Physical performance and physical activity in the later stage post-stroke

Cristiane Carvalho Meirelles

Department of Clinical Neuroscience and Rehabilitation
Institute of Neuroscience and Physiology
The Sahlgrenska Academy at the University of Gothenburg

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cristiane.carvalho@neuro.gu.se
cricous@hotmail.com

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From the Institute of Neuroscience and Physiology / Rehabilitation Medicine.
The Sahlgrenska Academy at the University of Gothenburg,
Göteborg, Sweden

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Luiz, Alice & Stella

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Cristiane Carvalho Meirelles, Institute of Neuroscience and Physiology / Department of Clinical Neuroscience and Rehabilitation
The Sahlgrenska Academy at the University of Gothenburg, Göteborg, Sweden

ABSTRACT

Aims: The overall purpose of this thesis was to increase knowledge about physical performance and activity in the later stage post-stroke by measuring walking performance in different environments coupled to muscle strength, cardiorespiratory fitness evaluation and self-reported physical activity.

Methods: The studies reported in the thesis included a total of 83 subjects with prior stroke living in the community and 144 clinically healthy subjects from the same area. In study I, walking performance (speed and distance) were assessed indoors and outdoors in 36 subjects after stroke, who were divided into slow and fast walkers. Study II evaluated the relationship between muscle strength in the lower extremities and walking performance (speed and distance) in 41 subjects after stroke and 144 healthy reference participants. The correlation between maximal exercise capacity measured during one-legged bicycling test and the 6-minute walking test (6MWT) were examined in 34 subjects after stroke in study III. The influences of motor function and balance on the 6MWT were also investigated. Study IV compared self-reported physical activity in 70 persons with stroke compared to 141 healthy subjects and explored the relationship between this and physical measures.

Results: There were no differences in the short and long distance walking test for the slow walkers between different environments. However, those who walked faster walked a longer distance in the outdoor setting. The actual distance walked in the 6MWT was significantly shorter than the distance predicted by 30-meter walking test (30mWT) for both groups in the indoor environment. The parametric model provided evidence for a non-linear relationship between walking performance and strength index. The model explained 37% of the variance in self-selected speed in the stroke group and 20% in the healthy group, and 63% and 38%, respectively, in maximum walking speed. For the 6MWT, the model explained 44% of the variance in the stroke group. Low to moderate correlations were found between the 6MWT and one-legged bicycling measurements in the paretic leg, such as VO_{2peak}, W_{max} and total exercise time. There was a moderate to high correlation between specific stroke impairments and the walking test. The self-reported physical activity was moderately correlated with walking speed. A regression model with the self-reported physical activity as the dependent variable and age and self-selected walking speed as independent variables explained approximately 30% of the variation in the stroke group. In both groups, only the walking speed showed a significant contribution to the model.

Conclusions: The environment has an impact on walking performance. Walking speed measured over a short distance seemed to overestimate long distance walking capacity for the slow walkers, despite the environment. A non-linear relationship was found between muscle strength in the lower extremity and walking performance. For those that are weak, changes in muscle strength have a stronger impact on walking. It seems that factors other than cardiorespiratory fitness influence the 6MWT. HR and SBP indicate cardiovascular stress, but the use of only the 6MWT distance as an indicator for cardiorespiratory fitness cannot be recommended. Physical performance including walking performance, muscle strength, cardiorespiratory fitness and self-reported physical activity was below the level of healthy controls. As low levels of physical activity are regarded as a large health-threatening problem in the general population, it is of major importance to find ways to promote physical activity for persons with disabilities.

Keywords*:* cerebrovascular accident, exercise test, gait, healthy control, muscle strength, physical activity, physical therapy, rehabilitation, secondary prevention, stroke, walking.
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LIST OF ORIGINAL PAPERS

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

I. **Carvalho C**, Sunnerhagen KS, Willén C.

Walking speed and distance in different environments of subjects in the later stage post-stroke.

Physiotherapy Theory and Practice 2010; 26: 519-527.

II. **Carvalho C**, Sunnerhagen KS, Willén C.

Walking performance and muscle strength in the later stage post-stroke: a non-linear relationship.

Submitted.

III. **Carvalho C**, Willén C, Sunnerhagen KS.

Relationship between walking function and one-legged bicycling test in subjects in the later stage post-stroke.

Journal of Rehabilitation Medicine 2008; 40:721-726.

IV. Danielsson A, **Carvalho C**, Willén C, Sunnerhagen KS.

Cross-sectional data on physical activity in community-dwelling stroke survivors compared to a healthy population.

Submitted.

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CONTENTS

ABBREVIATIONS

ADL	Activities of daily living
AFO	Ankle-foot orthosis
ATS	American Thoracic Society
BBS	Berg Balance Scale
BMI	Body mass index
BP	Blood pressure
CRF	Cardiorespiratory fitness
CIMT	Constraint-induced movement therapy
HR	Heart rate
LOA	Limits of agreement
m	meter
min	minutes
Nm	Newton meter
NP	Non-paretic leg
PA	Physical Activity
PASE	Physical Activity Scale for the Elderly
PL	Paretic leg
SBP	Systolic blood pressure
SD	Standard deviation
Sec	seconds
VO_2	Oxygen consumption
$VO_{2\ max}$	Maximal oxygen consumption
$VO_{2\ peak}$	Peak oxygen consumption
W_{max}	Maximal workload
6MWT	6-minute walk test
30mWT	30-meter walk test

DEFINITIONS

Borg CR-10 scale	Standard method to evaluate perceived exertion in exercise testing, training and rehabilitation. This is used especially in clinical diagnosis of breathlessness and dyspnea, chest pain, angina and musculo-skeletal pain. Category scale with ratio properties consisting of numbers related to verbal expressions, which allows rate comparison between intensities as well as a determination of intensity levels.
Maximal oxygen consumption ($VO_{2\ max}$)	The highest oxygen consumption achieved during dynamic exercise with large muscle groups. $VO_{2\ max}$ is regarded by most authors as the best single measure of aerobic capacity.
Peak oxygen consumption ($VO_{2\ peak}$)	The highest oxygen consumption achieved in a patient population where all the criteria for $VO_{2\ max}$ cannot be fulfilled.
Isokinetic testing	Exercise performed with a specialized apparatus that provides variable resistance to a movement so that, regardless of how much effort is exerted, the movement takes place at a constant speed.

1 INTRODUCTION

1.1 Stroke

Stroke is defined by the World Health Organization [1] as "a clinical syndrome consisting of rapidly developing clinical signs of focal (or global in case of coma) disturbance of cerebral function lasting more than 24 hours or leading to death, with no apparent non-vascular cause". Stroke includes cerebral infarction (approximately 85%), intracerebral hemorrhages (around 10%) and subarachnoid hemorrhages (5%) [2].

Stroke is the second most common cause of death worldwide [3] and the most common cause of long term adult disability [4]. In Sweden, with a population of nine million inhabitants, about 30 000 patients are hospitalized due to stroke annually, and 23 000 of these suffer a first-ever stroke [5]. Stroke risk increases with age. For each decade after age 55, the risk of stroke doubles. In Sweden the median age for having a stroke is 74 years for men and 78 years for women, with more than 20% younger than 65 years old [5, 6]. In Brazil, the latest year with official health statistics available (2005), considering all causes of death, stroke (either type) is still the leading cause of mortality, with 90 000 deaths; and coronary heart disease is the second most common cause, with 85 000 deaths [7]. There are several risk factors for stroke, many similar to those for cardiovascular disorders. Generally, risk factors for stroke can be classified as non-modifiable and modifiable. Well-documented non-modifiable risk factors for stroke include age, gender, family history, ethnicity and previous stroke or transient ischemic attack. The modifiable risk factors can be classified as (I) modifiable behavioral risk factors, such as tobacco use and smoking, alcohol use, unhealthy diet, obesity and physical inactivity; and (II) treatable risk factors, such as hypertension, diabetes mellitus, hypercholesterolemia and heart disease such as atrial fibrillation [8, 9].

A recent systematic review of population-based studies of the incidence and early (21 days to 1 month) case fatality of stroke based on studies published from 1970 to 2008 found a 42% decrease in stroke incidence in high income countries and a greater than 100% increase in stroke incidence in low to middle income countries [10]. Furthermore, there is a predicted increase of stroke frequency along with other non-communicable diseases in the future, especially in rapidly developing regions, which means that disability is also a growing problem [11].

However, the absolute number of strokes continues to increase because of the ageing population [2]. Stroke is associated with significant morbidity, as well as mortality, leaving many survivors permanently disabled. Despite modern medical treatment, new drugs, multidisciplinary rehabilitation and stroke units, still about half of stroke survivors are discharged with disabling sequelae often remaining for the rest of their lives [12].

1.2 Disability after stroke

Disability is the umbrella term for impairments, activity limitations and participation restrictions referring to the negative aspects of interaction between an individual and that individual´s contextual factors [13]. Disability following stroke affects all levels of functioning [14-16] and frequently persists many years after stroke [14] and seems not to change significantly over time [17].

The effects that stroke may have on survivors are as diverse as the individuals themselves. The manner and severity by which the victim is affected depends on the location in the brain of the stroke and the amount of brain damage that occurred. As some epidemiological studies illustrate, disability following stroke appears in the form of neurological dysfunctions (e.g. motor, sensory, visual) and limited ability to perform activities of daily living (ADL) [16], as well as neuropsychological deficits (e.g. attention, memory, language) [18].

Impairment of motor function involves paralysis or paresis of the muscles on one side of the body contralateral to the site of the brain lesion. Motor impairments are the most commonly reported impairments after acute stroke, with lower extremity motor deficits present in 72% of patients one week after the onset of first-ever stroke [19]. Impaired balance is also common after stroke, and about 50% of the patients admitted to further rehabilitation were found not to be able to stand without support one month after the onset of stroke [20]. Although ≈ 14% of stroke survivors achieve full recovery in physical function, between 25% and 50% require at least some assistance with ADL, and half experience severe long term effects such as partial paralysis [21]. The impairments resulting from stroke, in addition to the lack of accessible and appropriate community-based exercise programs, can lead to reduced tolerance to activity, continued sedentary lifestyle, and additional declines in function and disability status [22]. These individuals will continue to experience activity and participation limitations that will reduce their quality of life [16]. Evidence shows that most recovery seems to occur in the first few weeks after stroke [23]; however, people may present improvements months or even years later [24]. Even though it is stated that patients reach a limit in their recovery within 6 to12 months after their stroke [25], results of several studies suggest that these plateaus are not due to a reduced capacity for motor recovery but to adaptive states that occur as patients become physiologically accustomed to rehabilitation exercises [26, 27].

Some studies, although with a small number of patients, have indicated that chronic stroke patients can exhibit continued motor improvement with novel rehabilitation protocols [26]. According to the South London Stroke registry, between 20% and 30% of stroke survivors have a poor range of outcomes up to ten years after stroke [28].

1.3 Muscle function

Following a stroke, muscle weakness arises for two reasons: Primarily from the lesion itself, as a result of a decrease in descending inputs converging on the final motor neuron population, and hence a reduction in the number of motor units available for recruitment [29]. Since skeletal muscle adapts to the level of use imposed upon it [30], secondary cause of weakness arise as a consequence of lack of muscle activity and immobility [31]. The distribution of muscle weakness also varies among individuals, probably reflecting such factors as lesion location and size [29, 32]. Evidence suggests that both lower extremities after acute stroke seem to be affected when compared with control subjects [33-37]. In addition, the weakness seems to start to develop after as little as 48 hours after stroke onset [34].

Compared to the less affected leg (non-paretic leg, NPL), the paretic leg (PL) after stroke shows reduced blood flow, greater lactate production and a greater utilization of glycogen plus a diminished oxidative capacity [38]. Changes to muscle fiber type include severe atrophy of type II muscle fibers and a predominance of type I fibers (also atrophied) during later stages [39]. Paretic muscles also have reduced oxidative capacity and decreased overall endurance [40].

Reduced muscle strength has also been recognized as a limiting factor in stroke rehabilitation [41]. Moreover, previous studies have documented a positive relationship between muscle strength and functional performance. Increased strength in the lower extremity muscles (hip and knee flexors and extensors, ankle dorsal and plantar flexors) has been shown to be associated with improvements in mobility such as walking performance [42-45], ability to balance [43] and stair climbing [45].

Muscle weakness has traditionally been measured with the use of a manual muscle test, a 6-point ordinal scale that ranges from no strength to normal strength. Now, with the increasing availability of sophisticated computer interfaced equipment, weakness may be quantified more precisely. The isokinetic dynamometer has been used for isometric and isokinetic testing in subjects post-stroke and has been shown to be reliable and valid as an outcome measure in clinical trials [46, 47].

1.4 Walking after stroke

According to the International Classification of Functioning, Disability and Health (ICF), walking is one of the most important domains of the activities and participation components [48, 49]. Walking is a complex, whole-body action that requires the cooperation of both legs and coordination of a large number of muscles and joints to function together [29]. Functional walking recovery depends on many factors such as the adaptive reorganization of cortical and sub-cortical structures, including the spinal cord and the spared sensorimotor pathways that communicate at many different levels [50].

Restoration of mobility in an attempt to regain the ability to walk independently is one of the main goals in stroke rehabilitation. A patient's independent mobility at home and in the community can be severely restricted after a stroke [51]. The Copenhagen stroke study [52] 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. A recent study showed that walking activities were among the major restricted and limited activities [53].

The asymmetrical nature of hemiparetic walking is well documented in persons after a stroke [54], with the asymmetries in spatiotemporal, kinematic and kinetic parameters of walking related to disturbances in motor coordination [55]. A typical finding in hemiparetic walking is that the stance phase of the non-paretic leg is both longer and occupies a greater proportion of the gait cycle in comparison with the paretic leg [29]. Furthermore, during the stance phase, reduced hip extension, increased knee flexion or hyperextension, and, during the swing phase, insufficient hip and knee flexion and reduced ankle dorsal flexion are some of the consequences of hemiparetic walking [56]. Some of the walking deficits following a stroke include both decreased walking speed [51, 57] and decreased walking endurance [58]. Balance can also be affected and may influence functional mobility and increase the risk for falling [59]. In addition, impaired walking is itself a risk for falling during the first year after stroke [60]. Furthermore, walking dysfunction arises not only from impairments associated with the lesion but also from secondary cardiovascular and musculoskeletal consequences of disuse and physical inactivity [29].

