# MUSCLE STRENGTH, GROSS MOTOR FUNCTION AND GAIT PATTERN IN CHILDREN WITH CEREBRAL PALSY

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*“May the torque be with you!”*

(with inspiration from George Lucas films Star wars)

# Abstract


## Aim

The main purpose was to explore the relationship between muscle strength and walking ability in children with bilateral spastic cerebral palsy (CP), and to analyse whether muscle strength training can improve walking ability.

Another aim was to establish normative values for muscle strength in terms of torque in typically developing children and adolescents, and in relation to sex, age and body weight.

## Methods

A total of 174 typically developing children and 63 children with CP between the ages of five and 15 years participated in the studies. Muscle strength was measured with a handheld myometer. Motor function in children with CP was classified with the Gross Motor Function Classification System (GMFCS), graded with the Gross Motor Function Measure (GMFM) and gait pattern was measured with computerised three dimensional gait analysis. Muscle strength training in 16 children was conducted during eight weeks, three times a week.

## Results

Normative data for muscle strength showed an increase in torque with age and weight, and strong correlations with both. There were few differences between boys and girls. Equations for predicted torque based on age, weight and sex were developed. Muscle strength in the legs was below predicted values in children with CP. It was lowest in the ankle, followed by muscles around the hip. Weakness increased with severity of motor involvement, strength over 50% of the norm was needed for independent walking. Muscle strength was correlated to walking ability and gait pattern, most obvious at the ankle. The gait moments (torque) in the children with CP were closer to their maximal muscle strength than in typically developing children. With eight weeks of strength training there was an increase in muscle strength, walking ability and push off in gait.

## Conclusions

Muscle weakness was found in children with CP, increasing with severity of gross motor impairment and most pronounced at the ankle. There were correlations between muscle strength and walking ability and between muscle strength and gait pattern, most obvious at the ankle. After training, there was an increase in muscle strength and in walking ability and gait pattern.



Keywords: child, muscle strength, reference values, cerebral palsy, motor skills, gait, resistance training

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# Sammanfattning


## Syfte

Huvudsyftet var att utforska sambandet mellan muskelstyrka och gångförmåga hos barn med bilateral spastisk cerebral pares (CP), samt undersöka om styrketräning kan förbättra gångförmågan.

Ytterligare ett syfte var att ta fram normalvärden för muskelstyrka mätt som vridmoment hos friska barn och ungdomar och i relation till kön, ålder och kroppsvikt.

## Metod

Totalt deltog 174 friska barn och 63 barn med CP mellan fem och femton års ålder i studierna. Muskelstyrka mättes med en handhållen myometer. Motorisk funktion hos barnen med CP klassificerades med Gross Motor Function Classification System (GMFCS), graderades med Gross Motor Function Measure (GMFM) och gångmönster mättes med datoriserad tre dimensionell gånganalys. Muskelstyrketräning genomfördes av 16 barn tre gånger i veckan under åtta veckor.

## Resultat

Normalvärden för muskelstyrka visade på en ökning av vridmoment med ålder och vikt och en stark korrelation med båda. Det var få skillnader mellan flickor och pojkar. Ekvationer utvecklades för ett predikterat värde på vridmoment baserat på ålder vikt och kön.

Muskelstyrka i benen låg under predikterade värden för barn med CP. Lägst värden uppmättes runt fotleden och därefter muskelgrupper runt höftleden. Svagheten ökade med svårigheten på det motoriska funktionshindret, styrka över 50% av normal behövdes för att kunna gå utan stöd. Muskelstyrka korrelerade med gångförmåga och gångmönster, tydligast runt fotleden. Kraftutvecklingen under gång hos barn med CP låg närmare deras maximala styrka än hos de friska barnen. Efter åtta veckors styrketräning ökade muskelstyrka, gångförmåga och frånskjut i gång.

## Konklusion

Vi fann muskelsvaghet hos barn med CP, ökande med grad av motoriskt funktionshinder och som var mest uttalat runt fotleden. Det var ett samband mellan muskelstyrka och gångförmåga och mellan muskelstyrka och gångmönster, tydligast runt fotleden. Efter styrketräning förbättrades muskelstyrka, gångförmåga och gångmönster.

# List of papers

I. Meta Nyström Eek, Anna-Karin Kroksmark and Eva Beckung.
Isometric Muscle Torque in Children 5 to 15 Years of Age: Normative Data.
*Archives of Physical Medicine and Rehabilitation (2006) Aug; 87: 1091-99.*

II. Meta Nyström Eek and Eva Beckung.
Walking ability is related to muscle strength in children with cerebral palsy.
*Gait & Posture (2008) 28; 366-71.*

III. Meta Nyström Eek, Roy Tranberg and Eva Beckung.
Muscle strength and gait pattern in children with bilateral CP.
*Manuscript.*

IV. Meta Nyström Eek, Roy Tranberg, Roland Zügner, Kristina Alkema and Eva Beckung.
Muscle strength training to improve gait function in children with cerebral palsy.
*Dev Med Child Neurol. 2008 Oct;50(10):759-64.*

# Contents

# Abbreviations

| | |
|---|---|
| 3D | Three-dimensional |
| CP | Cerebral palsy |
| EMG | Electromyography |
| GMAE | Gross Motor Ability Estimator |
| GMFCS | Gross Motor Function Classification System |
| GMFM | Gross Motor Function Measure |
| ICF | International Classification of Functioning, Disability and Health |
| MMT | Manual Muscle Testing |
| Nm | Newton meter |
| ROM | Range of motion |
| SCPE | Surveillance of Cerebral Palsy in Europe |
| SD | Standard deviation |
| SDR | Selective dorsal rhizotomy |
| UN | United Nations |
| W | Watt |
| WCPT | World Confederation for Physical Therapy |
| WHO | World Health Organization |

# Introduction

## *Cerebral Palsy*

Cerebral palsy (CP) is the most common cause of severe physical disability in childhood (Koman, Smith et al. 2004). The latest definition describes it as a multifaceted disorder:

*Cerebral palsy describes a group of disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, cognition, communication, perception, and/or behaviour, and/or by a seizure disorder* (Bax, Goldstein et al. 2005; Rosenbaum, Paneth et al. 2007).

Although this definition describes problems in many systems, the classification of CP is still based on motor involvement. Varying classifications have been used in different countries, which give rise to confusion when comparing prevalence and outcome of treatment. A European research group, Surveillance of Cerebral Palsy in Europe (SCPE), has recently agreed on a new classification (2000). It emphasizes diagnosis by the dominant symptom and introduces the use of the concept of unilateral and bilateral CP, to replace hemi-, di- and tetra/quadriplegia. The SCPE classification also classifies CP into subtypes: spastic (unilateral or bilateral), dyskinetic and ataxic.

The prevalence of CP has been fairly stable over the years and is reported as 2.08 per live births in a European survey of children born in 1980-1990 (SCPE 2002). There have been changes both in the prevalence and in the proportion of the subtypes, closely linked to the development of maternal and neonatal care. The increase in survival of children born very pre-term led to a rise in the prevalence in the 1970s and then a gradual decline. In the latest reported cohort of children born in 1995-1998 in western Sweden, the prevalence is about 1.92 per 1000 live births (Himmelmann, Hagberg et al. 2005). The bilateral spastic type was the most common, 54% of all CP in the SCPE and 41% in western Sweden (Himmelmann 2006, p 38).

### Gross motor function in CP

The motor manifestation typically involves a variety of neuromuscular and musculoskeletal problems. These problems include spasticity, dystonia, contractures, abnormal bone growth, poor balance, loss of selective motor control, and muscle weakness (Giuliani 1991; Gormley 2001). Although CP is

not a progressive disease in itself, its motor manifestations often change due to the abnormal tone and overactive muscles that can lead to muscle contractures, which in turn, can lead to changes in skeletal alignment during growth.

Table 1. Description of GMFCS levels in age band 6-12 years

| Between 6th and 12th Birthday | |
|---|---|
| Level I | Children walk at home, school, outdoors, and in the community. Children are able to walk up and down curbs without physical assistance and stairs without the use of a railing. Children perform gross motor skills such as running and jumping but speed, balance, and coordination are limited. Children may participate in physical activities and sports depending on personal choices and environmental factors. |
| Level II | Children walk in most settings. Children may experience difficulty walking long distances and balancing on uneven terrain, inclines, in crowded areas, confined spaces or when carrying objects. Children walk up and down stairs holding onto a railing or with physical assistance if there is no railing. Outdoors and in the community, children may walk with physical assistance, a hand-held mobility device, or use wheeled mobility when traveling long distances. Children have at best only minimal ability to perform gross motor skills such as running and jumping. Limitations in performance of gross motor skills may necessitate adaptations to enable participation in physical activities and sports. |
| Level III | Children walk using a hand-held mobility device in most indoor settings. When seated, children may require a seat belt for pelvic alignment and balance. Sit-to-stand and floor-to-stand transfers require physical assistance of a person or support surface. When traveling long distances, children use some form of wheeled mobility. Children may walk up and down stairs holding onto a railing with supervision or physical assistance. Limitations in walking may necessitate adaptations to enable participation in physical activities and sports including self-propelling a manual wheelchair or powered mobility. |
| Level IV | Children use methods of mobility that require physical assistance or powered mobility in most settings. Children require adaptive seating for trunk and pelvic control and physical assistance for most transfers. At home, children use floor mobility (roll, creep, or crawl), walk short distances with physical assistance, or use powered mobility. When positioned, children may use a body support walker at home or school. At school, outdoors, and in the community, children are transported in a manual wheelchair or use powered mobility. Limitations in mobility necessitate adaptations to enable participation in physical activities and sports, including physical assistance and/or powered mobility. |
| Level V | Physical impairments restrict voluntary control of movement and the ability to maintain antigravity head and trunk postures. All areas of motor function are limited. Functional limitations in sitting and standing are not fully compensated for through the use of adaptive equipment and assistive technology. At level V, children have no means of independent mobility and are transported. Some children achieve self-mobility using a power wheelchair with extensive adaptations. Children are transported in a manual wheelchair in all settings. Children are limited in their ability to maintain antigravity head and trunk postures and control arm and leg movements. Assistive technology is used to improve head alignment, seating, standing, and and/or mobility but limitations are not fully compensated by equipment. Transfers require complete physical assistance of an adult. At home, children may move short distances on the floor or may be carried by an adult. Children may achieve selfmobility using powered mobility with extensive adaptations for seating and control access. Limitations in mobility necessitate adaptations to enable participation in physical activities and sports including physical assistance and using powered mobility. |

The severity of motor involvement in CP can be classified using the Gross Motor Function Classification System (GMFCS) (Palisano, Rosenbaum et al. 1997). The GMFCS is based on gross motor development of self-initiated movement, with the emphasis on sitting and walking. It consists of a five level classification system (table 1) with descriptions on five age bands, <2, 2-4, 4-6, 6-12 and 12-18 years. Children at levels I-II learn to walk without aids, children at level III walk with aids, children at level IV rely mainly on wheelchair mobility and children at level V have no means of independent mobility. The GMFCS has good stability over time (Palisano, Cameron et al. 2006). The SCPE classification and GMFCS together create a good clinical picture of a child and also provide a platform for comparisons of the effects of interventions. Children with bilateral spastic CP are classified at all these levels, one study reports14% at level I, 34% at level II, 10% at level III, 25% at level IV and 17% at level V, see figure 1 (Himmelmann, Beckung et al. 2007).

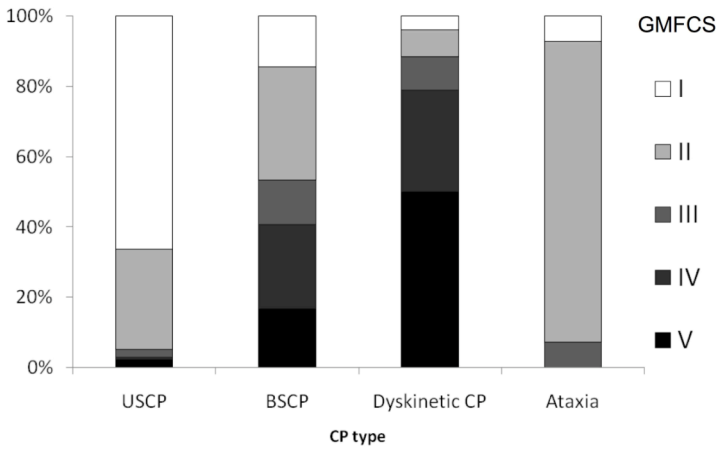



Figure 1. Distribution of gross motor function by CP type in children born 1991-1998. USCP=unilateral spastic CP, BSCP= bilateral spastic CP (Himmelmann 2008, personal communication).

