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Rehabilitation of Gait in Chronic Stroke Patients

Doctoral dissertation

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ABSTRACT

Functional outcome of stroke patients depends on various factors such as rapid access to the emergency ward, care in the stroke unit and level of the rehabilitation. Stroke, infarction or intracerebral hemorrhage may cause motor weakness, sensory and proprioceptive deficits, intellectual impairment, emotional distress and motivational and social problems. Although most stroke patients regain walking independence, many have continuing problems with mobility due to impaired balance, motor weakness, and decreased walking velocity. The main purpose of this study was to evaluate gait rehabilitation in patients over six months post-stroke. First, the amount and content of the exercise of a tailored three-week gait-oriented physiotherapy program was analysed in an in-patient rehabilitation setting. Subsequently, the postural control, the spatio-temporal gait characteristics and the effects of the gait-oriented rehabilitation were analysed. Static balance was assessed with the emphasis on differentiating the left and right hemiparesis. The gait-oriented rehabilitation was compared with conventional rehabilitation. Additionally, three gait-oriented rehabilitation strategies were compared: the body-weight supported (BWS) gait trainer exercise with functional electrical stimulation (FES), the BWS gait trainer exercise without FES and active walking exercise.

The study population consisted of 59 patients with chronic stroke and 30 healthy subjects. Their motor abilities were studied with a battery of measurements and the details of the therapy were recorded. Comparison of three gait-oriented rehabilitation strategies revealed no differences between groups in motor improvements. Gait improved 14 – 24 % after 28 hours of instructed physiotherapy and self-initiated training in the gait-oriented groups and their dynamic balance improved by 28 – 48 %. The patients seemed to depend on a larger postural sway than healthy subjects to maintain their static balance and there may be specific features due to the side of the hemiparesis. Gait-oriented rehabilitation improved certain spatio-temporal gait characteristics not seen in less intensive conventional rehabilitation. All gait-oriented strategies were good choices for ambulatory stroke patients. The follow-up of six months showed no decline in gains in gait. The same time frame in the gait trainer allowed more repetitions of steps and a longer walking distance. Intensive training improved gait in patients with chronic stroke and may lead to increased options for daily activities.

National Library of Medicine Classification: WB 320, WB 495, WB 541, WE 103, WL 355
Medical Subject Headings: Cerebrovascular accident/rehabilitation; electric stimulation therapy/methods; gait disorders, neurologic/rehabilitation; motor skills; physical therapy techniques; recovery of function; rehabilitation/methods; walking/physiology

To Tuulia, Tuomas and Tiila

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Kuopio, May 2005

Sinikka Peurala

ABBREVIATIONS

ADL	activities of daily living
AFO	ankle foot orthosis
AI	Asymmetry Index
ANOVA	analysis of variance
AP	anterior-posterior
AS	affected side
BWS	body-weight support
COP	center of pressure
CPG	central pattern generator
CT	computerised tomography
FAC	Functional Ambulation Category
FAP	Functional Ambulation Profile
FES	functional electrical stimulation
FI	fecal incontinence
FIM	Functional Independence Measure
FMA	Fugl-Meyer Stroke Assessment
GT	walking exercise in the gait trainer
GT_{stim}	walking exercise in the gait trainer with functional electrical stimulation
HR	heart rate
ICC	intraclass correlation coefficient
ICF	International Classification of Functioning, Disability and Health
KAFO	knee ankle foot orthosis
MAS	Modified Ashworth Scale
MFES	multichannel functional electrical stimulation
ML	medial-lateral
MMAS	Modified Motor Assessment Scale
MMF	music motor feedback
MRC	Medical Research Council
MRI	magnetic resonance imaging
NDT	neurodevelopmental technique
NAS	non-affected side
RCT	randomized controlled study
SCI	spinal cord injury
SSS	Scandinavian Stroke Scale
UI	urinary incontinence
VM	velocity moment
WALK	walking exercise with necessary walking aids

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original publications that are referred to in the text by the Roman numerals **I – IV**.

I **Peurala SH**, Pitkänen K, Sivenius J, Tarkka IM. 2004. How much exercise does the enhanced gait-oriented physiotherapy provide for chronic stroke patients? Journal of Neurology 2004;251:449–453.

II **Peurala SH**, Könönen P, Pitkänen K, Sivenius J, Tarkka IM. Postural stability in patients with chronic stroke. Submitted

III **Peurala SH,** Titianova EB, Mateev P, Pitkänen K, Sivenius J, Tarkka IM. Gait characteristics after gait-oriented rehabilitation in chronic stroke. In press (Restorative Neurology and Neuroscience)

IV **Peurala SH**, Tarkka IM, Pitkänen K, Sivenius J. The effectiveness of body-weight supported gait training and floor walking in chronic stroke patients. In press (Archives of Physical Medicine & Rehabilitation)

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CONTENTS

1 INTRODUCTION

Stroke is one of the leading causes of severe handicap in the Western world (Stegmayr and Asplund 2003). The effects of stroke are variable and may include impairment in motor and sensory systems, emotion, language, perception, and cognitive function. Impairment of motor function involves paralysis or paresis of the muscles on the side of the body contralateral to the side of the supratentorial lesion. Damage to the descending neural pathways results in abnormal regulation of spinal motoneurons, causing alterations in postural and stretch reflexes and voluntary movement. Abnormalities in the temporal and spatial recruitment of motor units slow the ability of muscles to generate tension, leading to prolonged agonist contractions.

One crucial component of the rehabilitation of stroke is the restoration of mobility in an attempt to regain independent living and walking. The time course and degree of the recovery of walking function after stroke and the influence of initial lower extremity paresis were studied prospectively in a community-based population of 804 consecutive acute stroke patients in Copenhagen study (Jorgensen et al. 1995b). They reported that at the time of admission to rehabilitation, 51 % of subjects had no walking function and another 12 % needed assistance in ambulation. After rehabilitation, only 18 % of the participants still had no walking function, and 11 % required assistance. Those who are independent walkers, however, have usually an abnormal walking pattern and they are slow compared to healthy subjects (Titianova et al. 2003).

Although the incidence and mortality of stroke have declined, the prevalence of stroke has remained stable or it may even be increasing due to the increase in the numbers of elderly people in community (Tuomilehto et al. 1996, Immonen-Raiha et al. 2003, Sivenius et al. 2004). The most commonly used rehabilitation methods are based on theories originating from the 60's and 70's (Brunnstrom 1970, Bobath 1978) and appear to be less efficient than recently introduced methods, which involve more dynamic, task-oriented and repetitive training. More studies are needed to compare different methods and amounts of rehabilitation in order to collect evidence in favour of one particular method. In addition, new research findings have indicated that even in the chronic phase of stroke, there exists the potential for rehabilitation. It has been clearly shown that constraint induced movement therapy for the paretic upper extremity, which includes a large amount of exercise has resulted in improved paretic hand use in chronic stroke (Taub et al. 1993). A large amount of gait training for rehabilitation of acute and subacute phase of stroke has suggested that there is potential for improvement, but the research of gait rehabilitation during the chronic phase of stroke is inconclusive. The main purpose of this study was to assess the effects of in-patient gait rehabilitation in patients with chronic stroke, i.e. over six months since they had a stroke. This was achieved by detailed investigation of specific areas affecting the total gait rehabilitation outcome.

2 REVIEW OF THE LITERATURE

2.1 STROKE

2.1.1 Epidemiology and risk factors

The WHO MONICA project of 12 224 registered stroke patients in eleven countries (Stegmayr et al. 1997) identified the highest attack rates (first and recurrent stroke) in men in Finland and Russia (350/100 000 per year). Their attack rates were three times higher than the lowest rates found in Italy and Germany. The incidence rates (first-ever stroke) in men were 280/100 000 in Finland and 220/100 000 per year in Russia. In women, the highest attack (270) and incidence rates (190) were seen in Russia, where stroke events were more than three times higher than in Italy. In half of the eleven national populations of the WHO MONICA study, the stroke incidence was twice as high in men compared to women.

In this population survey of eleven countries, the presence of smoking and elevated blood pressure explained 21 % of the variation in stroke incidence in men and 42 % in women (Stegmayr et al. 1997). A meta-analysis of 22 studies indicated that smoking can double the risk of ischemic stroke (WHO 1988, Shinton and Beevers 1989). Subjects who stop smoking reduce this risk by 50 % (Colditz et al. 1988). In middle-aged women who smoke, the relative risk for stroke may be as high as 2.6 times that of aged-matched non-smokers (Kawachi et al. 1994). Lowering high blood pressure can substantially reduce the risk to vascular complications and overall mortality, depending on the magnitude by which blood pressure is lowered (Neal et al. 2000, Staessen et al. 2001). It is recommended that blood pressure should be lowered to normal levels below 140/90 mmHg and it should be lowered more aggressively in diabetics to achieve levels below 135/80 mmHg (Turner et al. 1999). The other stroke risk factors are hyperlipidaemia, heavy alcohol drinking and the use of hormone replacement in healthy women (Hack et al. 2003). In addition to decreasing blood pressure and cholesterol levels and smoking cessation, lifestyle modification includes additional factors to reduce the risk of stroke e.g. regular physical activity and use of a low salt, low saturated fat, high fruit and vegetable diet rich in fibre (Hack et al. 2003).

The population-based FINSTROKE register included 5 650 stroke patients (Sivenius et al. 2004). The average annual decline during 1983 – 1997 in the age-standardized incidence of first stroke events was 2 % among men and 1.7 % among women. Although the incidence as well as the mortality of stroke events have declined significantly in Finland during this 15-year period, the prevalence is stable or it may even be increasing as the population ages (Tuomilehto et al. 1996, Immonen-Raiha et al. 2003, Sivenius et al. 2004).

2.1.2 Neuropathological changes

Stroke can be defined as rapidly developing clinical signs of focal disturbance of cerebral function lasting more than 24 hours with no apparent cause other than a vascular origin (WHO 1988, Shinton and Beevers 1989). Stroke is either occlusive (due to closure of a blood vessel) or hemorrhagic (due to bleeding from a vessel). Insufficiency of blood supply is termed ischemia; if it is temporary, symptoms and signs may be found with little or no pathological evidence of tissue damage (Bryan et al. 1991). Ischemia reduces blood supply, thereby depriving tissue of oxygen, glucose, and prevents the removal of potentially toxic metabolites such as lactic acid. When ischemia is sufficiently severe and prolonged, neurons and other cellular elements die. Hemorrhage may occur at the brain surface. Alternatively, hemorrhage may be intraparenchymal causing a blood clot or hematoma within the cerebral hemispheres, in the brainstem, or in the cerebellum.

Infarction in the territory of the middle cerebral artery causes the most frequently encountered stroke syndrome with contralateral weakness, sensory loss, and visual field defect, and, depending on the hemisphere, it can involve either language disturbance or impaired spatial perception (Bogousslavsky and Caplan 1995). Weakness and sensory loss affect the face and arm more than the leg because of the somatotopy of the motor and sensory cortex. The more proximal limbs and the trunk may be less affected because these are controlled by both hemispheres. Visual field impairment is the result of damage to the optic radiation, the deep fiber tracts connecting the thalamic lateral geniculate nucleus to the visual cortex. Destruction of left opercular cortex in human causes aphasia, and this may take a variety of forms depending on the degree and distribution of the damage (Pedersen et al. 2004). Left hemisphere convexity may also cause a disturbance of learned motor acts called motor apraxia (Pedersen et al. 2001). Right hemisphere convexity infarction tends to cause disturbances in spatial perception. (Stone et al. 1993).

2.1.3 Diagnosis and clinical characteristics of chronic stroke

The European Stroke Initiative (EUSI) executive committee and the EUSI writing committee have updated the recommendations for stroke management (Hack et al. 2003). Recommendations emphasize that the acute stroke patient has to be transported to an emergency ward, and the physician must assess the patient with the priority for a life-threatening and disabling illness. Symptoms and signs such as a space-occupying infarction or bleeding, recurrent stroke, and medical conditions such as hypertensive crisis, co-existing primary motor area, aspiration pneumonia and renal failure must be recognized early. It is crucial that the early assessment of stroke subtypes is based on a detailed physical and neurological evaluation. Early evaluation of physiological parameters, blood chemistry and hematology, and cardiac function is recommended in the management of acute stroke patients. After the emergency assessment, the neurologist should perform a targeted neurological examination with a careful medical history.

Computerised tomography (CT) of the head is the most important diagnostic tool in patients with suspected stroke to distinguish hemorrhage and ischemic stroke or subarachnoid hemorrhage (Hack et al. 2003). Early infarct signs include sulcus effacement, swelling of the basal ganglia and the hyperintense middle cerebral artery sign. Early signs of extensive infarction with intracranial midline shifts indicate a very serious event and a high risk both for secondary hemorrhage and large malignant oedema formation. Parenchymal hemorrhage can be identified almost immediately either in deep structures in patients with hypertension or in atypical areas in patients without hypertension or during adequate treatment. Infratentorial hemorrhage or cerebellar infarcts can readily be identified, but smaller hemorrhages/ischaemic infarcts, in particular in the brain stem, may easily be missed. Magnetic resonance imaging (MRI) is more sensitive and is increasingly used as a standard procedure. Vascular imaging (ultrasound, CT angiography and MR angiography) provides additional information about the vessel patency in the brain and neck vessels and recommendations for stroke management emphasize that this should supplement all imaging procedures already in the acute phase.

In the Copenhagen study, 9 % of the stroke patients had intracerebral hemorrhage (Jorgensen et al. 1995a). The relative frequency of intracerebral hemorrhage rose exponentially with increasing stroke severity. Stroke type had no influence on mortality, neurological outcome, functional outcome or the time course of recovery. Initial stroke severity was the all-important prognostic factor. In the Finnish study (Kotila 1986), one year after stroke there were the following disturbances: hemiparesis 37 %, dysphasia 28 %, dysarthria 21 %, dysphagia 4 %, incontinence 9 %, visuospatial disturbances 41 %, memory disturbances 31 % and depression 29 %. In the Copenhagen study, the prevalence of full urinary incontinence (UI), partial UI and no UI at six months post-stroke were 8 %, 11 % and 81 % (Nakayama et al. 1997). The prevalence of full fecal incontinence (FI), partial FI and no FI were 5 %, 4 % and 91 % at six months post-stroke. Risk factors for UI and FI were age, severity of stroke, diabetes and comorbidity of other disabling diseases. In the Copenhagen study (Pedersen et al. 2004), the type of aphasia always changed to a less severe form during the first year. One year after stroke, the following frequencies for aphasia were found: global 7 %, Broca’s 13 %, transcortical motor 1 %, Wernicke’s 5 % conduction 6 % and anomic 29 %. The outcome for language function was predicted by initial severity of aphasia and by initial stroke severity, but not by age, sex or type of aphasia. A later Finnish study indicated (Kotila et al. 1998), that the incidence of depression was more common than in the earlier study (Kotila 1986). However, fewer patients living in the districts with outpatient rehabilitation and activities of the local divisions of the Finnish Heart Association were depressed (41 % had depression) than in the areas without after-hospital-discharge interventional programs (54 %) at three months. The difference remained at one year (41 % versus 55 %). Seizures occur in about 10 % of stroke patients (Olsen 2001). Five percent experience early-onset seizures and another 5 % late-onset seizures (peak onset within 6 to 12 months after the stroke). Epilepsy develops in 3 % to 4% of the stroke patients. There is a strong positive correlation between stroke severity and the risk of post-stroke seizures. Disturbances of motor control are described in next sections with special emphasis on balance and gait.

2.2 MOTOR CONTROL

2.2.1 Central motor system

The central motor system can be subdivided into three levels (Bear et al. 2001). The highest level, represented by the association areas of neocortex and basal ganglia of the forebrain, is concerned with motor strategy: the goal of the movement and the movement strategy that best achieves that goal. The middle level, represented by the motor cortex and cerebellum, is concerned with tactics: the sequences of muscle contractions, arranged in space and time, required to smoothly and accurately achieve the strategic goal. The lowest level, represented by the brain stem and spinal cord, is concerned with motor execution: activation of the motor neuron and interneuron pools that generate the goal-directed movement and make any necessary adjustments of posture. The correct function of each level of the motor control hierarchy relies heavily on sensory information. At the highest level, sensory information generates a mental image of the body and its relationship to the environment. At the middle level, tactical decisions are based on the memory of sensory information from past movements. At the lowest level, sensory feedback is used to maintain posture, muscle length, and tension before, during and after each voluntary movement.

In humans, 60 % of the cortico-spinal axons originate from the primary motor cortex, and the remainder from the premotor area, the supplementary area, and the parietal lobe (Bogousslavsky and Caplan 1995). The cortico-spinal fibers converge within the corona radiata and pass downward through the internal capsule, crus cerebri, pons, and medulla. At the junction of the medulla and spinal cord, some 75 – 90 % of the fibers cross the midline, and three separate cortico-spinal tracts are formed (crossed lateral, ventral, and uncrossed lateral)

It is common in stroke that infarction or hemorrhage involves the sensory-motor system. Shepherd has described impairments in muscle activation and motor control (Shepherd 2001). One major feature, muscle weakness, is due to loss of motor unit activation, changes in recruitment order, and changes in firing rates. Weakness from these sources is confounded by changes in the properties of motor units and in morphological and mechanical changes in the muscles, which occur adaptively as a consequence of denervation, but also of decreased physical activity and disuse. Muscle weakness and disordered motor control combine to evoke the functional movement disability.

2.2.2 Postural control

Postural stability consists of the static balance, i.e. the ability to maintain a chosen posture with minimal postural sway and the dynamic balance, i.e. the ability to move the center of mass in relation to the base of support in a controlled manner (Nichols 1997). Postural control includes both inborn reactions and those built up by learning. The sensory-motor organization for postural orientation includes neural mechanisms for active control of joint stiffness and variables such as trunk and head alignment (Kandel et al. 2000). The vestibular nuclear complex in the medulla and pons is an important center for the integration of vestibular, somatosensory, and visual information that has a large part in the control of postural orientation and equilibrium. Vestibulospinal pathways from this region as well as reticulospinal pathways from the adjacent reticular formation, terminate on both motoneurons and interneurons that influence neck, axial, and limb musculature. The basal ganglia have an important role in postural alignment and control of stability. The cerebellum plays several different roles in the control of posture involving sensory-motor integration. Cortical involvement is most important in the anticipatory postural adjustments that accompany voluntary movement. Biomechanical models of posture suggest that much of the coordination and control of posture emerges from biomechanical constraints inherent in the musculo-skeletal system and that the nervous system takes advantage of these constraints (Winter 1995). The control of dynamic equilibrium has a reflex component, yet it is anticipatory postural adjustments that are instrumental in voluntary, focal movement. The relative roles of the somatosensory, vestibular, and visual inputs for postural orientation and equilibrium can change, depending on the task and on the particular environmental context (Woollacott et al. 1986, Nashner et al. 1989, Popovic and Sinkjaer 2003). Somatosensory afferents include mechanoreceptors in the skin, pressure receptors in deep tissues, muscle spindles, Golgi tendon organs, and joint receptors. The vestibular receptors in the semicircular canals and macular otoliths are sensitive to angular and linear acceleration of the head. The static vision detects stable spatial features and relative position in a configuration space whereas the dynamic vision monitors the continuous motion of a stimulus as an image drift on the retina. Finally, postural coordination is significantly influenced by previous experience, practice, and training.

2.2.3 Motor control of gait

Walking occurs once the equilibrium ceases to exist because of the change of internal forces caused by muscle activity (Popovic and Sinkjaer 2003). Human walking starts after the redistribution of internal forces allowing the center of gravity to take over the stability zone. Falling is prevented by bringing one leg in front of the body providing a new support position. Once the first leg supports the body weight and then the other leg pushes the body up and forward due to the momentum, and thus the body will move in the direction of progression, and ultimately come directly above the supporting leg. This inverted pendulum position is transitional; momentum and gravity will again bring the body into the falling pattern. Cycling repetition of the described events is defined as walking.

Several critical insights into the mammalian neural mechanisms controlling stepping were made nearly a century ago. It was discovered that stepping on the hind legs could be induced in cats and dogs after complete transection of the spinal cord. The stepping movements in these spinal preparations were similar to normal stepping. There are different kinds of preparations used in studies of the neural control of stepping (Kandel et al. 2000). In spinal preparations, the spinal cord is transected at the lower thoracic level. In acute spinal preparations, adrenergic drugs are administered immediately after the transection. These drugs lead to the spontaneous generation of locomotor activity about 30 minutes after administration. In chronic spinal preparations, animal locomotor activity without drug treatment can return spontaneously in kittens, but in adult cats daily training sessions are usually required (Rossignol 2000). This means, that supraspinal structures are not necessary for producing the basic motor pattern for stepping. In the decerebrate preparations, the brain stem is completely transected at the level of the midbrain. In one decerebrate preparations, the locomotor rhythm is generated spontaneously, while in the other it is evoked by electrical stimulation to the mesencephalic locomotor region (Shik et al. 1969). When supported on a motorized treadmill both decerebrate cat preparations walk with a coordinated stepping pattern in all four limbs, and the rate of stepping is matched to the treadmill speed. These decerebrate preparations demonstrate that the basic rhythmicity of stepping is produced by neuronal circuits contained entirely within the spinal cord. Already in 1911 Brown showed, that rhythmic locomotor patterns were generated even after complete removal of all sensory input from the moving limbs (Brown 1911). This deafferentition is accomplished by transection of all the dorsal roots that innervate the limbs and is rarely used today. The spinal circuits can be activated by tonic descending signals from the brain. Immobilized preparations have revealed that the spinal pattern-generating networks do not require sensory input but nevertheless are strongly regulated by input from limb proprioceptors. The neuronal networks capable of generating rhythmic motor activity in the absence of sensory feedback are termed central pattern generators (CPG) (Kandel et al. 2000). Descending signals, drugs, or afferent signals could modify the temporal motor activity pattern by altering the functioning of interneurons in the patterning network. Three important types of sensory information are used to regulate stepping: somatosensory input from the receptors of muscle and skin, input from the vestibular apparatus, and visual input. Input from proprioceptors in muscles and joints are involved in automatic regulation of stepping. Exteroceptors are located in the skin and adjust stepping to external stimuli. Exteroceptors have a powerful influence on the CPG for walking. Current evidence indicates that the signals that activate locomotion and control its speed are transmitted to the spinal cord by glutaminergic neurons whose axons travel in the reticulospinal pathway.