A walking speed of 1.1 to 1.5 m/s is considered to be fast enough to function as a pedestrian in different environmental and social contexts [29]. However, according to the study of Hill et al. [61], only 7% of post-stroke patients discharged from rehabilitation met the criteria for community walking, which included the ability to walk more than 500 m at a speed necessary to cross a street during a green light. After stroke, subjects walked shorter distances and at slower speeds in comparison with healthy controls [57]. Walking speed and endurance, such as short distance walking (10-m walk test [10mWT] [62] or 30-m walk test [30mWT] [63]) and long distance walking (6-minute walk test [6MWT] [58, 64]), have been used in both clinical practice and research and are also often used to predict and assess community ambulation [65]. In addition, to obtain sufficient information on adequate walking speed, both self-selected and maximum walking speed must be recorded. Maximum speeds may be important in order to function in community-based activities such as crossing a street [66]. Moreover, a recent study showed that the majority of subjects in the chronic phase after stroke preferred to walk longer distances than to walk at faster speeds in order to better engage in activities both at home and away from home [67].

1.4.1 Walking in different environments

Different environments may require different walking capacity since the performance of the activity emerges from an interaction of the individual with the task and the environment [68]. It seems that environment has an impact on walking capacity in healthy populations [69, 70]. Physical performance may vary with indoor and outdoor activity. In addition, most walking tests are performed in laboratory and hospital settings, which may not reflect the different environments in which post-stroke subjects usually ambulate on a daily basis. The laboratory and hospital settings are less complex than the environment typically encountered in outdoor settings. Moreover, the results obtained from indoor walking tests in stroke rehabilitation programs are frequently used to advise patients about outdoor activities, but those recommendations are not based on any scientific evidence. Only a few studies [71-73] have compared walking performances of stroke populations in varied environments (e.g. suburban street, shopping mall, car park, supermarket as outdoor environments), which are very different from tests in the clinic, and there is limited information about the relevance of walking ability measured indoors for outdoor walking.

1.5 Cardiorespiratory fitness and physical activity

Cardiorespiratory fitness (CRF) reflects a person's ability to carry out large-muscle, dynamic, moderate-to-high intensity exercise over a prolonged period of time [74]. CRF varies with age, gender, level of physical activity, body composition and the absence or presence of a chronic disease or disability [75]. Physical activity is defined as any bodily movement produced by skeletal muscles resulting in energy expenditure. Exercise is classified as a subcategory of physical activity, and the definition is a physical activity that is planned, structured and repetitive for the purpose of conditioning any part of the body [76]. Reduced CRF and inactivity after stroke appear to be related to a combination of pathological (comorbid cardiovascular disease, coronary artery disease), physiological (decreased muscle activation and motor control, and changes in muscle length and stiffness) and environmental factors (little opportunity or incentive for physical activity) [77]. In addition, stroke survivors are also predisposed to a sedentary lifestyle that limits the performance of activities of daily living and affects their independence and community participation, increases the risk for falls and may contribute to a heightened risk for cardiovascular disease, recurrent stroke [78] and stroke mortality [79]. A recent systematic review demonstrates that $VO_{2\ peak}$ among the stroke population is substantially lower than that of age and gender matched healthy controls (~53%) and probably remains lower for many years after stroke [80]. Stroke patients may self-select a speed that requires the least energy [81] and may not have the ability to increase this without increasing energy demands beyond their capacity [82]. In addition, patients' CRF can deteriorate during the recovery phase of a stroke and can impair active rehabilitation [78].

The individual physical activity level is an independent risk factor for cardiovascular disease, stroke and death, as well as a possible target for improving health outcome [83]. Therewith it is important to continuously assess physical activity (PA) levels after stroke and to identify persons who need support to increase their PA level, which may be lower than optimal [84, 85]. In general, questionnaires are an easy, acceptable and relatively inexpensive method to assess PA levels in large study populations [86]. The Physical Activity Scale for the Elderly (PASE) questionnaire contains items on leisure, household and occupational activities and has been found to correlate with measures of strength, aerobic activity and balance capacity in persons with mild stroke [87].

CRF is not only an objective measure of habitual physical activity but also a useful diagnostic and prognostic health indicator for patients in clinical settings. Most often, CRF is measured using a metabolic cart for gas analysis and exercise equipment (e.g. treadmill, recumbent stepper or cycle ergometer) to determine peak oxygen-consuming capacity ($VO_{2\ peak}$) and is quantified during exercise to complete exhaustion [88-90]. $VO_{2\ peak}$ is considered the "gold standard" indicator in the assessment of cardiovascular fitness and this type of test requires sophisticated and expensive equipment and specialized personnel and is time-consuming [74]. Pedaling is a functional activity that can be used by patients after stroke at a very early stage of rehabilitation and has been used as a tool to evaluate aerobic capacity in this population [91]. One-legged bicycling has been used as an assessment tool in patients with hemiparesis [38, 92] in order to reduce the effect in the test of the leg with the greatest impairment. The 6-mimute walk test (6MWT) has been found to be a valuable measure of cardiovascular exercise capacity in elderly subjects with respiratory disease and chronic heart failure [93, 94]. The distance walked in 6 min in this population has been demonstrated to have a moderate to high correlation with $VO_{2\ peak}$ during bicycle or treadmill exercises tests [95, 96]. Studies have investigated the relationship between endurance exercise capacity (VO_{2max} or $VO_{2\ peak}$) and walking capacity (6MWT) in sub-acute patients and those after chronic stroke, but the results are contradictory [97-99].

A meta-analysis (*n*=480) supported the use of aerobic training to improve CRF in individuals with mild to moderate motor deficit post-stroke and suggested that aerobic training is an important component of stroke rehabilitation [100].

1.6 Rehabilitation

Rehabilitation aims to enable people with impairments and activity limitations to reach and maintain optimal functioning in physical, intellectual, psychological and/or social domains [49]. Rehabilitation goals can shift from initial input to minimize impairment to more complex interventions that are designed to encourage active participation [101]. There is substantial evidence in support of the multidisciplinary team, such as nurse, physiotherapist, occupational therapist, physician, psychologist, social work and speech therapist for effective delivery of stroke rehabilitation [102]. They provide an organized package of care through a cyclical process involving assessment, goal setting, intervention and reassessment, which is typical of stroke rehabilitation [103].

Stroke rehabilitation is of increasing interest because of recent developments in brain research. Cortical plasticity and reorganization can be stimulated by sufficient and focused rehabilitation [104]. Three principals have been identified to achieve an effective rehabilitation after stroke: functional approach targeted at specific activities (e.g. walking, activities of daily living), frequent and intense practice, and rehabilitation commencement in the first days or weeks after stroke [105]. Stroke rehabilitation also provides an opportunity to ensure that patients are not only prepared for discharge but also understand the need to continue physical activity after discharge in order to increase their motor skill and fitness levels [77].

The Stroke Unit Trialists' Collaboration has demonstrated improved survival and functional outcomes for patients treated in a dedicated stroke unit care [102]. Furthermore, a systematic review suggested that therapy-based rehabilitation services for patients living at home after stroke reduce the odds of a poor outcome, i.e. death or deterioration in ability to perform activities of daily living, and has a beneficial effect on a patient's ability to perform personal activities of daily living and extended activities of daily living [106]. In addition, a meta-analysis has shown that community stroke rehabilitation of any kind delivered within one year of hospital discharge reduces the incidence of functional deterioration and maintains or improves ADL [107]. However, there are few studies of rehabilitation offered in the "chronic" phase of stroke, i.e. more than one year after the acute event [108].

Although some individuals with stroke will have received some rehabilitation during the acute and sub-acute phases, rarely does rehabilitation extend beyond one year post-injury owing to the belief that a plateau in functional recovery has been reached by this time and also owing to a lack of resources for long term services [109].

1.6.1 The International Classification of Functioning, Disability and Health (ICF)

The ICF [49] provides among other things a frame of reference that is helpful for choosing the proper measures for an intervention when the outcome variable is known. ICF is considered relevant for clinical settings, health services or surveys at both the individual and population level, and has gained increasing attention in rehabilitation medicine. The consequences of a stroke can be understood in the context of the ICF model. The model includes body structure and function, activity and participation. Furthermore, the model is not restricted only to treatment of the body but also embraces environmental and personal factors that are important to understand the complexity of the rehabilitation [49]. The present thesis addresses the subsequent ICF domains: body structures and function and activity.

1.7 Physiotherapy

According to the World Confederation for Physical Therapy, physiotherapy includes developing, maintaining, and restoring maximum movement and functional ability throughout life, and comprises different circumstances where movement and function are threatened by ageing, injury, diseases, disorders, conditions or environmental factors. In addition, physiotherapy is concerned with identifying and maximizing quality of life and movement potential in the spheres of promotion, prevention, treatment/intervention, habilitation and rehabilitation [110].

The specific aims of physiotherapy following stroke are to optimize: (I) functional motor performance, (II) physical fitness, strength and endurance, (III) interest and motivation, and (IV) mental and physical vigor [111] in order to further the recovery process, increase confidence and improve well-being [21]. The substantial growth in the number of clinical trials in rehabilitation in the past 20 years shows the increased interest of rehabilitation clinicians in evidence-based treatments. Available evidence supports the efficacy [112] and recognition [113] of providing stroke-based physiotherapy. Although there is no clearly superior model of physiotherapy for stroke rehabilitation [112, 114], some evidence exists to support specific interventions [115]. In a Cochrane review of 21 studies, it was concluded that there is no evidence confirming that a single physiotherapy approach is better than another for improving balance, muscle strength in the leg, walking speed or the performance of everyday tasks in subjects after stroke [114]. However, the results were better after physiotherapy where components from different treatment approaches were used. Modern concepts of motor learning have drastically modified the framework of rehabilitation from a conventional neurodevelopmental therapy to a more dynamic, task oriented and repetitive approach [50]. Several interventions have a potential effect on arm function, at least in the selected populations that have been studied. These interventions include constraint-induced movement therapy (CIMT), electromyographic (EMG) biofeedback, mental practice with motor imagery and robotics [116]. CIMT has gained considerable popularity as a treatment technique for upper extremity rehabilitation among patients with mild-to-moderate stroke. While substantial evidence has emerged to support its applicability, issues remain unanswered regarding the best and most practical approach [117]. Furthermore, the role of robotics in neuro rehabilitation is still unclear and constitutes another challenge in stroke research that needs to be further investigated [118]. In recent years, treadmill training with and without partial body weight support has been introduced for the rehabilitation of subjects after stroke. However, there is conflicting evidence that partial body weight support with treadmill training results in improved walking and motor recovery as compared to conventional therapy using over ground walking training [119, 120]. In addition, virtual reality appears to be a promising approach that may enable simulated practice of functional tasks at a higher dosage than traditional therapies, although further studies are required to confirm these findings [121].

Therapists need to move away from a reliance on one-to-one therapy toward a model in which the patient practices not only in individualized training sessions with a therapist but also in groups, and in circuit training, where patients practice at work stations set up for weight-bearing strength training exercises, and where the practice of specific actions is encouraged. Patients are semi-supervised and assisted as necessary by a therapist and aide, with attitudes and methods similar to people who work in sports training [77]. An earlier review showed the effectiveness of circuit class therapy in improving walking capacity and other aspects of mobility in both the post-acute and chronic stage after stroke [122].

The improvement of ambulation is known to be dependent on the intensity of walking training [123]. According to a previous study [124], when the time spent in active and focused exercise is sufficient, even chronic stroke patients (after six months after stroke onset) can obtain successful results. It is also increasingly evident that muscle weakness after stroke is modifiable through strength training of an appropriate intensity, even in very elderly individuals [42, 125]. Intensive mobility training, which incorporates functional strengthening, balance and cardiorespiratory training, and practice in a variety of walking tasks improve gait ability both in sub-acute and chronic stroke [109, 126-128].

2 AIMS OF THE THESIS

The overall aim of this thesis was to increase knowledge about physical performance and activity in subjects in the later stage post-stroke by measuring walking performance in different environments coupled to muscle strength, cardiorespiratory fitness evaluation and self-reported physical activity.

The specific aims were:

- To assess short and long distance walking performance in indoor and calm outdoor environments of subjects divided into slow and fast walkers (*Paper I)*.
- To describe lower extremity strength and its relation to walking performance (speed and distance) *(Paper II)*.
- To study the correlation between maximal exercise capacity measured during a one-legged bicycling test and the 6-minute walk test *(Paper III)*.
- To compare the self-reported physical activity levels in persons with stroke with a population-based sample, and to explore the relationship between PASE scores and physical measurements *(Paper IV)*.

3 SUBJECTS AND METHODS

3.1 Study participants

3.1.1 Subjects in the later stage post-stroke

The study group consists of a community-dwelling population of 83 subjects (male and female) older than 40 years (Figure 1). Former patients were recruited from the Rehabilitation Medicine Clinic at Sahlgrenska University Hospital, Gothenburg, Sweden, all of whom were discharged from the rehabilitation program. The clinic provides comprehensive rehabilitation to persons of working age living in the area of Gothenburg. Demographic and functional characteristics of participants are presented in Table 1.

Inclusion criteria

Stroke diagnosis according to WHO criteria, at least six months prior to the study, hemiparesis, ability to walk in the community for at least five minutes without personal assistance (self-reported). Assistive devices and ankle-foot orthoses (AFOs) were permitted. The selected time since onset of stroke was based on the concept that stroke patients are in a stable phase six months after stroke [129]. The subjects were also asked to continue their usual medication and to refrain from caffeinated drinks and tobacco cigarettes for two hours before the test.

Exclusion criteria

Severe heart disease, uncontrolled hypertension, leg wounds, pain or non-stroke induced gait disability, or inability to follow instructions or to communicate in Swedish.

