Assessment of Functions and Functional Activities of the Upper Extremity

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Assessment of Functions and Functional Activities of the Upper Extremity

Het meten van functies en functionele activiteiten van de bovenste extremiteit

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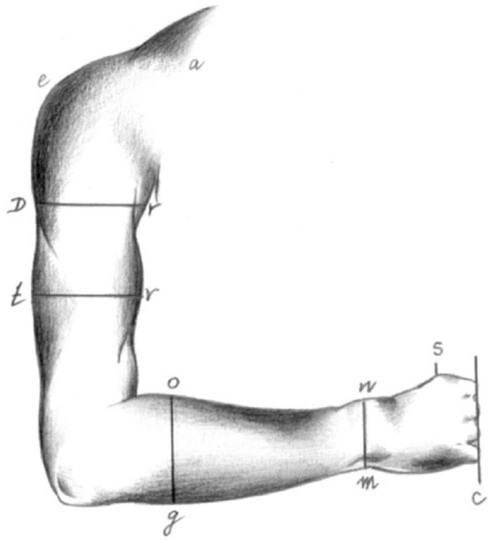
CHAPTER 1

Introduction



In 2001 the World Health Organisation (WHO) published the International Classification of Functioning, Disability and Health (ICF) (1) to describe the functioning of human beings. The ICF approaches such functioning from three perspectives:

- the human being as organism, describing the body functions or anatomical structures or, in other words, capacity to perform
- activities of subjects, or ability to perform
- participation in community, or opportunity to function

Unrestricted and independent functioning in daily life is obvious for most human beings, but acute or chronic disorders may lead to impaired body functions, limitations in activities, and restrictions in participation.
The ICF model does not assume a direct causal relation between the seriousness and kind of impaired functions and limitations in functional activities. The domains of body function, functional activities and participation are also influenced by personal characteristics of an individual, as well as the environmental context that represents a person's physical and social circumstances.

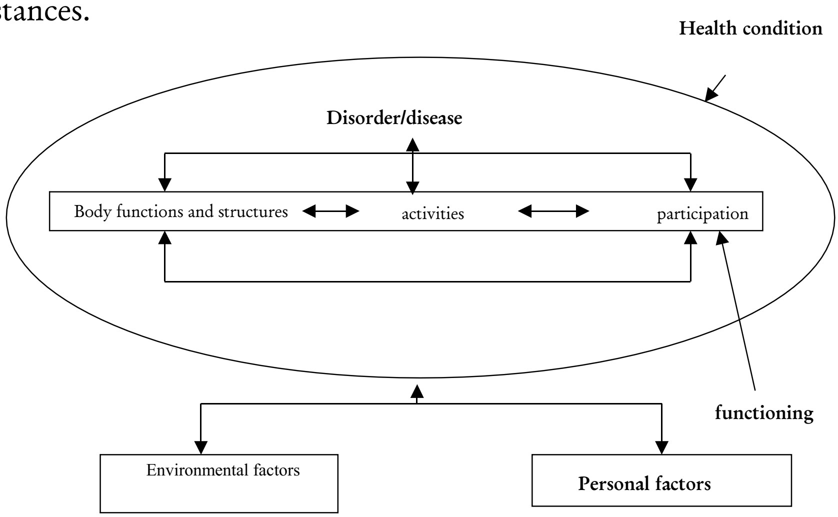


Figure 1. Model of the ICF showing the relations between the different aspects of health situations and external and personal factors

In Dutch one often says "meten is weten", meaning "measuring is knowing". Measuring is important to discriminate between patients and healthy subjects, to conduct follow-up in (chronic) diseases or disorders, to establish determinants for (future) participation, and to evaluate the effectiveness of treatments. Much of rehabilitation practice is based on the presumption that the interventions acting at the levels of disease, body function and impairments should be reflected in changes in participation (2). Therefore, the assessment of participation and its major determinants is essential, not only to understand the broad health-related impacts of chronic disorders, but also to evaluate the effectiveness of rehabilitation interventions.

The ICF model may be used to guide the selection of measurement tools, and Rosenbaum et al. (3) emphasized that outcome measures need to be multidimensional to evaluate the effect of treatment at the different levels of function, functional activities and participation. Measuring body functions (such as muscle strength, range of motion, and pain) is straightforward and there are well-known methods to do this. Measuring functional activities is more complex; for these aspects of functioning, assessments of capacity or performance can be made, for which tests and questionnaires exist. In analyzing the effectiveness of treatment it is important to discriminate between what a person can do (capacity) and what a person does do (performance) in daily life. Measuring restrictions of participation can be done by means of questionnaires, sometimes measuring both functional activities and participation. Information about measuring other important factors such as personal and environmental factors is scarce.

Arm-hand function is crucial in most activities in daily life; therefore, in this thesis, we focused on arm-hand function. Shoulder, arm and hand function can be impaired because of a temporary or chronic disorder. Examples of temporary disorders are fractures, infections (such as a non-inflammatory arthritis) and muscles tears. Chronic disorders may be either congenital or (early in life) acquired. Cerebral palsy (CP) is a rather common congenital disorder, leading to life-long impairment of the upper extremity.
In temporary, mostly (sub)acute disorders the patient has impaired functions, which can generally be resolved by various interventions. To evaluate interventions in temporary disorders, measurements at the level of function, for

example pain, range of motion and muscle strength, are the most important. In chronic disorders impaired, sometimes progressive, functions remain for a long time and result in several limitations in activities and restrictions in participation. For instance, in CP spasticity, reduced muscle strength and other neurological deficits result in a broad range of limitations of functional activities and restrictions in participation. Therefore, rehabilitation management needs to focus not only on treatment of the impaired functions, but also provide interventions on the level of functional activities and participation. As a result of this multi-level approach outcome measurement is targeted on the three ICF levels of functioning.

Outline of this thesis

The main focus of this thesis is the measurement of function and functional activities of the upper extremity in relation to participation. After studying the reliability of isokinetic dynamometry of the shoulder joint in healthy subjects we concentrated on patients with a capsulitis, which is a very common temporary disorder. The second part of this thesis focuses on arm-hand function in young adults with CP, which is a chronic disorder predominantly characterized by spasticity and loss of muscle strength.

In the first part, measurements of function of the shoulder joint are described, whereby muscle strength and range of motion are measured by isokinetic dynamometry. The measurements are done in patients with a common temporary disorder of the shoulder joint, i.e. a capsulitis, also known as a non-inflammatory arthritis. Before analysing these outcomes, we determined the reliability of isokinetic dynamometry of the shoulder joint in healthy subjects (chapter 2). Subsequently, we investigate which parameters of isokinetic dynamometry were clinically applicable (chapter 3). Responsiveness of the outcome measures of isokinetic dynamometry and pain was determined in patients with a capsulitis (chapter 4).

The second part, describes arm-hand function in young adults with CP. First we measured grip strength parameters, as representatives of function, in hemiplegic patients and compared these measurements with outcome measures of functional activities (chapter 5). Furthermore, we investigated which outcome measures of functional activities of the upper extremity are useful for young adults with CP, since most measures were developed either for children or adults. Additionally, we determined whether functional activities of the upper limb are important determinants for restrictions in participation (chapter 6). Subsequently, we investigated whether the Manual Ability Classification System (MACS) is a valid classification system to be used in young adults with CP (chapter 7).

Shoulder disorders

Shoulder disorders are a frequent problem in general health care (4), as well as in rehabilitation, orthopaedic and sports medicine. In most shoulder disorders the impaired functions are temporary, but sometimes persist for a longer period. During this period these impairments can cause limitations in functional activities and restrictions in participation. Diagnosis and treatment of shoulder disorders is difficult; however, there is ample consensus regarding the classification of shoulder disorders into distinguishable diagnostic categories (5,6). The heterogeneity of patient groups makes the interpretation of studies on interventions difficult. Many accepted forms of conservative treatment are available for shoulder disorders, but evidence of their efficacy, especially their long-term effectiveness, is not well established (4,6,7).
Both clinical practice and research on shoulder disorders is hampered by the limited availability of reliable, valid and responsive outcome measures of shoulder function. In this thesis we investigate whether the use of isokinetic dynamometry could be an additional useful outcome measure.

Isokinetic dynamometry

Generally, outcome measures in studies on the efficacy of treatment of shoulder disorders include range of motion and pain. However, it has been reported that the reliability of measuring passive range of motion by physical examination of the shoulder is low (8,9), while pain is a measurement outcome with limited reliability (10,11), construct validity (11,12) and responsiveness (13). Because of these problems, it seems desirable to have an additional outcome measure that is objective, valid, sufficiently reliable and responsive. For this, muscle strength and active range of motion measured with an isokinetic dynamometer may prove useful.

Isokinetic dynamometry of the shoulder has been increasingly used in clinical practice since 1980 (14). The technique can be used to evaluate both the function of a joint and the effectiveness of therapy, because objective parameters (e.g. muscle strength and range of motion) can be measured. Research on isokinetic dynamometry has primarily focused on the lower extremity, especially the knee joint, also because the common isokinetic systems were particularly suitable for testing the knee joint. Isokinetic dynamometry of the knee is known to be reliable with good instruction, and standardization of the test procedure, and familiarization with the equipment (14,15).
Although several studies on isokinetic dynamometry of the shoulder are available, these do not address test-retest reliability of the measurements (15-17). An important prerequisite for correct interpretation of measurement results is that they are reliable. Some parameters will influence the reliability of isokinetic dynamometry of the shoulder. First, no standard examination position is established (18). Second, it is known that the axis of the glenohumeral joint moves 8 cm superiorly during flexion and abduction (19), which hampers correct alignment of the axis of the dynamometer to the axis of movement of the joint. Third, there is no consensus about which angular velocities have to be used during testing; the choice is arbitrary rather than scientific (14). In **chapter 2** we present a study on the test-retest reliability of isokinetic dynamometry of the shoulder joint. In 20 healthy subjects the muscles of the rotator cuff are measured with a Biodex® dynamometer. The measurements were repeated after a 2-week interval.

In literature, many parameters of isokinetic dynamometry have been mentioned. Overall, peak torques and peak torque ratios of the agonist and antagonist muscles are most often used. However, parameters such as angle-based torque, angle of peak torque, average torque, contractional power, contractional work, and contractional impulse have also been reported (14). There is no consensus

about which parameters are most appropriate in order to discriminate between healthy subjects and patients.

When using peak torques in patients with shoulder disorders, it would be useful to compare these data with data from a population of healthy subjects, or with the uninvolved shoulder of the patient. However, one of the problems associated with comparing peak torques with normative data is the relatively large range of normal values in healthy subjects (20). Therefore, comparing peak torque in the involved shoulder with the uninvolved shoulder of the same patient might better discriminate between pathology and normal function, assuming that healthy subjects will have only small differences between peak torques of both shoulders. This seems to be supported by studies reporting no significant difference in peak torques between the dominant and non-dominant shoulder (20-26). However, all these studies mentioned a tendency towards a higher peak torque of the dominant shoulder, while other studies reported significant differences between the dominant and non-dominant shoulder for internal

rotation in pitchers (27,28). Thus, the question remains as to whether bilateral comparison within patients is suitable.
One can assume that in healthy subjects the muscle strength of agonists and antagonists is in balance and, therefore, the strength of agonist and antagonist muscles will be correlated and the variation in the agonist-antagonist ratios will be relatively small. In patients with shoulder disorders there is often an imbalance between agonist and antagonist muscles. Thus, measuring these ratios might be useful to discriminate between healthy subjects and patients. The discriminative characteristic of these ratios is not known. In **chapter 3** we present a study that determines which outcome parameters are appropriate for clinical use. The outcome parameters, such as peak torques, agonist/antagonist ratios and peak torques ratios of the dominant and non-dominant shoulder, of 20 healthy subjects are compared with the outcome parameters of 9 patients with a unilateral capsulitis of the shoulder. The discriminative characteristics of these parameters between healthy subjects and patients are investigated.

For evaluation of the effectiveness of treatments, responsiveness of an outcome measure is important. The responsiveness to change of isokinetic dynamometry of the shoulder joint has not yet been investigated or compared with other outcome measures, such as pain and assessment of functional activities. Although there is no consensus as to what constitutes a responsive measure or how responsiveness should be quantified, two major aspects of responsiveness can be distinguished (29). The first aspect is defined as “internal responsiveness”, which characterizes the ability of a measure to change over a specified time period. One of the methods to assess “internal responsiveness” is to use a single group repeated measures design with a known efficacious treatment. The second aspect is defined as “external responsiveness”, which reflects the extent to which changes in a measure over a specified time period relate to corresponding changes in an external standard of health status. In case of lack of an external standard one has to focus on the internal responsiveness. In **chapter 4** we investigate the internal responsiveness of the isokinetic parameters, pain and functional activities in 9 patients with a unilateral capsulitis of the shoulder treated with a well-known intervention. The intervention consisted of 3 intra-articular injections with a 2-week interval. During the intervention the patients were measured 4 times, i.e. before the treatment started, and at 2, 4 and 12 weeks after starting the treatment.

Arm-hand function in young adults with cerebral palsy

Cerebral palsy (CP) is an umbrella term for multiple aetiologies and clinical manifestations. CP is not an etiologic diagnosis, but a clinical descriptive term. A usual definition is: a persistent disorder of posture and movement caused by a non-progressive pathological lesion of the immature brain (30,31). Besides motor impairments such as spastic paresis, also sensory disturbances, cognitive impairments, visual and auditory problems, and epilepsy are frequently present. In nearly 50% of the patients with CP the arm-hand function is impaired (32-35). Although the lesion is non-progressive, symptoms persist in adulthood and can have consequences for functions, functional activities and participation while growing up. Arm-hand function has received little attention, although we assume that arm-hand function will be as important as gross motor function. In this thesis we aimed to gain insight in the relations between function and functional activities of the upper extremity and participation.

As stated earlier, in rehabilitation medicine most therapies focus on treating body functions with the ultimate goal to minimize limitations in functional activities and restrictions in participation.
Children with CP are extensively treated in rehabilitation medicine with, for example, physiotherapy, occupational therapy, and speech therapy. Many of these children receive special education. The effectiveness of these interventions, especially the effect on participation in adult life, is not really known; knowledge on the relations between functions, functional activities and participation might lead to better advice for treatment modalities.

A well-known method to investigate hand function is grip strength measurement. Studies comparing grip strength between CP patients and control subjects have reported conflicting results. For example, one study reported decreased maximal grip strength in CP patients (36), while others (37,38)

reported no differences in static grip force between CP patients and controls. Whereas in hemiplegic CP the involved hand can be compared with the uninvolved hand, this may be problematic since it has been suggested that the uninvolved hand may also be impaired (39,40). For example, Gordon et al. (41) have described an impaired coordination of fingertip forces of the uninvolved hand of hemiplegic CP patients in comparison with hand function of normal subjects.
The relation between grip strength parameters and functional activities is not known for CP patients, and there is no consensus about the relations between grip strength measurements and functional activities in other patient groups. In patients with early rheumatoid arthritis, grip strength was an accurate indicator for upper limb ability (42). In other studies on patients with peripheral nerve lesions a weak relation was found; these studies reported that, besides motor recovery (measured as grip strength), other functions (such as sensory disturbance) also had a relation with functional activities (43,44). In **chapter 5**, we present a study in which we compared maximal grip strength, muscle coordination and muscle endurance of both hands of 26 hemiplegic CP patients with that of healthy subjects. Subsequently, we determined in young adults with CP the relation between the grip strength parameters, as a representative of function, and functional activities of the upper extremity, measured with the Melbourne assessment and Abilhand Questionnaire.