Although the basic motor pattern for stepping is generated in the spinal cord, fine control of walking involves numerous regions of the brain, including the motor cortex, cerebellum, and various sites within the brain stem (Dietz 1996, Kandel et al. 2000). Supraspinal regulation of stepping includes activations of the spinal locomotor system, controlling the overall speed of locomotion, refining the motor pattern in response to feedback from the limbs and guiding limb movement in response to visual input. The spinal locomotor system is activated by signals from the mesencephalic locomotor region relayed via neurons in the medial reticular formation. The cerebellum receives signals via spinocerebellar pathways from both peripheral receptors and the spinal CPG and this structure adjusts the locomotor pattern via brain stem nuclei. The brain stem nuclei influenced by the cerebellum during walking include the vestibular nuclei, red nucleus, and nuclei in the medullary reticular formation. Cerebellar output to the vestibular nuclei may be involved in integrating proprioceptive information from the legs with vestibular signal for the control of balance. Modification of stepping by the visual signal is mediated via the motor cortex. Human locomotion differs from four-legged animal locomotion in that it is bipedal, placing significantly greater demands on the descending systems that control balance during walking. The spinal networks that contribute to human locomotion are more dependent on supraspinal centers than those in quadrupedal animals.

Two types of impaired motor control, which appear immediately after stroke, particularly affect gait performance. These are weakness or loss of volitional movement of the arm and leg on the side opposite to the brain lesion, known as paresis and inappropriately timed or graded muscle activations (decreased descending inputs, reduced motor unit synchronization as reviewed by (Shepherd 2001). Other types of disruptions that appear later include hyperactive stretch reflexes and hypoextensibility of the muscle-tendon complex (Dietz 1987, Richards et al. 1999)

2.3 RECENT FINDINGS IN MOTOR LEARNING

Modern concepts of motor learning have recently modified drastically the framework of rehabilitation from a conventional neurodevelopmental therapy to a more dynamic, task-oriented approach (Barbeau and Fung 2001). Barbeau and Fung have described the possible mechanisms involved in locomotor recovery. First it is known that the spinal cord severed from the descending pathways still possesses the capacity to learn complex motor skills such as locomotion (Rossignol 2000). Second, the training paradigms must be locomotor specific (Lovely et al. 1986). Third, the modulation of different reflexes is also task and phase specific. For example, hip extension and low load extensor muscles produce important sensory signals that allow decerebrate or spinal cats to move from stance to swing phase during locomotion (Dietz and Duysens 2000). An appropriate sensory stimuli, in addition to sensory input, e.g. the movement produced by the moving belt on a treadmill can be used as facilitatory input while training. Fourth, spinal reflexes such as the stretch reflex could also change following training (Wolpaw 1997). Fifth, recent study demonstrated remarkable adaptation of the spinal cord even without the supraspinal inputs (Bouyer et al. 2001). Thus, the spinal cord is capable of achieving a functional compensation after partial peripheral nerve lesions. Finally, neuropharmacological studies in conjuction with motor training are offering new hope for the recovery of function (Rossignol 2000).

Plautz et al. (2000) trained adult squirrel monkeys to perform a motor task that required pellet retrievals from a large diameter well to induce repetitive use of a limited set of distal forelimb movements in the absence of motor skill acquisition. Detailed analysis of the motor behavior of the monkeys indicated that their retrieval behavior was highly successful and stereotypical throughout the training period, suggesting that no new motor skills were learned during the task. Comparisons between pretraining and posttraining maps of primary motor cortex movement representations revealed no task-related changes in the cortical area devoted to individual distal forelimb movement representations. They concluded that repetitive motor activity alone does not produce functional reorganization of cortical maps. Instead, they proposed that new motor skill acquisition, or motor learning, is a fundamental factor in driving representational plasticity in primary motor cortex.

Thus, neurorehabilitation is increasingly taking into account novel scientific findings. Recent changes in intervention strategies include placing more emphasis on active exercise and task specific training as well as active and passive methods of preserving muscle extensibility (Shepherd 2001). Training has the potential to promote brain reorganization and to optimize functional performance. Research findings underpin the development of training programs, and therapists are relying less on one-to-one, hands-on service delivery, making more use of circuit training and group exercise and of technological advances in training equipment which increase the time spent in active practice, aiming to increase strength, control, skill, endurance, fitness, and social readjustment. Shepherd has noted that rehabilitation services remain slow to undertake the changes necessary to upgrade environments, attitudes, and rehabilitation methodologies to those shown to be more scientifically rational and for which there is evidence of effectiveness.

Rosebaum (1991) has pointed out that movement becomes more skilled with learning, and this is probably due to improvement in timing, tuning, and coordinating muscle activation. Training walking should, therefore, include exercises to strengthen weak muscles, to preserve muscle length, plus the practice of walking. Motor learning and developing the walking skill require practice with concrete goals and objective feedback about its effectiveness. The learner must have the opportunity to practice actively and to understand the importance of frequent repetitions. It is still not clear how best to encourage learning in disabled individuals. For example, good results were obtained by Silver and his group who carried out their task-oriented program for chronic stroke patients to improve gait (Smith et al. 1999). Patients practised walking on the treadmill three times a week, 50 minutes at a time for three months. The program improved volitional torque and torque/time generation and reduced reflexive torque/time in the hemiparetic limb, the gait velocity, cadence and time to get-up, walk and return-to-sit improved (Smith et al. 1999, Silver et al. 2000).

2.4 GAIT REHABILITATION OF STROKE PATIENTS

Traditional physiotherapeutic approaches to gait re-education have focused primarily on spasticity and abnormal reflexes. For example, the so-called Neurodevelopmental Technique (NDT) established by Bobath (Bobath 1978, Davies 1985, Davies 1990) assumes that an abnormal postural reflex activity is the major cause of dysfunction, and as such a significant proportion of therapy time involves inhibiting spasticity and other abnormal responses. In the Brunnstrom technique, synergistic movements are used to strengthen and practice single movements (Brunnstrom 1970). Proprioceptive Neuromuscular Facilitation PNF (Voss 1985) techniques consist of assisted isometric and isotonic leg flexion-extension exercises, which are thought to improve strength and control of leg musculature in preparation for walking. Hesse et al. (1994) studied the influence of NDT technique on gait (the gait rehabilitation related studies referred to in the next three sections are listed in table 1 in the same order). They assessed gait symmetry and absolute changes of vertical ground reaction forces of 148 stroke patients (39 – 962 days post-stroke, mean 130.5 days). Both parameters are process-oriented variables of the Bobath technique in which physiotherapists who are trained in NDT strictly control weight acceptance and push-off of both lower limbs. Patients received 45 min of physiotherapy based on Bobath concept, five times per week during four weeks of rehabilitation. Additionally, patients were instructed in a self-administered training program for at least 30 min daily. Stance duration, weight acceptance, push-off of both legs, and the stance duration symmetry improved, independent of changes of gait velocity. The symmetry of the ground reaction forces did not improve. The treatment even worsened heel strike and the loading rate at the end of four weeks of treatment.

2.4.1 Active bracing assisted walking

Therapeutic methods to improve gait have traditionally included walking with essential walking aids and with verbal and manual guidance (fig 1). Walking aids allows the therapist to begin to walk with patients who still require mild to moderate assistance to sit on a mat. The hemi-bar provides a rigid support for the patient to grasp with the unaffected hand. The therapist stands on the paretic side and prevents the patient’s pelvis from shifting away from the bar, and advances the patients’s paretic leg. Knee buckling during single stance phase on the paretic leg can be controlled manually with an ankle foot orthosis (AFO), an AFO and knee splint, or a knee ankle foot orthosis (KAFO). The least restrictive brace needed to assist with ambulation is chosen. Patients are usually able to begin using a hemi-walker or quadruped cane once they are able to walk 4 – 8 m at the hemi-bar (Kosak and Reding 2000). Walking exercises are undertaken usually on the floor, but also in other circumstances such as on stairs or outside. Using a limb-load monitor feedback, resisted exercises in the upright position with an isokinetic device and walking on a treadmill can also be used in task-specific intensive walking training program (Richards et al. 1993).

If one wishes to reinforce the increased step length, then visual cues can be supplied in the form of nonslip footprints. When step length is closer to normal, the subjects can be encouraged to walk faster and they can be timed for feedback. The step width can be reduced and the balance challenged by forcing the subjects to walk within one row of floor tiles or to walk along a line forward or walk sideways and backwards. The workload can be increased by making the individual climb stairs and slopes and automaticity can be promoted by the introduction of dual tasks. Overground walking can be also focused on walking alignment by encouraging an increase in hip extension and trunk verticality. To obtain this, subjects are asked to walk sideways with their heels and shoulders in contact with a wall to encourage hip extension and trunk verticality (Ada et al. 2003). Also musical motor feedback (MMF) can be exploited. In the study of Schauer and Mauritz (2003), stroke patients (44 days post-stroke) using a portable MMF device resulted in greater improvement than the group receiving common exercises such as slow walking with support of parallel bars and handrails, stepping sideways and backwards, etc. In both groups, the patients practised for five days per week, 20 min each day, for a total of 15 sessions. The MMF device consists of sensor insoles that detect the ground contact of the heels, and a portable music player compatible with the musical instrument digital interface standard. The music was played at an adjustable speed, which was estimated from the time interval between two consecutive heel-strikes. The time period required to play a quarter meter was stretched or compressed instantly to coincide with the patient's current step duration. The portable MMF device was fixed to the patient's belt and thin wires led to the insoles. The music was presented via plugged headphones.

Figure 1. Active bracing assisted walking with verbal and manual guidance.

Figure 2. Patient practises walking on the treadmill.

Ada et al. (2003) studied four weeks of gait training consisting of both treadmill (fig 2) and overground walking. Thirteen chronic stroke patients (7 – 60 months post-stroke) practised three times per week for 45 min at a time. They required initially more than 8.3 s to walk 10

m. The proportion of treadmill walking decreased by 10 % each week from 80 % on week 1 to 50 % on week 4. The treadmill component was structured to increase step length, speed, balance, fitness, and automaticity. The overground walking component aimed to reinforce improvements in walking pattern and speed achieved on the treadmill. It was defined as whole-task practice involving propulsion forward, backward, or sideways, or stairs climbing. The twelve sessions of walking training increased walking speed (10 m), walking capacity (6 min), and step length compared with the control group (n=14) who received a low-intensity home exercise program and regular telephone contact. The Stroke adapted 30-item of the Sickness Impact Profile (van Straten et al. 1997) did not change in either group.

Silver et al. (2000) have also studied effects of walking exercise on the treadmill in chronic stroke patients (9 – 70 months post-stroke). Five independently ambulatory patients walked on a treadmill three times per week for three months with the handrail support permitted. The exercise intensity was individualized initially and advanced as tolerated to 40 min duration at approximately 60 – 70 % of maximum heart rate reserve. Five-minute warm-up and cool-down periods were included in each session. The time needed to arise from a chair, to walk 3.1 m in a straight line without their normal assistant device(s) as fast as safely possible, turn and return to sit in a separate chair at the opposite end of the walkway exhibited 21 % decline after the training period. Also the straight-away walk segment time was faster, this being reflected in increased velocity and cadence. Mean stance and swing duration diminished for both affected and non-affected sides, but the asymmetry index of stance and swing durations remained unchanged.

2.4.2 Body-weight supported gait training

The gait rehabilitation strategies have been recently enlarged by providing treadmill training with partial body-weight support (BWS), combined with enforced stepping movements (fig 2). This method is based on animal studies showing that the adult spinal cord can recover a near-normal walking pattern after a period of interactive locomotor training on a treadmill in which weight support for the hindquarters is provided, hence facilitating stepping on a treadmill (Barbeau and Rossignol 1987). On the basis of such studies, treadmill training with BWS has been applied in patients with spinal cord injury (Dietz et al. 1997, Basso 2000, Behrman and Harkema 2000, Wernig et al. 2000), stroke (Hesse et al. 1995a, Visintin et al.

1998), Parkinson's disease (Miyai et al. 2000), cerebral palsy (Schindl et al. 2000) and Down Syndrome (Ulrich et al. 2001).

In nonambulatory hemiparetic patients (3 months – 1 year post-stroke) treadmill training with BWS (A-phase) was shown to be more effective than physiotherapy based on the commonly used Bobath (B-phase) concept in improving gait (Hesse et al. 1995a). The study was carried out in an A-B-A single case study with seven patients. The first three week phase (A-phase) consisted of 30 min treadmill training each workday. The subsequent three week (B-phase) consisted of 45 min physiotherapy sessions daily followed by another A-phase. The gait parameters improved only during the A-phases. In a study of the 79 subacute hemiparetic patients (27 – 148 days post-stroke) with abnormal gait patterns, six weeks of training at a frequency of four times per week, 20 min at a time on a treadmill with BWS or without BWS was compared (Visintin et al. 1998). Patients in the BWS group were provided with up to 40 % BWS at the beginning of training, and the percentage of BWS was progressively decreased as the patient's gait pattern and ability to walk improved. Patients in both groups showed improvements in balance, motor recovery, walking speed, and endurance when scores at post-training and at three months follow-up were compared. However, the patients started with BWS, scored significantly higher for those variables and they continued to have higher scores for over ground walking speed and motor recovery at the three month follow-up assessment. It seems also that more severely impaired patients and/or older subacute stroke patients can be mobilized more effectively using the treadmill with BWS than without this modality (Visintin et al. 1998, Kosak and Reding 2000, Nilsson et al. 2001, Barbeau and Visintin 2003).

Several studies have compared walking on a treadmill with BWS with walking on the floor in subacute stroke patients. Eighteen stroke patients (2.9 – 11.2 months post-stroke) walked on a treadmill with 15 % and 30 % BWS and on the floor (Hesse et al. 1999a). The treadmill speed was chosen according to the patient's gait velocity during floor walking, but some patients were more comfortable at a slower treadmill speed. On the treadmill, the gait was characterized by its higher symmetry, a prolonged single stance period of the affected limb, less plantar flexor spasticity indicated by the amount of premature activity in the plantar flexors and the co-contraction of the shank muscles. Further, the activation pattern of the erector spinae became more physiologic on the treadmill. In the study of Kosak and Reding (2000), fifty-six stroke patients (40 ± 3 days post-stroke) needing at least moderate assistance for ambulation were randomized to receive treadmill training with BWS or aggressive early therapist-assisted ambulation using knee-ankle combination bracing and a hemi-bar if needed. A treatment session of 45 min and an additional 45 min session of functionally oriented physical therapy was given daily in both groups. After a mean of 12.5 treatment days, no significant difference in walking endurance or speed was seen between the groups. Patients in both groups continued to improve their walking function up to the 10-month follow-up. A subgroup analysis of the more seriously handicapped patients receiving 12 or more days of training that these patients in the treadmill group showed a greater improvement in walking endurance and speed. Nilsson et al. (2001) showed similar results in their study of 66 stroke patients (8 – 56 days post-stroke) who initially required more than 14 s to walk 10 m. The treadmill training with BWS group and the control group received 30 min of training for five days a week throughout length the patients’ stay (1 – 4 months). In the control group, the walking training consisted of walking on the ground according to the Motor Relearning Programme for stroke devised by (Carr and Shepherd 1998). The additional 30 min for both groups consisted other types of physiotherapy training to improve motor control and to strengthen functionally weak muscles and techniques to improve motor function in the paretic side. A similar improvement in groups was seen in walking velocity, motor performance and balance.

In the study of Werner et al. (2002a), 28 non-ambulatory stroke patients (2 – 8 months post-stroke) participated in a comprehensive 9-week rehabilitation programme. The first 3-week period consisted of daily physiotherapy and occupational, speech and neuropsychological therapy according to individual need. During the subsequent 3 weeks of specific intervention, patients in group A received treadmill training with BWS for 30 min and other forms of physiotherapy for 40 min five times a week. Physiotherapy following the Bobath concept included gait preparatory manoeuvres whilst sitting and standing and the practice of gait itself either on the floor or on the stairs. The patients in group B received only treadmill training with BWS for 30 min five times a week. Afterwards, patients in both groups participated in a comprehensive rehabilitation programme for another 3 weeks. Patients regained better walking ability by treadmill training with BWS plus physiotherapy. However, it has to be noted that the A group received twice as much therapy as B group. The obtained difference waned by four months as a result of a further improvement of gait ability in all patients in group B.

There have been few studies conducted into the effectiveness of treadmill training with BWS conducted in chronic, over six months post-stroke, patients. Trueblood (2001) showed treadmill training with BWS in chronic stroke patients was able to improve gait and balance. The mean time since onset of stroke was 12.8 months, but the range was 2 – 42 months. All patients were able to ambulate independently for at least 10 m with or without the use of an assistant device or AFO. In the first part, the patients were randomised to three modes of walking: level ground ambulation with assistant device; level ground ambulation with BWS and treadmill ambulation with BWS. The velocity was kept constant at their normal walking speed for all modes of ambulation. During BWS, at least 30 %, but no more than 40 % BWS was used. During all modes of walking, surface EMG of the pre-tibial and quadriceps bilaterally was recorded as well as on/off foot patterns using a stride analyser. The results showed improved symmetry when walking with BWS either over level ground or on a treadmill. Improved timing of muscle activity was apparent during ambulation with BWS, and this was even more pronounced in the group receiving BWS on the treadmill. In part two, thirteen stroke patients (10.9 months post-stroke, range 4-36 months) participated in the study. In the intervention group, eight patients received BWS training for six weeks, three times per week. On the first week, patients started at 40 % BWS and progressed over a four week period to 0 % BWS. On the last two weeks they ambulated over level ground with a harness but without BWS. In the control group, five patients practised with their necessary walking aids for the same amount of time. All experimental patients showed significant improvements in velocity, stride length, sound limb swing and stance time, involved initial and terminal double limb support, and total double limb support. In the control group, the variables remained the same or even deteriorated. No significant differences pre-post testing between control and experimental groups in their EMG characteristics occurred following the intervention. In part three, thirteen stroke patients (9.8 months post-stroke, range 4 – 20 months) participated in the study. In this study, the intervention consisted of 8 weeks of BWS treadmill training three times per week for 75 minutes per session. The weight bearing was progressively increased throughout each intervention session on the treadmill until full weight bearing status was achieved as long as an appropriate gait pattern was evidenced upon visual inspection. They also ambulated on level ground to promote motor learning and carryover. Those results were similar to those described in their previous study. In addition, results from Tinetti balance and total Tinetti scores (Tinetti 1986) were better in the intervention group. No significant differences were apparent in the six minutes’ walking test.

It has been claimed that the amount of BWS should be limited to 30 % (Danielsson and Sunnerhagen 2000). In a study with 11 hemiparetic patients reported by (Hesse et al. 1999a), the gait of the hemiparetic patients was analyzed on a floor and on a treadmill under full weight-bearing conditions and with BWS of 15 % and 30 %. These amounts of body weight relief were chosen based on clinical experience and a preliminary study that found a BWS of more than 30 % was not advisable because of a significant reduction of the performance of the relevant weight-bearing muscles in the affected lower limb of hemiparetic subjects (Hesse 1997). Single-stance duration of the affected leg increased, the relative double-support time decreased, and the swing symmetry improved with increasing BWS (15 % and 30 %). Simultaneously, vertical ground-reaction forces and the functional activity of antigravity muscles decreased. The analysis of EMG showed less plantar flexor spasticity on the treadmill with 15 % BWS, in 13 of 18 subjects. In the study of Danielsson and Sunnerhagen (2000), 9 hemiparetic and 9 healthy subjects walked on a treadmill with 0 % and 30 % BWS at their self-selected and maximum walking speeds. At the self-selected speed as well as at the maximum walking speed, the mean oxygen uptake was significantly lower with 30 % BWS. The patient group walking at their self-selected speed, the mean oxygen uptake was 10.8 ml $\cdot$ $kg^{-1} \cdot min^{-1}$ with 0 % BWS and 9.4 ml $\cdot$ $kg^{-1} \cdot min^{-1}$ with 30 % BWS. At the maximum speed, their corresponding values were 11.2 ml $\cdot$ $kg^{-1} \cdot min^{-1}$ and 9.9 ml $\cdot$ $kg^{-1} \cdot min^{-1}$. The heart rate was also lower with 0 % BWS in both groups. The respiratory ratio was unchanged throughout the four measurements.

Hesse and his coworkers devised a mechanical gait trainer (fig 3), enabling patients to perform repetitive practice of gait-like movement without overstraining the therapists (Hesse et al. 1999a; Hesse et al. 1999b; Hesse et al. 2000). In the device, the patients are supported by a harness and stand with their feet on the motor-driven footplates. Patients can practice gait-like movements on the gait trainer, and this is intended to achieve better symmetry of posture, larger hip extension during stance, less knee flexion and less ankle plantar

Figure 3. The patient practises walking on the gait trainer.

flexion during swing when compared with the treadmill walking (Hesse et al. 1999b). Only one therapist is necessary to assist the patient on the gait trainer. In a study of subacute, nonambulatory stroke survivors performing six weeks of walking exercises (Werner et al. 2002b), no differences were found between treadmill training with BWS and gait trainer exercises using such outcome measures as Functional Ambulation Category (Holden et al. 1984), gait velocity, Rivermead Motor Assessment (Collen et al. 1990) or Modified Ashworth Score (Bohannon and Smith 1987). The gait trainer was at least as effective as treadmill therapy with partial body weight support but required less input from the therapist. Dietz and his group made an adaptation to the treadmill by supplementing it with driven gait orthosis (DGO) (Colombo et al. 2000) . With this modification the patient can move his/her legs in a physiological way on the moving treadmill. The orthosis is adjustable in size to allow different patients to use it. The actuators at the knee and hip joints are controlled by a position controller. The patient's legs are guided individually according to a pre-programmed physiological gait pattern. With DGO, the legs of patients with different degrees of paresis and spasticity can be trained for more than half an hour resulting in physiological gait patterns.

