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Movement Control after Stroke

*Studies on Sit-to-walk and on the Relations between
Clinical and Laboratory Measures*

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Abstract

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Aims: The principal aims of this research were 1) to extend existing knowledge of the everyday sit-to-walk (STW) transfer in subjects with stroke and in matched controls by exploring temporal, kinematic, and kinetic aspects, and 2) to investigate the relations between some clinical and laboratory measures of postural control and locomotion in stroke rehabilitation and research.

Methods: Ten community-living subjects with stroke (mean age 59 years) and ten matched controls were enrolled in the STW studies (Studies I, II, and IV). In the study regarding relations between clinical and laboratory measures the same samples (part of Study II) and also 20 outpatient subjects with stroke (mean age 50 years) participated (Study III). Data collections were performed in laboratory environments with clinical assessment instruments, video cameras, force plates and a movement analysis system.

Results: 1) *Study I:* A temporal aspect of STW was studied. Four phases were defined. The subjects with stroke used significantly more time during the 2nd STW phase, defined from seat-off to the loading peak of the 1st swing leg. *Study II:* A movement aspect of STW was investigated. The stroke subjects generated significantly less centre of mass momenta in horizontal and vertical directions, and the momenta peaks occurred significantly earlier than in the controls. *Study IV:* A force aspect of STW was explored. The subjects with stroke generated significantly larger propulsive impulse beneath the (non-paretic) stance buttock and significantly more braking impulses were exerted by both buttocks and particularly by the stance foot.

2) Part of *Study II:* A strong correlation was found between the clinical measure Fluidity Scale and the laboratory measure Fluidity Index. *Study III:* Moderate correlations were shown between Berg Balance Scale, ratings of weight distribution during quiet stance, and force measures.

Conclusions: The findings of the STW studies show a changed force interaction between the lower extremities post-stroke, likely influencing movement patterns and temporal characteristics of the everyday transfer. The results are considered to reflect compensatory motor strategies. The results of the studies on relations between some clinical and laboratory measures indicate that the strength of the relation is multidimensional.

Keywords: stroke, sit-to-walk, movement analysis, force analysis, postural control, Berg Balance Scale

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To Rajul

“Leben ist Bewegung” - Liv är rörelse

Life is movement

from

“Funktionelle Bewegungslehre” (1984),
written by the Swiss physiotherapist
Susanne Klein-Vogelbach

List of Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

- I Frykberg GE, Aberg AC, Halvorsen K, Borg J, Hirschfeld H. Temporal coordination of the sit-to-walk task in subjects with stroke and in controls. *Arch Phys Med Rehabil.* 2009;90(6):1009-17.
- II Frykberg GE, Åberg AC, Thierfelder T, Halvorsen K, Hirschfeld H, Borg J. Locomotor coordination during the sit-to-walk transfer is different in subjects with stroke and controls. Manuscript.
- III Frykberg GE, Lindmark B, Lanshammar H, Borg J. Correlation between clinical assessment and force plate measurement of postural control after stroke. *J Rehabil Med.* 2007;39(6):448-53.
- IV Frykberg GE, Thierfelder T, Åberg AC, Halvorsen K, Borg J, Hirschfeld H. Impact of stroke on strategies for force generation prior to seat-off during sit-to-walk. Submitted for publication.

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The figure on the cover page
was created in collaboration
with Lotta Sjölander

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Abbreviations

ADL	Activities of Daily Living
AP	Anterior-posterior
BBS	Berg Balance Scale
COG	Centre of gravity
COM	Centre of mass
COP	Centre of pressure
DoF	Degrees of freedom
FI	Fluidity Index
FS	Fluidity Scale
GI	Gait Initiation (from standing)
GMF	General Motor Function assessment scale
GRF	Ground reaction forces
ICC	Intraclass correlation
ICF	International Classification of Functioning, disability, and health
ML	Medio-lateral
PHM	Peak horizontal momentum
PVM	Peak vertical momentum
SEM%	Standard error of measurement in percentage of the mean
STS	Sit-to-stand
STW	Sit-to-walk
TO	Toe-off
TUG	Timed Up and Go
WHO	World Health Organisation

Definitions of concepts

Centre of pressure, COP	the point location of the vertical ground reaction force vector (Winter, 1995)
Centre of mass, COM	a point representing the weighted average of the COM of each body segment in a 3D space (Winter, 1995)
Impulse	the area under a force-time graph (N*s) (Enoka, 2008)
Kinematic	referring to a description of motion in terms of position, velocity, and acceleration (Enoka, 2008)
Kinetic	relating to motion, a description that includes consideration of force as the cause of motion (Enoka, 2008)
Momentum	the quantity of motion possessed by an object, a vector quantity (Enoka, 2008)
Pp measure	percentage contribution from the paretic leg to total propulsion during walking (Bowden, Balasubramanian, Neptune & Kautz, 2006)

INTRODUCTION

General introduction

Human beings are constantly interacting with the environment, using movements as means to reach everyday goals (Brooks, 1986). In physiotherapy, movement is one of the central concepts (European region of the World Confederation for Physical Therapy). Movement analysis is used by physiotherapists to evaluate disabilities in individuals with movement disorders. The disabilities can be divided into different categories: prerequisites for movement, movement ability, and/or movement behaviour (Tyni-Lenné, 1987). Movements are used as therapeutic tools in the interaction with the patient (Sahrmann, 1998), with the aim of reaching goals in everyday life such as being able to move more safely indoors and outdoors, to walk faster in order to catch a bus, or to fetch things from a cupboard with less pain and more precision, and so on. Sometimes the goal can even be to experience joy of movement.

Stroke (brain infarction and/or haemorrhage) influences many different aspects of a person's being: physical, perceptual, emotional and cognitive (Strokeboken, 2001). Being afflicted by stroke often implies being unable to move in the same way in everyday activities as before the onset.

During the 1980s, research on neuronal plasticity (Bach-y-Rita, 1980) resulted in new and challenging knowledge about the capacity of the central nervous system to reorganise after a brain injury. Different mechanisms of such reorganisation have been described and are suggested to be utilised in the recovery process after stroke (Nudo, 2006).

In rehabilitation, interventions are made to promote motor recovery in the individual, by some researchers called restitution. However, true motor recovery is difficult to discriminate from motor compensation due to lack of precision in measurement (Levin, Kleim & Wolf, 2009).

There are advanced laboratory methods, such as different neuroimaging techniques and force and movement analysis systems that offer possibilities of obtaining new knowledge in stroke research. However, these methods are far from always available in clinical reality. Physiotherapists in clinical settings use standardised assessment instruments that provide information about different aspects of the patient's movement disorder.

Some researchers (Latash, 1993; Garland, Willems, Ivanova & Miller, 2003; Leroux, Pinet & Nadeau, 2006) consider that the theoretical basis of

movements can be enhanced by studying relations between clinical and laboratory measures. Thus, there seems to be a need to explore these relations further, with the aim of revealing information of relevance to movement control after stroke.

Investigation of the coordination of posture and voluntary movements during everyday motor tasks, such as transfers, is considered to be important for the development of neurological rehabilitation (Hirschfeld, 2007). Regarding forward-oriented locomotion this is not an easy task, as motor coordination is extremely complex, considering that human beings transport and balance their bodies in a 3D space, often on a small support area defined by the feet.

In the following section the area of research is outlined.

Stroke

The World Health Organisation (WHO) defines stroke as "rapidly developing signs of focal (or global) disturbance of cerebral function lasting more than 24 hours (unless interrupted by surgery or death), with no apparent nonvascular cause" (Thorvaldsen, Kuulasmaa, Rajakangas, Rastenyte, Sarti & Wilhelmsen, 1997). Stroke is the most common acutely acquired brain injury in adults in the western world and an important cause of disability. Stroke includes brain infarction (> 85 %), intracerebral haemorrhage (c. 10%), and subarachnoid haemorrhage (c. 5%) (National Stroke Register in Sweden, 2008).

The incidence of stroke in Sweden is about 30 000 per year. Approximately 70% of these cases are first-ever stroke and the remainder are recurrent stroke. Since the year 2000, the proportion of first-ever stroke has decreased by about 10% in both men and women. The decline is most evident in the elderly age group. The mean age at incidence of stroke is 73.2 years for men and 78.3 years for women. The same proportions of men (50.1%) and women (49.9%) are afflicted by stroke (National Stroke Register in Sweden, 2008). About 20% of persons suffering from stroke are younger than 65 years. In this age group, there is a male predominance (65%) of stroke (Medin, Nordlund & Ekberg, 2004).

Stroke-related disability

The symptoms post-stroke are varied and mainly comprise sensorimotor dysfunctions, problems in swallowing, perceptual deficits, affected vision and dizziness, emotional and cognitive disturbances, and communication difficulties (Stroke-boken, 2001). Fatigue (Choi-Kwon, Han, Kwon & Kim,

2005) and depression (Jönsson, Lindgren, Hallström, Norrving & Lindgren, 2005) are common symptoms after stroke, and have a considerable impact on daily activities. Walking function post-stroke is impaired in 67% of the patients and most of the improvement of walking occurs within the first three months after the stroke onset (Jørgensen, Nakayama, Raaschou & Olsen, 1995a). Approximately half of all surviving patients have residual disabilities concerning activities in daily living (Jørgensen, Nakayama, Raaschou, Vive-Larsen, Stöier & Olsen, 1995b).

The consequences of a stroke may influence body function and structure, activity, and participation, as defined in the International Classification of Functioning, disability, and health, ICF (WHO, 2001). The corresponding components of dysfunction are described as impairment, activity limitation, and participation restriction. This classification was developed to facilitate communication and documentation among health professionals worldwide.

Within the body function and structure component of ICF, muscle weakness post-stroke is considered to be a major contributor to limitation of physical activity (Ada, Dorsch & Canning, 2006). Moderate to strong correlation between knee muscle strength and walking ability has been reported (Flansbjerg, Downham & Lexell, 2006), thus reflecting association between different ICF components. After stroke, muscle strength has been shown to be impaired bilaterally (Andrews & Bohannon, 2000).

Spasticity occurs in about 20% of stroke patients (Sommerfeld, Eek, Svensson, Holmqvist & von Arbin, 2004; Lundström, Terént & Borg, 2008). About 4% of the patients experience disabling spasticity, i.e. an increased muscle tone with a pronounced impact on everyday life, one year after stroke onset (Lundström, Terént & Borg, 2008). Spasticity used to be in focus in stroke rehabilitation, and treatment methods aimed at inhibiting this symptom were developed. Currently however, stroke rehabilitation is focused on how to improve muscle strength and physical activity (Van Peppen, Kwakkel, Wood-Dauphinée, Hendriks, Van der Wees & Dekker, 2004).

Impaired postural control is a common stroke-related disability (de Haart, Geurts, Huidekoper, Fasotti & van Limbeek, 2004). It influences daily life activities with respect to the ability to maintain a position (Genthon, Rougier, Gissot, Froger, Péliissier & Pérennou, 2008), to perform voluntary movements such as reaching for an object (Kusofsky, Apel & Hirschfeld, 2001), climbing over obstacles (Cameron, Bohannon, Garrett, Owen & Cameron, 2003), as well as regaining balance after external perturbations (Holt, Simpson, Jenner, Kirker & Wing, 2000). Moreover, loss of balance is often reported as a cause of falls (Hyndman, Ashburn & Stack, 2002).

There is a high risk for falls during all stages after stroke onset (Weerdesteyn, de Niet, van Duijnhoven & Geurts, 2008). During the rehabilitation period, falls most often occur during transfers indoors (Nyberg & Gustafson, 1995; Suzuki, Sonoda, Misawa, Saitoh, Shimizu & Kotake, 2005), whereas community-dwelling individuals fall while walking (Harris,

Eng, Marigold, Tokuno & Louis, 2005). Many different risk factors are suggested as predictive of falls after stroke, including fall-related self-efficacy (Hellström & Lindmark, 1999; Pang & Eng, 2008; Andersson, Kamwendo & Appelros, 2008).

Within the participation component of ICF, it has been demonstrated that impairments of the lower and upper extremities post-stroke correlate with handicap (i.e. participation in the updated version of ICF) (Desrosiers, Malouin, Bourbonnais, Richards, Rochette & Bravo, 2003). Disability of the leg was found to be more strongly associated with handicap than was disability of the arm. Long-term participation after stroke is reported to be best predicted by lower extremity coordination as well as by age, comorbidity and affect (Desrosiers, Noreau, Rochette, Bourbonnais, Bravo & Bourget, 2006). These research results emphasise the importance of improving locomotion in order to enable integration into the community after stroke.

Challenges in stroke rehabilitation

Assumptions concerning the potential for functional recovery after stroke have changed over time. According to the Copenhagen Stroke Study (Jørgensen, Nakayama, Raaschou, Vive-Larsen, Stöier & Olsen, 1995b), a valid prognosis of walking function in stroke patients with initially mild or moderate leg paresis is possible three weeks post-injury. It was suggested by the investigators that no further recovery should be expected after nine weeks.

Later, a quite different view of functional recovery after stroke based on studies of plasticity within the brain emerged (Dobkin, 2004). There is increasing evidence for functional and structural changes in the brain, so-called adaptive plasticity, after brain injury. Even in the chronic period after stroke, reorganisation of cortical function is possible, but is likely to be widespread and not just confined to the peri-infarct regions (Nudo, 2003). Several studies during the past decade have shown correlations between cortical reorganisation and clinical outcomes in stroke patients regarding both upper extremity function (Liepert, Bauder, Wolfgang, Miltner, Taub & Weiller, 2000; Lindberg, Schmitz, Forssberg, Engardt & Borg, 2004) and gait (Miyai, Yagura, Oda, Konishi, Eda, Suzuki et al. 2002).

There are many areas in the field of stroke rehabilitation where research and development of treatment approaches are ongoing.

Improved postural control is considered a key characteristic of functional recovery after stroke (Fong, Chan & Derrick, 2001). In a recent Cochrane review of 21 studies (Pollock, Baer, Pomeroy & Langhorne, 2007) it was concluded that there is no evidence confirming that a single physiotherapy approach is better than another for improving balance, muscle strength in the

leg, walking speed, or the performance of everyday tasks. However, the results were better after physiotherapy where components from different treatment approaches were used as compared with no treatment or use of placebo.

The concept of walking competency, including different aspects of walking such as endurance, obstacle avoidance, and cognitive tasks concomitant with walking, is an area of study in physiotherapy research (Malouin & Richards, 2004).

Further, locomotor treadmill training with partial body-weight support is also under investigation in stroke rehabilitation. Promising results have been obtained in a pilot study (McCain, Pollo, Baum, Coleman, Baker & Smith, 2008).

Overground gait training is often performed in stroke rehabilitation, but there is no evidence (States, Pappas & Salem, 2009) as to whether this type of training really improves gait function. Insufficient evidence also applies to repetitive task training (French, Thomas, Leathley, Sutton, McAdam, Forster et al, 2007), which is implemented intensively and aimed at improving functional ability after stroke.

In constraint-induced movement therapy, where movement of the unaffected arm and hand is restricted, the subject with stroke is forced to use the paretic limb. Short-term improvements have been demonstrated, but there is no evidence of long-term benefits (Sirtori, Corbetta, Moja & Gatti, 2009).

Mental practice with motor imagery and training in a virtual reality environment are areas in focus within stroke rehabilitation and these methods are investigated with both clinical and laboratory measures (Malouin & Richards, 2004).

The role of robotics in neuro-rehabilitation is still unclear and constitutes another challenge within stroke research, which needs to be further investigated (Pignolo, 2009).

In a systematic review of 151 studies, including many randomised controlled trials and some clinical controlled trials, the impact of physical therapy on functional outcomes after stroke was investigated. Strong evidence for task-oriented programmes aimed at restoring balance and gait was found. However, the effects were mainly observed in the tasks being trained. One of the conclusions in the review was that a more thorough theoretical understanding of the underlying mechanisms of disordered movements is needed in order to be able to develop more specific treatment approaches (Van Peppen, Kwakkel, Wood-Dauphinée, Hendriks, Van der Wees & Dekker, 2004).

Movement control

Movements and postures are critical for humans in their interaction with the environment. Thoughts and emotions are expressed through movements and postures (Brooks, 1986).

Movement is said to emerge through interplay between an individual, a task to be performed, and the environment in which it all takes place (Shumway-Cook & Woollacott, 2007a), as illustrated in Figure 1. Within the individual, many systems dealing with perception, cognition, and action interact to produce goal-directed everyday movements. The present thesis is mainly focused on action during the everyday sit-to-walk (STW) transfer.

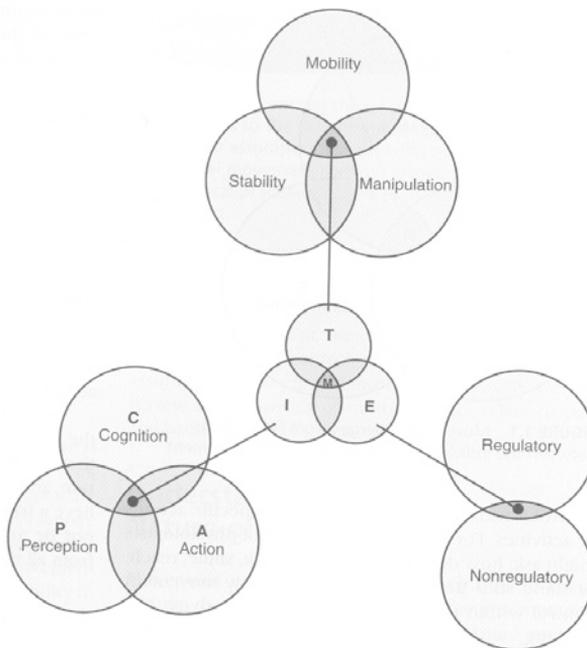


Figure 1. Factors within the individual (I), characteristics of the task (T), and constraints in the environment (E) contribute to the organisation of movement (M). Figure from Shumway-Cook & Woollacott, 2007 – used with permission from the publisher Lippincott Williams & Wilkins.

Movement science is proposed as a foundation for physiotherapy practice (Carr, Shepherd, Gordon, Gentile & Held, 1987). Previously, physiotherapists had to extract scientific information from the research of other professionals. However, physiotherapists are now developing their own scientifically based body of knowledge related to movement and

movement disorders in humans, and physiotherapy is evolving into a clinical science within the rehabilitation sciences (Sahrmann, 1998; Richards, 2005).

