Treadmill walking with body weight support

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In loving memory of my father, Steinar Aaslund

Your warmth, kindness and positivity are forever a part of me

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Scientific environment

This project was carried out at the Physiotherapy Research Group, Department of Public Health and Primary Healthcare, University of Bergen, Norway. The main research group have consisted of, in addition to myself, my main supervisor PT, PhD, Professor Rolf Moe-Nilssen, University of Bergen and co-supervisor PT, PhD, Researcher Jorunn Lægdheim Helbostad, Norwegian University of Science and Technology, Trondheim. In addition, a group responsible for recruiting patients and participating in the testing was established at Department of Physiotherapy, Haukeland University Hospital, Bergen, Norway, consisting of PT Torunn Grenstad, PT Kari Øen Jones and PT Unni Moen. The Department of Physiotherapy, the Neurology Clinic and the Department of Physical Medicine and Rehabilitation at Haukeland University Hospital were involved in the recruitment of patients. The Norwegian Fund for Post-Graduate Training in Physiotherapy has funded the work presented in this dissertation.

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Abbreviations

AP	Anteroposterior
BWS	Body Weight Support
BWSTT	Body Weight Supported Treadmill Training
FAC	Functional Ambulatory Category
ML	Mediolateral
m/s	Meters per second
RMS	Root Mean Square
steps/min	Steps per minute
TM20	Treadmill walking with 20 percent body weight support
TM40	Treadmill walking with 40 percent body weight support
V	Vertical
WR	Walk ratio

Abstract

Background: Rehabilitating walking in patients post-stroke with safe, task-specific, intensive training of sufficient duration, can be challenging. Body weight supported treadmill training (BWSTT) has been proposed as an effective method to meet these challenges and may therefore have benefits over training overground walking. However, walking characteristics should not be aggravated during BWSTT or require a long familiarisation time compared to overground walking.

Objectives: To investigate kinematic walking characteristics during treadmill walking with body weight support (BWS), how kinematic characteristics stabilise during treadmill walking with BWS, and the consequences of altering walking speed and percentage of BWS during treadmill walking.

Method: Cross-sectional, repeated measures designs were used. A body worn sensor assessed trunk acceleration. The effect of treadmill, harness and BWS-system were investigated in non-impaired participants. Ambulatory patients post-stroke were investigated to study kinematic characteristics during a five-minute familiarisation trial, how treadmill walking with BWS differed from overground walking, and the effect of altering speed and percent BWS.

Results: Kinematic walking characteristics were affected by the treadmill, the harness and the BWS-systems in non-impaired participants. For patients post-stroke relatively stable walking patterns were achieved within a five-minute familiarisation trial. Kinematic characteristics differed between overground walking and walking on the treadmill with BWS, but were generally not aggravated. Altering walking speed affected kinematic characteristics more than altering BWS. Fast walking speed had a positive influence on several walking characteristics.

Conclusion: Kinematic walking characteristics during walking on a treadmill with BWS are different compared to overground walking, and tend to be more normalised in ambulatory patients post-stroke. The advantages of BWSTT to practice safe walking with high intensity and long duration therefore make BWSTT a good alternative in walking rehabilitation for ambulatory patients post-stroke.

List of publications

Paper 1

Aaslund, M. K. and Moe-Nilssen, R. Treadmill walking with body weight support. Effect of treadmill, harness and body weight support systems. Gait Posture, 2008. 28(2): p. 303–8.

Paper 2

Aaslund, M. K., Helbostad, J. L. and Moe-Nilssen, R. Familiarisation to body weight supported treadmill training for patients post-stroke. Gait Posture, 2011. 34(4): p. 467-72.

Paper 3

Aaslund, M. K., Helbostad, J. L. and Moe-Nilssen, R. Characteristics of treadmill walking with body weight support in ambulatory patients post-stroke. Effect of walking speed and degree of body weight support. Submitted.

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1. INTRODUCTION

1.1 Stroke

1.1.1 Definition

Stroke is the brain equivalent of a heart attack and has been defined by the World Health Organisation as “rapidly developing clinical signs of focal (at times global) disturbance of cerebral function, lasting more than twenty-four hours or leading to death with no apparent cause other than that of vascular origin” (Hatano, 1976).

The brain needs sufficient blood flow to function and survive. If blood supply to the brain is disrupted by occlusion or narrowing of blood vessels, or by rupture of blood vessels, the brain cells are deprived of oxygen and nutrition. This results in brain cells that damage or die, causing a stroke. The size and location of the stroke within the brain will determine whether the stroke is fatal, or leads to temporary or permanent disabilities (Carroll, 2001; MacKay and Mensah, 2004). Approximately 85 percent of strokes are caused by infarction and 15 percent by haemorrhage. Risk factors for stroke includes hypertension, irregular heart rhythm, smoking, diabetes, obesity, heavy drinking and inactivity (MacKay and Mensah, 2004; The Stroke Association, 2006; American Heart Association, 2009). The risk of stroke rises with increasing age and the average age for getting a stroke is approximately 75 years. Overall, more women than men suffer from stroke, while for people aged under 75 years, the number of men suffering from a stroke is greater than for women (Carroll, 2001; American Heart Association, 2009).

1.1.2 Burden of stroke

Worldwide, stroke is the third largest cause of death after heart disease and cancer, and annually 15 million people suffer from stroke. In Norway, almost 15 000 people is diagnosed yearly from a first-ever or recurrent stroke (Ellekjaer et al., 1997; Warlow et al., 2003; MacKay and Mensah, 2004). Approximately one-third of the patients post-stroke will suffer permanent disability (MacKay and Mensah, 2004), and stroke causes a larger range of disabilities and has greater disability impact than any other conditions (Adamson et al., 2004). Therefore, strokes represent a major burden on public health budgets, and the lifetime costs for a stroke survivor can be extensive. Costs are closely related to degree of disability and the age of the person (Warlow et al., 2003; Fjaertoft and Indredavik, 2007a; American Heart Association, 2009). In Norway, lifetime cost has been estimated to be approximately 600 000 Norwegian kroner for every stroke, totalling a yearly cost of seven to eight billion Norwegian kroner for all strokes (Fjaertoft and Indredavik, 2007a). In developed countries incidence of stroke is declining as both prevention and treatment has become more effective. However, with a growing elderly population, the number of strokes has been estimated to increase over the years (Waaler, 1999; Warlow et al., 2003; MacKay and Mensah, 2004).

1.1.3 Signs and symptoms

The signs and symptoms of a stroke vary between stroke sub-types (Rathore et al., 2002). Common acute signs and symptoms involve sudden confusion, communication difficulties, problems with vision, dizziness, headache, numbness or weakness of the face, arm or leg, walking difficulties, and loss of balance and coordination (Jauch et al., 2010). When the neurological deficits have reached its maximum, the stroke is completed. This usually happen within twenty-four hours after onset (Kumar and Clark, 1994).

After the stroke is completed, sequelae can lead to a range of impairments and disabilities. Since the brain controls almost anything we do, a stroke has the potential to affect virtually any human function (Mayo et al., 1999). Typical long term signs and symptoms of a stroke are hemiparesis, sensibility loss, dysphagia, visual field defects, reduced balance, reduced attention, impaired consciousness, reduced mental function, psychological problems, pain, and bladder- and bowel disturbances

(Indredavik et al., 2010). 70-85 percent of strokes are accompanied by hemiplegia, and half a year after the stroke, 40 percent of the patients that needed inpatient rehabilitation have not achieved functional independence in activities of daily living such as toileting and walking short distances (Dobkin, 2004).

1.1.4 Recovery and management

The main goal of stroke management is to minimise acute brain injury and maximise patient recovery (Jauch et al., 2010). Damaged cells can persist in a compromised state for several hours post-stroke, and these cells can be saved if treatment starts early. Identifying and diagnosing stroke early is therefore uppermost important. During the recent years, Stroke Associations around the world have used public education campaigns, such as the British "Act FAST-campaign" [1], to promote the importance of recognising stroke as a medical emergency and to inform about common symptoms (Bray et al., 2010). There is no cure for stroke, but modern stroke care includes early management in specialised stroke units, thrombolysis, early use of aspirin, and physiological monitoring. The instant goal is to resolve the ischemic penumbra[2], the cerebral oedema, and comorbidities such as infection. If the occluded blood vessels are targeted by thrombolysis, the ischemic penumbra may stop growing and regain its function by increased perfusion. Thrombolysis however, must be administered within the first few hours after stroke in order to be safe and effective (Warlow et al., 2003; Zaheer et al., 2011).

Care for stroke patients in specialised stroke units has been found to increase the chance that the acute stroke patient survive, return home and gain more independent function (Stroke Unit Trialists' Collaboration, 2007). Stroke units with good results have multidisciplinary teams with a strong focus on rehabilitation (Fjaertoft and Indredavik, 2007b). Other characteristics of a successful stroke unit has been recognised to be the use of comprehensive assessment of medical problems, impairments and disabilities, active physiological management, early mobilisation,

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[1] FAST: Facial weakness, Arm weakness, Speech problems, Time to call 9-9-9.

[2] Ischemic penumbra: the area peripheral to the stroke (the ischemia) where metabolism is active, but blood flow is reduced.

skilled nursing staff, and early setting of rehabilitation plans and discharge needs (Langhorne and Pollock, 2002). Indredavik and colleagues found early start of mobilisation as the most important aspect of stroke unit care, followed by stabilisation of blood pressure (Indredavik et al., 1999). The Norwegian National Guidelines for Treatment and Rehabilitation of Stroke recommend that as soon as the patient is medically stable, as a general rule within 24-hours, the patient should be mobilised. Mobilisation should be functional and task-specific, and high intensity should be aimed for as soon as possible to regain function and avoid secondary complications (Indredavik et al., 2010). In a randomised controlled trial it was found that patients post-stroke receiving very early mobilisation (within 24-hours) together with stroke unit treatment were able to walk unassisted earlier than patients who received standard stroke unit treatment alone. The patients mobilised early were also discharged from hospital sooner, and they were more likely to be discharged directly to home (Cumming et al., 2011).

To optimise long-term outcome, rehabilitation must begin immediately after the stroke is recognized and life-threatening problems are under control. Whereas in the acute phase focus should be on managing general health functions, secondary prevention, mobilisation, restoration of self-care, and emotional support to the patient and the family, the focus in the post-acute phase should be on assessment and recovery of physical and cognitive functions, as well as compensation for remaining impairments (Duncan et al., 2005). Intervention during rehabilitation should be aimed at increasing and optimising the individuals' level of independence and assisting people in re-achieving meaningful activities and participation in their chosen roles in life (Aziz, 2010; Hillier and Inglis-Jassiem, 2010). Rehabilitation is multidisciplinary and involves a team of professionals such as physicians, nurses, physiotherapists, occupational therapists, speech therapists and social workers. Physiotherapy has a large role, and a European multicentre-study found that physiotherapy contributed to nearly 40 percent of the total therapy time (De Wit et al., 2007).

1.1.5 Neuroplasticity post-stroke

Neuroplasticity can be defined as “the ability of the nervous system to respond to intrinsic or extrinsic stimuli by reorganizing its structure, function and connections” (Cramer et al., 2011). Neuroplasticity is the brain’s ability to reorganise in response to changes in behavioural demands, and describes the adaptive capacities of the nervous system. Plasticity is always active in both the healthy and the injured brain, and may be a basis for the ability to learn and for recovering after injury (Bach-y-Rita, 1990; Rossini et al., 2003; Kwakkel et al., 2004; Hubbard et al., 2009). Plastic changes post-stroke may occur as a result of several factors; passive adaption as a result of lesion, spontaneous recovery of partially damaged brain tissue, behavioural responses to the lesion such as decreased use of the affected lower limb, or because of therapeutic intervention (Rossini et al., 2003). There are indications that physical training enhances plastic mechanisms, and that therapies combining elements of task-specificity and high intensity and duration have a particular impact (Kwakkel et al., 2004). Augmented use of body parts in behaviourally relevant tasks enhances the representation of those body parts in the cerebral cortex, and is a type of use-dependent plasticity (Liepert et al., 2000). Conversely, inactive connections between cells in the brain tend to weaken or disappear. This means that not all neuroplasticity results in improvement of function, but can also lead to increased disability. For example, after a stroke the patient often have difficulty using the affected body-side resulting in reduced activity of this side, and thereby little stimulation of the areas representing the affected body-side in the brain. The main attention of the patient will be towards the opposite and least affected side of the body, and a situation of learned non-use of the affected side may evolve (Wolf et al., 1989; Taub et al., 1994). Patients long-term post-stroke have learned through situations, as well as through rehabilitation, how they can optimally use the least affected side in order to manage functional tasks. They have learned to compensate for loss of skilled motor behaviour by adapting the motor behaviour (compensation) or by using alternative motor elements (substitution) to achieve the goal. The challenge is that they at the same time may have learned not to use their most affected side, and this may hinder recovery of function (Wolf et al., 1989; Levin et al., 2009). To avoid situations of learned non-use, therapies has evolved involving “forced use” of the most affected body side post-stroke. Examples of such therapies are constrained induced movement therapy (CIMT) and body weight supported treadmill training (BWSTT) (Kwakkel et al., 2004). Task-specific activity with many repetitions and high intensity to promote neuroplasticity and decrease disability seems to be the current gold standard in neurorehabilitation (Kwakkel et al., 2004; Dobkin, 2008; Dimyan and Cohen, 2011).