2.4.3 Gait training with functional electrical stimulation

The single channel electrical stimulation to prevent foot drop in stroke patients was introduced already in 1961 (Liberson et al. 1961). The technique is now generally known as functional electrical stimulation (FES), because stimulation replaces or assists a functional movement that is lost after injury or diseases of the central nervous system. Different peroneal stimulators in stroke patients have been studied in several studies (Granat et al. 1996, Burridge et al. 1997, Taylor et al. 1999). The interventions have mostly been carried using surface electrodes, with the cathode on the skin close to the nerve as it passes around the head of the fibula and the anode on the motor point of the tibialis anterior or in the popliteal fossa (fig 4). The FES stimulation is a symmetrical biphasic output waveform. It is normally delivered with using 0.3 ms pulse duration, frequencies of 25 up to 50 Hz and amplitude of 20 mA up to 60 mA. Most commonly, the patients use stimulation without the therapist, however only after receiving training of its use from the therapist.

Figure 4. Patient receives functional electrical stimulation to prevent foot drop during walking exercise

Vodovnik et al. (1965) devised a six channel stimulator, which started a period of development of different multichannel stimulators. This also promoted the study of control principles, stimulation sequences, correction of gait abnormalities, and therapeutic effects of multichannel functional electrical stimulation (MFES). Bogataj et al. (1995) compared MFES to conventional therapy in 20 subacute stroke patients. They found that progress during MFES combined with traditional therapy was better than could be achieved by conventional therapy alone. The improvement was assessed by gait speed, stride length, gait cadence and Fugl-Meyer physical performance scores (Fugl-Meyer et al. 1975). The patients were randomly allocated to one of two groups. One group received first the MFES program followed by the conventional therapy program. The other group received first the conventional therapy followed by MFES (AB/BA study design). Each patient was monitored with the same methods throughout a period of 6 weeks, participating for three weeks in each therapeutic program. Each patient participated in one therapy session per day, five times a week, one to two hours per day. The conventional therapy consisted of passive and active approaches. The reflex activity was reduced, the range of motion in the joints was increased or preserved and sensory input was enhanced with the passive approach. The active methods included Bobath technique, proprioceptive neuromuscular facilitation to normalize posture and facilitating activities to achieve a good functional movement. Gait training was performed by using AFO or KAFO. During the MFES therapy period, the conventional gait therapy was replaced by MFES-assisted gait training. Each MFES therapy session lasted from 30 minutes to one hour with MFES being delivered with surface electrodes on the peroneal nerve for ankle dorsiflexion, the soleus muscle for ankle plantar flexion, the hamstring muscles for knee flexion, the quadriceps femoris musculature for knee extension, the gluteus maximus muscle for hip extension and stabilization of the pelvis during stance, and optionally the triceps brachii muscle for reciprocal arm swing during the swing phase of gait for the ipsilateral leg. The stimulation was electrically synchronized to the gait pattern. It was delivered, when the patients walked on a 100-m walkway. The review by Daly et al. (1996), stated that the stimulation was useful, but the more muscles which were stimulated, the better improvements in gait to be expected. They also stated that intramuscular electrodes were more efficient than surface electrodes. The additional benefit of intramuscular electrodes has also been described in a single case study of two chronic stroke patients (Daly and Ruff 2000).

MFES has also been combined with BWS treadmill training resulting in an improvement in the walking ability of non-ambulatory chronic (3 months – 1 year) stroke patients (Hesse et al. 1995b). The study was carried out in an A-B-A single case study design with seven patients. The first three week phase (A-phase) consisted of 30 min BWS treadmill training with MFES each workday. The subsequent three weeks (B-phase) consisted of 45 min comprehensive neurodevelopmental physiotherapy sessions daily. Finally, there was another A-phase. MFES was delivered almost identically as in the study of Bogataj et al. (1995). The walking ability (FAC) and gait velocity improved only during the A-phases. The Rivermead scores for leg and trunk and gross functions improved steadily throughout the study.

The number of the patients in different studies of gait training has varied (table 1). In six studies there was an intervention and a control group with comparable interventions. Four of these were randomized controlled studies (RCT) (Visintin et al. 1998, Kosak and Reding 2000, Nilsson et al. 2001, Schauer and Mauritz 2003). In these RCT studies the group sizes varied from 11 to 43. However, the patients in these four studies were 8 – 148 d post-stroke, i.e. they were patients in the subacute state. The line between subacute and chronic stroke is difficult to draw. The Copenhagen Study indicated that recovery of walking function occurs in 95% of the patients within the first 11 weeks after stroke. This rapid recovery period may be the subacute state. There are also studies in which patients over six months post-stroke have improved their walking speed and walking capacity (Silver et al. 2000, Ada et al. 2003). However, these studies lacked either the control group or there was no comparable method used in a control group. It would be useful to have information of the degree of brain plasticity in different phases of stroke recovery to determine exactly when the spontaneous recovery is over.

Table 1. Gait rehabilitation related studies referred to in the text.

	n (inter./contr.)	post-stroke mean or range	reported effects	comments
Hesse et al. 1994	148	39 – 962 d	+	no controls
Schauer & Mauritz 2003	23 (11/12)	44 d	++	comparable interventions
Ada et al. 2003	27 (13/14)	7 – 60 mo	++	different aims for interventions
Silver et al. 2000	5	9 – 70 mo	++	no controls
Hesse et al. 1995a	7	3 – 12 mo	+	no controls, ABA design
Visintin et al. 1998	79 (43/36)	27 – 148 d	++	comparable interventions
Hesse et al. 1999a	18	3 – 11 mo	-	no intervention
Kosak & Reding 2000	56 (34/22)	40 d	-	comparable interventions
Nilsson et al. 2001	60 (28/32)	8 – 56 d	-	comparable interventions
Werner et al. 2002a	28 (14/14)	2 – 8 mo	+	different durations in groups
Trueblood 2001	10	2 – 42 mo	-	no intervention
Trueblood 2001	13 (5/8)	4 – 36 mo	+	comparable interventions
Trueblood 2001	13 (8/5)	4 – 20 mo	+	comparable interventions
Werner et al. 2002b	30 (15/15)	1 – 3 mo	-	comparable interventions
Granat et al. 1996	18	3 – 36 mo	+	no controls
Burridge et al. 1997	32 (16/16)	43 mo/59 mo	+	different durations in groups
Taylor et al. 1999	101	5½ y	++	no controls
Bogataj et al. 1995†	20 (10/10)	49 d	++	different aims for interventions
Hesse 1995b	7	3 – 12 mo	+	no controls, ABA design

d = days, mo = months, y = years, reported effects by researchers: - = no effect, + = mild effect, ++ = clear effect,
comparable interventions = same time and amount of walking exercise in different methods,
different aims for interventions = method used in control group did not improve walking or in AB/BA study design† the other method did not concentrate on walking

2.4.4 Other exercises supporting gait re-education

Postural balance is closely related to gait ability (Nichols 1997, Shimada et al. 2003). In a study of balance rehabilitation program with visual cue deprivation, outcome measures consisted gait velocity, timed stair climbing, and self-assessment of ease of gait in addition to balance under six sensory conditions (Bonan et al. 2004). Twenty patients (over one year post-stroke) were assigned either to group with or without visual cue deprivation. Each session lasted for 60 min five days a week for four weeks. Both groups improved, but balance improved more in the vision-deprived group than in the free-vision group. The improvements in gait measures correlated significantly with improved balance. Particularly in gait interventions, special balance exercises are usually included in other physiotherapy in addition to the walking exercises (Kosak and Reding 2000). However, walking exercises are at the same time balance exercises. In the study of Jaffe et al. (2004), 20 patients (1.3 – 8.7 years post-stroke) participated in training of stepping over obstacles while walking. Ten identical stationary obstacles of a selected height and length were used. Ten patients in the real object training method wore a gait-belt and stepped over foam obstacles in a hallway. In the virtual object training method, ten patients walked on a treadmill at a self-selected walking speed with harness without BWS. While walking on the treadmill, the patients stepped over the virtual obstacle with each foot for a total of 10 steps. The lateral view of the legs provided a visual cue, collision with the obstacle produced vibro-tactile and auditory feedback for stepping. Twelve trials over these ten obstacles in both groups constituted one session and six sessions of approximately one hour duration over two weeks were provided.

The effects of muscle strengthening and physical conditioning training has been studied in chronic stroke patients (Teixeira-Salmela et al. 1999, Teixeira-Salmela et al. 2001). Thirteen patients participated (1 – 34 years post-stroke) in a ten week training program. Each 60 – 90 min training session included 1) a warm-up consisting of calisthenics, mild stretching, and range of motion exercises, 2) aerobic exercises, consisting of graded walking plus stepping or cycling, 3) strength training, and 4) a cool-down period, consisting of muscular relaxation and stretching exercises. Patients demonstrated increases in strength of the affected muscle groups, in their general level of physical activity (Human Activity Profile, Fix and Daughton 1988), in quality of life (the Nottingham Health Profile, Ebrahim et al. 1986), and in gait speed and rate of stair climbing even though there were no measurable changes of spasticity in either quadriceps or ankle plantarflexors (Teixeira-Salmela et al. 1999). In association with the improved speed, increases in cadence and stride length were observed, while stance time, double support time and symmetry ratio remained unchanged (Teixeira-Salmela et al. 2001).

In the study of Moreland et al. (2003), 130 patients (on the average 37.5 weeks post-stroke) underwent 9 lower-extremity exercises three times per week for varying lengths of stay (mean 6.8 weeks). The thirty min exercise sessions were designed to be performed in functional patterns of movements, with the exception of the ankle exercises. The first four exercises were performed in the standing position, the fifth was from sit to stand, and the last four were ankle movements with an ankle exerciser while sitting. Patients received also conventional physical therapy; techniques to facilitate and inhibit abnormal movements, balance retraining, motor control exercises, stroke mat classes, gait training, and gross motor skills training. In contrast to Teixeira-Salmela et al. these workers detected no improvement in gross motor function (Chedoke-McMaster Stroke Assessment including two meters walking test, Gowland et al. 1993), whether the patient performed progressive resistance exercise with conventional physiotherapy or the same exercises without added resistance and with conventional physiotherapy (Moreland et al. 2003).

Also home-based exercise for stroke patients is claimed to be feasible (Duncan et al. 1998). Twenty patients (on average 61 days post-stroke) were randomized into two groups. In the intervention group, the exercise program was designed to improve strength, balance, and endurance and to encourage greater use of the affected extremity. The program included 23 visits by a physiotherapist for 90 min in duration for 8 weeks. Patients were instructed to continue the exercise intervention at home for an additional four weeks (35 session in total). The control group received usual care as prescribed by the patients' physicians varying in intensity, frequency, and duration. Six patients received home health visits, and 4 received outpatient therapy. Most often the therapy consisted of balance training and bimanual activities followed by progressive resistive exercises and facilitative exercises. None of the patients in the control group received endurance training. There was an average of 39 visits with the average duration of each visit being 44 min. At the 12-week follow-up, the experimental group demonstrated a greater improvement in lower extremity Fugl-Meyer scores than the usual care group. There were also significant differences in changes in gait speed between the groups. In the control group, the gait velocity was 0.57 ms^{-1} at the baseline and 0.65 ms^{-1} at the end of 12 weeks. In the experimental group, the speed were 0.42 ms^{-1} and 0.67 ms^{-1}. There were no statistical differences in changes in upper extremity Fugl-Meyer scores (Fugl-Meyer et al. 1975), the 6-minute Walk (Guyatt et al. 1984), the Jebsen Test of Hand Function (Jebsen et al. 1969), Bartherl Index (Mahoney and Barthel 1965), and Lawton Instrumental ALD Scale (Lawton 1988).

In the future it may become possible to combine gait training with pharmacotherapy. This technique has also been developed from animal studies and the first human studies were performed in SCI patients (Rossignol 2000). Amphetamine, a drug which releases noradrenaline from the presynaptic terminals, has been studied both in animals and in stroke patients. By releasing noradrenaline in the brain and spinal cord, amphetamine has been shown to promote recovery of function in animal models of brain injury. In spinalized cats, it was demonstrated that the combination of noradrenergic drugs with intensive locomotor training was efficacious in accelerating locomotor recovery. Francisco and Boake (2003) have reported positive results with intrathecal baclofen administration combined with physiotherapy in 10 chronic ambulatory spastic stroke patients (9 – 55 months post-stroke). The mean time interval from pump implantation to follow-up was 8.9 months. The walking speed increased from 0.37 ms^{-1} to 0.52 ms^{-1}, lower-extremity spasticity score from 2.1 to 0.4 and the functional mobility score from 18 to 21 (five items of the FIM). Since all participants received physiotherapy, the improvements in the outcome measures could have been due to either the intrathecal baclofen pump or the combination of intrathecal baclofen and physiotherapy.

3 AIMS OF THE STUDY

The main purpose of this study was to assess the content and effects of gait rehabilitation in patients with chronic stroke. This was done by detailed investigation of specific areas affecting the total gait rehabilitation outcome.

The specific questions of the present study were:

1) What is the amount and content of the performed exercise of a carefully tailored three weeks gait-oriented physiotherapy program for chronic stroke patients in an in-patient rehabilitation setting? (I)

2) What kind of postural balance and balance deficits do ambulatory patients with chronic stroke have and are there differences between the left and right hemiparesis? (II, IV)

3) What kind of gait characteristics do patients with chronic hemiparesis have and what are the effects of the gait-oriented rehabilitation (either body-weight supported training or physiotherapy not emphasizing any special therapy)? (III)

4) Are there differences in the effects of two gait rehabilitation exercise strategies, one with body-weight supported electromechanical gait trainer exercise and the other with active walking exercise, in patients over six months post-stroke? (IV)

4 SUBJECTS AND METHODS

4.1 SUBJECTS

The study population consisted of a total of 89 subjects: 59 chronic stroke patients and 30 healthy subjects (table 2). The study was approved by the Hospital District of Northern Savo Research Ethics Committee, and written informed consent for participation in the study was obtained from all subjects. Patients in the different studies were from the same group of 59 patients (Fig 5). All patients were initially diagnosed with MRI or CT. The patients fulfilling the inclusion criteria were selected from the patient material of the Brain Research and Rehabilitation Center Neuron between years 2001 – 2003. The randomized 45 patients were selected between 2002 – 2003 and control stroke group in study **III** was selected retrospectively from the year 2001.

Table 2. Characteristics of study population (mean ± SD).*

Study		n	age (years)	post-stroke (years)	gender (m/f)
I	patients	20	53.3 ± 9	2.6 ± 2.5	17/3
II	patients	30	52.9 ± 9	2.6 ± 2.5	24/6
	healthy subjects	30	49.9 ± 5		10/20
III	patients	37	53.8 ± 8	2.6 ± 2.3	33/6
IV	patients	45	54.3 ± 8	2.9 ± 3.8	37/8

* Patients in different studies were from the same group of 59 patients

4.1.1 Patients

For study **I,** twenty chronically hemiparetic patients during their in-patient rehabilitation period participated in the study. Patients with first supratentorial, ischemic or hemorrhagic infarction at least 6 months earlier were selected to the study, if they had 1) slow or difficult walking, 2) no unstable cardiovascular disease, 3) no severe malposition of joints, and 4) no severe cognitive or communicative disorders. Ten patients had left-sided and ten right-sided hemiparesis. The cause was a supratentorial infarction in 11 cases and an intracerebral hemorrhage in 9 cases. The patients' gait abilities varied at the onset of the three-week inpatient period. The Functional Ambulation Category (FAC) was assessed to record the level of walking ability (0 – 5) (Holden et al. 1984). None of these patients belonged to FAC

1 (needs two assistants to walk) or FAC 2 (needs someone for support to maintain balance while walking). Three of the patients needed to have someone walking beside them to give them confidence (FAC 3), 11 could move independently but needed help with stairs or on uneven ground (FAC 4), and five were fully independent in walking (FAC 5).

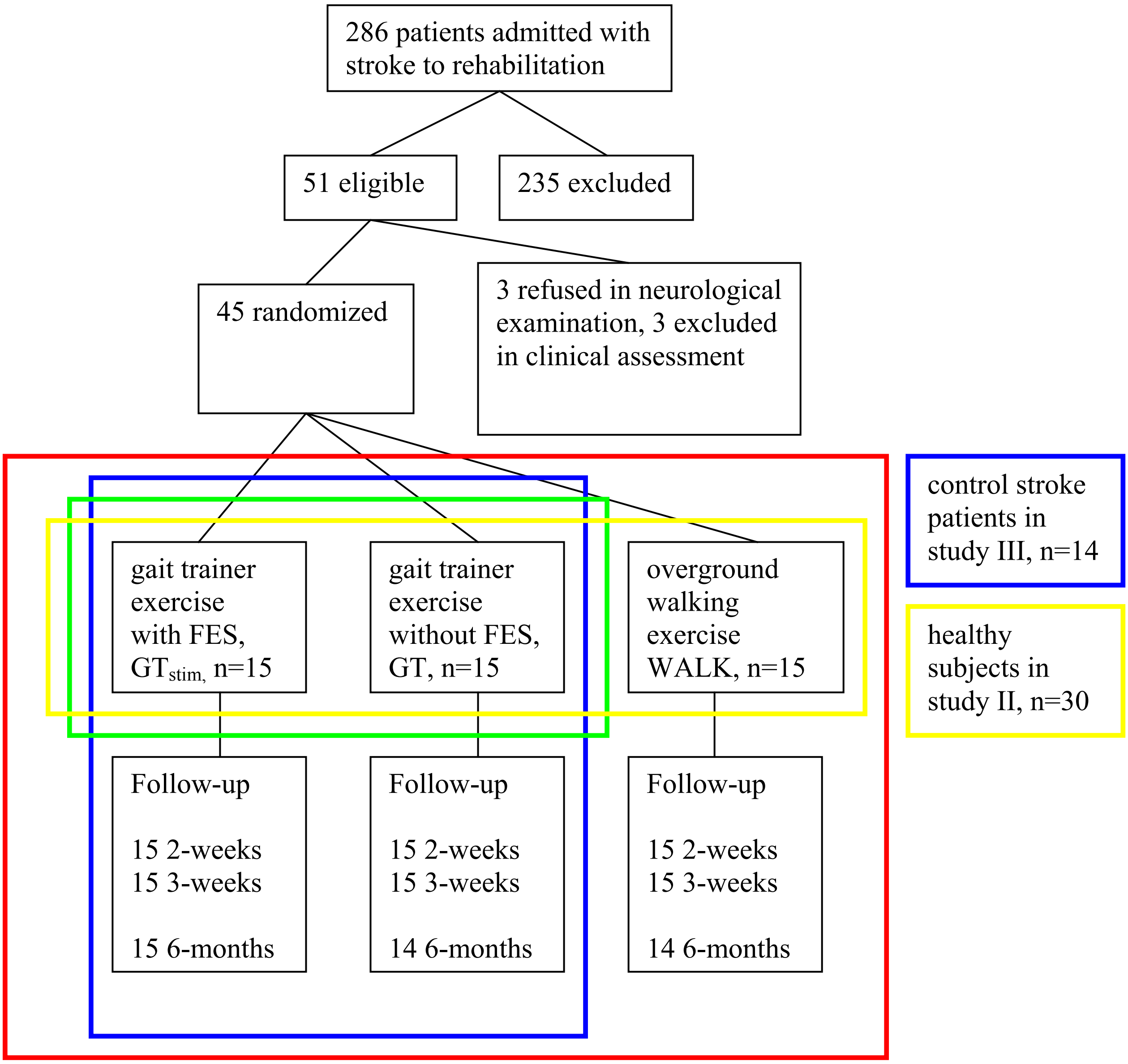


Figure 5. Subjects in the different studies. In study I, the first 20 chronic stroke patients randomized to gait trainer groups were selected to further analysis (green). In study II, the first 30 patients regardless of the group were selected (yellow). In addition there were 30 healthy subjects in study II. In study III, the first 23 patients randomized to gait trainer groups were selected (blue). In addition there was a control group of 14 chronic stroke patients in study III. In study IV there were 45 randomized patients (red).

For study **II**, the group of patient consisted of 30 patients with chronic stroke fulfilling the same inclusion criteria as in study I. Fifteen patients had left-sided and 15 right-sided hemiparesis. All patients had clinically assessed asymmetrical hemiplegic gait pattern and most used a walking stick and/or an orthosis for everyday ambulation. One patient needed someone to support him to maintain balance while walking (FAC=2). Five of the patients needed to have someone walking beside them to give them confidence (FAC=3), 13 could move independently but needed help with stairs or on uneven ground (FAC=4), and eleven were fully independent in walking (FAC=5).

For study **III**, 37 chronic stroke patients fulfilling the same inclusion criteria as in study I participated in an in-patient rehabilitation period. Twenty patients had left-sided and seventeen had right-sided hemiparesis. The cause was an ischemic infarction in 21 cases and an intracerebral hemorrhage in 16 cases. The group of 23 patients fulfilling the inclusion criteria after the purchase of the gait trainer were selected to the intervention group. The control group consisted of 14 patients fulfilling the inclusion criteria, who did not receive body-weight supported (BWS) walking training. With the exception of the time since onset of stroke (p=0.007) the patient characteristics were similar in the intervention and control groups (table 3).

Table 3. Characteristics of patients (mean ± SD) of gait–oriented rehabilitation group (GT) and conventional rehabilitation group (control) in study III.