As a movement scientist, the physiotherapist is involved in research on human movement (Carr, Shepherd, Gordon, Gentile & Held, 1987). In the textbook “Motor control – Translating research into clinical practice”, Shumway-Cook and Woollacott state ...”understanding motor control and, specifically, the nature and control of movement is critical to clinical practice” (2007a). However, understanding the nature of movement and movement control requires interdisciplinary research collaboration (Winstein & Knecht, 1990), and physiotherapy is one of many important disciplines contributing to the rehabilitation sciences in this area (Richards, 2005).

Movements can be studied from a kinematic perspective, i.e. without considering the causes of movements. Exact descriptions of movements in terms of positions, velocities, and accelerations of different body segments or of the whole body, for example during gait, are frequently reported (Enoka, 2008).

A kinetic perspective, on the other hand, represents an approach where movements are studied with respect to forces causing them (Enoka, 2008). The question of how movements are controlled by different kinds of forces is a very complex and challenging research area.

At the beginning of the last century Nicholas Bernstein, a Russian scientist, performed pioneering work concerning movement control. He viewed the human body as a mechanical system (Bernstein, 1967). Bernstein emphasised the importance of considering external and internal forces acting on the human body when trying to understand the coordination and regulation of movements. The interplay between external forces, above all gravity, and internal forces, such as joint reaction, muscle and elastic forces, produces movements (Bernstein, 1967; Enoka, 2008). Thus, movements result from a cooperation between whole systems of impulses (i.e. force acting over time). The relationship between impulses and movements is extremely complex, implying that repetitions of the same movement are evoked by impulses, all of which differ from one another (Bernstein, 1967). More recent researchers have expressed a similar view on movement control; for example “It is active muscle forces, in combination with all the external and indirect forces that give rise to movement” (Horak & Macpherson, 1996a).

The transformation from muscle contractions to forces and subsequently to movements is very complex because of the redundant degrees of freedom (DoF) in the human body. Many joints and muscles have to be coordinated simultaneously for the dual purpose of maintaining or regaining balance at the same time as efficient functional movements are produced (Bernstein, 1967; Latash, 2003).

One way to address the rich complexity of the human locomotor system is to study and describe intralimb (within a limb) and interlimb (between

limbs) coordination. Within the scope of this thesis, the focus is on lower extremity coordination.

The intra- and interlimb interplay within the lower extremities is influenced by both external (such as properties of the ground) and internal (such as motor impairments in patients) constraints. In an experimental study with individuals without disability who walked on a treadmill at their own preferred speed, a successively increasing load was applied to one leg. It was found that the interlimb coordination was changed, whereas the intralimb coordination remained relatively unaltered (Haddad, van Emmerik, Whittlesey & Hamill, 2006). The ‘continuous relative phase’ variable, which was used to represent kinematic information on both the position and velocity of two adjacent body segments, was chosen as dependent variable to evaluate the effect of an increasing leg load. The data were collected with a movement analysis system.

A similar approach was used in a gait study, comprising six subjects with stroke and 18 controls, in which the impact of velocity and of an ankle-foot orthosis on intralimb coordination was examined (Barela, Whittall, Black & Clark, 2000). It was concluded that the dependent variable ‘relative phase of shank-thigh’ provides much more information on the true dynamics of walking than do data on angular displacement of the knee joint alone.

In a study in which a pedalling apparatus was used, with a possibility of either coupling or decoupling the contribution from each of the lower limbs, it was shown that the function of the paretic leg was improved by unilateral pedalling, but aggravated by bilateral pedalling (Kautz & Patten, 2005). This result indicates that assessments of motor performance post-stroke should include collection and reporting of data from both sides of the body. In many daily activities, such as rising to walk, interlimb coordination between the two body halves is used to accomplish the motor tasks.

The recovery of interlimb coordination in the acute phase post-stroke was investigated in a study where 53 subjects with first-ever stroke were randomised to one of three treatment conditions (Kwakkel & Wagenaar, 2002). Interlimb coordination was measured with four accelerometers, bilaterally positioned on the distal tibia and on the lateral part of the wrist. The main finding was that walking speed influenced the interlimb coordination post-stroke.

In a study with use of potentiometers mounted on a custom-built chair, where subjects with stroke performed interlimb coordination tasks either in a homologous (both arms; both legs) or non-homologous (one arm; one leg) way, no facilitation effect on the impaired limbs was observed (Garry, van Steenis & Summers, 2005). Further, the so-called unimpaired limb displayed coordination deficits, suggesting that interlimb coordination (arm + leg) might be influenced by neural centres in both hemispheres.

In an investigation of postural control with eyes open, eyes closed, and during a dual task, the non-paretic leg was shown to contribute more to

maintaining balance in standing (Roerdink, Geurts, de Haart & Beek, 2009). Unexpectedly, sensibility did not have a significant effect on the weight-bearing asymmetry.

The importance of taking the non-paretic leg into consideration was also highlighted in a study in which subjects with stroke were instructed to stand as still as possible and the controls were matched to the asymmetrical weight-bearing (Genthon, Rougier, Gissot, Froger, Pélissier & Pérennou, 2008). The findings suggested that the non-paretic leg could not completely compensate for the deficits of the paretic limb.

Motor control

Several scientists have contributed to the long history of different and overlapping theories of motor control, as outlined by Ragnar Granit (1981), a Finnish neurophysiologist with a devoted interest in motor control.

Many different theories of motor control still exist, and there is no consensus on how to define the concept. Vernon B. Brooks, an American neurophysiologist, suggested that motor control deals with the study of interaction between postures and movements and also with functions of body and mind that govern postures and movements (Brooks, 1986). Typical motor control is considered to be the ability within the central nervous system, using both current and previous information, to produce relevant and efficient functional movements (Horak 1991). A recently proposed definition of motor control is “the ability to regulate or direct the mechanisms essential to movement” (Shumway-Cook & Woollacott, 2007a).

Expanding knowledge within neuroscience, including the plasticity aspect, has led to the integration of old theories of motor control into new ones, and at the same time this process has had an important impact on the development of new rehabilitation models (Horak, 1991).

Efforts to describe motor control theories (Horak, 1991; Hirschfeld, 1996; Shumway-Cook & Woollacott, 2007a) have demonstrated a development from a reflex-hierarchical model, prevailing during the first half of the last century, to a systems theory of motor control. Bernstein was the first to propose this latter theory in the beginning of the 1930s (Horak, 1991). According to the systems theory of motor control, movements emerge as a result of interaction between several subsystems, each contributing to different aspects of control. The end-point of this control is to accomplish motor behaviour aimed at task goals (Horak, 1991).

During the last decades, the dynamic action theory has been combined with the systems theory into the dynamic systems theory (Shumway-Cook and Woollacott, 2007a). Clinical implications relevant to physiotherapists have been suggested (Perry, 1998). One of the fundamental viewpoints in the dynamic systems theory is “that motor tasks are problems to be solved and

the solutions to the problems are the movement strategies generated by the system” (Higgins, 1991). It is assumed that preferred motor patterns are used in motor behaviour when everyday tasks are accomplished (Heriza, 1991; Kamm, Thelen & Jensen, 1990). This view might explain difficulties in treatment when efforts are made to train patients to change inefficient movement patterns (Perry, 1998).

So-called internal models have been proposed as solutions to motor control when fast coordinated movements are to be performed. It is suggested that cerebellum plays an important role in these neural representations of motor acts, facilitating motor performance through predictive feed-forward control (Kawato, 1999; Manto, 2009).

In spite of tremendous development within the research area of motor control the fundamental questions as to what is being controlled and how that process is organised (Granit, 1981) remain to be answered.

Postural control

To date, there is no agreement on a general definition of postural control or on its underlying mechanisms (Massion & Woollacott, 2004). Hypotheses based on different perspectives have been proposed and assumptions originating from these influence the choice of how to assess and treat patients with postural control disorders (Horak, 1991).

Many physiotherapists nowadays agree with the systems theory (Bernstein, 1967). According to this framework, a network of subsystems exists in the body, each of which contributes to solving postural tasks in everyday life. These postural tasks in the human body, viewed upon as a multisegment system, include maintaining the body in a steady-state condition, preparing it for and supporting it during voluntary movements (proactive control), and regaining balance after external perturbations (reactive control) (Winter, 1995; Shumway-Cook & Woollacott, 2007c).

From a clinical point of view, postural control in standing is often explained as a person’s ability to maintain the vertical projection of the body’s centre of mass (COM) within the base of support, so called postural stability or balance. Further, postural control also deals with postural orientation, which is described as the capacity to orient different body segments appropriately in relation to one another and to the environment (Horak & Macpherson, 1996b). In a clinical context, considerations regarding prerequisites within the individual, task demands, as well as environmental constraints have to be taken into account, as these factors directly influence postural actions (Horak 1997; Huxham, Goldie & Patla, 2001; Shumway-Cook & Woollacott, 2007a).

Biomechanically, it is suggested that the interaction between the vertical projection of the body’s COM, often called the centre of gravity (COG), and

the centre of pressure (COP) is critical in postural control (Corriveau, Hébert, Prince & Raïche, 2001; Winter, Patla, Ishac & Gage, 2003). The COM is an abstract point around which the entire mass of the body is balanced and it is the point at which the resultant of the external forces acts. Through COM, the gravitational force is counterbalanced by ground reaction forces (GRF), which are exerted from the support area. The centre of pressure is the weighted average of the net forces applied over the base of support (Winter, 1995).

The motion of COM needs to be controlled and it is the responsibility of COP to be the controller (Winter, Prince, Frank, Powell & Zabjek, 1996). A similar model of postural control has been proposed by Zatsiorsky and Duarte (1999), with rambling defined as the motion of a moving reference point and trembling as the oscillation of COP around the reference point trajectory.

Even such a seemingly easy postural task as standing still is in fact quite difficult, as the body cannot be motionless in standing (Rougier, 2008). The trajectory of COP is considered to be a complex mix of the displacement of the vertical projection of COM and inertial forces (Winter, 1995).

Maintenance of quiet stance has been extensively studied post-stroke. Through use of force plates, it has been shown that subjects with stroke exhibit increased body sway activity during quiet standing (de Haart, Geurts, Huidekoper, Fasotti & van Limbeek, 2004), as well as a distribution of weight in favour of the non-paretic leg (Dickstein & Abulaffio, 2000; de Haart, Geurts, Huidekoper, Fasotti & van Limbeek, 2004).

The cognitive aspect of postural control has received increasing attention in stroke rehabilitation in recent years. It is often tested through use of dual tasks, i.e. execution of a motor task at the same time as solving cognitive problems (e.g. Bensoussan, Viton, Schieppati, Collado, de Bovis, Mesure et al, 2007).

Clinical measures

There are high demands nowadays for standardised evaluation in evidence-based physiotherapy (Herbert, Jamtvedt, Mead & Hagen, 2005). Clinical evaluation instruments should be reliable, valid, and responsive, i.e. able to detect minimal clinically relevant changes over time (Finch, Brooks, Stratford & Mayo, 2002; Polit & Beck, 2004). Outcome measures in rehabilitation have been scrutinised from a psychometric perspective, and put together in a guide to simplify clinical decisions (Finch, Brooks, Stratford & Mayo, 2002).

Physiotherapists in rehabilitation collect data from patients with movement disorders in mainly three ways: through rating scales, by observation, and/or by use of hardware instruments, such as a stopwatch, a dynamometer, or a goniometer.

Observer-based assessment instruments are often used in clinical practice for systematic collection of relevant information about a subject's movement ability, e.g. to determine whether the subject can perform different balance tasks independently and safely. One such instrument, the Berg Balance Scale (BBS) has been extensively studied for different psychometric properties (e.g. Berg, Wood-Dauphinée, Williams & Maki, 1992; Berg, Wood-Dauphinée & Williams, 1995).

Postural control is a complex concept, including integration of many body subsystems. This complexity has to be taken into account when assessing postural control and its subcomponents postural orientation and postural stability, i.e. balance (Shumway-Cook & Woollacott, 2007b).

Balance can be affected in many different task-specific ways. Steady-state balance control is needed in order to maintain different positions. Proactive balance control prepares the body in anticipation of potentially destabilising movements and supports the body during voluntary movements including locomotion. Reactive balance control helps us to recover from external perturbations, e.g. in stance or during locomotion (Shumway-Cook & Woollacott, 2007c). Thus, balance assessment instruments should take all these different aspects into account (Horak, 1997; Huxham, Goldie & Patla, 2001). Most balance assessment instruments focus on only one or a few of these aspects.

Recently, a new clinical balance assessment tool, the Balance Evaluation Systems Test (BESTest), has been developed (Horak, Wrisley & Frank, 2009). This balance tool is constructed to target six different balance control systems, namely biomechanical constraints, stability limits/verticality, anticipatory postural adjustments, postural responses, sensory orientation, and stability in gait. Its aim is to assist clinicians to decide upon specific treatments for their patients with balance disorders. Studies of the psychometric properties of this instrument are in progress.

Clinical measures of locomotor ability assess both balance control and locomotion, as these two activities are inseparable (Shumway-Cook & Woollacott, 2007c). In observational gait analysis, information is gathered in a more or less structured sequence. One structured example is Rancho Los Amigos' gait analysis form, where 3D information from different body segments and joints is collected (Perry, 1992).

However, in many observational instruments for assessing gait only a moderate level of reliability has been found with respect to both intra- and interrater assessments (Malouin, 1995). Similar results have been obtained regarding visual assessment of quality of movements during functional motor tasks post-stroke (Pomeroy, Pramanik, Sykes, Richards & Hill, 2003).

Laboratory measures

Human movement is the result of the interaction between a biological system, in this case the human body, and the environment, i.e. the physical world in which we live (Enoka, 2008). Human movements can be studied from a kinematic and/or a kinetic perspective, as mentioned earlier. Laboratory measures are used to describe both movements and forces.

Regarding the kinematic perspective, an example of a previously frequently used instrument is the electrogoniometer, which is strapped to the patient. Two video-cameras are employed to measure single joint movements (Gill-Body & Krebs, 1994). Accelerometry and electromagnetic systems are other examples of highly technological equipment being used for kinematic data collection (Kaufmann, 2004).

Camera-based systems, connected to a computer-processing system, are becoming more frequent, both in research and for clinical purposes. In order to conduct 3D analyses, two coordinate systems have to be defined. The global coordinate system is the fixed laboratory system, from which the positions of the markers on the moving body, i.e. the local coordinate system, are derived and defined. To align these two coordinate systems, calibration of the measuring volume is performed (Robertson, Caldwell, Hamill, Kamen & Whittlesey, 2004).

The camera systems utilise either passively reflecting or actively light emitting markers to collect data from different body segments or from the whole body. Information on masses of different body segments and on the locations of their respective COM is included in biomechanical analyses of the process of movements (Bernstein, 1967; Robertson, Caldwell, Hamill, Kamen & Whittlesey, 2004).

Reflective markers are attached by double-sided adhesive tape to the body, either separately on specific bony landmarks or in clusters, attached on light metal plates. Three markers per body segment are often used, in order to obtain 3D information about positions, velocities, and accelerations of the markers and body segments. Further, to generate 3D spatial coordinates of the markers, at least two cameras have to collect information from each marker (Robertson, Caldwell, Hamill, Kamen & Whittlesey, 2004). Thereby, the exact position and displacements in three dimensions can be described throughout specified movements, e.g. during gait (Kaufmann, 2004).

Force measures, i.e. a kinetic perspective on movements, can be obtained in different ways, e.g. by electromyographic recordings from the muscles themselves or by use of different kinds of force plates. Strain-gauge force transducers are used for example in AMTI force plates (Advanced Mechanical Technology Incorporation), where there is a change in resistance when the strain gauge is deformed by force. Pressure-sensitive so-called piezoelectrical crystals are used in Kistler force plates and produce a voltage

proportional to the pressure (Lanshammar, 1995; Robertson, Caldwell, Hamill, Kamen & Whittlesey, 2004).

Multiple trials during force data collection are preferably conducted, in order to get an average, which reflects the typical performance (Gill-Body & Krebs, 1994).

Kinetic and kinematic signals are recorded synchronously. Several different variables can be calculated from these signals. Laboratory-based force and movement analysis systems have good potentials to collect data objectively from multi-joint and multi-limb movements. Limitations such as inaccurate marker placement, movements of the markers, calculations and smoothing of the data, as well as difficulties in interpretation, should be considered (Schwartz, Trost & Wervey, 2004; McGinley, Baker, Wolfe & Morris, 2009).

To use force and movement analysis in rehabilitation research of everyday motor tasks is a challenge, which has substantial support in the literature (Gill-Body & Krebs, 1994; Richards, Wood-Dauphinée & Malouin, 2004; Hirschfeld 2007; Shumway-Cook & Woollacott 2007a).

Owing to the complex processes involved in postural control and locomotion, many variables have to be assessed. A division into task and performance variables has been suggested (Latash 1993). Task variables represent what is required of an individual concerning a specific task, e.g. the time needed and/or the amplitude of a movement. Performance variables describe how the task is being performed in terms of movements and forces during the process.

Relations between clinical and laboratory measures

Studies comparing clinical and laboratory measures have been conducted with different purposes.

One intervention study addressed the question of whether changes in biomechanical variables after treatment, compared to before, could explain clinical changes (Leroux, Pinet & Nadeau, 2006). In that study, ten subjects with stroke participated in an eight-week exercise programme, where the clinical measures BBS and Timed Up and Go (TUG) were compared with laboratory measures of GRF and COP displacement. Significant improvements in both clinical and laboratory measures of balance and mobility were found. However, seven of 11 investigated parameters showed weak correlation between clinical and laboratory measures. It was concluded that the clinical and laboratory outcome measures seem to assess different components of improvements.

Another study, evaluating the effect of a four-week stroke rehabilitation programme, had a similar purpose of furthering the understanding of the recovery process (Garland, Willems, Ivanova & Miller, 2003). Functional

improvements of balance and mobility were not paralleled by improvements in electromyographic and force plate data in ten of 27 participating subjects, suggesting that these patients used compensatory strategies to increase function.