1.1.6 Secondary prevention

An important goal in rehabilitation is to avoid recurrent strokes. Approximately 25 percent of all strokes are recurrent strokes, and the risk of experiencing a recurrent stroke depends on etiology and especially the risk factor profile. Increased blood pressure, smoking, inactivity, diabetes, irregular heart rhythm and high cholesterol should be evaluated carefully (Indredavik et al., 2010; Furie et al., 2011). Secondary prevention in the form of medication, surgery and lifestyle advice on smoking, nutrition and exercise leads to a reduced risk of a recurrent stroke (Indredavik et al., 2010). Physical activity has demonstrated advantageous effects on multiple risk factors such as reducing blood pressure and bodyweight, enhancing vasodilation, improving glucose intolerance and promote cardiovascular health (Furie et al., 2011). However, almost 50 percent of community-dwelling patients post-stroke live with sequelae after stroke that places them at risk for reduced activity level and social isolation (Mayo et al., 2002). A vast challenge during rehabilitation therefore, is to provide safe therapeutic exercise regimen allowing the patient to regain pre-stroke levels of activity, and then to achieve a satisfactory level of physical activity and exercise to optimize secondary prevention (Furie et al., 2011).

1.2 Human walking

Mobility is the “ability to independently and safely move oneself from one place to another” (Shumway-Cook and Woollacott, 2000), and involves many tasks including transfers, walking, running and steering through varied and complex environments. Human walking integrates both the concept of locomotion and gait. Locomotion can be defined as “the act of moving from place to place” and gait as “the manner of walking” (Galley and Forster, 1987). Walking requires body support, timing and power, and is a multi-dimensional task that put demands on systems such as the brain, spinal cord, peripheral nerves, muscles, joints, heart and lungs (Studenski, 2009). Shumway-Cook and Woollacott (2000) describe walking as being characterised by three essential requirements: progression, stability and adaptation. Progression is provided by coordinated rhythmic patterns of muscle activation of the trunk and legs to move the body in the chosen direction. Stability reflects the need for an upright posture together with a dynamic stability of the moving body. During walking, the balance criterion changes dramatically from standing still as dynamic stability must counteract the gravity component and other expected and unexpected external forces when moving the body from A to B by taking one or several steps. The line of gravity has to be moved outside the base of support in order to take a step, but without falling. This phenomenon is reflected in the definition by Galey and Forster (1987) where walking is defined as “a highly coordinated series of events in which balance is constantly challenged and regained continuously”. Following this it has been said that walking is like a series of controlled falls (Shumway-Cook and Woollacott, 2000; Lyon and Day, 2005). Continuous adaptation therefore is important in order to meet the goals from the individual and the demands of the environment.

1.2.1 Neural and non-neural contributions to walking

Studies of spinalized animals have revealed that when placed on a moving treadmill belt a stereotyped gait with some adaptive functions is produced even if there is no contact between the spinal cord and higher centres. Based on this there are indications that central pattern generators within the spinal cord play an important role in the generation of rhythmic movements underlying locomotion (Shumway-Cook and Woollacott, 2000; Edwards, 2001). On humans, it has been found that in patients with complete paraplegia stepping movements could be induced by the combination of a moving treadmill and body weight support (BWS) (Dietz et al., 1994). However, such findings in humans are rare, possibly because animals and humans have fundamental differences that may account for this. The behavioural goals for humans during walking are more sophisticated and require control that is more complex. In addition, because of the human bipedal pattern, there are also distinct differences in biomechanics. Humans require a more compound postural and equilibrium system to regulate a decreased base of support and tall height of the centre of gravity. As a result, humans may have more dependence of input from supraspinal centres and the collaboration between these. Especially important are the basal ganglia, the cerebellum and the brainstem. The basal ganglia is important in planning, initiating and providing smooth movements, the cerebellum in smooth execution and completion of movement and with providing truncal balance, and the brainstem in providing a background of posture and muscle tone. The cortical motor centres act as the supreme commander of voluntary movement (Mudge and Rochester, 2001; Gage, 2004).

Adapting walking in relation to the environment is fundamental, and sensory information therefore is central. In the absence of sensory information from the periphery, movement gets slow and stereotypical. Equilibrium is controlled by proactive and reactive modes. Proactive control is used to anticipate possible disturbances during walking, while reactive control is used when there are unexpected disturbances occurring. The somatosensory, the visual and the vestibular systems are all involved in the proactive and reactive control of walking. The somatosensory system contribute to keep an appropriate cadence and rhythm, vision helps determine walking speed and the vestibular system gives important information about position in space (Shumway-Cook and Woollacott, 2000; Mudge and Rochester, 2001).

Neurological control is important to modulate walking, but there are also important non-neural contributions from the musculoskeletal system and the environment. Humans walk with two thirds of the body mass located two thirds of body height above ground, and this inverted pendulum is inherently unstable when the forward momentum is considered. In particular, non-muscular forces such as gravity play an important role in walking. The inverted pendulum property of the body is an important drive giving a forward momentum during walking. Once swing phase is initiated, the forward movement of the foot is sustained by momentum and without the need for much active muscle work to swing the leg. The body's inertia also aids in the propulsion, therefore the main work must be done when starting to walk (to accelerate) and to stop walking (to decelerate) (Winter, 1995a; Shumway-Cook and Woollacott, 2000). In addition, there are acceleration and deceleration phases within each step, caused by opposing the breaking effect of footstrike in the anteroposterior (AP) direction, opposing gravity in the vertical (V) direction, and opposing the effect of weight shift in the mediolateral (ML) direction.

1.2.2 Walking characteristics

Temporal and spatial walking characteristics

The combination of neural control, muscle strength, joint mobility and energy, leads to a customary walking speed, cadence and step length that represent an individual's basic walking capability. Walking is therefore often described in terms of these temporal and distance parameters (Perry, 1992; Shumway-Cook and Woollacott, 2000). Walking can be subdivided into a stance and a swing phase. Stance is when one or both lower limbs are in contact with the ground, while swing is when a lower limb is not in contact with the ground. Stance phase therefore starts when the foot strikes the ground, and swing phase begins when the foot leaves the ground (Winter, 1991; Perry, 1992; Shumway-Cook and Woollacott, 2000).

A gait cycle, or one stride, consists of one step from both lower limbs. A step occurs between the heel contact of one lower limb to the heel contact of the opposite lower limb, while a stride occurs between the heel contact of one lower limb to the next heel contact of that same lower limb (two steps) (figure 1). Stance phase at preferred walking speed lasts for approximately 60 percent of the gait cycle, and swing phase for the remaining 40 percent (Galley and Forster, 1987). During stance phase both horizontal and vertical (V) forces are generated to move the body in the desired direction and to support the body mass against gravity, the horizontal forces are mainly generated to progress and vertical forces to stabilise. Flexibility of these strategies is important to accommodate changes in speed and direction or alterations in the support surface. During swing phase the swinging leg must advance and be repositioned in preparation for the weight acceptance (Shumway-Cook and Woollacott, 2000).

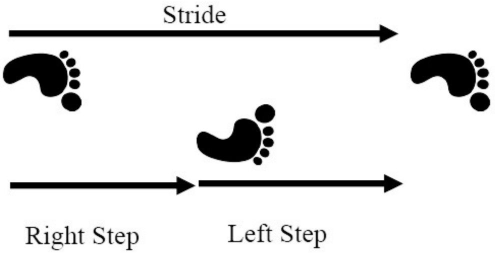

Figure 1. Illustration of step and stride

Walking speed can be defined as “the average horizontal speed of the body along the plane of progression measured over one or more stride periods” (Winter, 1991). Walking speed is described in metric terms, such as in meters per second (m/s), and for adult non-impaired persons a preferred walking speed of 1.3-1.4 m/s is considered normal (Perry, 1992). Age and gender affect walking speed. After the age of 70 years there is a significant decline in walking speed, and women tend to walk slower than men (Perry, 1992). In order for walking to be functional, a person must be able to walk at a given speed and for a required minimum distance (Patla and Shumway-Cook, 1999; Lord et al., 2004; van de Port et al., 2008). For example, in order to cross a light regulated pedestrian-crossing in Norway, a walking speed of approximately 1.2 m/s is necessary (The Norwegian Public Roads Administration, 2007). Walking speed is determined by cadence and step length, and these two variables are therefore closely correlated with walking speed (Winter, 1991; Patla and Shumway-Cook, 1999). Cadence or step frequency, is here defined as “the number of steps per unit time, expressed as steps per minute (steps/min)” (Winter, 1991). At a given walking speed, different combinations of cadence and step length may exist depending on personal factors or situation. Cadence changes throughout life, and is highest in children and elderly. Cadence also tends to be higher in females compared to males (Winter, 1991; Shumway-Cook and Woollacott, 2000; Edwards, 2001). Normal values vary with walking speed, but Perry (1992) reports 113 steps/min to be a normal value for adults. Natural cadence seems to be related to minimising energy requirements, as humans exploit the pendular properties of the leg and the elastics of the muscles. However, at walking speeds other than preferred speed the pendular properties breaks down and energy expenditure increases (Shumway-Cook and Woollacott, 2000). Step length is "the horizontal distance covered along the plane of progression during one step" (Winter, 1991), and can be reported for one step only, or as an average of several steps measured in cm or m. As with cadence, step length depends on how fast a person walks, but Perry reports a normal value for adults of 74 cm (Perry, 1992).

Walk ratio (WR) is step length in cm divided by cadence. WR therefore represents the relationship between amplitude and frequency of the rhythmic movement of the legs during walking, and is as such an index for temporal and spatial coordination at a given speed and therefore identifies a specific walking pattern. Normal values for WR have been reported to be around 0.60-0.70, with somewhat lower values for females than for males. Normative WR has been described as the most optimal in terms of energy consumption, movement consistency and attention (Nagasaki et al., 1996; Sekiya et al., 1996; Sekiya and Nagasaki, 1998). The advantage of WR is that while cadence and step length depend on walking speed, WR is relatively independent of speed (Sekiya et al., 1996). Deviations in WR during free walking may disclose degrees of abnormal walking patterns (Sekiya and Nagasaki, 1998), and WR has been found lower than in non-impaired in patients after stroke (Suzuki et al., 1999), in patients with Parkinson disease (Murray et al., 1978), and in patients after total knee replacement (Andriacchi et al., 1977). Smaller WR has also been found in elderly (Nagasaki et al., 1996), as walking during old age typically is characterised by slow speed, short steps and high cadence, a pattern described as cautious gait (Wall et al., 1991).

Trunk acceleration

Acceleration over the lower back (around the area of the COM) gives information about the fluctuations of movement over that area, and therefore the smoothness of the walking pattern. A smooth walking pattern without excessive movement is considered energy efficient and typical for pathological gait is less smooth and more inconsistent movement patterns (Waters and Mulroy, 1999; Shumway-Cook and Woollacott, 2000; Mizuike et al., 2009)

Walking regularity and asymmetry

Walking is not stereotypical, and there can be different degrees of inconsistencies in walking characteristics. Gait cycles may be characterised by consistency, but also by balance components characterised by variability. Variability therefore can be regarded as necessary adaptions allowing walking to be functional and effective, but can also be signs of impaired balance control (Moe-Nilssen and Helbostad, 2005; Moe-Nilssen et al., 2010). Walking characteristics depend on several factors, for instance the person walking, the goal of the walk, and the surface or environment walked in. In order for a person to adapt to such unique constrains; variability in movement systems may be necessary (Davids et al., 2003). Latash and Anson (2006) suggested an approach that movement variability can be regarded as both good or bad, good variability will assist in achieving a successful outcome and bad variability cause problems for a successful outcome. Different measures of variability during walking have been proposed as possible indicators of balance control. Variability in walking speed, step or stride length, stride width, stance and swing time, and measures of movement variability over the trunk or head has commonly been used (Moe-Nilssen and Helbostad, 2005). There is no gold standard for what measures should be used to investigate variability, but findings indicate that the available measures may represent different aspects of locomotor control (Moe-Nilssen et al., 2010). For example, it has been found that the different axes of interstride trunk acceleration regularity tell different stories. While AP and V interstride trunk regularity decreases (i.e. more variability) with certain demanding conditions or in less able participants, ML interstride trunk regularity increases (i.e.

less variability) (Moe-Nilssen and Helbostad, 2005; Helbostad et al., 2007). Moe-Nilssen and colleagues (2010) proposed that this may be an indication that ML interstride regularity increases due to a Bernsteinian freezing of degrees of freedom when walking is challenging, resulting in less regularity and less consistent propulsion in the direction of the walk.

Symmetry in walking is important as it contributes to the insight about the control of walking. Asymmetry may be associated with negative factors such as inefficiency in walking, impaired balance control, loss of bone mass density in the affected limb and risk of musculoskeletal injury because of overuse of one body side (Patterson et al., 2010). Walking symmetry has been suggested as a determinant for recovery in different patient groups such as patients post-stroke, and after limb amputation, osteoarthritis and hip replacement (Hodt-Billington et al., 2008). Commonly spatiotemporal footfall characteristics during walking such as step length, swing and stance time, and single support time has been used to assess symmetry (Patterson et al., 2010). However, asymmetry in footfall patterns may affect upper body movements and has been related to asymmetrical positioning of the trunk and asymmetrical arm swing (Kirtley, 2006). Hodt-Billington and colleagues (2008) have suggested that trunk movement asymmetry measures were better at discriminating patients post-stroke from non-impaired elderly compared to spatiotemporal asymmetry measures (single support and step length).