Measurements to assess functional activities of the upper extremity are available for children with CP, but for young adults and adults with CP no specific assessments are known. It is generally accepted that spontaneous use of the involved arm and hand does not change since childhood (34). Limitations in functional activities and restrictions in participation, however, could change whilst growing up and can even deteriorate in adults (45). In rehabilitation medicine an important goal of interventions is to diminish limitations in activities and in participation. Thus, it would be useful to have measures of functional activities for young adults or adults with CP which are valid, reliable and prognostic for restrictions in participation. In the study, presented in **chapter 6**, we determine whether instruments for the assessment of functional activities of the upper extremity used for both children and adults were determinants for participation. In 103 young adults with CP, functional activities of the upper extremities are assessed with the Melbourne assessment and the Abilhand Questionnaire, and relations with relevant participant characteristics are determined. Multiple regression analysis was used to establish whether the outcome measures are a determinant for participation.

The Surveillance of Cerebral Palsy in Europe (SCPE) has recommended that a functional classification system be applied to arm-hand function in children with CP in addition to the classification of gross motor function. Gross and fine motor function does not precisely run in parallel, and can and should be classified independently. A new classification system, the Manual Ability Classification System (MACS) developed for classifying the manual ability in children with CP, is valid and reliable (46). The MACS has been shown to be comparable with the Gross Motor Classification System (GMFCS) (47); both are based on subjective performance and consist of five levels with a clinically meaningful discrimination between the levels. **Chapter 7** presents a study investigating whether the MACS is a valid classification system of manual ability in young adults with CP. Eighty-three participants are classified according to the MACS and functional activities are assessed with the Melbourne assessment, the Abilhand Questionnaire and the Functional Independence Measure. Relationships between relevant participant characteristics and the MACS, and between assessments of functional activities of the upper extremity and the MACS, were determined. In addition, a multivariate analysis was used to establish whether the MACS is a determinant of participation.

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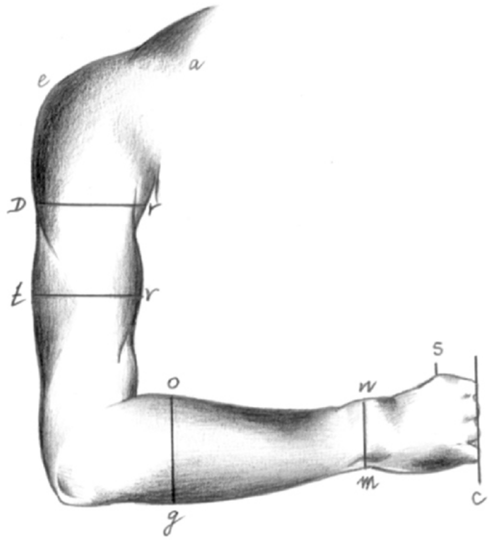
CHAPTER 2

Test-retest reliability in isokinetic muscle strength measurements of the shoulder



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ABSTRACT

Test-retest reliability is important for long-term follow-up; however, data on the reliability of isokinetic dynamometry of the shoulder are scarce. Twenty subjects (50% male) were measured; 10 with asymmetrical use of the arms (mean age 27 years) and 10 used their arms symmetrically (mean age 32 years). A Biodex® dynamometer (Multi joint system 2) was used. Abduction/adduction and external/internal rotation were measured following a standardized protocol. Performed scheme: two sessions with a two-week interval, all measurements were done with 60°/s (5 repetitions) and 120°/s and 180°/s (10 repetitions), respectively. Differences in the mean peak torques, split for muscle group and gender were significant. Intraclass correlation coefficients ranged from 0.69 to 0.92. This implies good to excellent reliability in research on groups. To determine test-retest reliability of two consecutive individual measurements smallest detectable differences (SDD) were computed and ranged from 21% to 43%. It is questionable whether the SDDs are small enough to detect real changes in muscle strength.

INTRODUCTION

Isokinetic dynamometry of the shoulder has been increasingly used in clinical practice since 1980 (1). The technique can be used to evaluate both the function of a joint and the effectiveness of therapy, because objective parameters (e.g. muscle strength and range of motion) can be measured. Much research on isokinetic dynamometry has been focused on the lower extremity, especially the knee joint. Isokinetic dynamometry of the knee is known to be reliable with a good instruction, standardization of the test procedure and familiarization with the equipment (1,2). Although several studies on isokinetic dynamometry of the shoulder are available, these do not address test-retest reliability of the measurements (2-5). We found only one study on this topic, addressing both intra and inter day variability of isokinetic shoulder abduction and adduction measurements (6). Their results indicated excellent reliability between days, with Pearson correlation coefficients varying between 0.87-0.97 for abduction and 0.95-0.99 for adduction measurements.

An important prerequisite for correct interpretation of measurement results is that they are reliable. Reliability depends on consistency of measurement results and, thus, to a relative absence of measurement errors. Reliability over two sessions, i.e. test-retest reliability, is necessary, because long-term follow-up is of clinical importance. When the test-retest reliability is good, unilateral comparison over a period of time is possible.

Several factors can influence the reliability of isokinetic measurements of the shoulder joint. First, in isokinetic dynamometry the axis of the dynamometer has to be lined out to the axis of the joint. The axis of the dynamometer has a fixed position, but there is no consensus about the localization of the functional joint axis of the shoulder. The glenohumeral joint has an extensive range of motion in several planes and the axis of the glenohumeral joint moves about 8 cm in flexion/extension and abduction/adduction movements (5). The influence of this phenomenon on the reliability of the measurement results is unknown.

Second, isokinetic measurements of the shoulder joint are done in several different positions, e.g. sitting, standing, lying supine and with different angles of abduction and flexion of the shoulder (7,8); however, it is not known which is the best or the most reliable position. The rotation movement is often done with 90 abduction or 90 flexion of the shoulder but with this method the subacromial structures are very vulnerable. Soderberg & Blaschak (7) studied six different positions for the rotational movement and reported significant differences in the maximal torque measured. The highest peak torque is seen in the neutral position, i.e. sitting with no abduction and flexion of the shoulder. The influence of the used position on reliability of the measurements is not known; most studies have used only one position. There is no consensus about the position to be used in the abduction and adduction movement.

Third, the choice of the preset angular velocity in isokinetic measurements of the shoulder joint is arbitrary rather than scientifically based. Low and high angular velocities are often used; the assumption is that a low angular velocity relates to maximal voluntary contraction and a high angular velocity relates to muscle coordination which is important in functional activities. The motivation for the used angular velocities (often 60/s, 180/s and sometimes 300/s) is not given. For sportsmen using their arms, high angular velocities (>180/s) are often used.

The aim of the present study was to determine the test-retest reliability of torques measurements of the shoulder joint in healthy subjects using a Biodex isokinetic dynamometer, Multi joint system 2.

METHOD

Subjects

In 20 subjects (healthy men and women of varying ages without pain and diseases) isokinetic measurements of the shoulders were done with a Biodex, Multi joint system 2. Ten of the subjects were active sportspersons with asymmetrical use of the arms (referred to here as the asymmetrical group) and 10 were either not sportspersons or sportspersons with symmetrical use of the arms (referred to as the symmetrical group). In both groups 50% was male. In the asymmetrical group 8 subjects were right-handed and two had no clear dominance; their mean age was 27 (SD 9.6) (range 22 to 54) years, mean body mass 70 (range 61 to 92) kg and mean height 177 (range 163 to 187) cm. In the symmetrical group 8 subjects were right-handed and 2 left-handed; their mean age was 32 (SD 12.7) (range 21 to 57) years, mean body mass 74 (range 62 to 97) kg and mean height 178 (range 152 to 196) cm. In the symmetrical group two examiners performed the measurements, whereas in the asymmetrical group only one examiner made measurements. All subjects were informed about the study and all gave informed consent. Approval for the study was obtained from the Ethics Committee of the University Hospital Rotterdam and Erasmus University Rotterdam.

Test protocol

All measurements were done according to a standardized protocol: measurements were done in a sitting position, subjects were strapped down with two bands across the chest, one across the pelvis and one across the contralateral leg, a footrest was used, gravity correction was used. The following muscle groups were measured: abductors, adductors, external and internal rotators. Assumptions for the abduction/adduction movement: chair was rotated 45° with the leg of the T-frame, back of the chair 45°, powerhead rotated 30° with the back of the chair, powerhead was overturned 45°, axis of the dynamometer was placed in the middle of the circle of movement during the abduction/adduction movement, this was done visually. Assumptions for the external/internal rotation: chair was rotated 90° with the leg of the T-frame, back of the chair was nearly vertical, powerhead parallel to the chair, powerhead was overturned 67.5°, axis of the dynamometer was placed in the longitudinal axis of the humerus through the olecranon.

Two sessions with a two-week interval were performed. As reported in other studies (2, 9-11) low and high angular velocities were used: for abduction/adduction 60°/s and 120°/s and for external/internal rotation 60°/s and 180°/s. In a pilot study we found that preset angular velocities higher than 120°/s in abduction/adduction movement and higher than 180°/s in external/internal rotation could not be exceeded by healthy subjects who were all active sportsmen (unpublished data). At the low angular velocity 5 repetitions were made and at the high angular velocity 10 repetitions were made. The maximal peak torque of these repetitions was determined, because this is reported to be the most used parameter in isokinetic dynamometry. Both shoulders were measured; the side where the measurements started was determined by randomization. Preceding the measurements there was a warming-up period in which the movement was done three times sub maximal. The rest period between the two angular velocities was 60 seconds. There was no verbal or visual feedback.

Statistical analysis

The scatter plot of the mean versus the difference of the peak torques of two sessions showed a greater difference at higher mean peak torques values (Fig. 1). Because of the proportional difference a logarithmic transformation (12) of the raw data was done (Fig. 2).

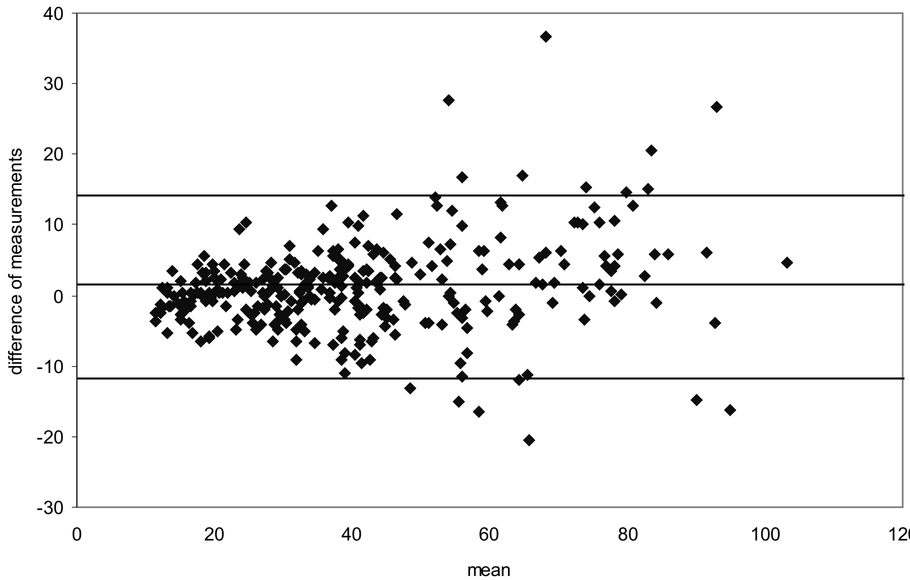

Figure 1. Scatter plot of the mean maximal peak torque of the two sessions versus the difference between the maximal peak torques. Reference lines of the mean of the differences and ± 2 standard deviations.

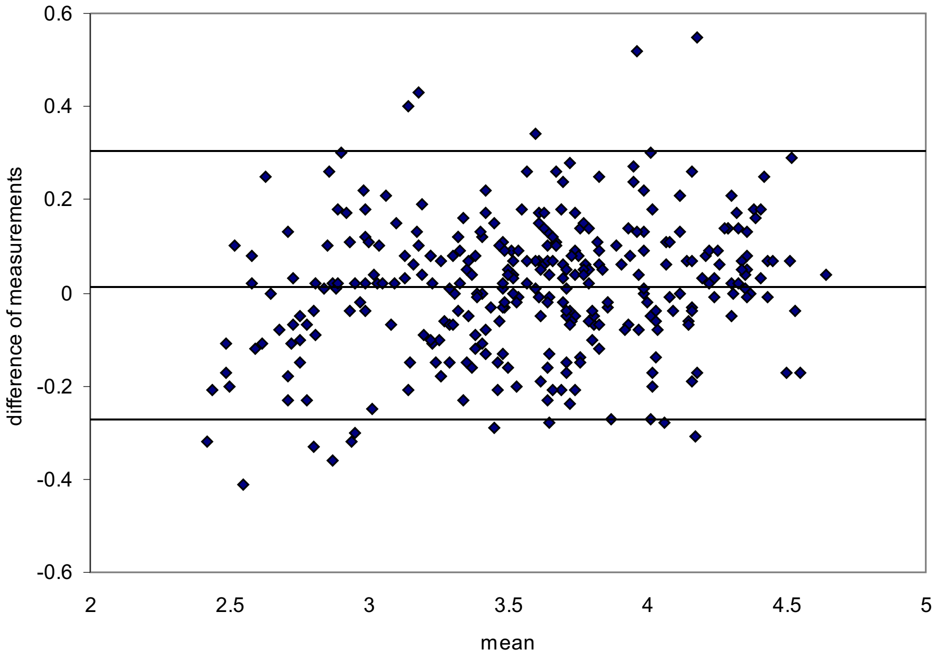

Figure 2. Scatter plot after logarithmic transformation of the data.

An ANOVA was performed using the transformed data. Analysis of the different subgroups, i.e. split for gender, sport, muscle group, side and angular velocity showed that the differences in error variance for sport, side and angular velocity were negligible. So, in further analysis only the two subgroups muscle group and gender were discerned. A general linear model of ANOVA was used with subject and session as random factors. The estimated variance components were determined: between-subject (var Subject) and within-subject (var Session and var Subject*Session). Analysis was performed using SPSS.
From the estimated variance components the intraclass correlation coefficient (ICC) was determined; the ICC is the ratio of variance of interest (between-subject variance) over variance of interest and error variance (between-subject plus within-subject variance) (13).
The standard error of measurement (SEM) was calculated with the estimated variance components; the SEM is the square root of the error variance (14,15). From the SEM the 95% confidence interval ($\pm$ 1.96 x SEM) and the smallest detectable difference (SDD) between two measurements (1.96 x $\sqrt{2}$ x SEM) were

determined. The latter index is practical in individual muscle strength measurements. Only differences between two measurements that exceed the SDD represent a real (non error) change in peak moment. Antilogs of the SEM, 95% confidence interval and SDD give the proportional indexes of measurement errors (in %).

RESULTS

Table I gives the mean peak torque (Nm) and standard deviation (SD) of two sessions for each muscle group, split for gender (n = 10). Analysis of the non-logarithmic data (ANOVA; F-value) shows that all differences between muscle groups and gender are statistical significant ($p < 0.05$).

Table I. Data (mean and standard deviation; SD) of peak torque for each muscle group for males (M) and females (F) of the two sessions.