Another reason to conduct a comparative study, regarding the relation between clinical and laboratory measures, is to validate a clinical tool, where the laboratory measures often are considered to be the “golden standard”. In the development of BBS, comparisons were made between scores on the balance scale and laboratory measures of “postural sway” during quiet standing and pseudorandom perturbations (Berg, Maki, Williams, Holliday & Wood-Dauphinée, 1992). The mean correlation between BBS and laboratory measures was moderate, with $r = - 0.55$. The laboratory measure with the strongest correlation to BBS was COP velocity in the anterior-posterior (AP) direction, $r = - 0.67$. The authors suggested that future studies should explore the dimensions of balance to further the understanding of the discrepancies between clinical and laboratory-based outcome measures.

A cross-sectional study with 15 men presenting hemiparesis was performed with the purpose of assessing the relation between functional evaluation as measured by the Fugl-Meyer form and objective measures of postural control (using a force platform) and walking (studied by light photography) (Dettmann, Linder & Sepic, 1987). Many of the correlations between section scores of the Fugl-Meyer form were not statistically significant, whereas total Fugl-Meyer scores showed moderate correlations to measures of postural control and walking ability.

Clinical measures of standing balance, maximum weight-bearing on the paretic extremity, and knee extension strength were compared with kinetic energy and task duration of rising to stand and curb climbing (Cameron, Bohannon, Garrett, Owen, & Cameron 2003). Moderate significant relationships, ranging from 0.40-0.50, were found between clinically assessed impairments and the laboratory-based measures in the 15 stroke subjects.

In order to investigate whether a clinical balance measure, the Functional Reach test, really tests anterior stability with accuracy, comparisons were made with laboratory measures (Jonsson, Henriksson & Hirschfeld, 2002). It was found that other factors than COP forward displacement influenced the results more. Thus, the Functional Reach test was shown to be a poor measure of stability limits.

Many investigators, as described above, have found results of moderate correlations between clinical and laboratory-based outcome measures, thus emphasising a need to further examine the relation between these two kinds of measures. It has also been proposed (Latash, 2003) that such studies might extend the knowledge base in movement science.

Forward-oriented movements during daily life

Forward-oriented movements, such as bending forward or taking a step in the forward direction, are often initiated during everyday activities. A close temporal correlation in lower limb muscles and a backward displacement of COP have been reported to be critical components of a motor programme, and to be involved in the preparation of specific forward-oriented movements (Crenna & Frigo, 1991).

In the next section, three daily forward-oriented movements, including STW, are described, first the typical performance and then the atypical performance displayed by subjects with stroke.

Sit-To-Stand

Rising to standing from a seated position, i.e. sit-to-stand (STS), and sitting down are basic everyday activities representing essential prerequisites for the completion of many other daily tasks such as getting in and out of bed and walking (Durward, Baer & Rowe, 1999). During STS the whole body's COM is transferred forward and upward to a new decreased base of support.

Sit-to-stand has been in focus of research from many perspectives. In a review of 39 STS studies with experimental set-ups, chair height, use of arm rests, and foot position were found to be determinants of the transfer. In most of the studies, the subjects were instructed to keep their arms crossed in front of the chest in order to prevent the use of the upper extremities while executing STS (Janssen, Bussmann & Stam, 2002). The facilitation of standing up by use of posterior foot placement has been highlighted by Kawagoe et al (2000). The distance between COM and COP was explored and found to be much shorter when the subject used a posterior foot placement, thus requiring less muscle activity, as revealed by hip and knee joint moment profiles.

Further, temporal phases of STS have been suggested (Schenkman, Berger, Riley, Mann & Hodge, 1990). Age-related reduction in muscle strength influences the velocity at which the STS task is performed (Gross, Stevenson, Charette, Pyka & Marcus, 1998). Many speed invariant variables during STS were found in eight healthy elderly. Hence, it was concluded that STS is mainly programmed (Vander Linden, Brunt & McCulloch, 1994). Furthermore, it has been demonstrated that interlimb force coordination between the buttocks and feet occurs during rising to stand (Hirschfeld, Thorsteinsdottir & Olsson, 1999).

Different COM variables have been investigated during STS in subjects without disability. The magnitude of COM peak horizontal momentum (PHM) did not vary between different speeds of ascents and age-groups (Pai & Rogers, 1990), whereas COM peak vertical momentum (PVM) was reduced in a group of elderly (mean age 72 years) as compared with young

adults (mean age 32 years) (Pai, Naughton, Chang & Rogers, 1994). The major contributor to PHM was the head-arm-trunk segment and to PVM the thigh segment (Pai & Rogers, 1991).

The effect of stroke-related impairments on the performance of STS has been studied mainly from a neuromuscular perspective. During rising, subjects with stroke load the paretic leg with a mean of 37.5% of body weight, whereas the corresponding value for the controls was 49.7% (right leg) (Engardt & Olsson, 1992). Several studies have shown reduced force production during STS in subjects with stroke (Cameron, Bohannon, Garrett, Owen & Cameron, 2003; Lomaglio & Eng, 2005; Bohannon, 2007; Roy, Nadeau, Gravel, Piotte, Malouin & McFadyen, 2007). Ankle dorsiflexion and knee extension moments on the paretic side as well as the degree of weight-bearing asymmetry significantly correlate to a prolonged duration of self-paced STS (Lomaglio & Eng, 2005). Similar results of a temporal effect were reported to correlate with reduced kinetic energy in 15 subjects with recent stroke (Cameron, Bohannon, Garrett, Owen & Cameron, 2003). Regarding onset time of muscular activity, an earlier onset in the soleus muscle and a delayed response in the anterior tibial muscle of the paretic limb have been found. Excessive anterior tibial and quadriceps muscle activities have been recorded on the non-paretic side (Cheng, Chen, Wang & Hong, 2004).

Foot position is one of the determinants of STS, as described above (Janssen, Bussmann & Stam, 2002). The effect of post-stroke foot position on the dynamics of standing up from a seated position has been tested on different kinematic and kinetic variables in some studies. The duration of subphases (Brunt, Greenberg, Wankadia, Trimble & Shechtman, 2002) as well as of the whole movement time (Camargos, Rodrigues-de-Paula-Goulart & Teixeira-Salmela, 2009) was found to increase with asymmetrical foot position. Asymmetries of trunk position (Lecours, Nadeau, Gravel & Teixeira-Salmela, 2008; Duclos, Nadeau & Lecours, 2008) and medio-lateral (ML) displacement of COP (Duclos, Nadeau & Lecours, 2008) were significantly reduced when the affected foot was placed behind. Changing the foot position and placing the paretic foot behind also significantly reduced weight-bearing asymmetry (Roy, Nadeau, Gravel, Malouin, McFadyen & Piotte, 2006; Lecours, Nadeau, Gravel & Teixeira-Salmela, 2008), knee moment asymmetry (Lecours, Nadeau, Gravel & Teixeira-Salmela, 2008) and significantly increased both vertical force production, and electromyographic activity in specific lower limb muscles (Brunt, Greenberg, Wankadia, Trimble & Shechtman, 2002). Contradictory results have been obtained by Camargos et al (2009), who found no significant differences in weight-bearing symmetry across the four foot positions being investigated.

Gait Initiation from standing

The typical performance of gait initiation (GI) from standing has a specific sequence from starting with loading of the forthcoming swing leg to lift-off of the stance leg, as revealed by GRF (Carlsöö, 1966; Nissan & Whittle, 1990; Elble, Moody, Leffter & Sinha, 1994; Brenière & Lepers, 1995).

An efficient pattern of intra- and interlimb coordination prepares the body for the first step (Mann, Hagy, White & Liddell, 1979). The different contributions from the two legs during GI from standing have been described. The swing leg is responsible for pushing laterally and thereby shifting the weight over to the stance leg, which generates momentum for a forward step (Brunt, Lafferty, Mckee, Goode, Mulhausen & Polk, 1991).

Gait initiation post-stroke has been documented in a few studies. A correct loading-unloading mechanism between the lower limbs was observed in 13 subjects in the chronic phase after stroke (Brunt, Vander Linden & Behrman, 1995). However, subjects with decreased weight bearing on the paretic side were not able to generate sufficient forces for forward momentum.

Spatio-temporal differences were noted when subjects after stroke initiated gait with either the non-paretic or the paretic leg (Hesse, Reiter, Jahnke, Dawson, Sarkodie-Gyan & Mauritz, 1997). Most deficiencies were evident when the non-paretic leg was used as 1st swing leg, such as a shorter swing period and shorter step length.

In a study on three subjects, who all had a spastic equinus varus foot, a lack of propulsion in the paretic leg was shown (Bensoussan, Mesure, Viton & Delarque, 2006). Early during GI from standing, a braking impulse was recorded beneath the paretic foot, whereas the 'sound leg' as well as both legs in the controls exhibited propulsive forces. Furthermore, the propulsive impulse beneath the 'sound' lower limb in the stroke subjects was greater than that in the healthy controls.

The influence of speed during gait initiation was investigated in 13 subjects in the chronic phase after stroke (Tokuno & Eng, 2006). Among many variables, it was only the magnitude of the anterior-posterior (AP) impulse generated by the paretic limb, independent of its role as either leading or trailing that remained different when speed was controlled.

Sit-To-Walk

The STS task has been extensively investigated, both in individuals with and without disability, whereas the probably more common everyday transfer of STW has been covered only in about a dozen studies. Sit-to-walk is a complex transfer, requiring central nervous system control of both equilibrium and locomotion in a 3D space, at the same time as the support area is drastically diminished.

Typical performance has been investigated in young and old adults.

Magnan et al (1996) studied STW in ten young men (mean age 28 years) and described two features characterising typical STW: taking the 1st step prior to the body's full extension and maintaining the forward progression of the body to the end of the task, defined as 2nd toe-off (TO). The timing of different events tended to occur earlier during STW than during STS, but the differences were not statistically significant. During STW, COM was transferred significantly more forward in a horizontal direction, compared with STS. The magnitudes of PHM and PVM were significantly larger during STW than during STS.

Kerr et al (2004) studied the STW movement in a group of 13 young adults (mean age 40 years). Four phases were defined from force data collected with one force plate beneath the feet and from movement data recorded with a movement analysis system. The consistency of the four phases was shown to be moderate to good.

A comparative design was used in the next study by Kerr et al (2007), in which three groups participated: young adults (mean age 33 years), older adults (mean age 70 years) and elderly at risk of falling (mean age 80 years). A seven-camera system and four switches (at the backrest, on the chair seat and two on the floor) were used to collect data, aimed at measuring time events during STW. Three phases were defined. The younger and older adults presented similar relative timing of the different phases, whereas the elderly at risk of falling spent significantly more time during the extension phase, defined from seat-off to the instant when the toe marker on the leading foot moved in the plane of progression. The switch system displayed excellent consistency regarding timing of the STW events, compared with the movement analysis system. The switch system was suggested as a screening tool for mobility problems in the elderly.

Dehail et al (2007) described STW characteristics in a group of 24 healthy elderly people (mean age 74 years). Kinematic data were collected by four video-cameras, and 3D motion analysis software was used. Electromyographic data were collected from several leg and back muscles. The participating elderly were free to use their arms and could reposition their feet if desired. Four phases of STW were defined from kinematic data. The anterior tibial and long peroneal muscles were activated early during the transfer, whereas no hip or back muscles were activated in anticipation. A negative significant correlation, $r = -0.63$, was found between isokinetic strength of the knee extensors and degree of trunk flexion, suggesting that the elderly used a strategy where they increased trunk flexion, probably with the purpose of decreasing the demands on knee muscle strength.

Buckley et al (2009) investigated the STW task in healthy younger (mean age 29 years) and healthy older (mean age 63 years) adults. The main finding was impaired STW performance in the older age group with respect to inability to merge the two subcomponents of STW. The younger adults

generated larger COM momentum in both the horizontal and vertical direction as compared with the older adults.

Three articles on STW in young men (Kouta, Shinkoda & Kanemura, 2006), in elderly persons (Kouta, Shinkoda & Shimuzu, 2007), and in both young and elderly men (Kouta & Shinkoda, 2008) have been published in a non-peer-reviewed journal.

Two articles have been published regarding the development of a clinical assessment instrument, the Fluidity Scale (FS) for the rise-to-walk task (Malouin, McFadyen, Dion & Richards, 2003; Dion, Malouin, McFadyen & Richards, 2003). In the process of developing this clinical tool, STW was assessed in subjects with stroke (n=19) and in unimpaired controls. The FS assesses the motor strategy employed while performing STW. A majority of the stroke patients exhibited a non-fluid strategy, i.e. first rising up to standing and then initiating gait.

The STW performance has also been investigated in persons with Parkinson's disease (Buckley, Pitsikoulis & Hass, 2008), in whom inability to merge the two subtasks of STW into a fluid motor strategy was found. The main delay was identified between seat-off and GI.

Rationale and scope of this research

Stroke-related movement disorder affecting everyday locomotion is an important research area within the rehabilitation sciences. An understanding of how movements are controlled is essential in order to develop treatment strategies aimed at improving safety and efficiency during daily transfers in subjects with disability.

During recent decades, substantial scientific knowledge has been obtained regarding how forward-oriented movements such as STS and GI from standing are performed, both typically and atypically. However, gait initiation from sitting, i.e. STW, which is a commonly performed everyday transfer involving a high risk of falls, has only been addressed in a few studies. For this reason, three of four studies described in the present thesis are focused on investigating how stroke influences different aspects of the complex transfer of STW.

Researchers have investigated the relations between clinical and laboratory measures with different purposes. The correlations have often been found to be moderate. To further the understanding of the relation between these two types of measures, some postural control and locomotion measures used in stroke rehabilitation and research were selected and the strength of the relation between them were investigated.

Aims

The two principal aims of this research work were

- to extend existing knowledge of the everyday sit-to-walk (STW) transfer in subjects with stroke and in matched controls by exploring temporal, kinematic, and kinetic aspects, and
- to investigate the relations between clinical and laboratory measures of postural control and locomotion in stroke rehabilitation and research.

The specific aims were

- to identify temporal events and to define phases of the STW transfer, to compare the relative duration of the STW phases in subjects with stroke and in matched controls, and to assess the variability of relative STW phase duration (Paper I);
- to describe and to compare the coordination of centre of mass horizontal and vertical momenta, and the fluidity during the STW transfer in subjects post-stroke and in matched controls (Paper II);
- to investigate the relations between clinical measures obtained from three assessment instruments (Fluidity Scale, Berg Balance Scale, and a rating scale of weight distribution in quiet stance) and laboratory measures (Papers II and III); and
- to explore the impact of stroke on strategies for anterior-posterior force generation prior to seat-off during the STW transfer (Paper IV).

METHODS

In the Methods section, information regarding the STW studies (Studies I, II, and IV, reported in Papers I, II, and IV) will be presented first, followed by a description of the studies on relations between clinical and laboratory measures (part of Study II and Study III, reported in Papers II and III).

Designs and subjects of Studies I-IV

An overview of the designs, samples, and settings of Studies I-IV is presented in Table 1. All subjects gave informed consent prior to data collection and the studies were approved by the local ethics committee of the medical faculty, Uppsala University, Sweden.

Table 1. *Overview of the four studies*

Study	I, II, IV	III
Design	Explorative, descriptive, comparative, cross-sectional (I, II, IV), correlative (II)	Descriptive, correlative, inter-rater reliability
Sample	Ten subjects with stroke and ten matched controls	20 subjects with stroke
Setting	Motor control and Physical Therapy Research Laboratory, Division of Physiotherapy, Department of Neurobiology, Care Sciences and Society, Karolinska Institutet, Stockholm, Sweden	The Gait Laboratory, Gå-skolan, University Hospital, Uppsala, Sweden

The subjects in the research studies described in this thesis comprised of three different groups. The characteristics of the participating subjects are presented in Table 2.

Table 2. *Characteristics of the three samples of subjects in Studies I-IV*

Study	I, II, IV		III
	Subjects with stroke (n=10)	Control subjects (n=10)	Subjects with stroke (n=20)
Gender (F/M)	5/5	5/5	8/12
Age (years)	59 ± 5.0 (50 – 67)	60 ± 7.7 (45 – 69)	50 ± 9.8 (21– 65)
Weight (kg)	79.2 ± 14.2 (62.4–103.7)	79.6 ± 13.9 (64.8 – 105)	77.8 ± 12.0 (60.0 – 97.0)
Height (m)	1.75 ± 0.10 (1.61–1.88)	1.76 ± 0.09 (1.65 – 1.90)	1.73 ± 0.08 (1.54 – 1.87)
BMI (kg/m ²)	25.9 ± 4.0 (21.6 – 33.4)	25.7 ± 3.2 (21.2 – 30.8)	-
Time since stroke (months)	56 ± 22 (9 – 96)	NA	28 ± 32 (6 – 132)
Side of paresis (Left/Right)	3/7	NA	9/11
Infarction/haemorrhage	5/5	NA	10/8 2 infarct. + haem.

Values are mean ± SD (range)

Abbreviations: BMI, body mass index; NA = not applicable

Studies I, II, and IV

The same samples of ten subjects with stroke and ten matched controls participated in the STW studies, generating Papers I, II, and IV. At the time of data collection, the subjects in the stroke group were community-living in Stockholm and Uppsala, Sweden. The control subjects were also recruited from Stockholm and Uppsala.

Explorative, descriptive, comparative, and correlative designs were used in these cross-sectional studies, where three different aspects of STW performance were investigated.

Inclusion criteria: age 40-70 years, at least 6 months post-stroke, residual hemiparesis of the lower extremity, ability to rise independently and walk 10 m indoors without a walking aid, and ability to understand verbal instructions. Exclusion criteria: any medical, musculo-skeletal or neurological disorder (other than stroke) that impaired locomotor capacity.

Five women and five men with stroke participated in the STW studies. The length of time since the onset of stroke was 0.8 – 8 years, with a mean of 4.7 years. Sensory function was normal or only slightly impaired in these stroke subjects. Muscle tone, as assessed by the modified Ashworth scale (Bohannon & Smith, 1987), was slightly increased (Ashworth 1-2) in plantar flexors, knee extensors and hip adductors in six of the subjects and showed marked resistance (Ashworth 4) against passive dorsiflexion of the paretic ankle joint in one subject. One subject with stroke wore an ankle-foot orthosis and used this aid throughout the tests.

All stroke subjects ambulated independently indoors. Nine subjects could walk >100 m without needing personal assistance. Three out of ten stroke subjects were able to climb stairs independently without banisters, while the remaining subjects needed some physical support.