1.2.3 Kinematics and trunk accelerometry

Kinematics is the “description of the characteristics of an object’s movement, including linear and angular displacements, velocities and accelerations” (Shumway-Cook and Woollacott, 2000). Kinematic data can be used to describe the body’s movement in space and to obtain information about the body’s movement during walking. Conversely, kinetics is “the analysis of the forces that cause movement, including both internal and external forces” (Shumway-Cook and Woollacott, 2000).

Acceleration is “the rate of change of velocity” (Galley and Forster, 1987). If speed is constant, there is no acceleration. Force such as muscle power or ground reaction force, is a necessity to produce acceleration. Acceleration therefore is directly linked to the force applied, and acceleration of a chosen body segment illustrates how forces are acting on that segment. Centre of mass (COM) is “a point equivalent of the total body mass in the global reference system and is the weighted average of the COM of each body segment in 3D space” (Winter, 1995b). The vertical projection of the COM onto the ground is called the centre of gravity. Accordingly, measuring acceleration around the COM when a person is walking is a way to render information about the forces working on the body and how the forces are controlled by the balance system. Acceleration can be decomposed to a 3D horizontal-vertical coordinate system and measured along one vertical axis and two horizontal axes, AP in the sagittal plane and ML in the frontal plane.

AP: anteroposterior. V: vertical. ML: mediolateral.

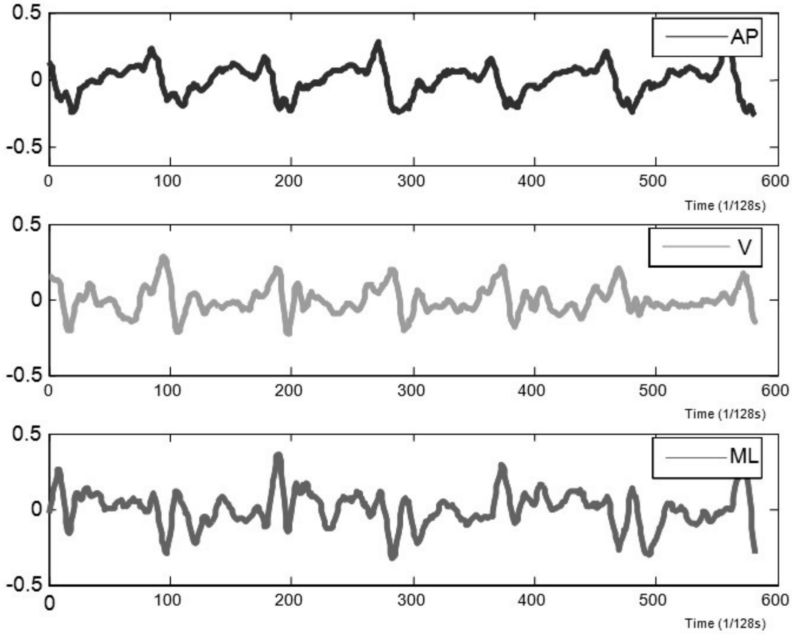

Figure 2. Example of trunk acceleration curves for six steps (measured over the lower back). The main cycle of the AP and V axes represents a step, while the main cycle of the ML axis represents a double step or a stride and is equivalent to a gait cycle.

Accelerometry is the quantification of movement patterns using body worn kinematic sensors to measure segmental accelerations during activities such as walking (Kavanagh and Menz, 2008). Accelerometry has evolved since the 1950s, and during the last decades, accelerometry has reached a satisfactory level of quantification of human movement (LeMoyne et al., 2008). The advantages of using kinematic sensors are that they are small, light and easy to use. They do not hinder movement or restrict the participant, and a person's natural walking can be measured without the person having to place their feet on specific targets as in force plate analysis, or to walk in a restricted area as in 3D video analysis. Trunk accelerometry quantifies movements over the trunk. Positioning the kinematic sensor over the lower back can quantify movements approximating the COM during walking. Due to the periodicity of the gait cycle and the breaking forces of the foot meeting the ground, acceleration curves have a recognisable pattern for each step and stride during walking (figure 2). Trunk accelerometry therefore can be used to describe trunk accelerations along different axes, and to estimate walking characteristics such as trunk regularity and symmetry between steps and strides. In addition, one can calculate cadence and average step length based on the periodicity described above.

1.2.4 Walking post-stroke

Walking ability is at risk when one or several body systems have reduced function or are disabled due to old age, pathology or de-conditioning. A stroke can greatly affect both physical and cognitive systems involved in walking, and after six months one of the biggest challenges for patients post-stroke living at home was that they could still not walk in the community safely and effectively. Many patients post-stroke express that their main goal during rehabilitation is to recover walking ability (Mayo et al., 1991; Mayo et al., 1999; Lord et al., 2004; Tilson et al., 2008). Patients post-stroke tend to walk slowly and for only modest distances, they have greater risk of falls, and much higher risk of hip fractures compared to non-impaired (Dobkin, 2004).

Walking post-stroke is heterogenic in character and a single common pattern does not exist. Typically, walking is characterised by slow walking speed, short step lengths, high cadence, long time in stance phase, decreased swing phase, and asymmetry between the hemiparetic and non-hemiparetic side (Turnbull et al., 1995; Hsu et al., 2003; Lin et al., 2006; Den Otter et al., 2007; Brouwer et al., 2009; Jonkers et al., 2009; Jonsdottir et al., 2009; Patterson et al., 2010). Average acceleration over the trunk has been found to be higher and regularity lower in patients post-stroke compared to controls (Mizuike et al., 2009). Metabolic cost has been found to be twice that of controls in walking post-stroke, indicating that the walking pattern is energy inefficient (Detrembleur et al., 2003; Platts et al., 2006). Paresis leads to reduced muscle mass available for contraction during activity, resulting in reduced ability to perform physical activity (i.e. reduced physical fitness). As physical activity becomes more difficult and hard to endure, the indirect effect can be immobility and additionally decreased physical fitness. Patients post-stroke therefore, often experience an unfortunate combination of increased energy demands during physical activity, while at the same time hemiparesis, decreased physical fitness and often old age impair the ability to perform muscular work and the capacity to tolerate it (Saunders et al., 2009). The consequences therefore may be restricted physical activity, leading to further declines in mobility and function. Such decline may be the start of a downward spiral for the patient in terms of additional deconditioning, increased risk for a recurrent stroke and for secondary problems, less participation in functional and social activities that may cause isolation, depression, and reduced life-quality. Since walking is an important manner of being physically active for patients' post-stroke, effective walking rehabilitation is very important for the individual patient, but can also greatly reduce use of resources and costs for public health.

1.3 Walking rehabilitation post-stroke

1.3.1 Definition, theoretical concepts and interventions

Irrespective of the amount of time in a rehabilitation setting and the level of walking function, patients post-stroke spend the majority of time during physiotherapy practicing walking (Jette et al., 2005; Latham et al., 2005). Walking activities have been reported to be included in 95 percent of all physiotherapy sessions, with more than 45 percent of the total physiotherapy intervention time spent doing walking activities (Jette et al., 2005). Goals for rehabilitation of walking should be individualised and take into account personal needs. Therapy must allow for safety, and comprise flexibility, endurance and speed, consistency, repeatability as well as variability, and adaptability to the environment. The achievement of goals are determined by the interaction between neurological deficits, other physical or cognitive deficits, compensation strategies, psychological factors, social environment and training procedures (Mauritz, 2004). Walking rehabilitation consists of a wide variety of physiotherapy interventions and therapeutic procedures, all aimed at optimising functional activity (Mauritz, 2004; States et al., 2009). Training overground walking is probably the most common approach to walking rehabilitation (States et al., 2009).

Different theoretical concepts of physiotherapy based on orthopaedic, neurophysiological and motor learning principles stress different features of walking rehabilitation (Mauritz, 2004; Pollock et al., 2007). During the last century, trends in physiotherapy have evolved from focusing on corrective exercises based on orthopaedic principles with strength exercises and training of the unaffected limb. From the 1950s, neurophysiology based therapies became important, stressing the importance of quality in movement with the aim to restore neurophysiological functions and avoid substitute mechanisms and technical assistance as far as possible. In the 1980s, the importance of motor learning and neuropsychology was highlighted, and the motor learning (or relearning) approach suggested active, repetitive practice of context-specific motor tasks. The aim was to get the patient moving and walking even with substitute and compensatory movements and/or technical aids. From the 1990s, physiotherapy has increasingly been based on scientific research in relevant areas such as medical science, exercise physiology, neuroscience and biomechanics (Mauritz, 2004; Pollock et al., 2007). In recent years, there seem to be a growing interest in the physical activity levels of patients post-stroke and the importance of focusing on training physical fitness. Physical activity is important both for prevention of recurrent strokes, but also in order for the patients to function with disabilities. Different theoretical approaches can result in different treatment programmes, but there is no evidence that one approach is superior in the promotion of recovery of lower limb function or postural control. However, there is some evidence that components from a mixture of theoretical approaches yields the greatest benefit in the recovery of functional independence post-stroke (Pollock et al., 2007).

An important development in walking rehabilitation is the range of available interventions and procedures that has widened during the last centuries enabled by development of new technical equipment. Training walking on treadmills with or without the use of BWS, training walking with functional electrical stimulation or biofeedback, using virtual reality during walking rehabilitation, and robotic gait training are all examples of interventions available and developing in modern walking rehabilitation (Teasell et al., 2003; Dobkin, 2004; Mauritz, 2004).

1.3.2 Challenges

Training patients post-stroke overground, with sufficient task-specificity (good quality), high intensity (fast walking speed) and long duration (long distance with many steps) while at the same time ensuring safety for both patient and therapist in patients with difficulties to walk, poses some challenges. Even apparently small adaptations of a motor task may result in the person using a different movement strategy (Majsak, 1996), and augmented use of body parts in behaviourally relevant tasks enhances the representation of those body parts in the brain (Liepert et al., 2000). In walking rehabilitation, this means that training walking should be as close to everyday walking as possible, and intuitively overground walking appears to be the most task-specific way of training walking. However, because of walking difficulties in patients post-stroke, walking is often very slow and limited to very short distances overground. Sometimes there is also a need for one or more physiotherapists to support the patient to ensure safety and/or to make walking possible. Training walking overground may therefore not utilise the walking strategy that is needed to improve independent, everyday walking. In addition, the intensity and duration of such training may be low. This can affect the outcome since transfer of the task to everyday walking may be limited and the effect from use-dependent neuroplasticity reduced. An alternative to overground walking that potentially avoids some of the challenges mentioned above is allowing the patient to train walking on a treadmill with BWS; a type of training termed BWSTT.

1.4 Body weight supported treadmill training post-stroke

1.4.1 Rationale for BWSTT

Training walking on a treadmill was suggested by Auxter already in the 1960s, and research on patients after spinal cord injury and stroke walking on a treadmill with BWS originated in Canada and Germany in the 1980s and 1990s (Auxter, 1969; Barbeau et al., 1987; Visintin and Barbeau, 1989; Wernig and Muller, 1992; Hesse et al., 1994; Visintin et al., 1998). BWSTT emerged from experimental studies using animal models where cats with completely dissected spinal cords could be re-trained to take coordinated weight-bearing steps after several months of treadmill training with support given to the hind limbs (Lovely et al., 1986; Barbeau and Rossignol, 1987). In BWSTT, the patient walk on a treadmill while wearing a harness attached to an overhead suspension system relieving a chosen percent of the body weight (figure 3).

Figure 3. A person walking on the treadmill with body weight support

The BWS system offers symmetrical removal of weight from the lower extremities, allowing patients who have difficulties taking full weight on their legs to be in a situation thought to facilitate walking. Patients secured in a harness can practice complex gait cycles as the harness assists or compensates for deficient equilibrium and the motor-driven treadmill belt enforces walking (Visintin et al., 1998; Hesse et al., 2001). The proportion of BWS should be dependent of the patients' needs or capability, and supporting 40 percent of total body weight has been recommended as maximum support to gain optimal outcomes (Hesse et al., 2001; Wernig and Müller, 2002). BWSTT is thought to provide "forced-use" for the lower limbs (Visintin et al., 1998; Kosak and Reding, 2000; Harris-Love et al., 2001; Nilsson et al., 2001; Dobkin et al., 2003). By placing the patient on a moving treadmill belt, the patient is required to enact the cyclical activity of walking driven by the movement of the treadmill. As a result, BWSTT may stimulate the initiation of activity dependent neuroplasticity (Dobkin et al., 2003; Kent et al., 2009).

The rationale behind BWSTT therefore is that BWSTT facilitates walking-related sensory input through repetitive, rhythmic practice of gait cycles even when independent or safe walking overground has not yet been obtained. As a result, safe and massed practice of walking can be started early post-stroke. Individuality and progression is provided by adjusting walking speed, time, distance, and percentage of BWS.

