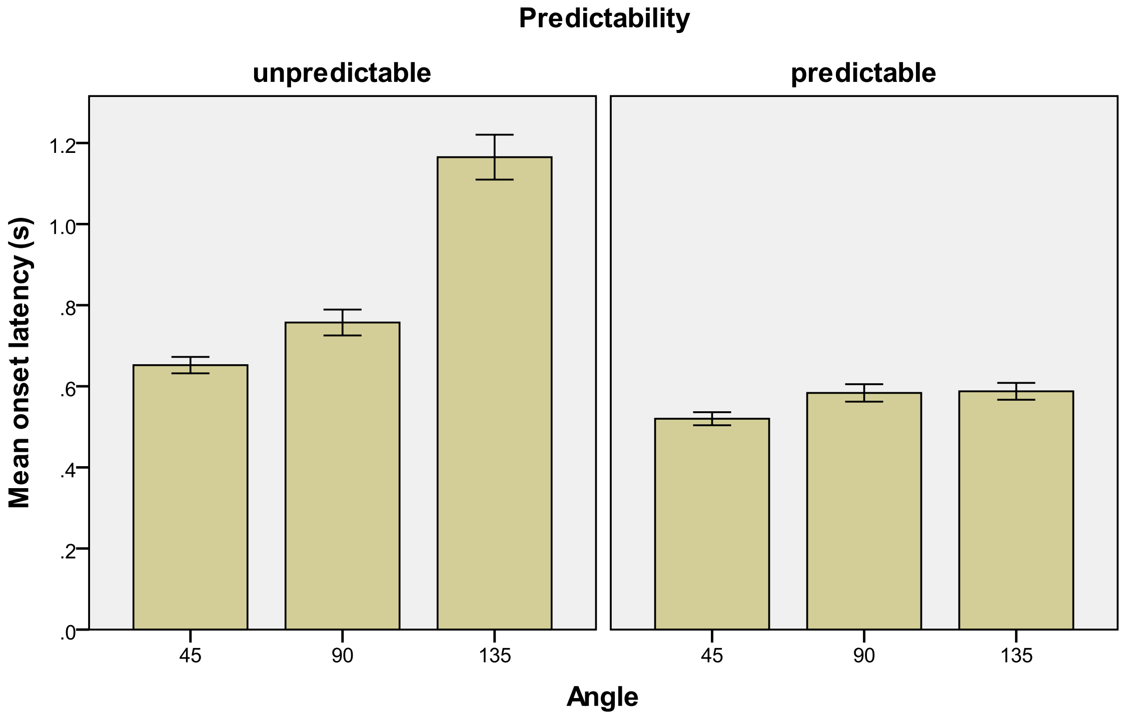


Figure 4.7. Mean and standard error (Error bars: +/- 1 SE) of onset latencies of eye, head, shoulder, pelvis and foot when turning to 45°, 90° and 135° for each predictability condition when averaged across the two directions, five segments and two groups.

The results showed that there was no difference in the onset latency of the segments while turning to both sides in both groups (figure 4.8). This was shown by the non-significant main effect of direction on the onset latency of the segments, $F(1, 18) = 0.966$, $p = 0.339$ and the non-significant interaction of direction and group, $F(1, 18) = 0.110$, $p = 0.744$. The mean (SE) of the onset latencies for turns to paretic and non-paretic sides in the stroke group averaged across the two predictability conditions, three turn angles and five segments were 0.853s (0.084) and 0.814s (0.056) respectively. For turns to dominant and non-dominant sides in the control group, the mean (SE) of the onset latencies were 0.596s (0.084) and 0.571s (0.056) respectively.

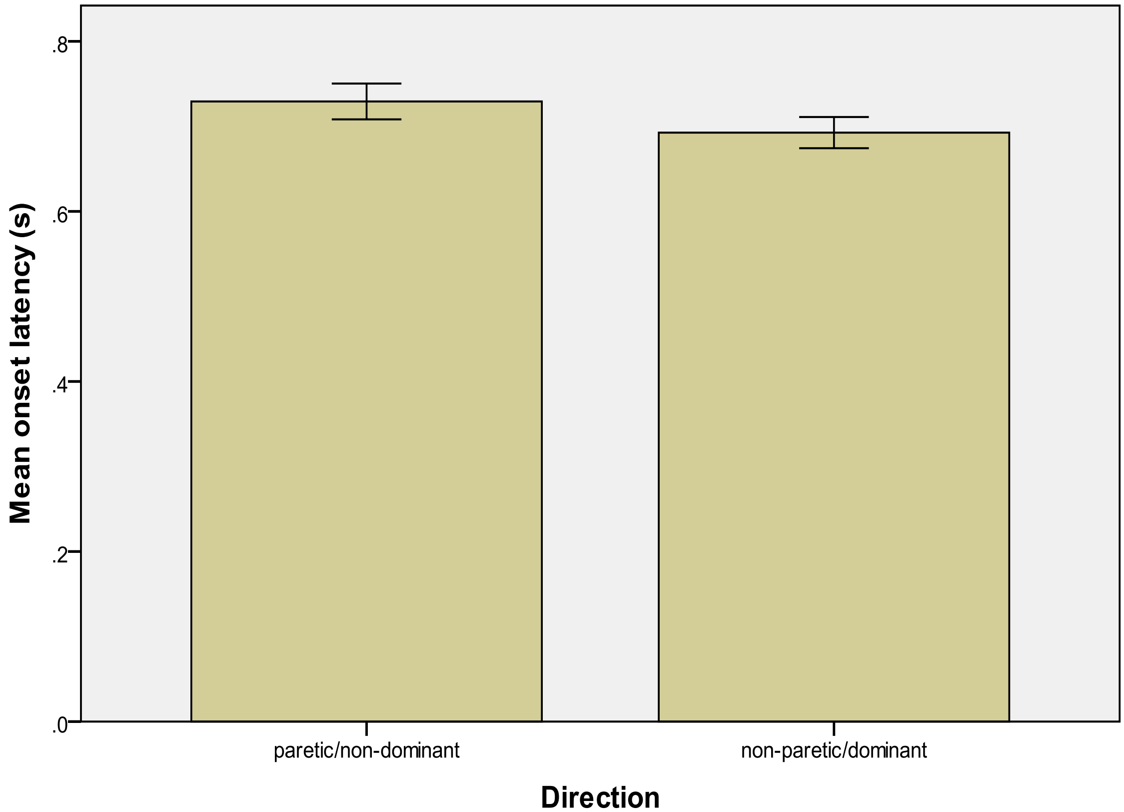


Figure 4.8. Mean and standard error (Error bars: +/- 1 SE) of the onset latency of body segments when turning to paretic/non-dominant and non-paretic/dominant sides averaged across the two predictablity conditions, three angles, five segments and two groups.

4.6.3.1. Summary of sequence of onset latency of body segments

The results showed a difference in the sequence of onset of rotation of segments when turning to unpredictable and predictable targets. When both groups turned to unpredictable targets, the eye, head and shoulder started to move simultaneously followed by the pelvis and foot, while on turning to predictable targets, the head and shoulder sometimes started to move before the eye. The pelvis and foot moved separately when turning to 45° and 90° to the unpredictable targets while the two segments started to move simultaneously when turning to 135°. When turning to predictable targets, the pelvis started to move before the foot when turning to 45° while the two segments started to move simultaneously when turning to 90° and 135°. There was no difference in the sequence of onset of rotation of the segments between the people with stroke and the healthy controls.

Although there was no difference in the sequence of onset of the segments between the two groups, the segments started to move significantly faster in the control group than in the stroke group. The segments started to rotate faster when turning to unpredictable targets as compared to turning to predictable targets. There was also an increase in onset latency with increase in turn angle in both groups. Finally, there was no difference in the sequence of onset of rotation of the segments when turning to paretic and non-paretic sides in the stroke group.

4.6.4. Sequence of peak velocity of body segments

Figure 4.9 to 4.12 showed that there was a similar pattern for the peak velocities of the head, shoulder pelvis and foot for all the tasks. The shoulder had the lowest peak velocity, followed by the head, then pelvis and finally the foot. This was confirmed by the results of the post hoc analysis for turns to all tasks in the stroke group and for turns to 90° and 135° to the dominant side in the control group. When turning to 90° and 135° to the non-dominant side in the control group, the peak velocity of the shoulder was lowest, followed by that of the head and pelvis (no significant difference between the peak velocity of the head and pelvis) and finally the foot. When turning 45° to both sides for both predictable and unpredictable conditions in the control group, there was no significant difference in the peak velocity of the head and shoulder.

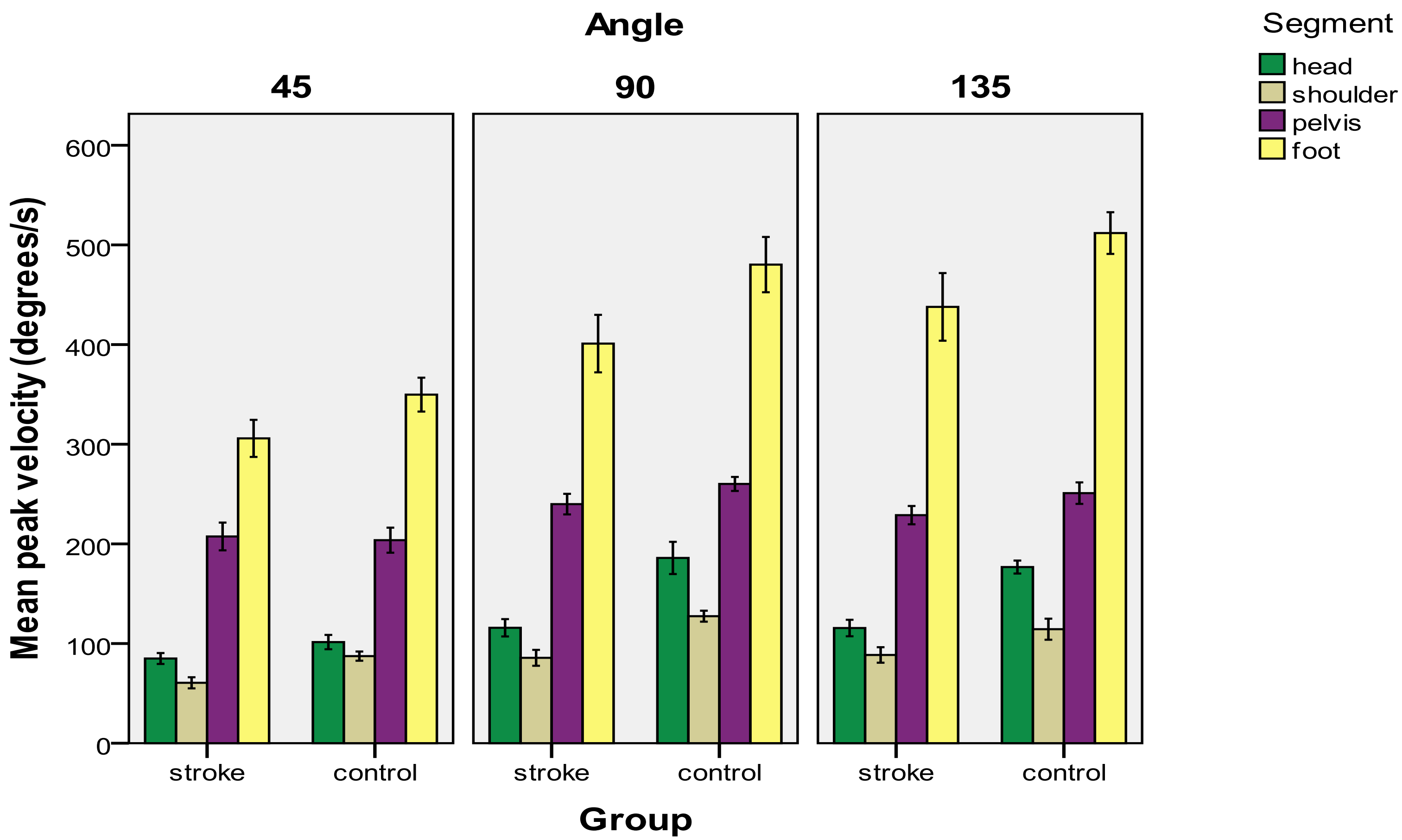


Figure 4.9. Mean and standard error (Error bars: +/- 1 SE) of the peak velocity of head, shoulder, pelvis and foot when turning to paretic/non-dominant side - Unpredictable condition.

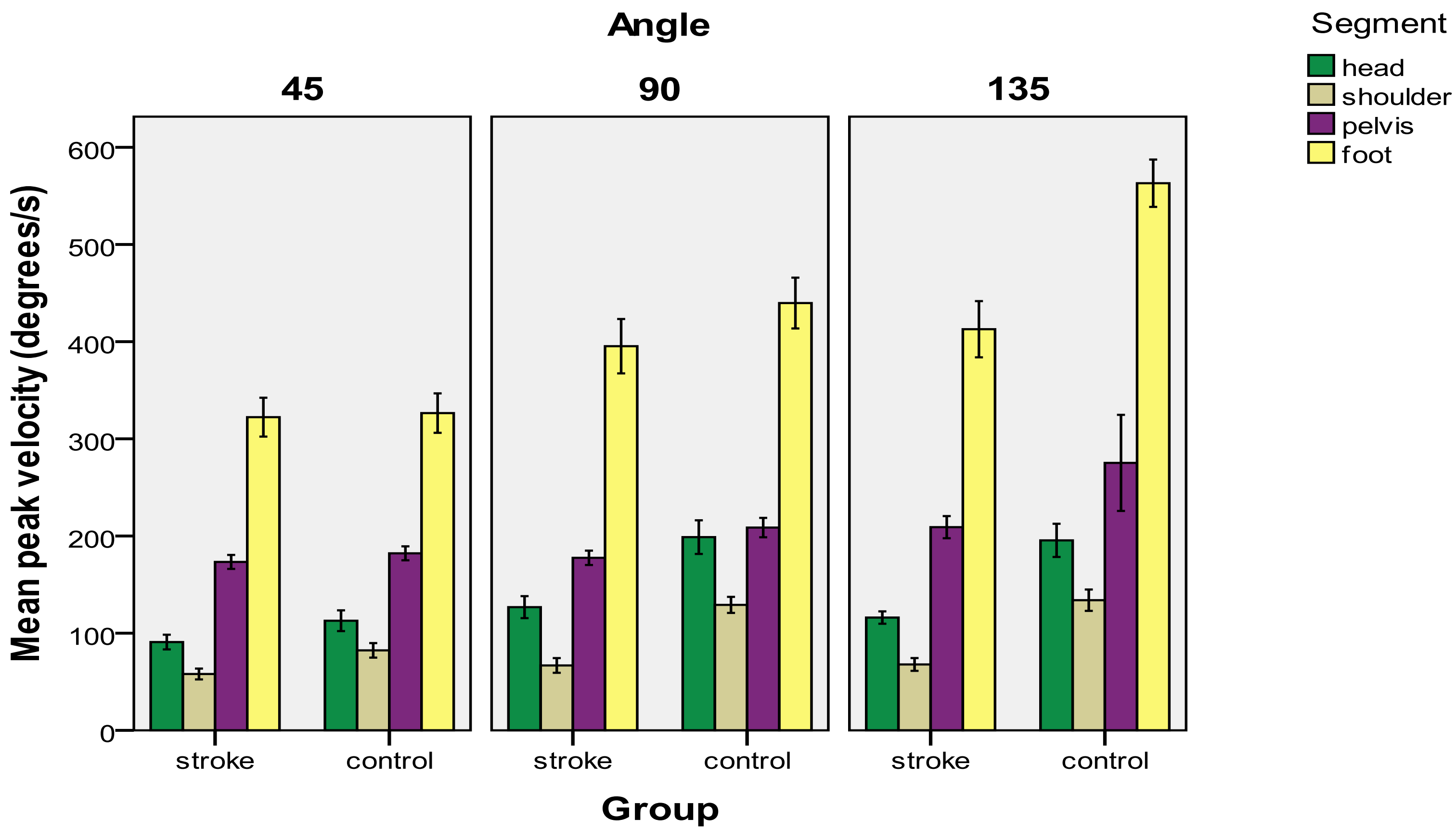


Figure 4.10. Mean and standard error (Error bars: +/- 1 SE) of the peak velocity of head, shoulder, pelvis and foot when turning to non-paretic/dominant side - Unpredictable condition.

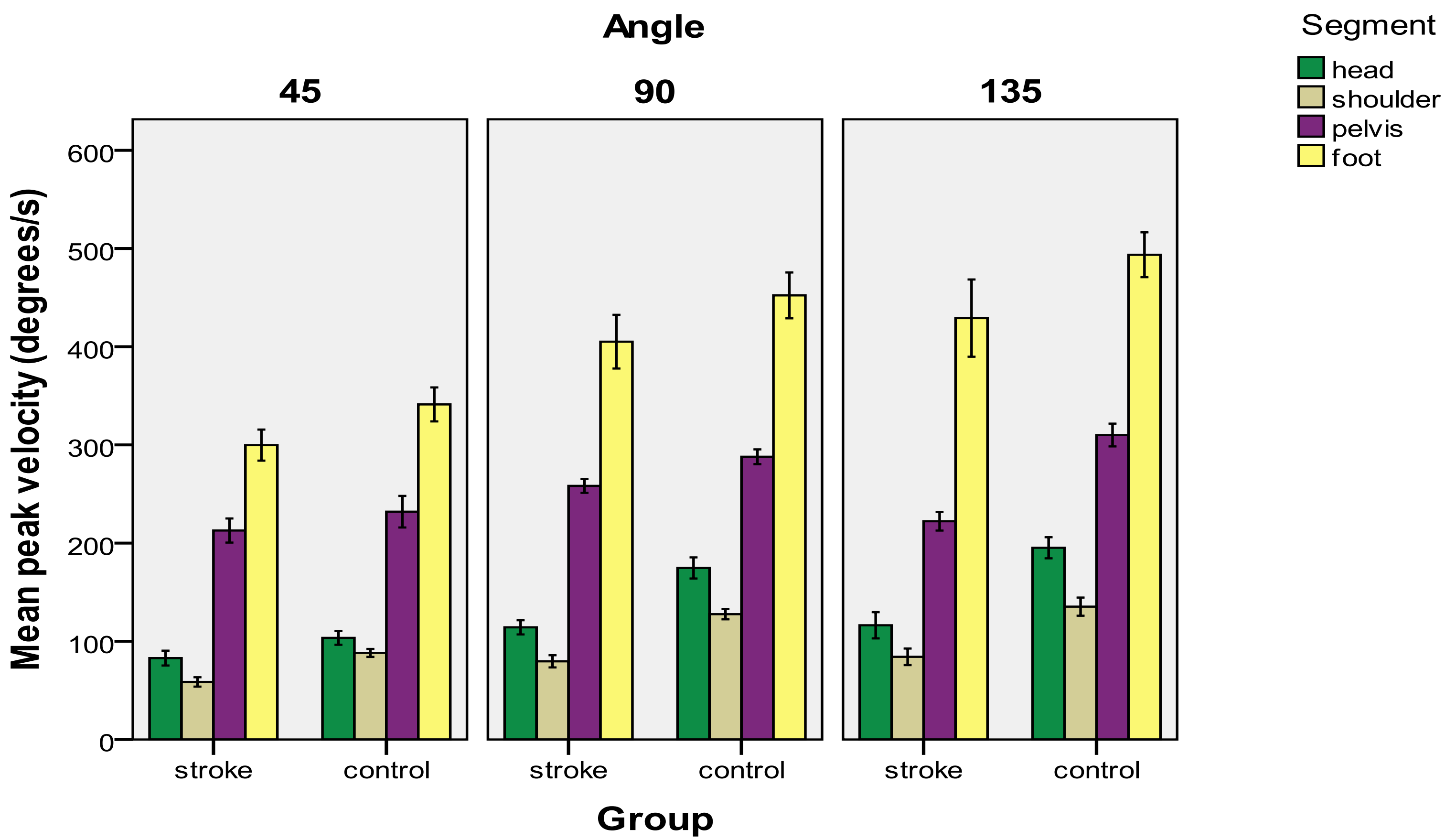


Figure 4.11. Mean and standard error (Error bars: +/- 1 SE) of the peak velocity of head, shoulder, pelvis and foot when turning to paretic/non-dominant side - Predictable condition.

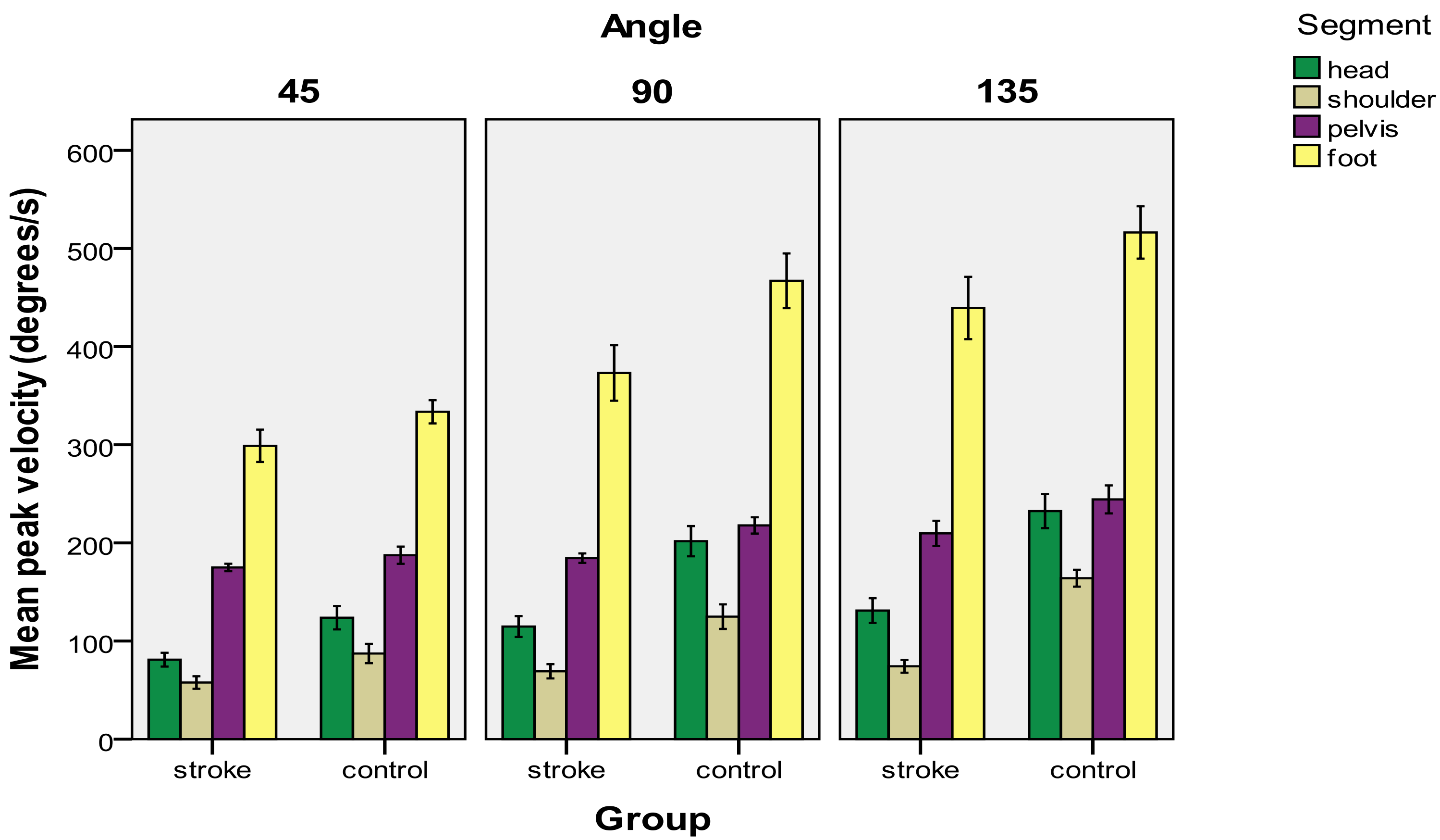


Figure 4.12. Mean and standard error (Error bars: +/- 1 SE) of the peak velocity of head, shoulder, pelvis and foot when turning to non-paretic/dominant side - Predictable condition.

The stroke group had lower peak velocities of the body segments as compared to the control group (table 4.6 and 4.7). This was shown by the significant main effect of group, F (1, 18) = 15.585, p = 0.001. The mean (SE) of the peak velocities of the stroke and control groups when averaged across the two predictability conditions, three angles, two directions and four segments were 190°/s (8.88) and 240.42°/s (8.88) respectively. The peak velocities of the segments were however not different when turning to predictable and unpredictable targets (table 4.10 and 4.11). This was shown by the non-significant main effect of predictability on the peak velocity of the segments, F (1, 18) = 1.173, p = 0.293. The mean (SE) of the peak velocities of the body segments when turning to predictable and unpredictable targets when averaged across the three angles, two directions, four segments and two groups were 216.96m/s (6.05) and 214.31m/s (6.73) respectively

There was an increase in the peak velocity of the segments with increase in turn angle (table 4.6 and 4.7). This was shown by the significant main effect of angle on the peak velocities of the segments, F (1.332, 23.971) = 222.685, p = 0.001. The mean (SE) of the peak velocities for turns to 45°, 90° and 135° when averaged across the two predictability conditions, two directions, four segments and two groups were 172.29°/s (4.36), 227.87°/s (6.91) and 246.75°/s (8.06) respectively. The pairwise comparisons between the peak velocities of the three groups showed that there was a significant difference between all the three paired combinations (45° vs 90°, p = 0.001, 90° vs 135°, p = 0.001 and 45° vs 135°, p = 0.001).

Table 4.6. Peak velocities when turning towards paretic/non-dominant side – Unpredictable condition

	45°		90°		135°	
	Stroke [mean(±SE)°/s]	Control [mean(±SE)°/s]	Stroke [mean(±SE)°/s]	Control [mean(±SE)°/s]	Stroke [mean(±SE)°/s]	Control [mean(±SE)°/s]
Head	85.00(5.50)	101.45(7.18)	115.81(8.69)	185.90(16.17)	115.58(8.29)	176.76(6.52)
Shoulder	60.62(5.58)	87.39(4.62)	85.68(7.98)	127.45(5.50)	88.54(7.79)	114.40(10.57)
Pelvis	207.45(13.92)	203.73(12.57)	239.89(10.33)	260.15(7.04)	228.83(9.19)	250.93(10.79)
Foot	305.87(18.61)	349.77(17.01)	400.98(28.85)	480.24(27.74)	437.80(33.94)	511.88(20.92)

Table 4.7. Peak velocities when turning towards paretic/non-dominant side – Predictable condition

	45°		90°		135°	
	Stroke [mean(±SE)°/s]	Control [mean(±SE)°/s]	Stroke [mean(±SE)°/s]	Control [mean(±SE)°/s]	Stroke [mean(±SE)°/s]	Control [mean(±SE)°/s]
Head	82.89(7.56)	103.47(7.02)	114.23(7.26)	174.70(10.76)	116.32(13.36)	195.24(10.73)
Shoulder	58.60(4.78)	88.16(4.04)	79.61(6.22)	127.63(5.23)	84.20(8.44)	135.29(9.25)
Pelvis	212.81(12.27)	231.98(16.06)	258.26(7.06)	287.92(7.53)	222.26(9.51)	310.05(11.59)
Foot	299.80(15.82)	341.23(17.31)	405.11(27.34)	452.24(23.34)	429.12(39.33)	493.64(22.85)

The results showed that there was a difference in peak velocity of the segments when turning to both sides. This was shown by the significant main effect of direction on the peak velocity of the segments, $F (1, 18) = 5.237$, $p = 0.034$. The mean (SE) of the peak velocities of the segments when turning to paretic/non-dominant and non-paretic/dominant sides averaged across the two predictability conditions, three angles, four segments and two groups were 219.31°/s (6.01) and 211.96°/s (6.92) respectively. However, the difference in the peak velocities when turning to both sides was found to be more obvious in the stroke group (figure 4.13) with turns to paretic side having higher peak velocities as compared to turns to non-paretic side. However, these differences were not found to be significant as shown by a non- significant interaction of direction and group, $F (1, 18) = 2.998$, $p = 0.100$.

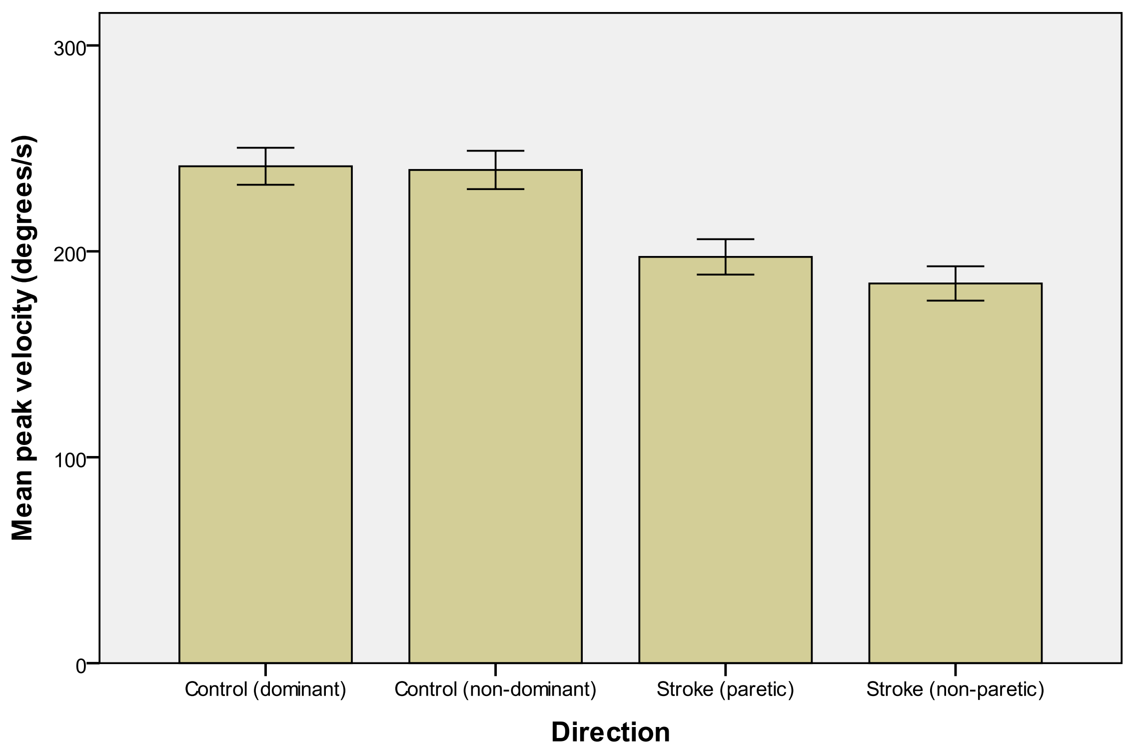


Figure 4.13. Mean and standard error (Error bars: +/- 1 SE) of peak velocities of head, shoulder, pelvis and foot for turns to paretic/non-paretic and dominant/non-dominant sides averaged across two predictability conditions, three angles, five segments and two groups.

4.6.4.1. Summary of peak velocity of body segments

The sequence of peak velocity of the segments was consistent for all the tasks in the stroke group. The shoulder had the lowest peak velocity, followed by the head, then pelvis and finally the foot. This was the same for turns to 90° and 135° to the dominant side in the control group. When turning to 90° and 135° to the non-dominant side in the control group, the peak velocity of the shoulder was lowest, followed by that of the head and pelvis (no significant difference between the peak velocity of the head and pelvis) and finally the foot. When turning 45° to both sides for both predictable and unpredictable conditions in the control group, there was no significant difference in the peak velocity of the head and shoulder.

The peak velocities of the segments were higher in the control group as compared to the stroke group. There was an increase in peak velocity with increase in turn angle in both groups. However, the peak velocities of the segments were the same when turning to the predictable and unpredictable targets.

4.6.5. Sequence of timing of peak velocity of body segments

The results of the ANOVA showed that the interaction effect of predictability vs segment [F (2.391, 43.042) = 5.132, p = 0.007] and angle vs segment [F (3.761, 67.706) = 6.199, p = 0.001] were significant. This indicated that there were differences in the sequence of timing of peak velocities of the segments between the two predictability conditions and across the turn angles. While the interaction effect of direction vs segment [F (1.863, 33.535) = 2.64, p = 0.090] was not significant, indicating no difference in sequence of the segments when turning to both sides. However, the post hoc analysis showed no regular pattern in the sequence of timing of peak velocities when looking at the effect of the three factors studied (target predictability, turn angle, turn direction and group). For most of the turning tasks there was no significant difference in the timing of peak velocities of the segments (head, shoulder, pelvis and foot). In other words, the peak velocity of the segments occurred at more or less the same time (figure 4.14 to 4.17). In other instances the timing of the peak velocity of the foot occurred last and separately from the other three segments (which had no significant difference between the timing of their peak velocities).