The development and changes in motor function, both natural and with therapy, can be assessed using the Gross Motor Function Measure (GMFM) created for children with CP (Russell, Rosenbaum et al. 1989) described in page 27. This test has made it possible to follow the development of children with CP in detail. On average, 90% of their motor development potential is reached around age five or younger, and there is a plateau in gross motor development around seven years of age (Rosenbaum, Walter et al. 2002; Beckung, Carlsson et al. 2007). Some children show a decline in walking ability or cease walking through adolescence and adulthood (Andersson and Mattsson 2001; Johnson, Damiano et al. 1997). The natural history of motor development in CP described using the GMFM provides a base for the evaluation of interventions.

# Muscle strength

Harris defines our understanding of muscle strength: *"Muscle strength can be defined as the ability of skeletal muscle to develop force for the purpose of providing stability and mobility within the musculoskeletal system, so that functional movement can take place"* (Harris and Watkins 1993, p 5). The production of force depends on the anatomy and physiology of the muscle and biomechanical conditions in the musculoskeletal system. Regulation of contraction takes place in interaction with the nervous system. The muscles are the effectors of both voluntary and automatic efferent neural signals.

The skeletal muscle consists of bundles of muscle fibres surrounded by connective tissue. There are two major categories of muscle fibres, slow-twitch red fibres (type I) and fast-twitch white fibres (type II). Type I fibres are better suited for long periods of activity at low tension levels and type II fibres are better suited for rapid contractions (Harris and Watkins 1993, p 9-11). Muscles used for phasic strength activity contain about equal proportions of both types while tonic postural muscles contain a higher percentage of type I fibres (Rose and McGill 1998). The muscle fibres are organised in "motor units", groups of muscle fibres innervated by one motor neuron. In muscles that control fine movement, a motor unit has only three to six muscle fibres and in a typical gross motor muscle it may have 2000 muscle fibres (Rowland 1991). Force production can be modulated by two strategies, recruitment of number of motor units and the firing rate of the unit. The communication between motor neuron and muscle fibre is electrochemical. An electric signal in the motor neuron triggers a release of transmittor substance at the neuromuscular junction, creating an action potential in the excitable membrane surrounding the muscle fibre (Rose and McGill 1998).

Muscle contractions can be divided into three types: concentric, eccentric and isometric. When the force generated by the muscle is greater than the externally applied force, the muscle will shorten in a concentric contraction. When the external force is greater, the muscle will elongate in an eccentric contraction. When forces are equal, no motion will take place, producing an isometric contraction. These different types of contractions allow the muscles to function as springs, movers, shock absorbers and stabilizers (Harris and Watkins 1993, p 6). There is a length – tension relationship for a muscle, a curve with the highest forces in mid-ranges, and lower force in very shortened or lengthened states (Harris and Watkins 1993, p 12). The recorded force in a patient is dependent on the length of the muscle, related to joint angle, and the internal lever arms.

## Measurement of muscle strength

In a clinical test context, muscle strength has been described as *"what we are measuring is the maximum short duration voluntary force or torque brought to*

*bear on the environment….it represents the final output of the central nervous system … the sum of agonist torque minus antagonist restraint"* (Bohannon 1993, p 188).

Watkins and Harris (1993, p 20) have described the general considerations for muscle strength testing related to the patient, the examiner and the instrument. It is a primary condition that the child/patient understands what to do and is willing to make a maximal effort. To be able to make comparisons between different occasions or patients, the procedure has to be standardized with respect to (among other things) instructions, demonstration, position of the patient, the effects of gravity, force moment arm, placement of the myometer and the direction of the resistance. Hinderer and Hinderer (1993) have focused on measurement in children. They also emphasize the importance of verbal encouragement, using the same short word(s) and noting the cooperation of the child. For children from four to five years of age it may be possible to make accurate measurements.

Almost all human movements pivots round a centre, the joint. Moment of force (also torque or simply moment) is the product when a force is applied around a pivot point. It is defined as follows: torque is equal to force multiplied by lever arm (the lever arm being the perpendicular distance between the force and the pivot point) (Whittle 2002). The Systèm International unit of torque is Newton meters (Nm). In the human body, joints act as pivot points, figure 2. It has been pointed out that data ought to be reported as torque to make it possible to compare between individuals and over time (Damiano, Dodd et al. 2002).

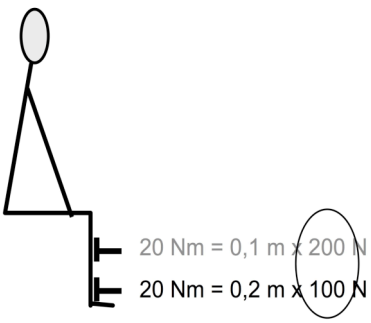



Figure 2. The same torque measured at different distances from the joint gives different readings on the myometer.

Muscle strength can be estimated and measured using different methods ranging from observation without equipment to laboratory examinations with expensive, non-portable isokinetic instruments (Watkins and Harris 1993; Jones and Stratton 2000), an overview is given in table 2. All methods are useful in different settings and for different purposes. Signs of weakness can be noted and graded through observation of spontaneous activity or structured activities. For younger children and children with difficulties following instructions, this may be the only method for estimating muscle strength/weakness. Functional testing

with structured items graded in nominal (can – cannot) or ordinal scales (such as in the GMFM) are often designed for a special diagnostic group, purpose or training goal. In most cases these items test not only muscle strength in one muscle group but also the ability to stabilize in adjacent joints, as well as coordination and balance.

In clinical practice a commonly used method is the manual muscle testing technique (MMT) (Hislop and Montgomery 2007) with grading of strength in one muscle group by testing using manual resistance in standardized positions. The grading ranges from 0-5 with 0=no contraction, 1=visible/palpable contraction without movement, 2= movement without the weight of extremity, 3=movement through the whole range of motion against gravity, 4=manual resistance, 5= full resistance. However the sensitivity of MMT to detect changes in muscle strength is poor, especially in grades 4-5 (Aitkens, Lord et al. 1989; Schwartz, Cohen et al. 1992).

A portable, hand-held dynamometer (myometer) has been shown to be a reliable and easy-to-use method to measure muscle strength in clinical practice (Stratford and Balsor 1994; Taylor, Dodd et al. 2004). A myometer provides a measurement of isometric contraction. There are two types of measurement techniques, “make test” and “break test” (Bohannon 1993). The make test is characterized by the examiner holding the myometer in a stationary position with the subject pushing against it. In the break test, the examiner pushes the myometer against the subject’s limb until the subject’s maximal effort is overcome and the joint gives way. The break test can generate higher recordings (Newham 1993, p 62), but the make test has been shown to have higher test-retest reliability (Stratford and Balsor 1994). To obtain a valid recording, the examiner must have sufficient muscle strength to be able to stabilize the myometer and resist the patient’s force. Higher reliability when measuring weaker muscle groups may depend on this. Agre, Magness et al. (1987) found higher reliability when testing arm muscles than leg muscles, and reliability was higher when testing the affected than the non-affected side in patients with hemiparesis (Riddle, Finucane et al. 1989). Muscle strength in children with CP can reliably be measured with handheld devices (Taylor, Dodd et al. 2004; van der Linden, Aitchison et al. 2004).

Isokinetic testing is done with a laboratory device with a resistance arm pivoting around an axis aligned with the segment tested. Resistance can be set to different velocities, and there is a registration of torque through the whole range of motion. Both concentric and eccentric contraction is possible. The device may be difficult to adapt for children because of the size and the time it takes to adjust for testing of different muscles.

A measurement tool in the clinical setting needs to be easy to use in an ordinary physiotherapy department, give reliable data and have the ability to detect meaningful changes. The handheld myometer best satisfies these demands.

Table 2. Methods for measurement of muscle strength.

| | ICF domain | suitable for |
|---|---|---|
| Observation | activity/participation | young children |
| Functional tests | activity | specific task/diagnosis |
| Manual muscle test | body function | screening, asymmetry |
| Handheld devices | body function | over time, clinical evaluation |
| Isokinetic equipment | body function | research, few individuals and muscle groups |

## Norms/reference values

To determine whether or not muscle weakness is present in a child, reference values in typically developing children are needed. It has been shown that muscle strength in normal children is highly correlated with age, height and weight (Backman, Odenrick et al. 1989; Beenakker, van der Hoeven et al. 2001). In spite of this normative data is often only presented by age. But a child with a disability does not always fit into the curves of normal growth, which makes comparisons by age data only less appropriate. Himmelmann, Beckung et al. (2007) reported that children with bilateral CP had a significant difference between mean weight deviation at birth and at the time of follow up, four to12 years later.

The relation between muscle strength and body mass is of interest in a growing child. Gage (2004, p 47) describes this relationship as follows: *"... as a child grows her/his mass increase as a function of the cube, but strength increases only as a function of the square ... as children grow their strength does not keep pace with their mass .... if a young child is ambulating marginally, s/he may cease walking in the midst of the adolescent growth spurt because of the falling power/mass ratio".*

## Muscle strength and spasticity

Although physiotherapists long have measured and trained muscle strength in different patient populations, children with CP were not included out of fear that muscle strength training could aggravate spasticity and also because it was thought not possible to measure muscle strength owing to the spasticity (Bobath 1969; Bobath 1980). Spasticity is a common finding, present in over 80% of all children with CP (SCPE 2002). In clinical practice it can be defined as a velocity dependent increase in muscle tone (Sanger, Delgado et al. 2003). It is mostly an obstacle for normal motor function but can sometimes have a stabilising effect on trunk, hips and knees, which can be utilised in sitting and for weight bearing when standing, e.g. for transitions. Spasticity may in this way disguise muscle weakness. The use of spasticity reducing interventions such as botulinum-toxin injections, selective dorsal rhizotomy (SDR) and baclophen pumps has revealed

underlying muscle weakness in children with cerebral palsy (Peacock and Staudt 1991; Albright and Ferson 2006; Simpson, Gracies et al. 2008).

The concerns about increasing spasticity after muscle strength training have not been confirmed. A few studies have addressed spasticity in relation to muscle strength and found no relation (Damiano, Martellotta et al. 2000; Ross and Engsberg 2002). Fowler, Ho et al. (2001) tested spasticity directly after a session with strength training and found no increase in spasticity, a couple of other studies even found spasticity to decrease after training (Morton, Brownlee et al. 2005; Engsberg, Ross et al. 2006).

## Muscle strength and CP

In recent years there has been a focus on muscle weakness in CP. It has been described as being more pronounced distally and with an imbalance across joints (Wiley and Damiano 1998; Ross and Engsberg 2002). Plantarflexors in children with CP were significantly reduced as compared with controls, and there was greater relative weakness in plantarflexors as compared with dorsiflexors (Elder, Kirk et al. 2003; Stackhouse, Binder-Macleod et al. 2005). A relationship between muscle strength and gait has been demonstrated in terms of velocity, stride length, gait kinematics and the GMFM (Damiano, Martellotta et al. 2000; Desloovere, Molenaers et al. 2006; Ross and Engsberg 2007).

Several authors have reported increased muscle strength after different types of strength training (MacPhail and Kramer 1995; Damiano and Abel 1998; Dodd, Taylor et al. 2003; Morton, Brownlee et al. 2005; Liao, Liu et al. 2007). In four of these five studies, increased strength was accompanied by a statistically significant increase in the GMFM. Only one of these studies measured muscle strength in terms of torque (MacPhail and Kramer 1995).

There have been several suggestions as to possible causes of muscle weakness in CP, including both structural/morphological and neuromotor control mechanisms. Structural changes were seen in the muscles as type I fibre predominance (Ito, Araki et al. 1996), varying degrees of muscle fibre type atrophy, or hypertrophy and increased fat or connective tissue (Castle, Reyman et al. 1979). Rose and McGill (2005) found an inability to recruit higher threshold motor units or to increase firing rate, and there was also reduced amplitude of “turns” (Elder, Kirk et al. 2003). Higher levels of co-activation of antagonists or adjacent muscles have also been reported (Elder, Kirk et al. 2003; Stackhouse, Binder-Macleod et al. 2005; Tedroff, Knutson et al. 2008).

# Walking - gait

Walking can be defined as *"a method of locomotion involving the use of the two legs"* (Whittle 2002). Walking on two legs distinguishes humans from other mammals and is a central function for locomotion. The importance of the ability to walk is highlighted by the fact that the first question from parents of children with CP is often: will s/he be able to walk? Disturbance of motor function affecting walking is a major obstacle for the individual, and much time and effort and many different methods are utilised to achieve and maintain walking ability.

The word "walking" is used to describe if, where and how you can walk, whereas the word "gait" describes the manner or style of walking.