Ten control subjects, matched for gender, age, weight, height, and body mass index, without any history of neurological or orthopaedic symptoms, were also enrolled (Table 2). There were no statistically significant differences in demographic characteristics between the stroke and the control groups.

Study III

A descriptive and correlative design (Table 1) was applied to examine the strength of the relations between clinical and laboratory measures of postural control after stroke, with data collected under similar spatial and temporal conditions.

Included in the study were individuals living in the community, 20-65 years of age, late after stroke onset (> 6 months), with residual impairment of the lower extremity, and able to remain in quiet stance for at least 2 minutes and to follow verbal instructions. The exclusion criteria were similar to those in Studies I, II, and IV.

Twenty subjects with stroke (Table 2), eight women and twelve men (mean age 50 years), were selected from an outpatient register. The length of time after stroke onset varied, ranging from 0.5 – 11 years, with a mean of 2.3 years. All subjects were able to walk independently outdoors, three of them needed a walking aid.

Procedures and data collection

The focus in this research work was on impairments and activity limitations post-stroke, and the collected data regarding stroke-related movement disorders describe mainly physiological functioning.

Studies I, II, and IV

Data were collected at the Motor Control and Physical Therapy Research Laboratory at Karolinska Institutet, Stockholm, where the necessary equipment and software were available.

Initially, the set-up was demonstrated to the subject, who was encouraged to practise STW a few times to feel comfortable with the task. The subjects were interviewed about their medical and falls history and their dependency/independency during daily activities. Thereafter, the subject dressed in tight sport shorts, a bra (for the women) and ordinary shoes. Weight was measured on a digital scale and height was measured against a wall with a measuring-tape. Reflective markers were applied on specific landmarks.

Reference measurements were made with the subject sitting on two force plates, situated on a platform (with a standard height of 0.45 m), and with the feet positioned on two other force plates, embedded in a 5 m long and 1.2 m broad walkway. The feet had to be positioned a little forward on the lower force plates and the arms were held slightly away from the body, in order to avoid hiding of the markers. A reference standing trial was also conducted.

A telephone was situated on a table on the walkway 5 m in front of the subject, who was instructed to walk forward to the phone as it rang. The semi-standardised procedure allowed free choice in repositioning the feet after the auditory signal, as well as an opportunity to use the arms during STW, as long as the subject did not push from the platform.

Simultaneously with the STW trials, the motor strategy was assessed using an ordinal scale, the FS for the rise-to-walk task (Malouin, McFadyen, Dion & Richards, 2003). Some modifications of the original protocol were made: the arms were free, the subjects could choose which leg to initiate gait with and the target (the telephone) was situated at a distance of 5 m and not at the prescribed 2 m.

Ten STW trials per subject were recorded. Five trials of STS were also recorded, but the STS data are not reported in this thesis.

Finally, extensive anthropometric measurements of the trunk, thighs, shanks, upper arms and forearms (Vaughan, Davis & O'Connor, 1999), as well as clinical assessments, were made.

Muscle tone of the ankle plantar flexors, knee extensors, and hip adductors was evaluated in both groups with the modified Ashworth scale (Bohannon & Smith, 1987). The passive range of motion of the ankle joints

was measured with a goniometer (Clarkson, 2000), with the knee in flexion (sitting position) and in extension (standing position), respectively.

The balance and mobility assessment instruments used in the STW studies are described in the following text. A short note will be given after the description of each instrument, proposing which component of postural control that is being measured (Shumway-Cook & Woollacott, 2007c) and whether the focus of assessment is on task or performance variables (Latash, 1993). Components of postural control and the concepts of task and performance variables have been described in the Introduction section.

General Motor Function assessment scale– used for description of the stroke group in Papers I, II, and IV

The General Motor Function assessment scale (GMF) was developed to assess three components (dependence, pain, and insecurity) related to motor performance during daily life activities in older adults (Åberg, Lindmark & Lithell, 2003a). Eleven mobility tasks, e.g. transfers in and out of bed, rising and sitting down, and walking in- and outdoors, are assessed by asking the subject to perform the tasks, one by one.

The percentage of agreement among raters has been reported to be high (Åberg, Lindmark & Lithell, 2003a). The concurrent validity between the subscale of dependence (GMF) and the Katz Index of activities of daily living (ADL) was studied and a high correlation was found (Åberg, Lindmark & Lithell, 2003b). All subscales of GMF correlated significantly with mobility in the ADL taxonomy instrument and with TUG (Gustafsson & Grahn, 2008).

The data collection in this thesis was part of a larger study, comprising also elderly with fear of falling. The GMF assessment scale was the instrument chosen to describe motor performance in all participating subjects.

- The GMF assessment scale does not measure any specific component of postural control. The subscale dependence measures task variables, whereas the other components pain and insecurity are subjectively rated by the elderly person.

Standing balance – reported in Paper II

The test “Standing balance” is an ordinal scale with seven levels (0-6), which measures an individual’s ability to stand unassisted without falling and with a subsequent decrease in the base of support (Bohannon & Leary, 1995). The ability to maintain standing double-legged, with feet together, and on one leg is timed (<30 or >30 s). The scale has been tested with good results for intra- and inter-rater reliabilities and for test-retest (Bohannon, Walsh & Joseph, 1993; Bohannon & Leary, 1995). The

responsiveness of “Standing balance” in acute rehabilitation (mean = 17.5 days) revealed significant changes in patient performance. Significant correlations between “Standing balance” and function, measured by the Functional Independence Measure, were demonstrated, both cross-sectionally and longitudinally, supporting the validity of the “Standing balance” test (Bohannon & Leary, 1995).

- “Standing balance” measures the steady state component of postural control. The test measures task parameters in terms of seconds, and of whether the balance task is successfully completed or not.

Timed Up and Go, TUG – reported in Papers I and II

The “Get up and Go” Test was originally developed to measure mobility, balance and locomotor performance in elderly people with balance disturbances (Mathias, Nayak & Isaacs, 1986). A modified version, the TUG, where the time to accomplish rising from an armchair, walking 3 m at a comfortable speed, turning, walking back, and sitting down, has been created (Podsiadlo & Richardson, 1991). The TUG test has not been tested on subjects with stroke, but in other patient populations such as people with Parkinson’s disease (Morris, Morris & Iansek, 2001) and in people with lower limb amputations (Schoppen, Boonstra, Groothoff, de Vries, Goeken & Eisma, 1999), with excellent inter- and intra-rater reliabilities, although the results of validity vary (Finch, Brooks, Stratford & Mayo, 2002).

- The TUG test measures the proactive component of postural control. The test measures task parameters, in seconds.

The Fluidity Scale, FS – reported in Paper II

The FS assesses the rate of change in the body’s forward progression when rising to walk in subjects with stroke (Malouin, McFadyen, Dion & Richards, 2003). It is an ordinal scale with four levels, 0-3 (Appendix 1). Zero represents a pronounced non-fluid strategy in performing the rise-to-walk task, and 3 implies normal performance, where gait is initiated before the body is fully extended (Magnan, McFadyen & St-Vincent, 1996). The inter-rater agreement, calculated by means of weighted kappa between three newly trained observers, was 0.78. Between the new raters and an expert rater the weighted kappa coefficient was 0.71 (Malouin, McFadyen, Dion & Richards, 2003). The performance of STW has also been studied concerning the time needed to complete the task, measured with a stopwatch. Excellent test-retest values (intraclass correlation coefficients, ICC = 0.99) were demonstrated (Dion, 2001). The concurrent validity concerning the duration of the rising-to-walk task has been shown to be strongly related to measures obtained from an

optoelectronic movement analysis system, $r = 0.97$ (Dion, Malouin, McFadyen & Richards, 2003).

- The FS, regarding motor strategies used during the transfer, assesses the proactive component of postural control. It measures performance parameters.
- The FS, regarding time used to complete the transfer (in seconds), measures task parameters.

The 10 m timed walk – reported in Papers I and II

Timed walking tests, such as the 10 m timed walk, have been recommended as reliable, valid, and sensitive measures of an individual's gait performance (Wade, 1994).

- The 10 m timed walk assesses the proactive components of postural control. The test measures task parameters, in seconds.

The laboratory-based assessments in the STW studies consisted of kinetic and kinematic measurements. Data collections from the force plates and from the movement analysis system were synchronised. Kinetic data collection will be presented first, followed by kinematic data collection.

Kinetic measurements

Four AMTI force plates (Watertown, MA, USA; size 457x203 mm; accuracy 0.25 N) recorded GRF in three dimensions (AP, ML and vertical) with a sampling frequency of 100 Hz. Two of the force plates were positioned on the platform (Fig. 2), with a distance of 0.041 m between them. The other two were embedded in the walkway, which was 5 m long, 1.2 m broad and 0.09 m high.

Calibrations of the room and of the positions of the force plates were carried out once a day before data collection. Prior to each STW trial, baseline data were recorded during at least 3 seconds.



Figure 2. The experimental set-up with eight cameras, two web-cameras and four force plates to obtain whole-body kinematic and kinetic data.

Kinematic measurements

The Elite system (BTS, Milan, Italy), which is an optoelectronic movement analysis system, was used to collect movement data during the STW trials. The system consists of eight cameras, emitting infrared beams of light at a sampling rate of 100 Hz. The light is reflected by passive markers, positioned on specific anatomical landmarks on the subject (Fig. 3). Thus, the subjects had to be lightly dressed. Forty-four markers (including six extra markers for reference measurements) in a whole-body set-up were attached with double-sided adhesive tape directly onto the skin. Clusters were used on the upper arms (on T-shaped metal pieces) and on the thighs and shanks (on rectangular aluminium plates with padding). The head markers were attached to a hair band (Fig. 3). The same person applied the markers and clusters on all participants throughout the data collection.

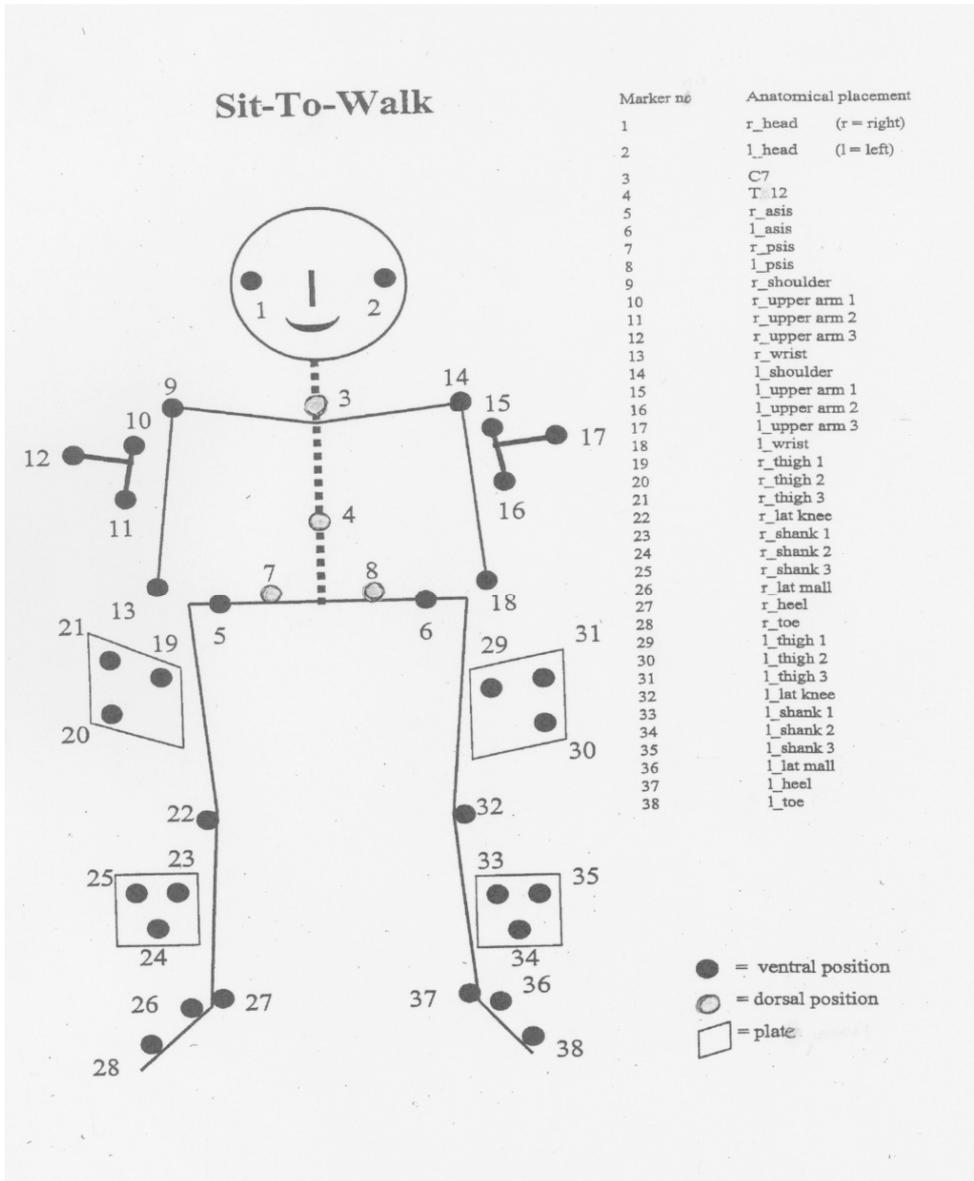


Figure 3. Schematic illustration of the marker set-up with 38 markers used during the STW trials. Abbreviations: asis, anterior superior iliac spine; psis, posterior superior iliac spine; lat, lateral

Three reference measurements in sitting and one in standing were conducted, to provide exact information on joint centres. Thereafter, the six medially placed markers at elbows, knees, and ankles were removed. The remaining 38 markers (Fig. 3) were used throughout the STW trials.

During 2-3 trials/subject, two web cameras were used, to obtain videotape records of sagittal and frontal views of the STW performance.

Study III

Data collection was conducted at the Gait Laboratory, Uppsala University Hospital, where the Vifor system was installed.

The procedures were as follow: Videotape recordings of the stroke subjects were made during a period of 15 s from the front and 15 s from behind, with the subject standing quietly, lightly dressed and wearing ordinary shoes (except one subject who chose to be barefoot).

Thereafter, the stroke subjects performed the balance items close to or on the force plate. The BBS was used for clinical assessment of balance in the stroke sample (n=20) and was chosen for its good psycho-metric properties.

Berg Balance Scale, BBS – reported in Paper III

The BBS is frequently used in geriatric and neurological rehabilitation. Originally, it was developed to assess balance disorders in the elderly (Berg, Wood-Dauphinée, Williams & Gayton, 1989), but it has also been used in clinical practice and in research to assess moderate to severe balance dysfunction in stroke patients (Stevenson & Garland, 1996). The scale consists of 14 items, where the patient performs balance tasks with differing degrees of difficulty, such as maintaining balance in different positions with a decreasing base of support, during transfers, and while performing voluntary movements. The BBS is an ordinal scale, rating balance from 0-4. The maximum score is 56, which equals typical balance function.

The BBS has been extensively tested and proven to possess very good psychometric properties with respect to intra- and inter-rater reliabilities (Berg, Wood-Dauphinée & Williams, 1995), internal consistency (Berg, Wood-Dauphinée, Williams & Gayton, 1989; Berg, Wood-Dauphinée & Williams, 1995), and prognostic and concurrent validities (Berg, Maki, Williams, Holliday & Wood-Dauphinée, 1992; Stevenson & Garland, 1996).

Blum & Korner-Bitensky (2008) evaluated the usefulness of the BBS in a systematic review that included 21 studies, investigating the psychometric properties of this balance assessment tool in subjects with stroke. Eight of the studies focused on responsiveness of BBS and moderate to excellent sensitivity was reported from all studies.

To enhance clinical decision making, the ICF (WHO, 2001), has been used as a framework when selecting clinical assessment tools (Beninato, Portney & Sullivan, 2009). The BBS was chosen to represent the activity domain in attempts to determine which measure was able to predict falls in individuals with stroke. The BBS was found to have reasonable accuracy in identifying subjects likely to have multiple falls.

- The BBS measures the steady state and proactive components of postural control. It measures task parameters, in terms of for example how long (in seconds) a given position can be maintained.

During data collection in Study III, seven BBS items were performed at the same time as the kinetic data were collected. The foot position on the force plate was not standardised. The remaining balance tasks were accomplished immediately afterwards.

Rating scale of weight distribution in quiet stance

A rating scale with five categories, describing different degrees of weight bearing on the left or right side (significantly more, somewhat more, equal), was constructed specifically for the postural control study (Study III) (Appendix 2). This rating scale has not been tested, but is considered to resemble routine practice by physiotherapists in stroke rehabilitation.

On a later occasion, three experienced physiotherapists used the rating scale to independently rate the patients' weight distribution in quiet stance from the video recordings.

Vifor system

The Vifor (= Video force) system, for collecting force data, consists of two video cameras and a force plate (Kistler, type 9284), which are interconnected (Lanshammar, 1988). The sampling frequency is 50 Hz.

Many different measures can be retrieved from force plates. To allow comparison with an earlier study (Berg, Maki, Williams, Holliday & Wood-Dauphinée, 1992) and to record force data, which have been reported to be relevant in assessing postural control (Goldie, Bach & Evans, 1989; Geurts, Nienhuis & Mulder, 1993), six force measures were chosen and calculated in Study III:

- standard deviation of the displacement (in mm) of COP in AP and ML directions;
- mean velocity of the displacement of COP (mm/s) in the AP and ML directions and
- standard deviation of the GRF (mm/s^2), normalised with respect to body mass, in the AP and ML directions.

Information from the force plate was also used to calculate the mean position of COP in the frontal plane during 30 s. This information was compared with the physiotherapists' ratings of the stroke subjects' weight distribution in quiet stance.

Data processing in Studies I-IV

Force data – kinetics

Different components of force data were analysed in Studies I, III, and IV. The processing of force data in the STW studies (reported in Papers I and IV) will be presented first, followed by data processed in the study on relations between clinical and laboratory measures (reported in Paper III).

Study I – processing of vertical force data

Force data from the four AMTI force plates were exported from the Elite system as c3d files for analyses in Visual 3D, a biomechanics analysis programme. Six trials per person were analysed, i.e. in total 120 trials (6 trials x 10 subjects with stroke + 6 trials x 10 controls). The force data were normalised to per cent body weight.