	Gender	Mean (SD) (Nm)	
		Session 1	Session 2
Abduction	F	36.4 (7.9)	36.9 (8.2)
	M	63.2 (15.5)	63.1 (18.7)
Adduction	F	37.6 (6.9)	41.1 (10.8)
	M	66.7 (14.1)	70.5 (15.8)
External rotation	F	17.0 (3.6)	15.9 (3.3)
	M	29.5 (5.8)	29.3 (7.1)
Internal rotation	F	24.9 (6.9)	26.1 (7.0)
	M	48.5 (12.4)	50.0 (14.1)

Table II gives the estimated variance components and the intraclass correlation coefficient (ICC). The between-subject variation is larger than the within-subject variation. The contribution of the factor session to the within-subject variance is smaller than that of the interaction component, i.e. interaction between subject and session. The ICC ranges from 0.69 to 0.92.

Table II. Test-retest reliability results by muscle groups and gender: the estimated variance components and the intraclass correlation coefficient (ICC), determined with logarithmic transformed data.

		Between-person (var Su)	Within-person (var Se)	(var Su*Se)	ICC
Abduction	F	0.044	0.0001	0.007	0.86
	M	0.073	0.0001	0.013	0.85
Adduction	F	0.038	0.006	0.011	0.69
	M	0.049	0.0009	0.004	0.91
External rotation	F	0.040	0.002	0.012	0.74
	M	0.055	0.000	0.008	0.87
Internal rotation	F	0.062	0.0003	0.014	0.81
	M	0.072	0.0004	0.006	0.92

Var Su=varSubject, var Se=varSession, var Su*Se=varSubject*Session.
ICC= var Su/(var Su + var Se + var Su*Se)

Table III gives the proportional indexes of the measurement error (percentages). In women, the standard error of measurement (SEM) ranges from 8% to 14% and in men from 7% to 12%. The smallest detectable difference (SDD) in women ranges from 25% (abduction) to 43% (adduction) and in men from 21% (adduction) to 37% (abduction).

Table III. The proportional indexes of measurement error by muscle group and gender.

		SEM (%)	95% CI (%)	SDD (%)
Abduction	F	8	± 17	25
	M	12	± 25	37
Adduction	F	14	± 29	43
	M	7	± 15	21
External rotation	F	13	± 26	39
	M	9	± 19	28
Internal rotation	F	13	± 26	39
	M	8	± 17	25

SEM= standard error of measurement, 95% CI= 95% confidence interval and SDD= smallest detectable difference.

DISCUSSION

Few data are available on the test-rest reliability of isokinetic dynamometry of the shoulder joint. Most studies on isokinetic dynamometry have used a Cybex II®. In the present study a Biodex® was used. Compared with the Cybex II®, the Biodex® dynamometer has more possibilities including a greater range of angular velocities, greater maximal torque and the possibility to measure the active range of motion. Comparison of our data with that of other studies (1, 8-10) showed that the peak torques of external and internal rotation are similar: the range of other studies being respectively 9.5 to 35.3 and 23.1 to 62.4 Nm (1). In our study peak torques of abduction are somewhat higher and of adduction lower than in other studies which report abduction to range from 26.6 to 56.6 and adduction from 31.0 to 108.5 Nm (1). A possible explanation for this difference is that in our study gravity correction was made. As our measurements were done in a sitting position, muscle strength values may differ from those in studies which made no gravity correction.

Test-retest or inter-session reliability is important for the correct interpretation of measurement results in a clinical setting. Good or excellent test-retest reliability means that measurement results of two different sessions (when no differences in muscle strength are expected) are the same. In order to judge development or progression of a disease or effectiveness of a therapy, long-term follow-up of patients is necessary, thus measurements must be reliable between different sessions.

From the ANOVA it is clear that variance components refer to subject, session and the interaction between subject and session. Inter-session or test-retest reliability is not influenced by the variance component subject (i.e. inter-individual differences in muscle strength), but by the variance components session and the interaction of subject and session. Both the variance components session and the interaction between session and subject contribute to the error variance, with a relatively large contribution of the interaction component. Interaction of subject and session implies that some subjects achieved larger moments in the second session, whereas others achieved better results in the first session. In this phenomenon, both learning effects and some demotivation (which can differ between subjects) may coincide.

Although there is a displacement of the glenohumeral joint axis in abduction/adduction movements (5), it can be concluded from this study that this does not influence the reliability. In contrast to the abduction/adduction movement, there is no displacement of the joint axis in the external/internal rotational movement. In the present study there is no difference in reliability between the abduction/adduction and the external/internal rotational movements. In this study one position was used for the measurements, in both movements a sitting position; therefore, it is not possible to determine the influence on the reliability. The used position is practical and the subacromial structures are better protected than with 90° abduction of the shoulder. Furthermore, we found no influence of the angular velocity on the reliability. All measurements were done according to a standardized protocol which is important for reliability. In clinical use, in most cases, different therapists perform the measurements. In the present study the inter-tester reliability was not determined, but there was no difference in reliability between the symmetrical (two examiners) and asymmetrical group (one examiner).

We determined the intraclass correlation coefficient (ICC) for the different muscle groups in both males and females. In the present study the ICC ranged from is 0.69 to 0.92. This implies excellent reliability (16) of the measurements when used in research on groups of patients. The ICC of adduction in women was the lowest. For this muscle group in women the between-subject variance (varSu) is relatively small; which may be a reason for the moderate ICC. Comparison with other studies is not possible. One study (6) determined reliability at group level using regression analysis and Pearson correlation coefficients, which are not comparable with ICCs.

The ICC is a proportional index of reliability in which the error variance is weighted against the between-subject variance. For clinical use a proportional index of reliability is not informative, but rather indices of absolute reliability focusing on the error variance (such as the SEM, 95%-CI and SDD) which can be interpreted for two consecutive measurements in individuals. As said before, data were logarithmically transformed before ANOVA was done (12), for clinical use, however, a non-logarithmic index is necessary. The antilog of the difference between two values on a log scale is a dimension-less ratio. In this study the percentage resulting from the antilog ratio is used, implying that only differences of at least 21% to 43% of the first measurement should be interpreted as a real change in muscle strength.

Thus, we conclude that for isokinetic dynamometry of the shoulder the test-retest reliability of measurement results of individual subjects, expressed as the SDD is less satisfactory than for groups of subjects as was concluded from the ICCs . There are no studies of isokinetic dynamometry of the shoulder to compare with. If we compare the SDDs of the present study with estimated from data on knee flexion and extension of Harding et al.(17) and of Stratford (18) we see higher SDDs in our study. The SDDs of these studies (17,18) ranged from 12% to 16%. In order to improve the reliability in shoulder measurements additional measures can be considered, for example to perform an extra session. By using means over two sessions, the within-subject variance can be divided by two (13), resulting in a SDD ranging from 15% to 29%.

Test-retest reliability of isokinetic dynamometry of the shoulder is better for groups of subjects than for measurements for application in individuals. In individual measurements the SDD, found in this study, can be used. It is questionable whether the SDD is small enough to be sufficiently sensitive to detect clinically relevant change in patients, because no data about this subject are known. This needs further research. Another study could focus on bilateral comparison, i.e. a comparison between affected and non-affected joints can be used. If there is no significant difference between the dominant and non-dominant shoulder in healthy subjects, in patients the non-affected shoulder can be used as a reference.

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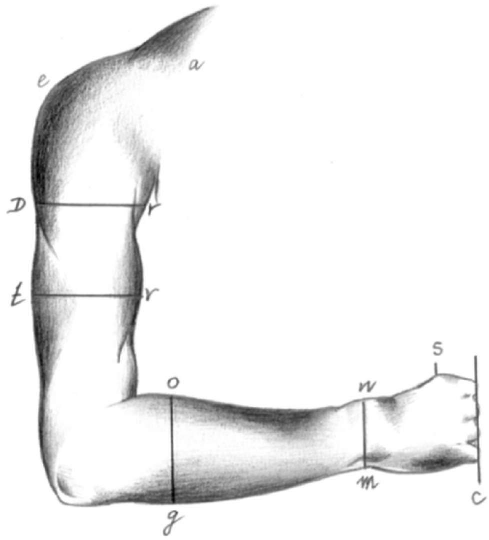
CHAPTER 3

Isokinetic dynamometry of the shoulder: which parameters discriminate between healthy subjects and patients with shoulder disorders?



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ABSTRACT

There is no consensus on the optimal isokinetic dynamometry parameters to clinically assess shoulder disorders. Therefore, this study aimed to establish which parameters are best able to discriminate between shoulder patients and healthy subjects, focusing on peak torques and peak torque ratios.
Isokinetic dynamometric measurements of both shoulders were made in 20 healthy subjects and these data were compared with baseline measurements in 9 patients with shoulder disorders. The different outcome measures were compared by testing for significant group differences between patients and healthy subjects and by scoring how the patient data compared to the normal range of values found in healthy subjects.
Significant differences between patients and healthy subjects were found for the peak torques, but not for the peak torque ratios. In addition, there were significant differences for the dominant/non dominant ratios of the peak torques but not for the dominant/non dominant ratios of the peak torque ratios. The percentage of patients with a standard deviation score outside the 90% normal distribution of healthy subjects was largest (> 78%) for the involved/uninvolved ratio of the peak torques.
It was concluded that bilateral comparison of peak torques is the most appropriate outcome parameter to distinguish patients from healthy subjects.

INTRODUCTION

Rehabilitation medicine, orthopedic surgery and sports medicine are often confronted with disorders of the shoulder joint that are related to a force imbalance of the shoulder muscles. In the shoulder, the static stability provided by the normal configuration of the bony structures and joint capsule is moderate. As a result, shoulder stability during activities largely depends on the dynamic stabilization provided by muscles of the rotator cuff (14). Muscle strength deficits and muscle strength imbalance of the rotator cuff muscles are therefore often thought to be associated with dysfunction and pain of the shoulder (16).

While isokinetic dynamometry is regularly used to quantify muscle strength, there is no consensus on the selection of the outcome variables. In the literature, many parameters have been used to discriminate between normal and abnormal muscle strength. Overall, peak torques and peak torque ratios of the agonist and antagonist muscles are most often used. However, parameters such as angle-based torque, angle of peak torque, average torque, contractional power, contractional work, and contractional impulse have also been reported (4). Several problems have been associated with the use of the above-mentioned parameters for the interpretation of measurement results of the shoulder in clinical practice. For example, for the angular-based variables (such as angle-based torque and angle of peak torque), increased measurement errors are related to the limited reproducibility of the alignment of the dynamometer with the rotational axis of the shoulder (8). Ivey et al. (8) reported large inter-subject variation for the angle of peak torque in measurements of the shoulder joint. Average torque (i.e. the average moment measured over the isokinetic range of motion) has been recommended in testing heavy segments, e.g. the hip joint and trunk (4). For contractional power, contractional work, and contractional impulse, it has been reported that although they are useful mechanical quantities that combine force information with movement velocity or movement time, due to the constant movement trajectory and time in isokinetic measurements only limited extra information can be gained by calculating the latter parameters (12).

Because of the above-mentioned problems associated with the alternative parameters, it might be argued that peak torques and peak torque ratios are most useful for the clinical evaluation of shoulder disorders. When using peak torques in patients to assess shoulder disorders, outcomes can be compared with data from a population of healthy subjects, or with the uninvolved shoulder in the same patient. However, one of the problems associated with comparing peak torques with healthy subject data is the relatively large range of normal values in healthy subjects. Therefore, comparing peak torque in the involved shoulder with the uninvolved shoulder of the same patient may better discriminate between patients and healthy subjects, assuming that healthy subjects will have only small differences between peak torques of both shoulders. This seems to be supported by studies reporting no significant difference in peak torques between the dominant and non dominant shoulder in healthy subjects (2,8,11,14) as well as in baseball pitchers (1,17,18). However, all these studies mention a tendency towards a higher peak torque of the dominant shoulder, while other studies reported significant differences between the dominant and non dominant shoulder for internal rotation in pitchers (3,6).

As an alternative to peak torque comparison, peak torque ratios of abduction/adduction as well as external/internal rotation might be used to evaluate muscle strength of a pathological shoulder function. Because the strength of the agonist and antagonist muscles is correlated in healthy subjects, variation in the agonist-antagonist ratios in healthy subjects might be relatively small, suggesting that measuring these variables might be useful to discriminate between patients and healthy subjects.

In the present study, we evaluated four outcome parameters of isokinetic dynamometry for possible use in the clinical evaluation of patients with shoulder disorders, that is: 1) comparing peak torques of the involved shoulder of patients with the dominant shoulder of healthy subjects, 2) comparing peak torque ratios of agonists-antagonists of the involved shoulder in patients with those of the dominant shoulder in healthy subjects, 3) comparing the involved/uninvolved ratio of the patients with equivalent data (dominant/non dominant ratio) of the healthy subjects, and 4) comparing the involved/uninvolved ratio of the peak torque ratios of the patients with equivalent data from healthy subjects. In this study we were primarily interested in establishing which of the outcome parameters had most potential to discriminate between muscle strength in shoulder patients and healthy subjects. Therefore, we tested for possible group differences in all parameters between patients and healthy subjects. In addition, we evaluated to what extent the values of the patients for each outcome parameter differed from the mean of the healthy subjects and had a score outside 90% of the normal distribution of the healthy subjects.

METHODS

Subjects

In 20 healthy subjects and in 9 patients with a unilateral arthritis of the shoulder, isokinetic measurements of both shoulders were done using a dynamometer (Biodex® Multi joint system 2, Biodex Medical Systems, Shirley, New York, USA). Ten of the healthy subjects were active athletes with clear asymmetrical use of their arms (referred to here as the asymmetrical group); the remaining 10 healthy subjects had no clear asymmetrical use of the arms (referred to as the symmetrical group). In both groups 50% of the subjects were male. In the asymmetrical group eight subjects were right-handed and two had no clear dominance; their mean age was 27 (range 22 to 54) years, mean body mass 70 (range 61 to 92) kg, mean height 177 (range 163 to 187) cm. In the symmetrical group eight of the subjects were right handed; their mean age was 32 (range 21 to 57) years, mean body mass 74 (range 62 to 97) kg and mean height 178 (range 152 to 196) cm. Of the 9 patients (six females), eight were right-handed and in seven patients the dominant side was involved (six right-sided and one left-sided). Their mean age was 55 (range 41 to 77) years, mean body mass was 76 (range 69 to 97) kg and mean height was 169 (range 162 to 175) cm. The data used in the present study were baseline measurements of patients who participated in an intervention study; results of that study will be published elsewhere.
All subjects were informed about the study and all gave informed consent.

Test protocol

The measurements were performed according to a standardized protocol (see Appendix). The following muscle groups were measured: abductors, adductors, external and internal rotators of the shoulder. Since previous studies have shown that an extra session improves the test-retest reliability (1,8,11,15), two sessions with a two-week interval were performed. Similar to other studies (1,2,4,16), lower and higher angular velocities were used: 60°/s and 120°/s for abduction/adduction and 60°/s and 180°/s for external/internal rotation. In a pilot study (unpublished data) we found that angular velocities higher than 120°/s in abduction/adduction movement and higher than 180°/s in external/internal rotation generally could not be reached by healthy athletes. Five repetitions were performed at the lower angular velocity and 10 at the higher angular velocity and the maximal peak torque each of these repetitions was determined. The resting period between the series of repetitions was 60 seconds. Both shoulders were measured; the side that was measured first was randomized. Three sub-maximal tests were performed as a warming-up, and no verbal or visual feedback was provided.

Data processing and statistical analysis

For the peak torque, the mean peak torque of the two sessions was computed. From these peak torques, the muscle strength ratios of agonists and antagonists were calculated for each subject and used to calculate group mean and standard deviation. T-tests for independent samples were used to determine differences in the peak torques and in the peak torque ratios between women and men, and between subjects with asymmetrical and symmetrical use of the arms. Paired t-tests were used to determine differences between the dominant and non dominant shoulder for the peak torques and the peak torque ratios. For all statistical analyses a significance level of 0.05 was used.