## Description and measurement of walking and gait

Descriptions of walking ability and gait pattern have long been of interest to researchers; the first known descriptions in print are by Aristotle (Baker 2007). In the 19th century the development of photography made it possible to observe motion in series of photographs. Estimation of forces could be made from the photographs, using mathematical calculations based on the positions of the segments and estimation of the mass of the segments from the person's weight. With 20th century inventions such as the force plate, video camera and computer, there have been immense developments in gait analysis during the last decades. Gait analysis has also moved from research to more clinical applications, playing a part in, for example, the decision-making process before surgical interventions in cerebral palsy (DeLuca, Davis et al. 1997; Cook, Schneider et al. 2003; Lofterod, Terjesen et al. 2007).

Walking and gait can be studied using many different techniques ranging from descriptions in words based on ocular observation, to full-scale gait laboratories with equipment for three dimensional (3D) measurements of movements and forces, as well as monitoring of muscle activity (EMG).

Observation with the eye (or with the help of a video camera) is useful for noting the achievement of motor milestones and grading of motor abilities. There are several instruments for grading walking ability on ordinal scales, often developed for different patient populations. The GMFM is an example for children with CP, where two of the five domains grades abilities in standing and walking.

Walking can be measured using simple equipment, a stopwatch and a tape measure can give time and distance parameters such as gait velocity, stride/step length and step frequency (also referred to as cadence). Stride is the distance travelled by one foot in the gait cycle, step is used for the distance between a point on one foot and the same point on the other foot. Gait velocity is dependent on step length and step frequency.

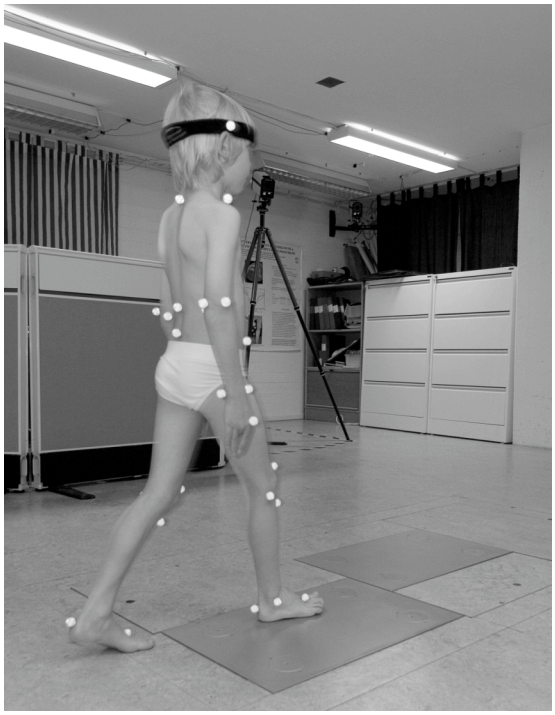


Figure 3. A child with reflective markers stepping on the force plates in the gait lab.

Measurement of gait pattern has become possible through the motion capture techniques with use of computers and wireless markers on the body, and measurement of ground reaction forces from force plates in the floor (Davis 2004), see figure 3. The 3D gait analysis provides a description of gait pattern geometry (kinematics) and forces (kinetics). Kinematics describes the movements of the body segments (segment positions and joint angles) and kinetics calculates the forces controlling the movements, described in terms of moments and power. This is done through modelling from segments and joint angles in combination with measurements from the force plates (Davis 2004). In gait analysis the term "moment" is used for the force of angular movement around a pivot point (the joint) and can arise through active muscle work or stabilising structures such as ligaments. It is measured in Nm and is usually normalised to body weight – Nm/kg. "Power" describes the velocity and the direction of the moment and is expressed in watts (W). It is calculated as the product of the moment and the angular velocity, and is also usually normalised by body weight, W/kg. Power tells us if there is active muscle work, which can be generating or absorbing (Whittle 2002). This detailed description of gait pattern can be compared with normal pattern to look for deviations.

Moment (or torque) (Nm) = Force (Newton) x lever arm (meter)

Power (W) = moment (Nm) x angular velocity (radians per second)

Gait analysis data are normally presented in a gait cycle – from initial contact with one foot until the next initial contact with the same foot. For a description of a normal gait cycle, see figure 4. The gait cycle can be divided into several phases, each of which has a distinct purpose and muscle activity. The two main divisions are the stance phase (60% of gait cycle) and the swing phase (40%). They can be further subdivided. The terminology presented by Gage (2004), in which the stance phase has five subdivisions and the swing phase three, is commonly used. In the figure, active muscles are indicated in grey. The ground reaction force vector is also marked, guiding our understanding of the mechanics of gait. When the vector falls through the centre of a joint, no force is needed for stabilization. Depending on which side of the joint the vector falls, it tends to flex or extend the joint. The perpendicular distance from the force vector to the joint centre multiplies this force, creating an external moment that has to be resisted with internal forces from muscles and joint structures to prevent the joint from giving way.

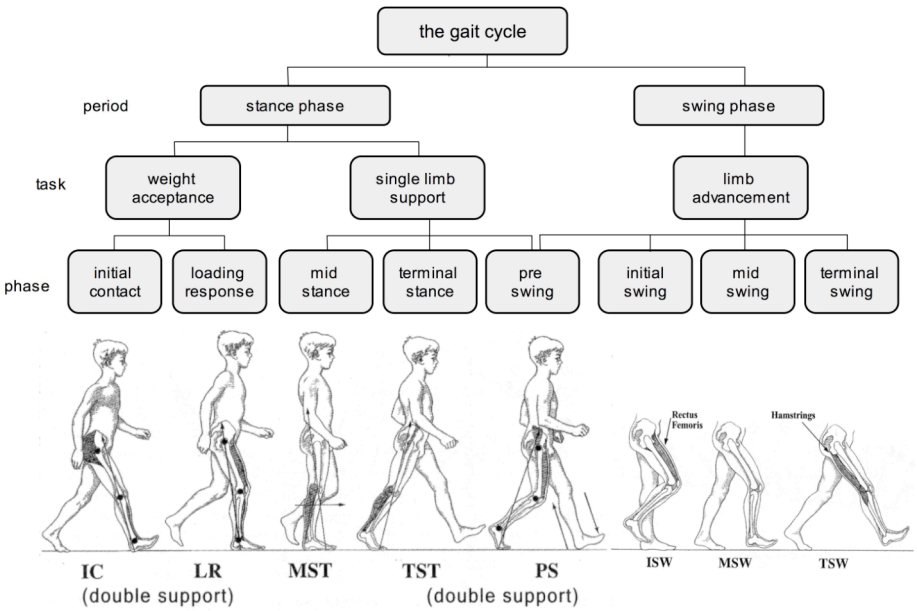



Figure 4. The gait cycle, adapted from Gage 2004.

Gage (Gage 2004) formulates five prerequisites for normal walking:

1. stability in stance
2. foot clearance in swing
3. pre-positioning of the foot for initial contact
4. adequate step length
5. and the global prerequisite - energy conservation

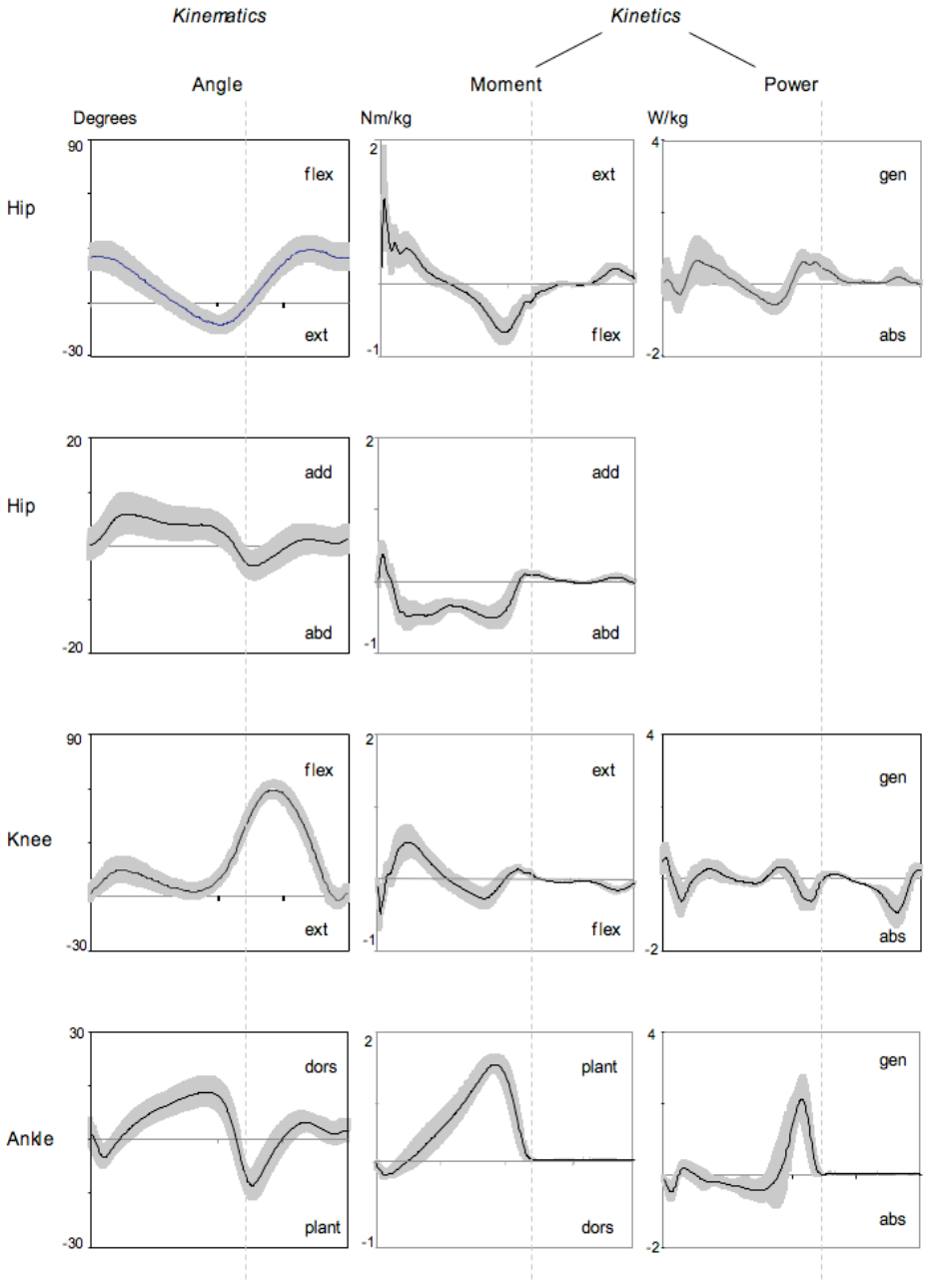



Figure 5. Normal kinematics and kinetics for hip, knee and ankle in the sagittal plane and for hip also in the frontal plane (only angle and moment). Black line = mean, grey band = 1 SD and dashed line indicating end of stance phase.

The major force generators for forward progression are the plantarflexor muscles, while the hip extensors and flexors provide most of the rest (Kepple, Siegel et al. 1997; Sadeghi, Sadeghi et al. 2001) see figure 5. For support in stance, hip and knee extensors are normally the main contributors at initial stance, hip abductors at midstance and plantarflexors at late stance (Anderson and Pandy 2003).

A mature kinematic gait pattern is achieved at about the age of five (Sutherland, Olshen et al. 1988), as is the kinetic gait pattern, except for the plantarflexing moment and power, that continue to change until about nine years of age (Ganley and Powers 2005; Chester, Tingley et al. 2006). Time distance parameters (velocity, stride and cadence) continue to change from the childhood with short stride and high cadence to adulthood with longer strides and reduced cadence. Normal gait velocity is age-dependent, with an adult velocity of 0.9-1.6 reached at about ten years of age (Whittle 2002). Typical gait pattern data for both adults and children have been presented by several authors (Sutherland, Olshen et al. 1988; Kadaba, Ramakrishnan et al. 1990; Öunpuu, Davis et al. 1996).

Good to high levels of repeatability of kinematic variables was found in both healthy adults and children with CP in a single-session (Redekop, Andrysek et al. 2008) and test-retest (Mackey, Walt et al. 2005). Data from the sagittal plane showed higher repeatability than from the frontal and transverse planes (Kadaba, Ramakrishnan et al. 1989; Mackey, Walt et al. 2005) and children at GMFCS level I exhibit the lowest within-session variability (Redekop, Andrysek et al. 2008). Typically developing children had less variability than children with CP, and kinetic data had better repeatability than kinematic (Steinwender, Saraph et al. 2000). Gait velocity may influence the gait parameters, so for comparison trials with the same velocity ought to be used (van der Linden, Kerr et al. 2002).