Additional criteria:

Study I: The participants were later divided into two subgroups: (1) Group A, subjects with self-selected speed in the clinical setting lower than 0.8 m/s; and (2) Group B, subjects with self-selected speed in the clinical setting of 0.8 m/s or faster [73].

3.1.2 Healthy subjects

An urban population sample (residents in Gothenburg) of 40 to 79-year-old men and women formed the group of clinically healthy subjects [130] (Studies II and IV). The sample (144 participants, 69 males and 75 females) included were those who agreed to participate in a study with the aim of establishing reference material, and they were randomly selected from a database representing all residents in Sweden. Contraindications for participation were prior neurological disease, musculoskeletal problems, cardiac disease affecting physical performance (heart failure, angina) or the presence of an active disease requiring treatment by a physician. A physical examination including history was made before the study to ensure that no medical contraindications were present.

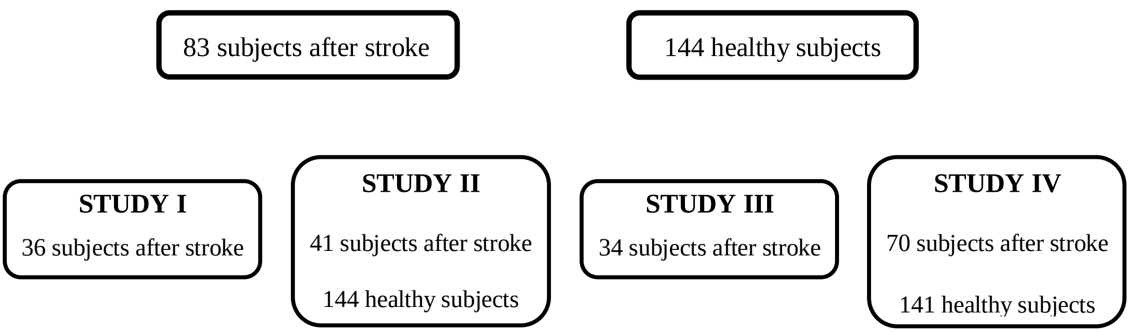

Figure 1. *Participants included in the different studies*

__Table 1__: Description of the participants

	Study I		Study II		Study III	Study IV	
	group A	group B	stroke	reference	stroke	stroke	reference
N	10	26	41	144	34	70	141
male/female	6/4	18/8	31/10	69/75	24/10	48/22	70/71
Age, years mean ± SD (range)	60±3 (56-67)	60±4 (53-68)	59±6 (40-68)	59±10 (40-79)	60±4 (53-68)	60±7	59±10 (40-79)
Type of stroke, ischemic/ hemorrhagic	5/5	18/8	27/14		23/11	43/27	
Paretic side right/left	3/7	14/12	20/21		15/19	37/33	
Time since stroke, years, mean ± SD (range)	5.7±3.6 (1-13)	4.9±2.2 (1-8)	4.4±3 (0.6-13)		5.2±2.7 (1-13)	6.1±3.1 (0.6-13)	
Assistive device (n)	10	1	14		11	23	
Body Mass Index, mean ± SD						26.6±3.8	26.0±5.0
Fugl-Meyer scale lower extremity, median (range)	19 (13-25)	31 (21-34)	30 (13-34)		30 (13-34)	29 (11-34)	
Berg Balance Scale, median (range)	42 (35-52)	52 (45-56)			51 (35-56)		
Medications (n) β-blockers ACE inhibitors Calcium antagonist Cholesterol inhibitor					 15 11 9 17		
Co-morbidities (n) Cardiovascular disease Hypertension Arrhythmia Diabetes mellitus Hypercholesterolemia Smoking history					 7 22 4 5 9 6	 14 39 12 11	 25

SD: standard deviation
ACE: angiotensin converting enzyme

3.2 Study Design

All studies had a cross-sectional design. The data were gathered on different occasions. Thirty six of the subjects (Studies I, II, III and IV) were assessed twice over the course of two weeks on separate days. In the first session, they were all assessed at the Rehabilitation Medicine Clinic at Sahlgrenska University Hospital by the author. This session included the collection of disease and medical histories and assessment of the Body Mass Index (BMI) [131], Fugl-Meyer scale for the lower extremity [132, 133] and Berg Balance Scale (BBS) [134] in the same order for all subjects. The 30-meter walking test (30mWT) [63, 135] and 6-minute walk test (6MWT) [95] were randomized and carried out in three different environments: (1) clinical setting; (2) basement setting; and (3) outdoor setting. In addition, the participants filled in a questionnaire of physical activity (PASE) [136]. The assessment took two hours, and the participants were invited to rest for a few minutes between each test so that the effects of fatigue would be reduced.

The next session was held at a laboratory at the Rehabilitation Medicine Department at Sahlgrenska University Hospital, where one-legged bicycling test [92] and muscle strength measurements in the lower extremities [137, 138] were performed. The test was conducted in the presence of the author, a physician and a research nurse.

Eight subjects (in Study II) had been assessed in the same way earlier for another study [92] and 39 subjects (in Study IV) had participated in another study at our research department [139]. Data from these assessments had not previously been used in this way and were merged to enlarge the data set.

3.3 Assessments

An overview of the assessments and environments used is presented in Table 2.

Table 2: *Overview of the assessments used in the studies*

Assessments	**Study I**	**Study II**	**Study III**	**Study IV**
Body structure and function				
Fugl-Meyer Scale	X	X	X	X
Muscle strength test		X		
Oxygen consumption, gas analysis			X	
Body Mass Index				X
Activity				
Berg Balance Scale	X		X	
30mWT				
clinical setting	X	X		X
basement setting	X			
outdoor setting	X			
6MWT				
clinical setting	X	X	X	
outdoor setting	X		X	
Physical Activity Scale for the Elderly				X

The different evaluation tests were included in the present research project and summarized as follows:

Fugl-Meyer Scale (I, II, III and IV)

Motor function in the affected lower extremity was assessed according to the Fugl-Meyer Scale [132]. The scale consists of a three-point ordinal scale: 0= cannot perform; 1= partially performs; and 2= performs fully. The summation of the scores of different items gives a maximum score of 34, which indicates normal movement control in the affected side compared with the non-affected side. Motor impairment was classified as < 17 severe, 17-28 marked, 29-31 moderate, 32-33 slight or 34 none. This scale is considered by many in the field of stroke rehabilitation to be one of the most comprehensive quantitative measures of motor impairment following stroke, and it has been shown to be valid and reliable [140, 141].

Muscle strength tests (II)

Measurements were performed on a Biodex® Multi-Joint System 3 PRO dynamometer[a] (figure 2). The equipment was calibrated before testing. The subject was seated comfortably with his or her back against a back rest. A seatbelt was strapped around the shoulders, waist and thigh to avoid unwanted movements. Before each measurement, the full range of motion was set and each subject's lower extremity was weighed; the Biodex software corrected the data to account for the influence of the gravity effect torque on the data. The lower extremity was adjusted to the actuator with the axis of movement adjusted to center axis of the knee joint. Warm-up submaximal exercises were performed on a bicycle ergometer before the muscle test. The test order was randomized for both the paretic and non-paretic leg (drawing lot) to exclude learning effects. Maximal isokinetic muscle strength (in Newton meters, Nm) was measured at a velocity of 60°/sec during concentric muscle action of knee extensors and knee flexors

***Figure 2**: Isokinetic knee muscle strength measurement, performed in a Biodex dynamometer (the subject gave his permission to publish the picture).*

for both lower extremities, as previously suggested [46, 138, 142]. The peak isometric strength of foot dorsal flexors and plantar flexors at a 30° angle of knee flexion and a 0° ankle angle was also measured. During the test, all subjects were given visual feedback from the system's monitor. They were also verbally encouraged by the examiner to make their maximal effort. Test values were compared with and expressed as a percentage of control values from the healthy reference subjects [130]. Strength testing in stroke populations has been shown to be reliable and valid as an outcome measure in clinical trials [46].

Strength Index (II)

The calculation of the strength index was based on a previous study [143]. The values from the strength measurements were transformed into a *strength index* representing all eight measurements, allowing all muscle groups to be equally significant. A factor for each muscle group was constructed by giving the strongest muscle group (knee extension 60°/sec) a factor of 1 and the other muscle groups' factors corresponded to the ratio between the average muscle strength of the healthy subjects and their knee extensor muscle strength. The same factors were used for the subjects with stroke and the healthy reference subjects.

The index was represented by the equation:
1x knee extension strength right and left + 2.2 x knee flexion strength right and left + 1.5 x foot plantar flexion strength right and left + 4.5 x foot dorsal flexion strength right and left

The following example illustrates the index in a 66 year old post-stroke man:
1 x 106 + 1 x 115 + 2.2 x 64 + 2.2 x 56 + 1.5 x 65 + 1.5 x 75 + 4.5 x 13 + 4.5 x 18 = 834

Oxygen consumption (III)

Peak oxygen uptake (VO_{2peak}) and maximal workload (W_{max}) were measured on an electrical bicycle ergometer [b] to evaluate cardiorespiratory fitness. Since the VO_{2max} measurement can sometimes not be achieved by an unfit and elderly population [144], we chose the highest, or peak, level of oxygen consumed (VO_{2peak}) to represent aerobic capacity. The exercise test was conducted testing each leg separately (one-legged bicycling) [92]. The exercise started at 0W after the individual had become familiar with the equipment and had been pedaling for three minutes without friction resistance. Subsequently, a ramp protocol with 10-W/minute step-less increment was used. The pedaling rate was approximately 60 revolutions/minute and the workload was maintained by the computer program controlling the bicycle. The maximal workload was the highest workload maintained for at least 30 seconds. Breath-by-breath gas exchange was recorded on-line by measuring the expired gas flow and expiratory oxygen gas meters via a facial mask [c]. The electrocardiogram, heart rate (HR) and blood pressure (BP) were monitored during the test. The individual perceived exertion was measured on the Borg category ratio scale (Borg CR 10 scale) [145] with exponential increments from 0 to 10. The exercise test duration was also noted and was the total time in seconds from the start of the test until the subject stopped pedaling. The reliability of the method for assessing oxygen consumption in a stroke population was established in a previous study [92]. The test order of the non-paretic and the

Figure 3*: One-legged bicycling test (the subject gave his permission to publish the picture).*

paretic leg was randomized. Subjects cycled with one leg while resting their non-working leg on a pillow placed in front of them on a stool (Figure 3). The exercising leg was fastened securely to the pedal with both the clip and Velcro straps. This position was quite comfortable and was immediately accepted by the participants without practice or need for any position adjustments.

There was a rest period before recommencing the test with the other leg. The subjects were required to rest, sitting in a chair, and were offered water to drink. Their BP was followed to assess normal values. Their HR was monitored, and the test only resumed once it had had returned to a resting level. This usually took between five and seven minutes.

The guidelines provided by the American College of Sports Medicine were used to determine whether the test should be terminated prematurely [74]. Subjects were also asked to identify the reason for stopping, e.g. leg pain, feeling of loss of muscle strength, generalized fatigue or other reasons.

Peak HR achieved at both tests (6MWT and cycle test) was expressed as a percentage of the age-predicted HR maximum (220 beats/min minus age in years) [146].

Body Mass Index (IV)

Body mass index was calculated from the individual’s weight in kilograms and height in meters squared, kg/m^2. For the Swedish population, values from 20.1 to 25.0 kg/m^2 in men and 18.7 to 23.8 kg/m^2 in women are considered to be normal [147].

Balance (I and III)

The Berg Balance Scale (BBS) was used to assess functional balance [134, 148]. Performance using this test was scored from 0 (cannot perform) to 4 (normal performance) on 14 different tasks, including ability to sit, stand, reach, lean over, turn in a complete circle and step. The maximum score on the BBS is 56. A higher score indicates better balance skills. The test has been shown to be reliable and valid in this group of patients [149].

30-meter walk test (30mWT) (I, II and IV)

The 30mWT was used to evaluate walking speed [63, 150]. First, the subjects were instructed to walk at a speed that they considered comfortable or normal (self-selected speed). Then, for maximum speed, they were asked to walk at a speed that they considered to be as fast as possible, without running. The time taken to walk each distance was measured using a stopwatch, and the observer walked behind the subject without interfering. The test has been found to be valid [151] and reliable [135] for individuals after stroke.

Six-minute walk test (6MWT) (I, II and III)

The 6MWT was originally developed to assess cardiopulmonary function [95]. Subjects were given six minutes to walk as far as they could at their usual pace, back and forth over a 30-meter course. The turn-around points were marked with a traffic cone and the distance covered in six minutes was recorded.

The instructions for the test were standardized according to American Thoracic Society (ATS) statement guidelines for the 6MWT [152]. At the end of each minute, subjects were given feedback on the elapsed time and standardized encouragement in the form of statements such as "you are doing well" and "keep up the good work". Subjects were allowed to stop and rest as they deemed necessary. The subjects could use their usual orthoses and assistive devices. The subjects wore a HR monitor [d] for continuous HR measurement. At the start and end of the test, HR, BP (only systolic blood pressure (SBP) was analyzed) and rating of perceived exertion (Borg CR 10 scale) [145] were noted. This test has been used extensively to monitor function in individuals with cardiopulmonary problems and has been used by researchers studying individuals after stroke [62, 98, 153], but its reliability or validity has not been established in this population.

Indoor and outdoor environments

The subjects performed the walking tests in three different environments: (1) a corridor in a clinic rehabilitation unit with doors and adjacent rooms, furniture, patients, and health professionals present (clinical setting) (figure 4); (2) an empty corridor in the basement without any patients or health professionals moving around (basement setting) (Figure 5); and (3) an outdoor walkway in a calm garden and quiet neighborhood (outdoor setting) (Figure 6). The two indoor corridors had the same regular wall-to-wall plastic carpet with an even surface, and were well kept and well lit. The outdoor walkway was made of concrete tiles (45 x 45 cm), which presented a somewhat uneven surface, but no slopes or curbs were present. The walkway was free of snow and ice and was treated with sand. The clinical setting, basement setting and outdoor setting widths were 2.6, 2.7 and 4 meters respectively. In each environment, a known distance (30 m) was marked.