	GT n=23	control n=14	p-value^
age (years)	52.5 ± 8.6	56.0 ± 6.3	0.194
post-stroke (years)	1.7 ± 1.2	4.1 ± 2.8	0.007**
weight (kg)	84.4 ± 12.2	78.4 ± 15.0	0.194
height (cm)	173.3 ± 7.6	171.4 ± 9.8	0.512
men/women	20/3	11/3	0.699
infarction/hemorrhage	15/8	6/8	0.653
left/right hemiparesis	13/10	7/7	0.183
FIM (points)	106.1 ± 9.4	109.6 ± 7.8	0.249
$MMAS_{1-5}$ (points)	19.2 ± 4.0	22.1 ± 4.6	0.054
10 meters' walking test (s)	25.3 ± 12.2	23.8 ± 12.5	0.726

^ = t-test, Pearson χ^2 or Fisher's exact test,
** = p<0.01
FIM = Functional Independence Measurement
$MMAS_{1-5}$ = First five items of Modified Motor Assessment Scale

For study **IV**, a total of 51 chronic stroke patients fulfilled the same inclusion criteria as in study I were entitled to an inpatient rehabilitation period. Three patients of the 51 patients refused to participate in the study, one was a too good walker in clinical assessment at the start and one considered that the protocol was too intense in clinical assessment. One patient interrupted the study for medical reasons. Thus, study **IV** consisted of 45 patients. The block randomization was used in the following way: patients, who filled the criteria in the neurological examination in the beginning of the rehabilitation period and gave their consent, were randomly allocated to three different walking exercise groups. The envelopes indicating the groups were sealed separately for patients with FAC 2 and 3 and with FAC 4 and 5. The clinician announced the FAC to the secretary, who made the allocation. Later it was observed, that patients with FAC 2 and 3 were rare and thus more FAC 4 and 5 envelopes were written. This explains why the number of patients with FAC 2 and 3 differed from that of FAC 4 and 5 (table 4). All patients had clinically assessed asymmetrical hemiplegic gait pattern and most used a walking stick and/or an orthosis for everyday ambulation. Four patients needed someone to support them to maintain balance (FAC=2), six of the patients needed to have someone walking beside them to give them confidence (FAC=3), 18 could move independently but needed help with stairs or on uneven ground (FAC=4), and seventeen were independent in walking (FAC=5). Although some of the patients were fairly independent in walking, their walking speed was extremely slow.

The presence of neglect was based on basic neuropsychological testing. Several tests, i.e. Behavioural Inattention Test (Wilson et al. 1987), visual memory testing and double simultaneous stimulation testing were used. The presence of aphasia was based on qualified assessment by a speech therapist, and Diagnostic Aphasia Examination was used (Goodglass and Kaplan 1983). All but two patients were fully right-handed before the stroke. One patient could use both hands and one patient was left-handed. After stroke, the left-handed patient with left hemiparesis learned to use his right hand. The patients with right hemiparesis learned to use their left hand to various degrees. Characteristics of the patients corresponded in all three groups (table 4).

Table 4. Characteristics of patients (mean ± SD) of the gait trainer groups (GT_{stim} and GT) and walking exercise group (WALK) in study IV.

	GT_{stim} n=15	GT n=15	WALK n=15	p value#	df	F/χ^2
age (years)	53.3±8.9	51.2±7.9	52.3± 6.8	0.770	2,42	0.26
post-stroke (years)	2.6±2.4	2.4±2.6	4.0±5.8	0.505	2,42	0.69
weight (kg)	79.8±12.9	89.9±13.5	79.4±14.9	0.072	2,42	2.81
height (cm)	171.5±7.2	175.6±7.0	172.5±6.9	0.263	2,42	1.38
heart rate at rest	72.4±12.6	68.8±9.7	63.5±10.5	0.097	2,42	2.47
SSS (points)	43.8±6.9	44.0±7.3	40.1±6.2	0.230	2,42	1.52
10 meters'walking time (s)	44.0±36.2	39.6±35.4	39.5±25	0.911	2,42	0.09
men/women	13/2	13/2	11/4	0.544	2	1.22
infarction/hemorrhage	10/5	7/8	8/7	0.533	2	1.26
left/right hemiparesis	9/6	8/7	5/10	0.315	2	2.31
aphasia no/yes	10/5	11/4	7/8	0.293	2	2.46
neglect no/yes	14/1	12/3	14/1	0.407	2	1.80
position sense norm/abnorm	10/5	10/5	8/7	0.685	2	0.76
patients in FAC 2 (n)	1	2	1	0.987^	6	0.95
patients in FAC 3 (n)	2	2	2			
patients in FAC 4 (n)	7	5	6			
patients in FAC 5 (n)	5	6	6			

SSS=Scandinavian Stroke Scale.
FAC=Functional Ambulatory Category 0–5: 2= need someone for support, 3= need to have someone walking beside them to give them confidence, 4= could move independently but need help with stairs or on uneven ground and 5=fully independent in walking.
# = p values obtained using one-way ANOVA or Pearson's chi-square.
^ = FAC and group table

4.1.2 Healthy volunteers

The healthy control group in study **II** consisted of 30 age-matched normal volunteers drawn from the personnel of the hospital and local inhabitants. Inclusion criteria for normal subjects were fit for work without illnesses affecting postural stability. Subjects were free from neurological diseases and used no medication influencing the central nervous system.

4.2 ASSESSMENT METHODS

4.2.1 Clinical assessment

The neurological examination was made at the beginning of the rehabilitation period. Medical records were used to find out basic information of the patients, for example the time since the onset of stroke. A neurologist also tested the patient filling the Scandinavian Stroke Scale

(SSS) (De Haan et al. 1993). SSS assesses the patient's functional status. It includes items on consciousness, orientation, eye movements, facial palsy, motor function of arm, hand and leg, gait and speech. Each item is scored (0–12) with a maximum of 58. In the validation of four scales for stroke patients (Roden-Jullig et al. 1994), fifty patients were examined by a physician over a period of five days from admission to the hospital with SSS (De Haan et al. 1993), Mathew (Mathew et al. 1972), Toronto (Cote et al. 1988) and Fugl-Meyer stroke scales (Fugl-Meyer et al. 1975) and the Barthel Index (Mahoney and Barthel 1965). The last ten patients were also investigated by another doctor in the same manner and by nurses with the SSS only. All scales correlated highly significantly. The interobserver agreement was excellent between the physicians but not as good between the physician and the nurses. Also in another study, acute stroke admissions to a hospital 50 stroke patients were examined (Barber et al. 2004) and thus had their SSS scores assessed by an experienced physician within four hours of the examination performed by the medical admission team. Two examiners, blinded to the patients' clinical condition, later independently estimated retrospective SSS scores using information documented in the medical admissions notes. Weighted kappa statistics for agreement between domains of the face-to-face and retrospective SSS were 0.73 for consciousness, 0.60 for eye movements, 0.83 for arm motor power, 0.71 for hand motor power, 0.81 for leg motor power, 0.81 for orientation, 0.80 for speech, and 0.53 for facial palsy. The intraclass correlation coefficient (ICC) for face-to-face and retrospective SSS composite scores was 0.97, $p<0.0001$. Inter-rater reliability for the different components of the retrospective SSS was excellent (kappa values greater than 0.75) apart from consciousness (0.71) and eye movements (0.58).

All other measures were performed at the start (**I, II, III, IV**), after two weeks (**III, IV**) and at the end of the three weeks (**I, III, IV**) of rehabilitation. Excluding the Functional Independence Measure (FIM) (Keith et al. 1987), all measurements were performed also at the six months follow-up (**III, IV**). FIM was performed by a nurse and the other tests by a researcher.

The FIM has been developed as a standard measure of disability for use in rehabilitation centers (Wade 1992). The FIM includes 18 items in the area of personal care, sphincter control, mobility, locomotion, communication and social cognition (**I – IV**). Each item is scored from 1 (total assistance required) to 7 (complete independence). Thus the FIM scale can range from 18 to 126. Based on a meta-analysis of 11 studies including 1568 patients

(Ottenbacher et al. 1996), FIM demonstrated acceptable reliability across a wide variety of settings, raters, and patients. The results revealed a median inter-rater reliability for the total FIM of 0.95 and median test-retest and equivalence reliability values of 0.95 and 0.92. The median reliability values for the six FIM subscales ranged from 0.95 for self-care to 0.78 for social cognition. For the individual FIM items, median reliability values varied from 0.90 for toilet transfer to 0.61 for comprehension. Median and mean reliability coeffiecients for FIM motor items were generally higher than for items in the cognitive or communication subscales.

4.2.2 Assessments of motor abilities

The motor abilities were studied with a battery of measurements. The spasticity was measured by the Modified Ashworth Scale (Wade 1992), muscle force by the Motricity Index (Wade 1992), motor ability by the Modified Motor Assessement Scale (Carr et al. 1985), postural balance by the force plate (Pajala et al. 2004), gait by the ten meters' walking test (Wade 1992), six minutes' walking test (Guyatt et al. 1984) and with a walkway embedded with pressure sensors (Cutlip et al. 2000, Bilney et al. 2003).

Spasticity of the paretic leg was assessed (**IV**) with the Modified Ashworth Scale (MAS) (Wade 1992) including hip, knee and ankle mobility. MAS is scored from 0 (no increase in muscle tone) to 5 (affected part rigid in flexion or extension). Muscle force was tested by the Motricity Index (**IV**) including hip flexors, knee extensors and ankle dorsiflexors, but grading according to the Medical Research Council (MRC) from 0 (no movement) to 5 (full range of movement against power and the same force as on the opposite side) (Wade 1992). The reliability of the MAS and muscle power measured by MRC were studied in 35 acute stroke patients (age 73 y, time since onset of stroke 40 d, Gregson et al. 2000). Two raters assessed each subject with a 10 min rest period between the measures at about the same time on two consecutive days. Each measurement was made three times after a rest period of 30 s and the optimal score was recorded. Statistics (κ) with quadratic weights (Kw) showed moderate inter-rater agreement (Kw=0.45–0.51) and moderate to good intra-rater agreement (Kw=0.59–0.64) for the measurement of tone in the ankle plantarflexors. Good inter-rater agreement (0.73 – 0.79) and good to very good intra-rater agreement (Kw=0.77–0.94) for the measurement of tone in the knee flexors was demonstrated. The inter-rater agreement for knee flexors and extensors (Kw=0.85–0.95) as well as ankle dorsiflexors and plantarflexors

(Kw=0.84 – 0.91) were very good. Similarly, intra-rater agreement for the measurement of power was good to very good for all muscle groups (Kw=0.70–0.96).

The patient's motor ability was assessed with the Modified Motor Assessment Scale (MMAS, Carr et al. 1985) The MMAS items, scored from 0 to 6 with a maximum of 48 points, were supine to side lying, supine to sitting over the side of bed, balanced sitting, sitting to standing, walking, upper arm function, hand movements and advanced hand activities. In study **III**, the first five items of the MMAS were used ($MMAS_{1-5}$), otherwise excluding the upper extremity items. In study **IV** the whole MMAS was used. The reliability of the Motor Assessment Scale was first investigated by (Carr et al. 1985). Fifteen stroke patients were videotaped while measured by one physiotherapist. Afterwards 20 physiotherapists or undergraduate students rated them by looking at the videotape. They had all practiced the scale with at least four patients. The percentage agreement was 87 and Pearson correlation was 0.95 between the first raters's scores and 20 other raters. The first rater observed 15 stroke patients two times, with a four week interval. The test-retest Pearson correlation was 0.98. The last item, tonus, was not reported, because it could not be observed from the videotape.

In two studies (Poole and Whitney 1988, Malouin et al. 1994), Motor Assessment Scale was compared to the Fugl-Meyer test (FMA) (Fugl-Meyer et al. 1975), a reliable and valid test for motor function in stroke patients (Duncan et al. 1983). The Spearman correlation coefficient between the total score on the MAS (except tone) and the total score on the FMA was 0.88 (n=30 stroke, age 63.3, time since onset of stroke 1.0 years, Poole and Whitney 1988) and 0.96 (n=32, age 60.0y, time since onset of stroke 64.5 days, (Malouin et al. 1994). The correlation coefficients for selected items on the Motor Assessment Scale and corresponding items on the FMA were all strong and significant at least at the level 0.01 except for sitting balance in both studies. The low correlation coefficient between sitting balance items was explained by differences in the nature of the items (Poole and Whitney 1988) or poor validity of the FMA balanced sitting item (Malouin et al. 1994).

The interrater reliability coefficient (Spearman) for the total score on the Motor Assessment Scale between two raters was 0.99 ($p<0.001$, Poole and Whitney 1988). The reliability coefficients for each item on the Motor Assessment Scale were high and statistically significant at the level 0.001 except for general tone (r=0.29). Thus low correlation of general tone lead to its omission and the current version is now called the Modified Motor

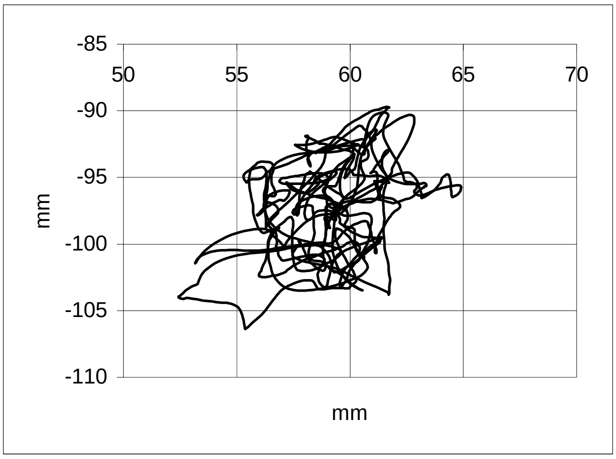
Assessment Scale. Seven stroke patients (age 73.6 years) were individually videotaped while the trained physiotherapist assessed their performance on the MMAS. The Kappa coefficient between 14 therapists rating the MMAS from the videotape ranged from 0.73 to 0.96 (Loewen and Anderson 1988). The range of Spearman rank-order correlation coefficients for the total MMAS were 0.83 to 1.00 with a median of 0.97. The mean Kappa values for the interrater reliability tests per individual item ranged from 0.56 (balanced sitting) to 1.00 (hand movements and advanced hand activities). Physiotherapists were trained to use the MMAS beforehand and they were given one month to practice the MMAS with patients. The therapists spent an average of four hours learning the MMAS and practised assessing the performance of an average of two patients with stroke. One month later, the video taped assessments were again shown to the therapist. The intrarater reliability tests for the MMAS, 85 % of the Kappa values were in the excellent agreement range (≥0.75). The range of Spearman rank-order correlation coefficients were 0.81 to 1.00 with a median of 0.98. Only 4 % of the Kendall’s Tau values for the intrarater reliability tests for individual item were non-significant.

4.2.2.1 Postural stability

The neurological examination included the clinical assessment of sitting and standing balance. Postural recordings were made using a force plate system (Good Balance®, Metitur Oy, Jyväskylä, Finland) with strain-gauge transducers connected to a three-channel direct-current amplifier and 12-byte analog-to-digital converter connected to a computer (Pajala et al. 2004). After all measurement points were read, X-Y, i.e. anterior-posterior (AP) - medial-lateral (ML) coordinates were calculated on the basis of these vertical force signals by using the system’s own software. COP is the point location of the vertical ground reaction force vector (Winter 1995). The sampling rate for the force plate data was 50 Hz.

The reliability of assessments of postural balance on the force plate has been described in several studies. However, only a few have analysed the COP variables of stroke patients (Rogind et al. 2005) and even fewer the reliability of the measurements (Dickstein and Dvir 1993). The intrasession reliability of several COP variables was estimated by using the ICC based on an ANOVA model during quiet standing in healthy elderly individuals (mean age 60 y, Lafond et al. 2004). They found that COP mean velocity was the most reliable COP variable. Averaging two trials of 120 s allowed an ICC of 0.90, whereas averaging of four trials allowed an ICC over 0.95 in both the AP and ML directions. In general, the reliability increased with the duration of the trial from 30 s to 120 s. In the study of healthy subjects of mean age 55.4 Du Pasquier et al. 2003) test-retest three months apart yielded reliability coefficients of about 80 % for the speed of COP displacements. The duration of the quiet standing was 30 s. Le Clair and Riach (1996) found that optimum test-retest reliability was obtained at 20- and 30 s trial durations. According to ICC, the dynamic stability tests, i.e. a healthy male standing on the force plate and moving his COP through the targets shown on a computer screen, showed moderate trial-to-trial reproducibility and test-retest stability over time (Punakallio 2004). The test-retest stability improved when the reliability was estimated from the best of at least five trials with the dynamic balance test.

In study **II** and **IV**, all subjects were allowed to choose a comfortable standing position on the force plate with feet slightly apart and were asked to stand quietly, keeping their feet still and facing a mark on the wall at a distance of about two meters. Patients with orthoses were recorded with shoes on (n=19). Only three of the eleven patients standing without any orthoses were recorded barefoot. All others felt too unstable to stand on the force plate without shoes. The patients kept their hands together in front of the trunk, the healthy hand holding the paretic wrist. The healthy subjects could choose which wrist was held by the other hand. First, after ten seconds, the body weight distribution was recorded. Then the static postural sway was recorded for 40 seconds in two consecutive trials (see movement of COP in one trial in fig 6). Absolute sway measures were corrected for the subject's height. In study **II**, the first trial was used and 20 seconds (10 – 30s) in the middle of that data was further analyzed. In study **II**, the analysis was concentrated on anterior-posterior (AP) and medial-lateral (ML) frequencies of center of pressure movements in different frequency bands separately in patients with left and right hemiparesis. The data of the patients were also compared with a group of age-matched healthy subjects. In study **IV**, a mean of two trials was used. The dynamic test included (**IV**) three screen-controlled lateral weight transfers, which were required to be performed as fast as possible (see movement of COP in one trial in fig 7). The mean time and distance of the COP movement were recorded in five consecutive trials.



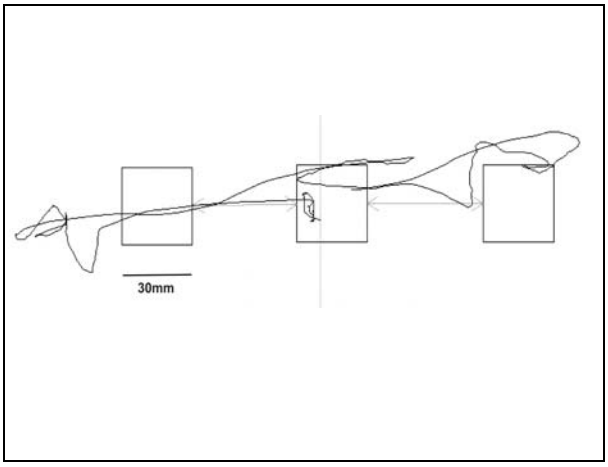


Figure 6. The movement (mm) of the center of pressure (COP) of the patient with left hemiparesis (male, 64 y, 1½ y since the onset of the stroke) during 40 seconds recording (Good Balance® force plate system).

Figure 7. The movement (mm) of the center of pressure (COP) of one patient with right hemiparesis (female, 44 y, 4½ y since the onset of the stroke, FAC 4, 10m test 24 s, 6 min test 264 m) during dynamic balance recording (Good Balance® force plate system).

In the static posture, the velocity of the COP displacements (speed) were derived for AP and ML directions. A further analysis of the frequency (**II**) characteristics was performed for 1000 samples in both X and Y directions. The power spectral density function (PSD) of AP and ML sway was calculated using Welch‘s averaged, modified periodogram method (Matlab® Comsol Ab, Stockholm, Sweden) with a Hamming window and linear detrending. This process yielded power spectral density functions and a maximum frequency of 25 Hz was considered. A frequency resolution of 0.05 Hz was used. Peak amplitudes for both AP and ML sway in nine frequency bands (from 0 to 2.7 Hz in 0.3 Hz bins) were collected. After analyzing the nine frequency bands, it was decided to combine them for further analysis to three final bands: 0.05 – 0.6 Hz, 0.6 – 1.5 Hz and 1.5 – 2.7 Hz. The final bands included over 99% of the recorded power.

4.2.2.2 Gait

The gait was assessed by the 10 meters' walking test, six minutes' walking test and with a walkway embedded with pressure sensors. In the 10 meters' walking test (Wade 1992) (**III, IV**), the patient was asked to walk as quickly as possible. Patients were asked to start walking about one meter before a start line and to walk until they crossed the line by one meter. In the six minutes' walking test (Guyatt et al. 1984) (**IV**), the patients were asked to walk as quickly as possible, but pacing themselves so that they could complete the task. The six minutes' test was performed by walking along the marked distance (one lap 54 m). A digital stopwatch was used to record time in the 10 meters' walking test and in the six minutes' walking test. In all walking tests, patients were allowed to use walking aids, for example a dynamic orthosis or a cane. The same walking aids were used on every test occasion.

The test-retest reliability of three timed walks to 10 meters repeated during two assessments one week apart proved that they were reliable for chronic stroke patients (Green et al. 2002). The ICC for all three within-assessment walks was 0.97 for both the first and second occasions. The between-assessment reliability was higher for the second and third walks (ICC 0.88) than for the first walk (0.87). The six minutes' test was originally developed for cardiovascular populations. It has been found to be a reliable and valid test in healthy elderly individuals (Kervio et al. 2003) and patients with Alzheimer's disease ICCs have ranged from .80 to .99 with 77 % of the variance explained by inter-subject difference. In chronic stroke patients, the Pearson correlations between self-paced gait speed over 8 m and six minutes' walking distance was 0.92 (Eng et al. 2002).

Spatial and temporal gait measurements were done (**III**) with a walkway embedded with pressure sensors (GAITRite®, MAP/CIR, Havertown, PA, USA (Cutlip et al. 2000). The length of the electronic walkway is 4.57 m consisting an active recording area of 3.66 m x 0.61 m. A total of 13 824 sensors, each 1,25 cm in diameter, are arranged in 48 x 288 grids. The sensors transmit information about the geometry of the footprints and provide dynamic pressure mapping during walking by recording the location of activated sensors and the time of the sensor activation/deactivation.

Correlation coefficients for temporal parameters measured with a GAITRite® walkway system and a video-based system were high (≥0.94, Cutlip et al. 2000). Subjects walked across a walkway with embedded pressure sensors. Reflective markers were attached to the subjects' shoes and video capture was simultaneously performed during each trial. Video data were then digitized manually using peak software. Significant differences between systems were found with analysis of variance (ANOVA) for two parameters, step length and stride velocity (p=0.003, 0.0002).