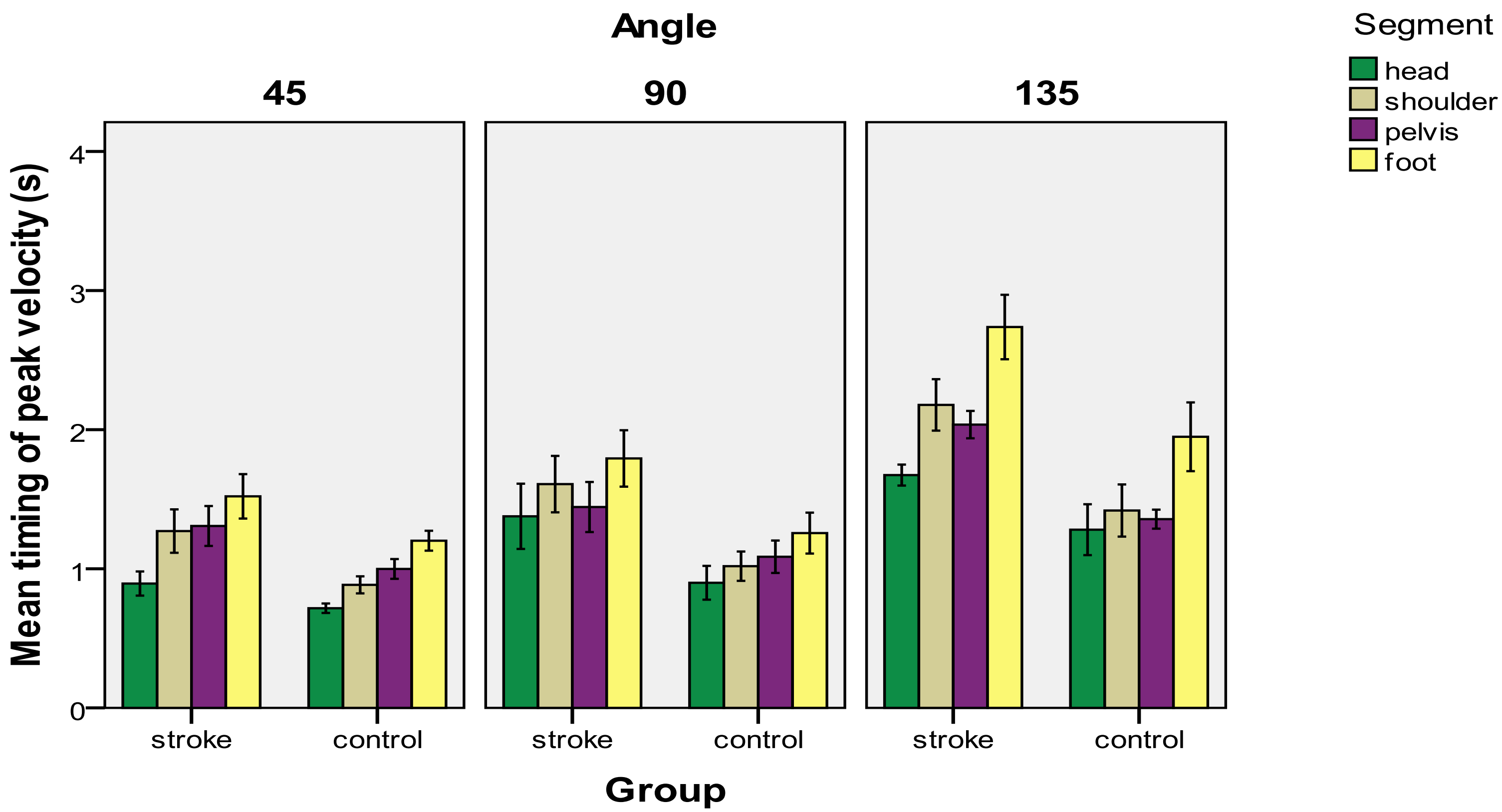


Figure 4.14. Mean and standard error (Error bars: +/- 1 SE) of timing of peak velocity of head, shoulder, pelvis and foot when turning to paretic/non-dominant side - Unpredictable condition.

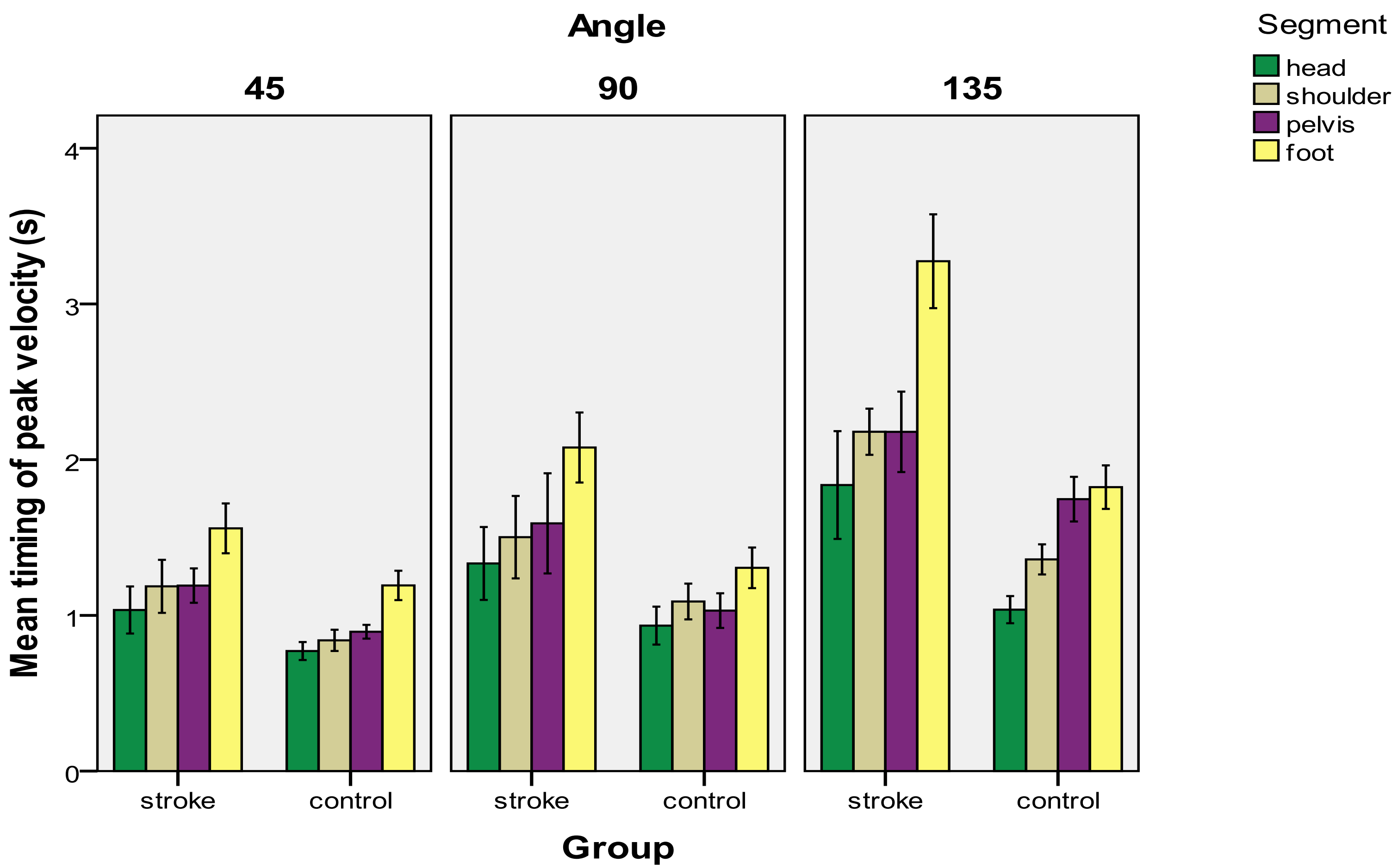


Figure 4.15. Mean and standard error (Error bars: +/- 1 SE) of timing of peak velocity of head, shoulder, pelvis and foot when turning to non-paretic/dominant side - Unpredictable condition.

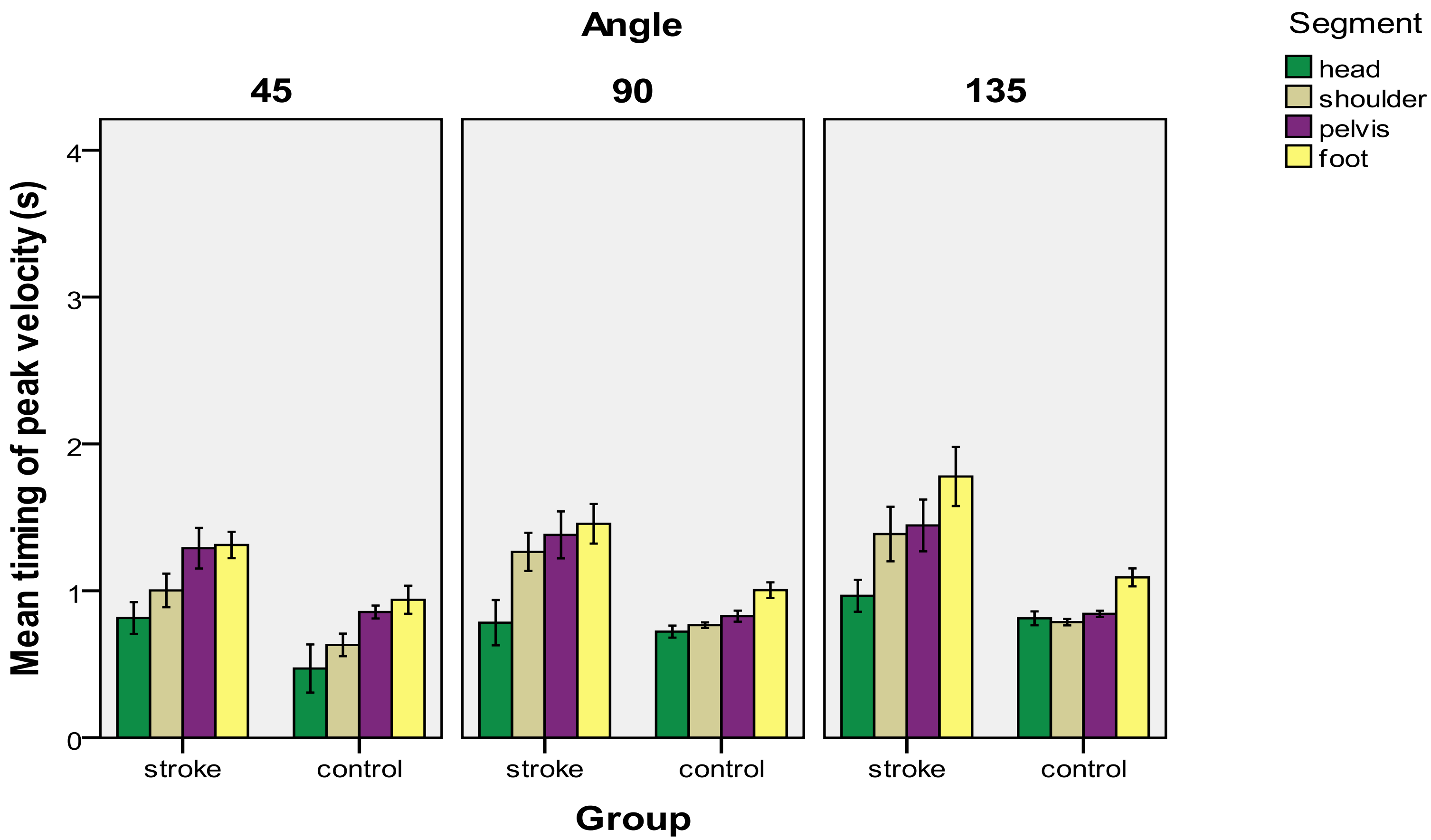


Figure 4.16. Mean and standard error (Error bars: +/- 1 SE) of timing of peak velocity of head, shoulder, pelvis and foot when turning to paretic/non-dominant side - Predictable condition.

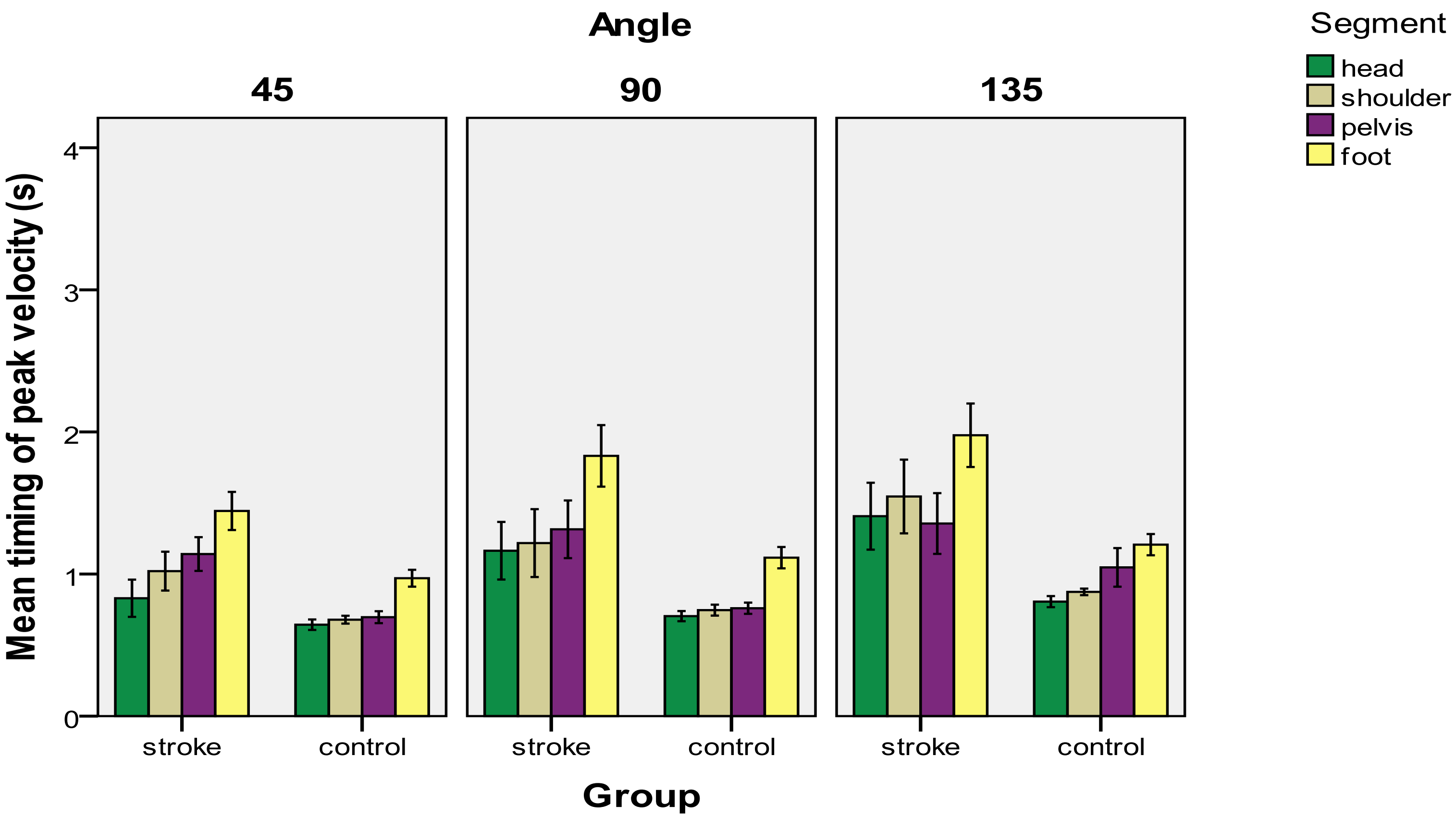


Figure 4.17. Mean and standard error (Error bars: +/- 1 SE) of timing of peak velocity of head, shoulder, pelvis and foot when turning to non-paretic/dominant side - Predictable condition.

The peak velocities of the segments occurred earlier in the control group as compared to the stroke group (table 4.8 and 4.9). This was shown by the significant main effect of group, $F(1, 18) = 13.254$, $p = 0.002$. The mean (SE) of the timing of peak velocities for the stroke and control group averaged across the two predictability conditions, three angles, two directions and four segments were 1.498s (0.096) and 1.002s (0.096) respectively. The peak velocities of the segments also occurred earlier when turning to predictable targets as compared to turning to unpredictable targets (table 4.8 and 4.9). This was shown by the significant main effect of predictability on the timing of peak velocities of the segments, $F(1, 18) = 68.278$, $p = 0.001$. The mean (SE) of the timing of peak velocities of the segments when turning to predictable and unpredictable targets averaged across the three turn angles, two turn directions, four segments and two groups were 1.065 (0.064) and 1.435s (0.018) respectively.

There was an increase in timing of peak velocities with increase in turn angle (table 4.8 and 4.9). This was shown by significant main effect of angle on the timing of peak velocities of the segments, $F(1.908, 34.335) = 86.143$, $p = 0.001$. The mean (SE) of the timing of peak velocities for turns to 45°, 90° and 135° averaged across the two predictability conditions, two directions, four segments and two groups were 1.006s (0.056), 1.200s (0.082) and 1.544s (0.076) respectively. The pairwise comparisons between the timing of peak velocities showed that there was a significant difference between all the three paired combinations (45° vs 90°, $p = 0.001$, 90° vs 135°, $p = 0.001$ and 45° vs 135°, $p = 0.001$). The increase in timing of peak velocities with increase in turn angle was shown to be more pronounced in the unpredictable condition (figure 4.18). This was shown by the significant interaction of angle vs predictability, $F(1.488, 26.778) = 12.575$, $p = 0.001$.

Table 4.8. Timing of peak velocities when turning towards paretic/non-dominant side – Unpredictable condition

	45°		90°		135°	
	Stroke [mean(±SE)s]	Control [mean(±SE)s]	Stroke [mean(±SE)s]	Control [mean(±SE)s]	Stroke [mean(±SE)s]	Control [mean(±SE)s]
Head	0.894(0.087)	0.716(0.034)	1.377(0.235)	0.899(0.122)	1.673(0.075)	1.281(0.183)
Shoulder	1.271(0.156)	0.884(0.061)	1.609(0.203)	1.019(0.105)	2.178(0.185)	1.419(0.187)
Pelvis	1.308(0.143)	0.999(0.071)	1.444(0.180)	1.086(0.117)	2.036(0.098)	1.357(0.068)
Foot	1.521(0.160)	1.202(0.072)	1.793(0.203)	1.256(0.147)	2.738(0.232)	1.949(0.247)

Table 4.9. Timing of peak velocities when turning towards paretic/non-dominant side – Predictable condition

	45°		90°		135°	
	Stroke [mean(±SE)s]	Control [mean(±SE)s]	Stroke [mean(±SE)s]	Control [mean(±SE)s]	Stroke [mean(±SE)s]	Control [mean(±SE)s]
Head	0.814(0.108)	0.471(0.164)	0.783(0.154)	0.722(0.041)	0.966(0.109)	0.813(0.047)
Shoulder	1.003(0.114)	0.632(0.077)	1.265(0.130)	0.766(0.019)	1.387(0.186)	0.787(0.022)
Pelvis	1.290(0.138)	0.856(0.044)	1.381(0.038)	0.827(0.038)	1.445(0.176)	0.843(0.021)
Foot	1.312(0.090)	0.939(0.100)	1.456(0.053)	1.004(0.053)	1.778(0.201)	1.091(0.061)

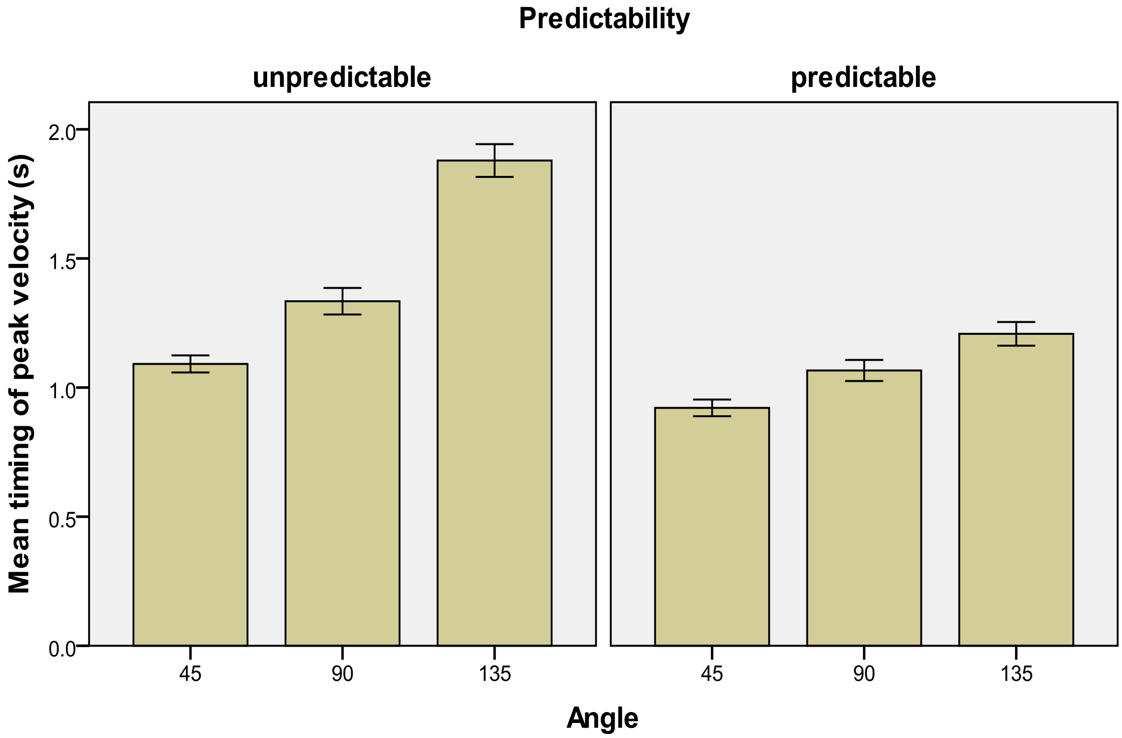


Figure 4.18. Mean and standard error (Error bars: +/- 1 SE) of timing of peak velocity of body segments when turning to 45°, 90° and 135° for each predictability condition averaged across two directions, five segments and two groups.

The results showed that there was no difference in the timing of peak velocities of the segments while turning to both sides in both groups (figure 4.19). This was shown by the non-significant main effect of direction on the timing of peak velocities of the segments, $F(1, 18) = 1.288$, $p = 0.271$and the non-significant interaction of direction and group, $F(1, 18) = 2.998$, $p = 0.100$. The mean (SE) of the timing of peak velocities for turns to paretic and non-paretic sides in the stroke group averaged across the two predictability conditions, three turn angles, four segments and two groups were 1.447s (0.080) and 1.550s (0.123) respectively. For turns to dominant and non-dominant sides in the control group, the mean (SE) of the timing of peak velocities were 0.992s (0.080) and 1.011s (0.123) respectively.

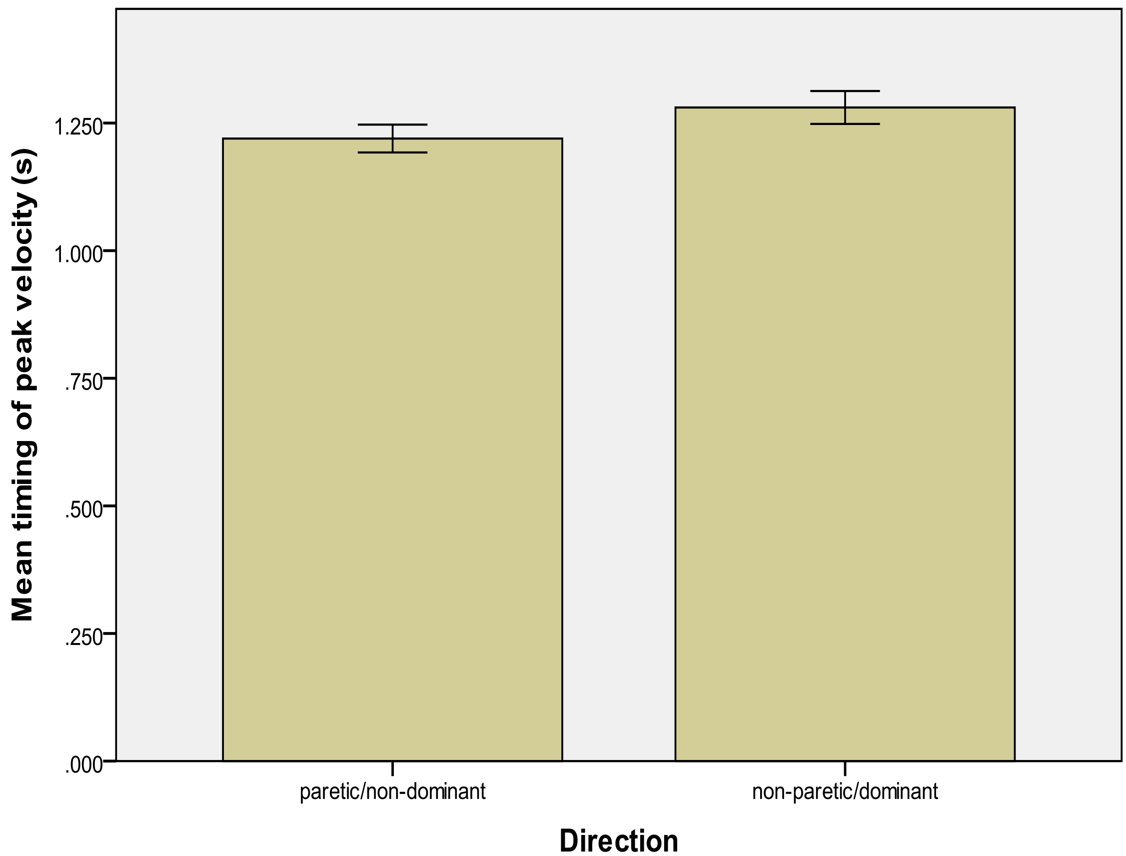


Figure 4. 19. Mean and standard error (Error bars: +/- 1 SE) of the timing of peak velocity of body segments when turning to paretic/non-dominant and non-paretic/dominant sides averaged across the two predictability conditions, three angles, five segments and two groups.

4.6.5.1. Summary of timing of peak velocity

For most of the turning tasks there was no difference in the timing of peak velocities of the segments (head, shoulder, pelvis and foot). In other instances, especially when turning to 135°, the timing of the peak velocity of the foot occurred separately from the other three segments. The peak velocities of the segments occurred earlier in the control group as compared to the stroke group. The peak velocities of the segments also occurred earlier when turning to predictable targets as compared to turning to unpredictable targets. There was an increase in timing of peak velocities with increase in turn angle which was more pronounced in the unpredictable condition. Finally, there was no difference in the timing of peak velocities of the segments while turning to both sides in both groups.

4.7. Discussion

This is the first study to investigate the effect of target predictability, turn angle and turn direction on the sequence of onset latency, peak velocity and timing of peak velocity of body segments during turning on-the-spot in people with stroke and age-matched healthy controls. Studies of sequence of rotation of body segments during turning on-the-spot in healthy individuals have investigated the effect of target predictability, turn angle and turn direction on the onset latency of body segments (Hollands et al., 2004, Anastasopoulous et al., 2009) but not the peak velocity and timing of the peak velocity of the segments. These parameters are important because the onset latency describes coordination of the segments at the onset of the turn only while the peak velocity and timing of peak velocity describes coordination of the body segments during the movement.

There is no known study that has investigated the effect of the three factors in people with stroke while turning on-the-spot. However, studies exist that investigated the sequence of the segments during turning while walking in people with stroke (Lamontagne et al., 2007, Lamontagne et al., 2009; Hollands et al., 2010a, Hollands et al., 2010b). It is unclear from these studies if the differences seen in the sequence of rotation of the segments were as a result of manipulating the three variables (target predictability, turn angle and turn direction) or as a result of differences in methodologies used since the variables were studied in four separate studies. Furthermore, due to the imposition of walking cycle on the turning process, kinematics of turning while walking may not suffice to explain kinematics of turning on-the-spot, especially since turning on-the-spot is a common activity of daily living on its own.

People with stroke initiated the rotation of the body segments slower, had lower peak velocities of the segments and achieved the peak velocities later than the controls. It was hypothesized that there would be differences in the sequence of onset latency, peak velocity and timing of peak velocity of body segments during turning on-the-spot between people with stroke and healthy controls. However, contrary to the hypotheses, the results showed similarities in sequence of onset latencies and timing of peak velocities between the two groups for all the turning tasks. There were also similarities in the sequence of the peak velocities of the segments between the two groups except that when the control group were turning to 45° to both sides and turning to 90° and 135° to the non-dominant side the sequence of the peak velocities were different from the stroke group.

The segments started to move significantly slower in people with stroke compared to healthy controls. People with stroke have been shown to have longer response times than controls in other reaction time studies (Kaizer et al., 1988, Mayo et al., 1990). People with stroke also had lower peak velocities and reached the peak velocities later than healthy controls. People with stroke are characterized by hemiplegia/hemiparesis which results in inability to generate normal muscle force. The reduction in muscle strength that ensues decreases the ability of the muscles to produce the force required for initiating and controlling a movement (Smidt and Rogers, 1982). Since muscle strength determines initiation and control of movement of body parts (Shumway-Cook and Woollacott, 2007), the reduction in strength of axial (Tanaka et al. 1998) and limb (Ada et al. 2003) muscles could explain the slower onset latencies and lower peak velocities in the people with stroke. Indeed, studies have shown delayed onset and reduced activity level in axial and limb muscles of people with stroke during movement (Chae et al. 2006 and Dickstein et al. 2004). One of the factors that affect movement timing during functional activities is the inability to stabilize the body in anticipation of potentially destabilizing movements (Shumway-Cook and Woollacott 2007). The impairment of postural stability in people with stroke especially with activities that require supporting the body weight on the paretic limb could result in slowing down of movement of body segments during turning.

The segments started to rotate significantly faster when turning to predictable targets when compared to turning to unpredictable targets in both groups. The location of the targets was unknown prior to the visual cue appeared in the unpredictable condition, the participants therefore had to locate the target before turning to it. The participants could therefore take longer to start the movement because of the delay in locating the target. Patla et al. (1999) and Hollands et al. (2001) have also shown that rotation of body segments was significantly sooner when healthy individuals turned to a cue that was provided at the beginning of a walk (predictable condition) as compared to turning to a cue provided 2 step length before the required turn (unpredictable condition). The same pattern was also observed in people with stroke when turning while walking (Hollands et al. 2010a). Furthermore, Dassonville et al. (1998) have also shown a significantly faster reaction time with predictable compared to unpredictable behaviour during finger tapping tasks. The visual system requires time to obtain information pertaining to the new direction of travel (Patla 1997). This information is then integrated by the CNS to plan the most efficient and appropriate motor plan. Hansen et al. (2006) reported that reaction time is fastest when there is no uncertainty about the location of the target.

The results of the study also showed that there was an increase in latency with increase in angle of turn. The duration of the initial agonist burst that forms part of the triphasic pattern of muscular activation has been shown to increase with increase in movement amplitude (Cooke et al., 1985). However, this difference was more pronounced in the unpredictable condition. A similar result was obtained by Holland et al. (2004) when young adults were turning to unpredictable lights placed at 45°, 90° and 135°. This is not surprising as the time it takes to locate the light when it is within the visual field (45°) should be less than what it takes to locate it when it is outside of the visual field (135°) in the unpredictable condition. Increase in latency with increase in turn angle was also observed when turning while walking. Hollands et al. (2002) showed that there was a significant difference in latency when turning to 30° (263±170ms) and 60° (407±250ms).

A longer onset latency has been shown to be associated with increased risk of falling (Mayo et al. 1990). People with stroke have been shown to take longer time to start turning as compared to healthy controls in this study and in previous studies (Lamontagne et al., 2005). The time to start turning is even longer when turning to unpredictable targets and when turning to larger angles in the people with stroke. This may be of concern as people with stroke may have more risk of falls while turning to unpredictable targets placed at large angles.

While target predictability affected the onset latency of the segments, it did not affect the peak velocity of the segments. This further emphasizes the role vision plays in movement preparation. Visual information about the location of the target was available prior to illumination of the turn cue in the predictable condition. The brain therefore had enough time to process the information and initiate the movement faster than in the unpredictable condition where the visual information became available only after illumination of the turn cue. When the movement has already been initiated, the visual system together with propriocetive system comes into play to guide the movement and ensure accuracy. Thus, the peak velocity which occurs after the brain is certain about the location of the target in both predictability conditions may not be affected by predictability of the target. The timing of the peak velocity was also different between the predictable and unpredictable conditions. However, it should be noted that the reference point for both the onset latency and the timing of the peak velocity was the appearance of the cue. Since the onset of the movement was earlier in the predictable condition, it is expected that the timing of the movement along the trajectory could also occur earlier. The effect of turn angle was observed for both onset latency and peak velocity. Visibility of the target was provided as the main explanation for increase in onset latency with increase in turn angle. On the other hand, the increase in peak velocity with increase in turn angle may be explained by the need to gather momentum to reach points that are farther in distance.

The results showed a difference in sequence of onset of rotation of body segments when turning to unpredictable and predictable targets. When both groups (stroke and control) turned to unpredictable targets, the eye, head and shoulder started to move simultaneously followed by the pelvis and foot, while when turning to predictable targets, the head and shoulder sometimes started to move before the eye. Anastasopoulous et al. (2009) reported a similar sequence in ten healthy participants during voluntary reorientations to targets placed at 45º, 90º and 135º to the left and right. The eye initiated the rotation when target presentation was unpredictable. With predictable target presentation, the head sometimes initiated the rotation. Since visual targets were used in the studies, locating the targets using the eyes before turning to them could have ensured that the eyes rotated first or at least not after the other segments in the unpredictable trials.

The simultaneous movement of the eye, head and shoulder in the unpredictable condition was in contrast to what was reported by Hollands et al. (2004) in five young healthy adults in which the movement of the three segments were separated and occurred in a top to bottom sequence. A possible explanation to the differences in the sequence of the segments in the current study and the study of Hollands et al. (2004) may be the age of the participants. Coordinated eye, head and shoulder movement is controlled by the interaction of the oculomotor, vestibular and motor systems, all of which can be impaired in people with stroke and older adults. Hence, the simultaneous movement of the three segments may have been due to the inability of the three systems to collaborate in separating the movement of the segments. Older adults have been reported to have sensory and motor problems (Lord et al., 1996), factors that could affect coordination of body segments during turning. Indeed, older adults have been shown to have incoordination of movement of body segments during turning tasks as compared to healthy young adults (Paquette et al., 2008).

However, before conclusions are made the procedures for measuring the onset latency of the body segments in the two studies need to be considered. Firstly, the onset of horizontal displacement of the eye was measured using electrooculography in the study of Hollands et al. (2004). This procedure involved placing electrodes on some eye muscles and the movement of the eye was recorded from the signals generated by the electrodes. On the other hand, the onset of horizontal displacement of the eye was measured directly in the current study by an eye tracking camera. Since the signals for the eye movement reached the eye before the actual movement began, the recording by the electrooculography may have shown earlier movement than the eye-tracking camera. Secondly, the current study reported the movement of the shoulder and pelvis while the study of Hollands et al. (2004) reported the movement of the upper trunk. The marker placement for the recording of the shoulder movement in the current study and that of the recording of the upper trunk in the study of Hollands et al. (2004) were different and may have caused differences in the recording of the timings of the segments. To resolve these differences efficiently requires a further study, comparing young healthy adults and older healthy adults in the same study using the same protocol and equipment.