To what extent a parameter can discriminate between patients and healthy subjects was evaluated using two criteria. The first criterion was whether there was a significant group difference between patients and healthy subjects. For the second criterion, we scored the standard deviation score (SDS) of each patient (13). This SDS was computed as the difference between the score of a patient on a specific parameter and the mean of the healthy subjects, divided by the standard deviation (SD) of the healthy subjects. This SDS shows how many standard deviations the score of a patient differs from the mean of the healthy subjects. From this SDS for each patient, we calculated the mean SDS for all patients. In addition, we scored the percentage of patients in which the SDS was larger than 1.64, which is equivalent to scoring how many patients had a score that was outside 90% normal distribution of scores of healthy subjects.

To compare the different parameters, first, we evaluated the comparison of peak torques and peak torque ratios of the involved shoulder of the patients with the dominant shoulder of the healthy subjects. The dominant shoulder in healthy subjects was chosen because in 78% of the patients, the involved shoulder is also the dominant shoulder. Then, we evaluated for both the peak torques and peak torque ratios to what extent the involved/uninvolved ratio of the patients differed from the dominant/non dominant ratios for the healthy subjects, which we referred to as bilateral comparison.

RESULTS

Peak torques

Table I. Mean peak torques (Nm) and standard deviation (SD) for all healthy subjects and for the subgroups, and results of the statistical analysis comparing the dominant shoulder of the subjects in the different subgroups.

	Healthy subjects (n=20)	F (n=10)	M (n=10)	p-value	Symmetrical (n=10)	Asymmetrical (n=10)	p-value	Dominant (n=20)	Non dominant (n=20)	p-value
Abduction	49.9 (18.3)	37.9 (8.7)	65.1 (16.1)	0.000	51.7 (22.4)	51.3 (15.0)	0.941	50.0 (18.1)	47.6 (18.0)	0.005
Adduction	53.9 (18.7)	39.2 (6.5)	73.6 (14.6)	0.000	54.4 (22.1)	58.4 (19.6)	0.545	55.0 (20.3)	50.7 (16.5)	0.013
Ext. rot.	22.9 (8.15)	17.4 (3.4)	31.0 (5.4)	0.000	23.1 (8.8)	25.3 (7.6)	0.409	24.2 (8.2)	21.6 (8.0)	0.000
Int. rot.	37.4 (15.7)	26.7 (7.8)	52.4 (14.0)	0.000	34.1 (13.4)	45.0 (19.0)	0.042	39.5 (17.2)	35.2 (14.0)	0.000

Ext. rot. = external rotation, int. rot = internal rotation, F = female, M = male.

Peak torques of the shoulder for each muscle group in all healthy subjects are given in Table I. We found significantly different peak torques of the dominant shoulder between males and females for all muscle groups, whereas no significant differences in the dominant shoulder were found between the asymmetrical and symmetrical group except for the internal rotation. In addition, significant differences for all muscle groups were found between the dominant and non dominant shoulder, with a mean dominant/non dominant ratio of 1.1 for all muscle groups (see also Table V). Table II gives data on comparison of peak torques between healthy subjects and patients.

Table II. Mean peak torques (Nm) and standard deviation (SD) of the healthy subjects and patients and results of the statistical analysis (p-value and SDS), % SDS > 1.64 refers to the percentage of patients that have a SDS score > 1.64.

	Healthy subjects (n=20)	Patients (n=9)					
	Mean (SD)	Mean (SD)	Mean difference	95% CI	p-value	SDS	%SDS > 1.64
Abduction	49.9 (18.3)	15.0 (13.3)	34.9	(24.3; 45.6)	0.000	-1.9	67
Adduction	53.9 (18.7)	21.0 (19.3)	32.9	(17.7; 48.1)	0.001	-1.8	67
External rotation	22.9 (8.2)	11.0 (8.1)	11.9	(5.6; 18.3)	0.002	-1.5	56
Internal rotation	37.4 (15.7)	13.6 (13.8)	23.8	(12.9; 34.6)	0.001	-1.5	56

For all muscle groups, the peak torques in the patients were significantly lower than in the healthy subjects. The average SDS scores for the patients ranged from 1.5 to 1.9, while the percentage of patients with an SDS > 1.64 was 67% in abduction and adduction and 56% in external and internal rotation, indicating that 67% and 56% of the patients had values that were outside the 90% normal distribution of scores of the healthy subjects.

Peak torque ratios

Agonist-antagonist peak torque ratios of the healthy subjects of the dominant and non dominant shoulder are given in Table III. No significant differences were found between the gender and symmetry groups.

Table III. Mean muscle strength ratios for both shoulders for all healthy subjects and the subgroups, with the p-value between the subgroups.

Ratio	Side	All healthy subjects (n=20)	Females (n=10)	Males (n=10)	p-value	Symmetrical (n=10)	Asymmetrical (n=10)	p-value
Abd/add	dom	0.93 (0.14)	0.97 (0.15)	0.89 (0.11)	0.05	0.95 (0.12)	0.91 (0.16)	0.30
	non dom	0.95 (0.17)	0.93 (0.19)	0.97 (0.15)	0.57	0.93 (0.20)	0.97 (0.13)	0.51
Ext/int	dom	0.65 (0.14)	0.68 (0.14)	0.62 (0.12)	0.10	0.70 (0.14)	0.60 (0.11)	0.01
	non dom	0.63 (0.10)	0.65 (0.09)	0.61 (0.11)	0.29	0.65 (0.10)	0.61 (0.10)	0.17

Abd/add = abduction/adduction ratio; ext/int = external/internal rotation ratio; dom = dominant; non dom = non dominant.

Table IV gives data on the comparison of peak torque ratios of abduction/adduction and external/internal rotation between the healthy subjects and the patients. The data are based on 8 patients, because one patient had peak torques of 0 Nm and for this reason the peak torque ratios could not be computed. We found no significant differences in peak torque ratios between the two groups. The mean SDS scores were 1.9 for abduction/adduction and 6.0 for external/internal rotation, while in 63% and 50% of the patients, respectively, the SDS was larger than 1.64.

Table IV. Mean peak torque ratios of the healthy subjects and patients and results of the statistical analysis (p-value and SDS), % SDS > 1.64 refers to the percentage of patients that have a SDS score > 1.64.

	Healthy subjects (n=20)	Patients (n=8)					
Ratio	Mean (SD)	Mean (SD)	Mean difference	95% CI	p-value	SDS	% SDS > 1.64
Abd/add	0.93 (0.14)	0.67 (0.46)	0.23	(-0.12; 0.57)	0.16	-1.9	63
Ext/int	0.65 (0.14)	1.50 (1.21)	-0.75	(-1.66; 0.15)	0.09	6.0	50

Bilateral comparison

Table V gives data on the comparison of the mean ratios of the dominant and non dominant shoulder of the healthy subjects with the equivalent in patients, i.e. the ratio of the involved and uninvolved shoulder. Both the peak torques and the peak torque ratios are compared. For the dominant/non dominant ratios of peak torques of all muscle groups we found significant differences between the healthy subjects and patients, whereas for the peak torque ratios no significant differences were found. The SDS scores for the peak torques ranged from 3.4 to 5.7, while the percentage of patients with scores outside 90% scores of the healthy subjects (SDS > 1.64) was 78% or 100%. For the peak torque ratios, both the SDS scores and the percentage of patients with an SDS > 1.64 were smaller compared to the bilateral peak torque comparison.

Table V. Mean dominant/non dominant ratios and standard deviation for the peak torques of the different muscle groups and for both peak torque ratios of all healthy subjects and patients and results of the statistical analysis (p-value and SDS), % SDS > 1.64 refers to the percentage of patients that have a SDS score > 1.64.

	Healthy subjects (n=20)	Patients (n=9)	Mean difference	95% CI	p-value	SDS	% SDS > 1.64
Abduction	1.07 (0.13)	0.33 (0.29)	0.74	(0.52; 0.96)	0.000	-5.7	100
Adduction	1.10 (0.20)	0.42 (0.32)	0.68	(0.43; 0.93)	0.000	-3.4	78
External rotation	1.14 (0.14)	0.53 (0.35)	0.60	(0.33; 0.87)	0.001	-4.4	78
Internal rotation	1.11 (0.14)	0.43 (0.43)	0.67	(0.34; 1.01)	0.002	-4.9	78
	Healthy subjects (n=20)	Patients (n=8)					
Abduction/adduction	1.01 (0.26)	0.75 (0.53)	0.27	(-0.18; 0.71)	0.202	-1.0	25
External/internal rotation	1.04 (0.15)	1.97 (1.26)	-0.93	(-1.99; 0.12)	0.075	4.5	50

DISCUSSION

Design of the study

In a previous study (10) we showed that the test-retest reliability of isokinetic muscle strength measurements of the shoulder was good for comparing groups of subjects; the intraclass correlation coefficients (ICCs) ranged from 0.69 to 0.92 for the different muscle groups. For application of measurements at an individual level the test-retest reliability was less optimal, with the standard error of measurement (SEM) ranging from 7% to 14% of the measured torque values. In the same study, it was shown that an extra session improved the test-retest reliability of the measurement; the ICCs increased to 0.80 to 0.96 and the SEM lowered to 5% to 10% (10). Therefore, in the present study, the mean peak torque of two sessions was used. In addition, in that same study (10), we found that the angular velocity at which measurements were performed was not a significant factor of variance. In contrast to reports on the hamstrings/quadriceps ratio (4), we found no evidence that the agonist/antagonist ratios for the abduction/adduction and for the external/internal rotation in isokinetic dynamometry of the shoulder are speed dependent (1,5,6,8,9). Therefore, for the peak torques and for the muscle strength ratios we combined the measurements of both angular velocities.

It should be noted that only 9 patients were included in the present study. In addition, for the agonist/antagonist ratios, data from one subject could not be used because for this patient the peak torques for all muscle groups were 0 Nm and therefore the ratios could not be computed. Despite the relatively small number of subjects, we found significant differences between patients and healthy subjects for a relatively large number of parameters, suggesting that the population size was sufficient for the purpose of this study. Future studies with a larger group of healthy subjects are needed to further refine the reference data for the healthy control subjects. In addition, measurement of a larger patient group in future studies will be needed to determine which parameters can be used to discriminate between patients with different types of shoulder disorders.

In this study, for clarity, we compared the involved shoulder of patients with the dominant shoulder of healthy subjects. This comparison was chosen because in 7 of the 9 patients the involved shoulder was also the dominant shoulder. Alternatively, in patients where the non dominant shoulder is involved, it is also possible to compare outcomes with reference data of the non dominant shoulder of the healthy subjects. When we analyzed the data from the two patients in which the involved shoulder was the non dominant shoulder, this did not change the conclusion as to whether the measurement results of these patients were outside the 90% normal distribution of scores of the healthy subjects.

Data comparison

In the present study, a significantly higher peak torque was found in the dominant shoulder than in the non dominant shoulder for each muscle group. This finding is in line with studies reporting asymmetry between the dominant and non dominant arm in athletic subjects (3,6) (mostly baseball pitchers), while in contrast with other studies on healthy subjects reporting no difference between both sides (2,8,11,14).

While some studies have reported peak torque ratios of abduction/adduction of 0.50 in healthy subjects (1,8,11), in the present study we found a mean peak torque ratio of 0.94. The different outcome of the present study might be explained by the fact that we used gravity correction on the torque data. In the sitting position used in the present study, the abduction movement is against gravity and, therefore, without gravity correction the abduction torque will be underestimated. In the adduction direction the reverse effect occurs. As a result of the gravity correction, therefore, the peak torque ratio will be higher. Other studies using gravity correction reported peak torque ratios of 0.70 to 0.90 (14,17,18), which is comparable with our results. In one study measuring abduction and adduction horizontally to avoid gravitational effects, a peak torque ratio of 1 was reported (15).

The mean peak torque ratio of external/internal rotation found in our study is comparable to that reported in other studies (i.e., 0.63 to 0.83 (1-4,7,8,11,14,17)). We did not find a difference in the external/internal rotational ratio between the dominant and non dominant shoulder, neither in the symmetrical group nor in the asymmetrical group. In contrast to other studies evaluating baseball pitchers and volleyball players (3,18,19), in our study we measured skilled tennis players. Further study is needed to elucidate this particular aspect.

Comparison of outcome parameters

Table VI. Summary of the main findings from the present study.

	Comparison of involved shoulder of patients with dominant shoulder of healthy subjects			Comparison of dominant/non dominant ratios between patients and healthy subjects		
	Significant group differences	SDS	SDS > 1.64	Significant group differences	SDS	SDS > 1.64
Peak torques						
Abduction	Yes	-1.9	67%	Yes	-5.7	100%
Adduction	Yes	-1.8	67%	Yes	-3.4	78%
External rotation	Yes	-1.5	56%	Yes	-4.4	78%
Internal rotation	Yes	-1.5	56%	Yes	-4.9	78%
Peak torques ratios						
Abduction/adduction	No	-1.9	63%	No	-1.0	25%
External/internal rotation	No	6.0	50%	No	4.5	50%

Table VI summarizes the results of the present study. The parameters were evaluated using the two aforementioned criteria to determine the ability to discriminate between patients and healthy subjects. The first criterion was whether there was a significant group difference between patients and healthy subjects. The second criterion focused on a correct judgment of an individual patient as having pathological shoulder force values as compared to the normal range of values found in healthy subjects, by scoring the standard deviation score (SDS) of each patient (13).

When comparing peak torques of the involved shoulder in patients with the dominant shoulder in healthy subjects, the present study shows that in 56% to

67% of the patients the measured peak torques deviate substantially from the range of values found in healthy subjects. In other words, although on a group level there are significant differences between the healthy subjects and patients for each muscle group, 33% to 44% of the patients can not be distinguished from healthy subjects when the peak torques are evaluated. This indicates that while peak torque comparison might be useful in, for example, intervention studies comparing different groups, these outcome parameters cannot be used to quantify pathological shoulder function in individual patients from the normal range of peak torques.
The same applies for the peak torque ratios of agonist and antagonist muscles. Despite relatively large mean SDS values for the external/internal rotation in the patients, we found no significant difference between both peak torque ratios of healthy subjects and patients, while the percentage of patients (63% for abduction/adduction and 50% for external/internal rotation) with a SDS $>$ 1.64 was relatively low, indicating that these outcome parameters can not be used to distinguish between normal and pathological shoulder function.

An alternative method of assessment may be to compare the involved shoulder with the uninvolved shoulder. This assumes that there is more bilateral symmetry in healthy subjects compared to shoulder patients. Comparison of the data of the patients with those of the healthy subjects showed that for the bilateral comparison of peak torque ratios between agonists and antagonists the group differences were not significant, while the %SDS $>$ 1.64 was relatively small. However, when comparing the involved/uninvolved ratio of the peak torques in patients with the dominant/non dominant ratio in healthy subjects, we found significant differences for all muscle groups. In addition, the percentage of patients with values outside the 90% normal distribution of the healthy subjects ranged from 78% to 100%.

Overall, we conclude that to establish whether the isokinetic dynamometry data from a shoulder patient shows abnormal values compared to healthy subjects, a ratio needs to be calculated between the peak torques of the involved and the uninvolved shoulder. Since this ratio is not always exactly 1 in healthy subjects, the ratio in a patient needs to be compared to the distribution of the same ratio in healthy subjects. In this study, we found that the 90% normal distribution of these ratios in healthy subjects is approximately 0.9 to1.2 (see Table 5), although slightly different for each muscle group. In other words, in clinical applications, we may interpret that abnormal muscle strength is present when the dominant/non dominant ratio of the peak torques is approximately less than 0.9 and greater than 1.2, depending on the muscle group tested. Future studies with a larger group of healthy subjects are needed to further refine the exact 90% normal distribution for each muscle group.