The ICCs between GAITRite® and stride analyser were moderate to high for single limb support (SLS) time (ICC (2,1)=0.69-0.91) and weak for the proportion of the gait cycle spent in double limb support (ICC (2,1)=0.44-0.57) performed by three walk trials at self-selected pace, three at fast pace and three at slow pace (Bilney et al. 2003). The stride analyser consisted of footswitches placed inside the shoes and attached to a portable data logger. There were very high correlations between the two measurement systems for gait speed (ICC (2,1)=0.99), stride length (ICC (2,1)=0.99) and cadence (ICC (2,1)=0.99). The reliability of repeated measures with these 25 healthy adults (aged 21-71 years, mean 40.5 years, S.D. 17.2) for the GAITRite® was good at preferred and fast speed for speed (ICC (3,1)=0.93-0.94), cadence (ICC (3,1)=0.92-0.94), stride length (ICC (3,1)=0.97), single support time (ICC (3,1)=0.85-0.93) and the proportion of the gait cycle spent in double limb support (ICC (3,1)=0.89-0.92). The repeatability of the GAITRite® measures were more variable at slow speed (ICC (3,1)=0.76-0.91).

Also Menz et al. (2004) obtained excellent ICCs for walking speed, cadence and step length (ICCs 0.82 – 0.92, coefficients of variations (CVs) between 1.4 and 3.5 %) in a group of 30 young adults (mean 28.5 y) and in a group of 31 older adults (mean 80.8 y). They walked at a self-selected comfortable walking speed across the walkway three times and repeated the process approximately two weeks later. Only base of support and toe in/out angles, although exhibiting high ICCs, were associated with higher CVs and it was concluded that these should be viewed with some caution, particularly in older people.

The following parameters were analyzed: velocity (cm/s), cadence (step/min), step time (s), step length (cm), stride length (cm), swing time of cycle, swing % of cycle, stance time of cycle, stance % of cycle, double-support % of cycle, double-support time (s), step-time differential, step-length differential and the Functional Ambulation Profile (FAP score, Nelson 1974). The calculations of the parameters were performed based on the geometric analysis of the footprints and are presented in more detail in the study of Titianova et al. (2003). The FAP scores are calculated automatically by the system, which uses different variables for this calculation (degree of asymmetry, base of support, the use of assisting devices, etc.). The final FAP score is derived by subtracting points from a maximum score of 100. The FAP scores from 98 to 100 are obtained at an ordinary walking speed when step extremity ratios and step times are symmetrical and a dynamic base of support is less than 10 cm. The concurrent validity and test-retest reliability of the GAITRite® walkway system has been shown to be excellent (Bilney et al. 2003). It is clear that this type of recording provides a considerable amount of data, but we concentrated on those variables which we considered to be most informative. All patients were asked to walk twice along the walkway as fast as possible. Both passes were used in the calculation. If the patient needed walking aids, the same walking aids were used on every test occasion. Asymmetry index (AI) of swing and stance times was calculated according to the study of Titianova et al. (2003). AI is a reflection of the asymmetry of walking. The sign of AI indicates the direction, positive values toward the affected side (AS) and negative toward the non-affected side (NAS). The magnitude of AI reflects the degree of asymmetry.

4.2.3 Perceived exertion and heart rate

Perceived exertion was recorded with the Borg Rating of Perceived Exertion Scale (Borg 1982). This scale uses numbers indicating exertion, for example 6=minimum, 7=extremely light, 13=slightly strenuous, 19=extremely strenuous, 20 maximum. The patients were asked how hard they perceived their working every time in the last minute of 20 minutes walking exercise (**I, III, IV**) and in the last minute of the other two physiotherapy sessions (**I**). Heart rate (HR) was recorded with a heart rate monitor with a chest transmitter (Polar®, Polar-electro Oy, Kempele, Finland). Heart rate (**III, IV**) was monitored continuously during the 20 minutes' walking exercise. The value of the last minute of the exercise was recorded.

Patients with cardiovascular disease have been shown to be able to estimate their own exercise intensity by Borg Scale in line with their heart rate (Ilarraza et al. 2004).

4.2.4 Assessment of therapy

The amount of therapy and its content were recorded in structured forms. The physiotherapists, nurses and the patients were familiarized with the detailed forms before the therapies began. The content of physiotherapy was recorded daily by the physiotherapist (**I**) detailing the gait on the floor, on the ground and on the stairs and other forms of physiotherapy methods. The chosen therapeutic alternative and duration of the therapy given were recorded.

The treatment protocol involving the gait trainer exercise (**I – IV**) recorded speed, duration of therapy, number of steps and amount of body weight support. In the WALK group (**IV**), the duration of therapy and distance were recorded. In addition, individual self-initiated training and participation in the groups were recorded daily on another form by the patient or by his/her nurse (**I**).

4.3 INTERVENTIONS

In study **I,** the reasons why the patients participated in the three-week inpatient period was to enhance their gait abilities and to improve their independence at home. Each patient received 75 min physiotherapy including two physiotherapy sessions daily every workday for three weeks. In the first session, patients practised for 20 minutes in the electromechanical gait trainer (Gait Trainer®, Reha-Stim, Berlin, Germany). In the gait trainer, the patient is supported with a harness and his/her feet are placed on motor-driven footplates. The speed of the gait trainer can be selected between 0 – 2 kmh^{-1} which determines the number of steps during each session. Several hundred meters of gait can be practised in each session. The amount of the body weight supported by the harness is chosen according to the patient's ability. The progression of the training was carried out individually by increasing speed and aimed at support less than 20 % of the body weight. Physiotherapy continued immediately for 25 minutes after walking in the gait trainer. Later during the same day, there was another physiotherapy session (30 min). The physiotherapy additional to gait trainer was carried out following individually set goals but always aimed at improving gait. The patients were also encouraged to practise by themselves with equipment available on the ward or in the fitness room. Equipment available for self-initiated training included active sitting equipment (motorised/non-motorised arm cranking and/or leg cycling restorators, rowing machine, exercise bicycle) and active standing equipment (a supported standing system that provides reciprocal movement of the arms and legs, a step ergometer). Patients could participate in different exercise groups such as a balance group, swimming pool group, a sitting exercise group and a relaxation group. Each group session lasted for 30 min. The group consisted of 3–8 participants and was supervised by a physiotherapist.

In study **III**, 37 ambulatory chronic stroke patients participated in an in-patient rehabilitation period for three weeks in order to improve coping independently in their homes. In this study, two different interventions were compared. The group of 23 ambulatory chronic stroke patients participated in an intensive gait-oriented training program. Their physiotherapy was similarly carried out as in study I. In the control group, 14 chronic stroke patients participated in the routine rehabilitation period provided in our rehabilitation hospital not emphasizing special therapy but attempting to maintain functional abilities. In the gait-oriented group, patients received a total of 75 minutes of physiotherapy per day. In the control group, patients received 45 minutes of physiotherapy daily. The patients in both groups were also encouraged to practise by themselves using various equipment available on the ward or in the fitness room and to participate in different exercise groups.

In study **IV**, participants were chronic stroke patients under 65 years of age entitled to receive an inpatient rehabilitation period provided by the National Social Insurance Institution. Each patient practised for 20 minutes walking either 1) in the electromechanical gait trainer with functional electrical stimulation (GT_{stim}, n=15), or 2) in the gait trainer without stimulation (GT, n=15) or 3) on the floor (WALK, n=15). The GT_{stim} group received functional electrical stimulation to two individually selected muscles. The stimulation was delivered (Bentrofit®, Bentronic, Munich, Germany) with surface electrodes on the gluteus maximus muscle for hip extension, the hamstring muscles for knee flexion, the quadriceps femoris musculature for knee extension, the peroneal nerve for ankle dorsiflexion on the paretic lower extremity. The frequency of the stimulation was 25 Hz with pulse width 0.3 ms. Duration of the stimulation for each muscle during the gait cycle was controlled individually. The stimulation was electrically synchronized to the gait pattern.

The progression of the training in both GT groups in study **IV** was carried out similarly as the gait trainer exercises in study **I**. The WALK group practised walking on the floor or out of doors with their individual walking aids. In the WALK group, the progression of training was carried out by increasing speed with the aim to decrease their reliance on walking aids or to permit them to walk in more difficult terrain. Physiotherapists guided verbally and/or manually the patients in all groups. Physiotherapy continued directly for 25 minutes after the walking exercises. Later during the same day, there was another physiotherapy session (30 min). The physiotherapy provided in addition to the walking exercises was carried out as in study I. Patients were allowed to perform self-initiated training and to participate in different exercise groups similarly as in study **I**.

4.4 STATISTICAL ANALYSIS

The statistical analyses were carried out with using SPSS 10.1 for Windows-program (SPSS Inc. Chicago, USA). The normal distribution of the variables was tested by the Kolmogorov – Smirnov or Shapiro – Wilk –test. If the distribution was not normal a logarithmic adjustment was performed. This adjustment was made for the result of the ten meters' walking test (**I – IV**), MMAS (**IV**) and sway parameters (**II, IV**). The age (**II, III**), time since onset of stroke (**III**), weight (**II, III**) and height (**I, III**), group means were compared using independent samples t-test. In study **IV**, age, time since onset of stroke, weight, height, heart rate, SSS, total distance of 15 gait sessions, and Borg Scale, means in GT_{stim}, GT and WALK groups were compared using one-way ANOVA with the Tukey test. The gender (**III, IV**) diagnosis (**III, IV**) and side of the hemiparesis (**III, IV**), aphasia (**IV**), neglect (**IV**), and FAC (**IV**) frequency were compared using Pearson's chi-square or Fisher's exact test (**III**). The mean values of the speed and amount of BWS in the gait trainer were compared using independent samples t-tests (**IV**). In study **II** we calculated the mean values (for left and right hemiparetic patients and also healthy subjects) of velocity moment (VM), speed of COP movement in AP and ML directions and the peak amplitudes of each frequency band of AP and ML sway. These mean values were compared using one-way ANOVA with the Tukey test. Pearson's correlation coefficients were used to test the correlation between the amount of weight on the paretic side for both AP speed and ML speed, and the correlation between the amount of weight on the paretic side and peak amplitudes for both AP and ML sway of three frequency bands. In study **III**, repeated measures ANOVA was used to evaluate the changes in $MMAS_{1-5}$, ten meters' walking time and gait information from the start of the rehabilitation to its end in the intervention group. When significant differences were found, a post hoc analysis was performed to distinguish the differences between assessment time-points using the Tukey test. In study **III**, a paired t-test was used to compare $MMAS_{1-5}$, ten meters' walking time and the gait variables at the end of rehabilitation and at follow-up to determine whether the variables in the follow-up remained stable in the intervention group. In the control group, a paired t-test was used to identify possible changes from the beginning to the end of rehabilitation (**III**). In study **III**, differences between the groups were tested by repeated measures ANOVA using a between factor for intervention and control groups. Correlations between gait variables and other assessed variables were identified using Pearson's correlation coefficients (**III**). In study **IV**, repeated measures ANOVA was used to evaluate the changes between the beginning and the end of the rehabilitation, and to study group differences and interactions between the study groups and rehabilitation duration. Since the interactions and group differences were found to be non-significant, the main focus was placed on study changes in rehabilitation duration, in which the repeated contrasts analysis was performed. Friedman tests were used to evaluate the changes from the start to the end of rehabilitation in non-parametric variables. When differences were found in the Friedman test, Wilcoxon signed – rank test was performed (**IV**). A paired sample t-test was used to compare MMAS, 10 m, 6 min, dynamic balance variables at the end of rehabilitation and at six months to see whether the variables remained stable (**IV**). In all studies, results were considered significant if $p<0.05$. The effect size for walking distance in each group was calculated. The effect size was considered small (Cohen's $d \geq 0.2$), medium ($d \geq 0.5$), and large ($d \geq 0.8$). Effect sizes were also interpreted in terms of the percentage of non-overlap of the scores of the GT_{stim} group with those of the GT and WALK groups.

5 RESULTS

The results of each study are presented separately from study **I** to study **IV**. Additional results not included in any of the original reports are presented in section 5.3.2.

5.1 THE CONTENT OF THE GAIT-ORIENTED PHYSIOTHERAPY PROGRAM (Study I)

A total of 20 chronic stroke patients participated in study I. They received an inpatient gait-oriented rehabilitation period, which included 75 minutes of physiotherapy daily, fifteen times during the three weeks' rehabilitation. Physiotherapy started with 20 minutes walking exercise in the gait trainer. Physiotherapy continued immediately for 25 minutes after walking in the gait trainer. Later during the same day, there was another physiotherapy session (30 min). The amount of the instructed physiotherapy was the same for all patients. Patients received 19 hours (1125 min) of instructed physiotherapy (gait trainer exercises and other physiotherapy) and together with self-initiated training they practiced for a total of 28 hours (1702 ± 404 min) in three weeks.

5.1.1 Walking exercises

The mean walking distance per patient performed in the mechanical gait trainer was 6400 ± 1500 meters in 290 ± 33 min during the three week rehabilitation period. The mean weight support in the gait trainer started with 25 % of the body weight and ended up with 9 %. The mean perceived exertion in the gait trainer was 13.5 ± 2 on the Borg Scale.

5.1.2 Other physiotherapy

The further analysis of the 20 patients indicated that the practice time in the upright position was 62 % of the total duration of instructed physiotherapy. Most of the physiotherapy sessions supplementing the gait trainer, were spent doing three therapy methods: exercises of arms or trunk while sitting, standing exercises and walking on the floor (table 5). The mean duration of evaluation/planning was 10 min per patient. However, the patients were carefully evaluated for this study at additional times not included into the physiotherapy content. These evaluations took three hours. The mean perceived exertion in the physiotherapy provided to supplement the gait trainer was 14.1 ± 1 on the Borg Scale.

Table 5. Total duration of individual physiotherapy in addition to the sessions on the gait trainer divided according to specific contents during the three-week inpatient period (n = 20 chronic stroke patients) in study I.

	Mean (min)	SD (range)
Tonus inhibition	33	±32 (0 – 100)
Stretching	107	±64 (15 – 290)
Soft tissue techniques*	14	±16 (0 – 55)
Exercises in lower initial positions^	38	±26 (0 – 85)
Upper limb/trunk exercises while sitting	143	±63 (40 – 305)
Lower limb exercises while sitting	52	±37 (0 – 110)
Exercise of transfers	15	±22 (0 – 65)
Exercises while standing	151	±54 (30 – 225)
Gait on even floor	149	±69 (30 – 285)
Stairs	79	±32 (35 – 140)
Gait on uneven ground	34	±35 (0 – 110)
Evaluation/planning	10	±15 (0 – 55)
Total duration	825	

* massage, lympha therapy

^ exercises in lying, crawling position, standing on knees

5.1.3 Self-initiated training

Self-initiated training occurred most often in the sitting position (table 6). The most favoured apparatus was the motorised leg cycling restorator; in this apparatus most of the patients performed the cycling exercise without resistance (fig 8).

Figure 8. Patient practises in the leg cycling restorator.

The total exercise time of all patients in that apparatus was 3960 minutes, with an average of 20 sessions/patient. However, some patients practised clearly more than others. There was large interindividual variability in the amount of self-initiated training including group exercises; these ranged from 60 to 1260 minutes per patient. Participation in voluntary group therapies was not very impressive: seven patients did not participate in any of the groups, eight patients exercised from two to three times in a group, and the other five patients exercised from four to eight times in a group.

Table 6. Total duration of participation in individual self initiated training (n = 20 chronic stroke) in the study I.

	Mean (min)	SD
Active sitting equipment	329	±294
Standing apparatus	30	±99
Active standing equipment	14	±39
Gait and stairs	79	±131
Fitness room equipment	46	±67

5.2 POSTURAL BALANCE IN CHRONIC STROKE (Study II)

5.2.1 Static postural balance

Static postural balance was assessed using the force plate system. The analysis of 30 patients and 30 healthy subjects demonstrated that the balance of the patients with chronic stroke had deteriorated. The mean velocity moment (VM) of healthy subjects was 6.4±4 mm^2s^{-1}, i.e. a parameter which combines the speed and amplitude of the COP displacement. The patients with stroke had more than four times higher VM. The mean VM of the patients with left hemiparesis was 29.1 ± 23 mm^2s^{-1} and it did not differ from 26.0 ± 30 mm^2s^{-1} in the right hemiparetic patients.

The mean speed of the COP displacement in the normal group was 5.6±2 mms^{-1} in the anterior-posterior (AP) direction and 3.1±1 mms^{-1} in medial-lateral (ML) direction. In the healthy subjects, the AP speed of COP was 1.8 times faster ($p=0.000$) than the ML speed. The COP displacement was more in the AP direction than in the ML direction also among stroke patients**.** The AP and ML speeds in the patients with left and right hemiparesis were

2.0 – 2.4 times faster ($p<0.001$) than those of healthy subjects. In the group of patients with left hemiparesis, the COP displacement in the AP direction was 1.5 times faster ($p=0.001$), and in the group of patients with right hemiparesis it was almost two times faster ($p=0.000$) than the ML speed. The patients with left and right hemiparesis did not differ in their mean AP and ML speeds from each other.

The power peak magnitudes of COP displacements obtained in the frequency analysis of healthy subjects were lower than those of the patients with stroke (fig 9). Patients with left or right hemiparesis did not differ in the analyzed frequency bands of the power peak magnitudes directly. However, they differed from the healthy subjects in their power peak magnitudes, depending on the lesion side. The patients with left hemiparesis had significantly higher power peak magnitudes than healthy subjects only in the ML direction at lower frequencies, i.e. in bands 0.05 – 0.6 Hz ($p=0.000$) and 0.6 – 1.5 Hz ($p=0.004$) (fig 9). The patients with right hemiparesis had higher power peak magnitudes compared with healthy subjects in both ML ($p=0.025$, $p=0.033$) and AP ($p=0.000$, $p=0.005$) directions at the higher frequency bands 0.6 – 1.5 Hz and 1.5 – 2.7 Hz (fig 9).

The weight distribution indicated that the patients with left hemiparesis had 35.4±14 % and the patients with right hemiparesis had 42.7±7 % of their body weight on the paretic side. The correlation between the percent of body weight on the paretic side and ML speed was –0.53 ($p=0.003$). When we correlated the weight distribution with the frequency bands of the COP displacement, the power peak magnitudes correlated with weight distribution at higher frequencies in ML direction, but no correlation existed in the AP direction. The correlation between the percent of body weight on the paretic side and peak amplitudes in ML direction at 0.6 – 1.5 Hz was –0.42 ($p=0.022$) and at 1.5 – 2.7 Hz it was –0.39 ($p=0.032$). The less the body weight remaining on the paretic side, the more the patient swayed in the ML direction.

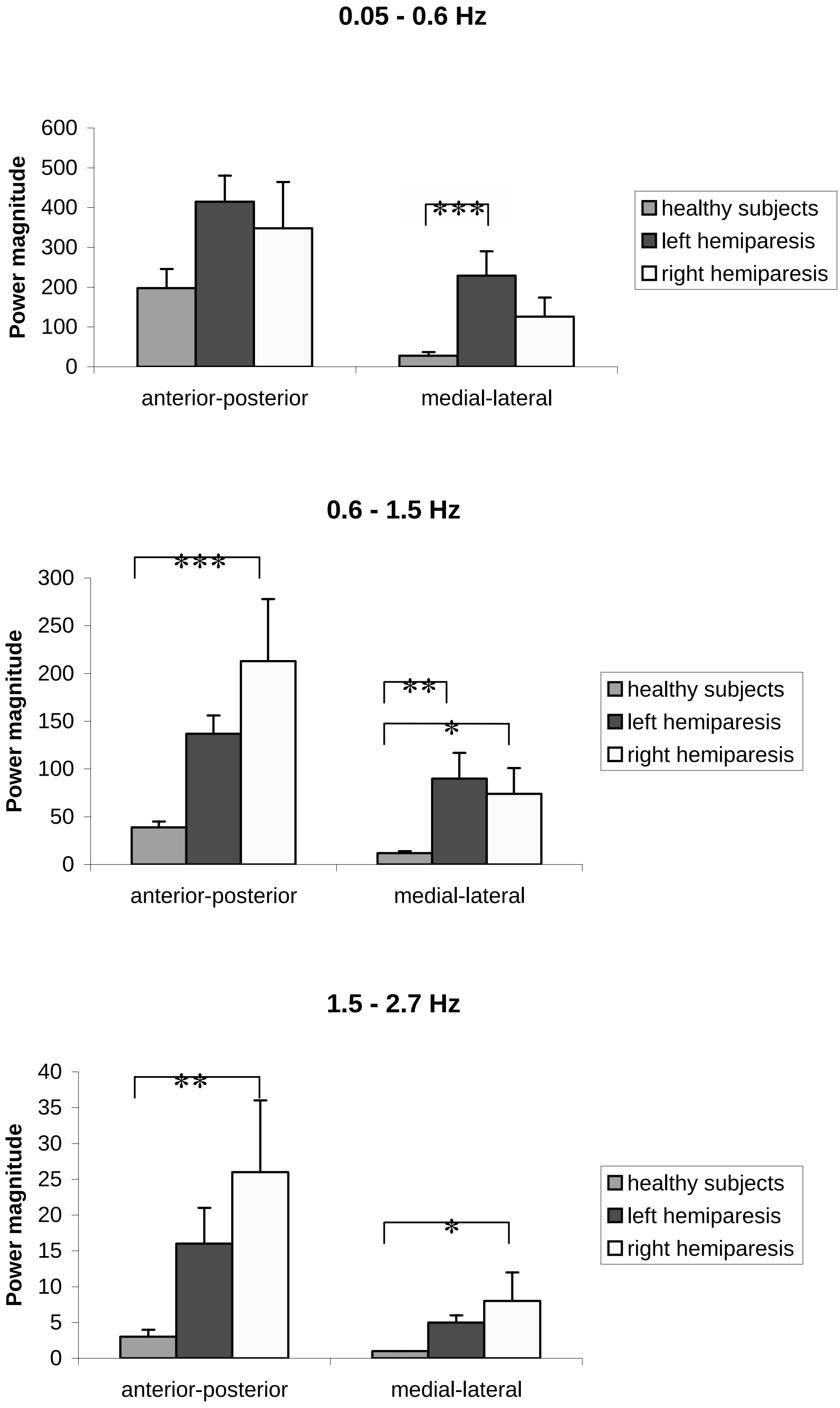


Figure 9. The power peak magnitudes of each frequency band of anterior-posterior and medial-lateral sway (mean values and standard errors) for the patients with left (n=15) and right (n=15) hemiparesis and normal subjects (n=30) in study II.