Vertical force data were used to identify events, separating STW phases. Seat-off of the two buttocks seldom occurred simultaneously. The last seat-off in each trial was therefore used to define the end of the first suggested STW phase. The pattern of unloading and loading between the forthcoming swing and stance leg was extensively explored, as this interlimb dynamic coordination has been found to be an important feature of gait initiation (e.g. Carlsöö, 1966). However, no definite identification of unloading could be established in the STW data. Therefore, the loading peak of the forthcoming swing leg, which could be identified in all trials and in all subjects, was chosen. Swing TO and stance TO were identified from the time when the force signals decreased to zero on the respective force plate.

Study IV – processing of anterior-posterior force data

Force data were transformed into ASCII files and processed with Axograph (Axon Instruments, Union City, USA), a MacIntosh-based software package. The AP force data were filtered with a cut-off frequency of 10 Hz and further processed.

The AP force data were organised with respect to swing and stance buttock, and swing and stance foot, respectively, to enable comparisons between the subjects with stroke and the controls. The AP force data were extensively explored. In 16 of the STW stroke trials, where the subjects chose to use their non-paretic leg as 1st swing leg, the data were found to differ considerably from those in the remaining trials. It was therefore decided to process, analyse, and report data from this subgroup of STW stroke trials separately. Thus, the statistical analyses in Study IV regarding AP force data comprised 44 trials from the stroke group and 60 from the control group, i.e. in total 104 trials.

In Study IV, the AP forces prior to seat-off were processed. The impulses of the AP force signals were measured by cursor read-outs and computed in

Axograph. Force onset and duration were determined from the net AP force impulse as well as from its propulsive and braking components beneath each buttock and each foot. Magnitudes of the net AP impulses and their sub-components were calculated and normalised to body weight (i.e. Ns/kg), to allow comparisons between the two study groups. Timing to seat-off and scaling of the AP force impulse peaks beneath each buttock were also calculated.

In addition, an outcome measure, called the Pp measure, which quantifies the proportion of propulsion contributed by the paretic leg to the net propulsion, was calculated. The propulsive impulse exerted by the swing buttock and by the swing side (i.e. buttock and foot combined) was divided by the net propulsive impulse beneath the buttocks and feet. It has been suggested that the Pp measure can serve as a quantitative measure of the coordinated output of the paretic leg during walking post-stroke (Bowden, Balasubramanian, Neptune & Kautz, 2006; Turns, Neptune & Kautz, 2007), and it was modified for use in Study IV.

Study III – processing of horizontal force data

Force data from the Kistler force plate were low-pass filtered with a cut-off frequency of 10 Hz in order to reduce measurement noise. The data of GRF, as well as of COP displacement and velocity in horizontal directions, i.e. AP and ML directions, were processed in Matlab.

To assess the weight distribution during quiet stance, the mean position of COP in the ML direction during 30 s was calculated for each of the 20 subjects with stroke. As the subjects did not use a standardised foot position, a translation to a new coordinate system centred on the midpoint between the feet was created.

Movement data – kinematics

Different components of movement data were analysed in Studies I, II, and III. The processing of movement data in the STW studies (reported in Papers I and II) will be presented first, followed by data processed in the studies on relations between clinical and laboratory measures (part of Study II and Study III).

Studies I, II, and IV

Kinematic data were processed in subsequent steps. Six trials, when possible from the middle of the ten collected in order to minimise influence of learning effects and fatigue on the dependent variables, were selected from each person. Initially, all markers throughout the STW transfer were identified in TrackLab in the Elite system. Thereafter, movement data were exported as text files to Qualisys Track Manager (Qualisys Medical AB, Gothenburg, Sweden), for interpolation of marker trajectories. Finally,

movement data together with the original force data were exported for further processing to Visual 3D, a data analysing and presentation programme. Kinematic data were filtered with a 4th order Butterworth filter with a cut-off frequency of 6 Hz.

A reference file in standing, with 44 markers, was prepared and used in the data processing. A whole body model, consisting of 13 segments, was constructed: head/neck, upper trunk, pelvis, right upper arm, right forearm, left upper arm, left forearm, right thigh, right shank, right foot, left thigh, left shank, and left foot. Anatomical frames for each body segment were defined from the position of the markers in the reference trial and from the anthropometric measures.

The 13-segment model was subsequently used for analysis of the kinematic data and for calculation of the whole body COM. The calculation of COM for each separate segment was based on the anatomical frame and on the documented relative mass and location of COM in a body segment (Dempster & Graughran, 1967). Whole body COM was then obtained as a weighted sum of each segment's COM. Finally, COM whole body linear momentum in horizontal and vertical directions was computed by multiplying COM velocity by body mass.

In Study I, onset of STW was defined from the peak of COM forward momentum. Momentum data were extensively investigated. Different percentages of COM forward momentum were tested to allow identification of STW-onset. Finally, 7% (Hanke, Pai & Rogers, 1995) could be identified as onset in all trials and in all subjects. Subsequently, all STW data were normalised in time, according to STW-onset, i.e. 100% movement time equals the time taken between STW-onset and STW-end.

In Study II, timing from STW-onset and seat-off to COM PHM and PVM was calculated. Additionally, the time between the two peaks was computed. The magnitudes of PHM and PVM were also calculated in both groups.

It has been suggested that an index of the fluidity (Fluidity Index, FI) in the body's forward movement during the early part of the STW transfer quantifies the amount of change in COM horizontal momentum (Malouin, McFadyen, Dion & Richards, 2003). This FI was calculated from the difference between the maximum peak and the thereafter following minimum values of COM forward momentum and expressed as a percentage. The FIs were calculated in all trials and in all participating subjects, i.e. in 120 trials. The FI was used as the golden standard when the relation to scores from the FS was investigated, as part of the study on the relations between clinical and laboratory measures.

Foot position at seat-off was determined by the difference in the sagittal positions of the lateral malleolus and the lateral knee markers.

Study III

In Study III, balance items of the BBS were divided into two subgroups, "maintaining a position" including static balance tasks and "dynamic balance" comprising the transfers and voluntary movements. This subdivision enabled comparisons to be made between clinical and force measures of similar balance tasks.

Statistical analyses

An overview of the inferential statistical methods used in the research studies of this thesis is presented in Table 3. Several statistical software packages were employed in the different analyses according to the specific issues to be analysed; SPSS version 14.0 (Study I), SAS software version 9.1 (Study I), STATISTICA, version 8.0 (Studies II and IV) and SPSS version 11.5 (Study III). In all cases, the level of significance was set to $p < 0.05$.

Table 3. *Overview of the inferential statistical methods used in Studies I-IV*

Inferential statistics	Study I	Study II	Study III	Study IV
Generalised linear mixed effects model	X			
Intraclass correlation coefficient	X			
Standard error of measurement	X			
Standard error of measurement in percentage of the mean	X			
Mixed model analysis of variance		X		X
Spearman's rank correlation		X	X	
Weighted kappa			X	

The research hypotheses in Studies I, II, and IV dealt with the effects of stroke on temporal, kinematic, and kinetic aspects of the STW performance. These effects were addressed by the experimental set-up, which was designed to supply dependent (covariance) structures across repeated measurements within each subject, as well as within matched pairs, structures that fit the assumptions of the various methods of statistical inference. When the temporal data of relative phase duration were addressed in Study I, a nominal response was constructed and addressed with a

combination of random and fixed factors in a binomial generalised linear mixed effects approach (mixed GLIM) (Olsson, 2002; Fitzmaurice, Laird & Ware, 2004). With the continuous kinematic and kinetic response variables (Studies II and IV), the indices of time and matched pair identity were perceived as random variables and combined with fixed factors in a mixed model analysis of variance (ANOVA) approach. In both cases, a restricted maximum likelihood approach to estimating asymptotic prob-values (p) was chosen (Searle, Casella & McCulloch, 1994).

In principle, statistical inference assumes independent observations, which is an assumption that does not hold in the presence of repeated measurements and within matched pairs. The inferential method therefore needs to be compensated for the presence of covariance, which is done by introducing random variables, where the variance-within-variables may be estimated and compared with the variance observed within the response variable. The concept of mixed models allows such random variables to be combined with traditional fixed factors, and thus introduces a method for addressing processes where independency cannot be assumed (Searle, Casella & McCulloch, 1994).

When the reliability of measurements in rehabilitation is addressed, the use of several statistical methods has been recommended (Lexell & Downham, 2005). Following these recommendations, two methods were used when temporal data regarding relative phase duration were analysed in Study I, namely calculations of relative (between subject variation; ICCs) and absolute (within subject variation; standard error of measurement in percentage of the mean, SEM %) reliabilities. Intraclass correlation coefficients were interpreted as proposed by Fleiss (1986).

In order to test the strength of the relations between clinical measures, observed at the ordinal level, and laboratory-based measures Spearman rank correlation was used (Studies II and III). The coefficients were assessed as suggested by Munro (2001).

Inter-rater agreement was assessed using weighted kappa statistics (Armitage & Berry, 1994) in Study III, where three physiotherapists rated weight distribution in quiet standing in 20 subjects with stroke.

RESULTS and DISCUSSION

The results and discussion in the next section will be presented according to the specific aims of Studies I-IV. The studies on STW (reported in Papers I, II, and IV) will be reported first, followed by the studies on the relations between clinical and laboratory measures (part of Study II and Study III).

Three different aspects of the everyday STW transfer were investigated. First, the coordination in time of specific events, i.e. a temporal aspect, was studied (Study I). Secondly, the locomotor coordination, i.e. a movement aspect, was examined in terms of COM momenta used to complete the STW transfer (Study II). Thirdly, strategies of AP force generation prior to seat-off, i.e. a force aspect, were explored with four force plates (Study IV).

Study I – STW from a temporal perspective

The aim of Study I was to identify temporal events and to define phases of the STW transfer, and to compare the relative duration of the STW phases in a stroke and a control group, through a whole body kinetic and kinematic set-up. In addition, the variability of the relative STW phase duration was assessed.

The results presented below are derived from 120 STW trials, i.e. from 60 trials in each study group.

- Five events (I-V) were identified and four phases (1- 4) of the STW transfer were defined. Sit-to-walk-onset (I) was identified as the instant when a threshold of 7% of COM PHM was exceeded in the beginning of the transfer. This percentage has been suggested by Hanke et al (1995) concerning the STS task.

Figure 4 illustrates the selected events and suggested phases.

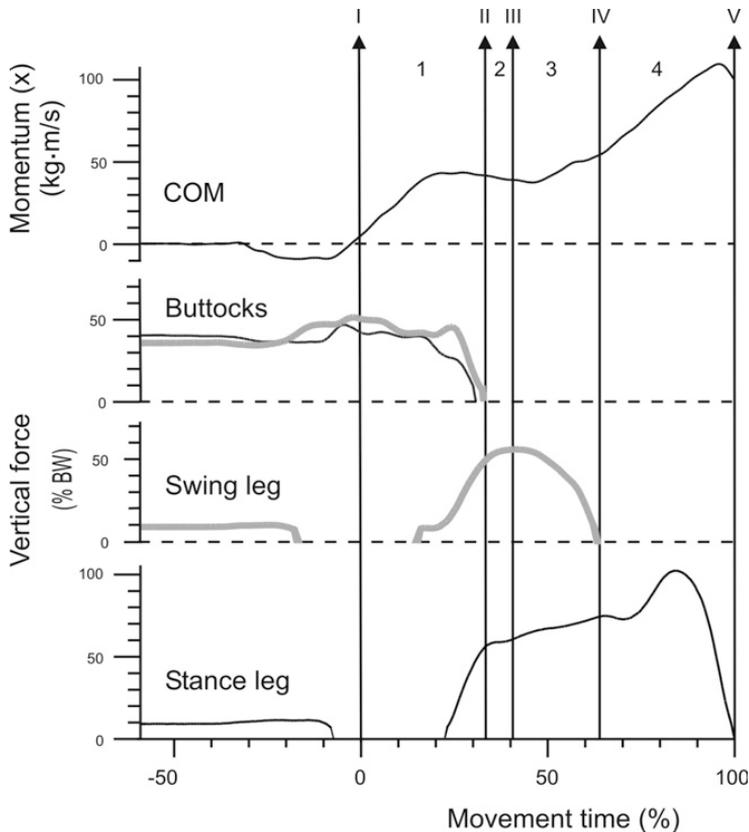


Figure 4. Temporal events (I-V; illustrated by vertical lines) and four phases (1-4) of sit-to-walk (STW). The graphs originate from a separate STW trial in a control subject. Thick lines represent traces of vertical forces from the initial swing leg and the ipsilateral buttock. Abbreviations: BW, body weight; COM, centre of mass; x, anterior-posterior. The period from STW-onset to stance leg toe-off represents 100% movement time.

The suggested STW phases are as follow:

- *Phase 1.* The rise preparation phase started at STW-onset (I) and ended at last seat-off (II).
- *Phase 2.* The transition phase lasted from last seat-off (II) to the loading peak of the forthcoming swing leg (III).
- *Phase 3.* The primary gait initiation phase started at the loading peak of the 1st swing leg (III) and ended at swing leg TO (IV).
- *Phase 4.* The secondary gait initiation phase lasted from swing leg TO (IV) to stance leg TO (V).

There is no consensus on how onset of forward-oriented transfers should be defined. Many different options are suggested by researchers investigating STS, STW, and GI from standing. Some examples are presented in Table 4. Onset events may originate from either kinetic or kinematic data, and moreover, from different aspects within these categories. This diversity makes comparisons between studies difficult. Furthermore, some of these onset events are calculated mathematically and some are defined by observation.

Table 4. *Definitions of onset of some forward-oriented everyday transfers*

Article	STS	STW	Onset defined from kinetic data	Onset defined from kinematic data
Schenkman, 1990	X			trunk and pelvis forward rotation
Hanke, 1995	X			COM forward momentum exceeds a threshold of 7% of its peak
Magnan, 1996	X	X		first shoulder movement
Brunt, 2002	X		AP and ML forces beneath the feet	
Kerr, 2004		X	change of vertical force, > 2 SD from the mean	
Roy, 2006	X		first perceptible change of vertical force	
Kerr, 2007		X		first forward displacement of COM
Dehail, 2007		X		angle between trunk and horizontal exceeds the mean (minus 2 SD)
Buckley, 2008		X	first detectable shift of force plate activity	
Buckley, 2009		X	change of vertical force, >2 SD from the mean	

Abbreviations: STS, sit-to-stand; STW, sit-to-walk; COM, centre of mass; AP, anterior-posterior; ML, medio-lateral

In the experimental set-up of the studies on STW, the choice of repositioning the feet before rising made it impossible to use an onset event defined by force data from the feet, as suggested in the studies by Kerr et al (2004) and Buckley et al (2008; 2009). The use of kinetic data from the force plates beneath the buttocks to define onset was not feasible either, because of the large variability within and between the subjects.

During data processing in Study I, as in the study by Hanke et al (1995), low percentages (1%, 3%, 5%) of the peak of COM horizontal momentum were tested as onsets, but could not be used as a definite onset, on account of fluctuations, probably reflecting body sway.

Finally, a threshold exceeding 7% of COM PHM, at the beginning of STW, was chosen as onset event and could be identified in all analysed trials. Centre of mass represents the whole body and its momentum takes inertial aspects into account, which is important when the body is to be elevated against gravity.

Further, an advantage of choosing an onset event from kinematics was the possibility of exploring and describing anticipatory force generation prior to STW-onset (as reported in Paper IV in this thesis).

The characteristics of GI during STW determined from vertical forces beneath the feet were thoroughly examined. Unloading of the stance leg, as reported in GI from standing (Carlsöö, 1966; Nissan & Whittle, 1990; Elble, Moody, Leffter & Sinha, 1994), could not be identified in all trials, as many different strategies of interlimb ML unloading and loading beneath the feet were detected within the data set. However, the loading peak of the initial swing leg was selected as event III, as it occurred in all subjects and in all trials.

The choice of seat-off, first TO and second TO as critical events to represent cut-off points between the different STW phases were all easy to detect from vertical data from the four force plates.

The choice of using observable events as onset and end of STW might be useful in clinical practice, e.g. when measuring total movement time with a stop-watch, as suggested by Dion et al (2003).

- The stroke and control groups took on average 2.38 s (\pm 0.52) and 1.55 s (\pm 0.23), respectively, to accomplish the STW transfer. The stroke subjects needed 54% longer movement time to complete the STW transfer than the controls.
- The relative duration of the transition phase (i.e. the 2nd STW phase), as defined from last seat-off to the loading peak of the initial swing leg, was the only phase that differed significantly ($p < 0.05$) between the stroke and control groups. The subjects in the stroke group used 18.9% of the total movement time for the transition phase of STW, as compared with 8.8% for the subjects in the control group.

There might be several reasons for this difference between the groups. Because of hemiparetic muscle weakness the subjects with stroke may not be able to generate sufficient forces for propelling the body forward and upward. The subjects with stroke may also have problems with coordination of COM horizontal and vertical momenta during rising to walk. Further, fear of falling might be a factor delaying the forward-oriented STW transfer.

Comparisons between studies regarding the duration of STW phases are hampered by the fact that different events have been chosen to define the phases.

Absolute times (in s) between STW-onset and different STW events, from previously published STW studies, are reported in Table 5.

Table 5. Mean absolute times in seconds from onset to subsequent events during sit-to-walk (STW). (Note: Frykberg, 2009: Timing to momenta is reported in Paper II.)

Article	To PHM	To SO	To PVM	To 1 st TO	To 2 nd TO = total time
Magnan, 1996 HYA	0.62	0.75	1.02	1.31	1.89
Kerr, 2004 HYA	-	0.81	1.06	1.15	1.7
Kerr, 2007 HYA	-	0.50	-	0.98	1.48
-“- HOA	-	0.53	-	1.20	1.8
-“- EARF	-	1.07	-	3.39	4.15
Dehail, 2007 HOA	-	-	-	-	1.84
Buckley, 2008 PWP	-	0.61	1.33	2.03	2.63
-“- HOA	-	0.50	1.01	1.28	1.82
Buckley, 2009 HYA	-	0.48	0.87	0.99	1.46
-“- HOA	-	0.50	1.01	1.28	1.82
Frykberg, 2009 stroke	0.46	0.63	0.97	1.58	2.38
-“- controls	0.43	0.49	0.84	1.02	1.55

Abbreviations: HYA, healthy younger adults; HOA, healthy older adults; EARF, elderly at risk of falling; PWP, persons with Parkinson’s disease; PHM, peak horizontal momentum; SO, seat-off; PVM, peak vertical momentum; TO, toe off

The results from the study performed by Magnan et al (1996) might be directly compared with the results reported in Paper I. The onset event, i.e.

first shoulder movement (Table 4) (Magnan, McFadyen & St-Vincent, 1996) might be comparable to the onset event described in Paper I (Frykberg, Åberg, Halvorsen, Borg & Hirschfeld, 2009). The end event, 2nd TO, is the same in both studies. The subjects with stroke (Study I) reached the events up to PVM earlier than did the 28-year-old men in the study by Magnan et al (1996). After PVM the subjects with stroke (Study I) were delayed.