During the test, walking speeds for the self-selected and maximum speeds over a 30-meter distance [63, 135] were assessed first in the three different environments. Walking distances for the 6MWT [95] were then assessed in two different environments (basement and outdoor settings), since it was not feasible to perform the 6MWT in the clinical setting (due to prolonged disturbance for the other patients and staff). The test order was randomized for all walking tests (numbers were drawn out of a hat). The subjects could use their usual orthoses and assistive devices, and there was a minimum rest period of five minutes between trials.

A predicted distance was calculated using the speed (m/s) over 30 meters for each subject multiplied by 360 (i.e. the number of seconds in six minutes), as suggested in earlier research [62] (Study I).

Results of the 30mWT and the 6MWT in the clinical setting were compared with reference data [130, 154].

***Figure 4**: Clinical Setting*

***Figure 5**: Basement Setting*

***Figure 6**: Outdoor Setting*

Physical activity scale for the elderly (IV)

The PASE questionnaire was developed for the purpose of assessing level of physical activity in middle-aged and elderly individuals [136, 155]. The questionnaire is a 12-item scale that measures the average number of hours per day spent on participating in different activities (walking outside the home, light sport, moderate sport, strenuous sport, exercises to increase muscle strength and endurance, light housework, heavy housework, home repairs, lawn work or yard care, caring for another person, working for pay and working as a volunteer). The PASE scoring algorithm was derived from physical activity measured by movement counts from an electronic physical activity monitor, activity diaries and self-assessed activity levels in a general population of non-institutionalized persons. The PASE score is calculated by taking the average number of hours spent on an activity per day over a seven-day period multiplied by an activity coefficient. Item scores are added to produce the PASE score. The PASE score can range from 0 to over 400, with a higher score meaning a higher level of physical activity. The PASE was found to be valid in elderly people with disabilities [156] and has been used for stroke subjects [139, 157].

3.4 Statistical Analysis

Conventional formulas were used for calculations of mean, median, standard deviation (SD), percentiles, confidence intervals and range. Differences within and between groups were analyzed using nonparametric tests, the Wilcoxon signed rank test (within groups) (Studies I and III) and the Mann-Whitney test (between groups) (Studies I and IV). A one-way repeat measure was used to analyze the results of the short distance walking test in three different environments (Study I). To examine the level of agreement between the measurements in different environments, the 95% limit of agreement (LOA) was used, visualized by Bland and Altman plots [158], with the difference between the two measurements plotted against their mean for each subject (Study I). Pearson's correlation coefficient (Study IV) and Spearman's rank correlation coefficient (rs) (Studies III and IV) were used to describe the correlation among the different variables. The strength of the correlation was defined by the correlation coefficient obtained: 0.26-0.49, low; 0.50-0.69, moderate; 0.70-0.89, high; and 0.90-1.00, very high [159]. A standard multiple regression analysis was used to assess the influence of impairments measures on the 6MWT distance (Study III). A p-value < 0.05 was used throughout the studies and considered significant in all analyses. Analyses were made using the SPSS computer package (version 13.0). An overview of statistical methods is given in Table 3.

Mathematical Model (Study II)

The same non-linear model was used for the three response variables, i.e. self-selected speed, maximum speed and 6MWT, and for each study group, i.e. subjects after stroke and healthy subjects.

The form of the model used was response = α X (1- exp [- β X index]). Response was self-selected, maximum speed or 6MWT, and index was the calculated strength index. Parameter α represents the asymptotic value of the curve. Parameter β refers to the slope of the curve. The value on the x-axis represents the strength index and on the y-axis the walking speed or distance (in meters per second or meters). Parameters α and β were estimated separately for each response and study group. The analysis was made by a statistical software program [d] (SAS). Inferential statistics (tests and confidence intervals) were based on the assumption of normality. No adjustments for multiplicity were performed.

***Table 3**: Overview of statistical methods*

	Study I	Study II	Study III	Study IV
Wilcoxon signed rank test	X		X	
Mann-Whitney test	X			X
One-way repeat measures	X			
Bland and Altman plot [158]	X			
Nonlinear model		X		
Spearman’s rank correlation coefficient			X	X
Pearson’s correlation coefficient				X
Multiple regression analysis			X	
Linear regression				X

3.5 Ethical Considerations

All subjects had previously been patients at the Rehabilitation Medicine Clinic at Sahlgrenska University Hospital, Gothenburg, Sweden. They were all now living in their own homes in the community and were no longer active at the unit but had health care elsewhere.

None of the tests were potentially harmful to the subjects, although soreness could appear in the lower extremities after the isokinetic muscle testing and one-legged bicycling test. Some subjects also find it uncomfortable to breathe through a mask. No adverse advents occurred during any of the tests. The patients stated satisfaction in being part of the research.

The studies were approved by the Ethics Committee of the University of Gothenburg, and informed written consent was obtained from all subjects.

4 RESULTS

4.1 Study I

The participants were later divided into two subgroups according to their results at self-selected speed in the clinical setting: (1) Group A, walking speed lower than 0.8 m/s; and (2) Group B, walking speed of 0.8 m/s or faster. The one-way repeat measures analysis from the performance of short distance walking (30mWT) indicated that there were no differences in both groups for self-selected (Group A: Wilks lambda=0.73, *p*=0.29; Group B: Wilks lambda=0.83, *p*=0.11) and maximum speeds (Group A: Wilks lambda=0.87, *p*=0.59; Group B: Wilks lambda=0.92, *p*=0.38) among the three different environments (Table 4).

For those who walked at slower speeds (Group A), no difference in the long distance walking was observed between the basement setting and the outdoor setting (*p*=0.64) (Table 4). However, it was observed that the subjects in Group B walked a longer distance (463 ± 84 m) (*p*=0.01) in the outdoor setting compared with the basement setting (452 ± 82 m) during the performance of long distance walking (Table 4).

In the indoor setting, the actual distances walked in the 6MWT were significantly less than the distance predicted by 30mWT speed for both groups (Group A: *p*=0.015; Group B: *p*=0.048) (Table 4). When tests were performed in the outdoor setting, only subjects in group A walked significantly less than the distance predicted by the 30mWT speed (*p*=0.022) (Table 4).

***Table 4** Results of the walking tests in different environments*

	Group A (n = 10)	**Group B (n = 26)**
Self-selected speed: Clinical setting (m/s)	0.51 ± 0.18†	1.26 ± 0.21
Self-selected speed: Basement setting (m/s)	0.52 ± 0.19†	1.30 ± 0.23
Self-selected speed: Outdoor setting (m/s)	0.51 ± 0.20†	1.31 ± 0.22
Maximum speed: Clinical setting (m/s)	0.61 ± 0.24†	1.66 ± 0.34
Maximum speed: Basement setting (m/s)	0.60 ± 0.23†	1.68 ± 0.29
Maximum speed: Outdoor setting (m/s)	0.60 ± 0.25†	1.69 ± 0.33
6-minute walk test distance (m): Indoor	178 ± 64†	452 ± 82*
6-minute walk test distance (m): Outdoor	175 ± 67†	463 ± 84
Predicted 6MWT distance (m) from 30mWT: Indoor	188 ± 69† ‡	470 ± 83‡
Predicted 6MWT distance (m) from 30mWT: Outdoor	186 ± 73† ‡	471 ± 81

Note. Data are mean ± standard deviation.

* Difference between indoors and outdoors within group (p=0.01)

† Difference between groups (p<0.001).

‡ Difference between predicted and walked distances within groups (p<0.05)

4.2 Study II

The average calculated strength index was 730±309 in the stroke group and 1112±362 in the healthy group. The parametric model used to analyze the data provided evidence for the non-linear relationship between walking speed at self-selected and at maximum speeds and the strength index in both subjects after stroke and healthy subjects (Figures 7). A non-linear relationship was also found between 6MWT and the strength index in the subjects after stroke. The model explained 37% of the variance in self-selected speed in the stroke group and 20% in the healthy group, and 63% and 38%, respectively, in maximum walking speed. For the 6MWT, the model explained 44% of the variance in the stroke group.

The asymptote[1] for the self-selected speed was 1.41 m/s in the stroke group and 1.48 m/s in the healthy group and the corresponding values for the maximum walking speeds were 2.01 m/s and 2.57 m/s, respectively. The asymptote for the 6MWT was 581.7 meters for the subjects after stroke.

Assuming that 1.2 m/s is the walking speed [160] required to ambulate safely in the community, a strength index of 700 for post-stroke subjects is acquired as compared with 650 for the healthy group. Corresponding values for maximum speed are 550 and 420, respectively.

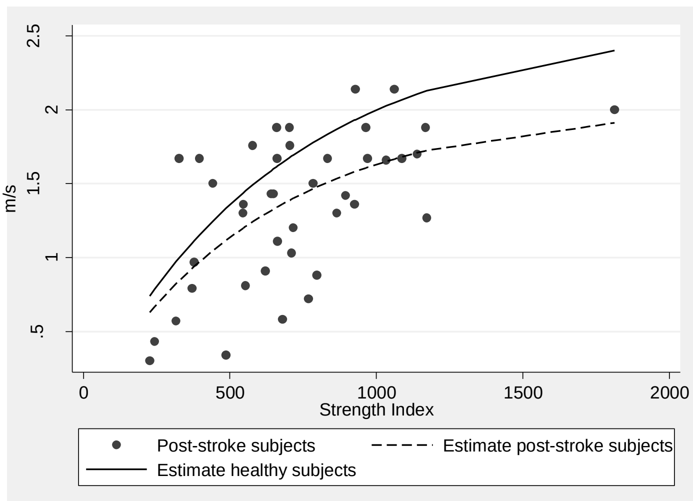

***Figure 7**: Nonlinear regression curves for maximum walking speed (m/s) and strength index (Nm) in subjects after stroke and in healthy subjects*

[1]*The asymptote of a curve is defined as the case in which the distance from a movable point on the curve to a straight line has the limit of zero, when the point goes towards infinity*

4.3 Study III

Low to moderate correlations were found between the 6MWT and one-legged bicycling measurements from the paretic leg, such as VO_{2peak}, W_{max} and total exercise time (Table 5). The 6MWT showed no significant correlation with variables from the non-paretic one-legged bicycling test. The only difference between indoors and outdoors is that 6MWT indoors did not significantly correlate with VO_{2peak} for the paretic leg (Table 5). There was also a correlation between specific stroke impairments and the walking test. The Fugl-Meyer scale for the lower extremity showed a highly significant correlation and BBS showed a moderately significant correlation with 6MWT (Table 6).

Table 5 *– Correlations between 6MWT, the Fugl-Meyer scale and BBS with one-legged bicycling (VO_{2peak}, W_{max} and total exercise time)*

	VO_{2peak}		W_{max}		Total exercise time	
	PL	NL	PL	NL	PL	NL
	rs	rs	rs	rs	rs	rs
6MWT						
Indoor dist	0.335	0.161	0.589***	-0.004	0.530**	0.190
Outdoor dist	0.391*	0.208	0.646***	0.054	0.583***	0.235
Fugl-Meyer†	0.097	-0.125	0.398*	-0.289	0.329	-0.109
BBS	0.194	0.119	0.370*	-0.104	0.396*	0.150

* $p \leq 0.05$; ** $p \leq 0.01$ *** $p \leq 0.001$

† Fugl-Meyer scale for the lower extremity

6MWT: 6-minute walk test; dist: distance in meters; BBS: Berg Balance Scale; PL: paretic leg; NL: non-paretic leg; rs= rank correlation.

Table 6 *– Correlation between 6MWT and specific stroke impairments*

	Fugl-Meyer scale†	BBS
6MWT		
Indoor dist	0.721^{***}	0.671^{***}
Outdoor dist	0.744^{***}	0.689^{***}

$^{***}p \leq 0.001$

† Fugl-Meyer scale for lower extremity

6MWT: 6-minute walk test; dist: distance in meters; BBS: Berg Balance Scale.

4.4 Study IV

The mean PA level in the stroke group, as reflected in the total PASE score, corresponded to 72% of the sex and age matched control values (Table 7 and Figure 8). A low correlation was seen between the PASE and the Fugl-Meyer scores. In the stroke group, PASE correlations with the self-selected and maximum walking speeds were moderate. Furthermore, the reference group showed a weak correlation between PASE and walking speeds. The model with PASE as the dependent variable and age and self-selected walking speed as independent variables could explain 29% of the variation in PA in the stroke group. In both groups, only the walking speed showed a significant contribution to the model.

Table 7 *– Walking speeds and physical activity levels*

	Stroke (n=70)	**Healthy reference (n=141)**
Self-selected speed, m/s, mean (SD)	1.0 (0.4)	1.4 (0.2)
Maximum speed, m/s, mean (SD)	1.3 (0.6)	2.0 (0.4)
PASE score, mean (SD)	119.2 (74.4)	161.3 (71.5)

SD, standard deviation; PASE, Physical Activity for the Elderly; m/s, meter per second

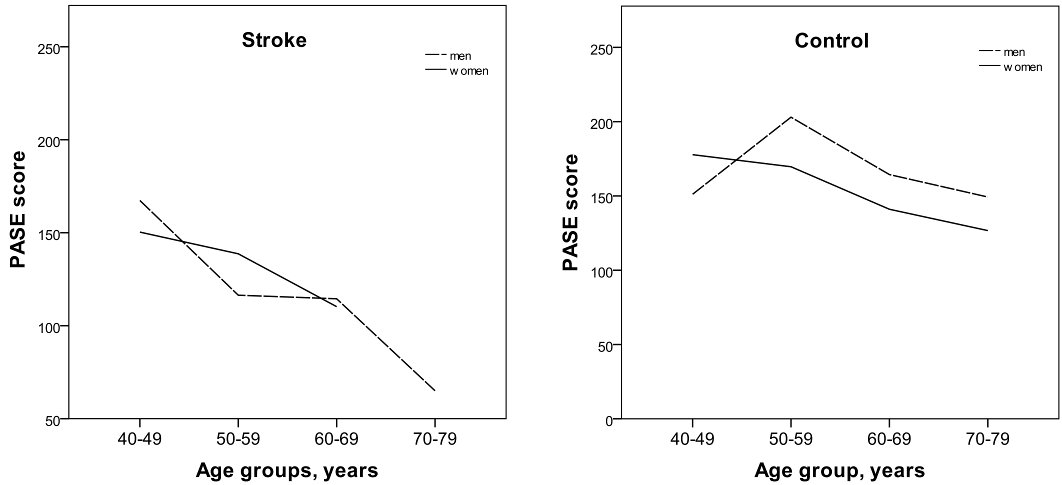

Figure 8*: Mean physical activity levels in subjects after stroke (left) and control group (right). The average PASE (Physical Activity Scale for the Elderly) score in the different age groups (male dotted line, female straight line).*

Walking capacity, physical performance and activity of post-stroke versus healthy

Subjects after stroke demonstrated lower results as compared with reference data (age and sex matched). The stroke group: walked at slower speeds in both self-selected and maximum speeds (Studies I, II and IV); achieved less than would be expected of their predicted normal distance during the 6MWT (Studies I, II and III); the average muscle strength values for both legs was decreased (Study II); mean HR was lower than the age-predicted maximal heart rate (Study III); and the mean self-reported physical activity level was lower than the healthy controls (Study IV).