Abnormal gait pattern at one level may be attributable to a primary problem located around the joint, but it may also be a compensatory strategy for problems at other levels of the body. In order to be able to differentiate the abnormal pattern as a primary problem or a secondary strategy, the gait analysis has to be supplemented with a clinical examination including joint range of motion (ROM), spasticity, muscle strength, and selective motor control. These measurements together can help to identify abnormal patterns and weaknesses.

Although walking is an activity most of us can manage without thinking, it is difficult to analyze. The eight distinctive phases described by Gage all take place within about one second, the normal time for one gait cycle. The complex of actions on several levels of the body (ankle, knee, hip, pelvis, trunk and arms) that take place in each phase give us a large amount of data, 96 variables per second, to analyze. In a gait lab it is possible to sample and store such data at a high frequency for further analysis and make comparison between groups of individuals or/and on individual basis.

## Gait regulation

Walking involves a complex interplay between automated neural activation patterns and voluntary muscle control. At the level of the spinal cord there are afferent and efferent nerves linked together in a web of interconnections called a central pattern generator (CPG) (Duysens and Van de Crommert 1998; Hultborn and Nielsen 2007), which can produce walking movements in the legs. This circuitry is controlled by supraspinal centres in the nervous system and by information from sensory systems to adapt the walking movements to the voluntary control and to the environmental demands (Jahn, Deutschlander et al. 2008). The task for this system is to keep the body balanced and to direct force to move the body (forward) in an energy efficient way.

## Walking – gait in CP

Population based studies show that about 70% of children with CP are classified as walking with or without assistive devices (Himmelmann, Beckung et al. 2006; Beckung, Hagberg et al. 2008). Age at start of walking is often delayed; the median age for walking debut has been found to be two years of age for all children with CP and four years in the group with CP spastic diplegia (Jahnsen, Villien et al. 2004). Rosenbaum, Walter et al. (2002) reported that for children at GMFCS I-III, 90% of their motor development potential was reached between 3.7 and 4.8 years of age. Development then levels off and optimal function is reached about the age of seven (Rosenbaum, Walter et al. 2002; Beckung, Carlsson et al. 2007). Another study found an apparent difference between GMFCS levels, with children at level II continuing to develop after the age of seven (Hanna, Bartlett et al. 2008).

There is a decrease in walking ability and gait pattern through adolescence expressed as a decrease in gait velocity, stride length and sagittal joint excursions over time (Johnson, Damiano et al. 1997; Bell, Öunpuu et al. 2002). Surveys of adults with CP show decreased walking ability or ceased walking in 44% (Andersson and Mattsson 2001), mainly between 15 and 35 years of age (Jahnsen, Villien et al. 2004).

Children with CP have been reported to have shorter stride length than peers, and consequent reduced velocity compared with normal children (Abel and Damiano 1996). Other frequent problems have been described as stiff knee in swing, equinus, in-toeing, increased hip flexion and crouch, all seen in over 50% of children in the diplegic and quadriplegic group (Wren, Rethlefsen et al. 2005).

The large number of different variables makes it difficult to obtain an overview of gait abnormalities/deviations. Several attempts have been made to classify deviations into groups with similar patterns, in order to reduce the number of variables to a more easy understandable level. This has been done with both observational analyses and statistical methods based on computerized gait analysis. However, none of these classifications has yet shown enough validity

and reliability to easily describe the complexity and individual differences in gait pattern (Dobson, Morris et al. 2007).

Normal walking is regulated to minimize energy expenditure, and an abnormal gait pattern tends to be more energy demanding (Waters and Mulroy 1999). This often results in reduced velocity and limited walking distance. Kerr, Parkes et al. (2008) found a correlation between energy cost and activity limitation in children with CP, and that energy cost increased with severity. The abnormal gait pattern puts a heavy strain on joints, ligaments and muscles (McNee, Shortland et al. 2004), which can lead to pain in the long run, as has been reported in adults with CP (Andersson and Mattsson 2001; Jahnsen, Villien et al. 2004).

There are several possible factors preventing or interfering with a normal gait pattern in CP, and there is a need to explore the effects of the different factors on walking ability and gait pattern. Spasticity as a primary problem prevents normal movement velocity and full range of motion, and can impede stability, foot clearance, pre-positioning for initial contact, and step length. Muscle contractures limit the joint excursion and can hinder foot clearance, pre-positioning and step length. Bony deformities can alter internal lever arm conditions for the muscles and by this create muscle weakness. Loss of selective control is a problem in terms of stability and a smooth movement pattern, foot clearance, pre-positioning, and step length. Muscle weakness may theoretically affect the prerequisites for a normal gait pattern, which is described by Gage (2004) in many ways:

- stability in stance can be compromised by weakness at both hip, knee and ankle
- foot clearance in swing can be compromised by weak dorsiflexors as well as weak hip and knee flexors
- pre-positioning of the foot for initial contact is dependent on dorsiflexors of the ankle, knee extensors and hip flexors
- adequate step length is mainly dependent on hip extensors and ankle plantarflexors
- energy cost can increase as a result of an abnormal gait pattern

## *ICF*

The World Health Organization (WHO) has defined health as: *"a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity"* (WHO 2006).

WHO has elaborated a system for description of health status with the following purpose: *"to provide a unified and standard language and framework for the description of health and health-related states",* the International Classification of Functioning, Disability and Health (ICF) (WHO 2001). This system takes a global perspective on the health of an individual (table 3 and figure 6), where health is seen as dependent on several factors both within the body/individual and in interaction with the environment/society. The definition of CP, given on page1, is congruent with the ICF.

Table 3. Definitions in the ICF.

| DEFINITIONS |
|---|
| In the context of health: |
| ***Body functions*** are the physiological functions of body systems (including psychological functions) |
| ***Body structures*** are anatomical parts of the body such as organs, limbs and their components |
| ***Impairments*** are problems in body function or structure such as a significant deviation or loss |
| |
| ***Activity*** is the execution of a task or action by an individual |
| ***Participation*** is involvement in a life situation |
| |
| ***Activity limitations*** are difficulties an individual may have in executing activities |
| ***Participation restrictions*** are problems an individual may experience in involvement in life situations |
| ***Environmental factors*** make up the physical, social and attitudinal environment in which people live and conduct their lives |

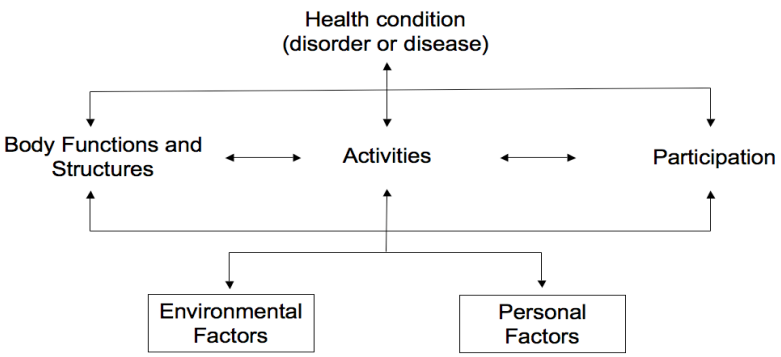



Figure 6. The ICF framework, interactions between the components of the ICF.

The ICF can be useful in the analysis and identification of problem areas and as a guide for choosing interventions as well as in evaluating the outcome of interventions in paediatric physical therapy (Darrah 2008).

The United Nations Conventions on the Rights of the Child (UN 1989), and on the Rights of Persons with Disabilities (UN 2007) are also a platform for health care systems and explicitly defines the rights of children with disabilities *"to take an active part in society and have the right to enjoy a full and decent life"* (article 23, Rights of the Child).

## *Treatment*

Treatment options for motor disorders in CP have changed over time, with orthopaedic surgery playing an important role since the late nineteenth century, when CP was recognised as a specific disorder (Little 1862). The use of orthoses was frequent as well as physiotherapy, and later also occupational therapy. During the last two decades several anti-spasticity treatments have been introduced for children with CP; medication with baclophen, selective dorsal rhizotomy (SDR) and botulinum-toxin injections.

### Physiotherapy

The World Confederation for Physical Therapy (WCPT) has made a position statement on the nature of physical therapy. Contemporary physiotherapy can be defined as: *"to provide services to people and populations to develop, maintain and restore maximum movement and functional ability throughout the lifespan…. Physiotherapy is concerned with identifying and maximizing movement potential"* (WCPT 2007). The physiotherapist is responsible both for treating immediate problems and preventing future problems.

The physiotherapy process is a model that describes the interaction between the physiotherapist and the patient/child, families and caregivers, and it includes examination, analysis, goal setting, interventions and evaluation. Examination and analysis has to go through the whole range of components of the ICF to locate the impairments, activity limitations and participation restrictions with a view to choosing the levels for intervention.

Problems in domain activity/participation need to be analyzed for underlying conditions in the body function domain. Typically the problem is a participation restriction. Testing of motor abilities in a structured environment will show what activities the child can and cannot do. If the child cannot accomplish a certain task, further examination and measurements will show what impairments of body functions there are, preventing them to accomplish the activity. If the child can manage the task in a structured testing situation but not in everyday life, then there must be factors in the environment preventing him/her.

Physiotherapy includes many different interventions aimed at either improving the patient (training, treatment or aids) or the environment (personal support or changes in the physical environment). On the level of "body function and structure", training can consist of both active and passive exercises for augmenting, for example, muscle strength, range of motion and balance. There are many possibilities for functional training of capabilities (activity - ability and performance) followed by practising of these abilities in everyday situations (participation). *"The efficacy of any physical treatment lies within the child's day-to-day environment"* (Scrutton 2004). Physiotherapy interventions can also be the provision of aids and orthoses. Working with environmental factors includes counselling, information and instruction to family and others. For the physical environment there are suggestions and solutions for adaptation of the environment. For success in therapy, attention must be paid not only to the motor condition but also to cognitive capabilities such as perception and understanding, when planning goals and methods. Although children with CP may have the same diagnosis they are all different with respect to medical, motor and personal characteristics, and need an individual analysis and plan for optimal treatment.

Many interventions used in CP can affect muscle strength negatively. Botulinum-toxin blocks the signal from nerve to muscle, rigid orthoses prevent/reduce motion in a joint, orthopaedic surgery alters the length-tension relationship (soft tissue surgery) and changing internal lever arms (skeletal surgery). Neurosurgical interventions such as SDR and baclophen pumps may reveal an underlying weakness when spasticity is reduced.

CP is a lifelong condition requiring a great deal of time and effort to be spent throughout life on treatment and training. In this perspective it is clear that the use of effective interventions/training methods is vital for the patient, and in terms of socioeconomic costs and resources, as well as for the health care system.

## Muscle strength training

Muscle strength training (or resistance training) is a common component of sports and physical training programs. It can be defined as *"methods to increase one's ability to exert or resist force"* (Bernhardt, Gomez et al. 2001). Several types of resistance can be used: free weights, weight machines, elastic bands and body weight. Intensity can be regulated by the resistance, the number of repetitions and frequency of training sessions. One repetition maximum (1 RM), the maximal weight that a person can lift in a single repetition, is a frequently used method for testing muscle strength and intensity is often graded in relation to this. A group of repetitions separated by scheduled rest periods is called a "set".

Many different approaches are used to obtain the most effective results. A meta-analysis of 140 studies on strength training in adults demonstrated different responses, based on the training status of the participants (Rhea, Alvar et al. 2003). For untrained individuals a mean intensity of 60% of 1RM and a frequency of three times/week elicits maximal gains, whereas 80% and two times/week is most effective in those who are well trained. Four sets per muscle group elicited maximal gains in both trained and untrained individuals. As more strength is gained, a progression of training is needed, by increasing the amount of weight or number of repetitions.

There has been some concern about heavy weight lifting in preadolescents, with risks of skeletal injuries. This has not been confirmed and for safety in training programs, paediatricians have published recommendations for resistance training in children and adolescents; methods and exercises appropriate for children and adolescents, warm-up and cool-down, low-to moderate-intensity resistance 2-3 times/week on non-consecutive days, 1-2 sets initially, progressing to 4 sets of 8-15 repetitions for 8-12 exercises (Bernhardt, Gomez et al. 2001; Behm, Faigenbaum et al. 2008).

There are both morphological and neurological adaptations to strength training (Folland and Williams 2007). Neurological factors are considered to make their greatest contribution at the early stages of a training programme. They consist of changes in coordination and learning, with improved recruitment and activation of involved muscles. ‘Cross education’ is a phenomenon, which describes a strength gain in the opposite, untrained limb following unilateral resistance training (Lee and Carroll 2007). Morphological changes can consist of increase in cross-sectional area owing to increase in myofibrillar size and number, changes in fibre type, muscle architecture, and the structure of connective tissue.