5.3 SPECIFIC GAIT CHARACTERISTICS AND EFFECTS OF REHABILITATION IN CHRONIC STROKE

5.3.1 The gait-oriented physiotherapy compared to ordinary physiotherapy (Study III)

5.3.1.1 Physiotherapy program

The intervention group of 23 chronic stroke patients receiving 75 minutes gait-oriented physiotherapy daily were compared to the control group of 14 patients receiving 45 minutes physiotherapy daily, which had no special effort on gait. The total duration of instructed physiotherapy was 1125 min in the intervention group and 675 min in the control group during three weeks' rehabilitation. In the intervention group, the patients practiced walking in the gait trainer for 7054 ± 1255 meters in 300 min. Their mean speed at the start was 1.3 ± 0.2 kmh^{-1} and this had increased at the end to 1.8 ± 0.3 kmh^{-1}. The mean body-weight support in the gait trainer started with 23.4 ± 15 % of the body weight and ended up with 4.4 ± 5 %. The mean perceived exertion in the gait trainer was 13.3 ± 2 and the mean heart rate was about 100 beats per minute throughout the rehabilitation. In the intervention group, the 825 min physiotherapy additional to the gait trainer exercises was similar as in the study I. In the control group, each patient received a total of 675 min of ordinary physiotherapy (45 min/day).

5.3.1.2 Gait characteristics

The motor ability measured by $MMAS_{1-5}$ (p=0.054) and ten meters' walking time (p=0.726) were similar at the start of rehabilitation in both groups (table 3). The improvements in $MMAS_{1-5}$ and ten meters' walking time did not differ between the intervention and control groups (p=0.217 and p=0.195). In the intervention group, the $MMAS_{1-5}$ increased 19.2 ± 4.0 to 22.0 ± 3.1 points (p<0.0005) and in the control group 22.1 ± 4.6 to 23.7 ± 3.8 points after three weeks of rehabilitation (p=0.005). In the intervention group, the ten meters' walking time decreased from 25.3 ± 12.2 s to 21.7 ± 12.1 s (p<0.0005) and in the control group from 23.8 ± 12.5 s to 21.4 ± 12.1 s (p=0.006).

The group comparisons showed that the spatial and temporal characteristics of gait improved only in the intervention group receiving gait-oriented rehabilitation. The spatial and temporal characteristics of gait of the intervention group before, after two weeks and after the intervention are presented in table 7. The Functional Ambulation Profile (FAP) score, identifying the severity of individual gait abnormality, increased from 54.6 to 61.4 scores after three weeks (p=0.023). The velocity of gait increased from 45.0 cms^{-1} to 51.0 cms^{-1} (p=0.015). With the increasing gait velocity, the decreases in step time on the AS (r = -0.45, p=0.031) and on the NAS (r = -0.49, p = 0.18) grew as did the step length (AS, r= 0.60, p=0.003, NAS, r=0.61, p=0.002). The step lengths, originally 43.1 / 34.0 cm (affected side, AS / non-affected side, NAS) increased to 46.3 / 36.8 cm at the end of rehabilitation (p=0.011 and p=0.040). Also the stride length increased both on the AS and on the NAS significantly (p=0.018 and p=0.006). At the start, the swing % of the cycle on the AS was typically only 24.3 whereas on the NAS it was 38.5. When both legs were examined, the step-time differential decreased during rehabilitation from 0.40 to 0.32 (p=0.043). For example, the cadence and step time changes did not reach statistical significance (table 7). All gait variables in the gait-oriented group had remained stable at the six months' follow-up (table 7).

The intervention group itself, using repeated measures analysis, improved in seven gait variables in three weeks, however the control group did not improve in any of the variables. When the control and intervention groups were compared, they differed in three variables. The 0.10 s increased step time on the AS of the control group differed from the 0.05 s decreased the step time in the intervention group (p=0.025). In the intervention group, the swing time of the cycle on the AS was at the start 0.72 ± 0.2 s and at end of the rehabilitation it was 0.69 ± 0.2 s, in the control group it was 0.63 ± 0.2 s at the start and 0.69 ± 0.2 s in the end (p=0.012). Moreover, the step-time differential in the gait-oriented group decreased whereas in the conventional group it actually increased (p=0.029). The Asymmetry index (AI) of stance and swing times were –21.4 ± 12 and 45.7 ± 26 at the start in the gait-oriented group and –18.3 ± 12 and AI 53.6 ± 43 in the control group. The AI values remained stable throughout the rehabilitation in both groups and they did not differ from each other.

Table 7. Spatio-temporal gait characteristics (mean ± SD) of chronic stroke patients of intervention group (n=23) at start, after two weeks and at the end of the rehabilitation and at the six months follow up in the study III. Post hoc p-values are in parenthesis.

Parameters	side	at start	two weeks	3 weeks	6 months	*3 w. vs follow-up p-value*	*Repeated measures p-value*
FAP, scores		54.6 ± 14	61.6 ± 16 (0.017*	61.4 ± 17 0.967)	61.5 ± 16	*0.509*	*0.023**
Velocity, cm/s		45.0 ± 23	49.5 ± 27 (0.029*	51.0 ± 29 0.269)	50.8 ± 25	*0.913*	*0.015**
Cadence, step/min		68.6 ± 21	71.9 ± 23	70.6 ± 22	71.0 ± 18	*0.780*	*0.151*
Step time, s	AS	1.17 ± 0.5	1.11 ± 0.4	1.12 ± 0.4	1.08 ± 0.4	*0.290*	*0.094*
	NAS	0.78 ± 0.3	0.78 ± 0.3	0.80 ± 0.4	0.75 ± 0.3	*0.212*	*0.555*
Step length, cm	AS	43.1 ± 10	44.8 ± 11 (0.136	46.3 ± 11 0.118)	45.4 ± 11	*0.293*	*0.011**
	NAS	34.0 ± 14	34.9 ± 15 (0.444	36.8 ± 15 0.046*)	37.6 ± 14	*0.416*	*0.040**
Stride length, cm	AS+NAS	77.7 ± 23	80.3 ± 24 (0.255	83.3 ± 24 0.078)	83.1 ± 23	*0.883*	*0.018**
	NAS+AS	77.3 ± 22	79.6 ± 23 (0.246	83.2 ± 25 0.021*)	83.1 ± 23	*0.950*	*0.006***
Swing time of cycle, s	AS	0.72 ± 0.2	0.68 ± 0.2	0.69 ± 0.2	0.70 ± 0.2	*0.464*	*0.063*
	NAS	0.44 ± 0.1	0.44 ± 0.1	0.46 ± 0.1	0.45 ± 0.1	*0.657*	*0.406*
Stance time of cycle, s	AS	1.22 ± 0.6	1.22± 0.6	1.24 ± 0.7	1.12 ± 0.1	*0.099*	*0.818*
	NAS	1.51 ± 0.7	1.44 ± 0.7	1.45 ± 0.7	1.38 ± 0.5	*0.917*	*0.267*
Double-support % of cycle	AS	37.0 ± 9	36.4 ± 12	34.9 ± 11	33.7 ± 9	*0.274*	*0.184*
	NAS	36.8 ± 9	36.8 ± 12	35.3 ± 11	33.9 ± 9	*0.187*	*0.319*
Double-support time, s	AS	0.77 ± 0.5	0.76 ± 0.6	0.74 ± 0.6	0.65 ± 0.4	*0.134*	*0.532*
	NAS	0.77 ± 0.5	0.77 ± 0.6	0.74 ± 0.6	0.66 ± 0.4	*0.158*	*0.515*
Step-time differential		0.40 ± 0.3	0.34 ± 0.2 (0.014*	0.32 ± 0.2 0.504)	0.33 ± 0.2	*0.795*	*0.043**
Step-length differential		10.5 ± 8	10.4 ± 8	10.6 ± 7	9.2 ± 7	*0.222*	*0.989*

FAP=Functional Ambulation Profile, AS=affected side, NAS=non-affected side

5.3.2 The efficacies of three methods of gait-oriented physiotherapy on spatial and temporal gait characteristics (not included in any of the original reports I-IV)

Study **IV** consisted of 45 patients receiving 20 minutes' walking exercises daily either 1) in the electromechanical gait trainer with functional electrical stimulation (GT_{stim}, n=15), or 2) in the gait trainer without stimulation (GT, n=15) or 3) on the floor (WALK, n=15). In addition, they received other forms of physiotherapy during the three weeks' rehabilitation. The new calculations of the changes of spatio-temporal gait characteristics of these patient groups are presented here. The exercise intensity and effects of gait-oriented rehabilitation in other measures are presented in chapter 5.4 (study **IV**).

In study **III**, the 20 minutes' walking exercises included only gait trainer exercises in 23 patients. Later more patients were added to the data. Two patients of the 45 patients were not able to walk along the walkway. Since there were no differences between the different walking exercise groups in the changes in the spatio-temporal gait characteristics (between groups p-values on the table 8), the mean gait characteristics of 43 patients are presented together in table 8. In these new calculations of 43 patients, some of the patients did walking exercises also overground or on uneven terrain. When the number of patients was larger in the calculations, some parameters showed different changes. Three parameters which indicated significant improvement were the same as noted in study **III**, i.e. gait velocity and stride length on both sides. The cadence and stance time on the NS improved only when all 43 patients were included (table 8). The FAP, the step length on both sides and the step time differential improved only when 23 patients (**III**) were analyzed (table 7).

Table 8. New calculations of spatio-temporal gait characteristics (mean ± std. error) of 43 chronic stroke patients at start, after two weeks and at the end of the rehabilitation period. Post hoc p-values are shown in parenthesis.

Parameters	side	at start	two weeks	3 weeks	repeated measures p-value	between groups p-value*
FAP		51.8 ± 1.7	54.2 ± 2.1	54.0 ± 2.2	0.056	0.792
Gait velocity, cms^{-1}		37.3 ± 3.2	41.0 ± 3.7 (0.007**	42.2 ± 4.0 0.185)	0.003**	0.909
Cadence, step/min		64.9 ± 3.3	67.5 ± 3.6 (0.017*	67.8 ± 3.4 0.773)	0.013*	0.959
Step time, s	AS	1.25± 0.08	1.19 ± 0.08 (0.011*	1.20 ± 0.08 0.636)	0.040*	0.541
	NAS	0.86 ± 0.05	0.84 ± 0.05	0.83 ± 0.06	0.536	0.897
Step length, cm	AS	39.1 ± 1.6	40.6 ± 1.6	40.9 ± 2.0	0.266	0.965
	NAS	28.5 ± 2.2	29.5 ± 2.3	30.6 ± 2.5	0.078	0.855
Stride length, cm	AS+NAS	68.2 ± 3.5	70.6 ± 3.8 (0.113	72.7 ± 3.9 0.043*)	0.009**	0.859
	NAS+AS	67.7 ± 3.5	70.2 ± 3.7 (0.069	73.5 ± 4.9 0.010*)	0.001**	0.514
Swing % of the cycle	AS	36.0 ± 1.4	35.5 ± 1.4	36.2 ± 1.5	0.648	0.683
	NAS	21.7 ± 1.1	22.2 ± 1.1	22.4 ± 1.1	0.380	0.494
Swing time of the cycle, s	AS	0.70 ± 0.03	0.67 ± 0.03	0.68 ± 0.03	0.242	0.610
	NAS	0.41 ± 0.02	0.41 ± 0.02	0.41 ± 0.02	0.894	0.556
Stance % of the cycle	AS	64.0 ± 1.4	64.5 ± 1.4	63.8 ± 1.5	0.651	0.678
	NAS	78.3 ± 1.1	77.8 ± 1.1	77.6 ± 1.1	0.373	0.493
Stance time of the cycle, s	AS	1.39 ± 0.11	1.37 ± 0.11	1.36 ± 0.12	0.675	0.825
	NAS	1.69 ± 0.13	1.62 ± 0.12 (0.023*	1.61 ± 0.12 0.616)	0.024*	0.856
Double-support % of the cycle	AS	42.7 ± 2.2	41.7 ± 2.2	40.6 ± 2.2	0.184	0.452
	NAS	42.3 ± 2.1	42.0 ± 2.2	40.8 ± 2.2	0.337	0.714
Double-support time of the cycle, s	AS	0.99 ± 0.12	0.94 ± 0.11	0.92 ± 0.92	0.133	0.884
	NAS	0.98 ± 0.11	0.95 ± 0.11	0.92 ± 0.11	0.158	0.893
Step time differential		0.41 ± 0.05	0.36 ± 0.04	0.37 ± 0.04	0.161	0.462
Step length differential		12.3 ± 1.4	12.0 ± 1.4	13.0 ± 1.3	0.416	0.355

FAP=Functional Ambulation Profile, AS=affected side, NAS=non-affected side, * = comparisons between GT$_{stim}$, GT and WALK groups

5.4 THE EFFECTS OF THE GAIT-ORIENTED REHABILITATION IN CHRONIC STROKE (Study IV)

5.4.1 Exercise intensity

The study IV consisted of 45 patients receiving 20 minutes' walking exercises daily either 1) in the electromechanical gait trainer with functional electrical stimulation (GT_{stim}, n=15), or 2) in the gait trainer without stimulation (GT, n=15) or 3) on the floor (WALK, n=15). In addition, they received other types of physiotherapy for 825 min during the three weeks' rehabilitation. Patients in the three groups were similar (table 4). The treatments in the gait trainer in the GT groups were performed similarly (table 9). The actual amount of walking exercise per patient was 300 min during the three weeks' rehabilitation. The walking distance that the patients were able to obtain in the mechanical gait trainer was over 6500 m in both GT groups (table 9). In the WALK group, the distance was below 4900 m, which was less than the walking distance obtained in the GT_{stim} group (p=0.023, WALK versus GT group only p=0.084). The effect size for the walking distance between GT_{stim} and GT was small (d=0.25) and their percentage of non-overlap was 18 %. The effect size between GT_{stim} and WALK was large (d=0.92) and their percentage of non-overlap was 52 %. The effect size between GT and WALK was medium (d=0.70) and their percentage of non-overlap was 43 %. The mean speed in the gait trainer started at 1.2 and 1.3 kmh^{-1} (GT_{stim} and GT) and ended at 1.7 kmh^{-1}. The mean weight support in the gait trainer started from 26.1 and 29.6 % of the body weight and ended at 8.5 and 9.1 %. The patients achieved the need for less than 20 % body-weight support in the gait trainer during their third training session. In the GT_{stim} group, the most often stimulated muscles were hip and knee extensors. In 6 patients, the two stimulated muscles of the paretic lower extremity of the patient were hip extensors + knee extensors, in three of patients hip extensors + knee flexors, in three patients knee extensors + knee flexors, in two patients knee flexors + ankle pronators, and one patient received stimulation only to the hip extensors (Fig 10). The intensity of the stimulation was about 40 mA. In the gait trainer, assistance was sometimes needed to prevent knee overextension. In the WALK group, eleven patients mainly used a cane during the 20 min walking but four patients walked without walking aids. Eight patients needed manual guidance during the walking. Many patients in the walk group practiced their gait also outside on the ground or even walking in the snow.

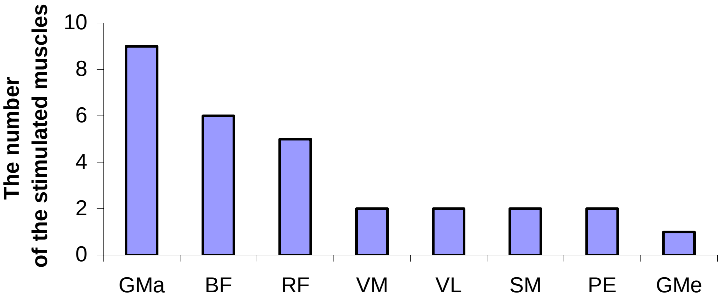


Figure 10. Fourteen patients in the GT$_{stim}$ group received functional electrical stimulation to the two paretic muscles and one patient to one paretic muscle. GMa=Gluteus maximus, BF=Biceps femoris, RF=Rectus femoris, VM=Vastus medialis, VL=Vastus lateralis, SM=Semitendinosus, PE=Peroneus, Gme=Gluteus Medius.

The mean perceived exertion in GT$_{stim}$, GT and WALK groups was similar during the 20 min walking training (table 9). The heart rate in different time-points remained stable, near 100 beats/min in every group. The content of their additional physiotherapy, which may have contributed to the 20 min walking exercises was presented in study **I**.

Table 9. The total amount of walking exercise (mean ± SD) and exertion in each group during rehabilitation (n=45) in study IV. The development of training speed and body-weight support (BWS) is presented for GT and GT$_{stim}$ groups. WALK group received traditional walking training.

	GT$_{stim}$ n =15	GT n=15	WALK n=15	p value#	df	F
Distance† (m)	6906 ± 1268	6523 ± 1735	4871 ± 2862	0.023*	2,42	14.11
Borg Scale (score)	13.1 ± 2.4	14.0 ± 1.7	14.0 ± 1.5	0.361	2,42	1.04
Speed_1 (kmh^{-1})	1.3 ± 0.2	1.2 ± 0.2		0.300		
Speed_2 (kmh^{-1})	1.7 ± 0.3	1.6 ± 0.3		0.644		
Speed_3 (kmh^{-1})	1.7 ± 0.3	1.7 ± 0.3		0.745		
BWS_1 (%)	26.1 ± 16.4	29.6 ± 20.1		0.610		
BWS_2 (%)	11.1 ± 17.9	12.0 ± 13.4		0.880		
BWS_3 (%)	9.1 ± 18.4	8.5 ± 12.0		0.916		
20 % BWS^	2.6 ± 2.0	3.2 ± 3.7		0.614		

= p values obtained using independent samples t-test or one-way ANOVA.
†= walking distance cumulated in 15 sessions
* = $p<0.05$
1 = in the first session, 2 = in the tenth session, 3 = in the last session
^ = session when below 20 % BWS

5.4.2 Effects of rehabilitation

Three weeks of gait-oriented rehabilitation significantly improved the motor abilities of chronic stroke patients (**III**, **IV**). The dynamic balance, gait speed, gait endurance and motor task performance improved irrespective of group (**IV**). At the start before the intervention, the mean ten meters walking time ranged from 39.5 s to 44.0 s in the three groups (table 10). After three weeks, ten meters' walking time decreased by 18 – 24 %. The improvement in speed was achieved at two weeks ($p<0.0005$) and additional benefit was achieved after one more week ($p=0.031$). The mean six minutes' walking distance was 112 m to 127 m at the beginning of rehabilitation (table 10). The six minutes' walking distance increased by 14 – 17 % ($p<0.0005$). One patient in the GT group was not able to walk on the floor for the required six minutes during the rehabilitation.

The dynamic test including three lateral weight transfers ranged from 956 – 1021 mm in 9.8 – 13.6 s in different groups (table 10). Two patients were unable to perform the dynamic balance test because they suffered too severe postural instability. The patients' dynamic postural stability improved. The dynamic test time shortened at each recording by 28 – 48 % ($p<0.0005$, table 10). The improved ability to control the center of the mass in relation to the base of support was seen also in the distance COP moved in the dynamic test. This distance decreased by 18 % ($p=0.005$). The static postural sway parameters did not change during rehabilitation. The mean VM of the patients in different walking exercise groups varied from 37.6 to 55.8 mm^2s^{-1} at the beginning of the rehabilitation (table 10). The speed of COP change ranged from 12.6 to 16.8 in the AP mms^{-1} direction and from 8.7 mms^{-1} to 11.5 mms^{-1} in ML direction at the beginning of the rehabilitation (table 10).

At the beginning, the mean MMAS ranged from 19 to 21 scores (table 10). The motor ability improved during the rehabilitation with MMAS scores increasing by 10 – 18 % ($p<0.0005$). The third week exhibited further improvement ($p=0.001$). The FIM did not change in our chronic stroke patients ($p=0.225$, table 10). The mean FIM ranged from 99 to 107 throughout the rehabilitation. The GT_{stim}, GT and WALK groups did not differ in the above measurements (table 10).

Table 10. The gait, balance and motor task performance (mean ± SD) of chronic stroke patients at start, after two weeks and at the end of the rehabilitation period in the study IV.

Parameters	group	n	at start	two weeks	3 weeks	repeated measures p-value	between groups p-value
10 meters' walking time, s	GT$_{stim}$	15	44.0±36.2	37.1±28.2	35.9±29.9		
	GT	15	39.6±35.4	33.7±30.9	30.3±23.6		
	WALK	15	39.5±25.5	31.8±14.7	32.1±15.9	0.000***	0.817
Repeated contrasts	p-value			0.000***	0.032*		
6 minutes' walking distance, m	GT$_{stim}$	15	127.1±87.2	145.4±95.6	151.7±97.4		
	GT	14	152.3±89.6	175.9±105.8	177.5±111.5		
	WALK	15	111.8±57.3	133.5±72.8	135.1±67.9	0.000***	0.990
Repeated contrasts	p-value			0.000***	0.531		
Static balance test, VM, mm^{2}s^{-1}	GT$_{stim}$	15	55.8±119.1	57.4±120.4	74.7±175.7		
	GT	15	37.6±29.4	46.8±47.0	33.3±28.9		
	WALK	15	42.1±31.5	44.7±29.0	36.1±20.8	0.142	0.649
Static balance test, AP speed of COP, mms^{-1}	GT$_{stim}$	15	16.8±19.1	16.0±16.1	17.6±23.5		
	GT	15	12.6±5.2	13.5±7.2	12.1±5.2		
	WALK	15	15.3±7.0	15.2±5.8	13.7±4.9	0.136	0.885
Static balance test, ML speed of COP, mms^{-1}	GT$_{stim}$	15	11.5±17.1	12.0±17.0	12.9±19.9		
	GT	15	8.7±5.3	9.0±6.7	7.6±4.3		
	WALK	15	10.2±5.5	10.4±5.1	9.0±3.9	0.256	0.642
Dynamic balance time, s	GT$_{stim}$	14	13.6±9.4	8.7±4.6	7.1±3.0		
	GT	14	10.8±5.6	7.9±3.3	6.5±1.9		
	WALK	15	9.8±5.3	8.0±4.9	7.1±3.3	0.000***	0.287
Repeated contrasts	p-value			0.000***	0.000***		
Dynamic balance distance, mm	GT$_{stim}$	14	955.9±520.9	903.6±709.7	786.6±342.8		
	GT	14	1015.6±640.9	794.4±434.2	841.1±407.3		
	WALK	15	1021.1±464.5	850.5±276.2	834.0±201.3	0.005**	0.824
Repeated contrasts	p-value			0.001**	0.883		
MMAS, points	GT$_{stim}$	15	19.0±7.2	21.1±6.8	23.2±7.1		
	GT	15	20.6±6.3	22.6±6.7	22.8±5.8		
	WALK	15	20.1±6.7	21.5±6.5	22.5±6.1	0.000***	0.239
Repeated contrasts	p-value			0.000***	0.001**		
FIM, points	GT$_{stim}$	15	99.2±12.8	98.9±10.8	100.9±12.3		
	GT	15	106.9±10.0	106.3±10.0	106.8±10.2		
	WALK	15	100.7±11.4	101.9±10.3	102.3±10.9	0.225	0.553

VM=velocity moment, AP=anterior-posterior, ML=medial-lateral, COP=center of pressure, MMAS=Modified Motor Assessment Scale, FIM=Functional Independence Measurement, ** = $p<0.01$, *** = $p<0.001$. If the distribution of the variable was not normal then logarithmic adjustment was used for statistics.