Regarding total movement time, this was longer for the young adults in the studies by Magnan et al (1996) and Kerr et al (2004), as well as the older adults in the studies by Dehail et al (2007), Kerr et al (2007) and Buckley et al (2008, 2009) as compared with the control subjects reported in Paper I. A possible explanation might be that the onset events in the studies performed by Kerr et al (2004) and Buckley et al (2008, 2009) were defined from kinetic data and thereby included anticipation.

The differences in results might be due to characteristics of the set-ups in the respective studies. Standardisation with respect to arm and foot positions, chair height and which leg to use as 1st swing leg, was implemented in many of the other studies (Magnan, 1996; Kerr, 2004; Kerr, 2007; Buckley, 2008), whereas the set-up in the present study was semi-standardised. The possibilities of generating forces and thereby momentum might be limited when strict standardisation is implemented.

Interestingly, the young adults (mean age 33 years) in the study by Kerr et al (2007), where a system consisting of four switches was used, needed approximately the same total movement time as the controls (mean age 60 years) in Study I. It should also be noted that the young adults (mean age 29 years) in the study by Buckley et al (2009) took about the same time for STW as the controls in Study I, in spite of being considerably younger and allowed to use the arms once the movement had begun.

Regarding patients with movement disorders, results similar to those reported in Paper I were obtained in the study by Buckley et al (2008), where persons with Parkinson's disease took longer time after seat-off to swing-off of the initial swing leg as compared with the controls.

Further investigation of critical variables during the transition from a stable support area to a much smaller base of support, concomitant with gait initiation, is needed in subjects both with and without impairments.

- The ICCs expressing the consistency of the relative duration of the STW subphases ranged from poor to good, with the lowest scores during the primary gait initiation phase (ICC = 0.38 in the stroke group and 0.22 in the control group). The SEM% regarding relative phase duration were considerable, with the highest values in the transition phase (54% in the stroke group and 50% in the control group).

It is important to quantify variability between measurements (Lexell & Downham, 2005). Similar high values of variability have previously been

reported concerning speech movements (Gracco & Abbs, 1986) and multijoint hand movements (Cole & Abbs, 1986) and have been considered to reflect biological variability. As STW is a multijoint and multilimb transfer, these high values of variability are not surprising. It is likely that the semi-standardised set-up further contributed to these values.

Study II – STW from a movement perspective

The aim of Study II was to describe and compare the coordination of COM horizontal and vertical momenta, and the fluidity during the STW transfer in subjects with stroke and in matched controls.

The results reported below are derived from 120 STW trials, i.e. from 60 trials in each group.

- Significant group differences were revealed regarding magnitudes of COM PHM and COM PVM, with the stroke subjects generating less COM momenta in both directions, as illustrated in Fig. 5 and reported in Table 6.

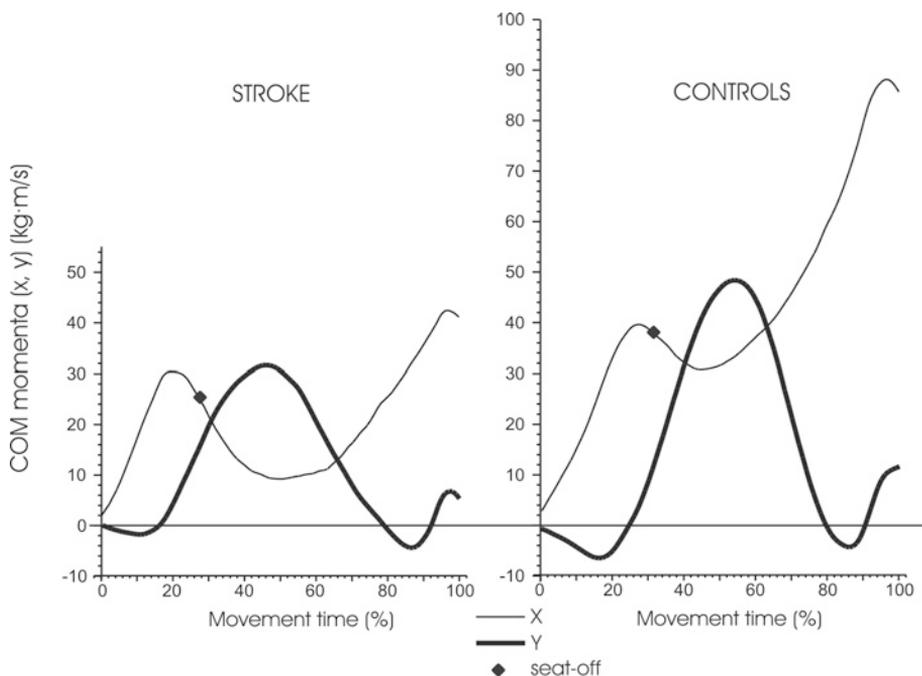


Figure 5. Mean graphs of centre of mass (COM) horizontal (x, thin line) and vertical (y, thick line) momenta from ten subjects with stroke and ten controls. Movement time in 100% starts with sit-to-walk-onset and ends with 2nd toe-off.

Data on magnitudes of COM horizontal and vertical momenta during both STS and STW have been reported by Magnan et al (1996) (Table 6). The young men in that study (1996) generated a PHM of 47.8 kg*m/s during STW, which was higher than that of the control subjects (42.5 kg*m/s) in Study II, and consequently also higher than that of the stroke subjects (36.4 kg*m/s). Regarding COM PVM, the young men (Magnan, McFadyen & St-Vincent, 1996) displayed a magnitude of 53.8 kg*m/s, which was higher than that of the control subjects (49.9 kg*m/s) and accordingly also higher than that of the stroke subjects (41.9 kg*m/s) in Study II.

The mean weight of the young men (Magnan, McFadyen & St-Vincent, 1996) was 74.6 kg, as compared with 79.2 kg in the stroke subjects and 79.6 kg in the controls, in Study II. Momentum is calculated as mass multiplied by velocity. Thus, the young men probably transferred from a seated position to walking with a higher speed as compared with both groups in Study II.

Another supplementary explanation for the differences in magnitudes of COM momenta between the controls in Study II and the young men in the study by Magnan et al (1996) might be different ways of calculating COM. In Study II, COM was calculated from a 13-segment model constructed with data from 38 markers, whereas the biomechanical model in the study by Magnan et al (1996) was based on 12 markers, excluding the arms and head.

The magnitudes of COM PHM and PVM from the STS trials in the study by Magnan et al (1996), as reported in Table 6, resemble the results from the stroke subjects in Study II, thus indicating that the magnitude values reflect that the stroke subjects used the motor strategy of first standing up and then walking.

Table 6. *Magnitudes of centre of mass peak horizontal and peak vertical momenta in Magnan et al, 1996 and in Study II*

Article	PHM (kg*m/s)	PVM (kg*m/s)
<i>Magnan et al, 1996</i> STS	39.1	44.7
<i>Magnan et al, 1996</i> STW	47.8	53.8
<i>Study II</i> Stroke subjects - STW	36.4	41.9
<i>Study II</i> Controls - STW	42.5	49.9

Abbreviations: STS, sit-to-stand; STW, sit-to-walk; PHM, peak horizontal momentum; PVM, peak vertical momentum

- Significant group differences were found concerning timing of COM PHM and PVM from both STW-onset and seat-off. The stroke subjects in Study II reached COM momenta peaks significantly earlier after STW-onset than did the control subjects.

The results with earlier attainment of the momenta peaks after STW-onset in the stroke group indicate that the stroke subjects did not bend the trunk as far forward as the controls. This is a possible explanation for the lack of negative vertical momentum in the early part of STW, as illustrated in Fig. 5.

Fear of falling could be one reason for this motor strategy, as this psychological aspect has been reported in subjects post-stroke (Hellström & Lindmark, 1999; Andersson, Kamwendo & Appelros, 2008; Pang & Eng, 2008). In order to rise up and walk safely, the COM has to approach the new base of support, even though it has been documented that the vertical projection of COM at seat-off often is situated behind the heels (Magnan, McFadyen & St-Vincent, 1996; Pai & Rogers, 1990).

Foot position is one of the determinants of the forthcoming area of support, and its effect on the possibility of rising up successfully during STW warrants further studies. Information about the ML momentum of COM during gait initiation is also needed in order to further the understanding of the motor strategies used.

- Significant group differences were found regarding fluidity during STW, irrespective of whether it was observer or laboratory-derived. Seven out of ten subjects with stroke performed STW with a non-fluid motor strategy. Nine out of ten controls performed STW with a fluid motor strategy. The mean FI in the stroke group was 15%, whereas the corresponding value in the control group was 71%.

The cut-off point of FI at 70% for discriminating between a fluid and a non-fluid motor strategy while rising to walk, as suggested in the literature (Dion, Malouin, McFadyen & Richards, 2003), could not be replicated. On the contrary, as low FI as 28% was rated as a fluid motor strategy by use of the FS. The discrepancies in results might be explained by the use of modifications of the original protocol in Study II, different ways of calculating COM horizontal momentum, and/or lack of training in the use of the FS in the present study.

Study IV – STW from a force perspective

The aim of Study IV was to explore the impact of stroke on strategies for AP force generation prior to seat-off during the STW transfer.

Examination of the AP force data revealed substantial differences between different stroke STW trials, depending upon whether the subject initiated gait with the paretic or the non-paretic leg. It was decided to make a separate analysis and interpretation of a subgroup of 16 stroke STW trials, where the subjects started to walk with their non-paretic leg.

The results reported below therefore derive from 104 STW trials, 44 of them originating from the stroke subjects who initiated gait with their paretic leg, and 60 from the control group. All controls used the same leg as 1st swing leg in all analysed STW trials.

The main results in the two groups, with respect to strategies of AP force generation prior to seat-off during STW, are illustrated in Fig. 6.

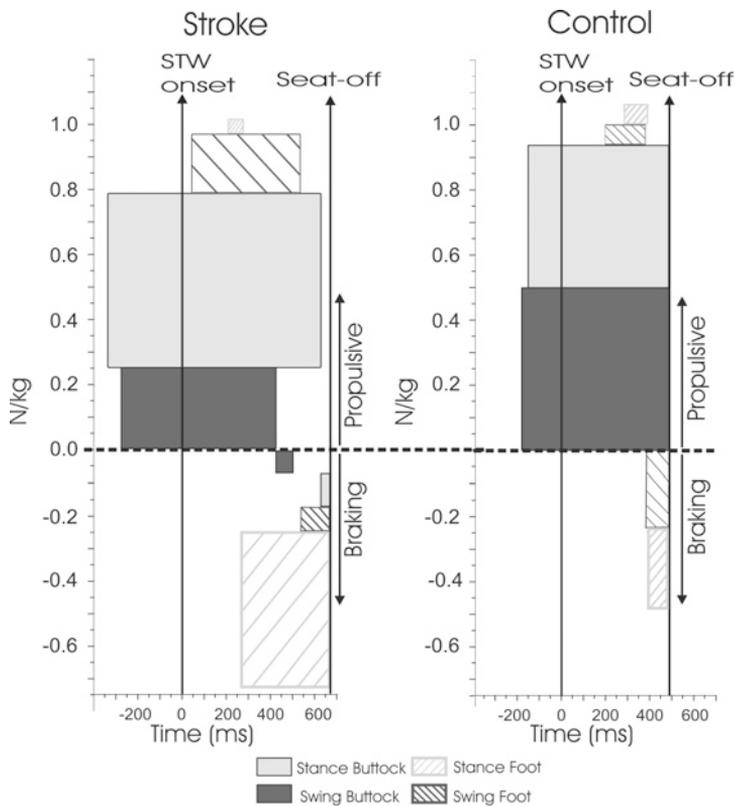


Figure 6. Schematic illustration of timing and scaling of the anterior-posterior (AP) force impulses generated prior to seat-off during the sit-to-walk (STW) transfer in the stroke (44 trials) and the control (60 trials) groups, respectively. The y-axis represents mean magnitude of the AP force (N/kg).

- In the control group, the AP force impulses prior to seat-off were smoothly coordinated between the buttocks and feet. The propulsion generated by backward pressure exerted by both buttocks produced a forward-oriented movement of the body. Just before seat-off, both feet exerted a forward pressure aimed at braking the forward propulsion of the body, in order to prepare for a well coordinated rise. The whole process in the controls took about 650 ms, of which about 165 ms occurred prior to the visible movement, i.e. in anticipation.
- In the stroke group, the coordination between the four body segments exerting pressure on the contact surfaces of the four force plates showed a quite different pattern of AP force impulse generation. The non-paretic stance buttock and stance foot dominated the interlimb coordination. An excessive propulsive force impulse was produced beneath the non-paretic stance buttock. The paretic swing foot added a considerable propulsive impulse to the forward-oriented movement. This substantial propulsive impulse prior to seat-off was counteracted by a braking force, mainly exerted by the non-paretic foot. Both buttocks also exerted some braking impulses prior to seat-off. In total, the AP force generation prior to seat-off in the subjects with stroke lasted about 1000 ms, of which about 300 ms occurred prior to the visible forward movement of the trunk.

The magnitude of the net AP force impulses generated by buttocks and feet prior to seat-off was not statistically significant between the two groups. However, when the contributions from different body segments were analysed, significant group differences were found in many of the AP force impulse variables.

- The impact of stroke on generation of AP force impulses was demonstrated through findings of a significantly smaller impulse exerted by the (paretic) swing buttock and a significantly larger impulse exerted by the (non-paretic) stance buttock, as compared with the controls. Further, the net AP impulse beneath the stance foot also differed significantly between the groups, with the stroke subjects generating a greater braking impulse than the controls. Significantly larger braking impulses were also found beneath the swing and stance buttocks in the stroke group.

Regarding the controls, similar results with well coordinated AP forces prior to seat-off have been reported during STS in seven healthy adults (Hirschfeld, Thorsteinsdottir & Olsson, 1999). The buttocks were shown to generate ‘rising forces’ in order to accelerate the body forward, while the feet exerted a ‘damping control’ prior to seat-off.

Interlimb influences during rhythmical motor activity, such as pedalling, have been shown to imply negative consequences for the paretic limb (Kautz & Patten, 2005). The results indicated that the coupling between the two limbs was impaired and that increased force in some muscles needed to be compensated for by reduced force in other muscles.

In a recent study (Genthon, Rougier, Gissot, Froger, Pélissier & Pérennou, 2008) the post-stroke contribution of each lower limb to quiet standing was investigated. The importance of interlimb coordination regarding postural stabilisation was highlighted. The researchers suggested that more focus should be directed to the compensatory role of the strong limb.

Efforts in quantifying the contribution of the paretic leg to propulsion during walking post-stroke resulted in the so called Pp measure (Bowden, Balasubramanian, Neptune & Kautz, 2006). A modified version of this measure was applied to the STW data in Study IV. The paretic swing buttock contributed by only 24% to the propulsive impulse prior to seat-off, whereas the corresponding value in the controls was 50%. This result indicates that even in the early part of STW, when the base of support is still quite large, consisting of the buttocks, thighs and feet, the paretic buttock and thigh show a pronounced reduction in force generation capacity. Furthermore, this implies that during the early period of gait initiation the non-paretic buttock totally dominates as force producer, as illustrated in Fig. 6. This motor behaviour might be considered to reflect “learned non-use” and be assumed to influence and remodel the structure and function within the motor areas of the brain (Sterr & Dean, 2008). It has been suggested that cerebellar networks may be important in regulating movement forces, especially in multijoint movements (Manto, 2009).

In Study IV it was demonstrated that a substantial propulsive impulse is generated from the buttocks prior to seat-off. Some of this force generation occurs prior to STW-onset, i.e. in anticipation. Surprisingly, in the study by Dehail et al (2007) in which electromyographic (EMG) activity from lower limb muscles, including the buttocks was investigated during STW and the only detectable muscular activity prior to STW-onset was recorded in the anterior tibial and long peroneal muscles. This is the only EMG study of STW so far, and follow-up studies are thus required.

Studies II – III

Relations between clinical and laboratory measures

A further aim in the research studies of this thesis was to examine the relation between scores from the clinical measure FS (Appendix 1) and the laboratory measure FI (reported in Paper II).

- A strong relation between FS and FI was found, $r_s = 0.84$, when calculated with Spearman's rank correlation.

A very strong relation, 0.99 (Eta root squared) was reported between FS and FI in the study by Malouin et al (2003). It should be noted that some modifications of the original version of the FS were applied in the present STW studies: free arms and foot positions, free choice of 1st swing leg, and that the goal (the telephone) was situated 5 m instead of 2 m ahead of the sitting subject. These circumstances might have influenced the result, as they introduce more variability into the data.

The finding of a strong relation between FS and FI was not surprising, as both measures assess the same component of balance control during locomotion, i.e. the proactive (Shumway-Cook & Woollacott, 2007c).

Clinical tools used for assessing the process of a motor act aimed at reaching a goal are rare. Many clinical assessment instruments assess the end result of a task, for instance how much time it takes to accomplish the task or how many times it can be performed within a specified time period. The importance of additionally assessing the process in reaching a goal on the basis of so-called performance parameters has been highlighted (Latash, 1993; Kaufmann, 2004; Jonsson, 2006).

The aim of Study III was to investigate postural control after stroke regarding the relations between clinical measures by use of BBS and a rating scale of weight distribution in quiet stance (Appendix 2), and laboratory measures from a force plate.

- Moderate correlations between scores on BBS and selected force measures were demonstrated. In the total group of subjects with stroke ($n=19$; as one subject was excluded in these analyses due to involuntary arm movements) the BBS items 'maintaining a position' correlated moderately to the force measure 'mean velocity of COP displacement in the AP direction', $r_s = - 0.50$.