The relationship observed between the onset of rotation of the eye and head in the unpredictable condition is consistent with the proposal that anticipatory head movements are generated in coordination with eye movements as part of the gaze reorientation process. This coordinated eye and head behaviour was also observed in healthy individuals when turning while walking (Grasso et al. 1998 and Hollands et al. 2002). The movement of the eye together with the head could be explained by the interaction of vestibular and ocular systems that coordinate movement of the two segments to ensure successful gaze transfer. Head movement signals arriving at the vestibular nucleus by primary labyrinthine and otolith afferents are sent to ocular motorneurones by secondary-order vestibular neurones (Delgado-Garcia 2000). It has also being observed that the firing rate of the vestibular nuclei cells was proportional to head rotational velocity (and the resulting eye velocity) and during eye movement alone (Keller and Daniels 1975). Movement of the eye is therefore strongly connected with movement of the head. However, onset of rotation of the eye and head together with the shoulder in the current study may mean that there could be some restrictions in the movement of the head that led to earlier rotation of the shoulder as in the study of Hollands et al. (2001) where restricting the head resulted in earlier movement of the trunk.

The onset of rotation of eye and head (gaze redirection) before other segments during turning activities was thought to be the trigger that guides rotation of other segments during turning. This is because most studies investigating sequence of rotation of body segments during turning while walking reported that the eye and/or head initiated the rotation. Reed-Jones et al. (2009) further supported this by showing similar sequence of rotation of body segments with the eye leading followed by the head when participants took steps on-the-spot while viewing a moving scene that simulated walking towards and turning a corner. They inferred that the coordination of body segments during turning is a robust pre-programmed synergy triggered by the eye and head movement. This underscores the importance of using visual cues to separate gaze and body orientations to enhance the role of gaze in providing a frame of reference for turning tasks. The implication of this role points to possibilities that deficits in performance of some turning tasks may be linked to oculomotor control deficits. It could be that the similarities between the two groups in the current study were because the people with stroke had no reported and clinically assessed visual problems.

In many real life situations, the first action is always an eye movement to the location of features of importance in the performance of a task (Land and furneaux 1997, Land 2004, Land et al. 1999). This could be an object that is being manipulated (Land 2004 and Land et al. 1999) or a target to turn to (Grasso et al. 1998, Hollands et al. 2002, Hollands et al. 2004). Land (2004) and

Land et al. (2009) observed that rather than the eyes leading other body segments during turning while manipulating objects, the movement of the eyes occurred after that of the other segments, presumably due to the eyes being fixed on the objects being manipulated at the beginning of the turn. This would mean that the concept of the eye being the trigger for movement of the other segments may only hold when there is need for scanning the environment in anticipation of obstacles in the turning pathway. While the eye and/or head were shown to lead the other segments during turns to predictable (Grasso et al. 1998, Patla et al. 1999, Fuller et al. 2007, Paquette et al. 2008, Akram et al. 2010) and unpredictable targets (Patla et al. 1999, Hollands et al. 2001) during walking, the current study has shown that the head and shoulder sometimes preceded the movement of the eyes in the predictable conditions.

When turning on-the-spot, participants already are aware of the immediate surrounding before the start of the turn. Therefore when turning to predictable targets, there may not be need for locating the target nor scanning the immediate environment with the eyes at the start of the turn. However, while turning during walking the environment keeps changing and hence it may be important to scan the immediate environment for both predictable and unpredictable conditions. This is supported by the findings that during turning while walking, for the large majority of the time participants' gaze was aligned with environmental features lying in their current plane of progression during both predictable and unpredictable trials (Patla et al. 1997). Hollands et al. (2002) also showed that participants' gaze was consistently aligned with environmental features lying in their current plane of progression, prior to, and following a change in walking direction. The movement of the eye and head before the other segments may therefore be meant for scanning the environment so that movement of the other segments will be programmed based on the information acquired. If there are obstacles that need to be avoided, the visual feedback sends information back to the brain for re-programming of the movement. If the ability to scan the environment prior to the whole body movement is lost, the movement may not be adapted to the environmental situation and may lead to loss of stability.

The results also showed that the pelvis and foot moved separately when turning to 45° and 90° to the unpredictable targets while the two segments started to move simultaneously when turning to 135°. When turning to predictable targets the pelvis started to move before the foot when turning to 45° while the two segments started to move simultaneously when turning to 90° and 135°. This pattern could have been influenced by the visibility of the target to turn to. The target was within the visual field of the participant when placed at 45° and 90° while the target at 135° was definitely out of the visual field and required the participant to guess its location. Therefore, when turning to 135° participants may have turned the upper segments first to confirm if the target was in the direction they were turning to before later turning the lower segments together to ensure the centre of mass remained within the base of support. Visual input plays a role in route planning for navigation to destinations that are not visible from the start. However, trying to scan the environment with the eyes and head only with targets out of the visual field is not possible. When the trunk accompanies the eye and head, there could be movement of the COM within the BOS. To avoid this in a compensatory strategy, the pelvis and foot may have started moving together in the 135° turn. The pelvis and foot started to move together even when turning to 90° in the predictable condition. McCluskey and Cullen (2007) and Anastasopoulous et al. (2009) have shown that standing turns greater than 50° require more contribution from body rotation and that body rotation was more en-bloc when turning to predictable targets placed at larger angles.

Hollands et al. (2004) suggested a ‘top to bottom’ paradigm for the coordination of body segments during turning. Their study was based on a protocol in which participants were asked to turn to unpredictable targets. Anastasopoulous et al. (2009) later modified that paradigm by showing that the coordination of body segments during turning is not always in a ‘top to bottom’ fashion but depends on the predictability of the target. They supported the ‘top to bottom’ sequence of onset of rotation of the segments when turning to unpredictable targets but showed a more en bloc rotation of the segments when turning to predictable targets. The current study has further questioned the paradigm suggested by Hollands et al. (2004) by showing simultaneous onset of rotation of segments even in healthy but older adults.

There was no difference in the sequence of onset of rotation of the segments when turning to paretic and non-paretic sides in the stroke group. This was not anticipated due to weakness on the paretic side. Reductions in strength of paretic muscles have been reported in the trunk and lower limbs of people with stroke (Chae et al., 2002a, Ada et al., 2003, Bohannon et al., 1995). However, Tanaka et al. (1997) reported that trunk isokinetic rotatory performance of hemiplegics was not different in the right and left directions. Lamontagne et al. (2007) reported eye rotation followed by the head, thorax and foot when people with stroke turned 90° to the non-paretic side and a more simultaneous onset of rotation of the segments when turning to the paretic side. It should be noted that the study employed very small number of participants (two people with stroke and one control) and therefore the sequence was described descriptively. Lamontagne and Fung (2009) carried out inferential statistics in a subsequent study on a similar data set and reported that people with stroke reoriented their eyes and head first when turning to the paretic side, whereas the pelvis was reoriented first when turning to the non-paretic side. However, the difference between turning to the paretic and non-paretic sides was attributed to the horizontal rotation of the pelvis toward the paretic side during walking in people with stroke. This indicates that during walking the pelvis rotates more towards the paretic side compared to the non-paretic side. Thus the onset of the pelvis before the other segments may be due to the fact that the excess rotation of the pelvis towards the paretic side has to be overcome when turning to the non-paretic side.

The differences observed when turning to paretic and non-paretic sides in the study of Lamontagne and Fung (2009) were however not noticed when turning to 45° while walking (Hollands et al. 2010a). The differences may be attributed to the angle of the turn. There are many biomechanical changes that occur during the transition from walking to turning. People with stroke use wider step widths and shorter step lengths at each step of the transition stride compared to healthy controls (Hollands et al. 2010a). However, they showed very small differences between paretic and non-paretic step widths during the transition steps when turning to 45° while walking (Hollands et al. 2010a). Turning to targets at larger angles may present with different biomechanical strategies of turning to paretic and non-paretic sides and may explain the differences observed in the sequence between the two sides when turning to 90° in the study of Lamontagne and Fung (2009). The current study employed turns to both 45° and 90° and even a larger angle of 135° but no differences were observed between turns to the paretic and non-paretic sides in any of the turn angles. This further supports the suggestion that the rotation of the pelvis towards the paretic side during walking contributed to the differences observed in the studies of turning while walking.

There was no difference in the sequence of onset of rotation of the segments between people with stroke and healthy controls. Since the two groups were matched for age, the effect of age was thought to balance out. The added problem of the disease was thought to account for differences just as in other turning studies during walking. The rotation of body segments started with the head followed by the trunk and finally the foot for both young (Patla et al. 1999; Hollands et al. 2001; Paquette et al. 2008) and older adults (Fuller et al. 2007; Akram et al. 2010; Paquette et al. 2008). However, people with stroke showed more en-bloc rotation of the segments (Lamontagne et al. 2007; Lamontagne and Fung 2009). Turning the body to interact with the environment, requires intact sensory and motor systems that ensure proper timing and sequencing of movement of the body segments required to carry the body to a target. Visual

(Jones and Shinton 2006, Rowe et al. 2009, Rowe and VIS group UK 2009), proprioceptive (Connell et al. 2009) and vestibular (Bonan et al. 2004) input may be impaired after stroke. Motor impairments in people with stroke could manifest as inability to generate normal muscle force (Bourbonnais and Noven 1989, Canning et al. 1999), abnormalities of muscle tone (Dewald et al. 1995, Kamper and Rymer 2001) and reduced synchronization between activation of pertinent muscular pairs (Dickstein et al. 2004). These sensory and/or motor impairments in people with stroke can compromise the coordination of segments needed to turn the body around.

On the other hand Hollands et al. (2010a and 2010b) have shown similarities in the sequence of rotation of body segments between people with stroke and healthy controls when turning to 45° (Hollands et al. 2010a) and 180° in the timed up and go test (Hollands et al. 2010b). However, an important distinction between the studies that reported differences in the sequence between people with stroke and controls (Lamontagne et al. 2007 and Lamontagne and Fung 2009) and those that reported similarities (Hollands et al. 2010a and Hollands 2010b) was the time after stroke. While the former recruited participants who were less than 1 year after stroke, the latter recruited participants that were more than 2 years after stroke. Our participants had a mean duration of 5.3 (SD=3.27) years after stroke. Verheyden et al. (2010) have shown that coordination of head and trunk may be modified early after stroke but recover over time toward the level of healthy subjects. This indicates that recovery of axial segment reorientation may occur with time and could explain the similarities between the people with stroke and age matched controls in the current study.

The similarities in the sequence of onset of rotation of segments between the two groups may also be explained by the age of the control group. The healthy controls in this study were matched according to the age of the people with stroke who were older adults. Older adults present with sensory and motor problems (Lord et al., 1996) which could predispose to movement incoordination.

Furthermore, the similarities may be because the people with stroke have regained independent mobility and balance as shown in the high scores in the Barthel index and Berg balance scores. Lamontagne et al. (2009) showed that low functioning people with stroke showed more incoordination of body segments as compared to high functioning people with stroke when turning while walking.

The sequence of peak velocity of the body segments was the same when turning to unpredictable and predictable targets in both groups. The relevance of the peak velocity to the coordination of body segments during turning is that when a segment or segments possess abnormally higher velocity than other segments, the movement of the centre of mass in the base of support may be altered and may thus lead to instability. The similarities in the sequence of the peak velocities when turning to predictable and unpredictable targets for all the tasks in both groups may mean that the two conditions may elicit the same response to postural disturbances. The investigation of how individuals respond to postural disturbances when turning to predictable and unpredictable targets especially at the point where the peak velocity occur could be the subject of another study.

The sequence of peak velocity of the segments was consistent for all the tasks in the stroke group. However, there was a difference in the sequence when turning to the dominant and non-dominant sides and across the three turn angles in the control group. When turning 45° to both directions in the control group, the peak velocity of the head and shoulder were not significantly different while the peak velocity of the two segments were significantly different when turning to 90° and 135° to both sides with the shoulder having the lowest peak velocity. The difference in the sequence between turns to 45° in one hand and turns to 90° and 135° on the other may be explained by the location of the target. The peak velocity of the head has been found to increase with increase in turn angle (Land, 2004). Therefore, the peak velocity of the head and shoulder may have been significantly different for the larger angles due to the increase in velocity of the head. The velocity of the head rotation may have exceeded that of the trunk when turning to 90° and 135° to facilitate view of the new travel path especially for turns to 135° which is initially out of view. Despite the head and shoulder beginning to reorient to the new direction of travel at the same time (as shown by a non-significant onset latency of the two segments), the head may have rotated faster than the shoulder afterwards. In other words, the head may have speeded up for the purpose of gathering information about the environment during the turn. This is supported by the findings of Akram et al. (2010) that the velocity of the head was higher with eyes open than eyes closed when turning on-the-spot. Indicating that when the eyes are closed and there is no chance for scanning the environment, the peak velocity of the head does not exceed that of the shoulder.

The current study therefore, indicates that healthy older adults increase the velocity of their head to facilitate scanning of the environment for turns to large angles (90° and 135°). When turning to smaller angles (45°) the velocity of the head may not have increased as much due to the fact that humans are capable of carrying out eye-only gaze shifts as large as 55° (Guitton and Volle 1987). People with stroke maintained the same pattern of peak velocity of the segments when turning to all the three angles. This may be due to some vestibular or ocular problems that prevented the eyes from scanning the environment alone even with an angle as small as 45°.

For most of the turning tasks there was no significant difference in the timing of peak velocities of the segments (head, shoulder, pelvis and foot) in both groups. In other instances, especially when turning to 135°, the timing of the peak velocity of the foot occurred separately from the other three segments. Akram et al. (2010) reported that the head reached its peak velocity earlier than the shoulder and pelvis when older adults were turning towards predictable targets located 90° to the right. However, the timing of the peak velocities of the shoulder and pelvis were not different as in the current study. The timing of the peak velocity of the segments was referenced to the time the cue for the turn was given in the current study. However, the reference for the timing of the peak velocity was not indicated in the study of Akram et al. (2010).

Chapter 5

Whole body coordination when turning on-the-spot in people with Parkinson's disease and healthy controls

5.0. Introduction

Impairments in people with Parkinson's disease (PD) and how they may affect their ability to turn around are presented in this chapter. The literature on whole-body coordination during turning in people with Parkinson's disease is reviewed and the results and discussions of the comparisons of the sequence of rotation of body segments during turning on-the-spot between people with Parkinson's disease and age-matched healthy controls presented. The aim of the study was to investigate the effect of target predictability, turn angle and turn direction on the sequence of onset latency, peak velocity and timing of peak velocity in people with PD as compared to age-matched healthy controls.

5.1. Parkinson's disease

Parkinson's disease is the second most common progressive neurodegenerative disorder in which the ability to control voluntary movement is lost (Blandini et al., 2000). It usually affects one side of the body before spreading to involve the other side (Jahanshahi et al., 2000). The incidence of PD ranges from 13.7 – 19 per 100,000 per year in Europe (MacDonald et al., 2000, Alves et al., 2009) while the prevalence rate range from 128 to 144 per 100,000 persons in the UK (Schrag et al., 2000, Hobson et al., 2005, Wickremaratchi et al., 2009). The prevalence is highest in the elderly group with mean age of onset of about 70 years and an onset of only 3.6% before the age of 45 years (Wickremaratchi et al., 2009). It is estimated to affect 1.6% of persons 65 years of age or older (De Rijk et al., 1997). The total cost of PD in the UK has been estimated to be between £449 million and £3.3 billion annually (Findley, 2007) with a total mean annual cost of care per PD patient reported as £5,993 (Findley et al., 2003). Researchers and clinicians have therefore intensified efforts to identify and proffer solutions to the many problems facing people with Parkinson's disease.

5.2. Impairments after Parkinson's disease

The pathologic hallmark of PD is degeneration of dopaminergic neurons in the substantia nigra pars compacta resulting in the loss of striatal dopamine. Dopamine regulates excitatory and inhibitory outflow of the basal ganglia (Jenner and Olanow, 2006). In Parkinson's disease, dopamine deficit leads to increase in excitatory and reduction in inhibitory capacity of the basal ganglia. Together, these actions result in reduced activation of cortical and brainstem motor regions (Rodriguez-Oroz et al., 2009). The basal ganglia and cerebellum modify movement by sending inhibitory and excitatory signals respectively to the cortex (Hallet, 1993, Brodal, 1998). Impairment in any of the two systems could disrupt the balance that ensures a coordinated movement.

The striatum is the main input structure of the basal ganglia and is abundantly innervated by fibers from the substantia nigra which modulates the striatal responses to the incoming inputs (Di Giovanni, 2009). The nigostriatal pathway is crucial in the control of movement and cognition (Aarsland et al., 2010). PD is responsible for the damage to the nigostriatal pathway and the loss of dopamine-containing neurons(Di Giovanni, 2009). The loss of dopamine content in the nigostriatal neurons accounts for many of the motor symptoms in people with PD. These motor symptoms manifest as bradykinesia, rigidity and tremor (Lang and Lozano, 1998).

5.2.1. Bradykinesia

Bradykinesia is characterized by the reduction in the speed of initiating and executing a movement and the progressive reduction of the speed and amplitude of the movement when it is repeated (Berardelli et al., 2001). The premotor area selects a movement pattern that could achieve a particular task. However, to adapt the task to specific situations considering the individual and the environment, the basal ganglia selects the appropriate components of the movement pattern that will give the desired speed and amplitude for the task (Blandini et al., 2000). In other words, the basal ganglia recognize patterns from cortical inputs with the goal of matching motor performances to task demands (Morris, 2000). The inability of the basal ganglia to properly select appropriate movement strategy could lead to delay in movement or unwanted movement. When the movement involves more than one body part, there is a higher demand for the function of the basal ganglia in facilitating the selection of a movement pattern (Rodriquez-Oroz et al., 2009). Thus, accounting for even greater slowness and inaccuracy in execution compared to single joint movements. Turning around is a multi-joint task, therefore people with bradykinesia may have problem with coordination of body segments when turning due to the slowness and inaccuracy of the movement of the segments.

5.2.2. Muscular rigidity

Rigidity in Parkinson's disease manifests as an increase in resistance to passive movement in both agonist and antagonist muscle groups (Mak et al., 2007). People with PD show increase in tonic background activity (Mak et al., 2007) and an increase in slow and sustained resistance to muscle stretching (Andrews et al., 1972). They also present with cocontraction of muscles during movement especially in axial muscles (Mak et al., 2007). The link between problems of basal ganglia output activity and rigidity is not clear. Dopamine deficiency leads to increased cortical inhibition which does not explain the increase in resistance to stretching and high tonic background activity presented by people with PD (Rodriquez-Oroz et al., 2009). It has therefore been suggested that Parkinsonian rigidity may be as a result of disinhibition of brainstem mechanisms that mediate muscle tone (Rodriquez-Oroz et al., 2009).

Parkinsonian rigidity has been shown to be present in both appendicular and axial musculature (Meara and Cody, 1992, Wright et al., 2007). The axial rigidity does not respond to levodopa (Wright et al., 2007), raising concerns over its consequences to movement and postural control. Many movement and postural impairments have been linked to the disturbance in control of axial segments (Schenkman et al., 2000). Hip to trunk torque ratio and torsional resistance to axial rotation were reported to be increased in people with PD (Wright et al., 2007). These could result in the loss of the fluidity that is required for the coordination of body parts during functional tasks.

5.2.3. Postural instability

Postural instability is one of the main symptoms of PD (Gelb et al., 1999). The importance of the basal ganglia in the maintenance of posture is evident by the descending connections to the brainstem nuclei important in the control of posture (Pahapill and Lozano, 2000). The control of posture is derived through the acquisition of information about the alignment of body parts to themselves and to the environment through visual, vestibular and proprioceptive systems. PD is characterized by failure to weight the importance of each system based on the situation at hand and the inability to make adjustments when the need arise (Bronstein, 1986).

The body maintains upright stance through the activity of extensor muscles. PD is associated with disturbance of the neurotransmitters that connect the activity of the basal ganglia to the brainstem regions that control the extensor muscle activity (Morris 2000). This can ultimately undermine control of posture. One of the factors that affect movement timing during functional activities is abnormal postural control, specifically the inability to stabilize the body in anticipation of potentially destabilizing movements (Shumway-Cook and Woollacott 2007). This impairment of postural stability in people with PD could result in abnormal timing and possibly sequencing of body segments during turning.

5.2.4. Cognitive impairments

Goal directed behaviour requires the gathering of relevant information that could be used to select appropriate movement pattern to achieve the desired goal. The cognitive system is tasked with the responsibility of utilizing relevant sensory information to design the components of a desired action. Studies have shown that the prefrontal cortex is central to the processes of the cognitive system

(Miller, 2000, Ridderinkhof et al., 2004). The connection between the basal ganglia and prefrontal cortex in time processing has been established (Jahanshahi et al., 2000). Damage to the basal ganglia can therefore lead to cognitive impairment. Indeed cognitive deficits have been shown to be present in 26 – 57% of people with PD (Foltynie et al., 2004, Williams-Gray et al., 2007, Aarsland et al., 2010).

One of the cognitive domains most affected in people with PD is working memory (Lewis et al., 2003, Lewis et al., 2005). The working memory is responsible for retaining the relevant sensory information and using it to plan the movements for the desired action (Baddeley, 1992). Doperminergic projections to the dorsolateral prefrontal cortex modulate the function of the working memory (Miller and Cohen, 2001). Impairment in the use of relevant sensory information to select appropriate movement pattern could lead to movement incoordination during functional tasks.

5.2.5. Sensory impairments

Studies have shown abnormal proprioception in people with PD (Jobst et al., 1997, Zia et al., 1997), however, it has been shown that the proprioception is only depressed due to the effect of doperminergic medication (O'Suilleabhain et al., 2001). People with PD also scored significantly worse than healthy adults on a comprehensive battery that assessed visual acuity, visual speed of processing and attention and visuoconstructional ability (Uc et al., 2005). Visual and proprioceptive information are integrated to form an internal representation of the body and the environment. This integrated information is used to plan the appropriate strategy for functional movement. Abnormality in visual and proprioceptive systems in people with PD could impair the planning of movement of body segments during turning and may contribute to movement incoordination.

5.2.6. Summary of impairments after Parkinson's disease

Performance of functional movements such as turning emanate from the proper processing of sensory and motor information. The basal ganglia is involved in this process by assisting in the selection of appropriate movement strategies and integration of proprioceptive and visual information that are necessary in forming an internal representation of the body and the environment. People with PD present with difficulty in selecting appropriate movement strategies and impairment in sensory information. People with PD are also characterized by postural instability and cognitive impairments. Together these factors expose people with PD to movement incoordination during turning which could lead to instability and subsequent falls.

5.2.7. Falls in people with Parkinson's disease

People with PD have been reported to have high incidences of falls. One or more falls have been reported in 46 – 75% of community dwelling people with PD (Stack and Ashburn, 1999, Gray and Hildebrand, 2000, Ashburn et al., 2001, Wood et al., 2002, Balash et al., 2005, Wielinski et al., 2005, Pickering et al., 2007). The impact of the falls is high due to the injuries sustained and immobility that arise due to fear of recurrent falls (Akdkin et al., 2003, Franchignoni et al., 2005). These falls have been shown to be associated with duration and severity of the PD symptoms, postural difficulties and freezing (Gray and Hildebrand, 2000, Balash et al., 2005). Turning difficulties which are reported in 52 – 62% of people with PD (Nieuwboer et al., 1998, Bloem et al., 2001, Stack et al., 2006) have also been shown to increase the risk of falls (Stack and Ashburn, 1999, Bloem et al., 2001). Falls during turning increase the risk of hip fracture by eight fold compared to falls during straight walking (Cumming and Klineberg, 1994). This makes turning an important area of research that could help in the prevention of fall incidences in people with PD.

5.3. Whole body coordination when turning in people with Parkinson's disease

The kinematics of rotation of body segments in people with Parkinson's disease (PD) have been investigated during turning on-the-spot and during change of direction while walking in a few studies. When turning 30° and 60° to the right and left while walking, people with PD and healthy controls started to rotate their head followed by the trunk and finally the foot (Mak et al., 2008). On turning to 90° to the left the people with PD started to rotate the head and upper trunk simultaneously while the healthy controls started rotating the head before the upper trunk (Crenna et al., 2007). The sequence of onset of the segments in the control groups is consistent with studies that investigated the sequence of onset of body segments during change of direction while walking in healthy adults (Patla et al., 1999, Hollands et al., 2001, Fuller et al., 2007, Paquette et al., 2008b, Akram et al., 2010).

The head and trunk started to rotate simultaneously when turning to 90° (Crenna et al. 2007) while the head started to rotate before the trunk when turning to 30° and 60° (Mak et al. 2008) in the people with PD. Two factors may explain the sequence of the onset of the head and trunk when turning to 30° and 60° on one hand and when turning to 90° on the other. Firstly, people with PD are characterized by axial rigidity which is capable of causing en-bloc movement of axial segments during turning. The en-bloc movement of the head and trunk was not observed when turning to 60° which is 30° shorter than 90°, however, since the healthy controls maintained the separate movement of the two segments across all the angles, the people with PD may have faced more challenge in turning to a higher turn angle and therefore presented with simultaneous movement of the head and trunk when turning to 90°.

Secondly, the predictability of the target may explain the variation in the sequence of the head and trunk. The participants where visually cued one step length before the turning point in an unpredictable manner when turning to 30°

and 60° (Mak et al. 2008) while the participants (in another study) turned voluntarily to the target placed at 90° in a predictable manner (Crenna et al. 2007). However, this explanation is not likely since the healthy controls maintained the same sequence for both predictability conditions. Similar sequence of rotation of body segments between turns to predictable and unpredictable targets during change of direction while walking in healthy adults have also been reported by Patla et al. (1999).

Differences in sequence of onset of body segments between people with PD and healthy controls have also been observed during turning on-the-spot. People with PD started to rotate the head followed by the shoulder and finally the pelvis when turning to 45° in response to an audio cue (Vaugoyeau et al., 2006). Healthy controls started to rotate the head followed by a simultaneous rotation of the shoulder and pelvis. The sequence in the healthy controls is in contrast to what has been reported in healthy young adults in which the three segments rotated separately in a top to bottom sequence (Hollands et al. 2004). However, the sequence was similar to another group of healthy adults of similar age group in which the participants were verbally cued to turn to 90° (Akram et al. 2010). Thus the age of the participants and the type of cue (audio) may have caused the en-bloc movement of the shoulder and pelvis in the older adults.

The separate onset of rotation of the segments in the people with PD is surprising because of the axial rigidity which was expected to cause more simultaneous rotation of the segments than the control group. People with PD presented with more simultaneous onset of rotation of head, shoulder and pelvis as compared to healthy controls when turning to 180° (Hong et al., 2009, Hong and Earhart, 2010). This is in contrast to the sequence in the study of Vaugoyeau et al. (2006) where the control group had more simultaneous onset of rotation of the segments. The differences in the turn angle (45° vs 180°), presence or absence of a cue for the start of the turn and differences in methodologies between the studies may be responsible for the differences. The details of the studies that investigated turning while walking and on-the-spot are presented on table 5.1.

It is difficult to synthesize the results of the studies because some of the factors that are thought to influence coordination of body segments during turning (predictability of a target, turn angle and turn direction) have been investigated in different studies with different methodologies. It is therefore not certain if the factors or the methodologies influenced the differences seen across the studies. It is therefore important to investigate the effect of the factors in a study with the same protocol.

Table 5.1. Literature review of sequence of onset latency of body segments when turning in people with Parkinson's disease

Author	Task	Measurements	Results
Vaugoyeau et al. (2006)	Ten people with Parkinson's disease (age: 62.2±5.5 years) and five age-matched healthy controls (age: 61.8±5.4 years) turned on-the-spot to 45° starting with a single step with preferred leg and ending with the other leg placed parallel to the first. The turn was cued by a loudspeaker situated in the required step direction.	The movement of the head, shoulder and pelvis were recorded with ELITE television image-processing system using four infrared cameras. Onset of rotation of the segments was referenced to onset of the postural phase of step initiation.	PD group: started rotating the head followed by the shoulder and finally the pelvis. Control group: started rotating the head followed by simultaneous rotation of shoulder and pelvis.
Hong et al. (2009)	Eleven people with Parkinson's disease (age: 67±7 years) and 12 healthy controls (age: 72±10 years)	The movement of head, trunk and pelvis were measured with KINTRAK motion analysis system. Onset of	PD group: the head, trunk and pelvis started to rotate simultaneously.

	turned 180° to the left and right. They were instructed to turn and face the wall behind when they are ready.	rotation of the segments was referenced to the lift off of the first foot.	Control group: The head started to rotate followed by the trunk and finally the pelvis.
Hong and Earhart (2010)	Ten people with Parkinson's disease (age: 67.1±7.6 years) turned 180 to the left and right. They were instructed to turn and face the wall behind when they are ready.	The movement of head, trunk and pelvis were measured with KINTRAK motion analysis system. Onset of rotation of the segments was referenced to lift off of the first foot.	The head, trunk and pelvis started to rotate simultaneously.
Crenna et al. (2007)	Fourteen people with Parkinson's disease (age: 67.1±6.5 years) and 15 age-matched healthy controls (age: 67.7±2.7 years) walked straight ahead along a 6 m pathway or around a	The movement of the head and upper trunk were measured by SMART, a nine-camera motion analysis system. The onset of rotation of the segments was referenced to the initiation of	PD group: The head and upper trunk started rotating simultaneously. Control group: The head started to turn followed by the upper trunk.

	90° corner to the left located 2 m from the starting position. There was no cue given for the start of the walking or the turning.	the approach step.	
Mak et al. (2008)	Ten people with Parkinson's disease (age: 65.1±10.7 years) and 20 healthy controls (age: 64.5±5.4 years) were visually cued to walk straight or to turn either 30° or 60° to the left or right, at the midpoint of a 9 m walkway. The cue was activated when they stepped on a force plate placed one step length before the turn point	The movement of the head, trunk and foot were measured by VICON motion analysis system. The onset of the segments was referenced to the cue delivery.	Both groups started rotating the head followed by the trunk and finally the foot.

5.3.1. Summary

Few studies have investigated the sequence of onset of rotation of segments during change of direction while walking and during turning on-the-spot. Healthy controls maintained a similar sequence of onset of rotation of segments (head before trunk and finally foot) when turning to 30°, 60° and 90° while walking. People with PD had similar sequence with the controls when turning to 30° and 60° but had simultaneous rotation of the head and trunk when turning to 90°. The difference between the sequence when turning to 30° and 60° on one hand and turning to 90° on the other hand in the people with PD may be due to the axial rigidity in the people with PD, however, this may not be certain due to some differences in the methodologies in the study looking at turning to 30° and 60° and the study looking at turning to 90°. The sequence of onset of body segments when turning to 45° and 180° on-the-spot were conflicting and the reason was thought to be the angle of turn which was markedly different.

5.4. Gap in knowledge

Turning while walking or on-the-spot is a common activity of daily living that could challenge the stability of an individual. The kinematics of turning may be influenced by the walking cycle (Lamongatgne et al. 2007) when turns are superimposed on walking. However, the body movements during turning on-the-spot including the steps taken are geared towards achieving the turn itself. Furthermore, many activities of daily living involve turning on-the-spot only. It is therefore crucial to investigate the kinematics of body segments during turning on-the-spot. The key points highlighted in the studies on whole-body coordination during turning on-the-spot in healthy adults is that the sequence of rotation of the segments depends on the task to be accomplished which is governed by sensory and environmental factors such as predictability of the target, type of cue triggering the start of the turn, direction of turn and angle of the turn.

Studies have shown an increased activation of motor areas of the brain with an unpredictable behaviour compared to a predictable one (Dassonville et al., 1998, Thickbroom et al., 2000). Indeed predictability of a visual target has been reported to influence sequence of segmental rotation during turning on-the-spot in healthy adults (Anastasopoulous et al. 2009). Turning to unpredictable visual targets resulted in a top to bottom sequence of onset of segments rotation (Hollands et al. 2004; Anastasopoulous et al. 2009) while turning to predictable visual targets resulted in more simultaneous onset of rotation of the segments (Anastasopoulous et al. 2009). Since people with PD present with reduced activation of the motor areas of the brain, could the sequence differ between the two predictability conditions as compared to healthy controls?

Turn angle has been reported to not alter the sequence of onset of segmental rotation during turning on the spot in healthy adults (Hollands et al. 2004; Anastasopoulous et al. 2009). However turning to different angles requires attention and cognition (Neville and Lawson, 1987), factors that could be impaired in people with PD, therefore people with PD may manifest different sequence of segmental rotation while turning to different angles. The side of initial onset in people with PD often remains more affected even when the symptoms are evident on both sides with disease progression (Lee et al. 1995). Although turning to the left and right has not been reported to alter the sequence of onset of segments rotation during turning in healthy individuals, the sequence may be different when turning towards and away from the initially affected side in people with PD.

The onset latency has frequently been used to investigate the coordination of body segments during turning. However, falls may occur not only at the onset of movement but during the movement. The peak velocity is a good point to study coordination of body segments during turning since where the speed is highest may present more risk to losing stability. There is no known study that has investigated the sequence of peak velocity/timing of peak velocity of body segments during turning in people with PD.

The reason for carrying out this study was to investigate how people with PD move their body during turning as compared to healthy controls by comparing the sequence of horizontal displacement of the eye and rotation of head, shoulders, pelvis and feet when turning to predictable and unpredictable targets placed at three different angles (45°, 90° and 135°) and two directions (initially affected/ initially unaffected and dominant/non-dominant sides). It was hoped that the results would help identify the problems that people with PD may encounter during turning which may predispose them to losing stability and subsequent falls.

5.5. Methodology

The aim of the study was to compare the sequence of rotation of body segments (eye, head, shoulder, pelvis and foot) during turning on-the-spot between people with Parkinson’s disease (PD) and age-matched healthy controls. The effect of target predictability, turn angle and turn direction on the sequence of rotation of the body segments was also investigated. It was hypothesized that people with PD will present with a different sequence of rotation of body segments during turning on-the-spot as compared to the healthy controls.