5 DISCUSSION

The overall aim of this thesis was to increase knowledge about physical performance and activity in subjects in the later stage post-stroke by measuring walking performance in different environments coupled to muscle strength, cardiorespiratory fitness evaluation and self-reported physical activity.

Regaining independent walking at home and in the community is important and often a primary goal of rehabilitation after stroke [161]. The use of feasible, reliable and valid walking tests is fundamental to assessing a patient's walking ability. Both the 30mWT and the 6MWT have been shown to be reliable and valid [135, 151, 162, 163] and have been used in stroke research and clinical practice. Since most of the walking tests are performed in the clinical environment, the idea of measuring walking capacity in different environments seemed interesting based on the hypothesis that the environment could influence the test performance and the participants could perform differently because of that. If this was not the case, this result could offer new information on the challenge for health care professionals to apply rehabilitation services, preferably in the patient's own environment, in the specific case where an indoor space could be limited and an outdoor place could be used instead. We decided to divide the participants into two groups according to their walking speed since there was a clear difference in the material. In that case, motor impairments seem to influence walking capacity more than age. Walking speed has been shown to be associated with survival among elderly populations in individual epidemiological cohort studies [164] and to reflect health and functional status [165]. Studenski et al. predicted life expectancy at the median for age and sex at about 0.8 m/s; faster gait speeds predict life expectancy beyond the median [166]. This speed was used in our study and in a previous one [73] as a cut-off to divide the participants into two subgroups. In addition, Perry et al. conclude that 0.8 m/s was the mean value for classifying people with stroke as community walkers [51].

It was interesting to observe that the short distance walking test in both the self-selected and maximum speeds did not differ in the different environments. This was also true for the long distance walking test in the slower walkers (Group A). Our sample walked on a daily basis in a range of environments in their community at an average speed where different environments may no longer influence the speed and distance. They seemed to be adapted to their everyday activities, although we did not ask whether or not they perceived problems while ambulating. A recent study investigating the relationship between perceived and measured changes in walking after stroke showed that a meaningful difference in 6MWT was observed between participants who did and those who did not perceive improvement [167]. Thus far, only a few studies have measured walking parameters (speed, step length and cadence) in various indoor and outdoor environments, such as a suburban street, a shopping mall and a car park [71-73]. Similar findings were reported where differences between environments were small and not clinically relevant [71-73]. A recent study held the 6MWT in the patients' own neighborhood environment using GPS and found the test to be reliable, responsive and valid [168]. The fact that the faster walkers (Group B) achieved longer distances in the outdoor environment is interesting. This might be explained by a larger visual field, both sideways and upwards, outdoors (calm garden), in addition to the positive impact of being outdoors and experiencing nature. A recent review showed some evidence that physical activity in an outdoor natural environment may give additional positive effects on measures of mental wellbeing that are not seen in participation in similar physical activity indoors [169]. The hypothesis that there are added beneficial effects to be gained from performing physical activity outdoors in natural environments is very appealing and may be a promising area of future research. Another finding in our study was that timed walk tests conducted over short distances, such as the 30mWT, tend to overestimate performance on the 6MWT and should complement, but not replace, the 6MWT. This is in agreement with previous studies [62, 71].

The relationship between walking performance and muscle strength in the lower extremities in subjects after stroke has been investigated in the past. However, these studies used different muscle strength variables for correlation with walking performance. Some used measurements from isolated muscle groups or actions, usually from the paretic side; others utilize the summation or subtraction of strength values from different muscles, assuming that all muscles had the same weight. The fact that functional movement involves simultaneous activation and coordination of a number of muscles should be taken into consideration. To our knowledge, our work represents the first attempt to evaluate a non-linear relationship between walking performance and a strength index based on a model allowing all muscle groups to be equally significant. A model was chosen with the same structure as that previously developed for a larger population of healthy subjects [143]. The model fitted the current data satisfactorily, and we chose not to develop a new structure owing to the limited number of observations available. Previous studies have supported the hypothesis that muscle strength has a non-linear relationship with walking performance in both healthy persons and individuals with late effects of polio [143, 170]. Functional measures such as balance, muscle strength, walking and activity have also been shown to decline non-linearly with age in healthy women [171]. A non-linear relationship represents a mechanism for how small changes in muscle capacity may have substantial effects on walking performance. However, for persons with good muscle function, large changes in muscle capacity have little or no effect on walking performance [170]. In other words, for individuals demonstrating relatively high muscular performance, the increase of muscle strength may not produce readily measurable effects on function. It may be also that, in individuals with severe weakness, increased muscle strength is not shown as improved functional performance. Lastly, there are persons who may have the greatest benefit from strength training, where a small increase in muscle strength could promote considerable improvement in function [172]. A speculation is that interventions intended to improve reduced muscle strength will result in improvements in walking. The post-stroke subjects here demonstrated a high variance (63%) when walking at maximum speed compared with the reference subjects (38%). The difference in variance was not as evident for walking at the self-selected speed, where the model explained 37% in subjects after stroke and 20% in the reference subjects. Impairments seem to be exacerbating when post-stroke subjects were challenged to walk at a higher speed. In addition, the findings of impaired muscle strength in the non-paretic leg reported here and elsewhere [35, 37, 173] demonstrate that this leg cannot be used as a reference for “normal” strength. Instead, reference data for age and sex matched subjects should be used to establish the presence and extent of weakness.

It is important to emphasize that, although subjects after stroke can increase walking performance by improvements in lower extremity muscle strength [174], other factors, such as cardiorespiratory fitness, balance, fear of falling and spasticity, also contribute to functional limitations. Nevertheless, the impairments that are the most important factors in determining walking performance in these subjects remain unknown.

The 6MWT is the most popular and commonly used sub-maximal exercise test and has been used to assess functional exercise performance across a variety of subjects such as patients with heart failure [175] and with a wide variety of pulmonary alterations [176]. Studies have reported contradictory findings on the relationship between maximal exercise capacity (evaluated by VO_{2max} or VO_{2peak}) and walking capacity in stroke subjects [97-99, 177, 178]. In agreement with previous studies, we found a poor correlation between peak oxygen consumption measured in a one-legged bicycling test and the 6MWT [97, 99]. Other studies have demonstrated high [98] to moderate [177, 178] correlations; the study populations differ from ours, however: they were younger and in the sub-acute phase after stroke. Comparison is also equally difficult owing to our choice to use a one-legged bicycling test to measure exercise capacity. Oxygen consumption was found to be higher at any given power output during one-legged exercise compare with two-legged exercise in healthy subjects [179], and the evaluation of each leg separately would probably better assess the effects of training. As hypothesized, the one-legged bicycling test performed with the paretic leg correlated better with the 6MWT distance than the test with the non-paretic leg. Stroke related impairments, such as lower motor function and balance ,seem to be more critical for the walking function than the cardiorespiratory status. Similar findings have been reported earlier [99, 180]. These impairments also appear to limit the performance on a maximal exercise test more than cardiorespiratory factors, since most participants stopped the test for non-aerobic reasons, such as leg pain and a feeling of loss of muscle strength. Nevertheless, both heart rate and systolic blood pressure were increased during the 6MWT, suggesting that the walking test did put strain on the cardiovascular system.

Physical inactivity is common after stroke and subjects post-stroke spent less than 20% of their day involved in activities potentially beneficial for their motor performance [181]. The potential benefits of physical activity have long been recognized, and physical exercise is recommended for stroke survivors [21]. Studies have shown that physical activity attenuates the re-incidence of strokes and improves quality of life post stroke [182]. Krarup et al. observed that a higher pre-stroke level of physical activity was associated with a less severe stroke and that higher activity levels were reported in patients with the most favorable outcomes [183]. Thus, the PA level is rather difficult to measure or assess in a reliable and valid way. The most objective measure is to use an activity monitor, e.g. an accelerometer or heart rate monitor, during all waking hours for several days, although the reliability may be uncertain in that case due to compliance with the use of the device. Despite the frequent use of activity diaries, their utilization requires time to use and interpret. Self-report questionnaires are convenient and inexpensive to use and therefore suitable for large population studies [184]; however, the reliability of self-reporting may be questioned. The PASE questionnaire was chosen as the instrument to assess physical activity because it was designed for elderly people and has been used in some studies on persons with stroke [14, 87, 139, 183, 185]. However, more evidence for the reliability and validity of the PASE questionnaire after stroke is needed.

We found a great variability with both very low and very high levels of PA in our stroke group, with a large dispersion in those who were physically well-recovered after stroke. The mean PASE score (mean 119.2) was much higher than in a multicentre study [185] where the participants (median age 70 years) in an intervention and control group two years after stroke had mean scores of 69 and 64, respectively. Lindahl et al. [87] also reported a lower PASE score of 99 in subjects after three to 12 months post-stroke (age range 41-87 years). These rather large differences may be explained not only by the fact that our data were collected an average of five years after stroke and the difference in age; it may also reflect a selection bias, with more physically active persons willing to participate in the study where the sample was not random. Physical performance, such as grip and leg strength, static balance and endurance, has been shown to be associated with PASE at low to moderate strength of the coefficients in both elderly [136] and disabled middle-aged persons [87, 156, 186]. Our results support this, since a moderate correlation between walking speed and PASE was found in the stroke subjects. As PA is influenced by many factors, strong correlations cannot be expected. Furthermore, it is necessary to have a thorough understanding of the factors that influence physical activity in subjects after stroke to develop effective programs and interventions strategies that will address the problem of physical inactivity in this population.

Once a patient is medically stable after a stroke episode, the focus of their recovery shifts to rehabilitation. During the subsequent phases of recovery, the primary goals include preventing secondary health complications, minimizing impairments and achieving functional goals that promote independence in activities of daily living [187]. While current evidence indicates that the most significant recovery gains will occur within the first three months following a stroke, recovery may continue at a slower pace for at least six months and in some cases recovery continues for up to one year [188]. The participants in our studies had experienced their stroke, on average, almost five years previously, with a maximum of 13 years after the incident. Physical performance, including walking performance, muscle strength, cardiorespiratory fitness and self-reported physical activity, was below the level expected in comparison to healthy controls. This cannot be attributed only to the stroke itself but also to the effects of increasing age and co-morbidities.

Over the past decade, many different types of treatments have been developed for use in rehabilitation in walking for subjects after stroke including treadmill-based programs (with and without body weight support), strengthening programs, therapies involving external aids and therapies that are derived from contemporary clinical practice [189]. An important component of these interventions is that they must be of the appropriate intensity, frequency and duration to maximize the capacity for neuromuscular plasticity and functional change [190]. Moreover, there is no universally accepted treatment at the present, and many different treatments aimed to improve walking after stroke result in similar effects. The current literature suggests that an ideal exercise intervention for improving walking performance after stroke includes a combination of motor control, dynamic balance, muscle strength and cardiorespiratory fitness [190]. Despite the growing research interest in particular in physical fitness training (strength and cardiorespiratory training), these interventions unfortunately are not routinely implemented in stroke rehabilitation [126].

Limitations of the Studies

Some limitations of the studies must be addressed. First, it would be of value to study a larger group of subjects. Second, our inclusion criteria restrict the generalizability of our results since we include subjects aged 40 to 68 years old, an age range which is lower than that of the average person with stroke. Third, the perception of post-stroke subjects of the effect of the environment on walking performance has not been investigated (Study I). Fourth, our strength data included muscle groups from the knee and ankle, which are not the only muscle groups that can affect walking performance (Study II). Fifth, as the inclusion criteria excluded subjects who could not walk for at least five minutes without personal assistance, we therefore assume that our study group is more “conditioned”, and it may be that our results do not reflect the cardiorespiratory condition in persons with stroke in general (Study III). Finally, the PASE questionnaire is validated from age 65 and above, and our study included younger subjects from the age of 40 years (Study IV).

6 CONCLUSION

In subjects in the later stage post-stroke:

Physical performance including, walking performance, muscle strength, cardiorespiratory fitness and self-reported physical activity were below the level expected when compared to healthy controls.

The environment has an impact on walking performance. Walking speed obtained over a short distance seemed to overestimate long distance walking capacity for the slow walkers, despite the environment.

Weakness in the lower extremities was associated with walking performance. Multiple impairments seem to affect walking ability, and it is important to prevent further deterioration of muscle strength that will ultimately affect walking ability.

It seems that factors other than cardiorespiratory fitness influence the 6MWT. HR and *S*BP indicate cardiovascular stress, but the use of only the 6MWT distance as an indicator of cardiorespiratory fitness cannot be recommended.

As low physical activity levels are regarded as a great health-threatening problem in the general population, it is of major importance to find ways to promote physical activity in persons with disabilities.

7 FURTHER QUESTIONS

- Can physical performance be improved by aerobic capacity training?
- Can the improvements achieved with muscle strength training result in functional gains?
- Which factors influencing physical activity are the most significant for activity and participation after stroke?

SAMMANFATTNING PÅ SVENSKA (SUMMARY IN SWEDISH)

Det övergripande syftet av föreliggande studie var att öka kunskapen om fysisk prestationsförmåga och fysisk aktivitet hos personer med stroke i senare skede.