1.4.2 Existing knowledge and previous research

The literature search for this dissertation has been continuing until autumn 2011. The literature search used as a basis for the research questions were completed during spring 2005 for paper 1 and during spring 2007 for paper 2 and 3.

Task-specificity of BWSTT

BWSTT has been proposed as a task-specific intervention for walking rehabilitation, but for BWSTT to be task-specific and transferable to everyday walking, there is a presumption that the kinetic and kinematic requirements of walking during BWSTT should resemble those during overground walking (Puh and Baer, 2008). Based on this, there are some differences between treadmill walking with BWS and overground walking in terms of motor control factors, mechanical factors, psychological factors and environmental factors worth remembering. When walking on a treadmill the body is not moving in relation to an external frame of reference and this makes the visual cues different from walking overground where the surroundings are constantly changing due to the moving body. Also on the treadmill, the feet are in contact with a moving surface and the stance foot is moved backwards by the moving treadmill belt. Rather than having to walk at self-selected walking speed in order to propel forwards, a person on a treadmill has to walk at a fixed walking speed in order to avoid moving backwards on the treadmill belt. In addition, when BWS is used the need for antigravity muscle activity decreases with the amount of BWS, and the harness itself may inhibit or make some movements difficult. There is also a psychological aspect, particularly for people who never have walked on a treadmill before the experience may be challenging. All these differences may affect treadmill walking with BWS and therefore making walking different from overground walking. An important question therefore is if and how the treadmill, the harness and the BWS affect walking during BWSTT, and if BWSTT is aggravating walking characteristics.

Several studies on non-impaired persons have investigated the resemblance between overground walking and treadmill walking without BWS (Strathy et al., 1983; Murray et al., 1985; Stolze et al., 1997; Alton et al., 1998; Dingwell et al., 2001; Vogt et al., 2002; Warabi et al., 2005; Riley et al., 2007). Studies have found that the treadmill affects several walking characteristics significantly, and common findings are increased cadence with decreased step length, and altered kinematics and kinetics. Some studies have compared treadmill walking (without BWS) to overground walking in patients post-stroke (Harris-Love et al., 2001; Harris-Love et al., 2004; Bayat et al., 2005; Puh and Baer, 2008). Findings indicate less asymmetry on the treadmill compared to overground. Puh and Baer (2008) also found lower cadence and longer step times on the treadmill compared to overground. Conversely, Bayat and colleagues (2005) found higher cadence on the treadmill compared to overground. No studies could be found investigating task-specificity of treadmill walking with BWS compared to overground walking.

Familiarisation to BWSTT

For most patients treadmill walking with BWS is a new and sometimes challenging task that may require familiarisation and practice. Therefore, it is important to know for how long a patient has to walk on the treadmill before walking pattern reaches a stable level. Despite the growing use of BWSTT worldwide, we could not find studies where time necessary for patients post-stroke to be familiarised to treadmill walking with BWS was investigated. Only studies investigating familiarisation-time for non-impaired persons walking on a treadmill without BWS was found, and findings indicate that non-impaired persons familiarise to treadmill walking within the first four to ten minutes of walking (Taylor et al., 1996; Matsas et al., 2000; Wass et al., 2005; Van de Putte et al., 2006). Also, Wall and Charteris (1981) found that the initial familiarisation was followed by a more gradual adaptation during the next hour, and this happened every time a subject started walking on the treadmill. Such findings however, should not be generalised to patients post-stroke. It is not known to what degree familiarisation to treadmill walking is similar in patients' post-stroke and non-impaired persons, and to what degree BWS will affect familiarisation time.

Effect of BWSTT

BWSTT is relatively costly in terms of equipment and human resources (Moseley et al., 2005). It has therefore been important to investigate the intervention in terms of its efficacy for patients post-stroke. However, results from such studies have been inconclusive; some studies favour BWSTT compared to other types of walking rehabilitation (Hesse et al., 1995; Visintin et al., 1998; Pohl et al., 2002; Eich et al., 2004; Sullivan et al., 2007; Yang et al., 2010) while others have not found BWSTT superior (Kosak and Reding, 2000; Nilsson et al., 2001; Franceschini et al., 2009; Ada et al., 2010; Duncan et al., 2011). In a Cochrane review where both treadmill training without BWS and BWSTT was investigated, statistical significant differences were not found between treadmill training with or without BWS and other forms of walking rehabilitation (Moseley et al., 2005). However, independent walkers' tended to increase walking speed more with treadmill training compared to conventional walking rehabilitation. In a systematic review, Manning and Pomeroy (2003) also concluded that BWSTT might be effective if the goal is to increase walking speed, but otherwise they did not find additional effect of BWSTT compared to conventional physiotherapy.

There may be several reasons for inconclusive effect of BWSTT. Different sub-groups of patients with different functional levels post-stroke were investigated, and protocols for BWSTT have diverged and been poorly described. The rationale and background for decisions about for example walking speed and percent BWS, as well as progression in training, were often not explained, discussed or controlled (Chen and Patten, 2006; Duncan et al., 2007; Carter et al., 2010). If described, choice of percent BWS and treadmill speed were often based upon subjective evaluation by the therapist(s) of the patients ability and tolerance during training (Chen and Patten, 2006). For example, BWS was increased to the point were less than 15 degrees flexion in the knee was achieved. For walking speed, the fastest walking speed possible was used while maintaining good posture and tolerated by the patient. On this basis, it is difficult to compare interventions or results between studies and also to acquire good conclusions about effectiveness.

Consequences of choices of BWS and walking speed during BWSTT

Knowledge about the consequences of clinical choices during BWSTT for walking characteristics is important. Examples of such clinical choices are what walking speed or percent BWS that is used during BWSTT. In a review from 2006 the rationale for activity-based therapies in neurorehabilitation such as BWSTT were reviewed by using principles of drug development (Dromerick et al., 2006). The investigators suggested that there has been a premature evaluation of efficacy, because knowledge about basic principles has not been good enough.

Only two small studies could be found where the implications on walking characteristics when altering percent of BWS and walking speed on the treadmill for patients post-stroke were investigated. Hassid and colleagues (1997) did a pilot study with seven patients post-stroke and concluded that choices about BWS did affect symmetry, but walking speed did not. Chen and colleagues (2005) also did a pilot study with six patients post-stroke, and found that BWS improved swing-time symmetry while faster walking speed increased the kinetic energy in both legs. Hesse and colleagues (1997) did a study with 11 patients looking at the effects of altering BWS, and found that BWS did not affect cadence, step length and symmetry, but relative single support time was increased with increased BWS. They also found that BWS increased gluteus medius activity and decreased activity in vastus lateralis and soleus. For the effect of modulating BWS during treadmill walking, two studies were also found investigating non-impaired persons (Threlkeld et al., 2003; van Hedel et al., 2006). Findings indicated that BWS influenced relative phases of the gait cycle, but changes on walking characteristics were in general small when BWS was less than 50 percent. Van Hedel and colleagues (2006) also investigated the effect of modulating walking speed on the treadmill, and unsurprisingly found that cadence and stride lengths increased with faster speed. However, they also found that when walking in speeds less than 0.69 m/s, the relative duration of the gait phases, joint trajectories of the knee and ankle joint, and leg muscle EMG activity patterns changed greatly.

Based on previous studies therefore, there is a need for additional and larger studies in order to increase knowledge about how walking characteristics are affected by BWSTT, the time needed to familiarise to walking on a treadmill with BWS, and the effect of clinical choices on walking characteristics during BWSTT.

2. Objectives

The objectives of this PhD project was to investigate how kinematic walking characteristics are affected by treadmill walking with BWS, how kinematic walking characteristics familiarise during treadmill walking with BWS, and the consequences of modulating walking speed and percentage of BWS during treadmill walking with BWS. Such knowledge is important to potentially improve specificity and thereby the result of gait training. In addition, more knowledge of principles for BWSTT may affect design and procedures of future clinical studies.

2.1 Paper 1

The objective of paper 1 was to investigate how treadmill walking with BWS affects walking by studying the isolated effect on walking characteristics of all components of BWSTT, namely the treadmill, harness and BWS systems.

2.2 Paper 2

The objective of paper 2 was to investigate if patients post-stroke manage to stabilise walking patterns during a five-minute familiarisation-trial on the treadmill with BWS.

2.3 Paper 3

The objective of paper 3 was to investigate if kinematic walking characteristics aggravate during treadmill walking with BWS compared to overground walking in patients post-stroke. In addition, effect of altering percent BWS and walking speed during treadmill walking with BWS was investigated.

3. METHOD

3.1 Design

Cross-sectional, repeated measures design was used in all three parts of the project. This design allows a description of the status of phenomena, or a description of relationships among phenomena at a fixed point in time (Polit and Beck, 2004).

3.2 Participants

3.2.1 Participants Paper 1

In paper 1, 28 non-impaired persons recruited by invitation through the intranet system at Haukeland University Hospital participated. Participants who were interested were given written information about the study. All participants included, reported to be healthy and in good physical form. None of the participants reported to be suffering from disease, injury or using medication affecting walking ability. Twenty-one of the participants had previous experience with walking or running on a treadmill. For further details about the sample, see table 2.

3.2.2 Participants Paper 2 and 3

Patients post-stroke at an acute stroke unit and a rehabilitation unit at Haukeland University Hospital were eligible for inclusion in the study. A convenience sampling method was used by physiotherapists working at these units to invite patients who could walk without physical assistance to participate in the study. The patients' attending physician approved participation. Inclusion in the main study was primarily based on walking ability; patients had to be categorised in category three, four or five of the Functional Ambulation Categories (FAC) (Holden et al., 1984) (table 1). These categories indicate that patients could walk without physical assistance from a person, but might need attendance for safety or guidance. The patients also had to be able to walk intervals of at least 10 meters with or without walking aids overground, be medically stable, and be between 16-85 years. Ability to understand verbal and written information was required. Exclusion criteria were FAC score category five without any walking difficulties observed by the physiotherapist, severe exercise intolerance, or walking difficulties not caused by stroke.

In total 56 patients post-stroke accepted the invitation, signed a written informed consent form, and were included in the study. In paper 2, a subsample of 35 patients who could complete the five-minute familiarisation protocol was selected. In paper 3, the 46 patients who could complete the treadmill protocol for this part of the study were included in the analyses. For further details about the samples, see table 2.

Table 1: Functional Ambulatory Category (FAC) based on Kollen and colleagues (2006).

Category		Description	Dichotomy
0	Non-functional walking	Person that is not able to walk or who require 2 or more persons for support	Physically dependent walking *(with manual support)*
1	Dependent (level 2)	Person that requires firm and continuous support from 1 person to help with carrying body-weight and with balance	
2	Dependent (level 1)	Person that needs continuous or intermittent support from 1 person to help with balance or coordination	
3	Dependent on supervision	Person that requires verbal supervision or stand-by help from 1 person but without physical contact *(with or without walking aids)*	Physically independent walking *(without manual support)*
4	Independent on level ground	Person that can walk independently on level ground, but who requires help on stairs, slopes, or uneven surfaces *(with or without walking aids)*	
5	Independent walking	Person that can walk independently anywhere (*without walking aids)*	

Table 2: Sample descriptives for all papers

CHARACTERISTICS	Non-impaired Paper 1		All patients included		Subsample Paper 2		Subsample Paper 3	
Demographic								
Number of subjects N	28		56		35		44	
Gender Male n (%)	9	(32)	38	(68)	26	(74)	31	(71)
Age (years) M (± SD)	38	(±10)	63	(±15)	63	(±13)	61	(± 15)
Body Mass Index (kg/m²) M (± SD)	23	(±3)	26	(±4)	26	(± 3)	26	(± 4)
Function								
Functional Ambulatory Category								
Grade 5 n (%)			24	(43)	19	(54)	22	(50)
Grade 4 n (%)			18	(32)	9	(26)	14	(32)
Grade 3 n (%)			14	(25)	7	(20)	8	(18)
Speed (m/s) M (± SD)								
Slow	.98	(± .19)	.50	(± .18)	.54	(± .15)	.54	(± .17)
Preferred	1.44	(± .15)	.68	(± .23)	.73	(± .21)	.73	(± .21)
Fast	2.12	(± .23)	.93	(± .40)	.97	(± .32)	1.01	(± .39)
Type of walking aids								
Stick/ One crutch n (%)			4	(7)	1	(3)	3	(7)
Rollator n (%)			3	(5)	1	(3)	1	(2)
None n (%)			49	(88)	33	(94)	40	(91)
Treadmill walking								
Previous experience (yes %)	21	(75)	21	(38)	17	(49)	20	(46)
Present condition								
Location present stroke								
Left hemisphere n (%)			21	(38)	13	(37)	18	(41)
Right hemisphere n (%)			19	(34)	10	(29)	12	(27)
Brainstem n (%)			7	(13)	5	(14)	6	(14)
Cerebellum n (%)			8	(14)	6	(17)	7	(16)
Multiple n (%)			1	(2)	1	(3)	1	(2)
Type of stroke								
Infarction n (%)			50	(89)	31	(89)	40	(91)
Haemorrhage n (%)			6	(11)	4	(11)	4	(9)
Days since present stroke								
Acute (<15 days) n (%)			34	(61)	22	(63)	27	(61)
Sub-acute (15-84 days) n (%)			15	(27)	10	(29)	12	(27)
Long term (>84 days) n (%)			7	(13)	3	(9)	5	(11)
Referred from								
Acute ward (%)			38	(68)	23	(66)	28	(64)
Rehabilitation ward (%)			14	(25)	10	(29)	13	(30)
Home (%)			4	(7)	2	(6)	3	(7)
Physiotherapy (yes %)			54	(96)	34	(97)	42	(96)
Orthoses (yes %)			5	(9)	3	(9)	4	(9)
Comorbidities / Risk factors								
Cardiocirculatory (yes %)			33	(59)	19	(54)	25	(57)
Neurological (yes %)			7	(13)	6	(17)	6	(14)
Respiratory (yes %)			4	(7)	1	(3)	2	(5)
Other (yes %)			14	(25)	5	(14)	9	(21)
Smoking (yes %)			16	(29)	11	(31)	13	(30)

3.3 Procedures

The setting for all parts of the project was a gymnasium located at Haukeland University Hospital. Testing were done after working hours, which made it possible to close the gymnasium for people not participating in the test and therefore improve the control of unwanted variables. A treadmill system located in the gymnasium was used, as well as the floor next to the treadmill for tests of overground walking. The floor in the gymnasium has a straight length of 16 metres. Participants were allowed to use glasses or contact lenses during testing. All participants were asked to wear trainers or walking shoes. Light leisurewear with trousers was used. This was important due to the use of a harness when walking with BWS. If the clothes were too baggy or if a skirt was used, the harness would be difficult to attach adequately.