5.5.1. Recruitment

Participants targeted for this study were community dwelling individuals with Parkinson’s disease (PD) that agreed to be contacted by the Faculty of Health Sciences, University of Southampton during previous studies. The healthy participants were individuals without any neurological conditions or any other condition that could affect the way they turn and who agreed to be contacted by the Faculty of Health Sciences, University of Southampton or were partners of the participants with PD. The inclusion and exclusion criteria for the PD and control groups are listed below:

5.5.1.1. Parkinson's disease group

5.5.1.1.1. Inclusion criteria

1. Diagnosis of Parkinson's disease,
2. Stage i-iii on Hoehn and Yahr scale: People with Parkinson's disease at stage i-iii of the Hoehn and Yahr scale were included because they were found to be able to complete the turning tasks in a similar study carried out recently by the same research team. Those in stage iv were found to have difficulty completing the tasks.

5.5.1.1.2. Exclusion criteria

1. Self-reported vision impairments that cannot be corrected with glasses,
2. Insufficient peripheral vision to follow a target,
3. Inability of the participants to understand and remember instructions: To be included in the study, the participants need to remember the instructions in the sequence in which it was explained to them. The instructions (you will be asked to keep looking at a light in front of you and when it goes off you should turn to the light that comes up on your right or left) was explained to the participants and they were asked to repeat the instructions in the sequence in which it was said to them,
4. Inability to stand and turn independently: the researcher stood at approximately 135º to the side of the participant making sure to be in close proximity in case the participant looses stability. The participant was asked to turn around and face the researcher. To be included in the study, participants must be able to turn approximately 135º to both sides,
5. Musculoskeletal disorders which could alter the participants' performance while turning,
6. Other neurological conditions such as stroke because they may serve as confounding variables by affecting the way the participants turn.

5.5.1.2. Control group

5.5.1.2.1. Inclusion criteria

1. Healthy individuals that were age-matched to the participants with Parkinson's disease.

5.5.1.2.2. Exclusion criteria

1. Self-reported vision impairment that cannot be corrected with glasses,
2. Inability to stand and turn independently,
3. Presence of self reported musculoskeletal and neurological disorders which could affect turning.

The study was approved by the Faculty of Health Science's ethics committee [ethics number: FoHS-ETHICS-2011-052 (appendix vi)] and all participants were informed about the study and asked to sign a consent form (appendix iv) prior to data collection.

5.5.2. Outcome measures

For the PD participants, clinical measures were taken to aid in describing the participants' level of functional independence, cognition and balance. The measurements were carried out as follows:

1. History of falls: The participants' history of falls was taken by using a questionnaire (Stack and Ashburn, 1999). The questionnaire asks the number of falls in the last 12 months, where the fall happened, what caused the fall, how the individual landed, number of near falls in the last 12 months, what the individual was doing during the near fall, what caused the near fall, and methods of saving oneself from falling.

2. History of freezing: The participants' history of freezing was taken by using the Freezing of Gait Questionnaire (Giladi et al., 2000). The questionnaire

asks the state of walking during worst time, how gait difficulties affect daily activities, whether the feet get glued to the ground during walking, making a turn or when trying to initiate walking and the duration of the freezing.

3. Unified Parkinson's Disease Rating Scale (UPDRS) (Fahn and Elton, 1987): The motor section (III) of the UPDRS was used to measure the motor function of the participants. This section examines a persons speech, facial expression, tremor at rest, postural tremor of hands, rigidity, finger taps, hand movements, rapid alternating movement of hands, leg agility, arising from chair, posture, gait, postural stability and body bradykinesia. The performances are scored from 0 (normal) to 4 (severe). Therefore, the higher the UPDRS score, the greater the disability from PD. The UPDRS has been reported to be a valid and reliable tool to measure motor function of people with Parkinson's disease (Ramaker et al., 2002).

4. Functional Reach Test (Duncan et al., 1990): This test is carried out using a yardstick mounted on a stand or wall at shoulder height. The participant is asked to position the body close to, but not touching the yardstick with arm outstretched and hand fisted. The starting position is noted by determining what number the metacarpophalangeal (MCP) joints line up with on the rule. The participant is asked to reach as far forward as possible ("Reach as far forward as you can go without taking a step") in a plane parallel with the measuring devise. The end position of the MCP joints against the ruler is noted. The difference between the starting and end position numbers is recorded. Scores less than 6 inches indicate limited functional balance. The Functional Reach Test has been reported to be a valid and reliable tool for measuring balance in people with Parkinson's disease (Schenkman et al., 1997).

5. Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005): The MoCA is a 30-point tool that measures cognitive status. It assesses

attention and concentration, executive functions, memory, language, visuoconstructional skills, conceptual thinking, calculations and orientation. A score of 26 or above is considered normal. The MoCA has been reported to be a valid and reliable tool for measuring the cognitive status of people with Parkinson's disease (Gill et al., 2008).

The research design and materials used for this study have been stated in chapter 3. The processes of data collection, extraction and analysis have also been detailed in chapter 3.

5.6. Results

5.6.1. Participants

Nineteen people with PD and 14 healthy individuals were given information sheets with details of the study. Twelve people with PD and 11 healthy individuals agreed to take part in the study. Two people with PD were excluded because they had musculoskeletal problems (hip surgery in one and humeral fracture in the other) that could affect the way they turn. One healthy individual did not make it to the lab for data collection and no reason was given for that. In total, data was collected from ten people with stroke and ten healthy controls. The details of the recruitment process are shown in a flow chart in appendix vii.

5.6.2. Demographic data/baseline measures

The ten people with PD had mean age of 70.9 (SD=8.99) years (2 males) and the ten healthy controls had mean age of 66.8 (SD=4.08) years (6 males). Eight of the participants with PD had the left side initially affected. All the healthy controls were right hand/foot dominant. The dominance was noted by asking the participants what hand they would use to write and what leg they would use to kick a football. Since there were more PD participants with initially affected left side (Eight), the initially affected side of the participants with PD was compared to the non-dominant side (left) of the controls. The mean number of years since having the PD was 6.1 (SD = 2.73). The demographic data and baseline measures of the participants are presented in table 5.2 (control group) and 5.3 (stroke group). The PD group had normal cognitive status (mean±SD of MoCA = 24±4), high motor function (mean±SD scores on motor section of UPDRS = 20.6±1) and high balance status (mean±SD of scores on functional reach test = 18±6) as shown in Table 5.3. Eight out of the ten people with PD had history of falls while all the ten people with PD had history of freezing.

Table 5.2. Demographic data of control group

Age (years)	Gender	Dominant side
65	M	R
73	F	R
68	F	R
58	F	R
70	M	R
64	F	R
65	M	R
68	M	R
69	M	R
68	M	R
Mean=66.8 SD=4.08		

Table 5.3. Demographic data/baseline measures of PD group

Age (years)	Gender	UPDRS	H&Y	FRT	MoCA	ISA	TSPD (years)	HFalls (NoF/1yr)	HFreeze (FOGQS)
90	F	25	3	13	19	L	5	Yes (2)	Yes (12)
65	F	17	1	19	29	L	8	Yes (1)	Yes (12)
59	F	17	2	15	20	L	10	No	Yes (9)
72	F	22	1	16	29	L	10	Yes (5)	Yes (6)
75	M	27	3	29	25	L	2	Yes(1)	Yes (10)
69	F	18	2	17	21	L	6	Yes (1)	Yes (20)
69	F	12	2	22	27	L	7	No	Yes (9)
63	F	14	2	12	26	L	6	Yes (1)	Yes (12)
80	M	27	2	25	25	R	4	Yes (1)	Yes (3)
67	F	27	3	12	28	R	3	Yes (3)	Yes (10)
Mean=70.9 SD=8.99		Mean=20.6 SD=5.72	Mean=2.1 SD=0.74	Mean=18 SD=5.75	Mean=24.9 SD=3.7		Mean=6.1 SD=2.73		

UPDRS = Unified Parkinson's Disease Rating Scale; H&Y = Hoen and Yahr score; FRT = Functional Reach Test; MoCA = Montreal Cognitive Assessment; ISA = Initial side affected; TSPD = Time since Parkinson's disease was diagnosed; NoF/1yr = Number of falls in the last 12 months; FOGQS = Freezing of Gait Questionnaire Score.

The following sections present the results of the onset latency, peak velocity and timing of peak velocity of body segments during turning on-the-spot in people with PD. The effect of target predictability, turn angle, turn direction, body segment and group on the onset latency, peak velocity and timing of peak velocity of body segments was analyzed in this study. Therefore to make the presentation of the data easier to follow, graphs are shown for a particular variable of interest averaged across other variables. Where differences exist across the level of another variable, graphs are presented to show the differences.

5.6.3. Sequence of onset of body segments

The sequence of onset of rotation of the eye, head, shoulder, pelvis and foot was different when turning to predictable and unpredictable targets (figure 5.1) when the onset latency was averaged across the turn angle, turn direction and group of the participants. This is shown by a significant interaction effect of predictability vs segment from the results of the ANOVA, $F(4, 72) = 19.16$, $p = 0.001$.

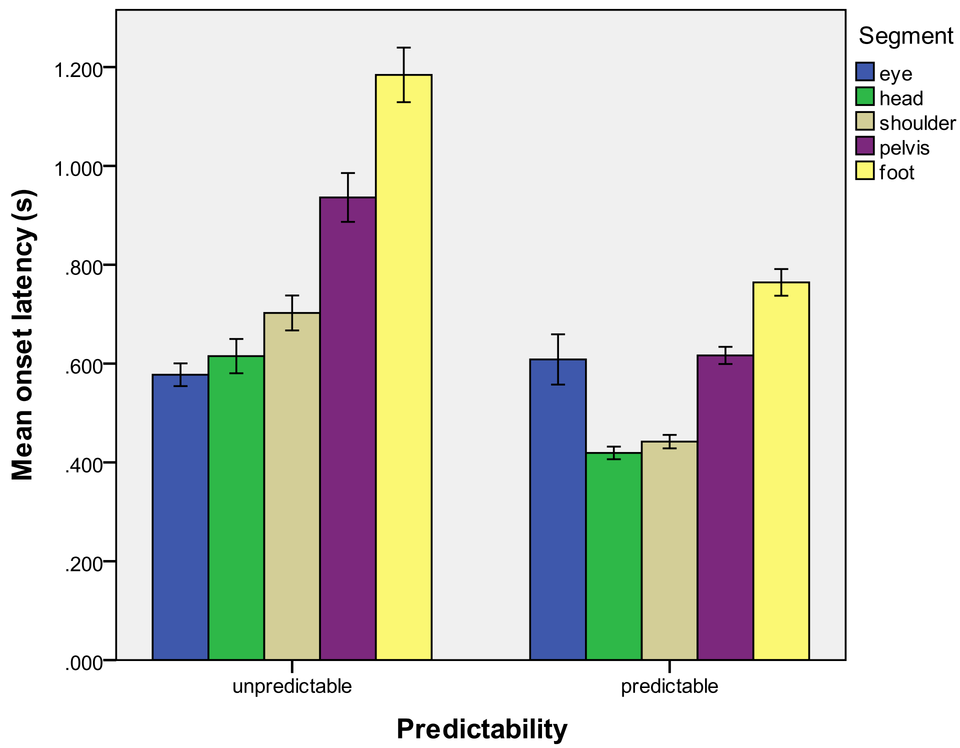


Figure 5.1. Mean and standard error (Error bars: +/- 1 SE) of the onset latency of the eye, head, shoulder, pelvis and foot when turning to predictable and unpredictable targets averaged across the three turn angles, two turn directions and two groups.

The results showed no difference in the sequence of the segments across the three turn angles when the onset latency was averaged across the two predictability conditions, two directions and two groups (figure 5.2). This is shown by a non-significant interaction effect of angle vs segment [F (2.402, 43.240) = 2.446, p = 0.089].

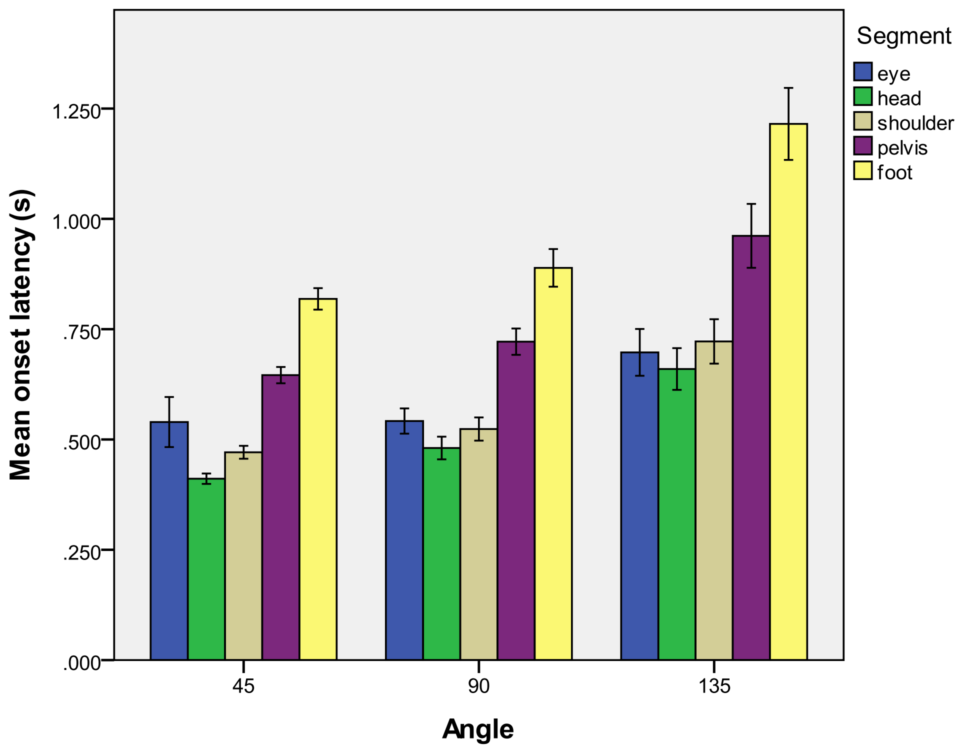


Figure 5.2. Mean and standard error (Error bars: +/- 1 SE) of the onset latencies of the eye, head, shoulder, pelvis and foot when turning to 45°, 90° and 135° averaged across the two predictability conditions, two turn directions and two groups.

Although the sequence of onset of the segments was not found to be different across the three turn angles when the onset latency was averaged across the two predictability condition, two turn directions and two groups, it was shown to be different across the three turn angles for each predictability condition (figure 5.3). This is shown by a significant interaction effect of predictability, segment and angle, $F (8, 144) = 5.118$, $p = 0.009$.

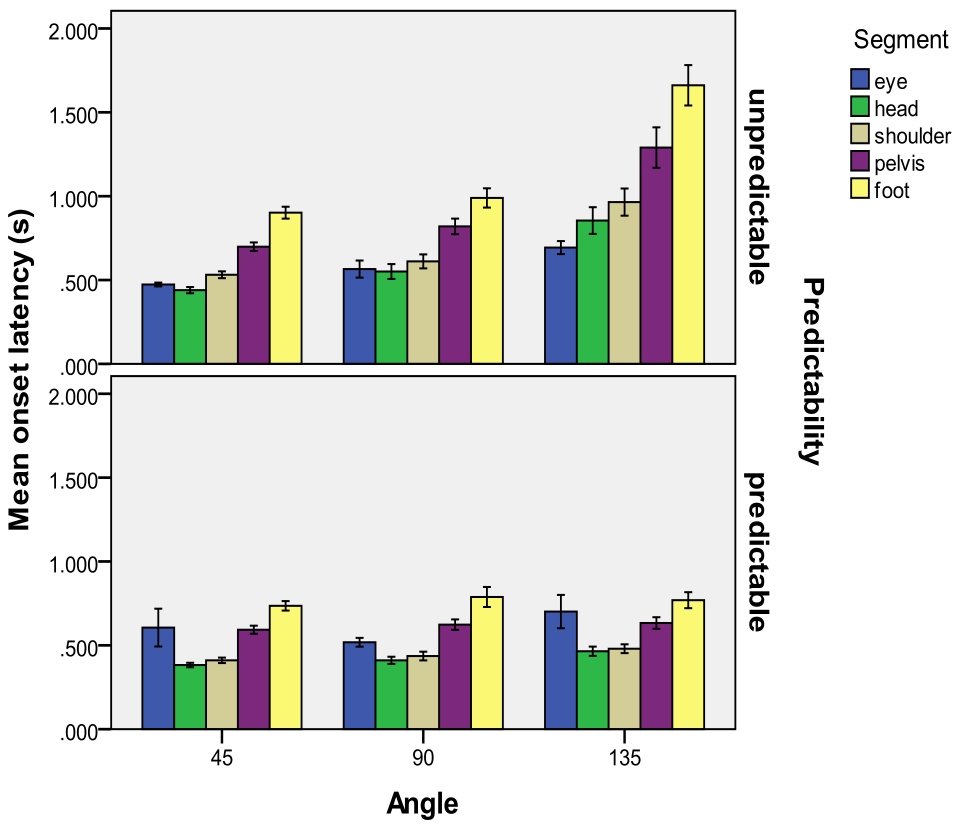


Figure 5.3. Mean and standard error (Error bars: +/- 1 SE) of the onset latencies of the eye, head, shoulder, pelvis and foot when turning to 45°, 90° and 135° for each predictability conditions averaged across the two turn directions and two groups.

The post hoc analysis showed that the eye, head and sholder started to move simultaneously when turning to unpredictable targets placed at all angles and both directions in both groups. The simultaneous movement of the eye, head and shoulder was followed by the pelvis and finally the foot when turning towards 45° in both groups. When turning to 90°, the pelvis and foot started to move simultaneously when turning to both sides in the PD group, while the two segments started to move separately (with the pelvis moving first) when turning to both sides in the control group. When turning to 135°, the pelvis and foot moved simultaneously with the eye, head and shoulder in the PD group, while the pelvis and foot moved simultaneously but separately from the eye, head and shoulder in the control group.

When turning to predictable targets, either the eye, head and shoulder moved simultaneously or the head and shoulder moved before the eye. The pelvis and foot moved simultaneously when turning to 90° and 135° to both sides (except when turning to 90° towards the dominant side in the control group) while the two segments moved separately when turning to 45° to both sides.

The post hoc analysis showed that there were differences in the sequence of rotation of the segments between the people with PD and the healthy controls when turning to the three turn angles for each predictability conditions (figure 5.4 and 5.5). However, both interaction effects of predictability vs segment vs group [F (1.406, 25.306) = 0.496, p = 0.550] and angle vs segment vs group [F (2.402, 43.240) = 0.278, p = 0.797] were not significant.

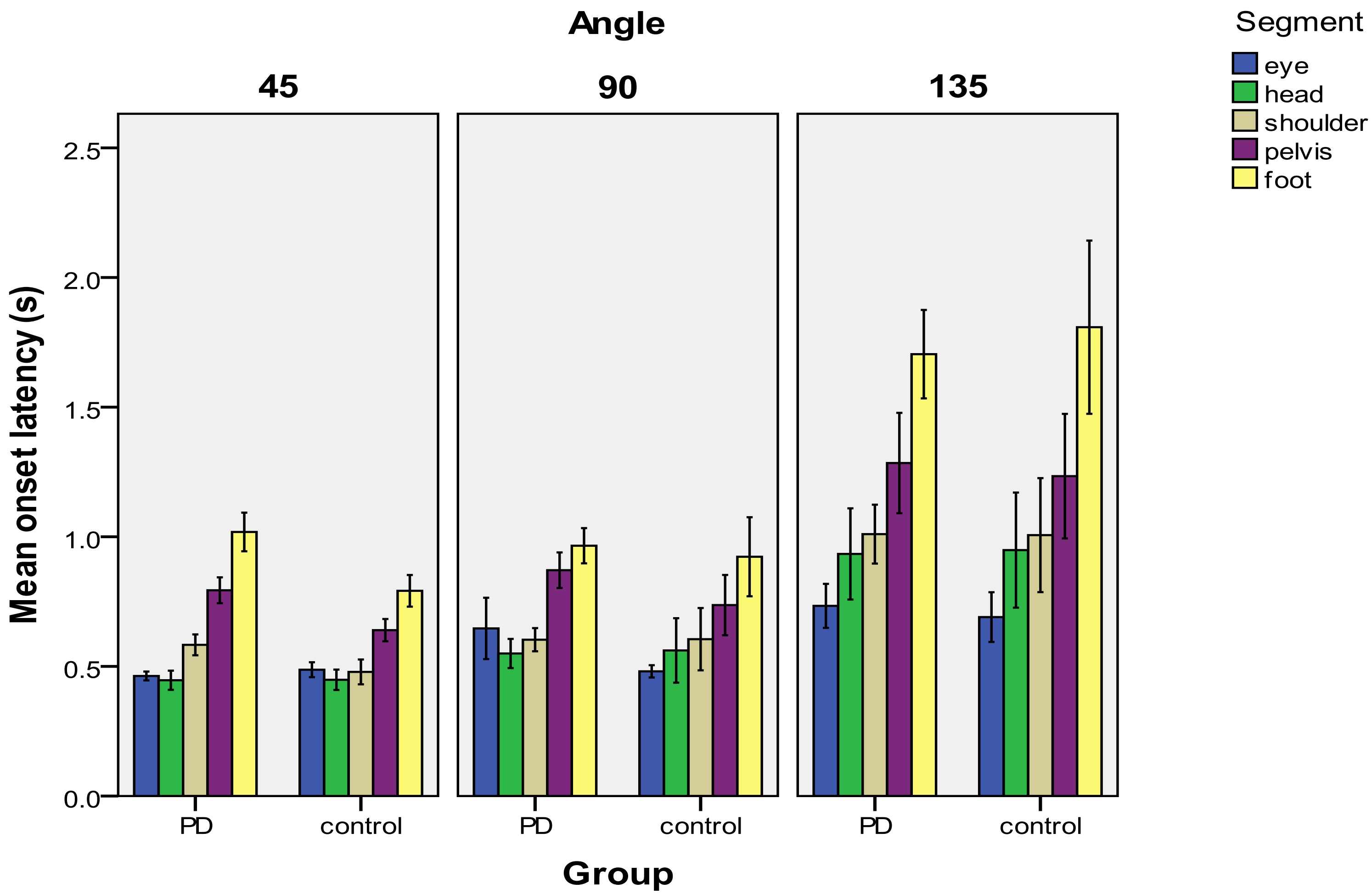


Figure 5.4. Mean and standard error (Error bars: +/- 1 SE) of the onset latencies of eye, head, shoulder, pelvis and foot when turning to initially affected/non-dominant side - Unpredictable condition.

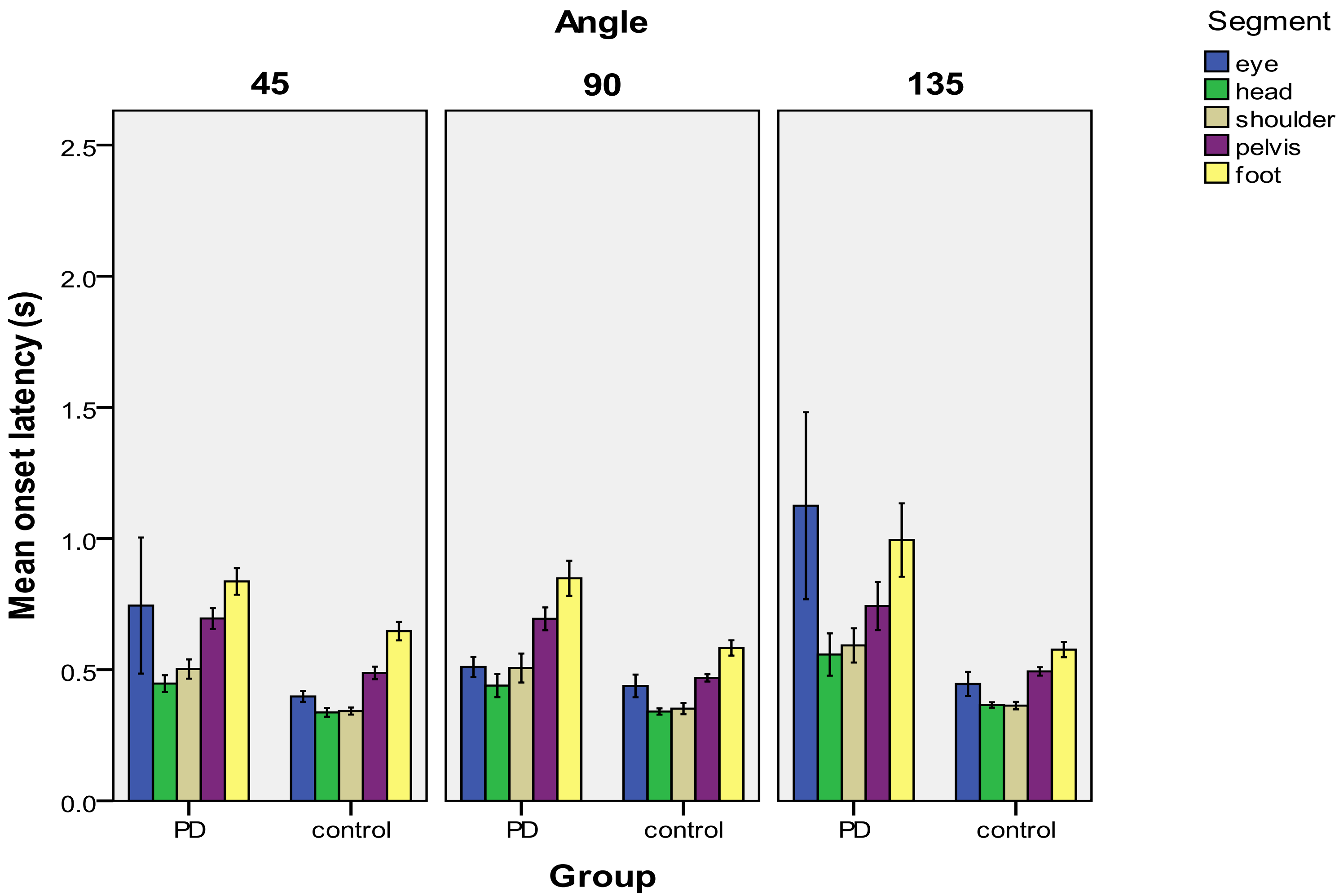


Figure 5.5. Mean and standard error (Error bars: +/- 1 SE) of the onset latencies of eye, head, shoulder, pelvis and foot when turning to initially affected/non-dominant side - Predictable condition.

There was no difference in the sequence of onset of the segments when turning to the initially affected/non-dominant side and the initially unaffected/dominant side (figure 5.6) when the onset latency was averaged across the target predictability, turn angle and group of the participants. This is shown by the non-significant interaction of direction vs segments [F (2.085, 37.530) = 0.519, p = 0.607].

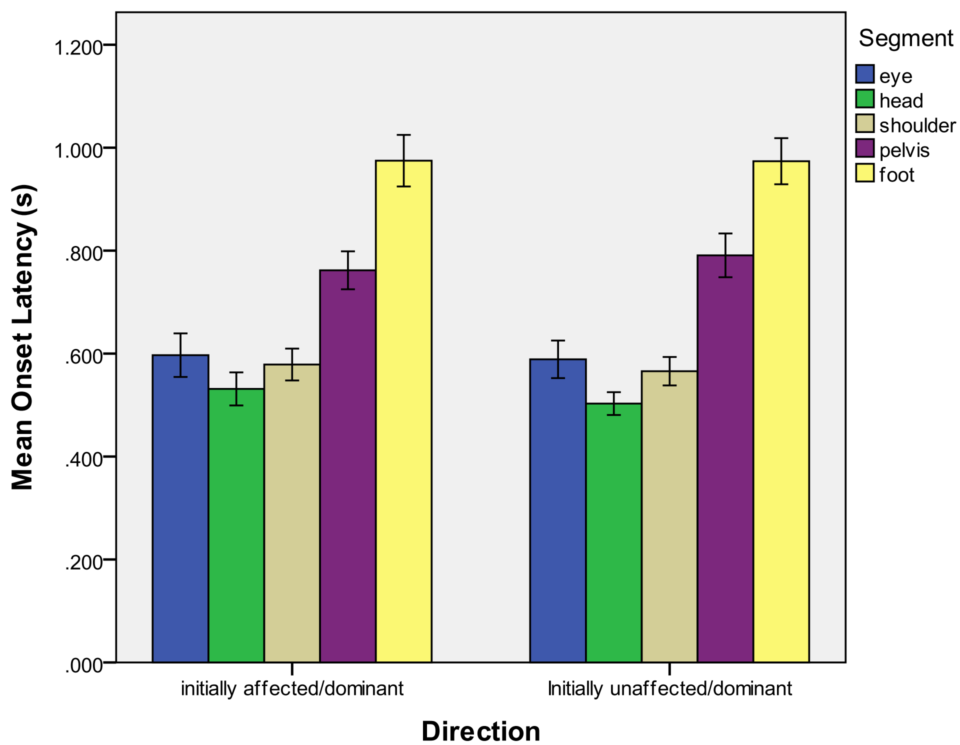


Figure 5.6. Mean and standard error (Error bars: +/- 1 SE) of the onset latencies of the body segmetns when turning to initially affected/non-dominant side and the initially unaffected/dominant side averaged across the two predictability conditions, three turn angles and two groups.

The results of the between subjects effects has shown a significant main effect of group, F (1, 18) = 9.696, p = 0.006, indicating that the people with PD started rotating the segments slower than the control group (table 5.4 and 5.5). The mean (SE) of the PD and control groups when the onset latencies of the segments where averaged across the two predictability conditions, three angles, two directions and five segments were 0.797s (0.048) and 0.570s (0.025) respectively.

Table 5.4. Onset latencies when turning towards initially affected/non-dominant side – Unpredictable condition

	45°		90°		135°	
	PD [mean(±SE)s]	Control [mean(±SE)s]	PD [mean(±SE)s]	Control [mean(±SE)s]	PD [mean(±SE)s]	Control [mean(±SE)s]
Eye	0.463(0.017)	0.487(0.029)	0.647(0.118)	0.480(0.024)	0.734(0.085)	0.690(0.096)
Head	0.447(0.037)	0.448(0.039)	0.550(0.056)	0.561(0.124)	0.934(0.176)	0.950(0.222)
Shoulder	0.583(0.040)	0.479(0.048)	0.603(0.045)	0.605(0.120)	1.010(0.114)	1.004(0.220)
Pelvis	0.794(0.050)	0.640(0.043)	0.871(0.069)	0.737(0.116)	1.284(0.194)	1.218(0.239)
Foot	1.019(0.075)	0.792(0.061)	0.965(0.068)	0.923(0.152)	1.704(0.171)	1.808(0.334)

Table 5.5. Onset latencies when turning towards initially unaffected/dominant side – Predictable condition

	45°		90°		135°	
	PD [mean(±SE)s]	Control [mean(±SE)s]	PD [mean(±SE)s]	Control [mean(±SE)s]	PD [mean(±SE)s]	Control [mean(±SE)s]
Eye	0.745(0.259)	0.398(0.021)	0.510(0.039)	0.438(0.043)	1.125(0.357)	0.445(0.046)
Head	0.447(0.032)	0.337(0.017)	0.440(0.044)	0.341(0.012)	0.558(0.081)	0.366(0.010)
Shoulder	0.503(0.037)	0.342(0.014)	0.506(0.055)	0.352(0.021)	0.593(0.065)	0.363(0.014)
Pelvis	0.695(0.040)	0.488(0.024)	0.694(0.043)	0.469(0.014)	0.743(0.092)	0.493(0.016)
Foot	0.837(0.051)	0.647(0.035)	0.848(0.067)	0.583(0.029)	0.994(0.140)	0.576(0.029)

The onset of rotation of the segments was faster when turning to predictable targets as compared to turning to unpredictable targets (table 5.4 and 5.5). This was shown by a significant main effect of predictability on the onset latencies of the segments, $F(1, 18) = 18.362$, $p = 0.001$. The onset latencies of the segments while turning to predictable and unpredictable targets when averaged across the three turn angles, two directions, five segments and two groups were 0.597s (0.039) [mean (SE)] and 0.770s (0.039) [mean (SE)] respectively.

There was a significant increase in the onset of movement with increase in turn angle when the onset latency of the segments was averaged across the two predictability conditions, two directions, five segments and two groups (table 5.4 and 5.5). This was shown by a significant main effect of angle on the onset latencies of the segments, $F(2, 36) = 22.896$, $p = 0.001$. The mean (SE) of the onset latencies for turns to 45°, 90° and 135° were 0.577s (0.023), 0.631s (0.034) and 0.842s (0.049) respectively. The pairwise comparisons between the onset latencies of the three turn angles showed that there was a significant difference between onset latencies of turns to 90° vs 135° ($p = 0.001$) and 45° vs 135° ($p = 0.001$), however there was no significant difference in the onset latencies of turns to 45° and 90° ($p = 0.204$). The increase in onset latency with increase in turn angle was found to be more prominent when turning to unpredictable targets as compared to turning to predictable targets (figure 5.7).

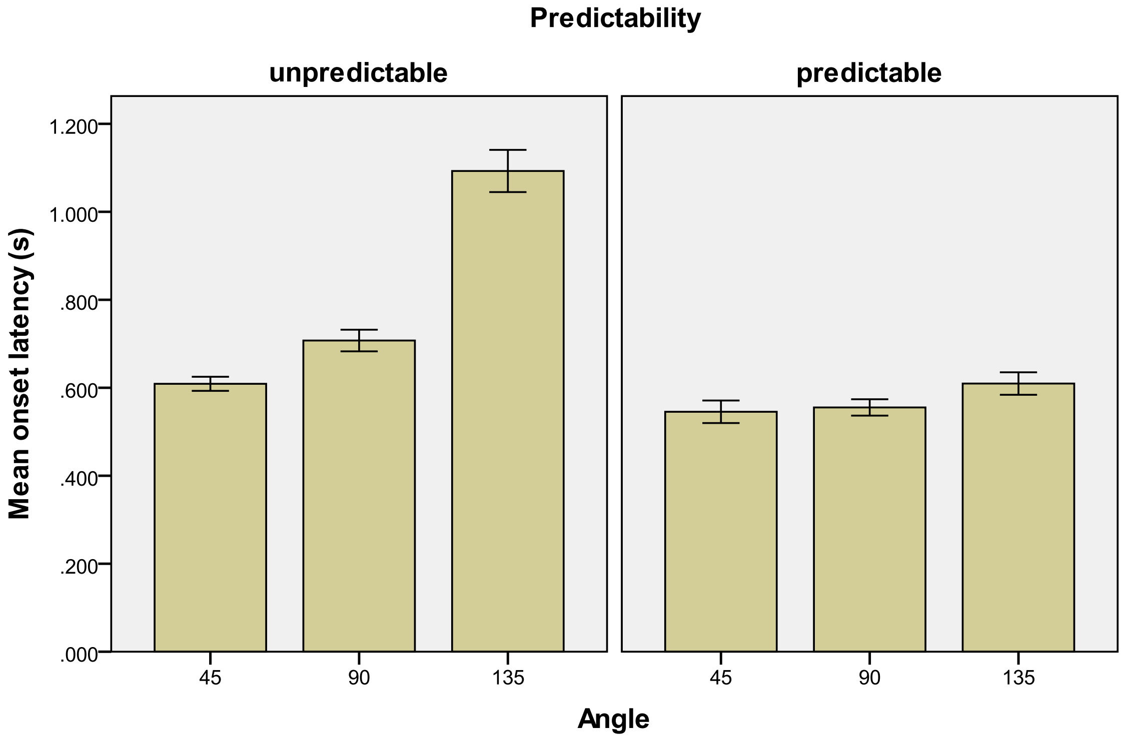


Figure 5.7. Mean and standard error (Error bars: +/- 1 SE) of the onset latencies of eye, head, shoulder, pelvis and foot when turning to 45°, 90° and 135° for each predictability condtion when averaged across the two turn directiosn, five segments and two groups.