I studien deltog totalt 83 personer med tidigare stroke boende i kommun liksom 144 kliniskt friska individer från samma område. I studie I undersöktes gångförmågan (hastighet och distans) i olika omgivningar såsom inomhus i lugn respektive rörlig miljö, samt utomhus. Sambandet mellan muskelstyrka i nedre extremiteterna och gångförmåga undersöktes i studie II och jämfördes med resultatet från en referensgrupp av friska. I studie III undersöktes sambandet mellan maximal fysisk kapacitet mätt under enbens-cykling samt 6-minuters gångtest, liksom betydelsen av motorisk funktion och balansfunktion för resultatet på 6-minuters gångtest. Självrapporterad fysisk aktivitetsnivå jämfördes mellan personer med stroke och kliniskt friska personer i studie IV och vidare undersöktes sambandet mellan den fysiska aktivitetsnivån och kroppsliga variabler.

Det fanns inga skillnader i gångförmåga mellan de olika miljöerna för de personer som gick långsamt (<0.8m/s). De snabba gångarna (>0.8m/s) gick emellertid längre utomhus. I en parametrisk modell framkom ett icke-linjärt samband mellan ett styrkeindex och gångförmåga. Modellen förklarade 37 % av variansen för den självvalda hastigheten och 63 % för den maximala hastigheten i stroke-gruppen. Motsvarande siffror för den friska referensgruppen var 20 % respektive 38 %. För 6-minuters gångtest förklarade modellen 44 % i stroke-gruppen. Ett lågt till måttligt samband förelåg mellan 6-minuters gångtest och resultatet från enbens-cyklingen (VO_{2peak}, W_{max} och total träningstid) för det paretiska benet. Ett måttligt till högt samband sågs mellan för stroke specifika funktionsnedsättningar och resultatet från 6-minuters gångtest. Den självrapporterade fysiska aktivitetsnivån var 72 % av för kön och ålder matchade kontroller. Ålder och självvald hastighet förklarade cirka 30 % av variansen i stroke-gruppen.

Den fysiska miljön kan påverka gångförmågan. Vidare tycks gånghastighet som uppmätts vid gång över 30 m överskatta kapaciteten för gång över längre sträckor hos de personer som går långsamt (<0.8m/s), oavsett typ av fysisk miljö. Det finns ett samband mellan muskelsvaghet i nedre extremiteten och gångförmåga. Ett flertal funktionsnedsättningar tycks påverka förmågan till gång och därmed är det viktigt att förhindra ytterligare muskelsvaghet som ytterst kan påverka förmågan. Andra faktorer än förmågan till syrgasupptag tycks påverka 6-minuters gångtest, varför detta test inte kan rekommenderas att enbart användas som en indikator på syrgasupptag. Fysisk prestation i form av gångförmåga, muskelstyrka, syrgasupptag och självrapporterad fysisk aktivitetsnivå, var under förväntad nivå i jämförelse med friska kontroller. Då en låg fysisk aktivitetsnivå allmänt anses vara ett stort hälsohot är det av största vikt att hitta sätt att erbjuda möjligheter till fysisk aktivitet för personer med funktionsnedsättningar.

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REFERENCES

1. Hatano S. Experience from a multicentre stroke register: a preliminary report. *Bull World Health Organ* 1976; **54**: 541-553.

2. WHO. The atlas of heart disease and stroke: World Health Organization, USA´s Centers for Disease Control and Prevention. 2004.

3. MacKay J, Mensah G. The atlas of heart disease and stroke. World Health Organization, Geneva; 2006.

4. Adamson J, Beswick A, Ebrahim S. Is stroke the most common cause of disability? *J Stroke Cerebrovasc Dis* 2004; **13**: 171-177.

5. Riks-stroke (2006) Analyserande rapport från Riks-Stroke för helåret 2006 (in Swedish). The National Stroke Register in Sweden; 2006. Available from: www.riks-stroke.org.

6. World Health Organization. WHO global infobase: data for saving lives. Geneva; 2004.

7. Ministério da Saúde / DATASUS. Departamento de Informatica do SUS, Brazil, 2005. Date accessed 4 June 2012.

8. Lopez AD, Mathers CD, Ezzati M, Jamison DT, Murray CJ. Global and regional burden of disease and risk factors, 2001: systematic analysis of population health data. *Lancet* 2006; **367**: 1747-1757.

9. Sacco RL, Adams R, Albers G, Alberts MJ, Benavente O, Furie K, Goldstein LB, Gorelick P, Halperin J, Harbaugh R, Johnston SC, Katzan I, Kelly-Hayes M, Kenton EJ, Marks M, Schwamm LH, Tomsick T, American Heart Association; American Stroke Association Council on Stroke; Council on Cardiovascular Radiology and Intervention; American Academy of Neurology. Guidelines for prevention of stroke in patients with ischemic stroke or transient ischemic attack: a statement for healthcare professionals from the American Heart Association/American Stroke Association Council on Stroke: co-sponsored by the Council on Cardiovascular Radiology and Intervention: the American Academy of Neurology affirms the value of this guideline. *Stroke* 2006; **37**: 577-617.

10. Feigin VL, Lawes CM, Bennett DA, Barker-Collo SL, Parag V. Worldwide stroke incidence and early case fatality reported in 56 population-based studies: a systematic review. *Lancet Neurol* 2009; **8**: 355-369.

11. Frontera WR. The World Report on Disability. *Am J Phys Med Rehabil* 2012; **91**: 549.

12. Andersen HE, Eriksen K, Brown A, Schultz-Larsen K, Forchhammer BH. Follow-up services for stroke survivors after hospital discharge--a randomized control study. *Clin Rehabil* 2002; **16**: 593-603.

13. Leonardi M, Bickenbach J, Ustun TB, Kostanjsek N, Chatterji S, Consortium M. The definition of disability: what is in a name? *Lancet* 2006; **368**: 1219-1221.

14. Danielsson A, Willen C, Sunnerhagen KS. Is walking endurance associated with activity and participation late after stroke? *Disabil Rehabil* 2011; **33**: 2053-2057.

15. Glassel A, Coenen M, Kollerits B, Cieza A. Validation of the extended ICF core set for stroke from the patient perspective using focus groups. *Disabil Rehabil* 2012; **34**: 157-166.

16. Jorgensen HS, Nakayama H, Raaschou HO, Vive-Larsen J, Stoier M, Olsen TS. Outcome and time course of recovery in stroke. Part I: Outcome. The Copenhagen Stroke Study. *Arch Phys Med Rehabil* 1995; **76**: 399-405.

17. White JH, Alston MK, Marquez JL, Sweetapple AL, Pollack MR, Attia J, Levi CR, Sturm J, Whyte S. Community-dwelling stroke survivors: function is not the whole story with quality of life. *Arch Phys Med Rehabil* 2007; **88**: 1140-1146.

18. Kase CS, Wolf PA, Kelly-Hayes M, Kannel WB, Beiser A, D'Agostino RB. Intellectual decline after stroke: the Framingham Study. *Stroke* 1998; **29**: 805-812.

19. Lawrence ES, Coshall C, Dundas R, Stewart J, Rudd AG, Howard R, Wolfe CD. Estimates of the prevalence of acute stroke impairments and disability in a multiethnic population. *Stroke* 2001; **32**: 1279-1284.

20. Benaim C, Perennou DA, Villy J, Rousseaux M, Pelissier JY. Validation of a standardized assessment of postural control in stroke patients: the Postural Assessment Scale for Stroke Patients (PASS). *Stroke* 1999; **30**: 1862-1868.

21. Gordon NF, Gulanick M, Costa F, Fletcher G, Franklin BA, Roth EJ, Shephard T, American Heart Association Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention; the Council on Cardiovascular Nursing; the Council on Nutrition, Physical Activity, and Metabolism; and the Stroke Council. Physical activity and exercise recommendations for stroke survivors: an American Heart Association scientific statement from the Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention; the Council on Cardiovascular Nursing; the Council on Nutrition, Physical

Activity, and Metabolism; and the Stroke Council. *Circulation* 2004; **109**: 2031-2041.

22. Mol VJ, Baker CA. Activity intolerance in the geriatric stroke patient. *Rehabil Nurs* 1991; **16**: 337-343.

23. Kwakkel G, Kollen B, Twisk J. Impact of time on improvement of outcome after stroke. *Stroke* 2006; **37**: 2348-2353.

24. Teasell R, Bayona NA, Bitensky J. Plasticity and reorganization of the brain post stroke. *Top Stroke Rehabil* 2005; **12**: 11-26.

25. Toschke AM, Tilling K, Cox AM, Rudd AG, Heuschmann PU, Wolfe CD. Patient-specific recovery patterns over time measured by dependence in activities of daily living after stroke and post-stroke care: the South London Stroke Register (SLSR). *Eur J Neurol* 2010; **17**: 219-225.

26. Page SJ, Gater DR, Bach YRP. Reconsidering the motor recovery plateau in stroke rehabilitation. *Arch Phys Med Rehabil* 2004; **85**: 1377-1381.

27. Kwakkel G, Kollen B, Lindeman E. Understanding the pattern of functional recovery after stroke: facts and theories. *Restor Neurol Neurosci* 2004; **22**: 281-299.

28. Wolfe CD, Crichton SL, Heuschmann PU, McKevitt CJ, Toschke AM, Grieve AP, Rudd AG. Estimates of outcomes up to ten years after stroke: analysis from the prospective South London Stroke Register. *PLoS Med* 2011; **8**: e1001033.

29. Carr JH, Shepherd RB. Stroke rehabilitation: Guidelines for exercise and training to optimize motor skill. Butterworth-Heineman Oxford, UK; 2003.

30. Lieber RL. Comparison between animal and human studies of skeletal muscle adaptation to chronic stimulation. *Clin Orthop Relat Res* 1988: 19-24.

31. Farmer SF, Swash M, Ingram DA, Stephens JA. Changes in motor unit synchronization following central nervous lesions in man. *J Physiol* 1993; **463**: 83-105.

32. Lukacs M, Vecsei L, Beniczky S. Changes in muscle fiber density following a stroke. *Clin Neurophysiol* 2009; **120**: 1539-1542.

33. Andrews AW, Bohannon RW. Distribution of muscle strength impairments following stroke. *Clin Rehabil* 2000; **14**: 79-87.

34. Harris ML, Polkey MI, Bath PM, Moxham J. Quadriceps muscle weakness following acute hemiplegic stroke. *Clin Rehabil* 2001; **15**: 274-281.

35. Newham DJ, Hsiao SF. Knee muscle isometric strength, voluntary activation and antagonist co-contraction in the first six months after stroke. *Disabil Rehabil* 2001; **23**: 379-386.

36. Carin-Levy G, Greig C, Young A, Lewis S, Hannan J, Mead G. Longitudinal changes in muscle strength and mass after acute stroke. *Cerebrovasc Dis* 2006; **21**: 201-207.

37. Sunnerhagen KS, Svantesson U, Lonn L, Krotkiewski M, Grimby G. Upper motor neuron lesions: their effect on muscle performance and appearance in stroke patients with minor motor impairment. *Arch Phys Med Rehabil* 1999; **80**: 155-161.

38. Landin S, Hagenfeldt L, Saltin B, Wahren J. Muscle metabolism during exercise in hemiparetic patients. *Clin Sci Mol Med* 1977; **53**: 257-269.

39. Edstrom L, Grimby L. Effect of exercise on the motor unit. *Muscle Nerve* 1986; **9**: 104-126.

40. Potempa K, Braun LT, Tinknell T, Popovich J. Benefits of aerobic exercise after stroke. *Sports Med* 1996; **21**: 337-346.

41. Ada L, Dorsch S, Canning CG. Strengthening interventions increase strength and improve activity after stroke: a systematic review. *Aust J Physiother* 2006; **52**: 241-248.

42. Teixeira-Salmela LF, Olney SJ, Nadeau S, Brouwer B. Muscle strengthening and physical conditioning to reduce impairment and disability in chronic stroke survivors. *Arch Phys Med Rehabil* 1999; **80**: 1211-1218.

43. Weiss A, Suzuki T, Bean J, Fielding RA. High intensity strength training improves strength and functional performance after stroke. *Am J Phys Med Rehabil* 2000; **79**: 369-376; quiz 391-364.

44. Dorsch S, Ada L, Canning CG, Al-Zharani M, Dean C. The strength of the ankle dorsiflexors has a significant contribution to walking speed in people who can walk independently after stroke: an observational study. *Arch Phys Med Rehabil* 2012; **93**: 1072-1076.

45. Kim CM, Eng JJ. The relationship of lower-extremity muscle torque to locomotor performance in people with stroke. *Phys Ther* 2003; **83**: 49-57.

46. Flansbjer UB, Holmback AM, Downham D, Lexell J. What change in isokinetic knee muscle strength can be detected in men and women with hemiparesis after stroke? *Clin Rehabil* 2005; **19**: 514-522.

47. Pohl PS, Startzell JK, Duncan PW, Wallace D. Reliability of lower extremity isokinetic strength testing in adults with stroke. *Clin Rehabil* 2000; **14**: 601-607.

48. Geyh S, Cieza A, Schouten J, Dickson H, Frommelt P, Omar Z, Kostanjsek N, Ring H, Stucki G. ICF Core Sets for stroke. *J Rehabil Med* 2004: 135-141.

49. WHO. International classification of functioning, disability and health (ICF). Geneva: World Health Organisation; 2001.

50. Barbeau H, Fung J. The role of rehabilitation in the recovery of walking in the neurological population. *Curr Opin Neurol* 2001; **14**: 735-740.

51. Perry J, Garrett M, Gronley JK, Mulroy SJ. Classification of walking handicap in the stroke population. *Stroke* 1995; **26**: 982-989.

52. Jorgensen HS, Nakayama H, Raaschou HO, Vive-Larsen J, Stoier M, Olsen TS. Outcome and time course of recovery in stroke. Part II: Time course of recovery. The Copenhagen Stroke Study. *Arch Phys Med Rehabil* 1995; **76**: 406-412.