# Aims

The aims of the study were:

- to establish normative values for muscle strength in terms of torque in typically developing children and adolescents, and in relation to sex, age and body weight.
- to evaluate muscle strength in children with CP and the relationship between muscle strength and motor function, walking ability, and gait pattern.
- to investigate the influence of muscle strength training on walking ability and gait pattern in children/adolescents with CP.

# Methods

## *Participants*

An overview of participants is given in figure 7.

Children with a diagnosis of bilateral spastic CP were recruited from county rehabilitation centres in the Gothenburg area. Exclusion criteria were dyskinetic CP, lower limb orthopaedic surgery in the preceding 12 months or botulinum toxin injections in the previous 6 months.

### Pilot study

A pilot study was conducted prior to the main study, including children with bilateral spastic CP and a reference group of typically developing children, 5 to 10 years old.

### Study I:

Typically developing children, 5-15 years old, from a school and a preschool were invited to participate in the study. Children were recruited to the study by age/school grade, five boys and five girls in each age.

### Study II:

Children with bilateral spastic CP, between 5 and 15 years of age and classified at GMFCS levels I-III, born between 1991 and 2001 were recruited for this study. Children from an earlier unpublished pilot study from the same centre, born between 1986-1990, who met the same inclusion/exclusion criteria, were also included. Two children at GMFCS level IV were added for comparison in the thesis.

### Study III:

Children with CP, 9 to15 years old, walking without aids and a reference group of typically developing children of the same ages were recruited for the study.

### Study IV:

Children with bilateral spastic CP, 9-15 years old and at GMFCS level I-II were invited to the study through physiotherapists in the area. Gait data from children in the same age groups in the gait lab reference database were used for comparison.

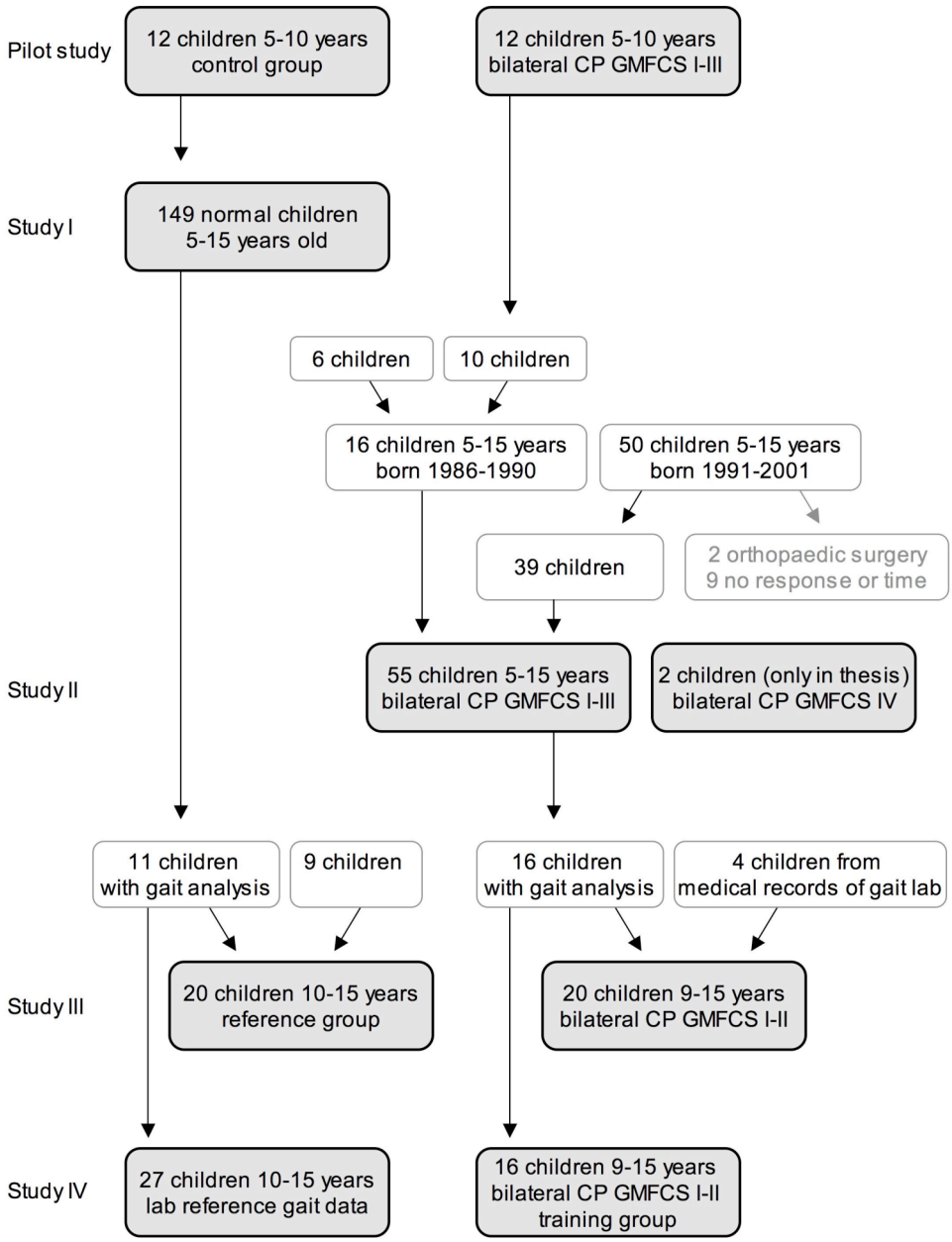



Figure 7. Overview of participants in the studies, participating subjects in grey fields.

## *Outcome measurements*

An overview of the measurement methods is presented in table 4.

Height and body weight was measured in all participants. Children in study I were asked about their leisure time activities.

Table 4. Measurement methods used in the different studies.

| | Pilot study | Study I | Study II | Study III | Study IV |
|---|---|---|---|---|---|
| Myometer | X | X | X | X | X |
| GMFM | | | X | | X |
| 3D gait analysis | | | | X | X |
| Question on physical activity | | X | | | |

### Muscle strength

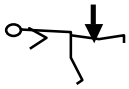
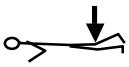
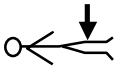
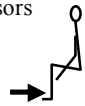
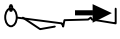
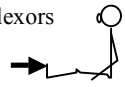
Muscle strength was measured using a hand-held electronic myometer (figure 8) (adapted Chatillon dynamometer; Axel Ericson Medical AB, Gothenburg, Sweden). The myometer can measure both traction and compression with a maximum force of ~ 550 Newton (N) and a precision of 0.5 N. The myometer was calibrated with known weights before and after the study.

Eight muscle groups in the leg were measured, see table 5 and figure 9. The procedure was standardized for every muscle group, subject position, myometer position and stabilization of subject. We used positions previously published with minor adjustments (Backman, Odenrick et al. 1989; Wiley and Damiano 1998; Beenakker, van der Hoeven et al. 2001).

Testing started with the child in a sitting position, where it was easy to become familiarized with the procedure and practice, followed by testing in supine and prone positions.

Figure 8. The myometer used in the studies.

Table 5. Description of position and stabilization of subject, position of the myometer's resistance to the body movement (arrows), and description of point for measuring lever arm.

| Muscle group | Position | Stabilization | Resistance | Lever arm from |
|---|---|---|---|---|
| Hip extensors 1  | Prone, legs outside couch<br>Not tested foot on floor | Hold on to bench | Femur distally | Greater trochanter |
| Hip extensors 2  | Prone | Hold on to bench | Femur distally | Greater trochanter |
| Hip flexors 1  | Sitting | Hold on to bench | Femur distally | Greater trochanter |
| Hip flexors 2  | Supine<br>Hip and knee flexed 90° | Hold on to bench | Femur distally | Greater trochanter |
| Hip abductors  | Supine<br>Hip and knee extended | Hold on to bench. Other leg stabilised | Femur distally | Greater trochanter |
| Hip adductors  | Supine<br>Hip and knee extended | Hold on to bench. Other leg stabilised | Femur distally | Greater trochanter |
| Knee extensors  | Sitting | Hold on to bench | Shank distally | Lateral knee joint |
| Knee flexors 1  | Sitting | Hold on to bench | Shank distally | Lateral knee joint |
| Knee flexors 2  | Prone<br>Knee flexed 90° | Hold on to bench | Shank distally | Lateral knee joint |
| Ankle dorsiflexors  | Supine<br>Hip and knee extended, ankle neutral | Hold on to bench | Dorsum of foot | Lateral malleolus |
| Ankle plantarflexors  | Sitting/supine<br>Knee extended | Hold on to bench | Metatarsal heads | Lateral malleolus |

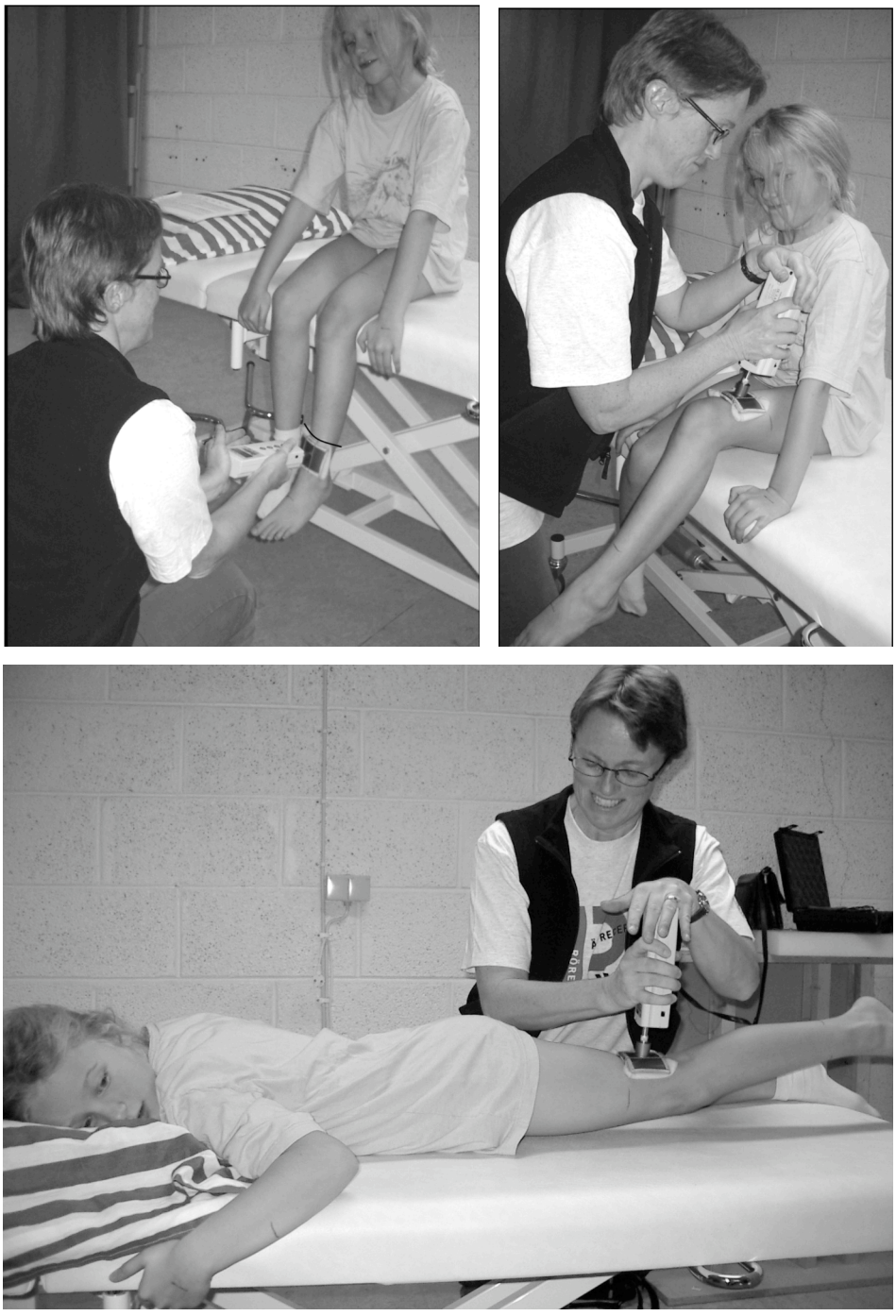
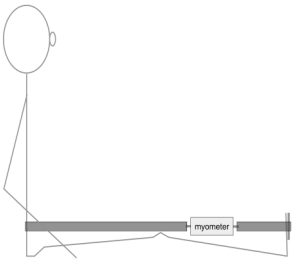


Figure 9. Measurements of three muscle groups.