The results showed that there was no difference in the onset latency of the segments while turning to both sides in both groups (figure 5.8). This was shown by the non-significant main effect of direction on the onset latency of the segments, F (1, 18) = 0.176, p = 0.680 and the non-significant interaction of direction and group, F (1, 18) = 1.269, p = 0.275. The mean (SE) of the onset latencies for turns to initially affected and initially unaffected sides in the PD group averaged across the two predictability conditions, three turn angles, five segments and two groups were 0.761s (0.048) and 0.779s (0.037) respectively. For turns to dominant and non-dominant sides in the control group, the mean (SE) of the onset latencies were 0.615 (0.048) and 0.578 (0.037) respectively.

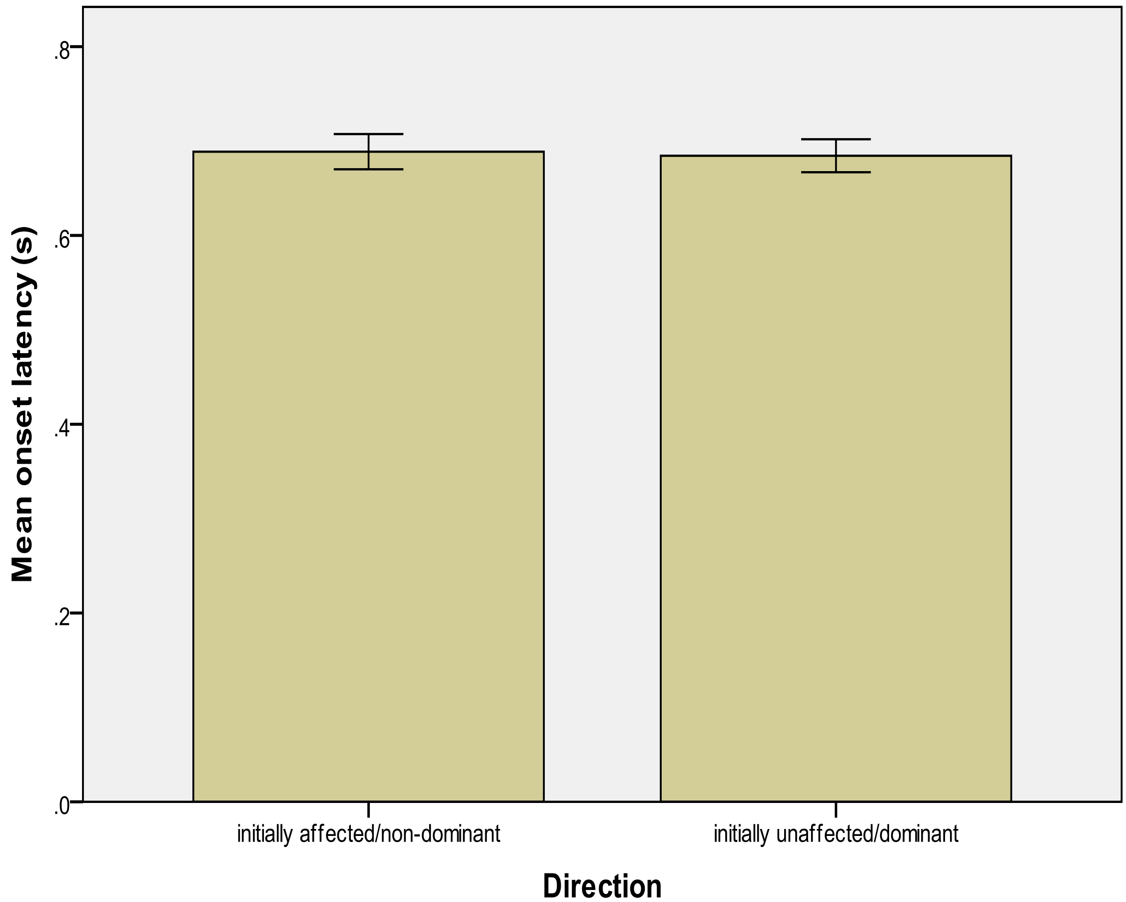


Figure 5.8. Mean and standard error (Error bars: +/- 1 SE) of onset latencies of body segments when turning to paretic/non-dominant and non-paretic/dominant sides averaged across the two predictability conditions, three angles, five segments and two groups.

5.6.3.1. Summary of onset latency of rotation of body segments

The results showed a difference in the sequence of onset of rotation of segments when turning to unpredictable and predictable targets. When both groups turned to unpredictable targets, the eye, head and shoulder started to move simultaneously, while on turning to predictable targets, the head and shoulder sometimes started to move before the eye. There was more simultaneous onset of segments with increase in turn angle when turning to unpredictable targets in the PD group. The pelvis and foot started to rotate separately when turning to 45° while they started to rotate simultaneously when turning to 90°. When turning to 135°, all the segments started rotating simultaneously.

The segments also started to move significantly faster in the control group than in the PD group. Turning to predictable target was also faster as compared to turning to unpredictable targets. There was an increase in latency with increase in angle of turn, however, this difference was more pronounced in the unpredictable condition. Finally, there was no difference in the onset latency when turning to both sides in both groups.

5.6.4. Sequence of peak velocity of body segments

The results showed that there was a consistent pattern of peak velocities of head, shoulder, pelvis and foot when turning to predictable and unpredictable targets for all the tasks (figure 5.9 to 5.12). This was shown by the non-significant interaction effect of predictability and segment, [$F (2.085, 37.529) = 2.777$, $p = 0.073$. However, there was a difference in the sequence of the peak velocity of the segments across the three turn angles (45°, 90° and 135°) and two directions (initially affected/initially unaffected and dominant/non-dominant sides) as shown by the significant interaction effect of angle vs segment [$F (3.003, 54.062) = 31.909$, $p = 0.001$] and direction vs segment [$F (2.474, 44.529) = 12.974$, $p = 0.001$].

The post hoc analysis showed that the peak velocity of the head and shoulder were similar followed by the peak velocity of the pelvis and finally the foot when turning 45° to the initially affected side and 90 to both sides in the PD group. When turning 45° to the initially unaffected side, the pelvis and foot also had similar peak velocities. When turning 135° to both sides in the PD group, the shoulder had the lowest peak velocity, followed by the head, then pelvis and finally the foot.

When turning 90° and 135° to the dominant side in the control group, the shoulder had the lowest peak velocity, followed by the head, then pelvis and finally the foot. When turning 90° and 135° to the non-dominant side in the control group, the peak velocity of the shoulder was lowest, followed by that of the head and pelvis (no significant difference between the peak velocity of the head and pelvis) and finally the foot. When turning 45° to both sides in the control group, there was no significant difference in the peak velocity of the head and shoulder.

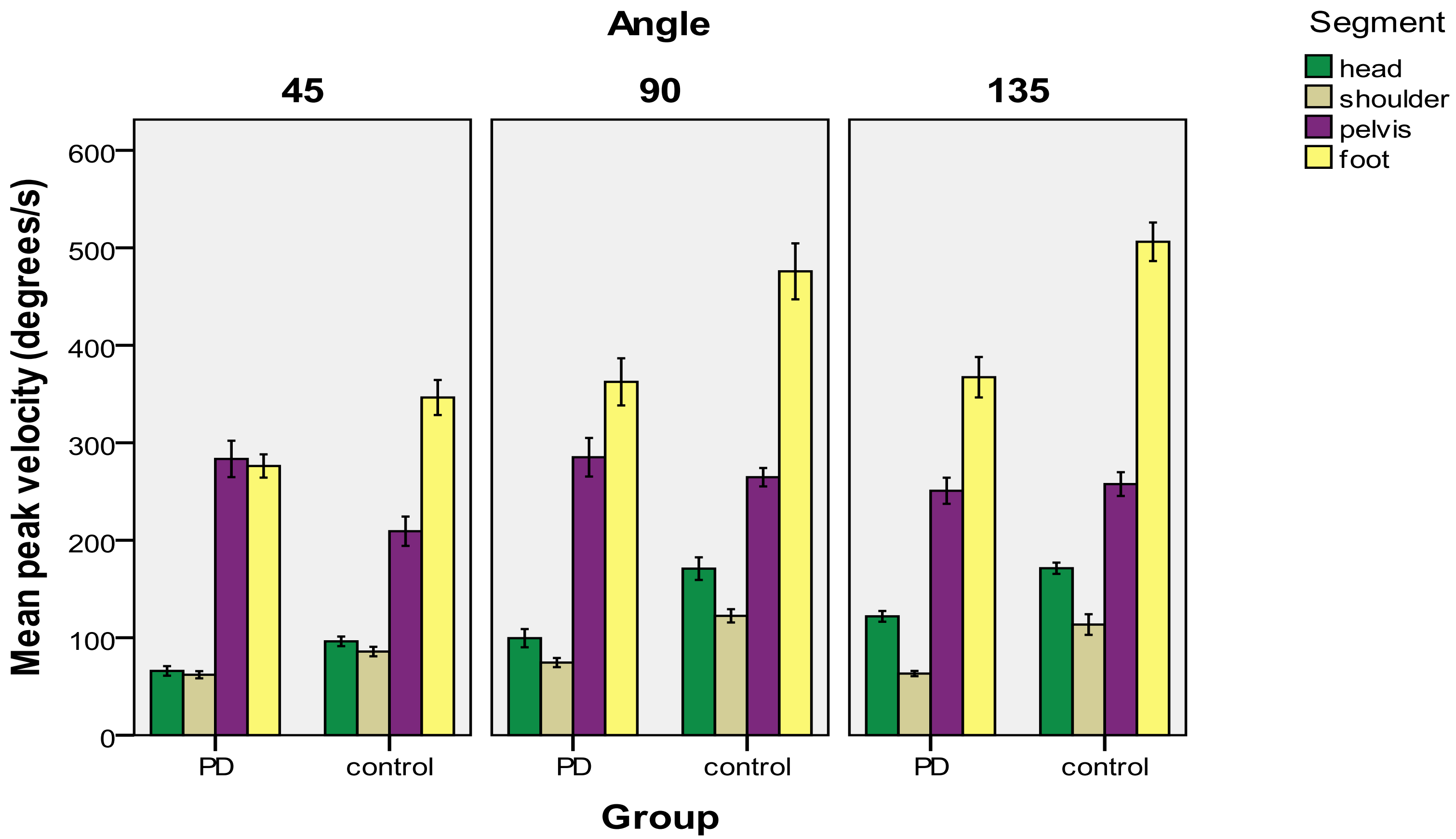


Figure 5.9. Mean and standard error (Error bars: +/- 1 SE) of the peak velocities of eye, head, shoulder, pelvis and foot when turning to initially affected/non-dominant side - Unpredictable condition.

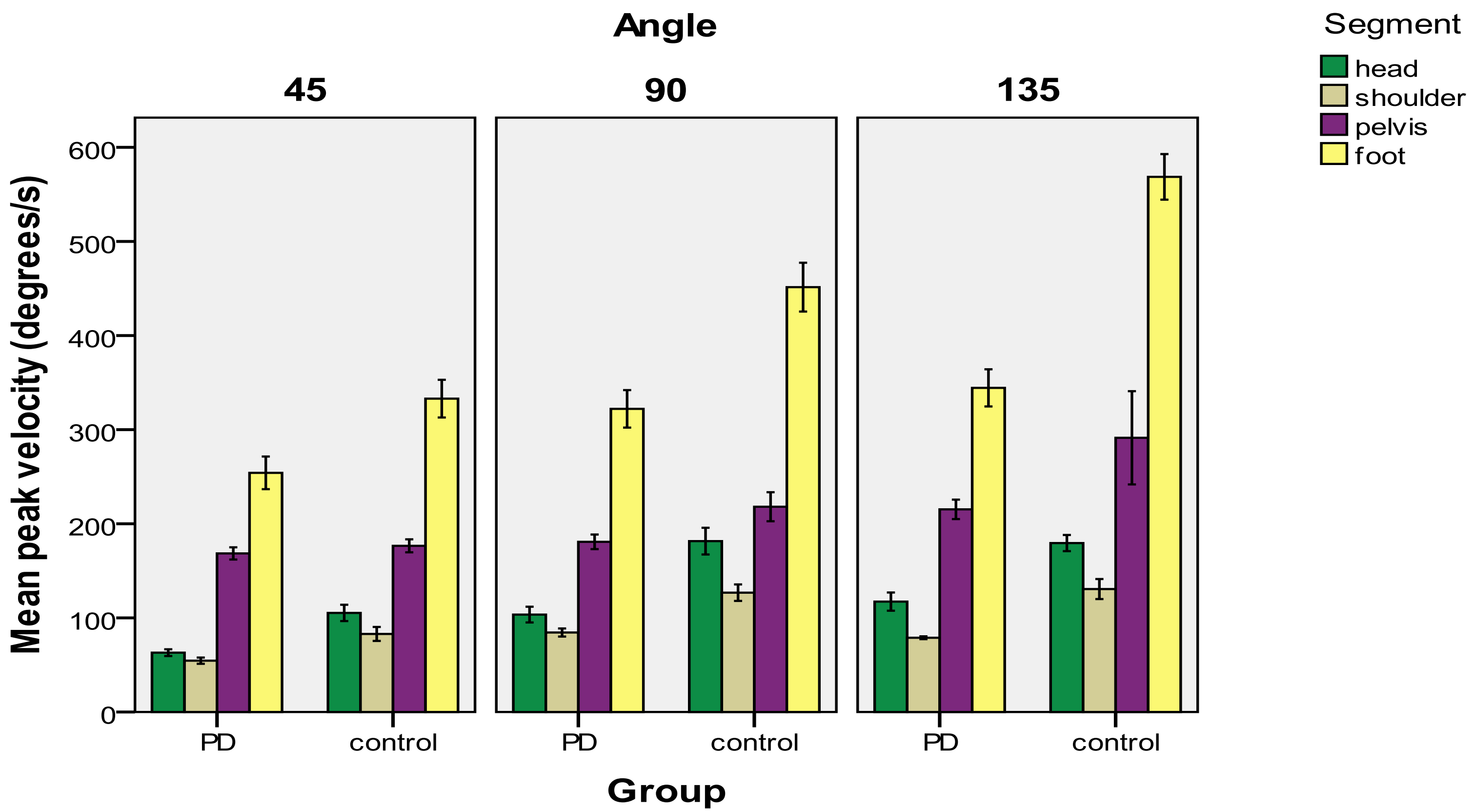


Figure 5.10. Mean and standard error (Error bars: +/- 1 SE) of the peak velocities of eye, head, shoulder, pelvis and foot when turning to initially unaffected/dominant side - Unpredictable condition.

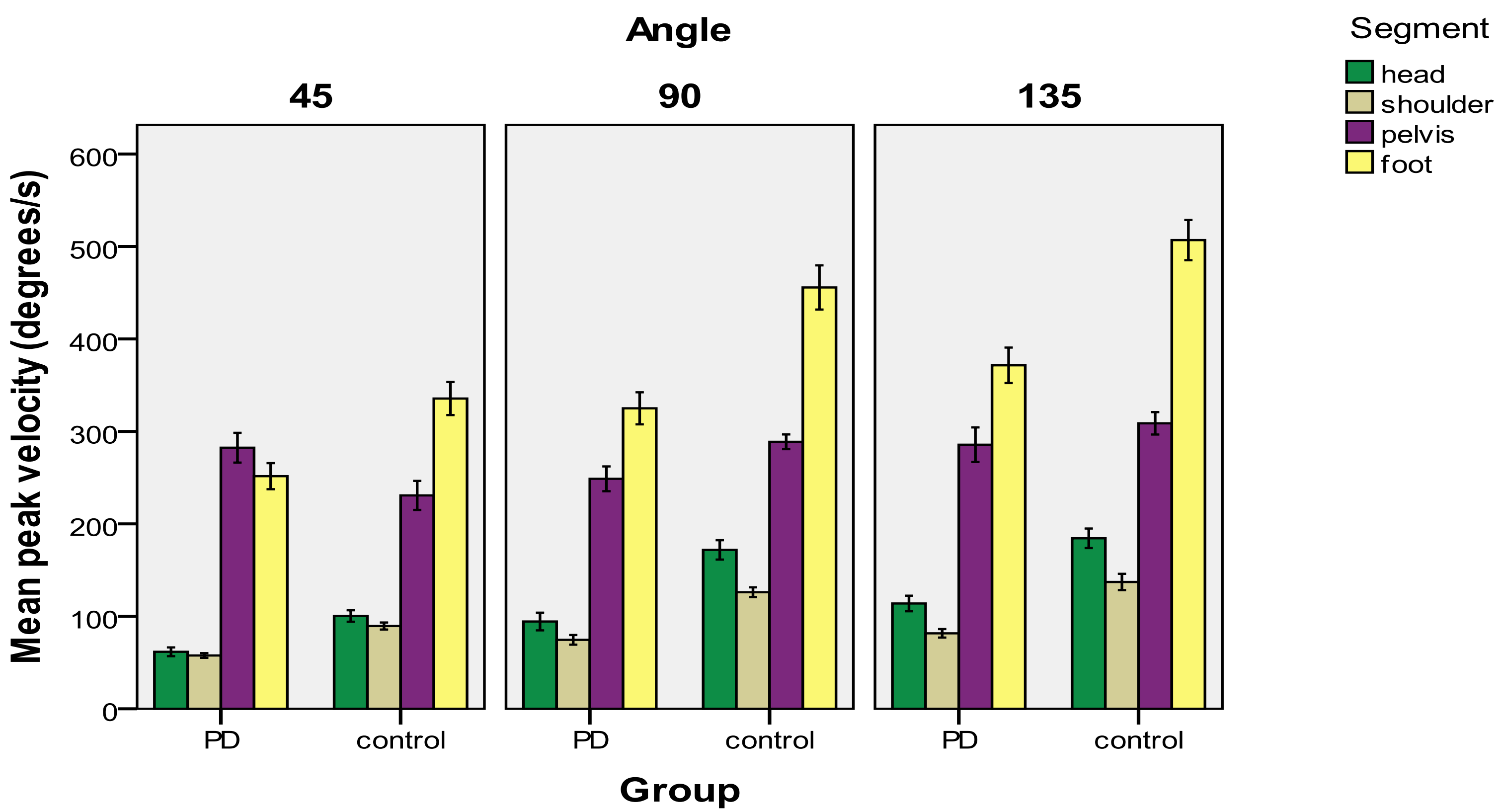


Figure 5.11. Mean and standard error (Error bars: +/- 1 SE) of the peak velocities of eye, head, shoulder, pelvis and foot when turning to initially affected/non-dominant side - Predictable condition.

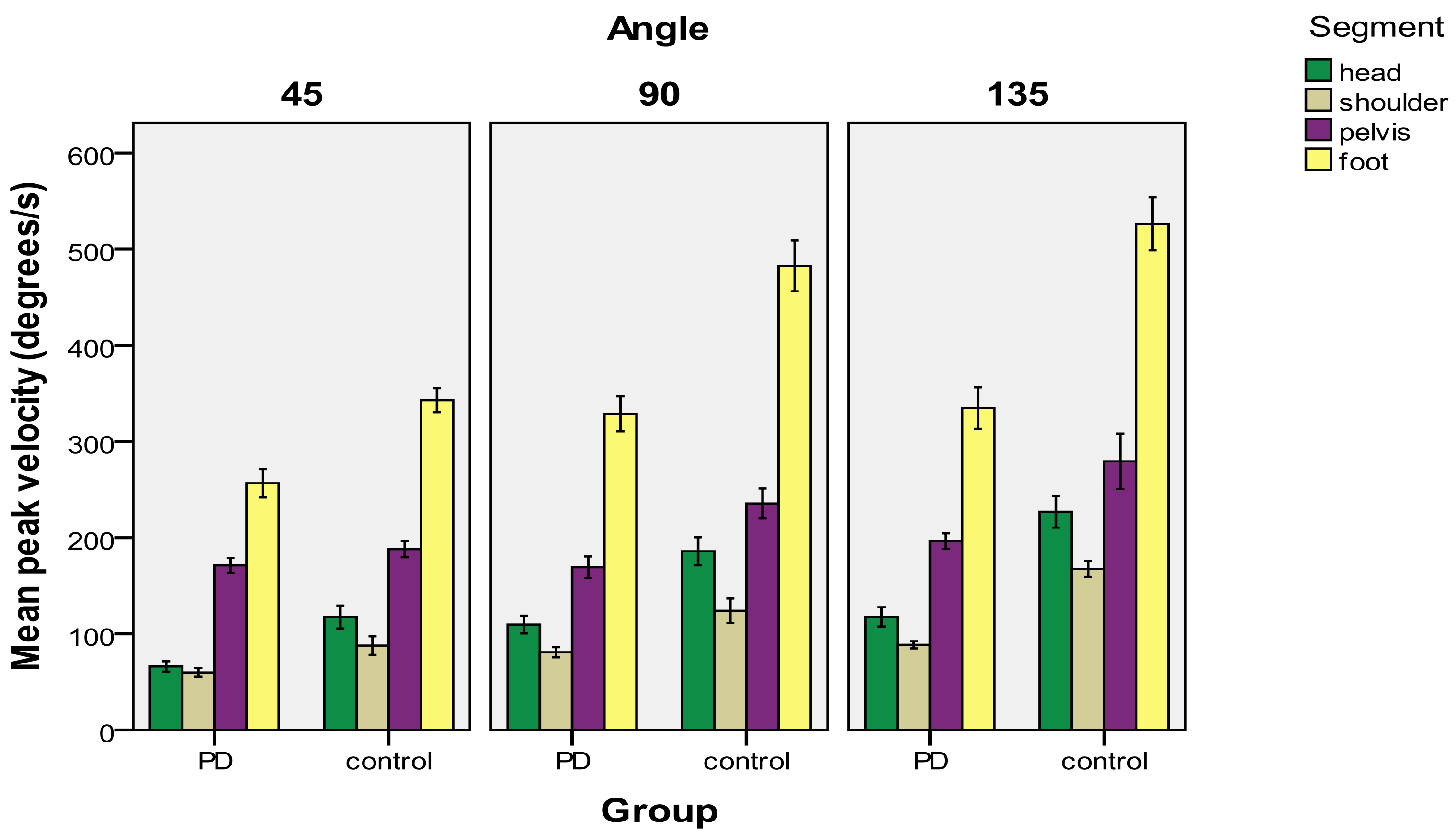


Figure 5.12. Mean and standard error (Error bars: +/- 1 SE) of the peak velocities of eye, head, shoulder, pelvis and foot when turning to initially unaffected/dominant side - Predictable condition.

The results have shown that the PD group had lower peak velocities as compared to the control group (table 5.6 and 5.7). This was shown by the significant main effect of group, $F(1, 18) = 48.609$, $p = 0.001$. The mean (SE) of the peak velocities for the PD and control groups when averaged across the two predictability conditions, three angles, two directions and five segments were 177°/s (6.42) and 240.97°/s (6.42) respectively. There was no significant main effect of predictability on the peak velocity of the segments, $F(1, 18) = 2.265$, $p = 0.150$. This indicates that, there were no significant differences in the peak velocities for the unpredictable [mean (SE) = 207.62°/s (4.95)] and predictable [mean (SE) = 211.01°/s (4.39)] conditions when the peak velocities were averaged across the three turn angles, two turn directions, four segments and two groups.

There was an increase in the peak velocity of the segments with increase in turn angle (table 5.6 and 5.7). This was shown by a significant main effect of angle on the peak velocities of the segments, $F(1.399, 25.185) = 203.201$, $p = 0.001$. The mean (SE) of the peak velocities for turns to 45°, 90° and 135° averaged across the two predictability conditions, two turn directions, four segments and two groups were 167.60°/s (3.43), 219.56°/s (5.02) and 240.79°/s (6.23) respectively. The pairwise comparisons between the peak velocities of the three turn angles showed that there was a significant difference between all the three paired combinations (45° vs 90°, $p = 0.001$, 90° vs 135°, $p = 0.001$ and 45° vs 135°, $p = 0.001$).

Table 5.6. Peak velocities when turning towards initially affected/non-dominant sides – Unpredictable condition

	45°		90°		135°	
	PD [mean(±SE)°/s]	Control [mean(±SE)°/s]	PD [mean(±SE)°/s]	Control [mean(±SE)°/s]	PD [mean(±SE)°/s]	Control [mean(±SE)°/s]
Head	65.95(4.91)	96.29(4.95)	99.55(9.36)	170.88(11.60)	121.93(5.51)	171.29(5.78)
Shoulder	062.03(3.69)	85.82(4.86)	74.51(4.72)	122.45(6.81)	63.23(2.70)	113.51(10.59)
Pelvis	283.42(18.68)	209.27(15.04)	285.15(19.79)	264.68(9.45)	250.79(13.40)	257.61(12.20)
Foot	276.18(11.93)	346.45(17.97)	362.49(24.17)	475.87(28.72)	367.24(20.73)	506.20(19.77)

Table 5.7. Peak velocities when turning towards initially affected/non-dominant side – Predictable condition

	45°		90°		135°	
	PD [mean(±SE)°/s]	Control [mean(±SE)°/s]	PD [mean(±SE)°/s]	Control [mean(±SE)°/s]	PD [mean(±SE)°/s]	Control [mean(±SE)°/s]
Head	61.64(4.75)	100.36(6.21)	94.41(9.56)	171.84(10.48)	113.90(8.43)	184.41(10.56)
Shoulder	57.66(2.53)	89.51(3.82)	74.56(5.23)	126.09(5.29)	81.63(4.60)	137.16(8.80)
Pelvis	282.38(16.10)	230.78(15.68)	248.73(13.39)	288.757.97)	285.61(18.69)	308.75(12.12)
Foot	251.59(14.08)	335.53(17.86)	324.98(17.35)	455.68(23.90)	371.48(19.19)	506.91(21.74)

The peak velocities of the segments were lower when turning towards initially affected/non-dominant sides as compared to turning towards initially unaffected/dominant sides (figure 5.13). This was shown by the significant main effect of direction on the peak velocity of the segments, $F(1, 18) = 6.322$, $p = 0.022$. The difference was however more obvious in the PD group (figure 5.14). The mean (SE) of the peak velocity for turns to initially affected and initially unaffected sides in the PD group when averaged across the two predictability conditions, three angles, four segments and two groups were 190.04°/s (5.99) and 165.39°/s (8.16) respectively. For turns to dominant and non-dominant sides in the control group, the mean (SE) of the peak velocities were 239.84°/s (5.99) and 242.10°/s (8.16) respectively.

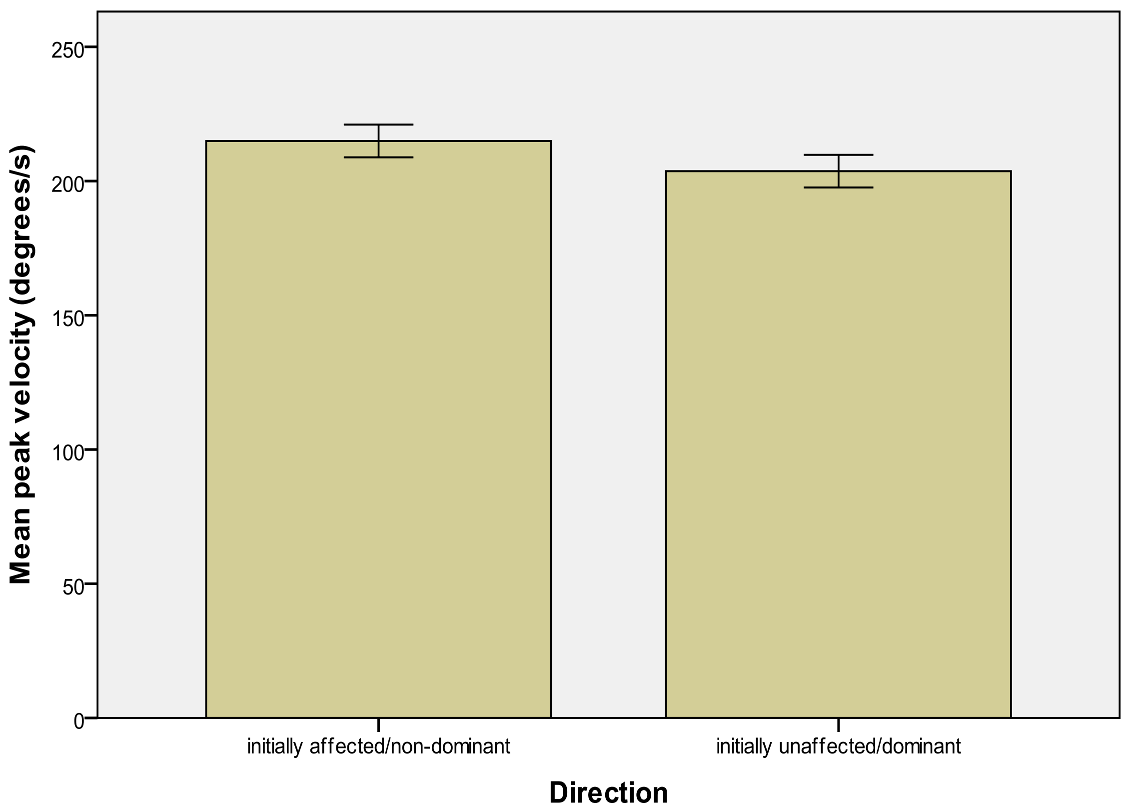


Figure 5.13. Mean and standard error (Error bars: +/- 1 SE) of the peak velocities of head, shoulder, pelvis and foot when turning to initially affected/non-dominant and initially unaffected/dominant sides averaged across two predictability conditions, three angles, five segments and two groups.

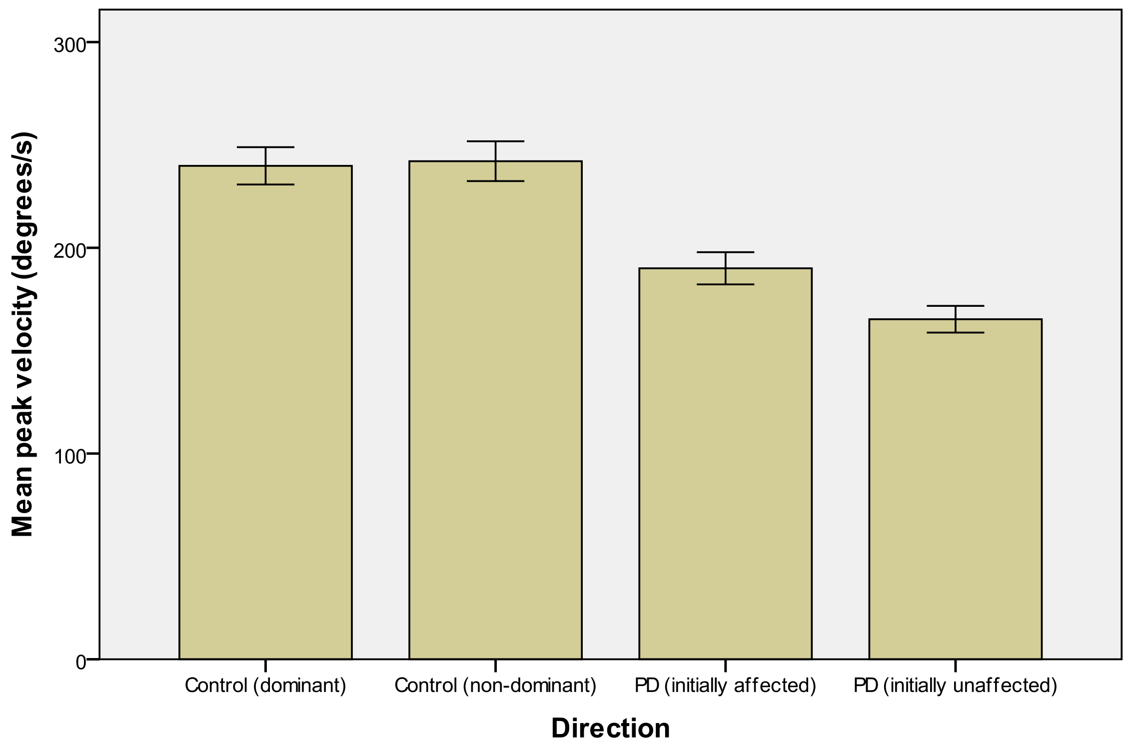


Figure 5.14. Mean and standard error (Error bars: +/- 1 SE) of peak velocities of head, shoulder, pelvis and foot for turns to both sides in the PD and control groups averaged across two predictability conditions, three angles, five segments and two groups.

5.6.4.1. Summary of peak velocity of body segments

The sequence of peak velocity of the segments was similar for the unpredictable and predictable conditions. However, the sequence was different across the three turn angles and two directions in both groups. The peak velocities of the segments were higher in the control group as compared to the PD group. There was an increase in peak velocity with increase in turn angle in both groups. However, the peak velocities of the segments were the same when turning to the predictable and unpredictable targets.