3.3.1 Procedures paper 1

Participants in study 1 were interviewed on issues regarding age, use of glasses/lenses, experience with treadmill walking, amount of organised exercise and walks longer than three kilometres. Body weight, body height and leg lengths of each subject were measured. The participants walked during six different conditions[3]:

- Overground walking
- Overground walking wearing a harness
- Treadmill walking
- Treadmill walking wearing a harness
- Treadmill walking with approximately 30 percent dynamic BWS
- Treadmill walking with approximately 30 percent static BWS

In order to control for a learning effect, the order of the walking conditions was randomised. During overground walking, the participants walked a distance of 11 meter. Data for the middle seven meters were registered by photocells connected to a

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[3] The terms here differ from the terms used in paper 1. This is in order for the terms to correspond better to the terms used in paper 2 and 3. In paper 1, the terms floor (F), floor wearing a harness (FH), treadmill (M), treadmill wearing a harness (MH), treadmill wearing a harness with dynamic BWS (dynamic BWS) and treadmill wearing a harness with static BWS (static BWS) were used.

computerized stopwatch synchronised with an accelerometry device. Walking speed was decided by the subject after the following verbal instructions: (1) “walk slowly, as if waiting at a bus stop or doing window shopping”, (2) “walk at a normal speed that feels comfortable for you” and (3) “walk as fast as you can without running”. All instructions were followed by “walk back and forth once”. Since the participants were walking back and forth on every instruction, six sequences of walking data were registered.

For treadmill walking, a computerised stopwatch was used and synchronized with the accelerometry device. This time, however, the stopwatch was started and stopped manually during each sequence by the researcher instead of the photoelectric cells. The registration period for each testing sequence lasted for 15 seconds. All conditions during treadmill walking were assessed at three walking speeds pre-set by the researcher (0.7 m/s, 1.2 m/s and 1.7 m/s). The testing started after the participant had performed a familiarisation trial at all three testing speeds. The familiarisation period lasted until the subject expressed confidence and this was acknowledged by the researcher. In addition, the researcher evaluated the subject to have reached steady state at each walking speed before registration started. The mean familiarisation time was three minutes (range one to five minutes).

During the harness and the BWS conditions, a harness was mounted on the patient while standing. The amount of BWS was based upon the participants’ body weight. The goal was that the BWS should be as close to 30 percent of the body weight as possible. Since the free weights of the dynamic system weighed four kg each, the total weight support had to be increased by at least eight kg at a time (1x4 kg on each side), and this was the basis for the weight categories.

3.3.2 Procedures paper 2 and 3

Overground the patients walked 11 meters with only the middle seven meters analysed allowing acceleration and deceleration phases not to be included in the analyses. Walking speed was self-administered based on the following three verbal instructions, ”walk at your usual speed”, ”walk slower than usual” and ‘‘walk as fast as you can safely walk without running'', from here on called preferred, slow and fast walking speed. All instructions were followed by ''walk back and forth once'', producing two intervals at each walking speed. Subsequently, average speed from the two intervals at each speed instruction was calculated. These walking speeds were used on the treadmill, allowing all participants to walk at their own self-selected slow, preferred and fast overground walking speed.

After overground walking, all participants had a familiarisation trial at preferred walking speed and with 20 percent BWS administered for five minutes if possible. If a minimum of five minutes familiarisation was not possible, the participant was not included in the familiarisation study (paper 2), if a minimum of three minutes was not possible the participant was not included in any of the studies. After familiarisation, the participants walked with 20 percent BWS (TM20) and 40 percent BWS (TM40). Order of TM20 and TM40 was randomised between participants. The TM20 and TM40 trials both consisted of one and a half minutes of walking at preferred, slow and fast speed respectively, giving a total walking time of four and a half minute in each of the BWS conditions. The last half minute at each speed was used for analyses. During the first 30 seconds of each treadmill condition, treadmill speed was set gradually to the patient's preferred walking speed calculated from the overground walking intervals. The participants did not get any physical support or guidance on how to walk on the treadmill during the testing, except for the first two minutes of familiarisation where they received some verbal advice and light physical guiding if necessary. Examples of verbal advice were "remember to take steps", "try to take longer steps", "straighten up" or "look up and forwards". Examples of physical guiding were that some of the patients were guided by placing a hand on the back to remind the participant to straighten up. The patients were not allowed to hold on to the handrails. Five-minute breaks were mandatory between the overground, familiarisation and BWS conditions. See figure 4 for a schematic presentation of the procedure.

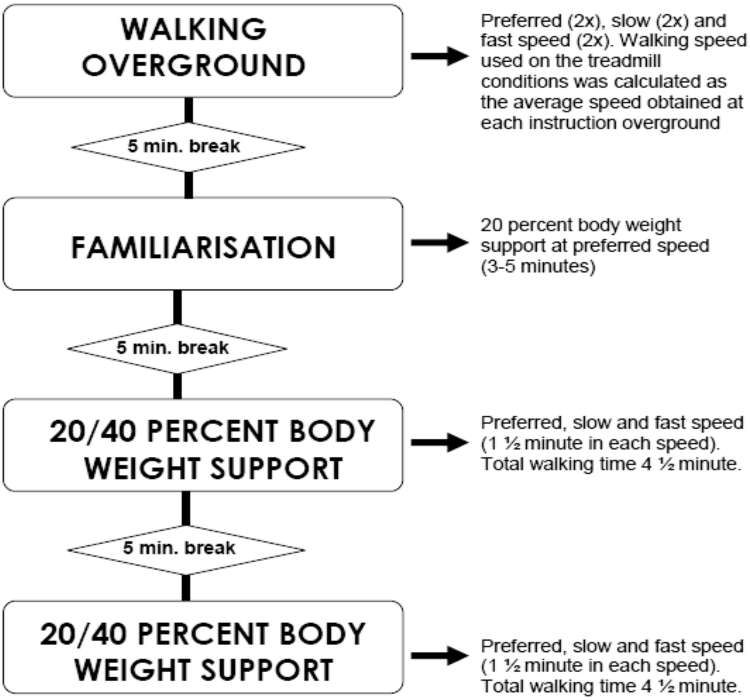

Figure 4. Schematic presentation of the test procedure of paper 2 and 3. The order of the two last conditions was randomised. Walking speed used on the treadmill conditions was calculated as the average speed obtained at each instruction overground.

3.4 Instrumentation

For all three papers, a Woodway LOKO system® S70, 2003 model (Woodway, Germany) was used during the treadmill conditions, consisting of a treadmill and two BWS systems. The static BWS system consists of a harness, pulleys and spring weights, and the dynamic BWS system consists of a harness, pulleys and free weights. Both systems allow support by a pre-determined percentage of body weight. In paper 1, both BWS systems were used, and in paper 2 and 3, only the static weight system was used. The harness was mounted on the participant by experienced physiotherapists in accordance with instructions in the treadmill manual (Wernig and Müller, 2002).

3.4.1 Instrumentation paper 1

Linear acceleration of the trunk was measured during walking using a triaxial piezoresistant accelerometer secured with a fixation belt, and connected to a 300 g battery operated data logger (Logger Technology HB, Sweden). The accelerometer was positioned over the lower back, close to the COM during walking. The accelerometer was placed outside the clothing, and when the participants walked with a harness, it was placed outside the harness (figure 5). Signals were low-pass filtered at 55 Hz and then sampled at 128 Hz to avoid aliasing. The digitised signals were transferred to a computer for off-line processing. An accelerometer positioned over the lower back may be tilted due to the lower back curvatures, postural alignment of the walking subject and inaccuracy in positioning of the instrument. The static gravity component was therefore corrected for in order to assess dynamic acceleration. Further details of the procedure have been described elsewhere (Moe-Nilssen, 1998a). The instrument has previously been tested for precision and accuracy (Moe-Nilssen, 1998a) and for test–retest reliability during walking (Moe-Nilssen, 1998c).

Figure 5: Person wearing a trunk accelerometer with a fixation belt and registration box (with and without wearing a harness) used in paper 1.

3.4.2 Instrumentation paper 2 and 3

In paper 2 and 3, acceleration was measured with an upgraded six degrees-of-freedom inertial sensor (MTx, XSens, Enschede, NL) that was attached over the lower back by an elastic belt to acquire accelerometric and orientation data (figure 6). The sensor contains tri-axial units of accelerometers, gyroscopes and magnetometers, and is connected to a battery operated communication unit also worn by the participants. Data were acquired at a sampling frequency of 100 Hz and transmitted to a laptop by Bluetooth technology.

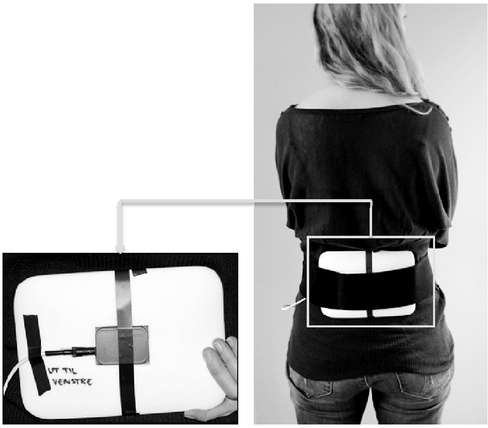

Figure 6: Person wearing a trunk accelerometer with a fixation belt used in paper 2 and 3.

3.5 Data analyses

In all three papers, a customized software application TRASK, run under Matlab 7.0.4 (paper 1) and Matlab 7.1 (paper 2 and 3) (The Mathworks Inc., Natick, MA) was used for signal analysis and calculations of walking variables. In paper 1, trunk acceleration data were transferred to a horizontal-vertical coordinate system, eliminating gravity bias (Moe-Nilssen, 1998a). Trunk acceleration data were reported along AP, ML and V axes where the AP axis is oriented along a pre-defined line of progression. In paper 2 and 3, acceleration data were obtained directly in a horizontal vertical coordinate system as computed by the sensor firmware.

In all papers, average trunk acceleration amplitudes for each walk interval were expressed by root mean square (RMS) values, from here on called trunk acceleration. An unbiased autocorrelation procedure was used to calculate cadence and average step length, and to describe the regularity of steps and strides based on acceleration curves. Unbiased autocorrelation use the overlapping parts of a time series and a time-lagged replicate of that time series to quantify the peak values representing phase shifts equal to one step and one stride respectively. The advantage of using an unbiased rather than a biased autocorrelation procedure is that the unbiased procedure is not affected by the length of the data series (Moe-Nilssen and Helbostad, 2004). A perfect replication of the signals between neighbouring steps or strides returns autocorrelation coefficients of one. This procedure has demonstrated good measurement properties for gait in fit and frail elderly (Moe-Nilssen and Helbostad, 2005).

In paper 1, the tilt of the trunk during walking was registered by the accelerometer, where a negative tilt indicates a forward lean. In addition, in order to compare all participants at the same walking speed, individual quadratic curve estimates were constructed for each walking characteristic over the range of walking speeds demonstrated by that participant during overground walking. A point estimate was then chosen for each curve at a normalised speed of 1.2 m/s. During treadmill conditions, data from a fixed speed of 1.2 m/s was used in the analysis. Thus, all data could be compared at the common walking speed of 1.2 m/s. The point estimating procedure has been described elsewhere (Moe-Nilssen, 1998b), and is illustrated in figure 7.

In paper 2 and 3, trunk asymmetry was calculated by subtracting the interstep trunk regularity from interstride trunk regularity, reflecting additional variability between left and right steps beyond the variability between strides. WR was also reported. WR is the ratio between step length and cadence (Sekiya et al., 1996; Sekiya and Nagasaki, 1998). WR has been found to be a reliable measure for evaluating pathological and aging walking patterns (Sekiya and Nagasaki, 1998).