Three attempts were made for each muscle group with the "make" technique, where resistance is gradually built up for about five seconds. The make technique was chosen because of better consistency and to minimize the risk of eliciting spasticity. Time for rest was given between trials to avoid fatigue. Verbal encouragement to achieve maximum effort was given in a standardized way. The maximum result for each muscle group was used. The myometer was placed distally at the segment tested to allow for as long a lever arm as possible, and at a location where a strong pressure on the skin did not hurt, and thus prevented a maximal contraction.




For measurement of plantarflexors, special equipment was produced where the myometer was attached between two belts (figure 10) to let the subjects be stabilised by their own bodies.

Figure 10. Equipment for measurement of plantarflexors.

The position of the myometer head was marked on the skin. The lever arm was measured with a tape measure using bony landmarks (acromial process, lateral humeral epicondyle, ulnar styloid process, greater trochanter, lateral knee joint, lateral malleolus) and the position of the centre of the myometer head. Torque was calculated in Nm. The study also included measurement of muscle groups in the arms, but they are not considered in this thesis.

Inter-rater reliability was tested between two testers. Three muscle groups (hip flexion, knee extension and knee flexion) were tested by two examiners in 25 children.

Children in study I were tested on the non-dominant side, as in a previous study (Backman, Odenrick et al. 1989). A study on healthy adults showed that upper extremity muscle force values were different between sides but that lower extremity muscles were not (Andrews, Thomas et al. 1996), so non-dominant side was based on hand dominance. Children with CP in studies II, III and IV were tested on both sides.

## Gait analysis

Three dimensional gait analysis was carried out with a motion capture system consisting of 6 infrared cameras (ProReflex™ Qualisys AB, Göteborg, Sweden) and two Kistler force plates (Kistler 9281C, Kistler Instruments AG, Winterthur, Switzerland) working synchronically at 240 Hz. Recordings of motion and calculations were made using the software QtracC™ version 2.51, QtracV™ version 2.60 and QGait 2.0™ (Qualisys Medical AB, Göteborg, Sweden). At least three acceptable trials for each child were collected. Parents confirmed that the performance was representative of their children's regular gait pattern. In

study III, gait data were compared to the reference group in the study, and in study IV data were compared to lab reference data for children 10-15 years old, consisting of 27 children. Kinematic and kinetic data in the sagittal plane were used in the analyses. Gait velocity, stride length and cadence were all compared with age norms (Whittle 2002). Stride length was normalised to body height in study III.

### Gross motor function

Gross motor function was tested in studies II and IV with the GMFM (Russell, Rosenbaum et al. 1989), a test constructed for children with CP. It consists of 88 items in 5 domains (lying, sitting, kneeling, standing and walk-run-jump). Every item is graded on a 4-point ordinal scale 0-3 where 0 is no attempt and 3 is full achievement of the item. The score from an individual child is divided by the maximum possible score, resulting in a percentage. A typically developing child can manage all items at the age of 5 years. There is also a version using 66 items, where items have been graded for difficulty using Rasch analysis, with a maximum score of 100. The 66-item version is more suited for children who can walk. Both versions have been proven to have good validity and reliability (Russell, Rosenbaum et al. 2002). Testing was carried out by two therapists familiar with administration of GMFM and experienced in using GMFM for over 10 years. The two domains for standing and walking were used (D: standing, and E: walking, running, jumping). The software Gross Motor Ability Estimator (GMAE) included in the GMFM66 version (Russell, Rosenbaum et al. 2002) was used to calculate a score with a 95% confidence interval.

## *Muscle strength training – procedure*

The muscle strength training in study IV was individually designed, including four muscle groups in each leg, based on the muscle weakness and gait deviations in the analysis. A functional goal was discussed and set up with each child and their parents. The children worked individually at home twice a week with parental assistance, and in groups of four once a week with a physiotherapist at the physiotherapy department. At home they carried out the individual programme with three sets of 10 repetitions for each muscle group. Resistance was provided by adjustable weight cuffs, rubber band and body weight with increasing load – the last set with 10 RM. Resistance was increased during the training period when the children could do more than 10 repetitions with the heavy weight. The group session consisted of a warming-up session followed by the individual programmes and stretching of hamstrings, rectus femoris and ankle plantarflexors. The sessions ended with different games chosen by the children.

## Statistics

Parametric tests were used in study I and II. In study I there were 149 participants. Study II included 55 children divided in three groups with measurements of muscle strength and GMFM. Here the muscle strength data was found to be sufficiently normally distributed for parametric testing. In study III, and especially study IV the number of participants was less and gait analysis data could not be proved to be normally distributed, thus non-parametric tests were used, as was also the case in the pilot study. An overview of statistical methods is presented in table 6.

Correlations were graded as; 0-0.25 little, 0.26-0.49 low, 0.50-0.69 moderate, 0.70-0.89 high and 0.90-1 very high correlation (Domholdt 2000). P-values of 0.05 or less were considered evidence of statistically significant findings. In the normative sample, at least five girls and boys in each age band (1 year) were considered sufficient for statistical analysis. Observed power for detecting differences was calculated in study III.

Software packages Statview (SAS Institute Inc., 100 SAS Campus Dr, Cary, NC 27513) and SPSS (SPSS Inc., 233 S Wacker Dr, 11th Fl, Chicago, IL 60606) were used for statistical analysis.

Table 6. Overview of statistical methods.

| | Pilot study | Study I | Study II | Study III | Study IV |
|---|---|---|---|---|---|
| Pearson product moment correlation | | X | X | | |
| T-test | | X | | | |
| Intra-class correlation (ICC) | | X | | | |
| Forward stepwise regression analysis | | X | X | | |
| One-way analysis of variance | | | X | | |
| Mann Witney U test | | | | X | X |
| Spearman rank correlation | X | | | X | |
| Observed power | | | | X | |
| Wilcoxon signed rank test | | | | | X |
| Paired sign test | | | | | X |

## Ethics

The local Ethics Committee at the University of Gothenburg approved the study. Written informed consent was obtained from the parents of each participant.

Ethical considerations were mostly the amount of time spent by children and their parents when participating in different testing and training sessions. None of the measurements were painful or harmful in other ways but the children had to undress and only wear underwear in the tests, which some children may find upsetting.

# Results

## *Pilot study*

The pilot study included 12 children with bilateral spastic CP (seven boys, five girls) at GMFCS levels I-III, and 12 typically developing children in a reference group (six boys, six girls). The participants were all between five and ten years old, with a mean age of eight years. The children in the reference group were taller (mean 130.3 cm compared to 123.3), and weighed more (mean 31.1 kg compared to 26.0) than the children in the study group. The pilot study showed a very high correlation between muscle strength, measured in Nm, and both age (r = 0.91) and weight (r = 0.95) for control children, but only with weight for children with CP (r = 0.75), where there were no correlation with age, see figure 11.

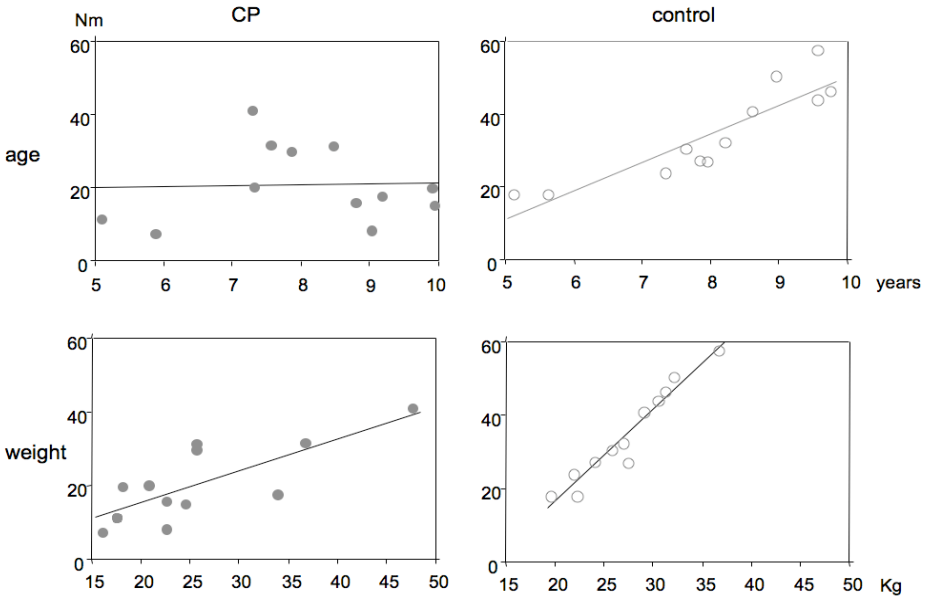



Figure 11. Correlation between muscle strength in knee extensors and age and body weight in children with CP and controls respectively. ● = Children with CP, ○ = control children.

## *Study I muscle strength – normative values*

A total of 149 children (76 boys and 73 girls) participated in the study. The children had no known diseases affecting muscle strength according to their parents' statements. An additional 41 children received but did not reply to the letter of invitation and 25 children declined participation.

The study established normative data for muscle strength, measured with a handheld myometer, in eight muscle groups in the legs, in children five to 15 years old. Muscle strength was reported as torque, and data were compared to age, weight and sex. Equations for a predicted value based on age, weight and sex were computed using regression analysis. The predicted values make it possible to make comparisons over time and between subjects and thus provide a tool for evaluation of physical status and efficacy of therapy.

Muscle strength in typically developing children increased with age and weight, and there were few differences between boys and girls. Plantarflexor strength was only possible to measure up to nine years of age.

Agreement between examiners was tested. There was no statistically significant difference between measurements by the two testers and intraclass correlation coefficients ranged from 0.93-0.97, which was graded as a very high correlation.

The children were asked about their activities outside school. In the age group five to seven there were 37 children, and 19 of them (51%) had an organised activity outside school. In the group of 112 children over eight years of age, 93 children (83%) were active in organised sports, the most frequent activities being football (soccer) (35 children) and floor hockey (27 children). Other activities were horseback riding, European handball, dance, track and field, tennis, swimming and golf. Many children took part in more than one activity. Comparisons revealed a statistically significant difference in muscle strength for hip flexors in both positions ($p=0.01$ and 0.04) and one of the two knee flexor positions ($p= 0.04$) between those who participated in organised sports and those who did not.

## *Study II muscle strength in CP – walking ability*

Fifty-five children (35 boys, 20 girls) with bilateral spastic CP, between five and 15 years of age and classified at GMFCS levels I-III, participated. Of them, 39 children were born between 1991 and 2001, and were recruited for this study. Sixteen children born 1986-1990 from the pilot study and the training study were also included. The sample represented about two thirds of the total population of children with bilateral spastic CP at GMFCS levels I-III in the

birth cohort 1986-2001 in the area. For comparison, two extra children at GMFCS level IV were added in the thesis, see figure 12a. Both of them had difficulties in activating all muscle groups, one could only activate hip flexors, knee extensors and flexors, and the other could not activate hip extensors or flexors.

Muscle strength was measured with a myometer and data for each muscle group in every child was compared with a predicted value, using the equation from study I, thus creating a percentage. Strength data were than compared to walking ability expressed using the GMFCS classification and the GMFM test (domain for standing and walking-running-jumping).

Muscle strength in the legs was below normative predicted value in most of the children, with muscle weakness most pronounced around the ankle, followed by the hip muscles (figure 12 a, b). There was a statistically significant difference in muscle strength between GMFCS levels: independently walking children had more than 50% of predicted muscle strength values. There was also a moderate to high correlation between muscle strength and the GMFM, indicating that muscle weakness affects walking ability.

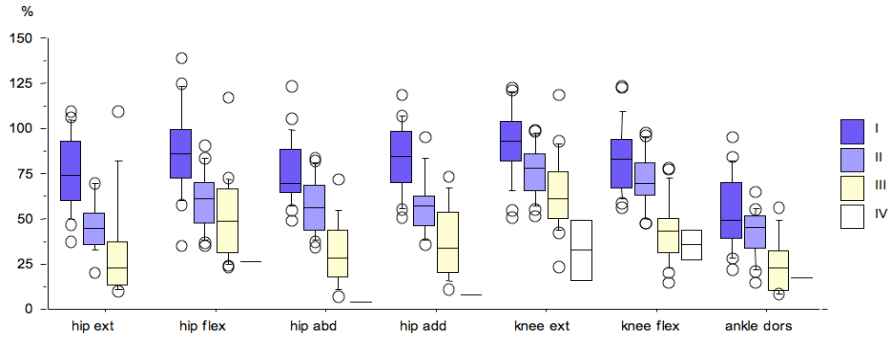



Figure 12a. Muscle strength, expressed as a percentage of predicted value, in seven muscle groups, divided by GMFCS level.