5.6.5. Sequence of timing of peak velocity of body segments

The results of the ANOVA showed that the interaction effect of predictability vs segment [F (2.479, 44.614) = 5.521, p = 0.004] and angle vs segment [F (5.281, 95.055) = 2.444, p = 0.037] were significant. This indicated that there were differences in the sequence of timing of peak velocities of the segments between the two predictability conditions and across the turn angles. While the interaction effect of direction vs segment [F (2.127, 38.293) = 2.408, p = 0.100] was not significant, indicating no difference in sequence of the segments when turning to both sides. However, the post hoc analysis showed no regular pattern in the sequence of timing of peak velocities when looking at the effect of the three factors studied (target predictability, turn angle, turn direction and group). For most of the turning tasks there was no significant difference in the timing of peak velocities of the segments (head, shoulder, pelvis and foot). In other words, the peak velocity of the segments occurred at more or less the same time (figure 5.15 to 5.18). In other instances the timing of the peak velocity of the foot occurred last and separately from the other three segments (which had no significant difference between the timing of their peak velocities).

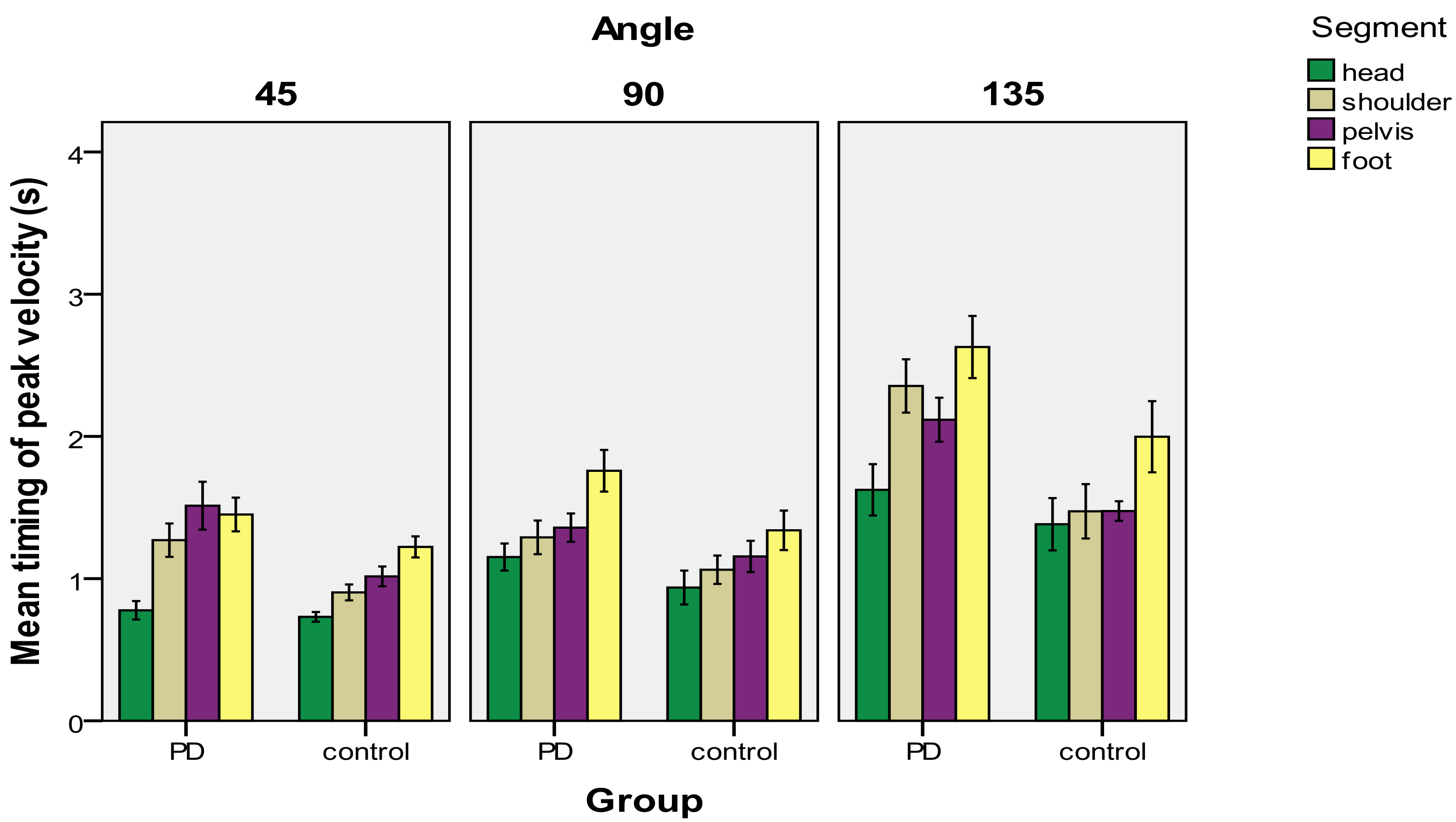


Figure 5.15. Mean and standard error (Error bars: +/- 1 SE) of the timing of peak velocities for the head, shoulder, pelvis and foot when turning to intially affected/non-dominant side - Unpredictable condition.

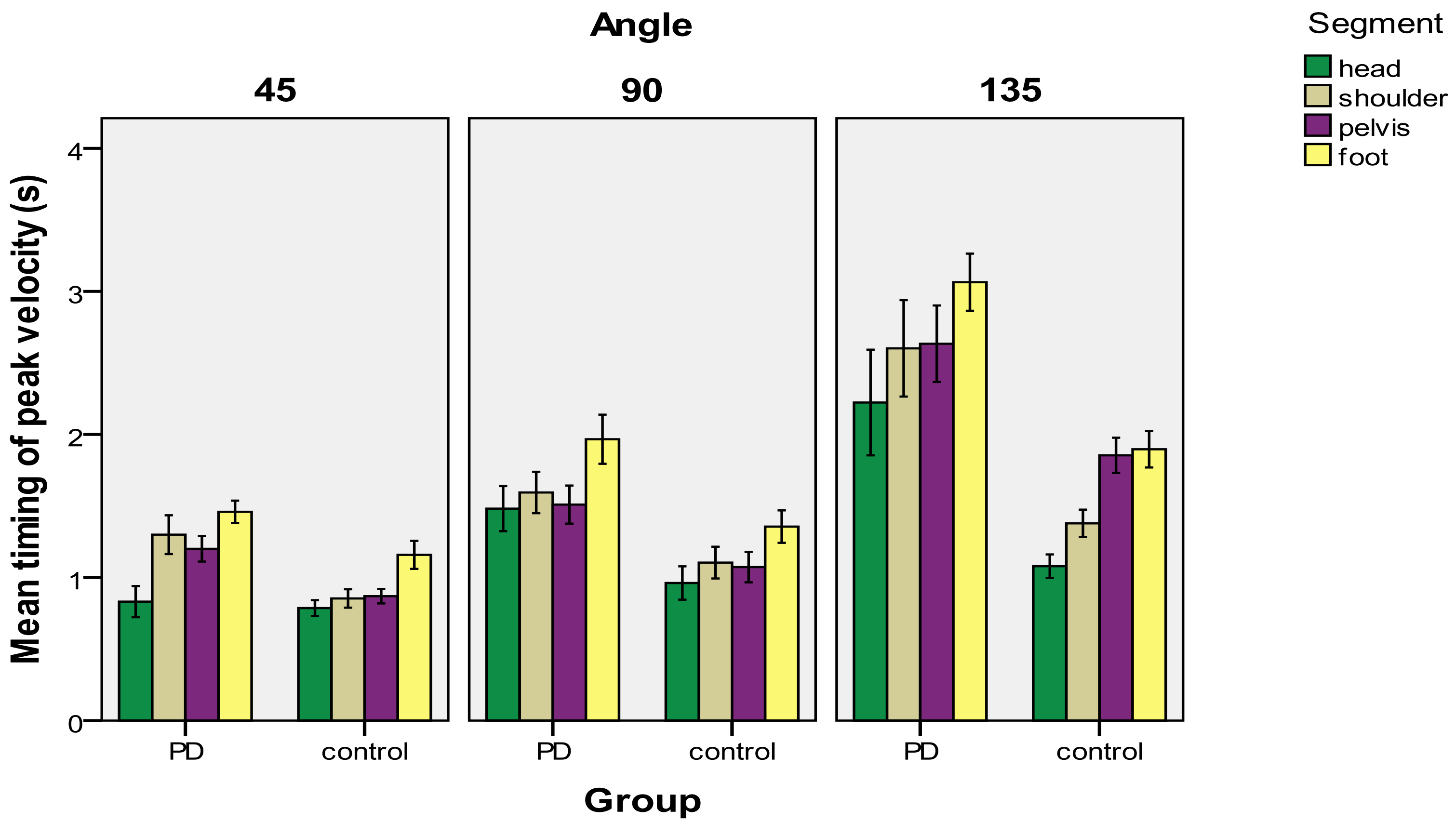


Figure 5.16. Mean and standard error (Error bars: +/- 1 SE) of the timing of peak velocities for the head, shoulder, pelvis and foot when turning to intially unaffected/dominant side - Unpredictable condition.

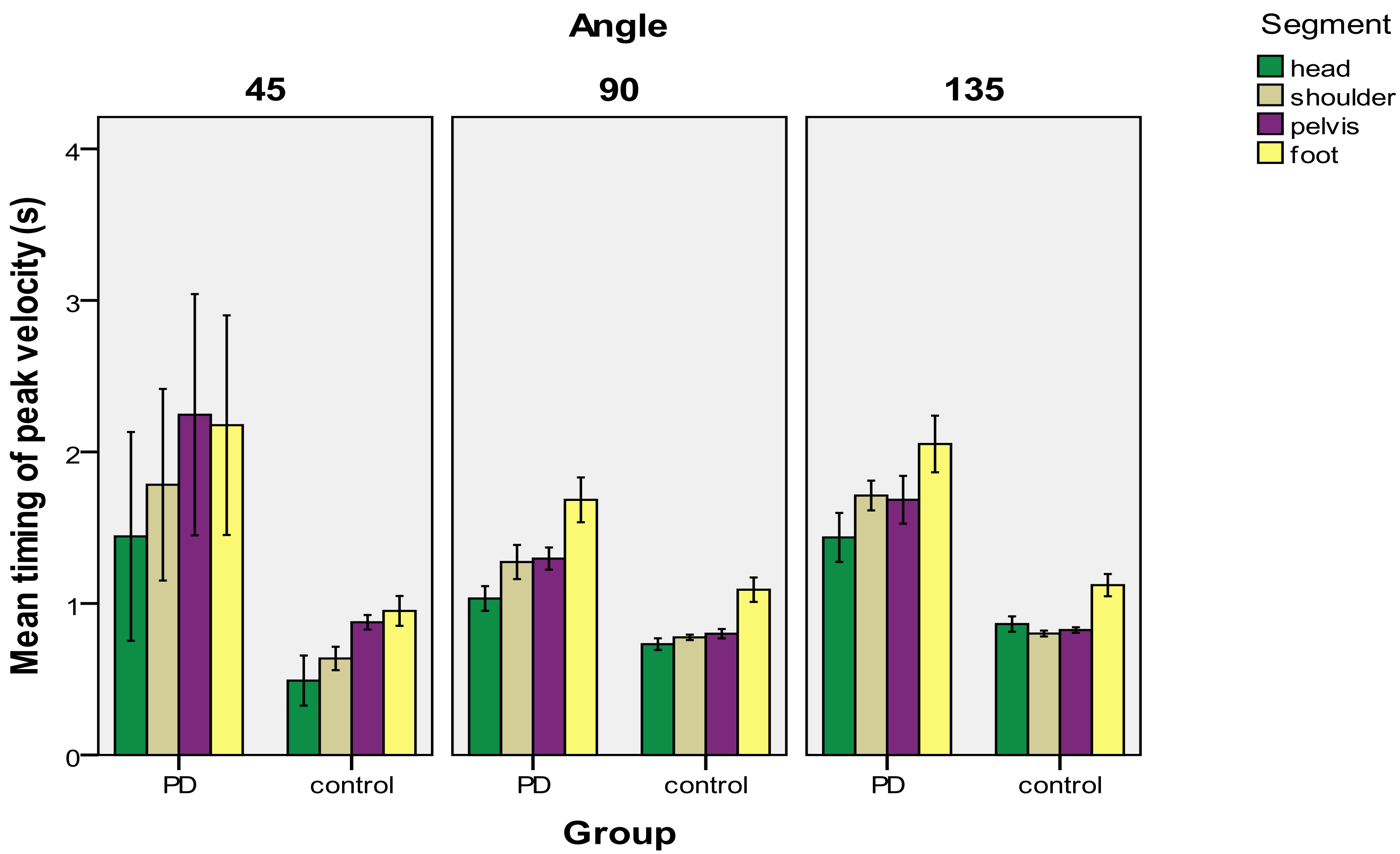


Figure 5.17. Mean and standard error (Error bars: +/- 1 SE) of the timing of peak velocities for the head, shoulder, pelvis and foot when turning to intially affected/non-dominant side - Predictable condition.

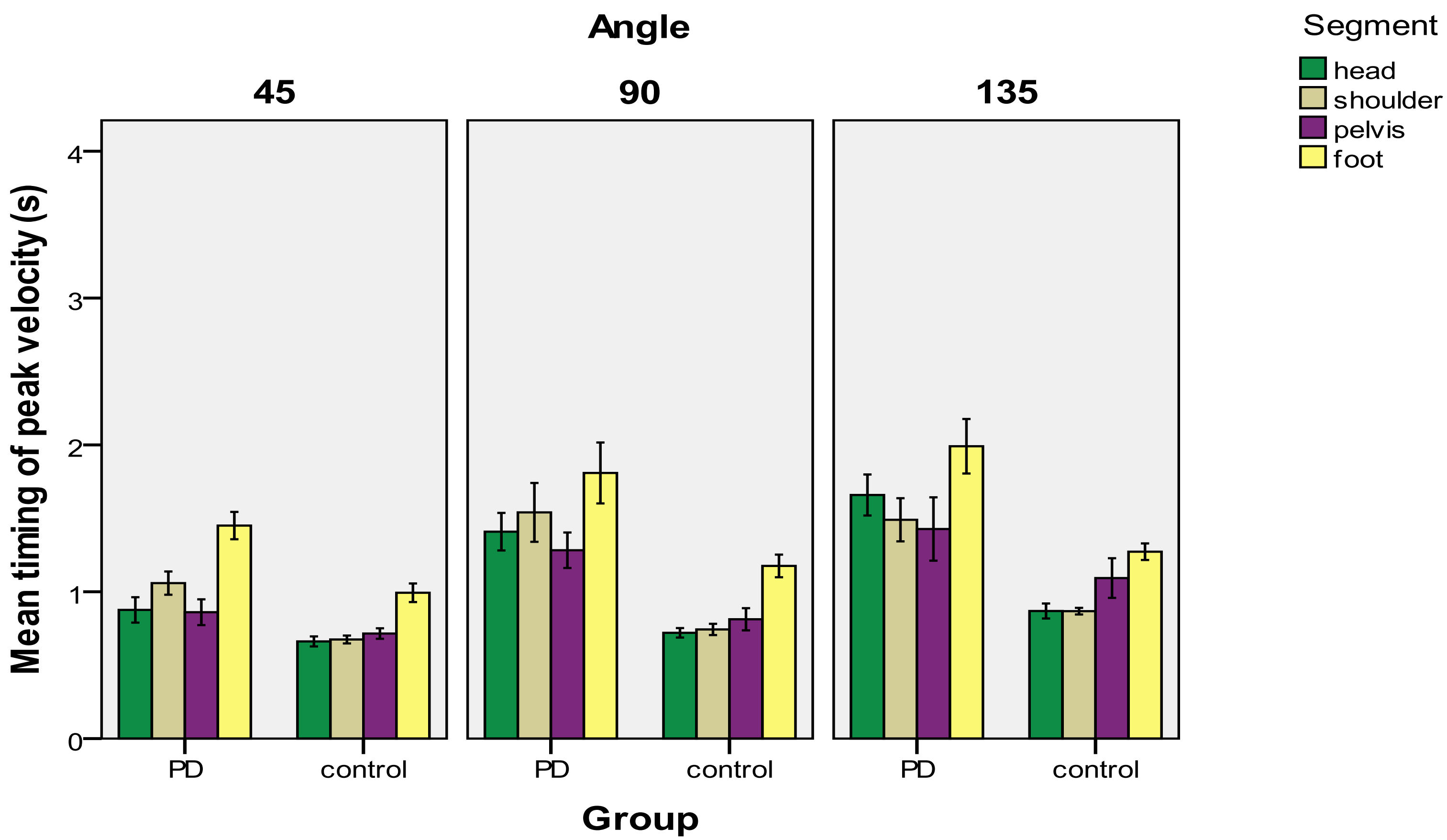


Figure 5.18. Mean and standard error (Error bars: +/- 1 SE) of the timing of peak velocities for the head, shoulder, pelvis and foot when turning to intially unaffected/dominant side - Predictable condition.

The peak velocities of the body segments occurred earlier in the control group as compared to the stroke group (table 5.8 and 5.9). This was shown by the significant main effect of group, $F(1, 18) = 26.918$, $p = 0.001$. The mean (SE) of the timing of peak velocities for the PD and control groups averaged across the two predictability conditions, three angles, two directions and four segments were 1.622s (0.080) and 1.034s (0.080) respectively. There was a significant main effect of predictability on the timing of peak velocity of the segments, $F(1, 18) = 8.364$, $p = 0.010$. This indicated that the peak velocity of the segments occurred earlier when turning to predictable targets as compared to turning to unpredictable targets. The mean (SE) of the timing of peak velocities for the predictable and unpredictable conditions averaged across the three turn angles, two turn directions, four segments and two groups were 1.193s (0.082) and 1.463s (0.063) respectively.

There was an increase in timing of peak velocities with increase in turn angle (table 5.8 and 5.9). This was shown by significant main effect of angle on the timing of peak velocities of the segments, $F(1.113, 20.035) = 25.206$, $p = 0.001$. The mean (SE) of the timing of peak velocities for turns to 45°, 90° and 135° averaged across the two predictability conditions, two directions, four segments and two groups were 1.101s (0.096), 1.228s (0.054) and 1.655s (0.064)respectively. The pairwise comparisons showed that there was a significant difference in the timing of peak velocities when turning to 90° and 135° ($p = 0.001$) and when turning to 45° and 135° ($p = 0.001$) but there was no significant difference when turning to 45° and 90° ($p = 0.354$). The increase in timing of peak velocities with increase in turn angle was shown to be more pronounced in the unpredictable condition (figure 5.19). This was shown by the significant interaction of angle vs predictability, $F(1.320, 23.758) = 11.906$, $p = 0.001$.

Table 5.8. Timing of peak velocities when turning towards initially affected/non-dominant sides – Unpredictable condition

	45°		90°		135°	
	PD [mean(±SE)s]	Control [mean(±SE)s]	PD [mean(±SE)s]	Control [mean(±SE)s]	PD [mean(±SE)s]	Control [mean(±SE)s]
Head	0.777(0.065)	0.731(0.034)	1.152(0.095)	0.937(0.119)	1.624(0.181)	1.382(0.184)
Shoulder	1.270(0.117)	0.903(0.056)	1.290(0.118)	1.063(0.100)	2.355(0.188)	1.473(0.191)
Pelvis	1.512(0.168)	1.016(0.070)	1.358(0.099)	1.156(0.110)	2.117(0.155)	1.475(0.068)
Foot	1.451(0.119)	1.223(0.074)	1.758(0.147)	1.340(0.139)	2.629(0.219)	1.998(0.250)

Table 5.9. Timing of peak velocities when turning towards initially affected/non-dominant side – Predictable condition

	45°		90°		135°	
	PD [mean(±SE)s]	Control [mean(±SE)s]	PD [mean(±SE)s]	Control [mean(±SE)s]	PD [mean(±SE)s]	Control [mean(±SE)s]
Head	1.443(0.689)	0.491(0.165)	1.033(0.081)	0.731(0.038)	1.436(0.162)	0.864(0.051)
Shoulder	1.784(0.632)	0.637(0.077)	1.274(0.113)	0.776(0.018)	1.712(0.098)	0.864(0.019)
Pelvis	2.246(0.796)	0.876(0.048)	1.296(0.073)	0.800(0.031)	1.684(0.158)	0.825(0.018)
Foot	2.177(0.725)	0.951(0.099)	1.684(0.148)	1.091(0.081)	2.053(0.187)	1.121(0.073)

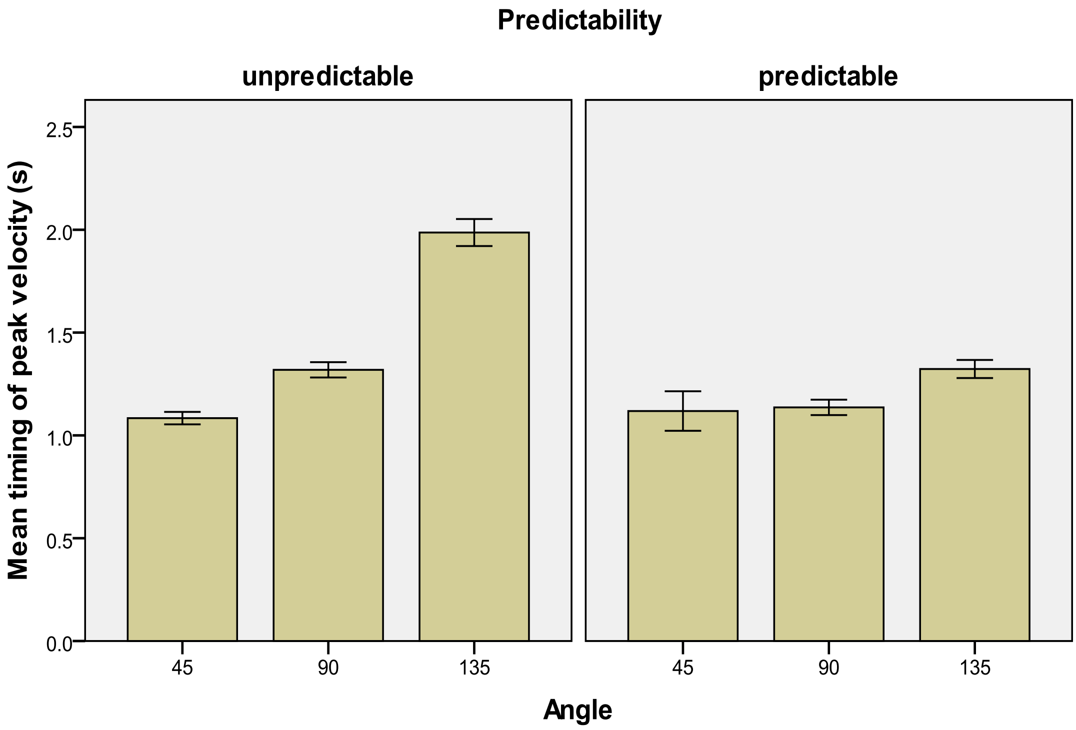


Figure 5.19. Mean and standard error (Error bars: +/- 1 SE) of timing of peak velocity of body segments when turning to 45°, 90° and 135° for each predictability condition averaged across two directions, five segments and two groups.

The results showed that there was no difference in the timing of peak velocities of the segments while turning to both sides in both groups (Figure 5.20). This was shown by the non-significant main effect of direction on the timing of peak velocities of the segments, F (1, 18) = 0.001, p = 0.980 and the non-significant interaction of direction and group, F (1, 18) = 0.046, p = 0.832. The mean (SE) of the timing of peak velocities for turns to initially affected and initially unaffected sides in the PD group averaged across the two predictability conditions, three turn angles, four segments and two groups were 1.630s (0.111) and 1.613s (0.072) respectively. For turns to dominant and non-dominant sides in the control group, the mean (SE) of the timing of peak velocities were 1.028s (0.111) and 1.041s (0.072) respectively.

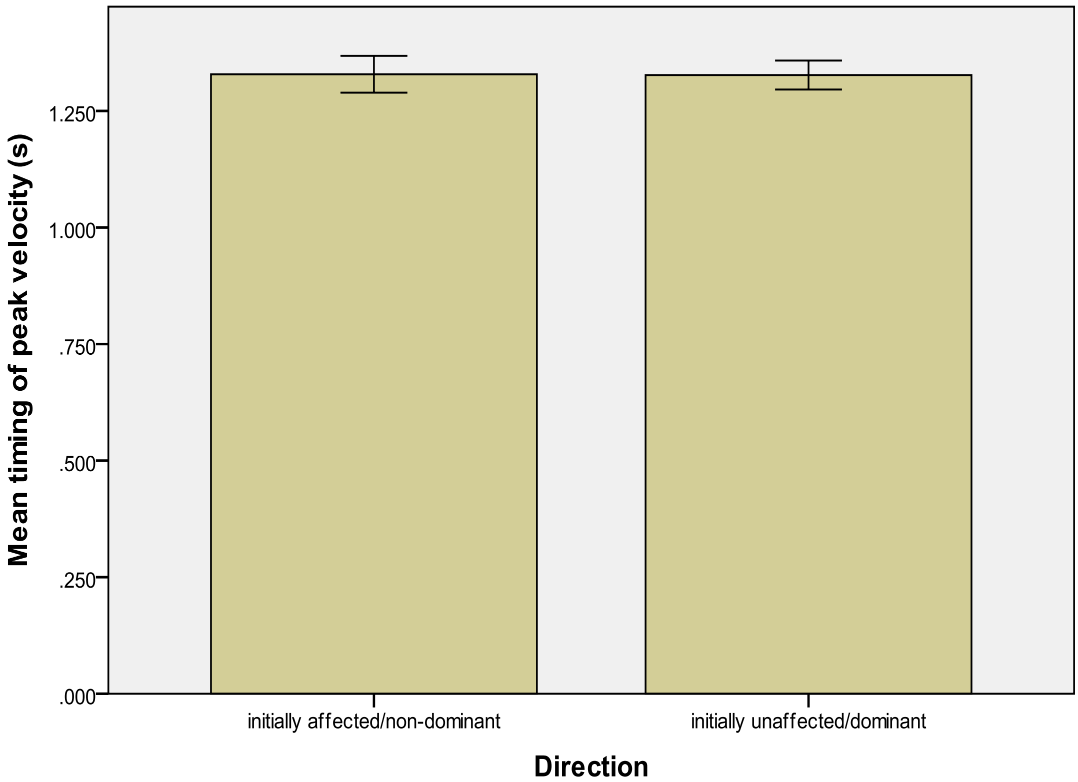


Figure 5.20. Mean and standard error (Error bars: +/- 1 SE) of the timing of peak velocities of body segments when turning to initially affected/non-dominant and initially unaffected/dominant sides averaged across the two predictability conditions, three angles, five segments and two groups.

5.6.5.1. Summary of timing of peak velocities

For most of the turning tasks there was no difference in the timing of peak velocities of the segments (head, shoulder, pelvis and foot). In other instances, especially when turning to 135°, the timing of the peak velocity of the foot occurred separately from the other three segments. The peak velocities of the segments occurred earlier in the control group as compared to the PD group. The peak velocities of the segments also occurred earlier when turning to predictable targets as compared to turning to unpredictable targets. There was an increase in timing of peak velocities with increase in turn angle which was more pronounced in the unpredictable condition. Finally, there was no difference in the timing of peak velocities of the segments while turning to both sides in both groups.

5.7. Discussion

This is the first study to investigate the effect of target predictability, turn angle and turn direction on the sequence of onset latency, peak velocity and timing of peak velocity of body segments during turning on-the-spot in people with Parkinson's disease (PD) and age-matched healthy controls. Previous studies have investigated the effect of target predictability, turn angle and turn direction on the onset latency of body segments in healthy individuals (Hollands et al. 2004; Anastasopoulous et al. 2009). There are also studies that have compared the sequence of onset of rotation of body segments when turning on-the-spot in people with PD and healthy controls (Vaugoyeau et al. 2006 and Akram et al. 2010). These studies investigated sequence of onset of head, shoulder and pelvis when turning to 45° and 90° in response to an audio cue. The studies failed to present data for the movement of the eye and foot which are vital in understanding kinematics of body movement during turning (Hollands et al. 2004). They also limited the investigations to predictable targets that were located at 45° and 90° only.

People with PD initiated rotation of the body segments slower, had lower peak velocities of the segments and achieved peak velocities later than healthy controls. It was hypothesized that there would be differences in the sequence of onset latency, peak velocity and timing of peak velocity of body segments during turning on-the-spot between people with PD and healthy controls. People with PD in this study showed more simultaneous onset of rotation of body segments compared to healthy controls when turning to unpredictable targets placed at 90° and 135°. However, contrary to the hypotheses, the results showed similarities in sequence of onset latencies for all the other turning tasks. There was also comparable sequence of timing of peak velocities between the two groups. When the PD group was turning to 45° to the initially affected side and 90° to both sides the sequence of the peak velocities were different from the control group.

The segments started to move slower and had lower peak velocities in people with PD compared to healthy controls. Vaugoyeau et al. (2006) also reported significantly longer onset latencies of head shoulder and pelvis when turning to 45° in response to an auditory cue. People with PD have been shown to have longer response times than controls in other reaction time studies (Rogers et al., 1987, Pullman et al., 1988, Georgiou et al., 1994). One of the cardinal features of Parkinson's disease is bradykinesia which is characterized by reduction in the speed of initiating and executing a movement and the progressive reduction of the speed and amplitude of the movement when it is repeated (Berardelli et al., 2001). The inability of the basal ganglia to properly select appropriate movement strategies could lead to delay in starting or executing the movement. Another factor that could lead to slowing down of movement in people with PD could be the cocontraction of muscles during movement especially in axial muscles (Mak et al., 2007). Instead of relaxing while the agonists are contracting, contraction of antagonistic muscles could slow down the movement.

The ability of the cognitive system to utilize relevant sensory information to plan a movement is important for the initiation and execution of functional tasks. However, this could be ruled out as the participants with PD in this study had high cognitive status as measured by the Montreal Cognitive Assessment. Other factors that could explain the slow movement during turning in people with PD may be fear of falls and freezing. All but two of the PD participants in this study were fallers and all reported freezing episodes. The slowness of movement due to fear of falls may therefore be a coping strategy to remain safe during the turn. However, when there is need to quickly avoid obstacles in the turning path the slow movement may be a cause for concern. Furthermore, if people with PD respond to postural disturbances slowly, then it could be detrimental to the appropriate postural adjustments needed to maintain balance. It is therefore important to investigate the response of people with PD to postural disturbances.

The current study also showed that the segments started to rotate faster when turning to predictable targets as compared to turning to unpredictable targets in both PD and control groups. Anastasopoulous et al. (2009) reported that healthy adults showed earlier onset of rotation of segments when turning to predictable targets. The location of the targets is unknown prior to the visual cue appeared in the unpredictable condition, the participants therefore had to locate the target before turning to it. The participants could therefore take longer to start the movement because of the delay in locating the target. This means that there is an advanced motor planning which specifies the components of muscle activity required for the movement even before illumination of the visual target in the predictable condition. This is in line with a model of movement preparation in which the spatial goal of the movement is first known before visual feedback is used to guide the movement (Hansen et al. 2006).

Although target predictability affected the onset latency of the body segments, the peak velocity of the segments was similar for the unpredictable and predictable conditions. The brain requires sensory information about the location of the target to turn to before issuing the command for the movement (Brodal 1998). With unpredictable target presentation, the brain awaits for that information to reach it after the cue for the turn has been given. This delay could have accounted for the differences in the onset latencies between the two predictability conditions. The peak velocity occurs after the onset of the movement and therefore may not be influenced by the information given before the start of the movement. Rather the peak velocity could be influenced by the constant updating of the central nervous system by the sensory systems which may be the same for both predictability conditions after the start of the movement. Patla et al. (1997) argued that the initial planning of movement from one direction to another has to be visually mediated. Once the movement has started, other sensory modalities, in particular the kinaesthetic system can come to play in the modulation of the movement.

The results outlined in chapter five showed that there was a trend for an increase in latency with increase in angle of turn. However, this difference was more pronounced in the unpredictable condition. A similar result was obtained by Hollands et al. (2004) while young adults were turning to unpredictable lights placed at 45°, 90° and 135°. However, in the current study there was no significant difference in onset latency when turning to 45° and 90° in both groups. This could be explained by the visibility of the target lights. The participants had to guess the location of the light (whether to the right or left) when turning to 135° in the unpredictable condition. The delay in deciding which side to turn to and the time it takes to ensure the choice was right could have caused the delay in onset of rotation when turning to 135°. The non-significant differences in onset latency when turning to shorter angles was mirrored in the study of Mak et al. (2008) when people with PD and controls turned to 30° and 60° while walking. When turn angle increased from 30° to 60°, there was no significant increase in the onset time for body segments in either group (Mak et al. 2008).

An effect of target predictability on the sequence of onset of rotation of the segments was observed. While the eye, head and shoulder started rotating at the same time in the unpredictable condition, the eye sometimes started to move after the head and shoulder in the predictable condition. Anastasopoulous et al. (2009) reported a similar sequence with the eye initiating the movement when target presentation was unpredictable while the head sometimes initiated the movement with predictable target presentation. Most studies investigating sequence of rotation of segments during turning while walking have shown a clear top to bottom sequence of rotation of body segments with the eyes and head leading (Hollands et al. 2002, Grasso et al. 1998, Patla et al. 1999). This was shown for turns towards both predictable and unpredictable targets. On the other hand, the sequence of rotation of body segments was shown to be different when turning on-the-spot to predictable and unpredictable targets (Hollands et al. 2004, Anastasopoulous et al. 2009). The current study also supports the differences between turns to predictable and unpredictable targets when turning on-the-spot.

The movement of the eye and head before that of other body segments when turning while walking may serve the purpose of scanning the environment so that movement of the other segments could be programmed based on the information acquired. If there are obstacles that need to be avoided, the visual feedback may send information back to the brain for re-programming of the movement. The environment keeps changing dynamically while walking, explaining why the eye and head may consistently have lead other segments when turning during walking. When turning on-the-spot, individuals are aware through memory of their immediate environment and therefore may not need to scan the environment at the start of the movement. However, the fact that the eye did not lag behind the other segments when turning to unpredictable targets could have been for the purpose of locating the target.