In a subgroup of stroke subjects (n=12), who did not obtain the maximum score on BBS (range 30-54), three moderate correlations were found between:

- total score of BBS and the SD of the GRF in the AP direction, $r_s = - 0.59$,
- the BBS items ‘maintaining a position’ and the SD of the GRF in the AP direction, $r_s = - 0.66$ and
- the BBS items ‘maintaining a position’ and the force measure ‘mean velocity of COP displacement in the AP direction’, $r_s = - 0.62$.

Katherine Berg et al (1992) conducted a similar investigation, with comparison of clinical and laboratory measures in an elderly population, where moderate correlations were found. The assessment of balance with BBS was performed at the subjects’ homes and took about 20-30 minutes to complete. The force measurements took place in a laboratory environment, i.e. in an unfamiliar milieu for the elderly subjects. Quiet standing as well as pseudorandom perturbations were assessed. The whole test battery took about 1½ hours to complete.

According to the task-oriented approach of treatment in rehabilitation (Shumway-Cook & Woollacott, 2007a), movement emerges as a result of the individual’s characteristics, the task to be performed and the surrounding environment. The experimental set-up in the study reported in Paper III was therefore adapted so that the selected balance tasks were performed under similar spatial and temporal conditions. In spite of this arrangement, the relations demonstrated between scores on BBS and force measures were only moderate.

The assessed component of balance control might be more important than the environmental circumstances. The items in BBS consist of steady-state and proactive balance components (Shumway-Cook & Woollacott, 2007c). Force measures in the present study assessed only the steady-state component and this might partly explain the stronger relations found between the BBS items ‘maintaining a position’ and the force measures. However, even when the same balance component is measured there seem to be many other factors influencing the relations between clinical and laboratory measures.

- Moderate correlations, ranging from 0.52 to 0.63, were found between clinical ratings of weight distribution in quiet stance, performed by three physiotherapists (according to a rating scale), and the force measure ‘mean position of COP in the frontal plane during 30 s’.

Similar findings of moderate correlations have been reported with respect to observational gait analysis (Malouin, 1995) and assessment of functional movements (Pomeroy, Pramanik, Sykes, Richards & Hill, 2003).

The rating scale used in Study III was not tested for psychometric properties, but could be considered to resemble how posture is being assessed in clinical practice. Limitations in the experimental set-up, such as the fact that the physiotherapists' assessments were indirect, based on video records, while the force measures of COP displacement were measured directly, probably influenced the results. Observational methods used in physiotherapy, for instance concerning weight distribution in different positions, need to be structured, and standardised protocols need to be developed.

Additionally, standing still might seem to be easy, but research studies have shown that this motor task is quite difficult, as illustrated by complex COP trajectories (Winter, 1995; Horak & Macpherson, 1996b; Rougier, 2008).

A combination of clinical and laboratory measures guiding clinical decisions might provide a basis for appropriate therapeutic interventions (Gill-Body & Krebs, 1994; Richards, Wood-Dauphinée & Malouin, 2004; Kaufman, 2004).

GENERAL DISCUSSION

In the following section, the two principal aims of this research work regarding studies on STW and on the relations between clinical and laboratory measures will be discussed.

Kinetic, kinematic, and temporal aspects of the sit-to-walk transfer

The first principal aim of the STW studies was to extend existing knowledge of the everyday STW transfer in subjects with stroke and in matched controls by exploring temporal, kinematic, and kinetic aspects of this complex transfer.

The main findings in the present STW studies were the existence of kinetic, kinematic, and temporal differences between a stroke and a control group.

From a force perspective, the subjects with stroke generated a significantly larger propulsive impulse beneath the (non-paretic) stance buttock and significantly larger braking impulses beneath both buttocks and beneath the (non-paretic) stance foot, than did the controls.

From a movement perspective, the subjects with stroke generated less COM horizontal and vertical momenta and the latencies from STW-onset to the momenta peaks were shorter, as compared with those in the controls.

From a temporal perspective, the subjects with stroke took a significantly longer time in the transition phase from seat-off to the loading peak of the initial swing leg.

These findings are assumed to be inter-related.

In the control group, the results indicated a well coordinated interplay between propulsive force impulses generated beneath both buttocks and braking impulses generated beneath the feet prior to seat-off (Fig. 6, Study IV). Both feet contributed, to a minor extent, to the propulsive impulse. An effective push-off from the buttocks, reported in Paper IV as a short time period from the propulsive impulse peaks to seat-off, seemed to prepare the body for the forward movement. The results reported in Papers II and IV

indicate that these coordinated forces produced enough horizontal momentum, allowing a fluid motor strategy while rising to walk, as reported in Paper II. This forward-oriented movement in the control group was only smoothly damped by the symmetrical braking forces beneath both feet. As indicated in Fig. 5 in Study II, the controls probably bent their trunk more forward prior to seat-off than did the stroke subjects. This brings the whole body's COM closer to the support area. This might be a characteristic of an effective buttock push-off. The foot position might here be an important determinant, which needs to be investigated in future STW studies.

The subjects with stroke exhibited quite different strategies for force generation prior to seat-off. The non-paretic stance buttock produced an enlarged propulsive impulse assisted by the paretic foot. This pronounced propulsive impulse might endanger the subject's equilibrium, if not damped. Both buttocks as well as both feet, particularly the non-paretic stance foot, contributed to the braking of this excessive forward movement. This might partly explain the observation that less COM horizontal momentum was generated in the stroke group, reported in Paper II. The forward movement of the trunk seems to have been interrupted by braking impulses, which might be one reason why the stroke subjects did not bend as far forward as the controls did, as illustrated in Fig. 5 in Study II. This pronounced braking, prior to seat-off, might also be responsible for a reduction of the effectiveness of buttock push-off observed as relatively long time periods from the peaks of the propulsive impulses to seat-off (reported in Paper IV).

The apparently smooth intra- and interlimb dynamic interaction between the buttocks and feet prior to seat-off in the control group (Study IV), reflected in COM horizontal and vertical momenta (Study II), might partly explain the relatively short transition phase of STW in this group (Study I).

The intra- and interlimb dyscoordination regarding AP forces (Study IV), non-fluidity reflected in COM momenta variables (Study II) and low FIs (Study II) seem to result in a disturbance of the ongoing forward-oriented movement. This might partly account for the prolonged transition phase during STW in the stroke group (Study I).

Several design factors have to be considered when interpreting research results from studies on everyday motor tasks, including the results of the STW studies in this thesis.

One of these factors is connected with the laboratory equipment, such as how many force plates are used.

In the collection of data, it is highly recommended to be as precise as possible (Enoka, 2008). For example it was considered essential in the present STW studies that a whole-body set-up should be used, regarding both kinetics and kinematics, in order to obtain as precise 3D information on

movements and forces as possible, allowing investigation of movement control.

In previous STW studies (Magnan, McFadyen & St-Vincent, 1996; Kerr, Durward & Kerr, 2004; Kerr, Rafferty, Kerr & Durward, 2007; Dehail, Bestave, Muller, Mallet, Robert & Bourdel-Marchasson et al, 2007; Buckley, Pitsikoulis & Hass, 2008; Buckley, Pitsikoulis & Hass, 2009) some events have been indirectly estimated, as only 1-2 force plates beneath the feet have been employed.

The event seat-off, for instance, has been defined in various ways, e.g. as the time of peak vertical GRF beneath the feet (Kerr, Durward & Kerr, 2004), as the time of peak AP GRF beneath the feet (Buckley, Pitsikoulis & Hass, 2008), as a knee angle exceeding the mean plus 2SD of the angle calculated in a period of 200 ms before a sound signal (Dehail, Bestave, Muller, Mallet, Robert & Bourdel-Marchasson et al, 2007), or as the first increase in vertical velocity of the COM (Kerr, Rafferty, Kerr & Durward, 2007).

Most of these suggested definitions of the seat-off event are probably close to the true time instant. It is of interest to note though that the peak of vertical force beneath the feet was used to represent seat-off, as mentioned above (Kerr, Durward & Kerr, 2004). However, probably the same vertical loading peak of the initial swing leg was used in Study I in this thesis, to define the end of the 2nd STW phase, which we suggested started at seat-off. The transition phase comprised 18.9% of the total movement time in the subjects with stroke and 8.8% in the controls (Frykberg, Thierfelder, Åberg, Halvorsen, Borg & Hirschfeld, 2009). Thus, this part of STW was more or less overlooked in the study by Kerr et al (2004).

The experimental set-up in the present STW studies was semi-standardised, which might have influenced the results considerably.

A standard chair height was chosen, resembling ordinary chairs used in everyday life. The influence of chair height on the asymmetry of vertical reaction forces during STS and stand-to-sit has been investigated in subjects with stroke (Roy, Nadeau, Gravel, Malouin, McFadyen & Piote, 2006). Surprisingly, the results showed that there was no significant difference between a standard and an elevated chair height in this respect.

Foot position has been pointed out as an important determinant during STS (Janssen, Bussman & Stam, 2002; Kawagoe, Tajima & Chosa, 2002), and this most probably also applies for STW. In the present STW studies foot position was not standardised. The intention was to investigate the STW transfer resembling that in everyday life as much as possible.

Kawagoe et al (2002) demonstrated that symmetrical foot placement during STS, either 0.10 m in front of or 0.10 m behind a vertical line, directly influences the patterns of extension in different body segments and thereby has an indirect effect on the distance which COM has to cover during the STS transition. Further, an asymmetrical foot position with the

paretic foot placed behind has a direct influence on the possibility of generating forces needed for the STS task after stroke (Brunt, Greenberg, Wankadia, Trimble & Shechtman, 2002). The duration of the so-called momentum transfer phase during STS was prolonged when the paretic foot was placed in a backward position (Brunt, Greenberg, Wankadia, Trimble & Shechtman, 2002), implying that interlimb coordination probably is affected by foot position. The influence of foot position during STW has not been investigated. In the research described in this thesis, spontaneous foot positioning was described (Study II), as a first step in extending knowledge regarding foot position during STW.

During STS, a timing relationship between arm flexion and lower limb extension has been found to occur, when spontaneous arm movements are allowed (Carr & Gentile, 1994).

The use of the arms as contributors to whole-body momentum has been hampered in most previous STW studies. The subjects have been instructed to keep the arms crossed over the chest in order to minimise variability between subjects. It is assumed that use of the arms plays an important role in assisting the generation of forward momentum during rising to walk. The experimental set-up in the present STW-studies allows examination of the contribution of the arms and this awaits to be studied.

In attempts to interpret the results from the present STW studies regarding movement control after stroke, a multitude of dimensions emerges.

From a kinetic perspective, different strategies of AP force generation regarding intra- and interlimb coordination in the stroke and control group were observed (Study IV). However, all subjects succeeded in achieving the STW transfer, but the neuromotor and subsequent movement processes in reaching the goal differed between subjects. The concept 'motor equivalence' reflects this phenomenon, where an invariant goal is reached by variant means (Abbs & Cole, 1988).

As we live in a 3D world, generation of forces as well as of movements takes place in three dimensions, thus highlighting the complexity of ongoing motor behaviour employed to reach everyday goals.

Attempts have been made to describe complex transfers and movements from a kinematic perspective by using collective variables. The Gait Deviation Index is such an attempt, where many components in a dysfunctioning gait are combined into an index (Schwartz & Rozumalski, 2008).

Regarding walking post-stroke, a similar attempt has been made. In this case, a measure to quantify the percentage contribution by the paretic leg to propulsion, the so-called Pp measure, was constructed (Bowden, Balasubramanian, Neptune & Kautz, 2006).

When this measure was adapted to the STW transfer, substantial asymmetry between the paretic and non-paretic leg in the early part of STW

was revealed (Study IV). A Pp value of 37% (paretic swing buttock and swing foot combined) was obtained, probably reflecting muscle weakness on the paretic side as well as imbalance in contributions to propulsion between the paretic and non-paretic parts of the body. These results support the ongoing trend in stroke rehabilitation to focus on strength training (Ada, Dorsch & Canning, 2006; Flansbjerg, Downham & Lexell, 2006). Development of the Pp measure for the STW transfer should include information on the proportion of braking, as this component seems to be a characteristic feature during locomotion post-stroke.

The increasing use of dual force plates (Genthon, Rougier, Gissot, Froger, Pélissier & Pérennou, 2008; Roerdink, Geurts, de Haart & Beek, 2009) enhances the possibility of detecting the unique contribution of each lower limb to the motor task being studied.

The results reported in Paper IV highlight the compensatory role of the non-paretic limb. High demands are placed upon the so-called unaffected leg, which in fact is very affected on account of the interlimb coordination. Some researchers have reported that the unimpaired leg present coordination deficits (Garry, van Steenis & Summers, 2005) and that it fails to compensate for deficits of the paretic limb (Genthon, Rougier, Gissot, Froger, Pélissier & Pérennou, 2008). These results, as well as the findings reported in Paper IV, emphasise the importance of also taking the non-paretic side into account in stroke rehabilitation and stroke research.

Atypical braking forces post-stroke during transfers have been observed in studies regarding gait initiation from standing (Brunt, Vander Linden, & Behrman, 1995; Bensoussan, Mesure, Viton & Delarque, 2006) and walking (Bowden, Balasubramanian, Neptune & Kautz, 2006; Turns, Neptune & Kautz, 2007). As braking was found to be more pronounced prior to seat-off during STW in the stroke subjects than in the controls (Study IV), this seems to be part of the recovery process, probably constituting compensation instead of function. An increased braking impulse prior to seat-off during the forward-oriented transfer of STW seems to counteract and reduce the amount of COM horizontal momentum being generated and also to delay the transfer of momentum to the lower extremities, as described during STS by Schenkman et al (1990).

From a movement perspective, COM momentum generated in different directions might also be considered a collective variable. Interestingly, in Study II it was found that there was no significant difference in timing of COM PHM and PVM between the two investigated groups. Thus, the coordination of the two momenta peaks was similar in the two groups. The differences were instead demonstrated in the scaling and timing characteristics.

As the arm-head-trunk segment has been shown to be the main contributor to PHM during STS (Pai & Rogers, 1991), this is probably also true for STW.

The thigh has been reported to be the main contributor to PVM during STS (Pai & Rogers, 1991). Here the foot position seems to be critical, as has been demonstrated during STS by many investigators (e.g. Brunt, Greenberg, Wankadia, Trimble & Shechtman, 2002; Roy, Nadeau, Gravel, Malouin, McFadyen & Pottie, 2006).

The contributions of different body segments to COM horizontal and vertical momenta during STW need to be analysed, both in persons with and without disabilities.

As interpreted from research results of STS studies, the focus in strength-training during stroke rehabilitation should probably be placed both on proximal muscles, as these are responsible for generation of forward momentum during the forward-oriented transfer, and on relatively more distal muscles, as these contribute to the generation of COM vertical momentum.

Many factors may influence the momenta variables after seat-off during STW. The interlimb coordination during the primary and secondary gait initiation phases (Frykberg, Thierfelder, Åberg, Halvorsen, Borg & Hirschfeld, 2009), defined here as the ML shift of weight between the swing and stance limb, puts a special demand on the integration of posture and movement. This special mechanism of loading/unloading is different as compared with the muscle control around the ankle joints, concerning the forward movement of the body (Winter, 1995). These mechanisms also warrant investigation in future STW studies.

Sit-to-walk is a complex transitional task, where a discrete movement is transferred into a rhythmical one, i.e. walking (Magnan, McFadyen & St-Vincent, 1996). High demands are placed on integration of postural control and locomotion during this forward-upward-sideways-forward etc. transfer. The time period after seat-off prior to established walking is critical, as revealed by a delay observed in research studies on elderly persons at risk of falling (Kerr, Rafferty, Kerr & Durward, 2007), persons with Parkinson's disease (Buckley, Pitsikoulis & Hass, 2008), and in individuals with stroke (Frykberg, Thierfelder, Åberg, Halvorsen, Borg & Hirschfeld, 2009).

The findings in the present studies on STW have shown an altered force interaction post-stroke in coordination between the lower extremities (Study IV), probably influencing movement patterns (Study II) and temporal characteristics (Study I) of the everyday transfer. The results are considered to reflect compensatory motor strategies.

Relations between clinical and laboratory measures

The second principal aim of this research was to investigate the relations between some clinical and laboratory measures of postural control and locomotion in stroke rehabilitation and research.

Studies regarding relations between clinical and laboratory measures are conducted with different purposes, such as to further the understanding of the recovery process (Leroux, Pinet & Nadeau, 2006; Garland, Willems, Ivanova & Miller, 2003), to validate clinical assessment tools (e.g. Dettmann, Linder & Sepic, 1987; Berg, Maki, Williams, Holliday & Wood-Daphinée, 1992; Malouin, McFadyen, Dion & Richards, 2003), and/or to investigate critical variables of e.g. postural control (Frykberg, Lindmark, Lanshammar & Borg, 2007).

Clinical measures often concern the time needed to accomplish a balance/motor task, or whether the task is completed with or without assistance, with or without the use of hands etc.; task parameters are in focus. Laboratory measures, on the other hand, provide information about the process of reaching the goal, e.g. electromyographic activity, trajectory of COM, COG-COP interplay etc.; thus, the emphasis is on performance parameters (Latash, 1993).

Mark Latash, an American researcher considered that “Studies of relations between task and performance parameters are crucial for the development of motor control, the theoretical basis of movement and for the field of physical therapy” (1993).

In Study II of this thesis, a strong relation ($r_s = 0.84$) was found between the clinical measure FS and the laboratory measure FI. Both measures are considered to assess the process (the performance) of the motor task.

Another question which may be of importance is whether an outcome constitutes a single entity or whether it can be considered to be a collective variable, i.e. including a combination of data (e.g. Barela, Whittall, Balck & Clark, 2000). The FI, derived from laboratory data, captures the degree of fluidity during rising to walk (Malouin, McFadyen, Dion, Richards, 2003; Dion, Malouin, McFadyen & Richards, 2003); that is, it gives information about a critical aspect of STW, but does not provide data from the whole process. The FS focuses on the same critical period of the STW transfer, and thus it is suggested that both FS and FI are collective variables.

A further dimension of the relations between clinical and laboratory measures seems to be the question of whether the measures assess the same subcomponent of balance control or not. The clinical FS and the laboratory FI both measure the proactive component of postural control, supporting the voluntary STW transfer (Shumway-Cook & Woollacott, 2007c).