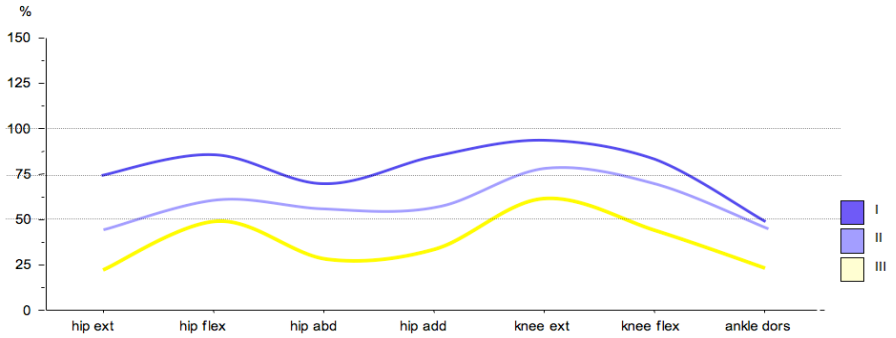



Figure 12b. Profiles connecting the medians for GMFCS level I-III.

*Results*

Age related reference values have been frequently used but, as shown in figure 11, may not be accurate in children with CP. An often-used way of normalising values is to divide by body weight. In the normative material, Nm/kg increased with age. The correlation was statistically significant ($p<0.0001$) in all muscle groups except plantarflexors (where there were too little data, only from 5-9 years) figure 13 and table 7. Correlations were considered high at hip and knee level and low at ankle level. In the CP group there was also a statistically significant increase in three muscle groups (hip flexors, knee extensors and knee flexors), but with values below the reference group.

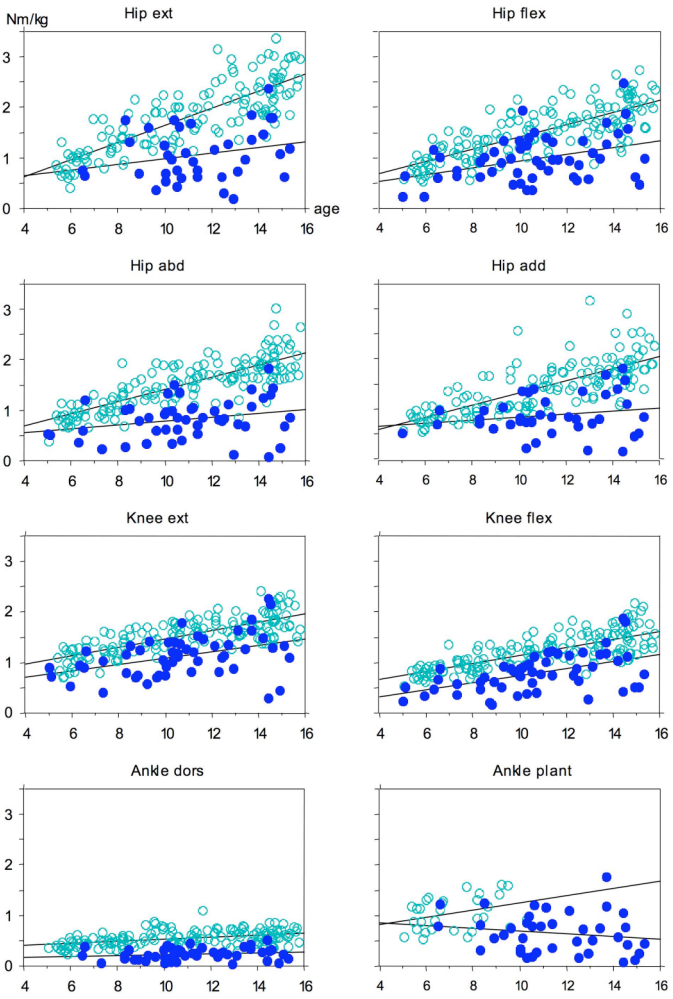



Figure 13. Correlation between torque and age in hip extensors-flexors, abductors-adductors, knee extensors-flexors, and ankle dorsi-plantarflexors. ● = Children with CP, ○ = reference children.

Table 7. Correlations between muscle strength (normalised to body weight) and age.

| | CP n = 38-54 | p = | Controls n = 137-149 | p = |
|---|---|---|---|---|
| Hip ext | 0.245 | 0.138 | 0.816 | <0.001 |
| Hip flex | 0.394 | 0.004 | 0.767 | <0.001 |
| Hip abd | 0.265 | 0.069 | 0.802 | <0.001 |
| Hip add | 0.196 | 0.228 | 0.757 | <0.001 |
| Knee ext | 0.416 | 0.002 | 0.745 | <0.001 |
| Knee flex | 0.506 | <0.001 | 0.749 | <0.001 |
| Ankle dorsiflex | 0.179 | 0.236 | 0.431 | <0.001 |
| Ankle plantarflex | -0.168 | 0.310 | 0.329 | 0.076 |

Regression lines in figure 13 may indicate that the children with CP do not keep pace with the typically developing children. However comparing the values for percent of predicted in the CP group to age shows only a minor downward trend, with low correlations that not are statistically significant.

A ratio between agonist – antagonist was computed to look for balance across joints, see table 8. There was a statistically significant difference between the children with CP and controls in hip flex/ext and knee ext/flex, the hip flexors and knee extensors being relatively stronger in the children with CP.

Table 8. Ratio between agonist and antagonist muscle groups, mean (SD).

| | n = | CP | n = | Controls | t-test p = |
|---|---|---|---|---|---|
| Hip flex/hip ext | 41 | 1.29 (0.85) | 137 | 0.89 (0.19) | <0.001 |
| Hip abd/hip add | 43 | 1.02 (0.26) | 142 | 1.10 (0.24) | 0.050 |
| Knee ext/knee flex | 57 | 1.63 (0.84) | 149 | 1.29 (0.23) | <0.001 |
| Ankle plant/ankle dors | 42 | 2.79 (1.18) | 30 | 2.37 (0.68) | 0.083 |

## *Study III kinetics – muscle strength*

Twenty children with CP, nine to15 years old, and a reference group of 20 typically developing children of the same ages participated in the study. All the children with CP walked without aids, 12 were classified at GMFCS level I, and eight at level II. Of the children with CP there were 15 boys and five girls, and in the reference group 13 boys and seven girls.

Muscle strength data was compared to gait forces (moment). There was a statistically significant difference in muscle strength in all muscle groups while gait moments only differed at the ankle. There was a correlation between plantarflexing moment and muscle strength in six of eight measured muscle groups in the group of children with CP.

*Results*

A ratio between muscle strength and gait moments was computed as described in a previous study (Fosang and Baker 2006). We also computed the inverted ratio, between gait moments and muscle strength, presenting gait moments as a percentage of muscle strength, table 9 and figure 14.

Table 9. Ratio gait moments/muscle strength, presenting gait moments as a percentage of measured muscle strength, mean (SD).

| | CP | Reference | t-test p = |
|---|---|---|---|
| Hip ext | 53 (28) | 33 (6) | 0.011 |
| Hip flex | 53 (22) | 39 (12) | 0.021 |
| Hip abd | 52 (21) | 35 (12) | 0.003 |
| Hip add | 55 (49) | 24 (13) | 0.009 |
| Knee ext | 58 (35) | 31 (13) | 0.003 |
| Knee flex | 42 (29) | 21 (12) | 0.005 |
| Ankle dors | 35 (50) | 38 (16) | 0.797 |
| Ankle plant | 155 (63) | - | |

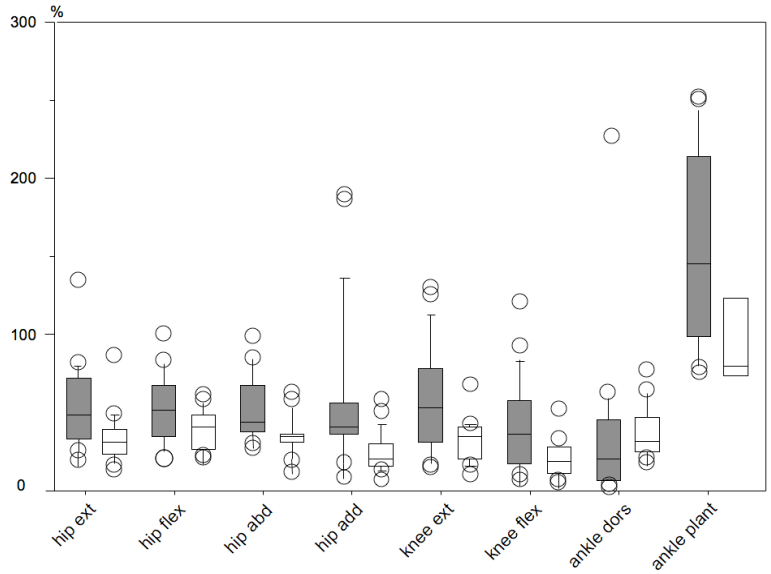



Figure 14. Ratio between gait moments and muscle strength, ■ = CP, □ = reference.

There was wide variation among the children with CP, and a statistically significant difference between the group of children with CP and the reference group for all muscle groups except at ankle level. The children with CP had a higher ratio, indicating that they were using more of their maximal muscle strength capacity. For ankle plantarflexors the gait moment exceeded the measured muscle strength, which indicates that other forces than active muscle work are creating the moment.

The observed power to detect differences between groups was calculated. For muscle strength data (except plantarflexors with too little data in the reference group), the observed power ranged from 96-100%. For ankle dorsi- and plantarflexing moment the observed power was 100%.

## *Study IV muscle strength training*

Sixteen children (14 boys and 2 girls) with bilateral spastic CP, 9-15 years old and at GMFCS level I-II participated in groups of four. Another eight children were invited but chose not to participate or the time was not convenient. For comparison, gait data from 27 typically developing children (14 boys, 13 girls) of the same age group from the gait lab reference database were used.

The children with CP were assessed with muscle strength measurements, GMFM and gait analysis before and after eight weeks of targeted muscle strength training. Muscle strength and walking ability increased after the training. Gait analysis showed a significant increase in generating plantarflexor power at push off. There were no changes in gait velocity. Individual ratings of improvements are presented in table 10. The current results support muscle strength training as a means of improving gait in children with CP.

Table 10. Individual ratings of change after eight weeks of muscle strength training.

| | GMFCS | Age | Muscle strength | GMFM | Overall gait |
|---|---|---|---|---|---|
| A | I | 9 | + | | + |
| B | I | 10 | + | max | = |
| C | I | 10 | + | (+) | + |
| D | I | 11 | | (+) | + |
| E | I | 12 | + | + | + |
| F | I | 12 | + | | + |
| G | I | 13 | | | + |
| H | I | 13 | | max | = |
| I | I | 14 | + | max | + |
| J | I | 14 | + | + | + |
| K | II | 10 | + | | + |
| L | II | 11 | + | | ± |
| M | II | 13 | | + | = |
| N | II | 13 | + | | + |
| O | II | 14 | + | + | = |
| P | II | 15 | + | | = |

GMFM + indicates increase outside the 95% confidence interval in the GMAE. Three children had a max score before training started. Overall gait is a combined judgement of changes in kinematics and kinetics at hip, knee and ankle level, and of symmetry.

# Discussion

## General considerations

The studies presented in this thesis include material with normative values for muscle strength measured with a handheld myometer. Data are reported as torque, and equations for a predicted value based on age, weight and sex are presented. This forms a platform upon which muscle strength differences and changes between children and over time in the other studies can be graded.

Study II explored the presence of muscle weakness in children with bilateral spastic CP and in relation to walking ability. Muscle strength in the legs was below predicted values in most of the children, with muscle weakness most pronounced around the ankle and hip muscles, and increasing with severity according to the GMFCS. A cut-off percentage of about 50% was needed to be able to walk without assistive devices. There were also moderate to high correlations between muscle strength and GMFM scores.

In study III muscle strength was compared with kinetic data from 3D gait analysis in a group of children with bilateral spastic CP, at GMFCS levels I-II, and a reference group with typically developing children. Results show muscle weakness in the children with CP and lower plantarflexing gait moments. The children with CP used a higher percentage of their muscle strength to obtain normal gait moments at hip and knee level. The study confirms previous findings of a correlation between muscle strength and gait pattern. The results indicate that plantarflexors are important muscles, often compromised in children with CP, with weakness that affects the kinetic gait pattern. Other muscle groups in the leg are also needed for effective ankle plantarflexing moment.

The aim of study IV was to investigate the influence of muscle strength training on gait outcomes in children with bilateral spastic CP, all walking without assistive devices. Training was performed during eight weeks, three times a week with an individually designed programme but with one session a week in a small group under the direction of a physiotherapist. After training, muscle strength and the GMFM increased. Velocity was unchanged but with increased stride length and decreased cadence. Ankle plantarflexor power generation at push off increased.