Conclusion

Isokinetic dynamometry can be used to discriminate between patients with shoulder disorders and healthy subjects when selecting the appropriate outcome measure. This study compared several peak torques and peak torque ratios outcome measures and demonstrated that bilateral comparison of peak torques is the most appropriate outcome parameter to distinguish patients from healthy subjects.

APPENDIX

Measurements with the Biodex are done in the following way:

Basic settings:

- measurements are done in a sitting position
- subjects are strapped down with two bands across the chest, one across the pelvis and hips and one across the contralateral leg
- a footrest is used
- gravity correction is used

Settings for the abduction/adduction:

- chair is rotated 45 with the leg of the T-frame
- back of the chair 45
- power head rotated 30 with the back of the chair
- power head is overturned 45
- axis of the dynamometer is placed in the middle of the circle of movement during the abduction and adduction, this is done visually

Settings for the external rotation/internal rotation:

- chair is rotated 90 with the leg of the T-frame
- back of the chair nearly vertical
- power head is parallel with the chair
- power head is overturned 67.5
- axis of the dynamometer is placed in the longitudinal axis of the humerus

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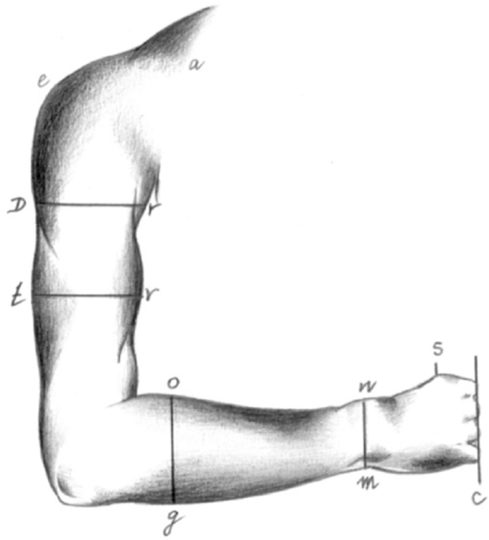
CHAPTER 4

Responsiveness of isokinetic dynamometry parameters, pain and activity level scores to evaluate changes in patients with capsulitis of the shoulder



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ABSTRACT

Objective To determine the responsiveness to change of isokinetic dynamometry of the shoulder and to compare this responsiveness with outcome measures of pain and activity level.

Design In patients with a capsulitis of the shoulder the responsiveness was evaluated as the change in outcome after intra-articular steroid injection. Effect sizes of all outcome measures, quantified as standardized response means, were compared. Relationships between change scores of shoulder function and activities were assessed.

Subjects Ten patients with unilateral capsulitis of the shoulder.

Main outcome measures Muscle strength and active range of motion were measured by isokinetic dynamometry. From these dynamometry measurements, we calculated involved/uninvolved ratios of the maximal peak torques of abduction, adduction, external and internal rotation, active range of motion of abduction and external rotation. In addition, pain was scored using the numeric rating scale (NRS-101) and activity level was scored using the Shoulder Disability Questionnaire.

Results The standardized response mean of all outcome parameters was equal to or greater than 0.8, except for active range of motion of abduction. No significant differences between the standardized response means were found. There is a significant correlation between the change scores of NRS-101 and Shoulder Disability Questionnaire. No significant correlations were found between the change scores of NRS-101 and Shoulder Disability Questionnaire on the one hand, and involved/uninvolved ratios of peak torques and active range of motion on the other.

Conclusions Responsiveness of all outcome measures is good. Parameters of isokinetic dynamometry may provide additional information as compared to the usual outcome measures of pain and functional level

INTRODUCTION

Both clinical practice and research on shoulder disorders is hampered by the limited availability of reliable, valid and responsive outcome measures of shoulder function. Generally, outcome measures in studies on the efficacy of treatment of shoulder disorders include passive range of motion and pain. However, it has been reported that the reliability of measuring passive range of motion by physical examination of the shoulder is low (1,2), while pain is a measurement outcome with limited reliability (3,4), construct validity (4,5) and responsiveness (6).

Because of the problems with these outcome measures of shoulder function, it would be useful to have an additional outcome measure that is objective, valid, sufficiently reliable and responsive. For this, muscle strength and active range of motion measured by an isokinetic dynamometer may be useful. It is known that pain limits active and passive range of motion and (maximal) voluntary muscle strength. Isokinetic dynamometry is appropriate in patients with pain, because they can control the movement and the produced muscle strength. Studies healthy subjects (7), have shown that isokinetic dynamometry of the shoulder is sufficiently reliable in while the validity with respect to specific aspects of muscle performance and for a number of specific dysfunctions is present (8). However, the responsiveness to change of isokinetic dynamometry has not yet been investigated.

Although there is no consensus as to what constitutes a responsive measure or how responsiveness has to be quantified, two major aspects of responsiveness can be distinguished (9). The first aspect is defined as “internal responsiveness”, which characterizes the ability of a measure to change over a specified time frame. One of the methods to assess “internal responsiveness” is using a single group repeated measures design with a known efficacious treatment. The second is defined as “external responsiveness”, which reflects the extent to which changes in a measure over a specified time frame relate to corresponding changes in a reference measure (external standard) of health status. The present study focuses on “internal responsiveness” of different outcome measures of shoulder function.

The aim of the present study is to determine whether outcome parameters of muscle strength and active range of motion could be used to evaluate change in patients with a shoulder disorder. In this study we focus on patients with pain due to a capsulitis of the glenohumeral capsule, treated by means of intra-articular injections. First, we will determine the responsiveness of muscle strength measurements and active range of motion measurements of the shoulder using isokinetic dynamometry, and compare this responsiveness with that of accepted outcome measures, such as pain and functional activities. Secondly, since the relation between change in function (such as pain, range of motion and muscle strength) and functional activities (such as measured with the Shoulder Disability Questionnaire (16)) is not straightforward, we will assess whether parameters of isokinetic dynamometry have additional value to outcome measures of pain and functional activities by evaluating the relationships between changes scores of the outcome parameters.

METHODS

Patients

Ten patients with unilateral capsulitis of the shoulder were included in the study. Capsulitis was characterized by unilateral pain in the C5 dermatome for at least 6 weeks, a limited passive range of motion conforming to a capsular pattern as assessed on physical examination by an experienced examiner (12). Patients were excluded if they had a limited range of the cervical vertebral column, had pain in the contralateral shoulder, neck or ipsilateral elbow, or had a trauma of the shoulder within the last 12 months.

Scheme of treatment and measurements

After the baseline measurement (T1) a first intra-articular injection with Xylocaine 2% 4 ml and Kenacort® A40 1 ml was given; the injection was repeated after 2 and 4 weeks. Twelve weeks after the baseline measurement a follow-up measurement (T2) was performed.

Measurements

Muscle strength was assessed by isokinetic dynamometry of both shoulders using a Biodex dynamometer (Biodex® Multi joint system 2, Biodex Medical Systems, Shirley, New York, USA). Peak torques of the abductors, adductors, external and internal rotators were measured using a standardized protocol published previously (7). In the present study 3 repetitions with low angular velocity and 5 repetitions with high angular velocity were performed. We previously determined that in 70% of the cases healthy subjects reached the maximal peak torque in the first 3 or 5 repetitions (7). Both shoulders were measured, starting with the uninvolved shoulder. Three sub-maximal tests were performed as a warming-up, and no verbal or visual feedback was provided. Outcome parameters of isokinetic dynamometry were the involved/uninvolved ratios of the maximal peak torques and the active range of motion of abduction and external rotation. The muscle strength parameters were selected because they were found to be the most discriminative between healthy subjects and patients in a previous study (17). In the present study we only report on the outcome measures of the low angular velocity. However, we found that measurements with the high angular velocity showed similar results.

Active range of motion was assessed using the Biodex®, assessing abduction and external rotation of the whole shoulder joint. In this study, physical examination of passive range of motion was used for diagnosis and to include the patients, while the isokinetic dynamometry measurement of active range of motion was used as an outcome parameter.

Shoulder pain was scored using the NRS-101. The NRS-101 is a single-item pain scale that asks the patient to rate the pain at that moment from 0 (no pain) to 100 (unbearable pain). The NRS-101 only scores the pain at the moment of measurement, since it is known subjects often overestimate past pain and this effect is greater due to emotional distress factors and in cases of chronic pain (3). The NRS-101 is a very practical index because it is easy to administer and score, it can be administered in verbal and written form and there are sufficient response categories (4).

Patient's activities were measured using the Shoulder Disability Questionnaire (Dutch version) (16). The Shoulder Disability Questionnaire is a pain-related disability questionnaire, evaluating functional activities in patients with shoulder disorders. The Shoulder Disability Questionnaire consists of 16 items with yes-no answer options, where yes indicates that the patient reports to be limited with respect to the particular activity. The recall period was limited to the past 24 hours; when an item was not performed in this period the answer option “non applicable” should be used. The ratio of the affirmative answers to the number of applicable items is multiplied by 100. It has been reported that the responsiveness of the Shoulder Disability Questionnaire, i.e. the ability to detect clinically relevant changes over time, was good in patients with shoulder disorders in primary care (16).

Statistical analysis

Responsiveness was evaluated following the recommendations of Husted et al. (9), focusing on the ability of a measure to change over a specified time frame. To achieve comparability between different outcome measures, negative scores on the NRS-101 and Shoulder Disability Questionnaire were taken as positive in the direction of improvement, which corresponds to less pain, and less functional limitations. The Wilcoxon signed rank test was used to test for significant differences between the follow-up measurement (T2) and the baseline measurement (T1). In addition to significance testing, effect sizes have been widely recommended as indicators of responsiveness (9). In this study, the effect size was quantified as the standardized response mean, calculated as the ratio of observed change (between T2 and T1) and the standard deviation reflecting the variability of the change scores (SD_{change}) (9,18). Interpretation of the magnitude of the standardized response mean was done using Cohen's arbitrary criteria (9,19,20), which are 0.2 = small, 0.5 = moderate and 0.8 = large. Additionally, after estimating the sampling variability of each standardized response mean using the jackknife procedure (21), paired t-tests were done to determine significant differences between the standardized response mean of the different outcome measures.

Relationships between the change scores of the different outcome measures were determined using the Spearman's Rho correlation coefficient (R_S).

RESULTS

Seven of the 10 patients were female, 9 were right-handed and in 8 patients the dominant side was involved (7 right sided and 1 left sided). The mean age of the patients was 52.8 (range 35 to 77) years; mean height was 169 (range 162 to 175) cm; mean body mass was 78 (range 69 to 97) kg. Due to technical problems, the baseline dynamometry measurements of one subject are missing, but the other outcome measures were used in the analysis.
We found significant differences for all outcome measures between baseline (T1) and follow-up measurement (T2), except for the active range of motion of abduction (Table I).

Table I. Mean values with standard deviation (SD) at baseline (T1) and follow-up (T2), mean change (SD) between T2 and T1 with and the standardized response mean of the different outcome parameters.

Outcome parameters	T1	T2	Change T2 - T1	p-value*	SRM
In/uninvolved ratio abduction	0.33 (0.29)	0.64 (0.31)	0.32 (0.23)	0.012	**1.4**
In/uninvolved ratio adduction	0.42 (0.32)	0.71 (0.37)	0.33 (0.36)	0.025	**0.9**
In/uninvolved ratio external rotation	0.54 (0.35)	0.80 (0.17)	0.28 (0.37)	0.051	**0.8**
In/uninvolved ratio internal rotation	0.43 (0.43)	0.80 (0.33)	0.37 (0.38)	0.036	**1.0**
Active ROM abduction	96.3 (52.4)	110.7 (38.1)	14.4 (29.8)	0.114	0.5
Active ROM external rotation	50.7 (24.0)	68.8 (22.8)	18.1 (15.6)	0.006	**1.2**
Pain (NRS-101)	79.5 (21.1)	24.0 (16.6)	56 (26.6)	0.005	**2.1**
Activity (SDQ)	88.9 (10.0)	47.9 (27.2)	41 (25.9)	0.005	**1.6**

* determined using the Wilcoxon signed rank test; SRM = standardized response mean = T2 - T1/SD_{change}; ROM = range of motion; SDQ = Shoulder Disability Questionnaire

Responsiveness, assessed using a standardized response mean (also Table I), was equal to or greater than 0.8 for all outcome measurements except for the active range of motion of abduction. According to Cohen's criteria the standardized response mean of active range of motion of abduction is therefore moderate and all the others are large. The standardized response means of the outcome

measures were not significantly different, except for the standardized response means of NRS-101 versus involved/uninvolved ratio of adduction (p=0.011) and NRS-101 versus active range of motion of abduction (p=0.014).
Table II shows the correlation coefficients between the change scores of the isokinetic dynamometry, pain and activity measures. We found significant correlations between the change in pain (NRS-101) and activity (Shoulder Disability Questionnaire), but no significant correlations between the changes in pain and activity on the one hand, and changes in involved/uninvolved ratios of peak torques and active range of motion scores on the other.

Table II. Correlation coefficients (Spearman's rho) between the change scores of the isokinetic dynamometry and the pain and activity measures. Correlations printed in bold were significant ($p < 0.05$).

	Change in. Pain (NRS-101)	Change in Activity (SDQ)
In/uninvolved ratio abduction	- 0.34	- 0.27
In/uninvolved ratio adduction	- 0.24	- 0.32
In/uninvolved ratio external rotation	- 0.51	0.05
In/uninvolved ratio internal rotation	0.09	0.45
Active ROM abduction	- 0.40	- 0.02
Active ROM external rotation	0.27	0.35
Pain (NRS-101)	-	**0.76**
Activity (SDQ)	**0.76**	-

DISCUSSION

The aim of the study was to determine if isokinetic dynamometry of the shoulder could be used to evaluate improvement or the effects of interventions in patients with shoulder disorders. In this study we focused on responsiveness (9) and on the value of isokinetic dynamometry as an addition to pain and activity level.

We compared the responsiveness to change of the outcome parameters of isokinetic dynamometry to pain and activity level, using a treatment with a known effectiveness on pain and range of motion (11). Responsiveness, as assessed using the effect sizes, was good for all outcome measures except for the active range of motion, which was moderate. For the Shoulder Disability Questionnaire, this finding is in line with Van der Windt et al. (16), who reported that the responsiveness of this outcome measure was good in several categories of patients. However, since Van der Windt et al. determined responsiveness using receiver operating characteristics curves, a direct comparison with our results is not possible. Based on the present results we conclude that the involved/uninvolved ratios of peak torques are sufficiently responsive to evaluate the treatment of a capsulitis of the shoulder.
At first glance, the effect sizes for the NRS-101 and Shoulder Disability Questionnaire were larger than those of the involved/uninvolved ratios of the maximal peak torques and of the active range of motion. However, we found no significant differences between the effect sizes. This finding may be related to the relatively small number of patients in the present study and a larger study would be needed to further differentiate between the responsiveness of the various outcome measures.

This study was conducted in patients with a capsulitis of the shoulder. In these patients pain is one of the most important symptoms, which decreased when the treatment was applied. It should be noted that generalization of the present results to other shoulder disorders, especially those that are not characterized by pain, is not warranted. In addition, it should be noted that the aim of the present study was to evaluate the responsiveness to change of the outcome measures and that due to the small population no conclusions should be drawn about the effectiveness of this treatment.