Concordance of these characteristics (task or performance parameter; single or collective variable; subcomponent of postural control) in the relations between clinical and laboratory measures might partly explain the strong relation between FS och FI.

In Study III, moderate correlations were found when the relations between scores from BBS and force measures were investigated. The strongest relation was a moderate negative correlation between COP mean velocity in the AP direction and scores from the BBS items of ‘maintaining a position’.

The BBS could be considered to mainly measure task parameters, whereas the force measures concerned performance parameters; thus, different kinds of parameters were compared.

It might be claimed that both types of measures are collective variables.

With respect to all items in BBS (where steady-state and proactive balance control are required) and force measures of quiet stance (where mainly steady-state balance control is required), different subcomponents of balance control are thus assessed.

Lack of concordance regarding the three proposed characteristics (task or performance parameter; single or collective variable; subcomponent of postural control) might partly explain why many relations between total scores of BBS and force measures were not significant.

Clinical ratings of weight distribution, as accomplished with a rating scale (Appendix 2), and force measures of postural control in quiet stance measure the same subcomponent of balance control, i.e. steady-state. It is proposed that both kinds of measures are collective variables, reflecting the performance of standing still. In spite of this accordance of the previously proposed characteristics, only moderate correlations were found.

There might be different reasons for this result. Standing still is in fact very difficult, as revealed by the complex pattern of the COP trajectory (Horak & Macpherson, 1996; Rougier, 2008). Hence, visual observation of dynamic interaction between different body parts within the human body is demanding, even when the subject is in quiet stance. Further, the human eye cannot perceive events that happen faster than 1/12 of a second (Gage & Ounpuu, 1989), and thus the use of technically advanced equipment is one possibility in the process of developing reliable, valid and responsive clinical tools.

Furthermore, it is suggested that information from laboratory measures can provide understanding of the underlying causes of particular movement dysfunctions (Gill-Body & Krebs, 1994) and of the recovery process (Richards, Wood-Dauphinée & Malouin, 2004).

The results indicate that other factors also have a considerable impact on the relations between clinical and laboratory measures. In an attempt to elucidate some of these, the structure of Fig. 1 might be helpful.

The perceptual aspect, such as spatial neglect (Genthon, Rougier, Gissot, Froger, Pélissier & Pérennou, 2008) may be a relevant factor to consider.

Sensation might be another factor of importance. Surprisingly however, sensation did not affect weight-bearing asymmetry, postural steadiness, or lateralised control post-stroke when studied during quiet stance. (Roerdink, Geurts, de Haart & Beek, 2009).

Cognitive and emotional aspects, such as divided attention (Hyndman & Ashburn, 2003), where falls have been reported to be more likely to occur, as well as fear of falling (e.g. Hellström & Lindmark, 1999), which by some researchers is considered to be more influential than balance disorders (Pang & Eng, 2008), are factors to consider when investigating relations between clinical and laboratory measures.

The results of the research described in this thesis regarding the relations between clinical and laboratory measures indicate that the strength of the relation is multi-dimensional.

Summary and conclusions

- Four phases of the commonly performed sit-to-walk (STW) transfer were defined, by use of a whole-body kinetic and kinematic set-up, in a group of subjects with stroke and in matched controls. The relative duration of the 2nd STW phase, defined from seat-off to the loading peak of the forthcoming swing leg, was significantly longer in the stroke group. The reasons for this warrant further studies. **(Study I; Paper I)**
- Scaling and timing differences regarding coordination of centre of mass horizontal and vertical momenta during STW were found between the stroke and control group. Most subjects with stroke exhibited non-fluid locomotor coordination while rising to walk, as reflected in significantly lower scores on the clinical measure Fluidity Scale (FS) and lower percentage on the laboratory measure Fluidity Index (FI), as compared with the controls. This atypical motor strategy used in the stroke group needs to be studied further before clinical recommendations are possible. **(Study II; Paper II)**
- Different strategies of anterior-posterior (AP) force generation prior to seat-off during STW were found, with the stroke subjects generating significantly more force beneath the (non-paretic) stance buttock as well as significantly greater braking impulses beneath both buttocks and particularly beneath the (non-paretic) stance foot as compared with the controls. Whether this atypical strategy of AP force generation is beneficial regarding fall prevention remains to be studied. **(Study IV, Paper IV)**
- A strong relation was found between the clinical measure FS and the laboratory measure FI. This indicates that the two tools assess the same dimensions of locomotion during STW. **(Study II; Paper II)**
- Moderate correlations were observed between scores on the Berg Balance Scale, as well as clinical ratings of weight distribution in quiet stance, and laboratory measures. The clinical and laboratory measures seem to assess different dimensions of postural control. **(Study III; Paper III)**

Methodological considerations

The conclusions from the four research studies in this thesis should be drawn with consideration of certain limitations.

The sample sizes in the STW studies were small. However, in studies analysing laboratory-measured kinematic and kinetic data, similar to those obtained in the current studies, the sample size is often 7-14 subjects. Repeated measurements are used, and thus the amount of data collected is considerable. The generalisability, however, is limited. Further, the subjects with stroke participating in the present studies were all from the younger age group of less than 65 years. These individuals represent 20% of younger subjects afflicted with stroke (Medin, Nordlund & Ekberg, 2004).

The variability within the data was assumed to be quite high, owing to the semi-standardised set-up. High values with regard to both within and between individual variations were found regarding relative duration of STW phases, as reported in Paper I. The experimental set-up as well as the biological variability probably contribute to these results. The concept 'motor equivalence', which is described as reaching invariant goals by variant means regarding multiarticular actions (Abbs & Cole, 1988), might be relevant in this context. Biological variability and its influence on everyday motor tasks is an area that needs to be explored in the future, also with respect to the advanced technical equipment available today, where multiple measurements of the same motor behaviour are possible.

The semi-standardised set-up in the STW studies, regarding chair height, foot position, and free choice of using the arms, was chosen to enhance ecological validity, i.e. that the investigation approximates real life as much as possible (Schmuckler, 2001). However, the laboratory environment, the unfamiliar carrying of markers and the experimental context are considered to have affected the motor behaviour of the study subjects and thus should be taken into account.

The impact of velocity while performing STW is another issue to consider in these research studies. Optimally, the experimental set-up in the STW studies should have included trials of the controls performing STW with the same velocity as their matched stroke subjects with. Studies on gait as well as on GI from standing have been performed at matched speeds (Chen, Patten, Kothari & Zajac, 2005; Tokuno & Eng, 2006).

Limitations also regarding the technical equipment have to be considered when interpreting the results. Data collection features such as marker movements, markers being occluded, and interpolation of data are examples that are important to keep in mind.

Further, there is a lack of interpretation standards of data retrieved by biomechanical analyses (Gill-Body & Krebs, 1994). Normative data bases on everyday motor tasks, except gait, are lacking.

Clinical implications

Several studies on the STW performance are needed before clinical recommendations are possible. However, the results of the present STW studies do indicate some clinical implications.

The current trend in stroke rehabilitation of focusing on strength training is supported by the results reported in Paper IV. Strength training of proximal hip muscles in different positions and during varying transfers might improve the possibility for the paretic buttock to contribute to the propulsive impulse. Improved interlimb coordination, prior to seat-off, is assumed to be an essential prerequisite for changing the dyscoordination and for producing an effective buttock push-off during STW. As the human body is influenced by 3D forces, it is suggested that the 3D perspective should be brought into both stroke rehabilitation and stroke research.

The present results regarding clinical and laboratory measures indicate the need for clinical assessment instruments measuring the performance of how a subject reaches the goal of a motor task. Information on the end result alone is probably not enough to guide clinical decision-making.

Future studies

As the STW transfer is a new research area and only few studies have been conducted regarding this everyday motor task in persons with disabilities, there are many important issues to address, both in fundamental and in clinical research.

In view of the potential risk of falls during STW, studies on balance mechanisms and on perceived fear of falling should be given priority. It is suggested that investigations should include studies of the interplay between the vertical projection of COM and COP (Corriveau, Hébert, Prince & Raïche, 2001; Winter, Patla, Ishac & Gage, 2003) throughout the STW transfer.

Information on 3D force generation during the critical time period from a seated position to 2nd TO during STW is considered to be important for the understanding of motor strategies employed after a brain injury. Further, the influence of foot position and its potential contribution to force generation is another important issue to study.

Thorough whole-body kinetic and kinematic analyses of failed trials might provide insights into what actually happens during a sit back or a step failure. This information could be of clinical importance.

A study on the contribution of the arms to COM momentum generation during the initial phases of STW will probably further the understanding of alternative strategies in accomplishing STW, and might provide relevant suggestions for treatment in neurological and geriatric rehabilitation.

The ultimate goal of all these proposed future studies is to enable persons with disability to independently and safely transfer from a seated position to walking, with the purpose of carrying out meaningful everyday tasks.

In stroke rehabilitation, as in all kinds of rehabilitation, many assessment instruments measure only the end result of movements and tasks, and there is therefore a need to develop clinical tools which also assess the performance during the process up to the end result. The Fluidity Scale for the rise-to-walk task (Malouin, McFadyen, Dion & Richards, 2003) is such an instrument which has displayed good psychometric properties, is easy to use, and takes only a short time to accomplish. However, further studies are required to investigate different aspects of reliability, validity and responsiveness of this clinical tool.

Appendix 1

Fluidity scale for the rise-to-walk task

Score	Descriptors
3	The foot (heel & toes) ^a is lifted off the ground while the subject's body is still moving forward; the trunk remains slightly flexed forward even when the subject stands up ^b
2	The forward movement of the body stops and <i>as soon as</i> the subject stands up with his body fully vertical, he lifts the foot
1	The forward movement of the body stops, the subject stands up with his body fully vertical and then stops momentarily before he lifts his foot
0	The forward movement of the body stops, the subject stands up with his body fully vertical, then stops momentarily before reaching for his cane and then lifts his foot

^aThe stepping limb is the affected limb.

^bStands up: is the maximal vertical position of the shoulder.

Description of the rise-to-walk task

Starting position

Subjects are seated on a chair without backrest and armrest, with the feet on the floor and two thirds of the thighs in contact with the seat; they are asked to keep their arms folded in front of them during the task.

Instructions

Subjects are instructed to look ahead, to distribute their weight evenly and, upon an auditory signal to stand up, without using their hands and walk, at a natural pace, towards the target (a table placed about 2 m in front of the subject), but are not required to cover the full distance.

Conditions

Patients are allowed to use a walking aid (cane) and wear their orthosis, but are not provided external support. The stepping limb is the affected limb.

Malouin, F., McFadyen, B., Dion, L., & Richards, C.L. (2003). A fluidity scale for evaluating the motor strategy of the rise-to-walk task after stroke. *Clin Rehabil*, 17, 674-684.

Appendix 2

Rating scale of weight distribution in quiet stance

Video records were taken from the front and from behind of each subject with stroke (15 s from each direction).

Does the subject with stroke take equal weight on the two legs, or does she/he take somewhat more or significantly more weight on the left or on the right leg when standing still?

Mark with a cross (X) in the columns below your assessment of weight distribution in each subject!

Stroke subject	Significantly more weight on the left leg	Somewhat more weight on the left leg	Equal weight on both legs	Somewhat more weight on the right leg	Significantly more weight on the right leg
A1					
B2					
C3					
D4					
E5					
F6					
G7					
H8					
I9					
J10					
K11					
L12					
M13					
N14					
O15					
P16					
Q17					
R18					
S19					
T20					

SAMMANFATTNING PÅ SVENSKA (Summary in Swedish)

Denna avhandling tar upp två tema som handlar om rörelsekontroll hos personer i efterförloppet till en stroke (Artikel 1- 4) och hos kontrollpersoner (Artikel 1, 2 och 4). Det ena temat handlar om den vardagliga förflyttningen att resa sig upp och gå (sit-to-walk), hur den genomförs och om det finns skillnader i genomförandet mellan personer med stroke och kontrollpersoner. Det andra temat handlar om samband mellan kliniska och laboratorie-baserade mått, som används inom stroke-rehabilitering och stroke-forskning.

Tema I

Att resa sig upp och gå, sit-to-walk (STW), är en komplicerad motorisk uppgift, där hela kroppen förflyttas framåt, uppåt och i sidled samtidigt som understödsytan snabbt minskar. Det ställs sålunda stora krav på både balans och förflyttningsförmåga. Det finns ännu så länge bara ett tiotal studier om STW, trots att många personer med funktionshinder ofta gör denna förflyttning och trots att det finns en stor risk för fall i samband med den. Det övergripande syftet inom detta tema i avhandlingen var att utöka kunskapen om denna vardagliga förflyttning genom att undersöka tre olika aspekter av den – en tids- (Artikel 1), en rörelse- (Artikel 2) och en kraft- (Artikel 4) aspekt.

Datansamlingen genomfördes på ett rörelselaboratorium tillsammans med tio personer med kvarstående halvsidig förlamning i benet efter stroke och tio matchade kontrollpersoner. Ett rörelseanalys-system med åtta kameror och fyra kraftplattor (placerade under respektive säte och fot) användes för att samla in data. På ett bord 5 m framför den sittande personen stod en telefon. Instruktionen till försökspersonen var att då telefonen ringde så skulle hon/han i normal hastighet gå fram för att svara. Förutom uppresningen till gående intervjuades samtliga personer och undersöktes med kliniska bedömningsinstrument.

I den första delstudien av STW, där den tidsmässiga samordningen mellan olika delmoment undersöktes, identifierades fem händelser, utifrån vilka fyra faser definierades. Resultat från jämförelser mellan grupperna visade att den andra fasen, definierad från det att sätet lämnar underlaget till det att

tyngden tillfälligt ökar under det första svängbenet, var signifikant längre hos personerna med stroke jämfört med hos kontrollpersonerna.

I den andra delstudien av STW, där förflyttningen undersöktes ur ett rörelseperspektiv, visade resultaten att storleken på den rörelsemängd som genereras för att förflytta kroppen framåt och uppåt var signifikant lägre hos personerna med stroke. Tidpunkten för maxvärdet för den framåtriktade respektive uppåtriktade rörelsemängden inträffade signifikant tidigare hos personerna med stroke jämfört med kontrollpersonerna. Dessa resultat tyder på att personerna med stroke först reser sig upp, står och sedan går, vilket också bekräftades av den skattning av flöde vid uppresningen som genomfördes i samband med datainsamlingen.

I den tredje delstudien av STW, där uppresningen till gående undersöktes ur ett kraftperspektiv med fokus på framåt-bakåt-riktade krafter i tidsperioden fram till det att sätena lämnar underlaget, visade resultaten att personerna med stroke genererar lika mycket kraft totalt som kontrollpersonerna, men att de motoriska strategierna som används för denna kraftgenerering skiljde sig åt mellan grupperna. Personerna med stroke använde sig av en signifikant större framåt drivande kraft under det icke-förlamade sätet och av signifikant mer bromsande kraft under båda sätena respektive under den icke-förlamade foten än vad kontrollerna gjorde. Detta innebär att den framåtriktade rörelsen vid STW påtagligt bromsas i strokegruppen.

Tema II

Det andra temat i denna avhandling fokuserar på samband mellan kliniska mått (insamlade data av, i det här fallet, sjukgymnast) och laboriemått (insamlade via teknisk utrustning), som används i stroke-rehabilitering och stroke-forskning .

I ett antal studier har måttliga samband kunnat påvisas mellan data från kliniska bedömningsinstrument, som används av sjukgymnaster, och information från mätningar med laborieutrustning. För att förstå bakgrunden till dessa samband genomfördes två undersökningar.

I den första studerades samband mellan Fluidity Scale (FS), ett kliniskt bedömningsinstrument där graden av flöde vid uppresningen till gående skattas och Fluidity Index (FI), ett mått på flödet där data erhålls via ett rörelse-analyssystem (delstudie i Artikel 2).

Ett starkt samband påvisades mellan det kliniska bedömningsinstrumentet FS och laboriemåttet FI. Till skillnad från många andra bedömningsinstrument så mäts själva processen med hjälp av FS, dvs hur uppresningen till gående genomförs och inte bara om personen når målet eller inte. I denna

delstudie skulle en del av förklaringen till resultatet kunna vara att den kliniska och laboratorie- undersökningen mäter samma fenomen, inklusive att samma delkomponent av balanskontroll mäts med båda undersökningarna.

I den andra undersökningen genomfördes en jämförelse mellan poäng på Bergs Balansskala (BBS), ett kliniskt instrument där olika balansuppgifter bedöms och data från en kraftplatta (Artikel 3).

Måttliga samband påvisades mellan poäng på BBS, där balansförmågan bedöms med hjälp av en femgradig skala (0-4), och data från en kraftplatta Bergs Balansskala värderar ffa om personen klarar av att genomföra balansuppgiften eller inte och vilken tid det tar för personen att utföra de olika balansuppgifterna, medan laboratorieundersökningen mäter själva processen. Den kliniska och laboratorie -undersökningen mäter sålunda inte samma fenomen, vilket troligen kan förklara en del av resultatet.

Det var balansuppgiften 'att stå still med öppna ögon' som mättes på kraftplattan. Vissa av balansuppgifterna i BBS bedömer en persons förmåga att bibehålla balansen, t.ex. i sittande och i stående. Mellan BBS poäng från denna typ av balansuppgifter och kraftplattemåtten var sambanden starkare, än då olika delkomponenter av balans jämfördes.

Sammanfattningsvis så undersöktes i denna avhandling *dels* hur uppresningen till gående (sit-to-walk) genomförs hos personer med stroke och hos kontrollpersoner och *dels* styrkan i samband mellan kliniska och laboratoriemått.

Resultaten visar att personer i efterförloppet till en stroke vid sit-to-walk använder signifikant mer tid i delfasen då sätena lämnat underlaget och fram tills dess att svängbenet tillfälligt tar mer tyngd. Vidare visades att personer med stroke använder sig av andra kraftgenererande strategier vid uppresningen till gående än vad kontrollerna gör. Resultaten anses reflektera kompensatoriska motoriska strategier som efter stroke används vid uppresningen till gående.

När det gäller sambandet mellan kliniska och laboratorie-mått så visar resultaten ett starkt samband mellan två mått för flödet vid uppresningen till gående och måttliga samband mellan Bergs Balansskala och vissa kraftplattemått. Resultaten tyder på att styrkan i sambandet mellan kliniska och laboratorie mått är multidimensionellt.

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