After consulting a statistician, five boys and five girls in each year-span was considered a sufficient number for statistical analysis in study I. Depending on exact age at the time of assessment some children had already passed to the next

year-span and extra children were recruited for this reason. Dividing the children into weight groups showed that there were too few children in some weight groups, so extra children were recruited to fill these gaps. This led to overrepresentation of 14-year-olds. The study ultimately included 149 children, with another 66 children (31%) who did not answer the letter of invitation or declined participation. Since we do not know the status of these children, this may have influenced our results. The sample was recruited from a school and a preschool in one geographical area, and there may be factors in the population affecting muscle strength. A potential factor for differences is the amount of physical activity, which may vary. Collecting data from areas of different socio-economic status would have been preferable. We asked the children in the normative study if they took part in organized activities outside school and the answers showed that the majority of both boys and girls were active. The amount of physical activity, 83% of the children from eight to 15 years old, was of the same magnitude as in two Swedish studies on physical activity in schoolchildren. Engström (Engström 2004) reported that about 20% were not active, which was an increase compared with a similar study from 1968. Persson and Schlyter (Persson and Schlyter 2007) compared children living in the countryside and in an urban area in the south of Sweden, and found that 84.9 % of children in the countryside were active in organised sports and 79.3% of children in the city. In our study, there were no differences in muscle strength in most of the measured muscle groups between children active in organised sports and children who were not active. This may reflect the fact that both legs are needed for transitions in everyday life and that this activity is sufficient for keeping normal strength. However, in the group with six-to-eight year old children studied by Macfarlane there was a difference: children who participated in three or more hours per week of organized sports were stronger in four of six muscle groups (Macfarlane, Larson et al. 2008).

The sample in study II represented about two thirds of the total population of children with bilateral spastic CP at GMFCS levels I-III in the birth cohort 1986-2001 in the area. The proportion of girls was slightly lower than expected according to a population-based study in the region (Himmelmann, Hagberg et al. 2005). A control in the data verified that the sex proportion in the study area differed from that of the whole region, with an overrepresentation of boys (Himmelmann, personal communication), so the sample seems to be representative of this area.

In the gait analysis and training studies (III and IV) there were only 5/20 and 2/16 girls respectively, which may limit the interpretability and generalizability of our findings. However, we have found no reports stating that there is a difference in gait pattern between girls and boys. One explanation for the loss of girls in the training study may be a lack of interest in muscle strength training and, as the children were recruited through their physiotherapists, it may also reflect the physiotherapists' choice of suitable training for girls.

## *Muscle strength*

To our knowledge this is the first paper reporting normative torque data in children from handheld measurements in relation to age, weight and sex. We have found one other study presenting torque data in children six to eight years old (Macfarlane, Larson et al. 2008). Values were comparable for knee extension and flexion and at ages six and seven for hip adduction-abduction, but they were different for hip extension-flexion. Differences may depend on a different position of the subject in hip extension-flexion and that a different type of dynamometer was used.

Measurements in growing children have to take into account the maturation and size of the child, which makes appropriate reference data extremely important. A method that is usable in adults may not be so in children because of changes during growth. A common method of normalising muscle strength data is to divide by body weight. Our normative data as well as a study by Wren and Engsberg (2007) shows that the strength measurements normalised to body weight (Nm/kg) increase with age in typically developing children and this method has to be used with care when evaluating muscle strength in children. The equations for a predicted value based on age, weight and sex presented in study I is an effort to minimize this problem and make data comparable between children and over time. In spite of this, Nm/kg was used in the studies comparing muscle strength to gait analysis (studies III and IV) as gait moments are reported in the same unit, and data primarily are compared within the individual and not with the group.

In children with CP only three of the eight measured muscle groups showed an increase in Nm/kg by age. This may indicate that muscle strength does not keep pace with typically developing children in the other five muscle groups. If this is the case, it ought to be visible when comparing the data for percent of predicted value to age. The data and graph show that there is a downward trend, although it is very small and not significant. This may reflect that children with CP do not keep pace with growth in typically developing children?? Failing power/mass ratio may be one reason why some children with CP cease walking in the adolescent growth spurt, as hypothesized by Gage (Gage 2004).

Muscle weakness was found in the children with CP, most pronounced at hip and ankle level and increasing with severity. Cut-off between GMFCS level II and III (to be able to walk without aids) was around 50% of predicted values. There is another difference between levels III an IV, where children at level III are able to voluntarily activate one muscle group at a time (though it may sometimes require concentration) and children at level IV have difficulties in voluntarily activating more than knee extensors and hip flexors. Wiley and Damiano reported an imbalance in muscle strength across joints (Wiley and Damiano 1998) with ratios in children with CP being different from comparison children. Our ratio data differed from Wiley and Damiano, both for the controls

and for the CP group, which may have several explanations. They measured strength in Newton and did not take account of the influence of lever arm. Positions in testing may also be different. The pattern of imbalance is similar in both studies, with hip flexors and knee extensors being relatively stronger. The imbalance may have consequences for the development of contractures and ought to be considered in treatment, as ought of course, the presence of muscle weakness per se.

Measurement of plantarflexor strength is a special problem with the high forces generated, which make it difficult to measure using a handheld instrument. In the normative study a special belt was constructed where the child was stabilised by his/her own body. Although the belt system worked well, the forces exerted were over the measurement range of the myometer, and so the method was not successful. It is of interest to quantify plantarflexor strength, as it is one of the most important muscle groups for forward propulsion. Other ways of measuring have been proposed, with a specially adapted machine or counting single leg heel-rises (Maurer, Finley et al. 2007; Örtqvist, Gutierrez-Farewik et al. 2007), both shown to have good reliability. In our experience plantarflexors can almost always be measured with a myometer in children with CP, which also indicates that muscle weakness in plantarflexors is a common finding in this group.

## *Gross motor function*

The median increase in GMFM66 in study IV was 5.2 points, which is more than the 1.58 points considered to be a clinically meaningful improvement and the 3.71 points considered to be the cut-off for discriminating as greatly improved, in a study by Wang (Wang and Yang 2006). This is also true despite the fact that three children scored full before training started, which points out that there is a ceiling effect for children at GMFCS level I, where changes cannot be measured with the GMFM. The GMFM has been used to create curves for normal development in children with CP according to GMFCS level (Rosenbaum, Walter et al. 2002; Beckung, Carlsson et al. 2007). These curves show that there is little or no change after the age of seven. The course may differ between children with different CP subtypes. The stability in gross motor function has also been confirmed by Voorman, Dallmeijer et al. who found that the GMFM scores were stable over a time of two years in children between 9 and 15 years of age (Voorman, Dallmeijer et al. 2007). The children in study IV were all older than 9, and the increase took place over eight weeks. This indicates that training can make a difference, and can increase gross motor function beyond the ages where a natural increase is expected.

There was a moderate to high correlation between muscle strength and the GMFM, indicating that other factors also influence walking ability. A couple of studies have reported selective control as being correlated with walking ability and gait pattern (Östensjö, Carlberg et al. 2004; Desloovere, Molenaers et al. 2006). There may be a link between selective control and muscle strength, also

visible in the difference between muscle strength in children at levels III and IV, but they are not entirely the same.

The GMFM items “standing on one leg” and “jumping on one leg” showed most improvement in the training study. These are abilities needed in many transitions in everyday life, such as walking on uneven ground and climbing stairs, which emphasizes their importance. The results from study IV indicate that muscle strength is one prerequisite for balance on one leg.

## *Gait analysis*

Lever arms are of utmost importance when dealing with a moving body, as they multiply forces, both internal and external. The internal lever arms are dependent on skeletal alignment, which may be changed and suboptimal during growth in children with CP, owing to spasticity and imbalance in muscle strength (Gage and Schwartz 2004). External lever arms arise from the position of the body and direction of movement in relation to gravity and ground reaction force. The normal gait pattern is optimized for energy conservation, which means using as little force as possible. This is achieved through a position of the body where the ground reaction force vector falls through the centre of the joints as much as possible, and by letting the leg act as a pendulum in swing phase, requiring no extra force than the force of gravity from the leg (Whittle 2002; Gage 2004). The point where resultant forces from the body can influence the direction to move is the contact between foot and ground.

Correlations for all muscle groups and all gait moments were computed, leading to multiple comparisons, which may have resulted in false positives. The pattern of correlation between ankle plantarflexing moment and muscle strength in almost all muscle groups was, however, very clear and can be interpreted as the plantarflexors and plantarflexing moment being important for walking. A study on children with unilateral CP also showed a reduced plantarflexor generating power with hip extensors compensating (Riad, Haglund-Akerlind et al. 2008).

## *Strength training*

According to the literature, sufficient intensity of muscle strength training is needed for results, and a longer period is needed for hypertrophy of the muscle. People have different preferences of whether to do something on a regular basis every day/every week, but a short period with higher intensity may often be more rewarding and easier to fulfil in everyday life. Three times a week for eight weeks, as in study IV, was possible for most of the children. A longer period would have been difficult to plan, as there are vacations within the school terms and many families travel or do other things that are difficult to coordinate with training.

Several studies have reported changes in muscle strength after 6-8 weeks of training (MacPhail and Kramer 1995; Damiano and Abel 1998; Dodd, Taylor et

al. 2003; Morton, Brownlee et al. 2005; Liao, Liu et al. 2007). The response with increased muscle strength in eight weeks suggests that it is mainly attributable to neuromotor mechanisms, resulting in better coordination, increased recruitment of motor units and/or increased firing rate. The phenomenon of "cross education" may be one reason for an increase in muscle strength in other muscle groups than the ones targeted in training in study IV.

A limiting factor for the interpretation is that the same individuals conducted both the training sessions and the testing of muscle strength and gross motor function, which can make them inclined to look for positive changes. To minimize bias the pre-testing protocol was not available/considered at the time of follow up.

The training study showed an increase in muscle strength directly after training but there were no follow up to see if the levels were maintained.

To have a specific functional goal for the training has been proven to be important to success in training (Bower, Michell et al. 2001). We applied this way of thinking and tried to set functional goals together with the children. Some of them were determined and knew what they wanted, but for others the training was more a decision of their parents and their parents' goals. The group was too small to investigate whether there was a difference in outcome depending on goal setting. In spite of this we think that there does not always have to be a functional goal for training, it may be fun just to be active, and movement can be a goal in itself. Just look at small children taking their first steps and their great joy in it. To have fun and meet other children may also be a goal and affect different aspects of life, and the strength gain can then be viewed as a positive side effect. Frequency is another factor for success in training, and if you enjoy an activity the chance for many repetitions is higher. The vast majority of children we have met during the studies have been interested in their muscle strength and very willing to participate and to do their best.

# Conclusions

Normative values for muscle strength in terms of torque were obtained for typically developing children 5 to 15 years of age. Equations for predicted torque taking into account age, weight and sex were calculated, thus providing a platform for comparison between subjects and over time.

Muscle weakness was found in children with CP, increasing with severity of gross motor function, approximately 50% of the predicted muscle strength was needed to be able to walk without aids. There was moderate to high correlation between muscle strength and the GMFM.

Muscle weakness was correlated to the kinetic gait pattern in terms of plantarflexing moment. Gait moments in children with CP were closer to their maximal muscle strength capacity than for typically developing children.

After eight weeks of muscle strength training, there was an increase in muscle strength and also in walking ability and gait pattern. This was seen in spite of the fact that the children were over the age where a natural increase in function was expected.

# Clinical implications

The outcomes of many interventions in CP affect, or are affected by, muscle weakness, not only in relation to physical training but also to medication and surgery. The ankle is a particular focus of many interventions such as orthoses, botulinum toxin and orthopaedic surgery. Orthopaedic surgery changes biomechanical conditions; soft tissue surgery can change the length of muscles and tendons and affect muscle strength by changing the length-tension relationship, most often negatively, and decreasing muscle strength, whereas skeletal surgery can change internal lever arms and affect the distance between origin and insertion of the muscle both positively and negatively (Gage and Schwartz 2004).

With the pronounced muscle weakness present in the muscle groups around the ankle and hip and the role of these muscles in relation to gait pattern and walking ability, it is easy to understand the importance of knowledge of muscle strength when planning interventions for children with CP.

This study focused on the impact of muscle weakness on motor function, and found a correlation with walking ability and an increase after training. Of special interest are the ankle plantarflexors, found as being important for walking ability and gait pattern, and the influence of muscle weakness, especially at hip and ankle level on the ankle plantarflexing moment. The moderate correlations, however, indicate that muscle weakness is only one of several factors that interfere with gross motor function. Although this study focused on ICF domains body function and activity, we would like to emphasize the importance of the carryover to everyday life and participation. In a study, the intervention has to be standardized to control for confounding variables, but in a clinical situation all ICF domains ought to be considered to obtain satisfactory results (Darrah 2008).

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