53. Quintas R, Cerniauskaite M, Ajovalasit D, Sattin D, Boncoraglio G, Parati EA, Leonardi M. Describing functioning, disability, and health with the International Classification of Functioning, Disability, and Health Brief Core Set for Stroke. *Am J Phys Med Rehabil* 2012; **91**: S14-21.

54. Wall JC, Turnbull GI. Gait asymmetries in residual hemiplegia. *Arch Phys Med Rehabil* 1986; **67**: 550-553.

55. Olney SJ, Richards C. Hemiparetic gait following stroke. Part 1: characteristics. *Gait Posture* 1996; **4**: 136-148.

56. Woolley SM. Characteristics of gait in hemiplegia. *Top Stroke Rehabil* 2001; **7**: 1-18.

57. Carvalho C, Sunnerhagen KS, Willen C. Walking speed and distance in different environments of subjects in the later stage post-stroke. *Physiother Theory Pract* 2010; **26**: 519-527.

58. Carvalho C, Willen C, Sunnerhagen KS. Relationship between walking function and 1-legged bicycling test in subjects in the later stage post-stroke. *J Rehabil Med* 2008; **40**: 721-726.

59. Harris JE, Eng JJ, Marigold DS, Tokuno CD, Louis CL. Relationship of balance and mobility to fall incidence in people with chronic stroke. *Phys Ther* 2005; **85**: 150-158.

60. Persson CU, Hansson PO, Sunnerhagen KS. Clinical tests performed in acute stroke identify the risk of falling during the first year: postural stroke study in Gothenburg (POSTGOT). *J Rehabil Med* 2011; **43**: 348-353.

61. Hill K, Ellis P, Bernhardt J, Maggs P, Hull S. Balance and mobility outcomes for stroke patients: a comprehensive audit. *Aust J Physiother* 1997; **43**: 173-180.

62. Dean CM, Richards CL, Malouin F. Walking speed over 10 metres overestimates locomotor capacity after stroke. *Clin Rehabil* 2001; **15**: 415-421.

63. Lundgren-Lindquist B, Aniansson A, Rundgren A. Functional studies in 79-year-olds. III. Walking performance and climbing capacity. *Scand J Rehabil Med* 1983; **15**: 125-131.

64. ATS. American Thoracic Society. ATS Statement: Guidelines for the Six-Minute Walk Test. *Am J Respir Crit Care Med* 2002; **166**: 111-117.

65. Park HJ, Oh DW, Kim SY, Choi JD. Effectiveness of community-based ambulation training for walking function of post-stroke hemiparesis: a randomized controlled pilot trial. *Clin Rehabil* 2011; **25**: 451-459.

66. Kollen B, Kwakkel G, Lindeman E. Hemiplegic gait after stroke: is measurement of maximum speed required? *Arch Phys Med Rehabil* 2006; **87**: 358-363.

67. Combs SA, Van Puymbroeck M, Altenburger PA, Miller KK, Dierks TA, Schmid AA. Is walking faster or walking farther more important to persons with chronic stroke? *Disabil Rehabil* 2012 oct 5.

68. Shumway-Cook A, Woollacott MH. Motor Control: Theory and practical applications. Lippincott Williams & Wilkins; 2001.

69. Li F, Fisher KJ, Brownson RC, Bosworth M. Multilevel modelling of built environment characteristics related to neighbourhood walking activity in older adults. *J Epidemiol Community Health* 2005; **59**: 558-564.

70. Sellers CE, Grant PM, Ryan CG, O'Kane C, Raw K, Conn D. Take a walk in the park? A cross-over pilot trial comparing brisk walking in two different environments: Park and urban. *Prev Med* 2012; **55**: 438-443.

71. Donovan K, Lord SE, McNaughton HK, Weatherall M. Mobility beyond the clinic: the effect of environment on gait and its measurement in community-ambulant stroke survivors. *Clin Rehabil* 2008; **22**: 556-563.

72. Lord SE, Rochester L, Weatherall M, McPherson KM, McNaughton HK. The effect of environment and task on gait parameters after stroke: A randomized comparison of measurement conditions. *Arch Phys Med Rehabil* 2006; **87**: 967-973.

73. Taylor D, Stretton CM, Mudge S, Garrett N. Does clinic-measured gait speed differ from gait speed measured in the community in people with stroke? *Clin Rehabil* 2006; **20**: 438-444.

74. American College of Sports Medicine: ACSM's Guidelines for Exercise Testing and Prescription. 7th Ed. Lippincott Williams & Wilkins Philadelphia, PA; 2006.

75. Billinger SA, Coughenour E, Mackay-Lyons MJ, Ivey FM. Reduced cardiorespiratory fitness after stroke: biological consequences and exercise-induced adaptations. *Stroke Res Treat* 2012; **2012**: 959120.

76. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep* 1985; **100**: 126-131.

77. Carr JH, Shepherd RB. Enhancing physical activity and brain reorganization after stroke. *Neurol Res Int* 2011; **2011**: 515938.

78. Gordon NF, Gulanick M, Costa F, Fletcher G, Franklin BA, Roth EJ, Shephard T, American Heart Association Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention; the Council on Cardiovascular Nursing; the Council on Nutrition, Physical Activity, and Metabolism; and the Stroke Council. Physical activity and exercise recommendations for stroke survivors: an American Heart Association scientific statement from the Council on Clinical Cardiology, Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention; the Council on Cardiovascular Nursing; the Council on Nutrition, Physical Activity, and Metabolism; and the Stroke Council. *Stroke* 2004; **35**: 1230-1240.

79. Saunders DH, Greig CA, Young A, Mead GE. Physical fitness training for stroke patients. *Cochrane Database Syst Rev* 2004: CD003316.

80. Smith AC, Saunders DH, Mead G. Cardiorespiratory fitness after stroke: a systematic review. *Int J Stroke* 2012; **7**: 499-510.

81. Grimby G. On the energy cost of achieving mobility. *Scand J Rehabil Med Suppl* 1983; **9**: 49-54.

82. Holden MK, Gill KM, Magliozzi MR. Gait assessment for neurologically impaired patients. Standards for outcome assessment. *Phys Ther* 1986; **66**: 1530-1539.

83. Rodjer L, Jonsdottir IH, Rosengren A, Bjorck L, Grimby G, Thelle DS, Lappas G, Borjesson M. Self-reported leisure time physical activity: a useful assessment tool in everyday health care. *BMC Public Health* 2012; **12**: 693.

84. Rand D, Eng JJ, Tang PF, Jeng JS, Hung C. How active are people with stroke?: use of accelerometers to assess physical activity. *Stroke* 2009; **40**: 163-168.

85. Alzahrani MA, Ada L, Dean CM. Duration of physical activity is normal but frequency is reduced after stroke: an observational study. *J Physiother* 2011; **57**: 47-51.

86. Ainsworth BE. How do I measure physical activity in my patients? Questionnaires and objective methods. *Br J Sports Med* 2009; **43**: 6-9.

87. Lindahl M, Hansen L, Pedersen A, Truelsen T, Boysen G. Self-reported physical activity after ischemic stroke correlates with physical capacity. *Advances in Physiotherapy.* 2008; **10**: 188-194.

88. Billinger SA, Tseng BY, Kluding PM. Modified total-body recumbent stepper exercise test for assessing peak oxygen consumption in people with chronic stroke. *Phys Ther* 2008; **88**: 1188-1195.

89. Ivey FM, Macko RF, Ryan AS, Hafer-Macko CE. Cardiovascular health and fitness after stroke. *Top Stroke Rehabil* 2005; **12**: 1-16.

90. Mackay-Lyons MJ, Makrides L. Exercise capacity early after stroke. *Arch Phys Med Rehabil* 2002; **83**: 1697-1702.

91. Yates JS, Studenski S, Gollub S, Whitman R, Perera S, Lai SM, Duncan PW. Bicycle ergometry in subacute-stroke survivors: feasibility, safety, and exercise performance. *J Aging Phys Act* 2004; **12**: 64-74.

92. Sunnerhagen KS, Mattsson K. One-legged bicycling as an assessment tool for patients with stroke. *Acta Neurol Scand* 2005; **111**: 373-378.

93. Peeters P, Mets T. The 6-minute walk as an appropriate exercise test in elderly patients with chronic heart failure. *J Gerontol A Biol Sci Med Sci* 1996; **51**: M147-151.

94. Butland RJ, Pang J, Gross ER, Woodcock AA, Geddes DM. Two-, six-, and 12-minute walking tests in respiratory disease. *Br Med J (Clin Res Ed)* 1982; **284**: 1607-1608.

95. Guyatt GH, Sullivan MJ, Thompson PJ, Fallen EL, Pugsley SO, Taylor DW, Berman LB. The 6-minute walk: a new measure of exercise capacity in patients with chronic heart failure. *Can Med Assoc J* 1985; **132**: 919-923.

96. Roomi J, Johnson MM, Waters K, Yohannes A, Helm A, Connolly MJ. Respiratory rehabilitation, exercise capacity and quality of life in chronic airways disease in old age. *Age Ageing* 1996; **25**: 12-16.

97. Eng JJ, Dawson AS, Chu KS. Submaximal exercise in persons with stroke: test-retest reliability and concurrent validity with maximal oxygen consumption. *Arch Phys Med Rehabil* 2004; **85**: 113-118.

98. Kelly JO, Kilbreath SL, Davis GM, Zeman B, Raymond J. Cardiorespiratory fitness and walking ability in subacute stroke patients. *Arch Phys Med Rehabil* 2003; **84**: 1780-1785.

99. Pang MY, Eng JJ, Dawson AS. Relationship between ambulatory capacity and cardiorespiratory fitness in chronic stroke: influence of stroke-specific impairments. *Chest* 2005; **127**: 495-501.

100. Pang MY, Eng JJ, Dawson AS, Gylfadottir S. The use of aerobic exercise training in improving aerobic capacity in individuals with stroke: a meta-analysis. *Clin Rehabil* 2006; **20**: 97-111.

101. Quinn TJ, Paolucci S, Sivenius J, Walker MF, Toni D, Lees KR. Evidence-based stroke rehabilitation: an expanded guidance document from the european stroke organisation (ESO) guidelines for management of ischaemic stroke and transient ischaemic attack 2008. *J Rehabil Med* 2009; **41**: 99-111.

102. Stroke Unit Trialists Collaboration. Organised inpatient (stroke unit) care for stroke. *Cochrane Database Syst Rev* 2007: CD000197.

103. Brewer L, Horgan F, Hickey A, Williams D. Stroke rehabilitation: recent advances and future therapies. *QJM* 2012 Sep 27.

104. Shepherd RB. Exercise and training to optimize functional motor performance in stroke: driving neural reorganization? *Neural Plast* 2001; **8**: 121-129.

105. Dewey HM, Sherry LJ, Collier JM. Stroke rehabilitation 2007: what should it be? *Int J Stroke* 2007; **2**: 191-200.

106. Outpatient Service Trialists. Therapy-based rehabilitation services for stroke patients at home. *Cochrane Database Syst Rev* 2003: CD002925.

107. Legg L, Langhorne P, Outpatient Service Trialists. Rehabilitation therapy services for stroke patients living at home: systematic review of randomised trials. *Lancet* 2004; **363**: 352-356.

108. Aziz NA, Leonardi-Bee J, Phillips M, Gladman JR, Legg L, Walker MF. Therapy-based rehabilitation services for patients living at home more than one year after stroke. *Cochrane Database Syst Rev* 2008: CD005952.

109. Eng JJ, Tang PF. Gait training strategies to optimize walking ability in people with stroke: a synthesis of the evidence. *Expert Rev Neurother* 2007; **7**: 1417-1436.

110. World Confederation for Physical Therapy. Policy statement: Description of physical therapy. Date accessed 27 Sep 2012.

111. Carr J, Shepherd R. Stroke rehabilitation: Guidelines for exercise and training to optimize motor skill. Butterworth-Heineman London, UK; 2003.

112. Van Peppen RP, Kwakkel G, Wood-Dauphinee S, Hendriks HJ, Van der Wees PJ, Dekker J. The impact of physical therapy on functional outcomes after stroke: what's the evidence? *Clin Rehabil* 2004; **18**: 833-862.

113. Pound P, Bury M, Gompertz P, Ebrahim S. Views of survivors of stroke on benefits of physiotherapy. *Qual Health Care* 1994; **3**: 69-74.

114. Pollock A, Baer G, Langhorne P, Pomeroy V. Physiotherapy treatment approaches for the recovery of postural control and lower limb function following stroke: a systematic review. *Clin Rehabil* 2007; **21**: 395-410.

115. Langhammer B, Stanghelle JK. Can physiotherapy after stroke based on the Bobath concept result in improved quality of movement compared to the motor relearning programme. *Physiother Res Int* 2011; **16**: 69-80.

116. Pinter MM, Brainin M. Rehabilitation after stroke in older people. *Maturitas* 2012; **71**: 104-108.

117. Reiss AP, Wolf SL, Hammel EA, McLeod EL, Williams EA. Constraint-Induced Movement Therapy (CIMT): Current Perspectives and Future Directions. *Stroke Res Treat* 2012; **2012**: 159391.

118. Pignolo L. Robotics in neuro-rehabilitation. *J Rehabil Med* 2009; **41**: 955-960.

119. States RA, Pappas E, Salem Y. Overground physical therapy gait training for chronic stroke patients with mobility deficits. *Cochrane Database Syst Rev* 2009: CD006075.

120. Moseley AM, Stark A, Cameron ID, Pollock A. Treadmill training and body weight support for walking after stroke. *Cochrane Database Syst Rev* 2005: CD002840.

121. Laver K, George S, Thomas S, Deutsch JE, Crotty M. Cochrane review: virtual reality for stroke rehabilitation. *Eur J Phys Rehabil Med* 2012; **48**: 523-530.

122. English C, Hillier SL. Circuit class therapy for improving mobility after stroke. *Cochrane Database Syst Rev* 2010: CD007513.

123. Kwakkel G, Wagenaar RC, Twisk JW, Lankhorst GJ, Koetsier JC. Intensity of leg and arm training after primary middle-cerebral-artery stroke: a randomised trial. *Lancet* 1999; **354**: 191-196.