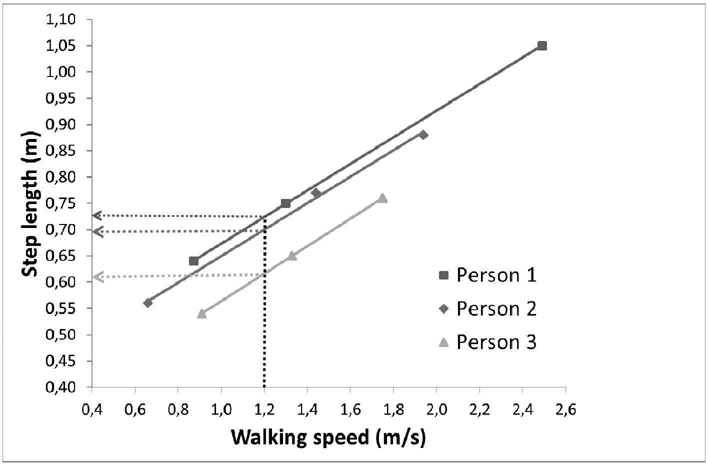

Figure 7: Point estimate procedure (examples from three random participants and with1.2 m/s). Based on Moe-Nilssen (1998b).

3.6 Statistical analyses

In all three papers, repeated measures analysis of variance (ANOVA) models were used to analyse data. ANOVA compares the ratio of systematic variance against unsystematic variance in an experiment. The distinct feature of repeated measures ANOVA is that the same participants contribute to the different means, namely the same people participate in all conditions and the within-participant variance gives the effect of the experiment (Field, 2005). An F-ratio is calculated representing the within participant variance caused by the situation, divided by the within participant variation caused by random factors. A large F-ratio indicates more variability caused by the independent variables than what is caused by chance (Field, 2005). If the F-ratio is large enough to be statistically significant, further analyses must be used in order to find what have caused the difference between conditions or groups. Either the variance in the model can be broken down into components by using planned contrasts, or one can compare every condition/group and use a stricter acceptance of statistically significance. The first option is a priori testing and involves having an expectation of the outcome in advance so specific hypotheses can be tested. The second option involves exploring data post hoc to find possible differences. When main effects are significant in post-hoc testing, Bonferroni adjustments should be used on the pairwise comparisons to adjust for the effect of multiple comparisons. This involves setting a more stringent alpha level for each comparison, and one can inspect the differences more realistically. ANOVA allow testing the effect of several independent variables and allow between and within effects in the same model, but then one must be aware of and adjust for interaction effects (Field, 2005).

Statistical analysis was performed in SPSS version 13 (Chicago, IL) in paper 1 and PASW Statistics version 18 (Chicago, IL) in paper 2 and 3. Microsoft® Office Excel 2002 (Microsoft Cooperation) in paper 1 and Microsoft® Office Excel 2003 (Microsoft Cooperation) in paper 2 and 3 was also used for analysis.

3.6.1 Statistical analyses Paper 1

Repeated measures mixed ANOVA was used to analyse the effect of within- and between-participant factors. A multivariate test investigated the main effect of treadmill by comparing overground and treadmill conditions and main effect of harness by comparing walking with and without a harness. Another multivariate test compared walking on the treadmill wearing a harness with the two different BWS systems. To adjust for possible confounding factors, gender and previous experience with treadmill were included as between-participant factors in the statistical models. When the main effects were significant, post-hoc Bonferroni adjustments were made to the pairwise comparisons between BWS systems and treadmill walking with harness.

3.6.2 Statistical analyses Paper 2

Intraclass correlation coefficient (ICC) model 1,1, were all within-participant variability was considered measurement error, was used for pairwise comparisons of successive 30 seconds intervals during familiarisation indicating the similarity between intervals. ICC can be used when repeated measures have been collected, and express the relationship between variability caused by measurement error and total variability in the data (Domholdt, 2000; Moe-Nilssen et al., 2008). Mean ICC for each 30 seconds interval (across all walking variables) and for each walking variable (across intervals 2-10) were determined by averaging Fisher's z transformed ICC values and back-transforming to ICC-values according to the method of Silver and Dunlap (Silver and Dunlap, 1987). The reason for the transformation is that averaging correlations leads to underestimation because the sampling distribution of correlation coefficients tends to be skewed. This is particularly important to take into consideration when sample size is small (Silver and Dunlap, 1987). Interval 1 was not included when assessing the mean ICC across intervals because the treadmill belt had not yet attained its targeted speed.

One-way repeated measures ANOVA with linear contrast was used to investigate if there was systematic change over time that was not revealed by comparison between neighbouring intervals.

3.6.3 Statistical analyses Paper 3

To test treadmill walking with BWS against overground walking a repeated measures ANOVA was used with condition (overground, TM20 and TM40) as main effect, adjusting for walking speed (slow, preferred and fast) and condition*speed interaction. A priori testing with simple planned contrasts was used to investigate whether overground walking was different from the treadmill conditions. To explore the effect of proportion of BWS and walking speed on the temporospatial walking characteristics during treadmill walking with BWS, a similar repeated measures ANOVA model with condition (TM20 and TM40) and speed (slow, preferred and fast) as main effects was used, adjusting for condition*speed interaction. If main effects of speed were significant, post hoc pairwise comparisons with Bonferroni correction were used. The reason for using two different models to answer the research questions was that we suspected that the differences between overground and treadmill would be so marked that differences between TM20 and TM40 could be masked if analysed in the same model as overground.

4. SUMMARY OF RESULTS

4.1 Paper 1

All the 28 non-impaired participants completed the testing and were included in the study. During treadmill walking without BWS, there was an increase in cadence, forward tilt of the trunk, and in V trunk acceleration during treadmill walking compared to overground walking. In addition, interstride trunk regularity decreased in the AP direction. Wearing a harness resulted in decreased V trunk acceleration, but did not affect any of the other kinematic walking characteristics significantly. Walking with 30 percent BWS, affected all kinematic walking characteristics significantly except for cadence and tilt of trunk compared to treadmill walking without BWS. Trunk acceleration decreased in all directions, AP and V interstride trunk regularity decreased, while ML interstride trunk regularity showed an opposing effect, displaying higher regularity under the BWS conditions. Pairwise comparisons indicated a reinforcement of these trends for the static BWS condition compared to the dynamic BWS condition in all variables except for the ML interstride trunk regularity.

4.2 Paper 2

Of the 56 patients post-stroke who were included in the project, 35 could complete the five-minute familiarisation protocol and was included in this part of the project. ICCs during familiarisation were low for all walking characteristics during the first minute. After three minutes however, mean ICCs across walking characteristics stabilised at ≥0.90.

Mean ICC for the separate walking variables across intervals showed that WR, cadence, step length and trunk acceleration all had ICCs that were high. These walking characteristics seemed to stabilise with ICCs above 0.90 already after the first two minutes. The regularity and asymmetry variables all had lower ICCs. The ICCs for these walking variables, especially the trunk asymmetry variables, were also more variable between intervals throughout the five-minute familiarisation trial. However, with the exception of ML trunk acceleration, there was no linear trend for any of the kinematic walking characteristics after three minutes.

4.3 Paper 3

Of the 56 patients post-stroke that were initially included in the study, 44 completed the protocol and were included in this part of the project. Of the participants not completing the protocol, 10 patients were unable to walk on the treadmill without holding onto the handrails or without physical support. Two participants had to stop before completion due to discomfort from the harness, the reason for this was that one participant had scar tissue just under one of the thigh straps that felt uncomfortable, while another participant felt uncomfortable pressure from the thigh attachments during TM40. The latter participant was the participant with the second largest BMI of all the 56 patients post-stroke. In general, compared to the participants completing the protocol, the 12 non-completers were more likely to be older, walk at slower walking speed overground, have right hemisphere strokes, and less previous experience with treadmill.

Cadence and AP asymmetry was not affected significantly by walking on the treadmill with BWS compared to overground walking, while WR and step length both had p-values close to 0.05 between conditions. All other kinematic walking characteristics were highly significantly different between walking overground and walking with both 20 and 40 percent BWS. Compared to overground walking, WR tended to increase and step length tended to be longer on the treadmill with BWS. Trunk acceleration in all directions decreased. AP and V interstride trunk regularity decreased on the treadmill with BWS, while ML interstride trunk regularity increased. ML trunk asymmetry decreased and V trunk asymmetry increased during walking on the treadmill with BWS. When rising BWS from 20 to 40 percent, AP and V trunk acceleration decreased, while ML interstride trunk regularity, as well as AP and ML asymmetry increased. With increasingly faster walking speeds cadence, step length, trunk acceleration, and V interstride trunk regularity increased. ML interstride trunk regularity decreased at faster speeds while V interstride trunk regularity increased. ML trunk asymmetry was higher during fast speed compared to slow speed. AP and V trunk asymmetry were not significantly different between speed conditions. ML trunk asymmetry was only significantly higher at slow compared to fast speed. WR had a significant main effect, but no pairwise comparisons demonstrated significant differences because of walking speed.

5. DISCUSSION

In this chapter, methodological strengths and limitations will be discussed, and ethical issues considered. Then, there will be a general discussion of the results based on the project as a whole and the possible implications of these results in the clinic and for future research. The general discussion will not go into detailed discussion about the individual research questions for the separate parts of this project since this is covered in the individual papers. Focus will be on discussing the joint contribution of the papers, and try to highlight in a broader perspective what is suggested to be important knowledge based on our findings.

5.1 Methodological discussion

5.1.1 Design and procedure

Repeated measures design allows for comparisons between conditions. In this study non-impaired persons and patients post-stroke were studied while walking under different conditions overground and on the treadmill, at one point in time, with the interest of describing potential differences between conditions. This allowed within-participant analyses to answer the research questions, as the participants were compared against themselves between conditions; the participants were their own controls. The repeated measures designs is recognised to be a strong design because it does not require a large sample and is extremely sensitive in detecting differences between conditions. However, a limitation is that it can be affected by carry-over effects because the same participants are exposed to the same conditions (Cozby, 1993; Robson, 1993; Polit and Beck, 2004). To decrease the interference of carry over effects between conditions (for example learning effect and fatiguing), randomisation of the order of the different walking conditions was done in advance of the testing procedure in paper 1 and 3. Diminishing possible carry over effects is particularly important when studying patients post-stroke, as they fatigue faster than non-impaired participants do. Also the design allowed for an isolation of different independent variables; making it possible to know more about how treadmill, harness, and the BWS systems respectively affect walking characteristics in paper 1, and how overground walking differs from treadmill walking with BWS, and the effect of walking speed and proportion of BWS in paper 3. In paper 2, the familiarisation effect during five minutes of treadmill walking with BWS could be analysed by splitting the data series into sequential 30 seconds periods.

Detailed procedures designed in advance, aimed to ensure standardisation during testing in respect to communication with participants, order of conditions, attachment of the harness and the kinematic sensor, proportion of body weight support, testing environment, and registration and handling of data. By such strict procedures, standardised testing for all participants was aimed at. In paper 1 however, a possible limitation to standardisation was the flexible familiarisation time chosen by subjective evaluation of the participant and the tester during warm up on the treadmill. In addition, because of a cable between the kinematic sensor and the separate body worn data storage unit, the sensor had to be moved on one occasion during the testing procedure when the harness was put on or removed. In paper 2 and 3, these limitations were avoided since familiarisation time was standardised and the new kinematic sensor allowed the unit to remain in place irrespective of the use of harness. On the other hand, even though the same accelerometry method was used in all papers, two different kinematic sensors were used to measure acceleration in paper 1, and in paper 2 and 3. This should be taken into consideration when discussing differences between non-impaired persons and patients post-stroke when looking at the overall result of this project. However, no direct comparisons were made between the non-impaired and the patients post-stroke, and therefore data from the different sensors were not analysed together.

5.1.2 Sample

In this project, convenience sampling was used to recruit participants. This sampling method implies that a sample is drawn from a population that is easily accessible (Polit and Beck, 2004). The samples therefore are not drawn randomly. This is a limitation to generalizability of the findings, but when comparing subjects to themselves, the effect of differing conditions may still yield results of clinical relevance.

The sample size of 28 non-impaired participants (paper 1), and 35 and 44 patients post-stroke (paper 2 and 3) might not be extensive, however compared to similar previous studies the samples in this project are large. A power analysis was not done, as similar studies could not be found. A challenge with power analyses is that knowledge of the expected variation in data should be known; therefore, we judged that the presumptions in advance of this project were not adequate to do a power analysis. The risk of having an insufficient number of participants is mainly that a type II statistical error can be made. A type II error means that true differences are not detected, and significance will not be met even if there is a true difference between (in this case) conditions. Inspecting the results of the project however, differences between conditions yielded several highly significant differences. This may be an indication of a sufficient size of the samples. In addition, as mentioned in the previous section, the repeated-measures design used is also robust in detecting differences even if number of participants is not extensive. The results from this project can give a basis for power calculations in later research using accelerometry when studying BWSTT in patients post-stroke.