The median of the ankle spasticity gave a value two and the median of the knee and hip spasticity gave a value of zero according to MAS. Ankle spasticity, but not knee or hip, had decreased only in the WALK group by the last week of rehabilitation (p=0.021). The median of the muscle force of the ankle dorsiflexion was zero and in hip flexors it was three as measured by MI. The ankle dorsiflexion force increased in the GT_{stim} group (p=0.033) as did the hip flexion force in the GT group (p=0.019). The median of the muscle power of the knee extension was four and this did not change during rehabilitation.

5.4.3 Maintenance the effects of rehabilitation

Follow-up tests were performed 23.5 ± 3.1 weeks after the rehabilitation (study **IV**). Only two patients were not available for follow-up assessments. One patient refused to attend and one had fallen ill. While no differences were found between the different gait exercise groups (GT_{stim}, GT and WALK) at three weeks, the comparisons between the end of rehabilitation and the follow-up were performed for all patients together (n=43). With the exception of MMAS, all of the parameters measured in these chronic stroke patients had remained unchanged since the end of rehabilitation (table 11).

Table 11. The gait, balance and motor task performance (mean ± SD) of chronic stroke patients in the end of the rehabilitation period and at follow up at six months in study IV.

Parameters	n	3 weeks	follow-up	t-test p-value
10 meters' walking time, s	43	32.4 ± 23.8	39.2 ± 47.9	0.343
6 minutes' walking distance, m	42	157.9 ± 92.9	160.9 ± 102.4	0.523
Static balance test, VM, mm^2s^{-1}	42	45.6 ± 105.3	39.5 ± 66.7	0.795
Static balance test, AP speed of COP, mms^{-1}	42	13.9 ± 14.3	13.4 ± 11.4	0.911
Static balance test, ML speed of COP, mms^{-1}	42	9.3 ± 11.8	8.9 ± 9.6	0.671
Dynamic balance time, s	41	6.9 ± 2.9	7.6 ± 4.3	0.297
Dynamic balance trip, mm	41	818.1 ± 326.3	855.3 ± 541.6	0.982
MMAS, points	43	22.3 ± 5.7	21.4 ± 5.7	0.018*

VM=velocity moment, AP=anterior-posterior, ML=medial-lateral, COP=center of pressure, MMAS=Modified Motor Assessment Scale, * = $p<0.05$

6 DISCUSSION

The main purpose of these studies **I – IV** was to evaluate gait rehabilitation and factors affecting it in patients with chronic stroke. Three weeks of gait-oriented rehabilitation significantly improved the motor abilities of chronic stroke patients. The total time of instructed physiotherapy was 19 hours and together with self-initiated training patients practised for 28 hours. The dynamic balance, gait speed, gait endurance and motor task performance improved irrespective of the gait-oriented rehabilitation strategies used and patients maintained their improved motor ability at least six months. The gait-oriented physiotherapy combined with BWS resulted also in an improvement of spatio-temporal gait characteristics not seen when compared to physiotherapy without any special effort on gait. Chronic stroke patients swayed three times more than healthy subjects. Frequency analysis of sway parameters suggested that the postural stability may have specific characteristics due to the side of the hemiparesis.

6.1. THE CONTENT OF GAIT-ORIENTED PHYSIOTHERAPY PROGRAM

The three-week gait-oriented physiotherapy program for chronic stroke patients accomplished plenty of active walking exercises and other physiotherapy. Although the in-patient rehabilitation time was only three weeks, within that time the patients received 19 hours of physiotherapy, which together with the self-initiated training meant that the total exercise duration was on average 28 hours. In previous gait-oriented rehabilitation studies for stroke patients the amount of therapy has been 12 hours during a four-week period (Pohl et al. 2002) and 17 hours during an eight-week in-patient rehabilitation period (Goldie et al. 1996). There are also studies where the amount of practice during the inpatient period has been reported for one day or one week, but the length of individual stay has varied (90 min/day, five days/week (Kosak and Reding 2000). Nilsson et al. (2001) reported the gait training being provided for 30 min five days a week during the varying length of the patients' stay (between 1 and 4 months). The amount of physiotherapy in addition to gait exercise is usually not mentioned. Previous gait-oriented rehabilitation studies (Goldie et al. 1996, Kosak and Reding 2000, Nilsson et al. 2001, Pohl et al. 2002) were directed to subacute patients (mean time from stroke onset to inpatient rehabilitation varied from 17 days to 16 weeks). In contrast, in our study all of the patients were chronic, i.e. more than six months had elapsed since stroke.

Our three-week rehabilitation period for chronic stroke patients concentrated on gait training. Thirty-eight percent out of the total mean duration of all exercises per patient was gait exercise including exercises in the gait trainer, on the floor, on the ground and on the stairs and thus it represented 50 % of instructed physiotherapy. Patients also practised in upright position (10 %) strengthening the affected lower limb in a functionally relevant way, such as doing weight-bearing and balance exercises and this formed 14 % of the instructed physiotherapy. These exercises allowed patients to practise in conditions of varying demands. Richards et al. support this kind of training approach that emphasizes task-oriented strengthening and coordination exercises to promote gait in various contextual and motivational environments (Richards et al. 1999).

From the total mean duration of all exercises per patient, 35 % was spent in sitting positions. Though this may seem to be rather much, one explanation is that 64 % of the sitting exercise time consisted of self-initiated training. When the patients practised by themselves, it was easier and safer for them to do the exercises in sitting positions. The time practised with the physiotherapist in sitting positions consisted of transfers, trunk control and mobility exercises, upper extremity exercises or patients practised in the fitness room for example with equipment such as the leg press. With respect to the passive methods, stretching accounted for 11 % and it was used to maintain elastic properties of the muscles and to prevent muscle shortening and increased muscle stiffness. The stretching was carried out most often during the last five minutes of the session.

In previous studies, the content of the supplemental physiotherapy has been poorly described. In the study of Nilsson et al. (2001) they aimed at improving motor control and strengthening functionally weak muscles. They used transfers and a variety of motion exercises as well as techniques to improve motor function in the paretic side. Patients also practised on their own or in a group under supervision. Kosak & Reding´s (2000) physiotherapy sessions were provided by the patient's individual therapist. They were functionally oriented, incorporated a variety of motor facilitation and motor control techniques, and often included the use of bracing and walking assist devices. In some studies, physical therapy methods additional to gait training were claimed to be based on the physiotherapeutic "dogmas", for example on the Bobath concept (Davies 2000) or on the Motor Relearning Programme (Duncan et al. 1998). In study **I**, we analysed and reported the actual amount and content of the active practice that the patients received.

While patients are in a rehabilitation center, a large amount of active practise can be accomplished when special effort is made to maximize this exercise. However, it has also been reported that stroke patients in rehabilitation spend many hours a day alone and inactive if no special effort is made to keep them active (Ada et al. 2003). In our study, the patients were encouraged to practise by themselves with equipment available on the ward or in the fitness room and they were helped with transfers if needed by nurses or physiotherapists. Patients could also participate in different exercise groups, but their participation rates were rather low. However, the amount of self-initiated training was quite impressive. The use of a structured form may have resulted in more self-initiated training than usually would occur during an in-patient period.

6.2 POSTURAL BALANCE AND REHABILITATION IN CHRONIC STROKE

Various balance functions are known to impact on gait (Nichols 1997, Nadeau et al. 1999, Chou et al. 2003). The more the patient sways, the worse is the balance and consequently his/her gait ability (Nichols 1997**.** In studies **II** and **IV**, patients needed a large postural sway to maintain their standing balance as seen in the speed of COP displacements. The static postural sway parameters did not change during rehabilitation, but the dynamic balance improved. The COP movement time and distance after lateral weight transfers decreased in all groups.

The patient groups with left or right hemiparesis did not differ from each other in their static balance when this was assessed by the VM **(II)**. The frequency spectrum analyses showed that high amplitudes are prevalent at low frequencies of COP displacement and low amplitudes are prevalent at high frequencies in all patients. The frequency content stayed below 2.7 Hz. In addition, patients did not differ in the analyzed frequency bands of COP displacements directly. However, the patient groups differed from healthy subjects in specific frequency power peak magnitudes in distinct ways depending on the lesion side. The patients with left hemiparesis had higher power peak magnitudes of COP than healthy subjects in the ML direction at low frequencies. Thus the patients with left hemiparesis swayed more slowly, with large amplitudes from side to side. The patients with right hemiparesis had higher power peak magnitudes than healthy subjects in both AP and ML directions at higher frequencies. This indicates that the patients with right hemiparesis swayed more rapidly with large amplitudes in all directions than healthy subjects. Although sensory and motor cortical areas are symmetric in both hemispheres, the hemipheres are known to have different functions. For example, cognitive deficits are often associated with left hemiparesis and aphasia with right hemiparesis. More aphasia was seen also in the present study among the patients with right hemiparesis. Right hemisphere convexity infarction tends to cause also disturbances in spatial perception. Cognitive deficits may have a role in the poorer outcome in the functional status of the patients with left hemiparesis (Cassvan et al. 1976, Kinsella and Ford 1980, Titianova and Tarkka 1995, Rode et al. 1997).

The difficulty in shifting the body weight toward the paretic side is seen in the asymmetry of weight bearing during quiet standing (**II**). The less the body weight rests on the paretic side, the more the patients have COP displacement in the ML direction. The patients with left hemiparesis had less body weight on the paretic side while standing than patients with right hemiparesis. This is in line with previous studies (Cassvan et al. 1976, Kinsella and Ford 1980, Titianova and Tarkka 1995) where the ambulatory deficit of the patients with left hemiparesis was more pronounced compared to the deficit noted in patients with right hemiparesis.

In the study of Esparza et al. (2003), patients with right hemiparesis had significantly lower amplitudes of trunk movement during pointing movements than patients with left hemiparesis. Since the control of the trunk is thought to be mediated bilaterally from both hemispheres (Bear et al. 2001), the difference in the trunk displacement between the left and right hemiparetic patients was considered to support the idea that the left hemisphere plays a greater role than the right one in the control of complex coordination between the arm and trunk. This may be connected to the finding of move-limited deficit in static balance of left hemiparesis in study **II**. In the study of Esparza et al. (2003), an interesting aspect of the hemispheric role in the control of movement in stroke patients was that the patients with right hemiparesis seemed to have more temporal coordination deficits for movements made with the ipsilesional, non-hemiparetic left arm than those patients with left hemiparesis for movements made with the ipsilesional right arm.

Important directional information is obtained by measuring COP displacements separately in the AP and ML directions. In the study of Winter et al. (2003) two force plates were used to separate the contribution of the individual limbs. They found that COP from the left foot and COP from the right foot moves forward and backward primarily under the control of the plantarflexor muscles. Further, they demonstrated that virtually 100 % of the COP in ML direction is controlled by the load/unload mechanism. An inverse dynamics analysis of the kinetic in the frontal plane showed that this mechanism is controlled by the hip abductor/adductor muscles. In addition to these two separate mechanisms, the COP displacements in AP and ML directions are different. As indicated in the **II** and other studies (Baloh et al. 1998), the COP displacement in the AP direction is greater than the change in the ML direction in healthy subjects. Study **II** also reveals the same situation in stroke patients but their displacements were of greater magnitude.

In comparison with other neurological diseases, patients with bilateral peripheral vestibular loss and cerebellar atrophy have shown greater COP displacements in the AP direction than in the ML direction (Baloh et al. 1998). The speed of COP displacements while standing seems to be greater in patients with bilateral peripheral vestibular loss and in cerebellar atrophy compared to chronic stroke patients. Further, in study **II**, patients with stroke were shown to have significant postural instability during quiet standing when compared with healthy age-matched subjects in agreement with previous studies (Nichols 1997, Rode et al. 1997, Dickstein and Abulaffio 2000). In the present study (**II**), the mean age of the patients was 53 years. Their mean velocity moment (VM) was four times higher and the speed of COP displacement was 2.0 – 2.4 times faster when compared with a group of age-matched healthy subjects.

6.3 SPECIFIC GAIT CHARACTERISTICS AND REHABILITATION IN CHRONIC STROKE

In study **III**, both groups improved in $MMAS_{1-5}$ and ten meters' walking time and the improvements did not differ in the gait-oriented physiotherapy and conventional physiotherapy groups. However, specific gait characteristics improved only in the gait-oriented group. Furthermore, all of the gait characteristics and also patient mobility in the gait-oriented group remained at the discharge level still at the six months follow-up. While no differences were found between the three gait-oriented groups with similar amounts of practice (**IV**), we consider that intensive gait-oriented physiotherapy was more efficient irrespective of the exact method of delivery compared to ordinary physiotherapy, which is dispersed trying to achieve several different aims. The greater improvements in the gait-oriented group were not only due to the greater amount of therapy (75 min > 45 min), but also due to the content of the therapy focusing on gait. Motor learning and developing walking skills require practice with concrete goals and the patients must have the opportunity to practice actively and to understand the importance of frequent repetitions (Rosebaum 1991).

Ottenbacher and Jannell (1993) were unable to detect any correlation between length or extent of therapy and the effect size. In the study of Kwakkel et al. (1997), adding more therapy in the experimental group compared with the control group increased the final effect sizes for activities of daily living (ADL) providing further evidence for the presence of an intensity-effect relationship. Later, in their randomised controlled trial of 53 patients with stroke these researchers showed that a greater duration of rehabilitation for the lower extremities during the first 20 weeks post-stroke led to improved recovery in terms of ADL, walking ability, and postural control compared to control group (Kwakkel et al. 1999). The greater duration of rehabilitation for the upper extremities differed only in dexterity from the control group. In addition, they found that greater durations of rehabilitation for the lower extremities resulted in increases in comfortable walking speed compared with longer durations of rehabilitation sessions for the paretic upper extremities or the control treatment (Kwakkel et al. 1999, Kwakkel and Wagenaar 2002). Both groups, lower extremity training group and upper extremity training group, both received training for 30 min five days a week. The control group received immobilization of the paretic lower and upper extremities by means of an inflatable pressure splint by the same amount of time. In addition all three groups participated daily in a basic treatment program of 30 min as well as a weekly 1½-hour session of ADL training. Patients maintained their functional gains for up to one year after stroke when they had received a 20 week upper or lower limb training programme (Kwakkel et al. 2002). However, a significant number of patients who experienced an incomplete recovery still showed improvements or deterioration in dexterity, walking ability, and ADL from 6 months onwards. The results of Kwakkel et al. (1999, 2002) are in line with these of study **III**, i.e. exercise therapy primarily induces treatment effects on the abilities at which training is specifically aimed. Thus, only the gait-oriented rehabilitation improved specific gait characteristics.

In a study somewhat comparable to study **III** in patients with chronic stroke (Ada et al. 2003), four weeks of treadmill and overground walking program significantly increased walking speed and walking capacity, but had no effect on handicap as assessed by Sickness Impact Profile. In study **III**, the gait velocity in the intervention group improved and we confirmed previous findings that the changes in walking speed in patients with chronic hemiparesis produce quantitative alterations in the overall gait variables (Zatsiorky et al. 1994). The individual FAP scores, which assess the severity of gait abnormality, described well the slow post-stroke velocity performance. The patients' improved gait velocity resulted in higher FAP scores and decreased step time and increased step and stride lengths bilaterally. Some of the patients may have benefitted even more a speed if faster than 2 kmh^{-1} had been available in the gait trainer.

Also Hesse et al. (2001) studied walking speed during gait rehabilitation and its influence on outcome of stroke patients. These workers studied the relationships between treadmill speed and energy consumption and lower limb muscle activity in 24 ambulatory hemiparetic patients (6 - 8 weeks after lesion). Initially, their minimum self-adopted overground walking velocity was 0.5 ms^{-1}. Three conditions were assessed during treadmill walking: walking at self-adopted speed (V SAS), walking slowly (V SAS – 25%), and walking fast (V SAS + 25 %). Patients wore a harness that did not support weight. With the exception for the increase in cadence and stride length, cycle parameters did not correlate with gait velocity. The ratio of cadence to stride length remained unchanged, indicating that walking speed increased in a physiologic manner. The mean activity of tibialis anterior, gastrocnemius, rectus femoris, biceps femoris, and vastus medialis muscles increased at higher walking speed. Gait velocity did not significantly influence the activity of the adductor longus, gluteus medius, and erector spinae muscles. At higher speeds, an early and more timely onset of activity was seen in the vastus medialis, biceps femoris, and gluteus medius muscles. At a low speed, the start of activity was delayed with the onset occurring during midstance. Energy cost measurements indicated a more efficient gait when walking faster. In studies **I – III,** these were taken into account by aiming to increase speed progressively as soon as possible, yet completing practise of 20 minutes at a time.

It is noteworthy, that the increase in maximum walking speed was found to increase gait asymmetry in the study of Kwakkel and Wagenaar (2002). Their findings and study **III** suggest that the recovery of walking speed and the restoration of gait pattern in the chronic stage of stroke may result from two different mechanisms (Wall and Turnbull 1986, Titianova et al. 2003). Gait velocity is mainly affected by weakness of the affected hip flexors and knee extensors whereas gait asymmetry is in part influenced by the degree of the spasticity of the affected ankle plantar flexors (Hsu et al. 2003). The patients with chronic stroke may achieve varying speed performance using different strategies to achieve motor control of their hemiparetic gait (Knutsson and Richards 1979, Lamontagne et al. 2000) resulting in more or less stereotyped but quantitatively different patterns of walking (Dietz 1996).

In study **III**, the step-time differential decreased significantly during rehabilitation, but calculating asymmetry index (AI) of swing and stance times did not identify any asymmetry changes. The AI values were similar to those of chronic stroke patients described by Titianova et al. (2003). The step-time differential is calculated directly from the step time on the AS minus the step time on the NS, but the AI takes into account the entire gait cycle ((AS-NS) x 100 / (AS+NS)/2). During our intervention, the gait trainer provided symmetrical removal of weight from the lower extremities, integrated weight bearing, provided stepping and balance and stimulated repetitive and rhythmic stepping. Also the weight bearing of the lower limbs was controlled and a gradual increase in weightbearing was achieved. The gait trainer exercises, while assisting the symmetrical removal of the weight during the gait training, did not result in significant improvements in the symmetry of walking of the intervention group. The control group did not improve in gait symmetry either.

In study **III**, there was extensive individual variability in the step time changes. The wide individual variability of the patients was also seen even when the number of patients was enlarged in the new calculations of gait characteristics presented in the section 5.3.2. Some parameters showed different changes, but the gait velocity and stride length on both sides improved in both calculations, i.e. in the published study **III** and with the supplemental patients too.

The step time decreased more after rehabilitation in those patients in study **III** who had longer step time on the AS at the beginning. Barbeau & Visintin (2003) also claimed that sub-acute stroke patients with slower walking speeds (<0.2 ms^{-1}), lower overground walking endurance and lower motor recovery scores and elderly patients would most likely benefit from BWS training. Even though the walking speed of all chronic stroke patients in study **III** was faster than 0.2 ms^{-1} and they were relatively young, they also benefitted from physiotherapy and even more from combined BWS and other types of physiotherapy.

Hesse and his coworkers (Hesse et al. 1999b, Hesse et al. 2000) developed the mechanical gait trainer to assist patients to perform repetitive practice of the gait-like movement without overstraining the therapists. In their study among subacute, nonambulatory stroke patients performing six weeks of walking exercises they found no differences between treadmill training with BWS and gait trainer exercises using such outcome measures as Functional Ambulation Category, gait velocity, Rivermead Motor assessment score or Modified Asworth Score (Werner et al. 2002). The gait trainer was at least as effective as treadmill therapy with partial body weight support but it required less input from the therapist. In studies **III** and **IV**, the enhanced gait-oriented rehabilitation improved significantly the patients' spatio-temporal gait characteristics and other motor abilities.

The stimulation for stepping movements is important in activating the rhythmic locomotor patterns generated in the spinal cord. Although the basic motor pattern for stepping is generated in the spinal cord, fine control of walking involves numerous regions of the brain, including the motor cortex, cerebellum, and various sites within the brain stem. The bipedal type of human locomotion places major demands on the descending systems that control balance during walking. The spinal networks that contribute to human locomotion are more dependent on supraspinal centers than is the case in quadrupedal animals. The mechanism responsible for gait improvements may also be related to the functional brain reorganization following stroke which can utilize residual descending motor pathways, which are unaffected by the lesion and bilaterally organized (Bach-y-Rita 2003, Hsu et al. 2003). It may be that delayed, but appropriate, gait-oriented rehabilitation can support functional neural reorganization even many years after stroke leading to improvement in the patients' stability of walking.