As we expected, a significant correlation was found between the change scores of pain (NRS-101) and activity level, since the Shoulder Disability Questionnaire (16) is a pain-related disability questionnaire. We found no significant correlations between changes in the outcome parameters of isokinetic

dynamometry and pain or activity level. While the absence of significant relations might partly be related to the small number of subjects, these data do suggest that these relations are at best weak.
From the absence of correlations between change scores in isokinetic dynamometry and pain and activities, it may be suggested that isokinetic dynamometry measures a different aspect of shoulder function than pain and is not linearly related to performance of activities. This is in line with other studies (22, 23) reporting no linear relation between impairment level and activity level in the lower extremity. One explanation might be that the constant angular velocity used in isokinetic dynamometry does not occur in functional movements. Alternatively, there might not be a linear relation between muscle strength and activity level within certain ranges of muscle strength but only a minimal muscle strength requirement for specific activities. As a result, for example, an improvement in muscle strength may still not lead to the minimal force level needed to perform a specific activity (24).

In this study responsiveness to change over time of different outcome measures of shoulder functions were compared. The present results indicate that responsiveness of the evaluated outcome measures in these patients is good, and that parameters of isokinetic dynamometry may provide additional information as compared to the usual outcome measures of pain and activity level.

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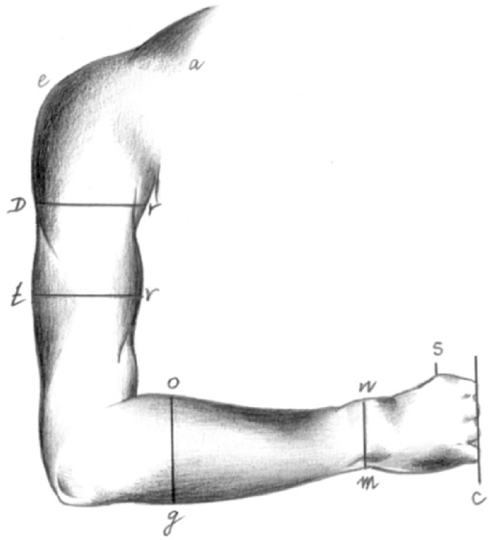
CHAPTER 5

Grip strength parameters and functional activities in young adults with unilateral cerebral palsy compared with healthy subjects



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Resubmitted.

ABSTRACT

Objective To compare maximal grip strength, muscle coordination and muscle endurance in young adults with unilateral CP and healthy subjects and to evaluate relationships with functional activities.

Subjects Eighteen healthy subjects and 26 young adults with unilateral CP recruited from a cohort study in young adults with CP.

Methods Maximal grip strength, a coordinative and endurance task were measured in both hands of all subjects. In 15 healthy subjects test-retest reliability was established. In the young adults with CP, the Melbourne assessment and Abilhand Questionnaire were used to determine functional activities.

Results Maximal grip strength of the involved hand of patients was reduced compared to the uninvolved hand as well as compared to healthy subjects. The coordination task and endurance task did not show a difference between the involved and uninvolved hand. For these tasks, however, a significant reduction in both hands was found compared to healthy subjects. Correlations between grip strength parameters and activity limitations were relatively weak and not linear. For the dominant and non-dominant hand the ICCs for the maximal grip strength were 0.91 and 0.90, for the coordinative task 0.78 and 0.85, and for the endurance task 0.59 and 0.56, respectively.

Conclusion Performance of activity is not directly related to grip strength parameters. The uninvolved hand of young adults with unilateral CP also has an impaired function.

INTRODUCTION

Cerebral palsy (CP) is an umbrella term for multiple aetiologies and clinical manifestations and is often defined as “a persistent disorder of posture and movement caused by a non-progressive pathological lesion of the immature brain” (1-4). Patients with CP can have a wide range of symptoms, including spastic paresis, ataxia, dyskinesia, impaired sensation, cognitive disorders, speech disorders, visual and auditory disturbance, and epilepsy (4,5).

It has been reported that in almost 50% of the patients with CP the arm-hand function is impaired, often resulting in limitations in activities and restrictions in participation (5-7). Many patients have reduced muscle strength due to weakness of agonists or a disturbance of muscle tone such as in spasticity. In addition, muscle coordination is often impaired due to co-contraction of agonists and antagonists, leading to an impaired dexterity.

Grip strength measurement is a well-known method to investigate hand function, providing insight in the combined action of a number of extrinsic and intrinsic muscles. In several patient groups, grip strength measurement with a dynamometer is known to have an excellent reliability (8,9). To establish abnormal grip strength in patients, grip strength is often compared with normative data, but a disadvantage of this method is that normative data have a large standard deviation (10). Studies comparing grip strength between patients with CP and control subjects have reported conflicting results. One study reported decreased maximal grip strength in patients with CP (11), while others reported no differences in static grip force between patients with CP and controls (12,13).
An alternative method to determine whether grip strength in patients is abnormal is to compare the outcome with the contralateral hand (9). However, while in unilateral CP the involved hand can be compared with the uninvolved hand, this may be problematic since it has been suggested that the uninvolved hand may also be impaired (14,15). For example, Gordon et al. have described an impaired coordination of fingertip forces of the uninvolved hand of patients with unilateral CP in comparison with normal subjects (16). Steenbergen et al.

suggested that dexterity of the uninvolved hand is impaired because of a deficit in forward movement planning, especially in left hemispheric lesions (14). Brown et al. found that one-third of patients with unilateral CP had bilateral lesions on a CT scan. In the same study, 50% of the children had unilateral lesions with bilateral impairment (15). Brown suggested that bilateral impairment might result from unilateral lesions since 10-30% of the lateral corticospinal tract consists of uncrossed fibres (17).

While assessment of maximal grip strength can provide valuable insight into the maximal strength of the muscle groups involved, this is not the only important aspect of muscle function. For example, muscle coordination and muscle endurance may not be reflected in a maximal voluntary contraction, while they may be similarly important in the performance of skilled manual tasks in daily activities. It is known that patients with CP have deficits in motor control, mainly due to involuntary co-activation of the antagonistic muscles (13). Several studies (12,13) reported an impaired force coordination of fingertip forces, resulting in a prolonged and uncoordinated release of a grasped object. In these studies, a strong correlation was found between the impaired force coordination pattern and the level of dexterity.

Thus, to evaluate hand muscle function in relation to manual activities, it might be useful to assess not only maximal grip strength, but also other aspects of muscle function, such as muscle coordination and muscle endurance. Both are complex phenomena that may be difficult to assess in a simple task. In the literature, several tasks have been defined to assess aspects of muscle coordination and endurance. For example, a simple task assessing sensorimotor control of the hand muscles was proposed by Kurrilo et al. (18). In this task, subjects had to perform a tracking task in which periodic muscle activation was needed to match a sinus-shaped line on a computer screen by adjusting the grip strength on a dynamometer. A simple task used to assess muscle endurance of the hand muscles is the sustained voluntary contraction. This task has been reported in several patient groups, including patients with multiple sclerosis. Schwid et al. performed a 30-seconds sustained maximal grip task in patients with multiple sclerosis and concluded that the fatigue index estimated as the area under the curve (AUC) was reliable and discriminative between patients and healthy subjects (19).

Grip strength parameters are often used to determine whether the hand function is impaired, which may cause limitations in functional activities. However, there is no consensus about the relation between grip strength and functional activities. In patients with early rheumatoid arthritis, grip strength was an accurate indicator for upper limb ability (20). Other studies, performed in patients with peripheral nerve injuries, reported that besides grip strength, other functions such as sensory disturbance also had a relation with functional activities (21,22). Within rehabilitation medicine, insight into relationships between the International Classification of Functioning, Disability and Health (ICF) levels body function and functional activities is relevant for a better understanding of the impact of impairments, and for a useful evaluation of the effectiveness of rehabilitation treatment (23). The ICF model does not assume a direct causal relation between the seriousness and kind of impaired functions and limitations in functional activities. The domains of body function, functional activities and participation are also influenced by personal characteristics of an individual, as well as the environmental context that represents a person's physical and social circumstances.

The aim of the present study is to assess which grip strength parameters (i.e. maximal grip strength, muscle coordination and muscle endurance) are able to differentiate between the involved and the uninvolved hand in young adults with unilateral CP. Since the uninvolved hand of unilateral CP patients may also have an impaired function, we compare these data with healthy subjects. Furthermore, we evaluate the relationships between the different grip strength parameters and performance of functional activities.

METHODS

Subjects

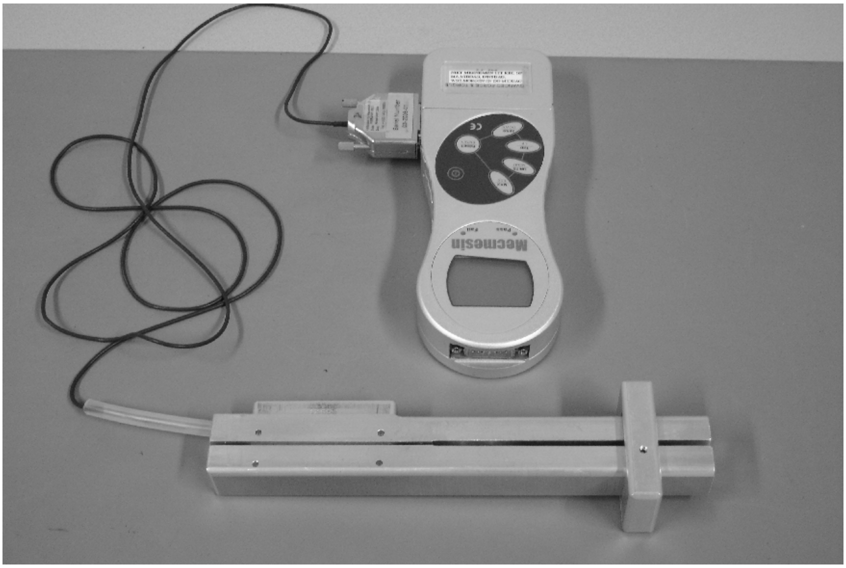
Twenty-six young adults with unilateral CP and 18 healthy subjects were included in the study. The young adults with CP were recruited from the CP Transition study in the South West Netherlands, a prospective cohort study (24). This cohort was recruited from eight participating rehabilitation centres and rehabilitation departments in the region. Young adults in this cohort study were diagnosed with CP, and born in the years 1982-1986. Exclusion criteria were severe learning disabilities (IQ below 70), additional diagnosis with lasting effects on motor functioning, and insufficient knowledge of the Dutch language. From this cohort, we randomly selected 26 young adults with a unilateral spastic paresis, aged between 20 and 24 years, for the present study (25). The healthy subjects were recruited from students, employees of the rehabilitation department and friends, aged between 17 and 37 years. The Medical Ethics Committee of Erasmus MC Rotterdam approved for the study. All subjects gave their informed consent.

Measurements

The following characteristics were recorded: gender, age, body mass and height. In the patients we also recorded the Gross Motor Classification System (GMFCS) level (26) and the Manual Ability Classification System (MACS) level (27). The GMFCS and the MACS are 5-level classification systems for gross motor functioning and manual ability, respectively.

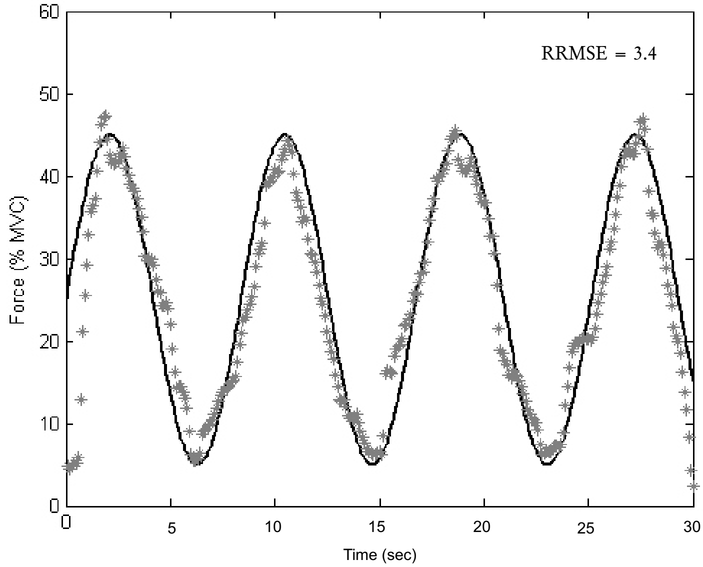
For the different tasks, a Mecmesin AFTI force gauge with the Lode handgrip dynamometer (handle position 2), similar to the Jamar hand dynamometer, and with 4.6 cm distance between the handles, was used. The measurement system was connected to a computer for data acquisition and real-time visual feedback. The force applied to the grip-measuring device was sampled with a frequency of 10 Hz.

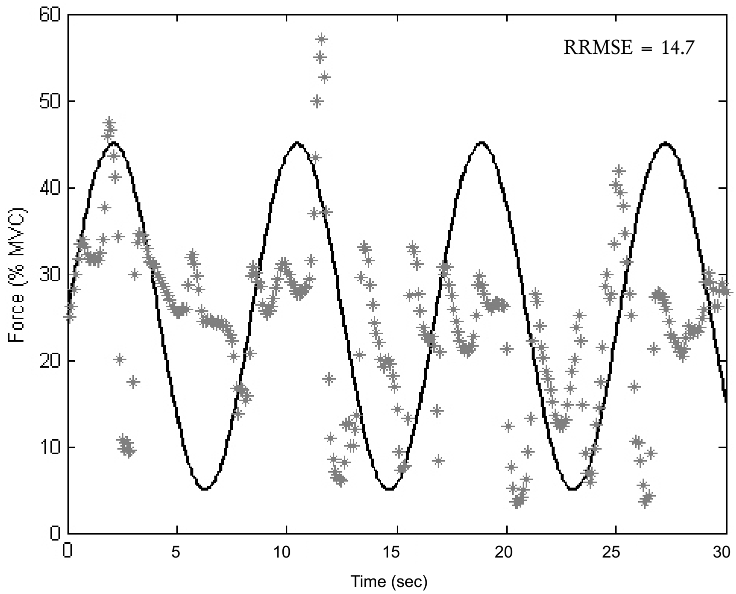
The subject was seated on a chair with both feet placed flat on the floor with the ankles, knees and hips 90° flexed. The upper arm was adducted, the elbow was 90° flexed and the forearm was in neutral position without support, as recommended by the American Society of Hand Therapists (28). Both hands were tested and each task was first performed with the dominant or uninvolved hand. The dominant hand was defined as the hand subjects use to write. During all tasks, the same researcher (RvR) verbally encouraged the subjects.



The first task was maximal grip strength, determined as the average of three maximal voluntary isometric contractions (MVC) (29). The maximal grip strength measurements were alternated between both hands. No visual feedback was given.
Secondly, a 30-seconds dynamic grip-force tracking (coordination) task was performed. In this task, a target signal was presented on the computer screen as a sinus-shaped line ranging between 5% and 45% of the measured MVC. The cycle duration of the sinus was 8.3 seconds. The goal of the task was to track the presented target as accurately as possible by applying the appropriate grip strength, presented as dots on the screen (see Figure 1). The tracking task was programmed in Matlab (The Mathworks, Inc., Natick, USA). No repetitions were performed.

Figure 1. Example of the coordinative task: the sinusoid line is the target signal presented on the computer screen and the dots represent the performance of the subject. Figure A shows the performance of a healthy subject and Figure B that of a CP patient.