BWSTT is used for patients with walking difficulties, and often with so severe walking difficulties that independent walking overground is not possible. However, in this project non-impaired persons and ambulatory patients post-stroke have been investigated. All patients post-stroke were ambulatory but with some walking impairments/difficulties. The participants in paper 1 were non-impaired. The reason for including only ambulatory patients was a need to standardise the test procedure. If non-ambulatory patients had been included who were not able to take unassisted steps, therapists would have been needed to help the patient take steps during walking on the treadmill with BWS. If differences between conditions had been found, the differences might have been affected by differing degree of assistance from the therapists or by the patient walking differently at different speeds or proportion of BWS. For this reason, only patients able to walk independently were included even though the limitations in generalisation were acknowledged. When investigating the BWSTT-systems' effect on walking in paper 1, only non-impaired participants were studied to limit uncontrolled variables. If the sample had consisted of patients post-stroke, it would be difficult to investigate the untainted effect of the components of the BWSTT-system on walking, due to the potential interaction between impaired function and the BWSTT-system.

The included patients post-stroke had a mean age of around 60 years, and this is about 15 years younger than the mean age for having a stroke. As the inclusion criteria were mainly based on the patients' walking function, age probably was less important. In fact, several patients who were appropriate for participation in the project in terms of function, and most likely would have had no problem completing the procedure, could not be included because of the upper age-limit of 85 years. In retrospect, this limitation was probably not necessary. It is interesting however, that in scientific literature in the area of neurorehabilitation and stroke; a mean age of around 60 years or even younger for the participants' is not atypical. There may be several reasons for this; there may be a fear of straining elderly patients, and therefore elderly as a group is excluded from such rehabilitation trials. Cognitive function may more frequently be impaired, making it more challenging to acquire appropriate consent from the participants. In addition, physical function in elderly patients may be lower and more variable than in younger patients, and the investigator may fear problems with standardisation of the protocol. These are important methodological and ethical concerns, but excluding a large group of patients as an entirety just as a precaution, is probably unnecessary. Rather, inclusion and exclusion criteria should be based directly on issues like cognition, function, and exercise tolerance.

5.1.3 Instrumentation and accelerometry

In this project, an instrument was needed that could be used to measure walking characteristics both when the participants walked overground and when walking on the treadmill with a harness and body weight support. Preferably, the instrument should also be positioned at the same location throughout the testing without having to be repositioned between conditions. This ruled out most of the available gait analysis instruments, as they would be impossible to use both when walking on the treadmill and overground. Quality, cost and practicality therefore advocated the use of a kinematic sensor. A limitation to this study therefore, is that we only have measured kinematics over the trunk; implying that differences in movement over the trunk between conditions can be described, but not what causes these changes in terms of for example changes in muscle work or footfall characteristics. However, utilising the relation of trunk movements to the placement of the feet, algorithms were applied that use information from the lower trunk to estimate step length, cadence, variability and asymmetry parameters. It has previously been pointed out that both trunk and footfall characteristics during walking are of clinical relevance for the control of gait (Winter, 1995b; Patla et al., 1999; Helbostad et al., 2007).

For an instrument to be useful the instrument must have consistency in measuring the same target characteristic every time (reliability), and it must measure what it is supposed to measure (validity) (Polit and Beck, 2004). If validity and reliability are satisfactory, findings will be results of the actual phenomenon studied, and not measurement error or erroneous interpretation of the outcome. The accelerometry method used in this project, and the point estimate procedure for walking speed used in paper 1, have been tested for reliability and validity issues in previous studies. Moe-Nilssen (1998c) examined test reliability of the accelerometry method by doing a test-retest procedure investigating mean acceleration during standing and walking conditions with good results. The reliability was good for the walking tests both when walking on even and uneven surfaces. In another study, test-retest reliability of the accelerometry procedure during walking were investigated in terms of trunk acceleration, step length, stride length and cadence, and test-retest reliability was found satisfactory (Henriksen et al., 2004).

Sensitivity of the accelerometry procedure to detect differences between walking with and without experimental back pain has also been studied previously with good results (Moe-Nilssen et al., 1999). Moe-Nilssen and Helbostad (2005) investigated how interstride trunk acceleration variability and step width variability can differentiate between fit and frail elderly people, finding that interstride trunk regularity, but not step width variability, could differentiate between the two groups. Hodt-Billington and colleagues (2008) used trunk accelerometry data to assess trunk asymmetry (AP, ML and V trunk asymmetry) in hemiplegic patients post-stroke and a control group with no known asymmetries. They also used footfall parameters (single support and step length asymmetry) obtained from an electronic walkway to assess asymmetry. While footfall parameters did not discriminate between the two groups, trunk accelerometry parameters did. Mizuike and colleagues (2009) also used a trunk accelerometry method similar to that used in this project, and found trunk acceleration and trunk regularity to discriminate between patients post-stroke and an age-matched non-impaired control group.

Sensitivity to change for an instrument is very important; but also to know how much change constitutes important change or a clinically relevant difference. Inspecting the data in this project, even though many of the kinematic walking characteristics have highly significant differences, the absolute differences for some variables seem small. There are often no cut-off values indicating when a difference is clinically important between conditions for a certain population, and this is a future challenge for investigators of impaired walking utilising novel methodologies for assessing walking.

5.1.4 Data analyses

Kinematic walking characteristics calculated by the trunk accelerometry method uses data obtained from an overall walking performance over a set distance. This means that several steps are used to obtain average kinematic walking characteristics for steps or strides during a walking-trial. An advantage is that the results are not based only on an individual step or stride, bur reflects how a person truly walks over a distance. This method also enables studying the similarity or diversity between several steps and strides, as done when using trunk regularity and symmetry measure. A disadvantage however, is that we cannot differ between a left and right step. When analysing data from patients post-stroke this is a limitation. Patients post-stroke often have hemiparesis or problems mainly affecting one side of the body, therefore to be able to have information on each separate step and how the patients walking strategy possibly changes between conditions, could have given additional insight into how BWSTT affects walking.

Using average step length as an outcome may be imprecise since patients post-stroke commonly have asymmetrical gait. In retrospect, using average stride length rather than step length could have been more intuitive and precise, as we cannot differ between left and right steps. Stride length do not distinguish between left and right steps, as both are included. Using stride length rather than step length however, would only have been rescaling the variable, as average stride length would have been average step length multiplied by two, and have no practical consequences for the results presented here.

In all three papers, the number of steps between the conditions was not standardised. Overground the participants walked a set distance, while on the treadmill the distance was not set, only time and walking speed. The time and the number of steps the participants used in order to walk the distance overground therefore, varied based on how fast they walked and how long steps they took. Overall, less time and steps were used overground compared to the treadmill conditions. This represents a potential limitation to standardisation because the kinematic walking characteristics are calculated as an average based on the number of steps taken. In retrospect, this effect could have been reduced or avoided if number of steps had been used as a covariate in the statistical analyses or if the same number of steps used overground had been extracted from the treadmill conditions.

When people of different body sizes are compared with movement analysis, it is good practice to correct for differences in weight and stature (Hof, 1996). Examples of such scaling are ratios between oxygen consumption and body weight, and between leg length and step length. For within-subject comparisons such as in this project however, where the participants are their own controls, the effect of adjusting for leg length is marginal.

The point estimate used in paper 1 to estimate walking characteristics during overground walking at 1.2 m/s can be seen as a theoretical estimate of walking characteristics at a chosen walking speed even if the person has not walked at that exact speed. The walking characteristics on the treadmill, however, were obtained directly from participants walking at 1.2 m/s on the treadmill. This was possible because walking speed was pre-set and delivered by the treadmill belt allowing speed to be set at exactly 1.2 m/s. The point estimate of each walking characteristics during overground walking was estimated for each person and condition by interpolation based upon a quadratic relation between speed and the speed dependent walking characteristic. If the underlying relations were more complex, these estimates might not be directly comparable with walking characteristics during treadmill walking. However, during data analysis, we checked the variability explained by the quadratic curve estimate. With the exception of some regularity measures, the explained variability was high. This supports the validity of the point estimates, but interpretation of variability characteristics should be made with some caution. Even if absolute walking speed was the same between conditions, this speed may represent different relative walking speeds for different participants. 1.2 m/s may for one person be close to the walking speed obtained during their usual preferred speed, while for others it may be closer to a fast or slow speed. Since analyses were done within-participants, as the participants were their own controls, this probably did not affect the results.

5.1.5 Statistical analyses

In all three parts of this project, a repeated measures ANOVA was used to test differences between conditions. The main advantages of using repeated measures ANOVA is that greater power to detect effects is provided as repeated measures ANOVA reduces unsystematic variability in the design, and fewer participants are necessary. The disadvantage is that normally in ANOVA (used between groups) there is an assumption that the scores for the different conditions should be independent to make the F-test accurate. However, when the same participants are tested under different conditions, this is dubious as the scores from the same participant are likely to be related. To solve this, an additional assumption must be taken into consideration for repeated measures ANOVA; it is assumed that the relationship between pairs of conditions is similar, meaning that there is equality of variances in the differences between conditions. This is called the assumption of sphericity. If this assumption is broken, corrections must be applied to the test. In this project, we used Greenhouse-Geisser corrections in paper 2 and 3. In paper 1, we used the results from a multivariate ANOVA and the assumption of sphericity was not necessary (Field, 2005).

In paper 2, Intraclass correlation coefficient (ICC) model 1,1 was used to test the similarity between neighbouring 30 seconds intervals during familiarisation. ICC considers variation caused by within-participant variability between intervals, and variation caused by the total between-participant variability in the data (Domholdt, 2000). A limitation is that ICC cannot differ between these causes of variability; low ICCs between neighbouring intervals may either be because of high variability in walking pattern or low variability between-participants. In the case of high ICCs however, which was generally found in this project, both low variability in walking pattern and sufficient variability between conditions were indicated.

5.1.6 Ethical considerations

All parts of the study were conducted in conformity with the Declaration of Helsinki. The protocols were approved by the Regional Science Ethical Committee and the Norwegian Social Science Data Services.

Ambulatory adults were tested while walking overground and on a treadmill with a BWS system that is designed for supporting patients with pareses or paralyses. On the treadmill, the participants walked within their own range of walking speed found during overground walking. The walking area on the treadmill is sufficiently large, and during walking with BWS, additional safety was provided by the support systems. On this basis, the testing equipment was considered safe. Only minor adverse events have been encountered in the literature for this type of treadmill and support system (Moseley et al., 2005), and we did not experience any injuries during testing. The physical demands were low for the non-impaired participants, but for some of the patients post-stroke, the treadmill conditions were physically demanding. However, at any time during the test procedure, there were two or three trained physiotherapists present, ready to intervene if necessary. Both the testers and the participants had access to the emergency stop button at all times during testing on the treadmill, and overground the tester walked close.

The study was based on voluntary participation and the participants were welcome to withdraw from the study at any time, and the personnel conducting the testing could stop the testing immediately if the patients looked tired or uncomfortable in any way. The participants were given detailed written information about the study in advance, and were asked to sign a written consent (the information and written consent was based on the declaration of Helsinki). Information was treated anonymously.

5.1.7 Validity of results

The validity of a research project is “the extent to which the conclusions of that research are believable and useful” (Domholdt, 2000), and must always be evaluated carefully. There are different types of result validity to consider, and in this section the internal and external validity will be summed up.

Internal validity "is the extent to which the results of a study demonstrate that a causal relationship exists between the independent and dependent variables" (Domholdt, 2000). In this project, internal validity therefore refers to the extent to which there is a causal relationship between the different walking conditions the participants have walked in (independent variables), and the different kinematic walking characteristics measured by the accelerometry method (dependent variables). To secure good internal validity, optimising control of all aspects of the project is necessary. In this project the cross-sectional repeated measures design aids good control because the same participants are compared against themselves at only one-point in time. This eludes or limits problems linked to history (changes between tests not related to the project), maturation (changes in the participant not related to the project), assignment (participants experiencing different conditions/interventions) and mortality (participants lost between tests). In addition, detailed protocols were prepared in advance of the testing to limit extraneous variables. A threat to internal validity in this project however, might be that in a repeated measures design there may be maturation in the form of a carry-over effect between conditions. The patients can get fatigued, and therefore be more tired and walk differently towards the end of the testing. This effect was diminished because of randomisation of the order of walking conditions. Other issues that might affect internal validity due to lack of standardisation is the re-positioning of the sensor between overground walking and treadmill walking, and the non-standardised familiarisation time in paper 1. A necessity for good internal validity is that the method used to measure the dependent variables has good reliability. Reliability is "the degree to which test scores are free from errors of measurement" (Domholdt, 2000). In section 5.1.3, both test-retest reliability and ability to detect differences between groups and conditions of the trunk accelerometry method was reported to be good. Therefore the ability of the independent variables in this project to detect differences in the dependent variables is well justified.

External validity is “concerned with the issue of to whom, in what settings, and at what times the result of research can be generalised” (Domholdt, 2000), and decreasing treats to external validity involves considering carefully to whom the results of the study can be applied, combined with practical considerations of the availability of participants for the study. In this project, the most important factor is to whom the results can be generalised. The setting, a gymnasium at a hospital, is the same as the usual setting for BWSTT, and there should be no time frame for applicability of the results. As discussed in section 5.1.2., in order to standardise the protocol effectively in paper 2 and 3, only participants who had some level of ambulatory function were selected. The participants were also somewhat younger than the average patients post-stroke. The samples therefore represent ambulatory and relatively young patients post-stroke, and generalisations of results to non-ambulatory and older patients are not substantiated. In paper 1, non-impaired participants were selected to increase probabilities that measured differences would actually be a result of the different walking conditions rather than uncontrolled variables caused by for example pathology or age.