Hollands et al. (2002) observed that participants' gaze was aligned with environmental features lying in their current plane of progression or on features related to known or potential future routes. Land and Furneuax (1997) also noted that gaze typically precedes initiation of any subsequent body action during driving. These show that the gaze anticipation is for scanning the environment to update the central nervous system (CNS) about possible obstacles and not just as part of a pre-programmed CNS role. If the gaze anticipation was a robust behaviour programmed by the CNS, then it would have been observed consistently when turning on-the-spot to both predictable and unpredictable targets.

The en bloc rotation of the eye, head and shoulder in the PD and control groups in the current study is in contrast to the separate onset of rotation of the segments in the study of Hollands et al. (2004) in healthy young adults. Eye movement is usually generated together with head movement as part of the gaze reorientation process. Coordinated eye and head movement have been shown in healthy adults when turning while walking (Grasso et al. 1998 and Hollands et al. 2002). The receptor cells of vestibular apparatus that detect rotational and translational motion of the head have been shown to project to the eye for fixation of the eye on objects during head motion (Kemp 2010). Therefore, a strong link exists between rotation of the eye and head as noted in the current study and in studies of turning while walking. The separate rotation of the eye and head in the study of Hollands et al. (2004) may have been due to the equipment used in measuring the eye movement (electro-oculography) which measures movement of the eye through signals generated from electrodes placed on certain eye muscles. However, the simultaneous onset of rotation of the head and shoulder could have been due to the axial rigidity in the PD group and the degenerative changes of an aging spine in the control group.

The results also showed that there was more simultaneous onset of segments with increase in turn angle when turning to unpredictable targets in the PD group. The pelvis and foot started to rotate separately when turning to 45° while they started to rotate simultaneously when turning to 90°. When turning to 135°, all the segments started rotating simultaneously. Healthy young adults have been shown to maintain a top to bottom sequence of onset of rotation of body segments with increasing turn angles during turns to unpredictable targets (Hollands et al. 2004). Although movement of the upper segments may shift the centre of mass within the base of support before the lower segments begin to move, young healthy adults may be equipped with appropriate postural adjustments that ensure balance is maintained.

Many factors could explain the more simultaneous onset of rotation of the segments in participants with PD. Firstly, axial rigidity is a common presentation in people with PD (Mak et al. 2007). These could result in the loss of the fluidity that is required for the coordination of body parts during turning. Secondly, the inability of the basal ganglia to properly select appropriate movement strategy could lead to inaccuracy in the facilitation of a movement pattern especially when the movement involves more than one body part (Rodriquez-Oroz et al., 2009). Turning around is a multi-joint task, therefore people with bradykinesia may have problem with coordination of body segments when turning due to the slowness and inaccuracy of the movement of the segments. People with PD also present with postural disturbances (Gelb et al., 1999) which could explain the simultaneous onset of rotation of the segments due to possible compensatory strategies.

People with PD have been reported to have more simultaneous onset of rotation of head, shoulder and pelvis as compared to healthy controls when turning to 180° in the absence of a cue (Hong et al., 2009). This is in line with the results of the current study which reported more simultaneous onset of rotation of segments when turning to 135° in people with PD as compared to healthy controls. However, It should be noted that in the study of Hong et al., (2009) the participants were instructed to start the turn when they were ready without any cue given while in the current study a visual cue was used for the start of the turn. Crenna et al. (2007) recruited people with PD with mild clinical impairments to observe if other factors could explain incoordination of body segment rotation apart from severe motor deficits. They reported that people with PD started rotating the head and upper trunk simultaneously when turning 90° while walking. On the other hand, their control counterparts started rotating the head followed by the upper trunk. Although the PD participants in the current study also had mild clinical impairments they started rotating the head and shoulders simultaneously just like their control counterparts. However, the participants in the study of Crenna et al. (2007) turned while walking while the participants in the current study turned on-the-spot.

The sequence of peak velocities of the segments was the same when turning to predictable and unpredictable targets in both groups. This indicates that predictability of a target does not affect sequence of peak velocity of segments during turning on-the-spot. However, the sequence of peak velocity of the segments was different across the three turn angles. The peak velocity of the head and shoulder were similar when turning 45° to both sides in both groups. The peak velocity of the pelvis was lower than that of the foot when turning to 45° in both groups except when turning to the initially affected side in the PD group. This could be due to the motor asymmetry that exists in people with PD with more marked involvement on the body side first affected (Toth et al. 2004, Djaldetti et al. 2006). This may have caused the reduction in the speed of the initially affected foot and hence the similar peak velocity with the pelvis. The peak velocity of the head and shoulder were not significantly different when turning 45° to both sides in the control group. However, the peak velocity of the head was higher than that of the shoulder when turning to 90° and 135°. Since humans are capable of carrying out eye-only gaze shifts as large as 55° (Guitton and Volle 1987), the velocity of the head may not need to be increased to facilitate scanning the turn pathway during the turn.

However, turns to 90° and 135° that are out of the range for eye-only gaze shifts, the velocity of the head may have increased more than that of the shoulder to facilitate scanning of the turning pathway.

The ability to maintain the centre of mass (COM) within the base of support (BOS) is very important during functional activities. An abnormally high or low speed of movement of body segments in relation to other body segments may challenge the maintenance of the COM within the BOS especially in people with PD who have postural disturbances and problems of freezing. When a PD patient encounters freezing during turning and some segments exhibit abnormally higher speed, the COM may move away from the BOS. Since the feet may have difficulty shifting to widen the BOS, stability may therefore be lost. Indeed all the PD participants in this study reported freezing of gait and all but two participants reported history of falls. However, it could not be known from this study if the coordination of their body segments had anything to do with the falls.

For most of the turning tasks there was no significant difference in the timing of peak velocities of the segments (head, shoulder, pelvis and foot). In other instances the timing of the peak velocity of the foot occurred separately from the other three segments. Akram et al. (2010) Reported that the head reached its peak velocity earlier than the shoulder and pelvis when older adults were turning towards predictable targets located 90° to the right. However, the timing of the peak velocities of the shoulder and pelvis were not different as in the current study. The head may have reached its peak velocity earlier than the shoulder in the study of Akram et al. (2010) due to the reference point for measurement of the timing of the peak velocity which was different from that of the current study.

Chapter 6

General discussions

6.0. Introduction

This chapter presents the general discussions, highlights the studies' contribution to knowledge and relevance of the findings to clinical practice. Limitations of the studies are stated and recommendations for further studies are also given.

6.1. General summary of findings

The results showed that the people with stroke and Parkinson's disease (PD) initiated the movement of the segments later, had lower peak velocities and attained the peak velocities later than their control counterparts. People with PD showed more simultaneous onset of rotation of body segments as compared to their age-matched control when turning to 90° and 135°. The sequence of onset of rotation of the body segments was similar between the people with PD and their age-matched controls for all the other turning tasks. People with stroke also had comparable sequence of onset of rotation of body segments with their age-matched controls for all the turning tasks. While people with stroke presented with a consistent pattern of peak velocity of the body segments for all the turning tasks, their control counterparts showed differences in the pattern of the peak velocities when turning to dominant and non-dominant sides. People with PD showed similar peak velocities of pelvis and foot when turning 45° to initially affected side as compared to separate peak velocities of the pelvis and foot in the stroke and control groups. The peak velocities of the segments (head, shoulder, pelvis and foot) occurred at the same time for most of the turning tasks.

6.2. General discussions

Turning around to interact with the environment is a common activity of daily living which is controlled by the interaction of sensory, motor and cognitive processes. Sensory systems (visual, vestibular and proprioceptive) provide information about the relationship of the body parts to each other and to objects in the environment (Brodal 1998). Integration of the sensory information by the cognitive system is essential for planning the movement strategy (Montgomery and Connolly, 2003). The brain utilizes the processed information to issue commands for the activation of specific movement components which, when linked together in the appropriate spatial and temporal sequence, make up the desired task (Carr and Shepherd, 1987).

People with neurological conditions such as stroke and Parkinson’s disease (PD) present with impairments of the sensory, motor and cognitive systems and thus could present with movement incoordination. Indeed, both people with stroke and PD have been reported to have high incidence of falls while turning around (Ashburn et al. 2001; Stack et al. 1999; Hyndman et al 2002; Harris et al 2005). The experience of a fall event is an important issue which needs to be prevented due to its adverse consequences such as injuries or fear of subsequent falls. In healthy adults, falling while turning was shown to be 7.9 times more likely to cause a hip fracture than falling while walking straight ahead (Cumming and Klineberg 1994). Injuries that result from falls are also high in people with stroke and PD. About 30% of people with stroke that fall sustain injuries (Nyberg and Gustafson 1995; Teasell et al. 2002). Injuries have also been reported to occur in about 65% of people with PD that fall (Wielinski et al. 2005; Balash et al. 2005). Apart from the injuries, fear of subsequent falls hinders performance of some activities of daily living (Bloem et al. 2001). To prevent falls and the consequences that ensue due to the falls, there is need to identify the cause of the falls. It is not well understood why people with stroke and PD fall often but impairment in movement coordination may partly explain the reasons for the falls (Lamontagne et al. 2007; Crenna et al. 2007).

Coordination of body segments during turning is an important aspect of functional movement which has not been fully investigated in people with stroke and PD especially since a number of factors such as target predictability, turn angle and turn direction could influence turning strategy in different ways. The current study therefore investigated whether people with stroke and PD present with impairment of movement coordination during turning. The effect of target predictability, turn angle and turn direction on the sequence of rotation of body segments (eye, head, shoulder, pelvis and foot) during turning in people with stroke and PD as compared to age-matched healthy controls was also investigated.

The results of this study have shown that people with stroke and PD started rotating their body segments later, had lower peak velocities and reached the peak velocities later than age-matched healthy controls. The healthy controls who were older adults, moved faster than the stroke and PD groups even though older adults have been shown to move slower than young adults (Thigpen et al. 2000; Hultsch et al., 2002). Significant earlier body segments rotations in healthy participants as compared to people with stroke (Lamontagne et al. 2005) and Parkinson's disease (Crenna et al. 2007) have been shown in turning studies. People with stroke and Parkinson's disease have also been shown to have longer response times than controls in other reaction time studies (Kaizer et al. 1998; Mayo et al. 1990; Rogers et al. 1987; Pullman et al. 1988; Georgiou et al. 1994).

The slower onset latency in the people with stroke and PD in the current study was even more when turning to unpredictable targets that are out of the visual field. Higher onset latencies of body segments when turning to unpredictable targets compared to turning to predictable targets have been shown in healthy adults during turning on-the-spot (Hollands et al. 2004) and while walking in healthy young adults (Patla et al. 1999; Hollands et al. 2001), healthy older adults and in people with stroke (Hollands et al. 2010a). The current study has therefore shown for the first time that the onset latency is slower when turning to unpredictable targets compared to predictable targets during turning on-the-spot in people with stroke and PD. The uncertainty in the location of the target in the unpredictable condition may have led to an increase in the time required to centrally process the movement (Hansen et al. 2006).

There was an increase in onset latency with increase in turn angle in the people with stroke and PD and their control counterparts in the current study. Hollands et al. (2004) reported a similar pattern in young adults when turning to the same turn angles as the current study (45°, 90° and 135°). However, Mak et al. (2008) reported no significant difference in onset latency when turning to 30° and 60° in people with PD and age-matched healthy controls. The presence of the cue within the visual field may explain the differences in the results of the studies. While targets placed at 60° may be detected by the eyes, targets placed at 90° may require a saccade to confirm the appearance and/or location of the targets before starting the turn. This delay could have ensured that there is a difference between onset latencies of the segments for turns to 45° which is within the visual field and turns to 90°.

The slowness of movement in people with stroke and PD could be explained by their pathologies. People with stroke present with inability to generate normal muscle force (Canning et al., 1999). This could be due to interruption of the excitatory impulses by the lesion (Kautz et al., 2005) or decrease and/or abnormal recruitment of motor neurone units (Choi et al., 2007). The muscular paralysis/paresis that ensues could decrease the ability of the muscle to produce the force required to initiate or control the movement. People with PD on the other hand present with reduced activation of cortical and brainstem motor regions due to degeneration of doperminergic neurons (Rodriquez-Oroz et al., 2009). They are also characterized by the slowing of information processing due to the impairment of working memory (Lewis et al., 2005). These factors could lead to an increase in response latency and decrease of speed of movement.

In our study, we found a relatively longer onset latency in people with stroke [onset latencies averaged across turning tasks= 0.839s (SE=0.066)] compared to people with PD [onset latencies averaged across turning tasks= 0.797s (SE=0.048)], however, the difference was not statistically analyzed. Furthermore, people with stroke showed relatively higher peak velocities compared to people with PD [stroke: 190°/s (SE=8.88), PD: 177°/s (SE=6.42)], as well as a relatively shorter time to reach the peak velocity [stroke: 1.498s (SE=0.096), PD: 1.622s (SE=0.080)]. How fast an individual initiates a movement depends on the integrity of the sensory, motor and cognitive systems. People with stroke and PD are both reported to have impairments of the sensory, motor and cognitive systems. The delay in initiating a movement may be compounded in people with stroke due to the postural concern of supporting the body weight on the paretic limb when initiating the turn with the non-paretic limb or due to delay in initiating the turn with the paretic limb which is weaker (Tokuno and Eng 2006). However, once the movement has started, people with stroke may move faster to reach the target to avoid prolonging the support of the weight of the body on the paretic limb (Hesse et al. 1997; Kim and Eng 2003). People with PD on the other hand are characterized with slowing down of movement (Berardelli et al., 2001) and the use of multiple steps (Stack et al. 2004), factors that could explain any possible shorter peak velocities and time to reach the peak velocities as compared to people with stroke.

Longer response times have been reported to be associated with high risk of falling (Mayo et al. 1990) as shown by an increase in risk of falling with increase in response time in people with stroke. Although slowness of movement in general may be a compensatory strategy to avoid losing stability during turning in people with stroke and PD (Lamontagne et al. 2005), slower onset latency may predispose them to falls in situations where an obstacle needs to be quickly avoided. An example is when a moving object is detected in the visual field and fast onset latency is required to avoid an encounter with the approaching object. When there is already an encounter with an obstacle, people with stroke and PD may present with a slower response to the perturbation that results and could end up falling (Marigold et al. 2005; Chong et al. 2000). However, since movement initiation and response to perturbation access different neurological pathways (Brodal 1998), it cannot be inferred from this study that people with stroke and PD would respond slowly to perturbation.

Turning involves the movement of several segments in a coordinated fashion and the response time of individual segments may not explain the relationship of the overall movement to stability. Hence, the investigation of the relationship of the movement of the various segments involved in turning is very important. To maintain upright stance while turning, movement and posture need to be coordinated. Movement can perturb posture through the generation of forces at the body segments involved in the movement (Massion, 1992). However, postural adjustments are available to prevent or minimize the displacement of the centre of mass and thereby ensure safe performance of the movement. The body is formed of multiple segments each linked to the next by sets of muscles. When movement is performed by a standing subject, the position of the segments change and as a result, the centre of mass is displaced within the base of support (Massion, 1992). The relative movement of the segments is controlled by the CNS through muscle contractions. However, sensory information through visual, vestibular, and proprioceptive systems, guide the movement and ensure the appropriate rotation of one segment upon the other. The representation of the position of body segments is based on muscle proprioception which conveys information about the position of a given segment with respect to the others (Ropper and Brown, 2005). Movement of the eye and head are also controlled by the visual and vestibular systems in a reflex referred to as vestibulo-ocular reflex (Laurutis and Robinson, 1986).

The information gathered about the position of body segments by the visual, vestibular and proprioceptive systems is sent to the primary cortex to guide the movement (Bear et al., 2001). However, the information is also sent to brainstem structures (Brodal, 1998) so that postural adjustments are set in place to prevent loss of stability. In a situation in which the nervous system fails to produce a coordinated movement of the body segments either due to a central lesion or impairment in the sensory systems, the maintenance of upright stance may be jeopardized. The postural adjustments that could counteract the problem may either receive inadequate information or may be defective placing an individual at risk of losing stability and subsequent falls. It is therefore important to ask the question, does damage to the CNS leads to impairment in coordination of body segments? The aim of this study was to investigate the coordination of body segments during turning on-the-spot in people with stroke and Parkinson’s disease as compared to age-matched healthy controls.

People with stroke and Parkinson's disease could present with sensory and motor problems that could compromise the coordination of their body segments during turning. Incoordination in people with stroke could result from disruption of muscle activation pattern (Bourbonnais et al. 1992) leading to inability to move a single joint without generating movement in other joints. Similarly, people with PD present with axial rigidity (Wright et al., 2007) which could result in the loss of fluidity that is required for the coordination of body parts during turning. Hence, it was hypothesized that people with stroke and PD would present with a different pattern of movement of body segments during turning as compared to healthy controls.

The results showed that when turning to unpredictable targets, people with PD had more simultaneous onset of rotation of the segments when turning to 90° and 135° than people with stroke who had similar sequence of rotation of the segments as their control counterparts. Both groups initiated the turn with the eye, head and shoulder in unison. However, the pelvis and foot started rotating in unison also in the people with PD as opposed to separate onset of rotation in the people with stroke when turning to 90°. When turning to 135°, all the segments started to turn simultaneously in people with PD, while the pelvis and foot started rotating after the eye, head and shoulder in people with stroke. This means that there was more simultaneous rotation of the segments when turning to unpredictable targets in the PD group. Although people with stroke present with spasticity and stiffening of muscles around the joints that could cause en-bloc rotation of body segments (Sommerfeld et al., 2004), people with Parkinson's disease present with axial rigidity, a factor that could be more restraining to the smooth movement of body segments (Mak et al., 2007). Furthermore, stroke is a chronic disease that is characterized by some recovery within the first few months while PD is a progressive disease. Indeed, Verheyden et al. (2010) have shown that coordination of head and trunk may be altered early after stroke but recover over time towards the level of healthy subjects.

There are many arguments with regards to the coordination of body segments during turning in people with stroke and PD. Hong et al. (2009) reported more simultaneous onset of rotation of head, trunk and pelvis in people with PD compared to healthy controls when turning on-the-spot to predictable targets placed at 180°. Similarly, Crenna et al. (2007) reported more simultaneous onset of rotation of head and upper trunk in people with PD when turning to predictable targets placed at 90° while walking. These results seem to be similar to the results of the current study in which there was more simultaneous onset of rotation of body segments in people with PD compared to healthy controls when turning to unpredictable targets placed at 90° and 135°. However, the current study showed similarities between people with PD and the controls when turning to predictable targets placed at all the three angles which are contrary to the results of Hong et al. (2006) and Crenna et al. (2007). On the other hand, there are no studies that have investigated coordination of body segments when turning on-the-spot in people with stroke. The results of the investigations of coordination of body segments during turning while walking in people with stroke are conflicting. While Lamontagne et al. (2007) and Lamontagne and Fung (2009) showed more simultaneous onset of rotation of eye, head, thorax and pelvis in people with stroke compared to controls when turning to 90° during walking, Hollands et al. (2010a and 2010b) showed similarities in onset of rotation of head, trunk and pelvis between people with stroke and controls when turning to 45° and 180°.

It is not clear what causes the differences in the sequence of rotation of the body segments across the studies for both people with PD and stroke. The effect of the factors that are associated with turning (target predictability, turn angle and turn direction) have been investigated in separate studies whose participants have different characteristics. The procedures and instruments for data collection were also different across the studies. Furthermore, the number of segments investigated varied across the studies. The current study is therefore unique as it provides information about the effect of the factors within a single study using the same procedure, equipment and participant sample. It also aids in comparing between conditions with different pathologies (stroke and PD).

There were similarities in the sequence of onset of rotation of the segments between the stroke and PD groups on one hand and the healthy controls on the other hand; we noted a simultaneous onset of rotation of the eye, head and shoulder in the unpredictable condition. Hollands et al. (2004) reported a different sequence in healthy young adults with the eye, head and trunk rotating separately in a top to bottom sequence. This raises the question as to whether age of the controls in the current study played a role in the similarities of the sequence. Older adults have been reported to have sensory and motor problems (Lord et al., 1996), factors that could affect coordination of body segments during turning. Indeed, the elderly have been shown to have incoordination of movement of body segments during turning tasks as compared to healthy young adults (Paquette et al., 2008). Therefore, the healthy controls in the current study may have had similar sequence of onset of rotation of segments as the stroke and PD groups due to the fact that they are also vulnerable to impairment in movement coordination. However, the differences in the sequence of onset of rotation of the segments between the study of Hollands et al., (2004) on one hand and that of the current study on the other should be interpreted with caution. This is because the studies used different equipments and marker placement procedures for the measurement of onset latencies of the eye.

Our results have also indicated that there was a difference in sequence of onset of rotation of the eye, head and shoulder between turns to predictable and unpredictable targets. While the eye, head and shoulder started to rotate simultaneously when turning to unpredictable targets, the head and shoulder sometimes started rotating before the eye when turning to predictable targets. This is contrary to what has been consistently reported when turning while walking. The eye and/or head have consistently being shown to lead the trunk when turning to both predictable (Grasso et al. 1998, Patla et al. 1999, Fuller et al. 2007, Paquette et al. 2008, Akram et al. 2010) and unpredictable (Patla et al. 1999, Hollands et al. 2001) targets while walking in healthy adults. People with stroke showed a similar pattern with the head leading the trunk and pelvis in both predictable and unpredictable turns while walking (Hollands et al. 2010a), however, the eye movement was not recorded in the latter study.

A review of the literature has shown a consistent pattern of coordination of body segments when turning while walking with the eye and/or head leading in both predictable and unpredictable conditions. The current study on the other hand has shown that the head and shoulders sometimes preceded the movement of the eyes in the predictable conditions when turning on-the-spot. A possible explanation for this difference in strategy of turning may be the need to scan the environment in anticipation of obstacles in the direction of turning. When turning on-the-spot, participants already are aware of the immediate surrounding before the start of the turn, however, while turning during walking the environment may keep changing and may require importance of the scanning for both predictable and unpredictable conditions. This is supported by the findings that during turning while walking, for the large majority of the time participants' gaze was aligned with environmental features lying in their current plane of progression during both predictable and unpredictable trials (Patla et al. 1997). Hollands et al. (2002) also showed that participants' gaze was consistently aligned with environmental features lying in their current plane of progression, prior to, and following a change in walking direction.

The movement of the eye and head before the other segments for both predictability conditions during walking may therefore be meant for scanning the environment so that movement of the other segments will be programmed based on the information acquired. If there are obstacles that need to be avoided, the visual feedback may send information back to the brain for re-programming of the movement. If the ability to scan the environment prior to the whole body movement is lost, the movement may not be adapted to the environmental situation and may lead to loss of stability. The current study has therefore pointed to the fact that the initiation of turning with the eye and head is not a robust mechanism that occurs in all situations but depend on the task at hand and the need to scan the environment for potential hazards. This is supported by the studies of Land (2004) and Land et al. (1999) who reported that the eye lagged behind the head and trunk when turning while manipulating objects.

The simultaneous onset of rotation of the head and shoulder in the people with stroke, PD and the healthy controls in the current study is also contrary to the sequence shown in healthy young adults when turning on-the-spot were the head started rotating before the trunk (Hollands et al. 2004; Earhart and Hong 2006; Anastasopoulous et al. 2009). However, it is in line with the sequence reported in healthy older adults (Akram et al. 2010) and people with PD (Hong et al. 2009) when turning on-the-spot. Onset of rotation of the head together with the shoulder in the current study may mean that there could be some restrictions in the movement of the head that led to earlier rotation of the shoulder as in the study of Hollands et al. (2001) where restricting the head resulted in earlier movement of the trunk. Thus, there was no significant difference between onset of head and trunk. Franzen et al. (2009) reported that people with PD had significantly higher tone in the body axis which was more prominent in the neck. People with stroke (Keshner 2000) and older adults (Trott et al. 1996) have also been reported to present with neck muscle stiffness that could restrict movement of the head.

Many researchers have suggested that the movement of the head plays an important role in transporting and stabilizing the eye to acquire information that is needed as a guidance platform for movement of other parts of the body during turning (Prevost et al. 2002). Restriction in the head movement may therefore lead to earlier trunk rotation that assists in transporting the head to acquire the necessary information. However, restrictions in the head movement and the earlier rotation of the trunk have been shown to cause postural changes that may have important postural consequences (Hollands et al. 2001). Spildooren et al. (2012) showed that a head-first attention strategy in people with PD who were instructed to start the turn with their head first helped in separating the onset of head and trunk. The current study has therefore identified an important potential coordination deficit (simultaneous onset of rotation of head and shoulder) which could be targeted clinically to improve the gathering of visual information by the visual system and postural stability during walking.

Onset latency is an important parameter for the description of motor coordination as explained by Bourbonnais et al. (1992; pg S58) that a coordinated movement “is the net result of activity in several muscles that share a precise temporal and spatial pattern of onset”. However, the onset latency relates the movement of the segments at the start of the turn only. Problems of body segment coordination during turning may be present at other points in the movement trajectory apart from the point of onset of the movement. Winter (2009) explained that with each body segment in motion, the centre of mass (COM) of the total body is continuously changing with time and depends on the trajectories of the COM of each body segment. The peak velocity is an important parameter that could explain coordination of body segments during the turn. Since the peak velocity is the point at which the movement of a body segment is fastest, alteration of the normal sequence of peak velocity of body segments during turning may challenge a person’s stability. Furthermore, the relationship between the centre of mass (COM) and the base of support (BOS) is characterized not only by relative position, but also by relative velocity (Besser et al., 1997). If a person’s COM is not over their BOS, but the velocity and/or acceleration of their COM is such that the COM will move back toward the BOS, the person will be able to recover their balance (Besser et al., 1997).

Predictability of a target was shown not to have an effect on the peak velocities of the body segments in all the groups. Patla et al. (1997) argued that the initial planning of movement from one direction to another has to be visually mediated. Meaning to initiate a movement, the visual system has to gather information about the environmental features to interact with. This manifests in the differences observed in the sequence of onset latencies of the body segments when turning to predictable and unpredictable targets in the current study. Once the movement has started, other sensory modalities, in particular the kinaesthetic system can come into play in the modulation of the movement. The peak velocity occurs after the onset of the movement and therefore may not be influenced by the information given before the start of the movement. Rather the peak velocity could be influenced by the constant updating of the central nervous system by the sensory systems which may be the same for both predictability conditions after the start of the movement.

Angle and direction of the turn were shown to have an effect on the sequence of peak velocities in people with PD and controls but not in people with stroke. People with stroke maintained a consistent pattern of peak velocities of the body segments for all the turning tasks. However, their age-matched controls showed a difference in the pattern of peak velocities when turning to 45° to both sides and when turning to 90° and 135° to the non-dominant side compared to the stroke group. The people with stroke may have lost the ability to adapt to these changes due to the pathology they have. People with PD showed no significant difference in peak velocities of pelvis and foot when turning to the initially affected side as compared to separate peak velocities of the two segments (pelvis having lower peak velocity than the foot) in their control counterparts and in people with stroke. This could be due to the motor asymmetry that exists in people with PD with more marked involvement on the body side first affected (Toth et al. 2004, Djaldetti et al. 2006).

Solomon et al (2004) reported that the peak velocity of the head was greater than that of the pelvis when healthy adults were instructed to make step turns to face targets placed at 90°. They also reported that the peak velocities of the head and pelvis were not significantly different when turning to the left (non-dominant) and right (dominant) sides. This is contrary to the findings of our present study in which differences were observed in the control group when turning to dominant and non-dominant sides. However, when the peak velocities of the dominant and non-dominant sides were compared for individual subjects in the study of Solomon et al. (2004), the peak velocity of the head was found to be different for the dominant and non-dominant sides in 11 out of the 20 participants (in four participants the peak velocity of the head was higher when turning to the dominant than the non-dominant side while the reverse was the case for seven participants). The peak velocity of the pelvis was also found to be different for the dominant and non-dominant sides in eight out of 20 participants (in three participants the peak velocity of the pelvis was higher when turning to the dominant side than the non-dominant side and vice versa in four of the participants). This indicates the presence of a high variability that could preclude the finding of a significant result with a small sample size.

The higher head peak velocity compared to pelvis peak velocity in the study of Solomon et al. (2006) was similar to the findings of Akram et al. (2010) and Land et al. (2004). However, the latter studies did not compare turns to the dominant and non-dominant sides either because data was collected when turning to one side only (Akram et al. 2010) or results for the two sides were pooled together (Land et al. 2004). None of the three studies (Land et al. 2004; Solomon et al. 2006; Akram et al. 2010) compared turns to different angles. Solomon et al. (2006) and Akram et al. (2010) investigated turns to 90° only. Although Land (2004) reported the results of turns to 50°, 105° and 135°, he presented the results as a range of the peak velocities of the head (250-350°/s) and the pelvis (100-250°/s) for all the angles. The current study has therefore gone further to present information about the effect of the turn direction, turn angle and target predictability on the sequence of peak velocities of body segments and therefore advanced knowledge in this area.

There was no significant difference in the timing of the peak velocities of all the segments (head, shoulder, pelvis and foot) in most of the tasks in the three groups. This means that the peak velocities of the segments occurred at relatively the same time. If the peak velocities of the segments had occurred at different timings in the movement trajectory, the relationship of the peak velocities of the segments may not explain any underlying mechanisms for falls. This is because a fall will occur at a particular point in time and if the peak velocity of a segment occurs after that point it may not explain the relationship of the peak velocities of the segments at that particular point (Besser et al., 1997).

It is necessary to maintain upright stance during functional activities to avoid losing stability and subsequent falls. Impairment in coordination of body segments during functional activities can challenge the maintenance of the upright stance. Frank and Earl (1990) postulated that maintaining upright stance during movement may involve postural preparations engaged well before movement, postural adjustments that occur simultaneously with initiation of voluntary movement and postural reactions that occur after movement initiation. Impairment in coordination of body segments will appear to be more challenging to the maintenance of upright stance at the initiation of the movement and during the movement. The information about the sequence of body segments at the onset of the movement and the point where the peak velocity occur in the studies in this thesis seem to coincide with maintenance of upright stance at the initiation of movement and during the movement respectively. However, how the sequence of body segments at these two points could challenge the maintenance of upright stance could be the subject of another study.

6.3. Advancement of knowledge

Predictability of a target, angle and direction of the target are factors that are associated with turning from one point to another. The effects of these factors on the kinematic sequence of body segments during turning have been investigated in healthy individuals. However, there is no known study that investigated the sequence of rotation of body segments during turning on-the-spot in people with stroke. On the other hand, few studies have investigated the sequence of onset of rotation body segments during turning on-the-spot in people with PD (Vaugoyeau et al. 2007 and Akram et al. 2010). However, these studies investigated the sequence of onset of head, shoulder and pelvis when turning to 45° and 90° in response to an auditory cue. The studies failed to present data for the movement of the eye and foot which are vital in understanding kinematics of body movement during turning (Hollands et al. 2004). They also limited the investigations to predictable targets that were within the visual field only (45° and 90°).

The results of the studies in this thesis have therefore added to the knowledge base, information on the kinematics of rotation of body segments in people with stroke during turning on-the-spot which was not known. They have also provided further information on the kinematics of rotation of body segments during turning on-the-spot in people with PD by investigating effect of factors that are associated with turning such as target predictability and turn angle that was out of the visual field which were not investigated in previous studies.

Questions were raised about the ‘top to bottom’ paradigm for the onset of rotation of body segments during turning that were recognized in studies in healthy individuals (Hollands et al. 2004 and Anastasopuouluous et al. 2009). It was as a result of the report from the current studies that simultaneous onset of rotation of segments could be seen even in healthy, older individuals; pointing to the fact that age may play a role in determining sequence of rotation of segments during turning.

The following are some of the results of the studies of this thesis that have been presented in earlier turning studies:

- People with stroke and PD move slower and have slower response times as compared to age-matched healthy controls
- There were differences in the sequence of peak velocities of segments when turning to dominant and non-dominant sides in healthy adults
- The eyes do not always initiate the movement during turning tasks as suggested by many studies of turning during walking

Important findings that have been shown for the first time in our studies are as follows:

- The shoulder rotates simultaneously with the head in people with stroke, PD and older adults
- People with PD showed more en-bloc onset of rotation of body segments when turning to 90° and 135° as compared to age-matched healthy controls and people with stroke
- People with stroke and PD showed lower peak velocities and delay in timing of peak velocities as compared to age-matched healthy controls

- Predictability of a target did not affect the peak velocity of body segments
- The sequence of peak velocity of body segments was consistent across all the tasks in the stroke group
- Similar peak velocities of pelvis and foot were found when turning 45° to initially affected side in people with PD as compared to separate peak velocities of the pelvis and foot in the stroke and control group
- There was no significant difference in the timing of peak velocities of head, shoulder, pelvis and foot in most of the turning tasks

6.4. Implications for clinical practice

A large number of studies exist that provide evidence for improvement in functional mobility and balance in people with stroke and PD during functional activities (Van Peppen et al. 2004 and Goodwin et al. 2008). However, these studies leave many questions unanswered due to lack of information on specific underlying deficits (Kautz et al. 2005). Various studies have attempted to pave the way for the understanding of specific underlying deficits during turning by investigating the kinematics of body movement during turning in healthy individuals (Hollands et al. 2004; Earhart and Hong 2006; Anastasopoulous et al. 2009). This is in line with the statement of Carr and Shepherd (1987; pg 4) that "the unique contribution of physiotherapy to the rehabilitation of stroke lies potentially, in the training of motor control based on an understanding of the kinematics and kinetics of normal movement, motor control processes and motor learning".

Many schools of thought in the field of rehabilitation such as Carr and Shepherd (1998) have used the concept of 'relearning' to describe the recovery process. Training activities of daily living (ADLs) requires information on specific coordination deficits in functional tasks, "only when one knows precisely what is being relearned, can one begin to come to terms with how relearning takes place" (Wagenaar and van Emmerik, 1996; pg 162). The results from the studies of this thesis provide further information about coordination of body movement during turning in people with stroke and PD. This may help in further understanding specific coordination deficits that may explain why people with stroke and PD fall often and in the development of interventions to counteract the problem.

The current study has shown that the eyes do not always lead the other segments when turning as suggested by many studies of turning on-the-spot (Hollands et al. 2004; Earhart and Hong 2006) and while walking (Grasso et al. 1998; Hollands et al. 2001). In fact, the current study has shown that the movement of the eyes could even occur after the shoulders. Although an individual may be aware of the immediate surrounding when turning to predictable targets, a sudden appearance of a moving body such as a pet could lead to loss of stability since the eyes that could detect the moving body lag behind other upper body segments. The ability to maintain balance in such situations may be complicated in people with stroke, PD and older adults who could present with postural impairments.