Thirdly, the subjects performed once the sustained grip strength (endurance) task for both hands. This task contained a maximal isometric contraction over a period of 20 seconds. The contraction was started by hearing a sound signal and ended by a sign of the researcher. The grip strength was continually recorded, but no visual feedback was provided during performing the task.

For the coordination task, no reliability data have been reported. Therefore, test-retest reliability of this task was established in 15 healthy subjects, as well as for the other grip strength tasks. Data were analysed using the intraclass correlation coefficient (ICC) as estimated from a two-way mixed effects model. We found ICCs for the maximal grip strength of 0.91 and 0.90 (dominant and non-dominant hand), for the coordinative task 0.78 and 0.85, and for the endurance task 0.59 and 0.56.

In the young adults with CP, functional activities were measured using a functional test, the modified Melbourne assessment, and a questionnaire, the Abilhand Questionnaire. The Melbourne assessment is a simple, reliable and easy-to-administer test of a child's unilateral upper-limb motor function that provides general information about levels of ability and disability (30). In this study, we used four items of the Melbourne assessment, concerning fine motor hand functions as grasping, manipulation and dexterity. These items were performed with both the right and left hand.

The Abilhand Questionnaire is a questionnaire on manual activities, rating the patient's perceived difficulty in performing everyday manual activities (31). An explorative Rasch analysis on data collected in the CP Transition study cohort confirmed the unidimensionality of the scale, but not the item hierarchy found in chronic stroke patients (31). Therefore, in the present study we used the raw sum score of the Abilhand Questionnaire.

Data analysis

Statistical comparison of the grip strength parameters between both hands of patients and healthy subjects was done using the paired t-test. To test differences between the groups, the independent-samples t-test was used.

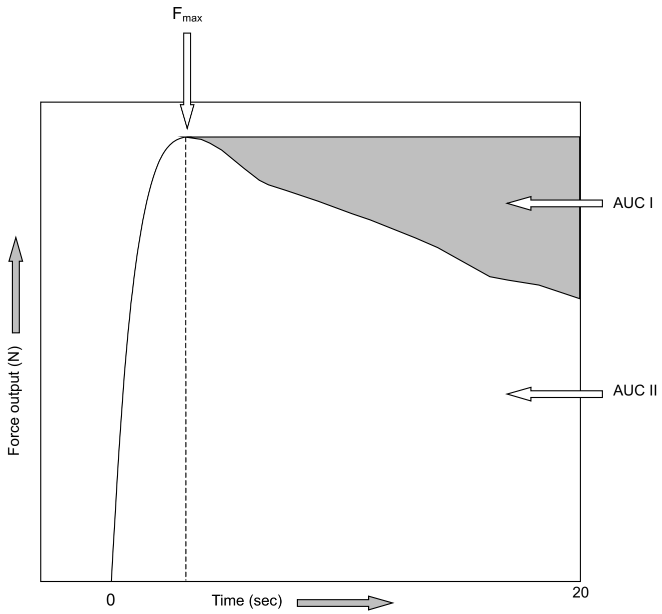
The performance on the coordinative task was assessed by calculating the relative root mean square error (RRMSE) between the target (F_T) and the

$$\text{RRMSE} = 100\% * \sqrt{\frac{1}{200}\sum_{n=100}^{n=300}\left(\frac{F_T - F_M}{MVC}\right)^2}$$

The endurance during the sustained grip strength measurement was quantified by a static fatigue index (SFI) (19). The SFI was calculated from the force-time graph, as the ratio of the AUC of the sustained contraction (AUC I, see Figure 2) through the hypothetical AUC when no force decline would occur (AUC I + AUC II). Both AUC I and AUC II were calculated from the moment of maximal grip strength until the end of the 20-seconds task. A higher SFI corresponds to more force decline, thus less endurance.

$$SFI = 100\% * \left(1 - \left(\frac{AUCI}{AUCI + AUCII}\right)\right)$$

Figure 2. A typical example of the curve of the 20-seconds endurance task. F_{max} is the maximal grip strength that was reached, AUC I is the area under the curve of the sustained contraction from the time of reaching F_{max}. The sum of AUC I + AUC II is the hypothetical area under the curve when no force decline would occur. SFI = 100% * (1-(AUC II/(AUC I + II))).



Relations between the grip strength parameters and measures of functional activities were investigated using correlation coefficients (Spearman's rho). We considered a p-value of 0.05 or less as statistically significant.

RESULTS

There was a significant difference in age between the young adults with CP and healthy subjects (Table I). Ten of the 26 patients and 7 of the 18 healthy subjects were female. All young adults with unilateral CP were classified as GMFCS level I. For the MACS 23 were classified in level I, 2 in level II and 1 in level III. Data from one young adult with CP could not be used due to technical problems with muscle strength recording.

Table I. Characteristics of CP patients and healthy subjects (mean values and standard deviations).

	CP patients (N=26)	Healthy subjects (N=18)	Significance
Age (years)	20.6 (1.2)	23.9 (5.5)	$p < 0.05$
Body mass (kg)	66.2 (8.3)	71.1 (12.1)	NS
Height (cm)	174.9 (8.7)	177.4 (9.2)	NS

Figures 3, 4 and 5 show the mean values, standard deviation and p-values of the grip strength tasks. In the young adults with CP, maximal grip strength of the involved hand was approximately 50% ($p<0.001$) of the uninvolved hand. No significant differences were found for the coordinative and endurance task between the involved and uninvolved hand in young adults with CP. In the healthy subjects, the maximal grip strength of the non-dominant hand was 82% ($p<0.002$) of the dominant hand. The coordinative task showed a small significant difference between both hands ($p<0.002$). No significant difference was found for the endurance task between both hands.

Figure 3. Mean values and standard deviation of the maximal grip strength (MVC) of CP patients and healthy subjects for the uninvolved or dominant hand (D) and for the involved or non-dominant hand (ND). The p-values of the paired t-test (between both hands) and the independent sample t-test (between both groups) are presented.

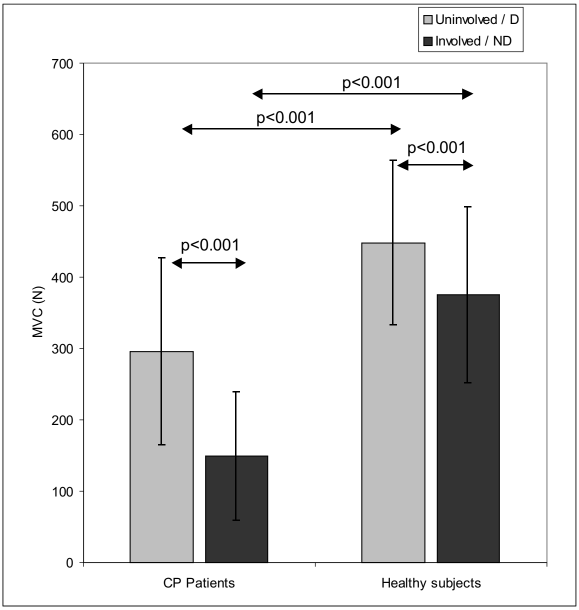


Figure 4. Mean values and standard deviation of the coordinative task (RRMSE) of CP patients and healthy subjects for the uninvolved or dominant hand (D) and for the involved or non-dominant hand (ND). The p-values of the paired t-test (between both hands) and the independent sample t-test (between both groups) are presented.

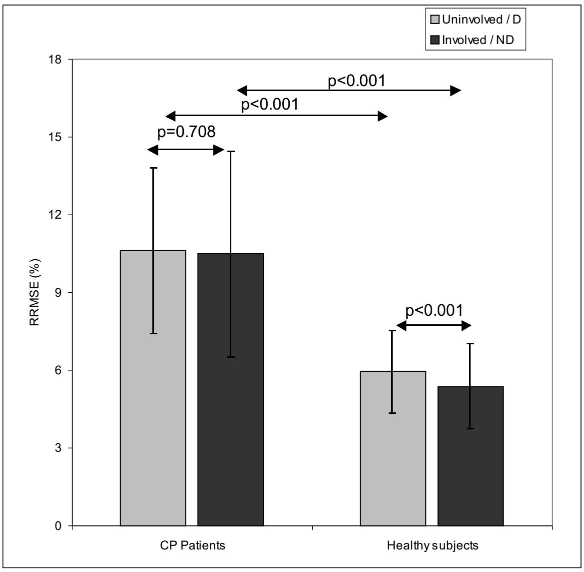
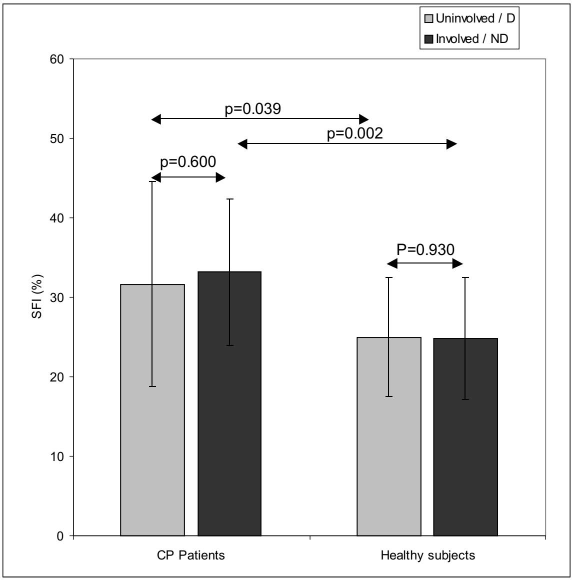


Figure 5. Mean values and standard deviation of the endurance task (SFI) of CP patients and healthy subjects for the uninvolved or dominant hand (D) and for the involved or non-dominant hand (ND). The p-values of the paired t-test (between both hands) and the independent sample t-test (between both groups) are presented.



Comparison of the uninvolved hand of the young adults with CP and the dominant hand of healthy subjects showed significant differences for the maximal grip strength ($p < 0.000$), the coordinative ($p < 0.000$) and the endurance task ($p = 0.04$). Similarly, all three tasks showed a significant difference between the involved side of the young adults with CP and the non-dominant hand of the healthy subjects.

Table II shows the correlation coefficients of the grip strength parameters (maximal grip strength, coordinative task and endurance task) and assessments of functional activities (modified Melbourne assessment and Abilhand Questionnaire). No significant correlations were found between the three grip strength parameters. A significant correlation was found between the Melbourne assessment and the Abilhand Questionnaire. We found significant correlations between the grip strength parameters and the measures of functional activities. The strongest relations were found between the maximal grip strength and the Melbourne assessment (0.64, $p = 0.001$) and the Abilhand Questionnaire (0.45, $p = 0.03$). The p-value (0.06) of the correlation between the coordinative task and the Abilhand Questionnaire just exceeded the significance level.

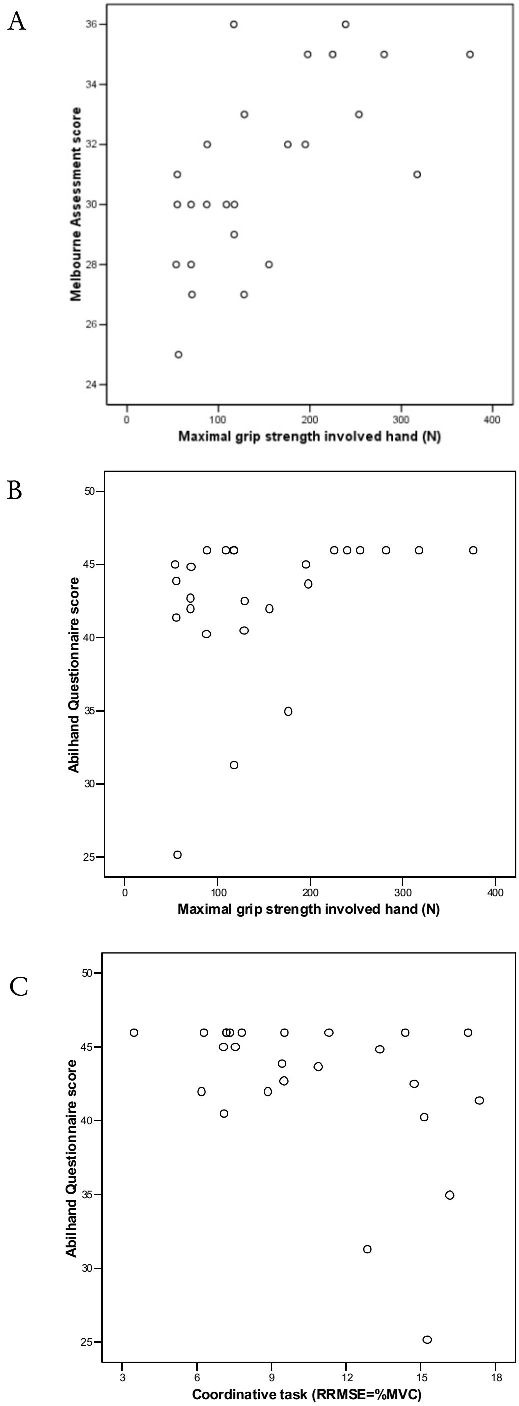
Table II. Correlation coefficients (Spearman's rho) between the grip strength parameters and measures of functional activities. The grip strength parameters are maximal grip strength (MVC), a coordinative task (RRMSE) and an endurance task (SFI).

	MVC	RRMSE	SFI	Melbourne assessment	Abilhand Questionnaire
Maximal grip strength (MVC)	-	- 0.31	0.12	**0.64**	**0.45**
Coordinative task (RRMSE)		-	0.01	- 0.11	- 0.39
Endurance task (SFI)			-	0.23	0.30
Melbourne assessment				-	**0.55**
Abilhand Questionnaire					-

Printed in bold = statistically significant; MVC = maximal voluntary contraction; RRMSE = relative root mean square error; SFI = static fatigue index.

The scatter plots (Figure 6 A-C) show a non-linear relation between the maximal grip strength and the scores of the Melbourne assessment and Abilhand Questionnaire, and between the coordinative task and the score of the Abilhand Questionnaire. Young adults with CP with a high maximal grip strength or good outcome on the coordinative task performed well on functional activities. However, while some young adults with CP with low maximal grip strength or a lower coordinative function also had low scores on functional activities, other young adults with CP performed functional activities equally well as young adults with CP with high maximal grip strength and a good result of the coordinative task.

Figure 6. Scatter plots of the maximal grip strength and the score of the Melbourne assessment (A) and the score of the Abilhand Questionnaire (B) and the coordinative task and the score of the Abilhand Questionnaire (C) of the CP patients.



DISCUSSION

In this study we compared three grip strength parameters (maximal grip strength, muscle coordination and muscle endurance) in young adults with unilateral CP and healthy subjects. In young adults with unilateral CP, we found that the maximal grip strength of the involved hand was reduced compared to the uninvolved hand as well as compared to healthy subjects. For the coordination task and the endurance task, we found no difference between the involved and uninvolved hand. However, for both these tasks, significant reductions in both hands were found compared to healthy subjects. Correlations between the three grip strength parameters and limitations in functional activities were relatively weak and were not linear.

A number of limitations of the present study should be noted. Although we included young adults with CP and healthy subjects from the same age group, the healthy subjects were on average three years older. Within the range of ages studied, this effect should be relatively small, since it is generally assumed that muscle strength does not significantly decrease until about 55 years of age (29,33). For the coordinative and endurance task, the effect of age is not known, but there is no reason to assume this would be different within this relatively small age range.