6.4 THE EFFICACIES OF THE GAIT-ORIENTED REHABILITATION OBSERVED IN OTHER MEASURES IN CHRONIC STROKE

In study **IV**, although all patients were over six months post-stroke, they improved some aspects of their motor performance during the three weeks' rehabilitation. The intensive gait-oriented rehabilitation was effective irrespective of the type of exercise. In the study of Werner et al. (2002), chronic non-ambulatory stroke patients regained better walking ability through physiotherapy plus treadmill training with BWS than could be achieved by conventional therapy. However, they provided twice as much therapy for the treadmill group than for the conventional group and the obtained difference waned by four months. Also Trueblood (2001) showed treadmill training with BWS in chronic stroke patients to normalize gait and improve balance in their non-randomized clinical trial. Their results remained at three months follow-up. In the rehabilitation of subacute stroke patients there is evidence that three types of walking training, 1) on a treadmill with BWS or 2) on the ground following Motor Relearning Program or 3) using aggressive bracing are similarly effective (Kosak and Reding 2000, Nilsson et al. 2001). Furthermore, treadmill training with BWS was shown to be more effective than physiotherapy based on the commonly used Bobath concept in improving gait (Hesse et al. 1995a). In study **IV**, when the same amount of walking training was given, walking in the gait trainer with BWS (with or without electrical stimulation) and walking on the floor resulted in similar motor performance improvements in chronic stroke patients and at the follow-up at six months most of the improvements were still present.

Patients considered the exercise to be only slightly strenuous or strenuous, even though the amount was more than usually provided. The results of studies **I**, **III** and **IV**, where there were many repetitions, support the results that repetitive training appears to be the key to improved activity and functional ability of the paretic extremity (Dombovy 2004). The mean walking distance in the gait trainer groups was over 6700 meters compared to 4800 meters in the WALK group (**IV**). In the same time frame, the gait trainer allowed more repetitions of steps and a longer walking distance. The effect size calculation indicated a beneficial effect; if we look at it as the percentage of non-overlap it showed that 52 % of the GT_{stim} group benefited and 43 % of the GT group benefited compared to the WALK group. An additional advantage is that less manual guiding effort of the therapist is required if the patient is using the gait trainer compared to walking exercises overground. Previous studies have also indicated that retraining gait with BWS leads to a more successful recovery of walking of stroke patients and that the progressive decrease of BWS improves walking more effectively (Visintin et al. 1998, Barbeau and Visintin 2003). In studies **I, III** and **IV**, the effectiveness of exercise in the gait trainer was enhanced by adding speed and decreasing BWS, the patients were provided with BWS in the gait trainer and this allowed the patients to achieve proper trunk and limb alignment, gait pattern and walk. Patients reached below 20 % of BWS in the third session. Low weight support is important if one wishes to activate effectively the lower limb muscles and to keep energy expenditure high (Colby et al. 1999, MacKay-Lyons et al. 2001). It has been reported that BWS at 40 % results in a significant reduction in electromyography of the quadriceps and oxygen consumption decreases by 12 % (Colby et al. 1999). Also walking with 20 % BWS decreases the energy cost by 6 %.

In a study of subacute ambulatory stroke patients, the use of an interval training program on the treadmill to increase gait speed resulted in faster overground walking, increased cadence, stride length and FAC compared to training without speed increases or conventional gait training (Pohl et al. 2002). In their study, the effectiveness of sprint training at maximum speed (STT), limited progressive treadmill training (LTT) and conventional gait training (CGT) was compared. Patients were able to walk without assistance and the time required to walk 10 m ranged from 5 – 60 s. All patients participated in 12 training sessions during the four weeks' rehabilitation. The patients in the STT and LTT group used a harness, but the body-weight support, no more than 10 %, was allowed only in the first 3 training sessions. In the STT group, a detailed sprint-training program was used. In the LTT group, the training speed was increased no more than 5 % of the maximum initial walking speed each week. All patients received also 8 sessions (45 min) of conventional physiotherapy. After four weeks of training, the STT group scored higher than the LTT and CGT groups for overground walking speed, cadence, stride length, and Functional Ambulation Category. The results of Pohl et al. (2002) support the importance of progression of speed in walking exercises. In study **IV**, the patients were able to increase the gait trainer speed by 0.5 kmh^{-1} during the three weeks. The speed was added progressively, not by sprint-training program. In study **IV**, the increases in GT_{stim} and GT groups were 23.5 % and 29.4 %, whereas in the study of Pohl et al. (2002) the increase in the case of same initial walking speed on a treadmill in the LTT group could have been 17.7 %. Still, their LTT group exhibited significantly better improvements in walking speed, cadence, and FAC scores compared to CGT group based on the proprioceptive neuromuscular facilitation and the Bobath concept.

The patients in GT_{stim} group received functional electrical stimulation to two muscles in the paretic lower extremity. Due to the fact that the gait trainer provides the mechanical support to the ankle dorsiflexion, the stimulation of the peroneal nerve was not useful whereas in many studies of chronic stroke patients it is commonly stimulated (Granat et al. 1996, Burridge et al. 1997, Taylor et al. 1999). Hesse et al. (1995b) have compared combined treadmill training and multichannel electrical stimulation to a comprehensive neurodevelopmental physiotherapy program in non-ambulatory subacute hemiparetic patients. The patients improved their functional ambulation capacity only with combined treadmill training and electrical stimulation. The combined therapy proved to be more effective also in its ability to improve walking velocity (Hesse et al. 1995b). Barbeau et al. (1998) recommended combining treadmill training with functional electrical stimulation. In the present study, the stimulation of two muscles during walking in the gait trainer with surface electrodes did not add significantly to the improvements of gait compared to exercising without stimulation. In the review of Daly et al. (1996), it is stated that stimulation is useful (especially with intramuscular electrodes), furthermore the more muscles that are stimulated, the better improvements in gait to be expected.

In study **IV**, the WALK group had more possibilities to increase the demands of practice than GT groups for whom the maximum speed was 2 kmh^{-1}. The WALK group could practise without a cane or in different conditions and these could have contributed to the good progress achieved by the WALK group. It has been reported that more severely impaired and/or older subacute stroke patients can be mobilized more effectively using the BWS (Hesse et al. 1995a, Kosak and Reding 2000, Barbeau and Visintin 2003). In the present study (**IV**), the number of severely impaired patients was too small to allow comparison between those severely or less affected. The rather independent walking ability and young age (mean age 52 y) may explain the similar results achieved by all groups. In addition, the walking speeds of our patients were variable, which further obscured the differences between the groups.

The enhanced gait-oriented rehabilitation resulted in improvement in gait speed, gait endurance and motor tasks. After rehabilitation, our patients with chronic stroke walked 0.07 ms^{-1} (18 - 24 %) faster and their six minutes walking distance increased about 24 meters (14 – 17 %). These improvements are very much in line with the studies of Silver et al. (2003)

and Ada et al. (2003) of chronic stroke patients. In the study by Ada et al. (2003), twelve sessions of four weeks of combined treadmill and overground walking training resulted in 0.18 ms^{-1} (24 %) increase in walking speed (10 m) and 99 m (26 %) increase in walking capacity (6 min). Their patients' initial walking velocity was 0.62 ms^{-1} whereas that of our patients' was 0.24 ms^{-1}. Their initial six minutes walking distance was 296 m whereas in the present study it was 112 – 152 m. It appears that with additional effort a 20 – 30 % increase in walking speed of chronic stroke patients can be obtained. The variability of the results showed that patients were quite heterogeneous irrespective of fulfilling the inclusion criteria, for example the walking speed range was 0.07 – 1.11 ms^{-1}.

The patients' initial MMAS was only about 42 % of the maximum score and this was mainly attributable to the asymmetrical weight shifting and the paretic upper limb. Two weeks of rehabilitation produced an improvement of two points and the third week gave another point in MMAS. On closer consideration, with the exception of the two hand items, improvements were seen in MMAS in all items (Fig 11). In previous studies of chronic stroke patients the motor performance improved, but the handicap/independence scales did not change (Ada et al. 2003). Also in the present study the total FIM remained stable throughout, but interestingly the subitems of personal care and locomotion improved significantly during the rehabilitation period (Fig 11).

Not only electromechanical walking training has been able to evoke improvement in overall fitness reserve in stroke patients (Macko et al. 1997a, Macko et al. 1997b, Danielsson and Sunnerhagen 2000, Macko et al. 2001, Katz-Leurer et al. 2003). The effects of three 40-min sessions of treadmill training weekly for six months were studied in 19 chronic hemiparetic patients (6 – 81 months post-stroke) (Macko et al. 2001). Treadmill training was started at a mean of 0.63 ms^{-1} and progressively increased to the 0.85 ms^{-1} at the end. The three months of training produced a significant 10 % increase in absolute Vo_2peak, from 1.18 $lmin^{-1}$ at baseline to 1.31 $lmin^{-1}$ at 3 months. The mean economy of gait improved 15 %, from 9.3 $ml \cdot kg^{-1} \cdot min^{-1}$ to 7.9 $ml \cdot kg^{-1} \cdot min^{-1}$. After 3 months, these improvements in peak exercise capacity and economy of gait enabled patients to perform the same constant-load submaximal effort treadmill walking task using 20 % less of their peak exercise capacity. Although improvements in Vo_2peak, economy of gait, and fractional utilization were maintained for 6 months of training, no further gains were found in patients who completed the entire training program, beyond the gains recorded after 3 months of training. The estimated peak ambulatory work load capacity increased progressively by 39 % across the 6-month training program. Mean respiratory exchange ratio and heart rate during peak effort exercise testing were virtually identical during those tests conducted at baseline and after 6 months, indicating equivalent cardiovascular-metabolic efforts. During three weeks of gait training every workday (study **IV)**, the heart (HR) level of the patients was around 100 beats/min throughout the walking exercises. It is possible that their medications could have accounted for the low HR level as the heart rate in rest showed that the change in HR was quite small. The heart rate at rest varied between 64 – 72 in the different groups (table 4). The results of subjective feelings of perceived exertion are in line of the results of low HR. They perceived that they were working only slightly strenuously during 20 minutes walking exercise (mean Borg Scale 13.1 p – 14.0 p, table 9, study **IV**) and the same situation occurred during additional physiotherapy (mean Borg Scale 13.5 p, study **I**). It might have been interesting to measure oxygen consumption, however we had only 15 sessions, which is not very much if one wishes to improve fitness reserve. However it is likely, that the poorer the fitness is in the beginning the more rapidly positive results can be achieved.

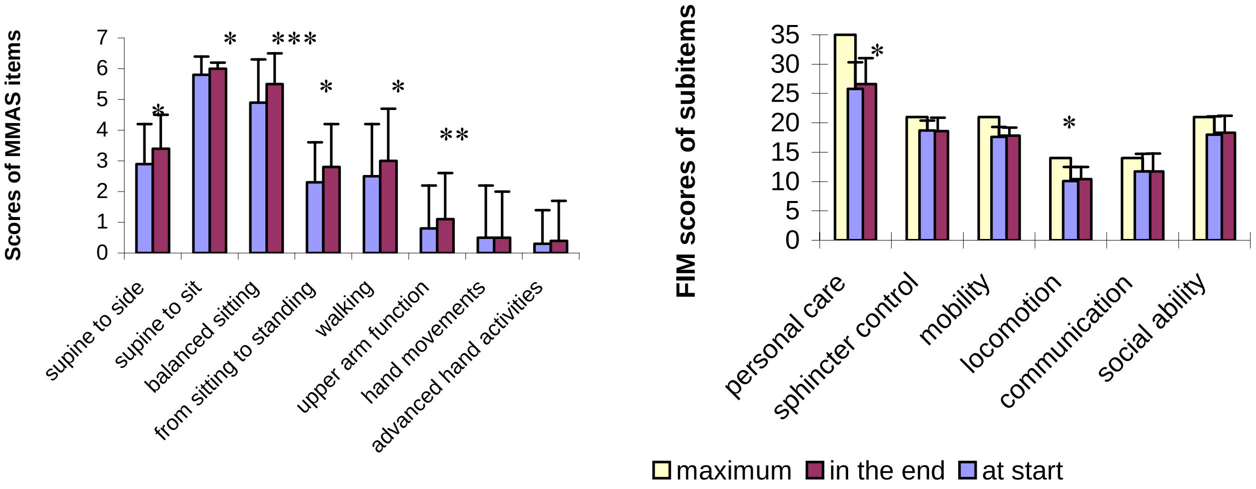


Figure 11. The scores of Modified Motor Assessment Scale (MMAS) items and Functional Independence Measurement (FIM) subitems at start and at the end of rehabilitation in 45 chronic stroke patients. The maximum of MMAS of each item is 6. The maxima for FIM scores in the various are 35, 21, 21, 14, 14 and 21. P values obtained using paired sample t-test * = p<0.05, ** = p<0.01, *** = p<0.001.

Smith et al. (1999) hypothesized that a 12 weeks program of regular “task-oriented” treadmill aerobic exercise would improve lower extremity muscle strength, reduce spastic reflexes, and normalize the symmetry in motor output between limbs in chronic hemiparetic stroke patients. Their fourteen patients (7 months – 6.7 years post-stroke) participated for three times per week for three months in the treadmill exercise. The training intensity was limited at the beginning of the study to 40 % of the calculated HR reserve and increased as tolerated to targeted levels. Patients progressed over the course of the training program to 40 min of continuous exercise at 60 % to 70 % of their previously calculated HR. Five-minute warm-up and cool-down periods at 30 % of HR were included in each training session. Repeated measures of reflexive and volitional torque were obtained from the hamstrings musculature bilaterally with the isokinetic dynamometry. Torque generation was measured at four angular velocities. At post-testing, the concentric hamstring torque production improved on both sides. The eccentric torque production was different depending on the limb tested and the angular velocity. The within-limb concentric torque/time production measure increased by 50 % and eccentric torque/time production increased by 21 % in the affected limb after the intervention. In the nonaffected limb, the increases were 32 % and 22 %. Passive torque/time generation in the paretic hamstrings decreased by 11 %. Reflexive torque/time was unchanged in the nonparetic hamstrings. In study **IV**, muscle forces were measured clinically by the Motricity Index. In the GT groups, the muscle force of the ankle dorsiflexion or hip flexion increased significantly, but the power of knee extension force did not change suggesting that muscle force can be increased by gait trainer exercise. In the WALK group, the muscle forces did not change.

In Finland, if a patient fulfils the handicap criteria, the National Social Insurance Institution provides rehabilitation for patients less than 65 years of age. That usually consists of one in-patient period once a year in addition to outpatient rehabilitation depending on the individual needs and aims. This study was made while the patients attended the rehabilitation period in a rehabilitation hospital. The mean age of the patients (study **I – IV**) was only 52 years, however it has been previously suggested that older patients benefit more from BWS training, we showed that younger patients benefit too. In the studies listed in table 1, mean age has varied from 52 to 71. In twelve of the studies, the mean age was 60 or over. The range was quite large in some studies (Visintin et al. 1998, 27 – 93 y, Werner et al. 2002a, 29 – 77 y and Hesse et al. 1994, 15 – 84 y). In study **IV**, the age range was 33 – 64. This study population (**I – IV**) represents the usual population in in-patient rehabilitation. Those patients with only a mild handicap or those very severely handicapped who are in institutional care are not included in these studies. The protocol was quite demanding (study **I, III, IV**). Twenty minutes walking exercises for patients with the FAC 1 (need two assistants to walk) could have resulted in dropouts. The four patients with FAC 2 (need someone for support to maintain balance while walking) ranked their exertion as rather high point on the Borg Scale. However the mean of the Borg Scale was at the level of only slightly strenuous. Finally, although the rest of the patients were quite independent walkers, they were all slow. For example, the safe speed to across the road is 1.2 ms^{-1}, but in study **IV**, their mean speed was 0.24 ms^{-1} at the beginning and the fastest speed was 1.25 ms^{-1}. During the studies, the principal researcher knew in part to which group the patients belonged. She supervised the physiotherapists about the exercise therapy and provided support and encouragement. Recordings were performed always at the same time of the day by the same researcher in the same order.

In the meta-analysis of 20 studies in stroke patients (Kwakkel et al. 2004), the duration of rehabilitation varied from four weeks to six months. In studies **I, III** and **IV**, the duration of rehabilitation was three weeks. In the future, a longer duration of rehabilitation could be beneficial. However, the daily minutes of physiotherapy in the gait-oriented groups were more than in most of the studies referred to by Kwakkel et al. (2004), where they presented the effects of intensity of augmented exercise therapy time on activities of daily living, walking, and dexterity in patients with stroke. Only in one study the patients had more than 75 minutes of daily exercise, Stern et al. 1970), 100 minutes in the intervention group). In studies **I, III**, and **IV**, the therapy time was calculated from the actual time of exercise. For example, the twenty minutes walking exercise was the actual time, but about 35 minutes was needed with the physiotherapist to achieve this 20 min. The time to put on the harness and to transfer to the gait trainer and the possible rest on the gait trainer was omitted.

General agreement on the concepts and on the instruments to be used in stroke disability assessment could facilitate the comparability of research findings and the improvement of stroke care. To achieve a comprehensive framework and classification, the new International Classification of Functioning, Disability and Health (ICF 2001) has been developed. For practical purposes, the consensus process of the special versions of the ICF Core Sets for different diseases is still on-going. The ICF Core Sets for stroke includes the Comprehensive ICF Core Set and the Brief ICF Core Set (Geyh et al. 2004). The preliminary studies identified a set of 448 ICF categories at the second, third and fourth ICF levels with 193 categories on body functions, 26 on body structures, 165 on activities and participation, and 64 on environmental factors. Altogether 130 second-level categories were included in the Comprehensive ICF Core Set with 41 categories from the component body functions, 5 from body structures, 51 from activities and participation, and 33 from environmental factors. The Brief ICF Core Set included a total of 18 second-level categories (6 on body functions, 2 on body structures, 7 on activities and participation, and 3 on environmental factors). In studies **I – IV**, the assessment of heart functions (HR), proprioceptive functions (position sense), muscle power functions (MI), muscle tone functions (MAS) and exercise tolerance functions (Borg Scale), memory functions (FIM) belong to body functions in ICF. Maintaining a body position (postural recordings), transferring (MMAS), walking (FAC, MMAS, 10 m, 6 min, walkway) and hand and arm use (MMAS) belong to activities and participation in ICF as well as toileting, dressing, eating, communication, social interaction and problem solving (FIM). Thus, we assessed and trained mainly in the area of activities and participation. Although both activities and participation belong in one subitem of ICF, the effects here were mainly observed in activities, however, the total FIM did not change. The concentration of the rehabilitation was mainly on gait, but all patients also received other professional stroke rehabilitation in addition to the walking training and other forms of physiotherapy. After returning to their homes, outpatient physiotherapy was continued from one to three times a week. This probably has helped patients to maintain their positive results.

Finally it is important to note that while the gait-oriented exercise groups did not differ in the measures used, in the GT groups patients performed more repetitions of steps and longer walking distance with less input needed from the therapist. While repetitions of practice can be increased, more information is needed to determine what kinds of patients would benefit most of those repetitions.

7 CONCLUSIONS

The main purpose of this thesis was to evaluate gait rehabilitation in patients with chronic stroke. This was done by detailed investigation of specific areas affecting the total gait rehabilitation outcome. The following conclusions can be drawn:

Walking tests indicated that all patients improved their gait after special effort. In contrast to the results of the Copenhagen study (Jorgensen et al. 1995c), which detected no further improvement of gait function in hemiparetic patients three months post-stroke, gait improvements in patients more than six months post-stroke were obtained. When sufficient time is spent in active and focused exercise, even chronic stroke patients can obtain beneficial results. In addition, they were motivated and perceived their exercise only slightly strenuous. In study I, the total time of instructed physiotherapy was 19 hours and together with self-initiated training patients practised for 28 hours resulting in improved motor ability after three weeks of gait-oriented rehabilitation. Patients practised in upright position 64 % of instructed physiotherapy including walking and standing exercises.

Patients seemed to depend on a large postural sway to maintain their standing posture as seen in the speed of center of pressure displacements. Chronic stroke patients swayed three times more than healthy subjects. During the intensive gait-oriented rehabilitation, the static balance did not change, but the dynamic balance improved by 28 – 48 %. Frequency analysis of sway parameters suggested that the postural stability may have specific characteristics due to the side of the hemiparesis. Further studies are needed to clarify this finding.

The gait-oriented physiotherapy combined with BWS assisted to increase the amount of walking practise resulting in an improvement of spatio-temporal gait characteristics not seen when compared to physiotherapy without any special effort on gait. The improvements in Functional Ambulation Profile, gait velocity, step lengths, stride lengths and step-time differential remained at the achieved level at the follow-up assessment at six months. However, less sensitive measures of motor ability showed no differences in improvements between gait-oriented physiotherapy and physiotherapy without any special effort on gait.

Moreover, no differences in motor abilities were found between different gait-oriented rehabilitation strategies. Patients with chronic stroke maintained their improved dynamic balance and improved walking speed, walking endurance, and improved gait characteristics at least six months after the intensive gait-oriented rehabilitation. Gait trainer exercise with BWS and overground walking exercise were both good choices for ambulatory stroke patients, who were slow but fairly independent in their gait. An additional advantage was that the gait trainer allowed more repetitions of the physiological gait cycle. Also less manual guiding input from the therapist is required if the patient is using the gait trainer compared to walking on level ground.

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APPENDIX: ORIGINAL PUBLICATIONS I – IV

I

How much exercise does the enhanced gait-oriented physiotherapy provide for chronic stroke patients?

Peurala SH, Pitkänen K, Sivenius J, Tarkka IM

Journal on Neurology 2004, 251; 449 – 453.

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II

Postural stability in patients with chronic stroke

Peurala SH, Könönen P, Pitkänen K, Sivenius J, Tarkka IM

Submitted

III

Gait characteristics after gait-oriented rehabilitation in chronic stroke

Peurala SH, Titianova EB, Mateev P, Pitkänen K, Sivenius J, Tarkka IM

Restorative Neurology and Neuroscience 2005, 20: in press

IV

The effectiveness of body-weight supported gait training and floor walking in chronic stroke patients

Peurala SH, Tarkka IM, Pitkänen K, Sivenius J

Archives of Physical Medicine and Rehabilitation 2005, 20: in press

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