The results of the studies in this thesis have shown how predictability of a target, turn angle and turn direction affect the coordination of body segments during turning on-the-spot in people with stroke and PD. Although the studies have not established a causal link between coordination of the segments and instability considering the factors (target predictability, turn angle and turn direction) in play, they have highlighted the importance of considering the factors when developing assessment and intervention strategies to solve turning problems. Interventions for managing turning difficulties such as Tai Chi (King and Horak 2009), podokinetic after rotation (Hong et al. 2007, Earhart and Hong 2006) and dance (Hackney and Earhart 2009) have been suggested. However, these interventions are generic and do not take into consideration the differences in coordination of the body segments as a result of change in the factors that are associated with the turn. If for example it is shown that incoordination of body segments during turning 135° to an unpredictable target in people with PD is associated with instability and subsequent falls, there will be need to focus on how to solve the incoordination problem for that particular task. Interventions that involve the application of appropriate facilitation/resistance to segments that move abnormally for the particular problematic task could also further be explored.

The current study has also shown that while people with stroke maintained a consistent pattern of peak velocity of body segments, their age-matched controls showed differences in the sequence when turning to dominant and non-dominant sides and across turn angles. People with PD also showed differences in the sequence when turning to 45° to the initially affected and initially unaffected sides. The centre of mass of the body continuously changes with time during movement (Winter 2009) and is characterized by both position of the body segments and their relative velocity (Besser et al. 1997). If the COM of a person is not over the base of support and the relative velocity of the body segments especially at the point where the velocity is highest is such that the COM will not move back toward the BOS, the person will not be able to recover their balance (Besser et al. 1997). It is therefore crucial to link the patterns of peak velocities of people with stroke and PD that were found in the current study to balance during turning to identify possible deficits in balance during turning.

Our studies have also shown that people with stroke and PD move slowly as compared to the healthy controls while turning on-the-spot. Mayo et al. (1990) reported an increase in risk of falls with increase in onset latency in people with stroke. Although people with stroke and PD may move slowly during turning as a compensatory strategy to avoid falling, they may be predisposed to falls in situations where there is need to respond quickly to avoid obstacles. Furthermore, a delayed response to perturbations may lead to falls. However, since the movement initiation and response to perturbation access different neurological pathways, it cannot be inferred from this study that people with stroke and PD would respond slowly to perturbation. It is therefore important to investigate their response to perturbation and develop ways of speeding up the response during encounter with obstacles. Weerdesteyn et al. (2008) have indeed shown that instructing healthy young adults to recover balance during perturbations of upright stance modulated postural responses. Furthemore, it is important to train people with stroke and PD about being aware of the task and the environment during turning to minimize the possibility of the perturbations.

6.5. Limitations of the study

1. One of the main limitations of this study is the sample size. A power calculation carried out during the pilot study revealed that about 19 participants would be required in each group (people with stroke and healthy controls). However, due to time constraints, financial limitations and difficulty recruiting participants only 10 participants were recruited in each group. The results of the study should therefore be interpreted with caution as some of the non-significant results might be as a result of lower sample size.
2. The studies investigated the effect of many factors (target predictability, turn angle, turn direction, segment and group) on the coordination of body segments. This makes the studies to be exploratory in nature.
3. The data extraction in the studies was carried out by exporting data from the CODA motion software onto a special excel sheet designed to indicate the onset latencies, peak velocities and timing of peak velocities of the movements. These values were visually checked and recorded, a process that could have caused bias. The use of MatLab could have ensured more accuracy in extracting the data.
4. To turn to the lights at 135° during the unpredictable condition, the participants had to guess whether the light was on the right or left. When they made a mistake in turning to the light, that particular task was not used for analysis. While five trials were recorded and averaged for analysis in other tasks, less than five trials were recorded for turns to 135° to unpredictable targets. This also could have caused bias.
5. While the onset latency of the movement of the eye was recorded from the VNG camera, the peak velocity and timing of the peak velocity of the eye movement was not available because it was difficult to accurately extract the peak velocity and timing of peak velocity of the eye movement from the VNG camera. This was because of the frequent eye saccades that accompanied the movement. An important

parameter (peak velocity and timing of peak of eye movement) was therefore missing.

6. The people with stroke and Parkinson's disease in this study had high cognitive, balance and functional status. The results of the study can therefore only reflect the coordination of body movements in patients with similar characteristics. People with stroke and Parkinson's disease with low cognitive, balance and functional status may have different coordination of body segments during turning on-the-spot.
7. Turning around does not occur in isolation but as part of activities of daily living. People pick up objects and turn around, sometimes turning occurs while talking or reaching for objects. Environmental circumstances may also vary during turning. People may respond to audio or visual cues or may turn voluntarily to interact with objects in the environment. Laboratory investigations usually constrain researchers' abilities to mimic real life situations due to space availability, restrictions in the use of equipments and the desire to narrow down on the involvement of some factors to see their effect on the parameters of interest. This study is therefore limited because it does not reflect real life situations. However, it has helped in identifying the effect of some important factors such as predictability of a target, turn angle and turn direction that are associated with turning.
8. Older adults present with sensory and motor problems that could impair the coordination of body movement during functional activities. It was therefore difficult to ascertain if the coordination pattern of people with stroke and Parkinson's disease was problematic since there were similarities between the patients and the controls who were older adults. An inclusion of healthy young adults would have helped in clarifying this issue.

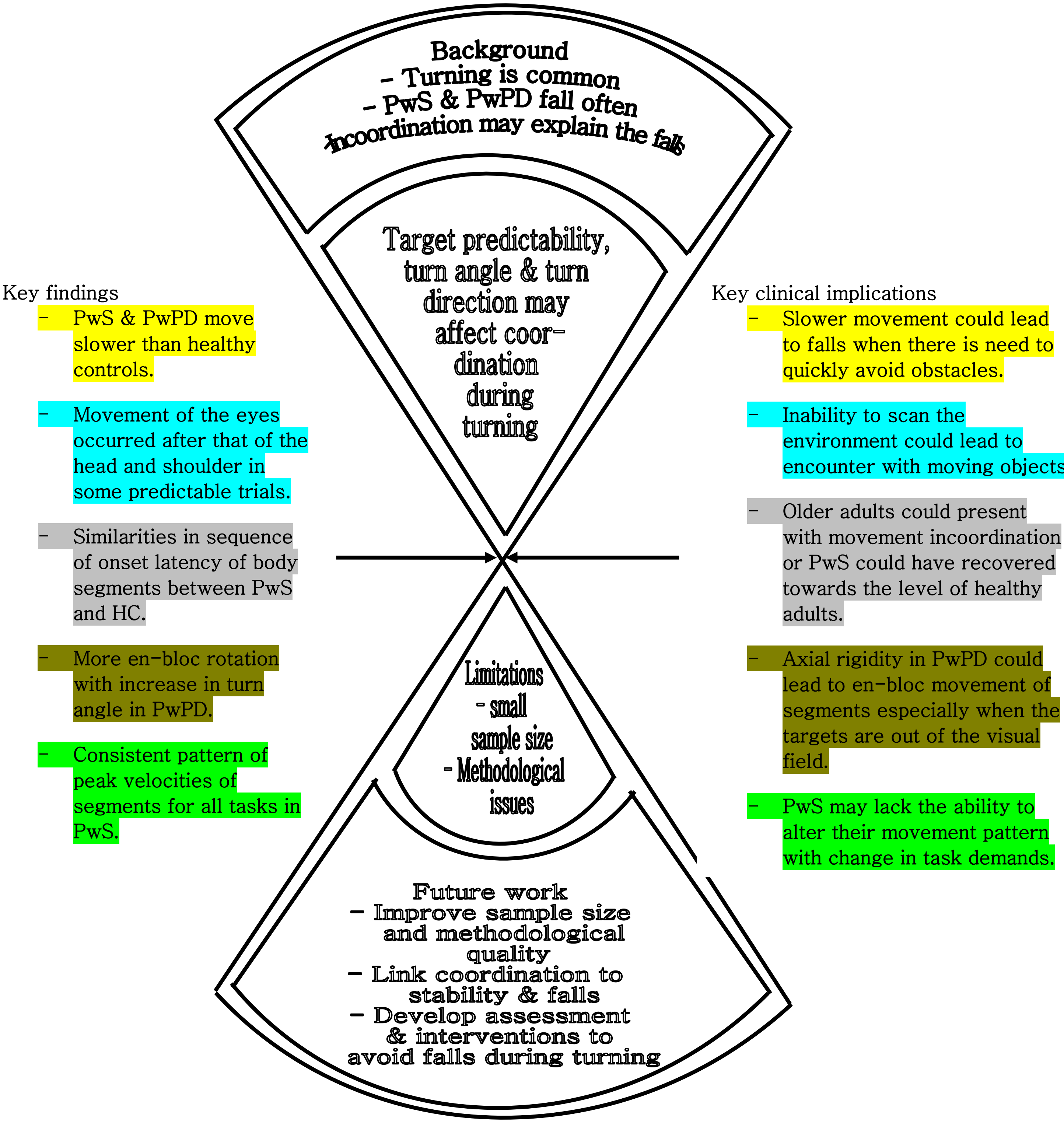
6.6. Implications for future research

Although the onset latency, peak velocity and timing of peak velocity are important parameters for the investigation of coordination of body segments during turning, they may not give a complete picture of coordination during the whole turn. Therefore, more sophisticated analyses such as principal component analysis or vector coding that look at variations of movement of body segments during the whole turn might be employed to further investigate coordination problems at other points of the turn other than the onset of the movement and the peak velocity.

The current study investigated the coordination of body segments during turning in people with stroke and Parkinson’s disease as compared to healthy controls. However, maintaining balance during functional tasks is achieved through the coordination of posture and movement. It is therefore possible that variation in coordination of body segments in different tasks could elicit different postural adjustments. For example, sequence of onset of body segments have been shown to be different when turning to predictable and unpredictable targets in healthy young adults (Hollands et al. 2004 and Anastasoupouolous et al. 2009). One of these two strategies may challenge balance more than the other, but due to the sound postural adjustment processes in healthy young adults, they may counteract the challenges. However, this may be different in people with stroke and Parkinson’s disease who have been reported to have postural adjustment problems (Gelb et al.,1999, Slijper et al. 2002). It is therefore imperative to further investigate how people with stroke and PD respond posturally to different strategies of turning as a result of change in environmental factors such as target predictability, turn angle and turn direction.

Finally, the various strategies of turning need to be linked to balance to identify which strategies predispose an individual to losing stability during a turn. This would help in channelling appropriate rehabilitation management to areas that are problematic.

A framework showing the background to the study, findings, clinical implications, limitations and future work is presented in figure 6.1.



PwS = People with Stroke; PwPD = People with Parkinson’s disease; HC = Healthy controls

Figure 6.1. A framework connecting important aspects of the study

6.7. Conclusions

This is the first study that investigated the effect of predictability of a target, turn angle and turn direction on the sequence of onset latency, peak velocity and timing of peak velocity of body segments during turning on-the-spot in people with stroke and Parkinson's disease. Another uniqueness of this study is in the fact that it investigated the effect of the predictability of a target, turn angle and turn direction in the participants using the same protocol and equipments. This prevents difficulty in synthesising studies that investigate the factors in different studies with different characteristics of participants and different protocols and equipments.

The results of this study showed that predictability of a target and turn angle affected the sequence of onset of rotation of the segments (eye, head, shoulder, pelvis and foot) while the sequence remained the same when turning to both sides in all the groups. The eye, head and shoulder started to rotate simultaneously followed by the pelvis and foot when turning to unpredictable targets. The head and shoulder sometimes started to rotate before the eye when turning to predictable targets. The onset of rotation of the segments was similar between the people with stroke and the healthy controls; however, the people with PD had more simultaneous movement of body segments across the turn angles. The shoulder had the lowest peak velocity followed by the head, then pelvis and finally foot during all the turning tasks in the people with stroke. When turning to 45°, the people with Parkinson's disease and healthy controls had no significant difference between the peak velocity of the head and shoulder. There was no particular pattern for the sequence of the timing of the peak velocities of the segments in the three groups. The peak velocity of the head, shoulder, pelvis and foot mostly occur at the same time (no significant difference in the timing of the peak velocities of the segments).

Impairment of the relative movement of body segments during functional tasks could challenge the balance of an individual. The sequence of movement of body segments in the different tasks could therefore be related to balance during turning to identify which of the strategies of turning could present with risk of falls.

Appendices

Appendix i

Parts of this work that have been presented in conferences

Abstract presented at the scientific meeting of Physiotherapy Research Society

Sequence of head and upper trunk rotations during head turns in people with stroke while sitting: A pilot study

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Background: Turning the head to see the environment is a common activity of daily living which is usually accompanied by trunk movement (Land 2004).

Aim: To compare the sequence of onset of head and upper trunk rotations during head turns while sitting between stroke participants and healthy controls.

Method: Ethical approval was obtained for the study. Participants were asked to look at visual targets placed at 90º to the right and left when a light in front of them went off (three trials for each task). Interval of onset latencies of the head and upper trunk rotations were obtained by CODAmotion analysis and reported as mean (SD) of the difference in latency between rotations of the two segments.

Results: Participants were three people with chronic first stroke (age range: 38-75years) and three healthy controls (age range: 37-91years). The head rotated before the upper trunk in all trials. The interval between onset latencies of head and upper trunk rotations was smaller in three people with stroke [range: 0.02(0.01)–0.07(0.04)] and an elderly healthy participant [0.01(0.04) and 0.03(0.16)] as compared to two healthy controls [range: 0.12(0.04)-0.35(0.05)]. There was no apparent difference between turning

towards and away from the lesion in the stroke participants or to the right and left in the controls.

Conclusion: This study suggests that stroke and aging may affect the dissociation of head and upper trunk rotations. This calls for clinical attention in facilitating the normal sequence of upper body segments when turning in sitting.

Reference: Land MF (2004) The coordination of rotations of the eyes, head and trunk in saccadic turns produced in natural situations Exp Brain Res 159(2): 151-160.

Abstract presented at the scientific meeting of the Society for Research in Rehabilitation

Whole-body coordination when turning on the spot in people with stroke and healthy controls

Ahmad RY, Verheyden G, Burnett M, Samuel D, Ashburn A, Faculty of Health Sciences, University of Southampton

Background: Turning around to interact with the environment is a common activity of daily living. Stroke could compromise coordination of body movement during turning which may pose a risk of losing stability and subsequent falls. The aim of this study was to investigate the sequence of rotation of body segments in people with stroke and healthy controls when turning on the spot to predictable and unpredictable targets.

Method: Eight people with stroke (Age:66.88±8.15) and eight healthy controls (Age:66.38±4.50) were asked to stand in front of a light and either locate and turn or turn to a known light placed at 90 degrees to the right or left when the light in front extinguished. The onset latency of the eye was measured by an

eye camera (VNG Ulmer) and that of the head, shoulder, pelvis and feet were measured by CODA motion analysis system.

Results: There was a top to bottom initiation of rotation of the segments when turning to unpredictable targets and a more overlap of movement initiation when turning to predictable targets in both groups (interaction of segment and predictability: $F=6.006$, $P<0.05$). However, this was not different between the stroke and control groups (Interaction of segment, predictability and group: $F=2.622$, $P>0.05$).

Discussion/conclusion: Predictability of a target affects the sequence of rotation of segments during turning on the spot. The clinical significance of this may be investigated by relating the sequence to measures of stability. The similarity in the sequence between the groups may be due to motor and sensory deteriorations in the elderly.

Abstract accepted for presentation at International Society for Gait and Posture Research conference

Whole-body coordination when turning on the spot in people with stroke and healthy controls

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INTRODUCTION: Turning around to interact with the environment is a common activity of daily living. The location of a target for interaction may be known or unknown prior to turning and the angle of a turn may vary depending on the task to be carried out. A stroke can compromise coordination of body movement during turning which may pose a risk for instability and subsequent falls. The aim of this study was to investigate the kinematic sequence of rotation of body segments in people with stroke and healthy controls when turning on the spot to predictable and unpredictable targets placed at three different angles (45°, 90° and 135°).

METHODS: Nine people with stroke [age: 64±9 (mean±SD) years] and nine healthy controls [age: 64±9 (mean±SD) years] were asked to stand in front of a light and either turn to a specific light (predictable condition) or locate and turn to a random light (unpredictable condition) placed at 45°, 90° or 135° to the right or left when the light in front extinguished. There were five trials for each task and the tasks were randomized. The onset latency of the horizontal eye movement was measured by an eye camera (VNG Ulmer) and that of the horizontal head, shoulder, pelvis and feet movement were measured by CODA motion.

RESULTS: There was a top to bottom initiation of rotation of the segments when turning to unpredictable targets and a more simultaneous initiation of the segments when turning to predictable targets in both groups (interaction of segment and predictability: F=27.004, p=0.001). However, this was not different between the stroke and control groups (Interaction of segment, predictability and group: F=2.887, p=0.082). In the unpredictable condition, there was more simultaneous onset of eye, head and shoulder movement when turning to 45 and 90 degrees as compared to more increasing latencies for the 135 degrees condition (interaction of segment, predictability and angle: F=19.443, p=0.001). There was no difference in the sequence of the segments when turning to both sides in the stroke participants (paretic/non-paretic sides) and controls (right/left sides) (Interaction of segment, direction and group: F=0.300, p=0.876.

CONCLUSIONS: Predictability of a target affects the sequence of rotation of segments during turning on the spot. The turn angle also affects the sequence when turning to unpredictable targets. The balance of an individual during a task is determined by the movement of the centre of mass within the base of support. This could be affected by the relative movement of the segments involved in the task. The clinical significance of the results of this study may be investigated by relating the sequence of the movement of the body segments to stability during turning. The similarity in the sequence between the groups may be due to motor and sensory deteriorations in the elderly.

Acknowledgements: The authors would like to appreciate Bayero University, Kano, Nigeria for supporting the lead author.

Appendix ii
Random sheet

ID 1 Date / /2010

Repeat	Task	CODA File		VNG	Notes
		recording	renamed		
1	Unpredicted-R90	011	01UR901	1 1 (Open1)	
	Predicted-L135	012	01PL1351	1 1 (Open2)	
	Predicted-R45	013	01PR451	1 1 (Open3)	
	Unpredicted-L45	014	01UL451	1 1 (Open4)	
	Unpredicted-R45	015	01UR451	1 1 (Open5)	
	Unpredicted-L135	016	01UL1351	1 1 (Open6)	
	Predicted-R135	017	01PR1351	1 1 (Open7)	
	Predicted-L90	018	01PL901	1 1 (Open8)	
	Unpredicted-R135	019	01UR1351	1 1 (Open9)	
	Predicted-R90	0110	01PR901	1 1 (Open10)	
	Unpredicted-L90	0111	01UL901	1 1 (Open11)	
	Predicted-L45	0112	01PL451	1 1 (Open12)	
2	Predicted-L135	0113	01PL1352	1 2 (Open1)	
	Predicted-R45	0114	01PR452	1 2 (Open2)	
	Unpredicted-L90	0115	01UL902	1 2 (Open3)	
	Unpredicted-R90	0116	01UR902	1 2 (Open4)	
	Unpredicted-L45	0117	01UL452	1 2 (Open5)	
	Predicted-R135	0118	01PR1352	1 2 (Open6)	
	Unpredicted-R45	0119	01UR452	1 2 (Open7)	
	Predicted-L90	0120	01PL902	1 2 (Open8)	
	Predicted-R90	0121	01PR902	1 2 (Open9)	
	Predicted-L45	0122	01PL452	1 2 (Open10)	
	Unpredicted-R135	0123	01UR1352	1 2 (Open11)	
	Unpredicted-L135	0124	01UL1352	1 2 (Open12)	
3	Unpredicted-L45	0125	01UL453	1 3 (Open1)	
	Unpredicted-R45	0126	01UR453	1 3 (Open2)	
	Predicted-L90	0127	01PL903	1 3 (Open3)	
	Predicted-R135	0128	01PR135	1 3 (Open4)	
	Predicted-R90	0129	01PR903	1 3 (Open5)	

	Predicted-L45	0130	01PL453	1 3 (Open6)	
	Unpredicted-R90	0131	01UR903	1 3 (Open7)	
	Unpredicted-L90	0132	01UL903	1 3 (Open8)	
	Unpredicted-R135	0133	01UR1353	1 3 (Open9)	
	Predicted-R45	0134	01PR453	1 3 (Open10)	
	Predicted-L135	0135	01PL1353	1 3 (Open11)	
	Unpredicted-L135	0136	01UL1353	1 3 (Open12)	
4	Unpredicted-R90	0137	01UR904	1 4 (Open1)	
	Unpredicted-L135	0138	01UL1354	1 4 (Open2)	
	Predicted-L90	0139	01PL904	1 4 (Open3)	
	Unpredicted-L45	0140	01UL454	1 4 (Open4)	
	Predicted-R45	0141	01PR454	1 4 (Open5)	
	Unpredicted-R135	0142	01UR1354	1 4 (Open6)	
	Predicted-L135	0143	01PL1354	1 4 (Open7)	
	Unpredicted-R45	0144	01UR454	1 4 (Open8)	
	Predicted-R135	0145	01PR1354	1 4 (Open9)	
	Unpredicted-L90	0146	01UL904	1 4 (Open10)	
	Predicted-R135	0147	01PR1354	1 4 (Open11)	
	Unpredicted-R45	0148	01UR454	1 4 (Open12)	
5	Predicted-L45	0149	01PL455	1 5 (Open1)	
	Predicted-R90	0150	01PR905	1 5 (Open2)	
	Unpredicted-R90	0151	01UR905	1 5 (Open3)	
	Unpredicted-L135	0152	01UL1355	1 5 (Open4)	
	Predicted-L90	0153	01PL905	1 5 (Open5)	
	Unpredicted-L45	0154	01UL455	1 5 (Open6)	
	Predicted-R45	0155	01PR455	1 5 (Open7)	
	Unpredicted-R135	0156	01UR1355	1 5 (Open8)	
	Predicted-L135	0157	01PL1355	1 5 (Open9)	
	Unpredicted-R45	0158	01UR455	1 5 (Open10)	
	Predicted-R135	0159	01PR1355	1 5 (Open11)	
	Unpredicted-L90	0160	01UL905	1 5 (Open12)	

Appendix iii
Ethical approval for stroke study

E04/Oct 2008/ v1.0

Rufai Ahmad
School of Health Sciences

02 February 2010

Dear Rufai

Ethics Submission No: SoHS-ETHICS-09-033
Title: Whole-body coordination when turning

I am pleased to confirm full approval for your study has now been given. The approval has been granted by the School of Health Sciences Ethics Committee.

You are required to complete a University Insurance and Research Governance Application Form (IRGA) in order to receive insurance clearance before you begin data collection. The blank form can be found athttp://www.soton.ac.uk/corporateservices/rgo/regprojs/whatdocs.html

You need to submit the following documentation in a plastic wallet to Dr Martina Prude in the Research Governance Office (RGO, University of Southampton, Highfield Campus, Bldg. 37, Southampton SO17 1BJ):

•Completed IRGA Research Governance form

•Copy of your research protocol/School Ethics Form (final and approved version)

•Copy of participant information sheet

•Copy of SoHS Risk Assessment form, signed

•Copy of your information sheet and consent form

•Copy of this SoHS Ethical approval letter

Continued overleaf

Building 67
School of Health Sciences, University of Southampton, Highfield Campus, Southampton SO17 1BJ United Kingdom Tel: +44 (0)23 8059 7979 Fax: +44 (0)23 8059 7900 www.southampton.ac.uk/healthsciences

Your project will be registered at the RGO, and then automatically transferred to the Finance Department for insurance cover. You can not begin recruiting until you have received a letter stating that you have received insurance clearance.

Please note that you have ethics approval only for the project described in your submission. If you want to change any aspect of your project (e.g. recruitment or data collection) you must request permission from the Ethics Committee and RGO (students should discuss changes with their supervisor before submitting the request to the Ethics Committee).

Yours sincerely

Professor Sue Latter
Chair, SoHS Ethics Committee

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Appendix iv

UNIVERSITY OF Southampton
School of Health Sciences

CONSENT FORM

Title of Project: Whole body coordination when turning on-the-spot in people with stroke, Parkinson's disease and healthy controls

Name of Researcher: Rufai Yusuf Ahmad

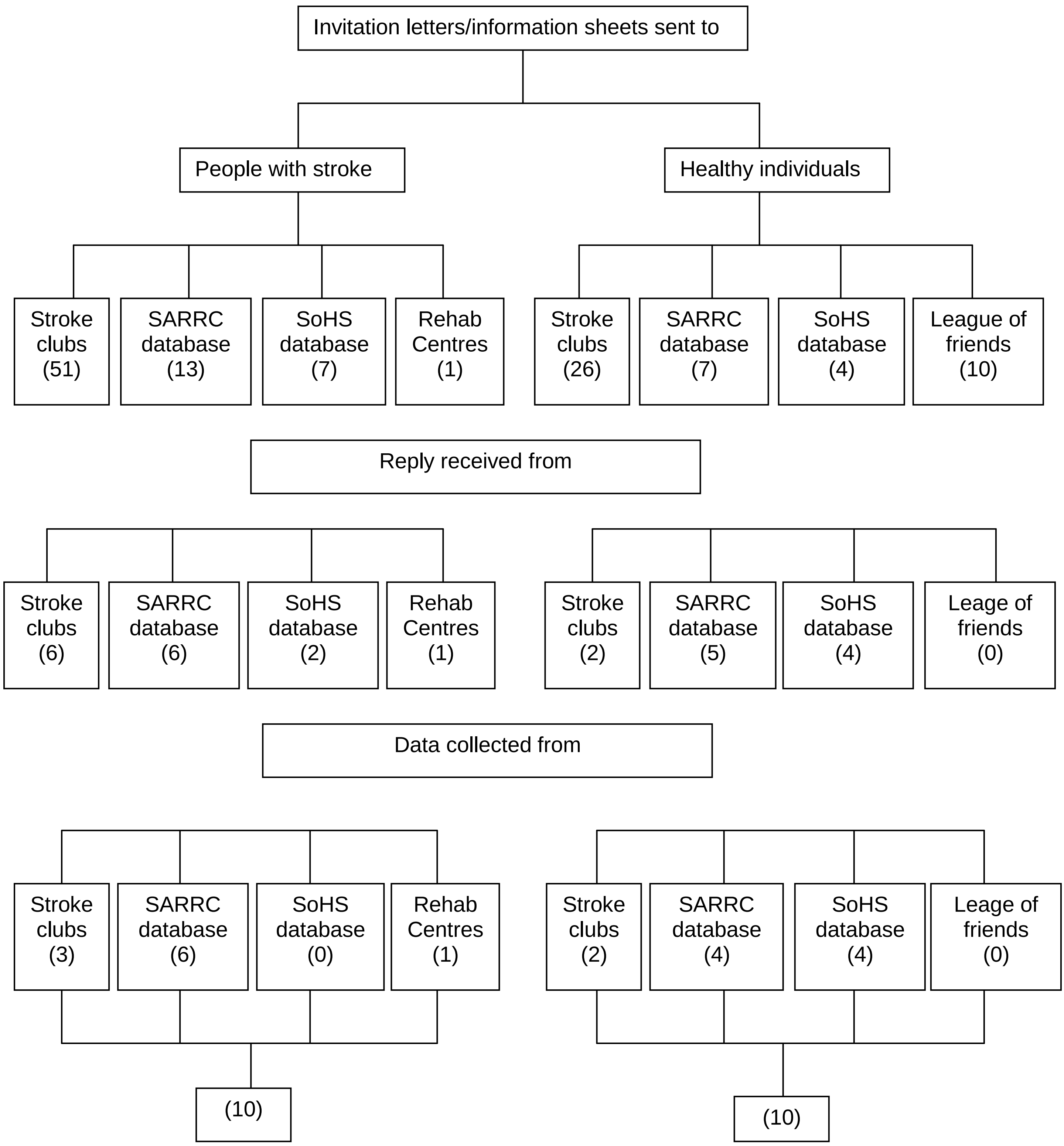
Please initial box

1. I confirm that I have read and understand the information sheet dated………(version....) for the above study and have had the opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my legal rights being affected. ☐
3. I understand that at the end of the study data collected from me will be securely stored at the University of Southampton for 15 years. ☐
4. I agree to take part in the above study. ☐

Name of Participant	Signature
Date	
Researcher	Signature
Date	

1 for participant, 1 for researcher

Appendix v
Recruitment flow chart (whole-body coordination when turning in people with stroke and healthy controls)



Numbers in brackets= number of participants; SARRC= Stroke Association Rehabilitation Research Center; SoHS= School of Health Sciences.

Appendix vi
Ethical approval for Parkinson's disease study

E04/Mar 2011/ v2.0

Rufai Ahmad
Faculty of Health Sciences

03 June 2011

Dear Rufai

Ethics Submission No: FoHS-ETHICS-2011-052
Title: Whole-body coordination when turning

I am pleased to confirm full approval for your study has now been given. The approval has been granted by the School of Health Sciences Ethics Committee.

You are required to complete a University Insurance and Research Governance Application Form (IRGA) in order to receive insurance clearance before you begin data collection. The blank form can be found athttp://www.soton.ac.uk/corporateservices/rgo/regprojs/whatdocs.html

You need to submit the following documentation in a plastic wallet to Dr Martina Prude in the Research Governance Office (RGO, University of Southampton, Highfield Campus, Bldg. 37, Southampton SO17 1BJ):

•Completed IRGA Research Governance form
•Copy of your research protocol/School Ethics Form (final and approved version)
•Copy of participant information sheet
•Copy of SoHS Risk Assessment form, signed
•Copy of your information sheet and consent form
•Copy of this SoHS Ethical approval letter

Continued overleaf

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Your project will be registered at the RGO, and then automatically transferred to the Finance Department for insurance cover. You can not begin recruiting until you have received a letter stating that you have received insurance clearance.

Please note that you have ethics approval only for the project described in your submission. If you want to change any aspect of your project (e.g. recruitment or data collection) you must request permission from the Ethics Committee and RGO (students should discuss changes with their supervisor before submitting the request to the Ethics Committee).

Yours sincerely

Dr Anne Bruton
Chair, FoHS Ethics Committee

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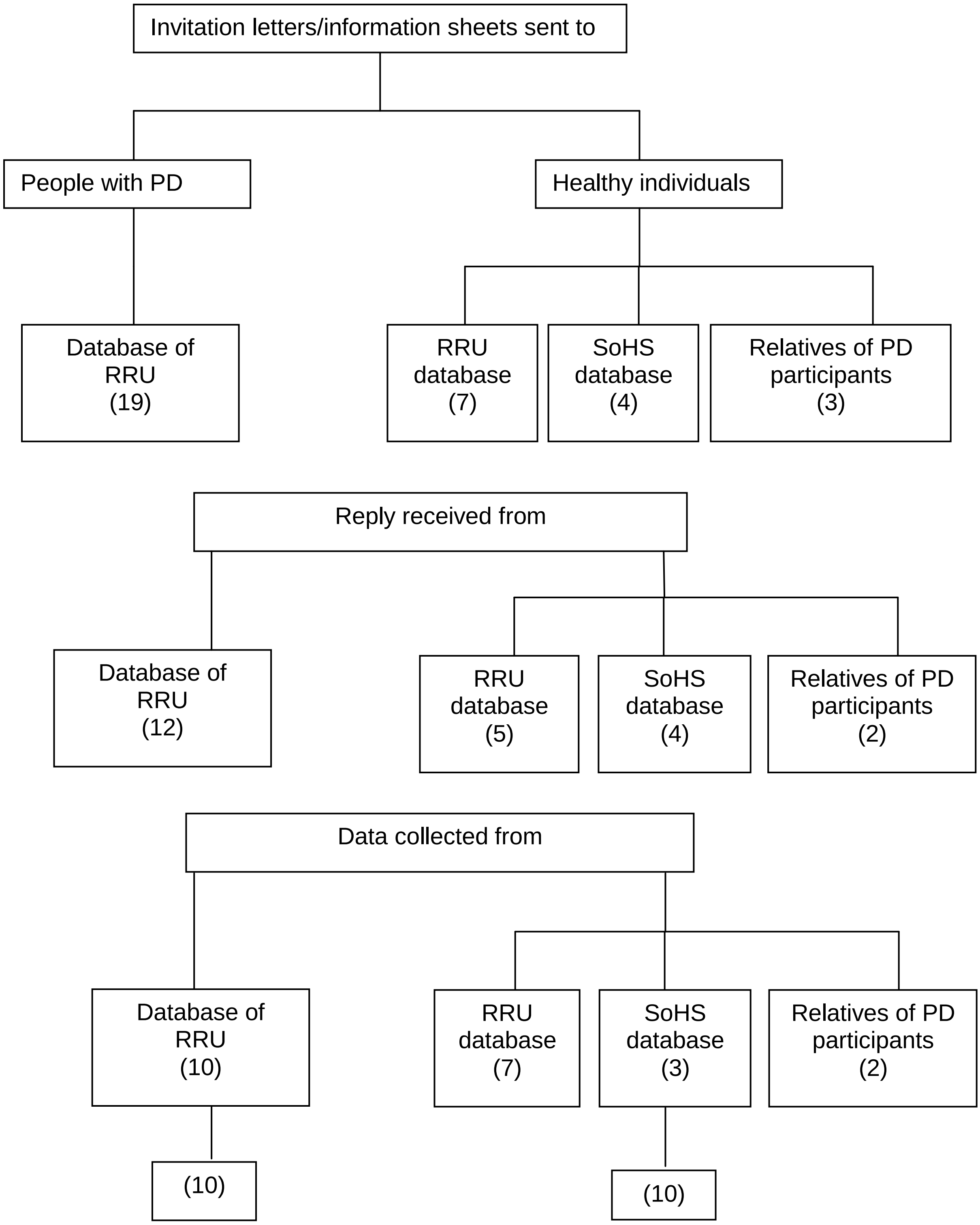
Appendix vii
Recruitment flow chart (Whole body coordination when turning in people with PD and healthy controls)



Numbers in brackets= number of participants; RRU = Rehabilitation Research Unit; SoHS= School of Health Sciences

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