124. Peurala SH, Pitkanen K, Sivenius J, Tarkka IM. How much exercise does the enhanced gait-oriented physiotherapy provide for chronic stroke patients? *J Neurol* 2004; **251**: 449-453.

125. Sharp SA, Brouwer BJ. Isokinetic strength training of the hemiparetic knee: effects on function and spasticity. *Arch Phys Med Rehabil* 1997; **78**: 1231-1236.

126. Brazzelli M, Saunders DH, Greig CA, Mead GE. Physical fitness training for patients with stroke: updated review. *Stroke* 2012; **43**: e39-e40.

127. Brazzelli M, Saunders DH, Greig CA, Mead GE. Physical fitness training for stroke patients. *Cochrane Database Syst Rev* 2011: CD003316.

128. Engardt M, Grimby G. [Adapted exercise important after stroke. Acute and long-term effects of different training programs]. *Lakartidningen* 2005; **102**: 392-394, 397-398.

129. Kwakkel G, Kollen BJ, Wagenaar RC. Long term effects of intensity of upper and lower limb training after stroke: a randomised trial. *J Neurol Neurosurg Psychiatry* 2002; **72**: 473-479.

130. Sunnerhagen KS, Hedberg M, Henning GB, Cider A, Svantesson U. Muscle performance in an urban population sample of 40- to 79-year-old men and women. *Scand J Rehabil Med* 2000; **32**: 159-167.

131. Kluding P, Gajewski B. Lower-extremity strength differences predict activity limitations in people with chronic stroke. *Phys Ther* 2009; **89**: 73-81.

132. Fugl-Meyer AR, Jaasko L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. *Scand J Rehabil Med* 1975; **7**: 13-31.

133. Fugl-Meyer AR. Post-stroke hemiplegia assessment of physical properties. *Scand J Rehabil Med Suppl* 1980; **7**: 85-93.

134. Berg K, Wood-Dauphinee S, Williams JI. The Balance Scale: reliability assessment with elderly residents and patients with an acute stroke. *Scand J Rehabil Med* 1995; **27**: 27-36.

135. Witte US, Carlsson JY. Self-selected walking speed in patients with hemiparesis after stroke. *Scand J Rehabil Med* 1997; **29**: 161-165.

136. Washburn RA, Smith KW, Jette AM, Janney CA. The Physical Activity Scale for the Elderly (PASE): development and evaluation. *J Clin Epidemiol* 1993; **46**: 153-162.

137. Bohannon RW. Strength deficits also predict gait performance in patients with stroke. *Percept Mot Skills* 1991; **73**: 146.

138. Eng JJ, Kim CM, Macintyre DL. Reliability of lower extremity strength measures in persons with chronic stroke. *Arch Phys Med Rehabil* 2002; **83**: 322-328.

139. Danielsson A, Willen C, Sunnerhagen KS. Physical activity, ambulation, and motor impairment late after stroke. *Stroke Res Treat* 2012; **2012**: 818513.

140. Duncan PW, Propst M, Nelson SG. Reliability of the Fugl-Meyer assessment of sensorimotor recovery following cerebrovascular accident. *Phys Ther* 1983; **63**: 1606-1610.

141. Gladstone DJ, Danells CJ, Black SE. The fugl-meyer assessment of motor recovery after stroke: a critical review of its measurement properties. *Neurorehabil Neural Repair* 2002; **16**: 232-240.

142. Flansbjer UB, Downham D, Lexell J. Knee muscle strength, gait performance, and perceived participation after stroke. *Arch Phys Med Rehabil* 2006; **87**: 974-980.

143. Willen C, Sunnerhagen KS, Ekman C, Grimby G. How is walking speed related to muscle strength? A study of healthy persons and persons with late effects of polio. *Arch Phys Med Rehabil* 2004; **85**: 1923-1928.

144. Howley ET, Bassett DR, Jr., Welch HG. Criteria for maximal oxygen uptake: review and commentary. *Med Sci Sports Exerc* 1995; **27**: 1292-1301.

145. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 1982; **14**: 377-381.

146. American College of Sports Medicine: ACSM's guidelines for exercise testing and prescription. 6 th Ed. Lippincott Willians & Wilkins Philadelphia; 2000.

147. Kuskowska-Wolk A, Rossner S. Body mass distribution of a representative adult population in Sweden. *Diabetes Res Clin Pract* 1990; **10 Suppl 1**: S37-41.

148. Berg KO, Maki BE, Williams JI, Holliday PJ, Wood-Dauphinee SL. Clinical and laboratory measures of postural balance in an elderly population. *Arch Phys Med Rehabil* 1992; **73**: 1073-1080.

149. Mao HF, Hsueh IP, Tang PF, Sheu CF, Hsieh CL. Analysis and comparison of the psychometric properties of three balance measures for stroke patients. *Stroke* 2002; **33**: 1022-1027.

150. Aniansson A, Rundgren A, Sperling L. Evaluation of functional capacity in activities of daily living in 70-year-old men and women. *Scand J Rehabil Med* 1980; **12**: 145-154.

151. Wade DT, Wood VA, Heller A, Maggs J, Langton Hewer R. Walking after stroke. Measurement and recovery over the first 3 months. *Scand J Rehabil Med* 1987; **19**: 25-30.

152. ATS. American Thoracic Society Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. ATS statement: guidelines for the six-minute walk test. *Am J Respir Crit Care Med* 2002; **166**: 111-117.

153. Eng JJ, Chu KS, Dawson AS, Kim CM, Hepburn KE. Functional walk tests in individuals with stroke: relation to perceived exertion and myocardial exertion. *Stroke* 2002; **33**: 756-761.

154. Enright PL, Sherrill DL. Reference equations for the six-minute walk in healthy adults. *Am J Respir Crit Care Med* 1998; **158**: 1384-1387.

155. Washburn RA, McAuley E, Katula J, Mihalko SL, Boileau RA. The physical activity scale for the elderly (PASE): evidence for validity. *J Clin Epidemiol* 1999; **52**: 643-651.

156. Martin KA, Rejeski WJ, Miller ME, James MK, Ettinger WH, Jr., Messier SP. Validation of the PASE in older adults with knee pain and physical disability. *Med Sci Sports Exerc* 1999; **31**: 627-633.

157. Krarup LH, Truelsen T, Pedersen A, Lerke H, Lindahl M, Hansen L, Schnohr P, Boysen G. Level of physical activity in the week preceding an ischemic stroke. *Cerebrovasc Dis* 2007; **24**: 296-300.

158. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; **1**: 307-310.

159. Munro BH. Statistical methods for health care research. JB Lippincott Philadelphia; 1993.

160. Bohannon RW, Andrews AW, Thomas MW. Walking speed: reference values and correlates for older adults. *J Orthop Sports Phys Ther* 1996; **24**: 86-90.

161. van de Port IG, Kwakkel G, Schepers VP, Lindeman E. Predicting mobility outcome one year after stroke: a prospective cohort study. *J Rehabil Med* 2006; **38**: 218-223.

162. Flansbjer UB, Holmback AM, Downham D, Patten C, Lexell J. Reliability of gait performance tests in men and women with hemiparesis after stroke. *J Rehabil Med* 2005; **37**: 75-82.

163. Fulk GD, Echternach JL, Nof L, O'Sullivan S. Clinometric properties of the six-minute walk test in individuals undergoing rehabilitation poststroke. *Physiother Theory Pract* 2008; **24**: 195-204.

164. Cesari M, Kritchevsky SB, Newman AB, Simonsick EM, Harris TB, Penninx BW, Brach JS, Tylavsky FA, Satterfield S, Bauer DC, Rubin SM, Visser M, Pahor M, Health A, Body Composition S. Added value of physical performance measures in predicting adverse health-related events: results from the Health, Aging And Body Composition Study. *J Am Geriatr Soc* 2009; **57**: 251-259.

165. Abellan van Kan G, Rolland Y, Andrieu S, Bauer J, Beauchet O, Bonnefoy M, Cesari M, Donini LM, Gillette Guyonnet S, Inzitari M, Nourhashemi F, Onder G, Ritz P, Salva A, Visser M, Vellas B. Gait speed at usual pace as a predictor of adverse outcomes in community-dwelling older people an International Academy on Nutrition and Aging (IANA) Task Force. *J Nutr Health Aging* 2009; **13**: 881-889.

166. Studenski S, Perera S, Patel K, Rosano C, Faulkner K, Inzitari M, Brach J, Chandler J, Cawthon P, Connor EB, Nevitt M, Visser M, Kritchevsky S, Badinelli S, Harris T, Newman AB, Cauley J, Ferrucci L, Guralnik J. Gait speed and survival in older adults. *JAMA* 2011; **305**: 50-58.

167. Tang A, Eng JJ, Rand D. Relationship between perceived and measured changes in walking after stroke. *J Neurol Phys Ther* 2012; **36**: 115-121.

168. Wevers LE, Kwakkel G, van de Port IG. Is outdoor use of the six-minute walk test with a global positioning system in stroke patients' own neighbourhoods reproducible and valid? *J Rehabil Med* 2011; **43**: 1027-1031.

169. Thompson Coon J, Boddy K, Stein K, Whear R, Barton J, Depledge MH. Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. *Environ Sci Technol* 2011; **45**: 1761-1772.

170. Buchner DM, Larson EB, Wagner EH, Koepsell TD, de Lateur BJ. Evidence for a non-linear relationship between leg strength and gait speed. *Age Ageing* 1996; **25**: 386-391.

171. El Haber N, Erbas B, Hill KD, Wark JD. Relationship between age and measures of balance, strength and gait: linear and non-linear analyses. *Clin Sci (Lond)* 2008; **114**: 719-727.

172. Patten C, Lexell J, Brown HE. Weakness and strength training in persons with poststroke hemiplegia: rationale, method, and efficacy. *J Rehabil Res Dev* 2004; **41**: 293-312.

173. Davies JM, Mayston MJ, Newham DJ. Electrical and mechanical output of the knee muscles during isometric and isokinetic activity in stroke and healthy adults. *Disabil Rehabil* 1996; **18**: 83-90.

174. Flansbjer UB, Miller M, Downham D, Lexell J. Progressive resistance training after stroke: effects on muscle strength, muscle tone, gait performance and perceived participation. *J Rehabil Med* 2008; **40**: 42-48.

175. Rostagno C, Olivo G, Comeglio M, Boddi V, Banchelli M, Galanti G, Gensini GF. Prognostic value of 6-minute walk corridor test in patients with mild to moderate heart failure: comparison with other methods of functional evaluation. *Eur J Heart Fail* 2003; **5**: 247-252.

176. Oudiz RJ, Barst RJ, Hansen JE, Sun XG, Garofano R, Wu X, Wasserman K. Cardiopulmonary exercise testing and six-minute walk correlations in pulmonary arterial hypertension. *Am J Cardiol* 2006; **97**: 123-126.

177. Courbon A, Calmels P, Roche F, Ramas J, Rimaud D, Fayolle-Minon I. Relationship between maximal exercise capacity and walking capacity in adult hemiplegic stroke patients. *Am J Phys Med Rehabil* 2006; **85**: 436-442.

178. Tang A, Sibley KM, Bayley MT, McIlroy WE, Brooks D. Do functional walk tests reflect cardiorespiratory fitness in sub-acute stroke? *J Neuroengineering Rehabil* 2006; **3**: 23.

179. Stamford BA, Weltman A, Fulco C. Anaerobic threshold and cardiovascular responses during one- versus two-legged cycling. *Res Q* 1978; **49**: 351-362.

180. Pohl P, Duncan P, Perera S, Liu W, Siu M, Studenski S, Long J. Influence of stroke-related impairments on performance in 6-minute walk test. *J Rehabil Res Dev* 2002; **39**: 439-445.

181. Mackey F, Ada L, Heard R, Adams R. Stroke rehabilitation: are highly structured units more conducive to physical activity than less structured units? *Arch Phys Med Rehabil* 1996; **77**: 1066-1070.

182. Sawatzky R, Liu-Ambrose T, Miller WC, Marra CA. Physical activity as a mediator of the impact of chronic conditions on quality of life in older adults. *Health Qual Life Outcomes* 2007; **5**: 68.

183. Krarup LH, Truelsen T, Gluud C, Andersen G, Zeng X, Korv J, Oskedra A, Boysen G, ExStroke Pilot Trial Group. Prestroke physical activity is associated with severity and long-term outcome from first-ever stroke. *Neurology* 2008; **71**: 1313-1318.

184. Bauman A, Phongsavan P, Schoeppe S, Owen N. Physical activity measurement-a primer for health promotion. *Promot Educ* 2006; **13**: 92-103.

185. Boysen G, Krarup LH, Zeng X, Oskedra A, Korv J, Andersen G, Gluud C, Pedersen A, Lindahl M, Hansen L, Winkel P, Truelsen T, ExStroke Pilot Trial Group. ExStroke Pilot Trial of the effect of repeated instructions

to improve physical activity after ischaemic stroke: a multinational randomised controlled clinical trial. *BMJ* 2009; **339**: b2810.

186. Dunlop DD, Song J, Semanik PA, Sharma L, Chang RW. Physical activity levels and functional performance in the osteoarthritis initiative: a graded relationship. *Arthritis Rheum* 2011; **63**: 127-136.

187. Duncan PW, Zorowitz R, Bates B, Choi JY, Glasberg JJ, Graham GD, Katz RC, Lamberty K, Reker D. Management of Adult Stroke Rehabilitation Care: a clinical practice guideline. *Stroke* 2005; **36**: e100-143.

188. Teasell R, Bayona N, Bitensky J (2011) "Background Concepts in Stroke Rehabiliitation". Evidence Based Review of Stroke Rehabilitation (Version 14): 1– 44. vol 2012. Date accessed 7 Sep 2012.

189. Bowden MG, Embry AE, Perry LA, Duncan PW. Rehabilitation of Walking After Stroke. *Curr Treat Options Neurol* 2012 Sep 20.

190. Bowden MG, Embry AE, Gregory CM. Physical therapy adjuvants to promote optimization of walking recovery after stroke. *Stroke Res Treat* 2011; **2011**: 601416.