To sum up, internal validity seems acceptable for all three papers, and external validity is good if generalisation based on paper 2 and 3 is done to ambulatory patients post-stroke within similar age groups. The results from this study also give valuable information about how non-impaired persons and patients may respond differently on a given task.

5.2 General discussion

A main goal of this project was to investigate if the advantages of BWSTT, such as safety for patients and therapists and training walking with sufficient intensity and duration, could be maintained without aggravating walking characteristics in patients post-stroke. This general discussion will therefore focus on findings of the effect of treadmill walking with BWS on walking characteristics, and implications for clinic and research.

5.2.1 Kinematic walking characteristics

Cadence and step length determines walking speed, and speed can be increased by increasing one or both. It is more energy demanding to walk at slow or fast walking speeds compared to preferred speed, or when using a higher than natural cadence to produce a certain walking speed. Patients and elderly often walk with high cadences and short step length relative to their waking speed, and therefore have energy demanding walking patterns. The reason for this may be an inability to take longer steps, for example because of paresis, contracture, limited muscle strength or impaired balance control. For patients post-stroke, this pattern is typical and often reinforced by reduced ability to stand on one leg and/or to swing the foot forwards. These limitations will also affect walking speed, as it is difficult and strenuous to walk fast if mainly cadence and not step length can be increased. A goal in training therefore is to encourage walking patterns with longer steps, and thereby a more effective walking pattern. A measure that reflects this pattern between step length and cadence is WR, computed as step length divided by cadence. In paper 3, WR was found to increase when walking with 40 percent BWS, compared to overground walking, and faster walking speed resulted in increased WR on the treadmill. This indicates that patients post-stroke manage to increase walking speed mainly by increasing step length during treadmill walking with BWS. This may partly explain why two systematic reviews found that increased walking speed was more effectively trained with BWSTT compared to training overground walking (Manning and Pomeroy, 2003; Moseley et al., 2005). However, even if the average step length was longer during treadmill walking with BWS, we do not know the underlying causes, but better stability and a feeling of security may contribute to the patient being able to take more active and longer steps on the affected side. On the other hand, the harness may also contribute to a more passive strategy as the patient can let the treadmill belt pull their feet backward without concern about balance control. A study on non-impaired found that during high proportion of BWS, the participants tended to shift the task of maintaining stability to the BWS device (Threlkeld et al., 2003). More intervention studies are warranted to investigate if BWSTT with fast speed has the potential of being a training method that increases step length and improves walking speed also during overground walking.

Trunk acceleration prominently decreased with BWS both in the non-impaired and in the patients. Increased acceleration and less smooth movement over the trunk has previously been found in patients post-stroke compared to non-impaired during overground walking (Mizuike et al., 2009). Decreased acceleration may therefore be an indication of more smooth and energy efficient walking. However, since the same also happened with the non-impaired during treadmill walking with BWS it may be just an indication that the BWS system with the harness attenuates movements around the trunk. Whether this will transfer to overground walking in patients post-stroke is not known.

Trunk regularity in all directions changed from overground walking to treadmill walking with BWS in patients post-stroke. In the ML direction, regularity increased quite distinctly, while in the AP and the V direction regularity decreased, but the change was less prominent. ML regularity was the only regularity measure affected significantly by increasing BWS from 20 to 40, with the regularity increasing with increased BWS. The finding that trunk regularity in the ML direction changed in the opposite direction to AP and V trunk regularity in patients post-stroke during walking with BWS, is similar to what was found previously in paper 1 for non-impaired, and in previous studies using trunk regularity measures to investigate responses to fatiguing exercises (Helbostad et al., 2007) and to differentiate between fit and frail elderly (Moe-Nilssen and Helbostad, 2005). This indicates that both being exposed to a new or demanding situation, or during walking in less able subjects, ML regularity increases while regularity in the direction of propulsion decreases. This may be due to a Bernsteinian freezing of degrees of freedom (Moe-Nilssen et al., 2010). In this project, treadmill walking with BWS may be experienced as a challenging task, and therefore this phenomenon may be elicited. Also, as suggested in paper 3, a passive pendulum-like swing from side to side caused by the BWS system in the frontal plane may contribute to increased ML regularity and decreased ML asymmetry during treadmill walking with BWS. In the sagittal plane, there is a constant need for adjustment of body position due to the moving treadmill belt and the restricted space causing decreased regularity in the AP and V direction. If the latter is the case, the idea that BWSTT creates a type of forced use of the affected side seems to be supported.

Asymmetry in walking is a characteristic of patients post-stroke due to hemiparesis; however, the pattern and direction of asymmetry may vary. Some patients post-stroke have shorter steps or single support phase on the hemiparetic leg, while others may demonstrate an opposite pattern (Hodt-Billington et al., 2008). In this project, a measure of asymmetry of trunk movements was used that previously has been shown to be more effective in discriminating between patients post-stroke and non-impaired elderly than temporospatial footfall parameters (Hodt-Billington et al., 2008). Hodt-Billington and colleagues studied stroke survivors with more long-term effects post-stroke than in this present project and with faster walking speeds (slow, preferred and fast walking speed of 0.69 m/s, 1.09 m/s and 1.56 m/s respectively). Trunk asymmetry was reported as an average representing all three speeds was 0.13 (AP), 0.16 (ML) and 0.09 (V). In our project, re-calculating trunk asymmetry accordingly, demonstrated trunk asymmetries of 0.14 (AP), 0.18 (ML) and 0.05 (V). Interestingly therefore, even if the patients in our study had shorter time since stroke and considerably worse function in terms of walking speed (slow, preferred and fast walking speed of 0.50 m/s, 0.68 m/s and 0.93 m/s respectively), trunk asymmetry was remarkably similar. This may indicate that the trunk asymmetry measures are efficient in differentiating between patient post-stroke and non-impaired, but not between sub-groups of patients post-stroke. A 10 percent general criterion for walking asymmetry was found to be valid for classification of asymmetry by Hodt-Billington and colleagues (2011). This criterion was met by our patients post- stroke in the AP and ML direction while walking overground, but not in the V direction. During treadmill walking with BWS, average trunk asymmetry across walking speeds during TM20 were re-calculated as 0.13 (AP), 0.08 (ML) and 0.10 (V), and during TM40 as 0.18 (AP), 0.12 (ML) and 0.13 (V). Using the 10 percent criterion, ML asymmetry changed from being asymmetrical overground to not being asymmetrical during TM20 and TM40. V asymmetry emerged during treadmill walking with BWS, and AP asymmetry increased with increased BWS. Understanding whether change in trunk asymmetry represents wanted or unwanted effects is not straightforward. However, one may speculate how decreased ML asymmetry and increased V asymmetry during treadmill walking with BWS is related. If decreased ML asymmetry is caused by a symmetrical pendulum swing during treadmill walking with BWS, prompting the weaker affected leg to carry more weight; less smooth movements and therefore more trunk acceleration may be produced in the V direction, resulting in increased V trunk asymmetry.

In general, most kinematic characteristics during walking with BWS did not demonstrate large deviations from overground walking. Some of the results related to regularity and asymmetry need support from longitudinal studies to be more fully understood. Of particular interest is the finding that step length increased during walking with BWS compared to overground walking in patients post-stroke, suggesting BWSTT may have a potential of being a training method to improve walking speed in these patients.

5.2.2 Walking speed

Even though walking speed was not a primary objective in this project, knowledge about walking speed in a relatively high functioning sample of patients post-stroke was obtained. Average preferred walking speed in the patients post-stroke was 0.68 m/s and fast walking speed was 0.93 m/s overground, implying that the patients were able to increase walking speed by 27 percent (0.25 m/s) beyond preferred speed. These results are quite similar to what has been found in previous studies on patients post-stroke (Hsu et al., 2003; Bayat et al., 2005; Jonsdottir et al., 2009), and also similar to the 32 percent increase in walking speed for non-impaired participants in paper 1. The absolute values also show that the patients walk far slower than non-impaired participants, demonstrating a need to focus on walking rehabilitation also for quite independent walkers among patients post-stroke. Slow walking speed can be disabling and having functional consequences, for example when crossing a light regulated pedestrian crossing and walk about effectively in the community. In fact, only about 20 percent of the patients in this project had a maximum walking speed that was faster than 1.2 m/s, which is the speed needed to cross a pedestrian crossing in Norway (The Norwegian Public Roads Administration, 2007).

5.2.3 Clinical implications and future research

When evaluating clinical implications of this research, the limitations discussed in chapter 5.1 should be kept in mind.

For ambulatory patients post-stroke, using BWSTT in addition to overground gait training seems relevant with an aim to influence walking characteristics. A main clinical implication is that BWSTT with fast walking speed should have higher priority than training with less BWS. However, our results do not illustrate transferability to everyday walking. Treadmill walking with BWS is possibly a different motor task compared to overground walking, but while such differences tend to disturb walking in non-impaired, treadmill walking with BWS tends to improve walking in patients post-stroke. It is also important to keep in mind that even if statistically significant differences were found between treadmill walking with BWS and overground walking, between different walking speeds, and between TM20 and TM40, the differences were generally small and the clinical importance of these findings has not been investigated. In order to investigate clinical implications of our findings, future effect studies may use protocols for BWSTT with fast walking speed, even if this requires a higher proportion of BWS. Effect of interventions should be evaluated by overground walking characteristics and physical activity in the patients' everyday life after training. In order to enhance our understanding, it would be beneficial to reproduce this study using additional outcome measures and including different sub-populations post-stroke (for example dependent walkers). Patients post-stroke with different walking deficits and other patient characteristics may possibly benefit from different gait training programs. We need to know more about individual requirements in order to specify optimal gait rehabilitation programs for the patients.

Of in total 56 patients, 44 completed the whole protocol of 14 minutes of treadmill walking with BWS without reporting discomfort, holding onto handrails or getting any physical support other than from the BWS system, and there were no adverse effects. Treadmill walking with BWS therefore seems to be a safe way of experiencing walking with relatively high intensity and long duration. However, heavy body weight may cause extra load on the tissue under the thigh straps, increasing the chance of irritation and discomfort. This should be taken into consideration when training heavy patients and using high proportions of BWS.

When investigating treadmill walking with BWS in ambulatory patients post-stroke a familiarisation trial should be undertaken before testing, and five minutes is adequate to obtain relatively stable walking patterns. To what degree this familiarisation has lasting effect or if familiarisation has to be repeated before each training session, needs to be investigated further. Familiarisation time under different walking speeds and BWS conditions, and for other patient groups, should also be considered.

During testing, some participants commented verbally that this was the first time after stroke that they got slightly out of breath, and asked if there was a chance of a new stroke if straining themselves. As pointed out in the introduction, to avoid patients being afraid of physical activity after stroke is essential to prevent secondary complications and recurrent strokes. Experiencing physical activity with relatively high intensity and in a safe environment with therapists close by is therefore important, and using BWSTT with fast walking speeds can provide this. Comments from the patients during treadmill walking with BWS both on how they experienced treadmill walking with BWS and their general situation were educational for the investigators. Unfortunately, we did not use any methodology to record this. Future research would benefit from including qualitative methods to increase knowledge about the patients' experiences, thoughts and questions that arise during training. It would be of interest to know more about beliefs about stroke and physical activity/training.

Trunk accelerometry was effective in exploring differences between walking conditions overground and on the treadmill as investigated in this project. However, there is a need to investigate further the relation between trunk movements and footfalls. This is particularly important in regards to understanding trunk regularity and symmetry measures more in depth.

To our knowledge, WR has rarely been used as outcome when investigating walking in patients post-stroke. In this project, WR was found to be a useful measure to understand better the relation between step length and cadence and how this relation is affected by walking speed and different conditions. WR therefore is a measure that should be used more extensively when evaluating walking characteristics in patients post-stroke in both research and clinic.

6. CONCLUSION

Kinematic walking characteristics in non-impaired participants were affected by walking on a treadmill, by walking with a harness and by using BWS-systems (paper 1). Patients post-stroke managed to walk with a relatively stable walking pattern within a five-minute familiarisation trial on the treadmill with BWS (paper 2). During treadmill walking with BWS, kinematic walking characteristics was not aggravated compared to overground walking, and choice of walking speed had greater impact than percent BWS. Faster walking speeds tended to affect the kinematic walking characteristics positively (paper 3).

The overall findings of this project therefore, indicate that walking on a treadmill with BWS is different from walking overground both for non-impaired persons and patients post-stroke, but kinematic walking characteristics for the patients post-stroke were overall not aggravated. Altering walking speed affected kinematic walking characteristics more than altering BWS and fast walking speed had a positive influence on several walking characteristics. Therefore, clinical choices concerning walking speed and percent BWS during walking on the treadmill with BWS have influence on walking patterns in patients post-stroke. The advantages of BWSTT in terms of practicing walking safely with high intensity (fast speed) and long duration (long distance), make BWSTT a good alternative in walking rehabilitation for ambulatory patients post-stroke. However, future studies should investigate if these results can be reproduced in other sub-samples of patients post-stroke and with other outcome measures. In future clinical trials, training should be designed to allow training with high intensity, and investigate if improvements during treadmill walking can be transferred to everyday walking.

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