The sample frequency of the grip-measuring device was limited to 10 Hz. As a result, high-frequency fluctuations in muscle strength may not have been recorded using this device. While the sample frequency might be relatively low to detect small differences in the coordination task, the differences between patients and healthy subjects in the coordination task were so large that this cannot be explained by the relatively low sample frequency.

Although the coordinative task used in this study has been described in patients with neuromuscular diseases (18), the test-retest reliability of this task had not yet been studied. Therefore, we evaluated the test-retest reliability of this task as well as of the other grip strength tasks in 15 healthy subjects. We found excellent ICC values for the maximal grip strength and coordinative task, while the ICC of the endurance task was moderate (34). The ICC for the maximal grip strength is comparable to studies on other patient groups (9,35,36). In addition, the moderate ICC for the endurance task is also in line with other studies (19,37). We assumed that the test-retest reliability in young adults with CP would be comparable with healthy subjects; we did not determine test-retest reliability in the present patient group because we considered this as too large a burden. Future studies should indicate the reliability of the coordinative task in different patient groups.

While in clinical practice maximal grip strength is used to assess hand muscle function in patients, in the present study we also evaluated two other grip strength tasks that we referred to as a 'muscle coordination' and a 'muscle endurance' task. It should be noted, however, that both muscle coordination and fatigue are complex phenomena that may not be optimally evaluated in a simple and easy to administer task. The goal of this study was to evaluate if the outcome on these tasks differed between the involved and uninvolved hand in young adults with unilateral CP, and between young adults with unilateral CP and healthy subjects. In addition, we evaluated how these tasks relate to limitations in functional activities. We found that both tasks were easy to administer and were able to discriminate between young adults with unilateral CP and healthy subjects. Scores on the coordination and endurance tasks did not correlate more strongly with functional activities than maximal grip strength.

Comparing the grip strength parameters between both hands in young adults with unilateral CP and healthy subjects, we found that both the involved and uninvolved hand scored significantly lower compared to the healthy subjects. This was consistently found in the maximal grip strength, the coordination task and the endurance task. Overall, these data suggest that the uninvolved hand of young adults with unilateral CP may not have a normal muscle function compared to healthy subjects.
A reduced function of the uninvolved hand is in line with other studies reporting an impaired function of the uninvolved hand of young adults with unilateral CP with respect to control of force (13-16). The underlying

mechanism of a bilateral impaired function has not yet been established. A possible explanation might be that muscle coordination of both sides is impaired due to bilateral instead of unilateral lesions. In the present study, young adults with CP were clinically assessed as unilateral CP without scans of the cerebrum. Therefore, it is not certain whether these patients have only a unilateral lesion. On the other hand, it is known that even in patients who have unilateral lesions on a scan, bilateral impairment can be found (15).

The finding that the uninvolved hand of young adults with unilateral CP might also have an impaired function compared to healthy subjects can have important implications for the limitations in functional activities. Although the young adults with CP in the present study had a high MACS level, indicating that they handle objects relatively easily and successfully, the young adults with CP did have limitations in activities based on the Melbourne assessment and the Abilhand Questionnaire scores. In both assessments, bimanual activities were scored; the adapted Melbourne assessment was performed for both hands and the Abilhand Questionnaire is a list of 23 bimanual items. While it is generally assumed that persons with unilateral CP patients are able to perform normally with the uninvolved hand, the present study indicates that this hand may also be involved. As a result, limitations in bimanual activity may not only result from impaired function of the involved hand, but also from impairment of the uninvolved hand.

To what extent impaired hand function has a relation with functional activities had not yet been investigated in these patients. In this study, moderate correlations between the grip strength parameters and functional activities were found. Functional activities were most strongly correlated with maximal grip strength, while the p-value of the correlation between the coordinative task and the Abilhand Questionnaire just exceeded the significance threshold. Inspection of the scatter plots (Figure 6 A-B) indicated that the relation between the strength parameters and functional activities was not linear. More specifically, it was found that young adults with unilateral CP with a high score on the grip strength parameters also had high scores on functional activities, while young adults with unilateral CP with relative low scores on the grip strength parameters showed a large variation on functional activity scores. This non-linear relation indicates that limitations in functional activities cannot be estimated directly from maximal grip strength.

The finding that young adults, clinically assessed as unilateral CP, may also have impaired function of the uninvolved hand suggests that more research is needed to understand the underlying reasons for the impaired function of the hand that is considered to be uninvolved. For example, improved brain imaging techniques might increase the sensitivity of detecting cerebral pathology and determine more accurately whether lesions in patients with CP are unilateral or bilateral. Bilateral involvement in patients diagnosed as having unilateral CP may have important implications for treatment. At present, little is known about the efficacy of treatment of hand function. Today, treatment such as physical therapy to improve function mainly focuses on the involved side. It would be interesting to investigate in a randomized trial if the efficacy of a hand function training protocol, focusing on both sides as compared to focusing primarily on the involved side, would result in improved function of both hands and maybe in fewer limitations in activities.

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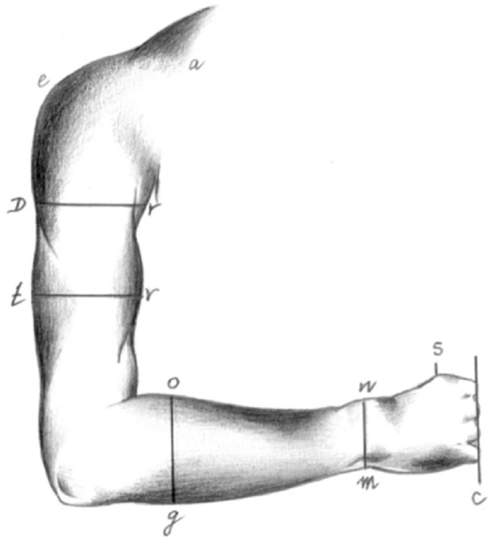
CHAPTER 6

Functional activities of the upper extremity of young adults with cerebral palsy: a limiting factor for participation?



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ABSTRACT

Purpose To assess functional activities of the upper extremity of young adults with cerebral palsy (CP) and to determine relationships with participant characteristics and with participation.

Method In 103 participants (aged 16-20 years) assessment of functional activities of the upper extremity was performed with the Melbourne assessment and the Abilhand Questionnaire; participation was measured with the Life Habits Questionnaire. Recorded participant characteristics were age, gender, limb distribution of the spastic paresis, educational level and gross and fine motor function. Relationships were studied by means of correlation coefficients and linear regression analysis.

Results Limitations in functional activities of the upper extremity were present in the different sub-groups, based on the limb distribution of the spastic paresis, especially in quadriplegic participants. Significant correlations between participant characteristics and measures of functional activities were present. Limitations in functional activities of the upper extremity, measured with the Abilhand Questionnaire, were an important determinant for participation, in addition to the gross motor function and educational level.

Conclusion Limitations in functional activities of the upper extremity are an important determinant for restrictions in participation in young adults with CP. It is recommended to include assessment of functional activities of the upper extremity in patients with CP.

INTRODUCTION

Cerebral palsy (CP) is a disorder developed in early childhood with a lesion that is non-progressive. The impaired functions, such as spastic paresis, joint contractures, sensory disturbances, cognitive impairments, visual and auditory problems and epilepsy (1,2) persist into adulthood and may even deteriorate at later age (3). A large number of adult patients present both medical and social problems (1,4-6); reported problems in participation predominantly address employment and participation in community, social and civic life (7,8). Østensjø (9) found that the Gross Motor Function Classification System (GMFCS) (10) was the strongest predictor for mobility, self-care and social function of children with CP, with age and learning disabilities as significant contributing factors. Comparably, for young adults with CP Donkervoort (7) reported that restrictions in daily activities and participation were largely attributable to impaired gross motor functioning, a lower educational level and younger age. To what extent specific limitations in functional activities of the upper extremity contribute to restrictions in participation is not known.

In patients with CP arm-hand function received scant attention compared with gross motor function, although it is reported that in nearly 50% of the CP patients the arm-hand function is impaired (11,12). Based on clinical experience, we assume that arm-hand function, in addition to gross motor function, might be a limiting factor for functional activities and participation. In several studies it was found that hemiplegic children hardly ever use their involved arm and hand spontaneous in play and activities of daily life (11,13). Furthermore, in early adolescence spontaneous use of their involved hand in bilateral manipulation had not changed since childhood, even when there was improvement in grip function (11). From this finding we may conclude that limitations in functional activities of the upper extremity might be an important characteristic to include in a comprehensive assessment of functioning of patients with CP.

During childhood, CP patients receive intensive and structured rehabilitation treatment aiming to improve the function and functional activities of the patient, with the ultimate goal to optimize participation. Nevertheless, the effectiveness of these treatments and the long-term consequences for functioning in adulthood are not known. Within rehabilitation medicine knowledge on participation and its major determinants is essential not only to understand the impacts of a chronic disorder, but also to evaluate the effectiveness of rehabilitation treatment (14).

Firstly, the present study aimed to get insight in functional activities of the upper extremity of young adults with CP. To assess functional activities of the upper extremity we used different instruments that were available either for children or for adults, because age-specific instruments for young adults are not available. Second aim of the study was to assess the relations between functional activities of the upper extremity and participant characteristics, such as gross and fine motor function, limb distribution of the spastic paresis and educational level and, subsequently, between limitations in functional activities of the upper extremity and restrictions in participation.

METHODS

In this study 103 young adults with CP (aged 16-20 years) were assessed with respect to functional activities of the upper extremity and participation. These young adults participated in the CP Transition study in the South West Netherlands, a prospective cohort study into the course and determinants of functioning of young adults with CP. Every two years measurements are performed. The participants were recruited from eight participating rehabilitation centres and rehabilitation departments in the region. Inclusion criteria at the start of the study were diagnosis of CP, and born in the years 1982-1986. CP is defined as a persistent disorder of posture or movement, caused by a non-progressive pathological disorder of the developing brain (15,16). Exclusion criteria were severe learning disabilities (IQ below 70), additional diagnosis with lasting effects on motor functioning, and insufficient knowledge of the Dutch language. The response rate was 56%. The responders did not differ from the non-responders with respect to gender, age, type of CP and limb distribution of the spastic paresis (7).

We used two measures of functional activities of the upper extremity. Firstly, at baseline we performed the Melbourne assessment for the least affected arm (17). Secondly, the raw sum scores of the Abilhand Questionnaire (18) of 83 participants were collected, using data of the 2-years follow-up measurements. At this time, 16% of the participants have been lost to follow-up; loss to follow-up was not selective with respect to age, gender, gross motor function, limb distribution of the spastic paresis and educational level. At baseline, participation was measured with the Life-Habits Questionnaire (19,20). Participants received verbal and written information about the study and filled in a written informed consent. The Medical Ethics Committee of Erasmus MC Rotterdam approved this study.

Measurements

Characteristics of the participants

At baseline the following characteristics were recorded: age, gender, limb distribution of spastic paresis, educational level and GMFCS level. In the 2-years follow-up measurement the Manual Ability Classification System (MACS) (21,22) was recorded. We included this characteristic in the present study, because we assumed that manual ability had not changed since baseline measurements. Limb distribution of spastic paresis was subdivided into diplegia, hemiplegia and quadriplegia (23). Educational level was divided into 3 levels; low is pre-vocational practical education or lower, moderate is pre-vocational theoretical education and upper secondary vocational education, and high is secondary general education, higher educational institutes and university (7).

Melbourne assessment

The Melbourne assessment is a simple, easy-to-administer test of a patient's unilateral upper-limb motor function. It provides general information about levels of ability and disability and, by measuring change, can evaluate the effectiveness of various treatments or interventions (17). The assessment is developed for children aged 5 to 15 years and consists of 16 items addressing 37 item-scores (24). The items address for example range of movement, target accuracy, fluency of movement or accuracy of release. Each component is scored on a 3, 4 or 5-point scale. The total score is the sum of all item-scores, converted to a percentage score (0-100). The Melbourne assessment is a reliable tool for measuring the quality of unilateral upper-limb function (17), but has not been standardized in children with hemiplegic CP (11). We assessed the least affected arm with the Melbourne assessment, since we assumed that functioning of this arm is most critical for functional activities of the upper extremity and participation.

Abilhand Questionnaire

The Abilhand Questionnaire is a questionnaire on functional activities of the upper extremity. The Abilhand Questionnaire measures the patient's perceived difficulty in performing everyday bimanual activities, such as cutting nails, opening a zipper, wrapping up presents and skinning potatoes (18). It has been studied in patients with rheumatoid arthritis with wrist arthrodesis and in chronic stroke patients (18,25). Rasch analysis in chronic stroke patients led to a hierarchical list of 23 bimanual items, 3-level scaled (18). For children with CP a different questionnaire, i.e. Abilhand-Kids, has been developed (12). The Abilhand-Kids is intended for children with a mean age of 10 years. We used in the present study the Abilhand for chronic stroke patients, because we assumed that young adults with CP were comparable to this patient group (12,18). An explorative Rasch analysis on own data, collected in the CP Transition study cohort confirmed the unidimensionality of the scale, but not the item hierarchy found in chronic stroke patients. Therefore, in the present study we used the raw sum score of the Abilhand Questionnaire, with a maximum score of 46.

Life-Habits Questionnaire (Life-H)

The Life-H was designed to assess the handicap situations observed in daily life of individuals with disabilities (19). Life habits were defined as “daily activities and social roles that ensure the survival and development of a person in society throughout his or her life” (20). The questionnaire assesses the difficulty and the need of assistance with activities and determines satisfaction. The Life-H produces a mean continuous score ranging from 0 to 9, by combining sub-scores addressing the degree of difficulty and type of assistance; 0 indicates total dependence and 9 indicates optimal social participation (19). In this study the short version of 69 items in 12 categories is used. The first 6 categories address daily activities while the other 6 are associated with social roles, thus referring to functional activities and participation according to the International Classification of Functioning, Disability and Health (ICF) (8,26). The Life-H total performance score has a good reliability; the different categories have a moderate reliability. Construct validity of the Life-H was supported by a study in older adults (27).

Statistical analysis

Using the independent samples t-test we compared mean values of measures of functional activities of the upper extremity between different sub-groups of participants, regarding the limb distribution of the spastic paresis.
Relations between participant characteristics, such as age, limb distribution of the spastic paresis, educational level, GMFCS level and MACS level, and functional activities of the upper extremity, assessed by the Melbourne assessment and Abilhand Questionnaire, were determined by correlation coefficients (Pearson's R).
Using the two measures of functional activities of the upper extremity, multivariate models for prediction of restrictions in participation were assessed by means of a stepwise multiple linear regression analysis. The independent variables (age, limb distribution of CP, educational level, GMFCS level, and Melbourne assessment or Abilhand Questionnaire, respectively) were entered stepwise. Outcome variables were domain scores on daily activities and on participation (Life-H), respectively. The standardised regression coefficients (Beta, β) and explained variance (R^2) of the regression models were presented.

RESULTS

Characteristics of the participants are shown in Table I. Nearly 50% of the participants is classified as hemiplegic. Seventy-six percent of the participants is classified as level I of the GMFCS and 81% as level I of the MACS, indicating no limitations in ambulation and manual ability. As a result of the inclusion criteria, participants had no severe learning disability. Fifty-nine percent followed secondary theoretical or higher education (7).

Table I. Characteristics of the participants.

Gender (N=103)	Male	62 (60%)
	Female	41 (40%)
Age (N=103)		17.9 (1.5) years, range 16-20
Educational level (N=103)	Low	40 (39%)
	Moderate	35 (34%)
	High	26 (25%)
CP limb distribution (N=103)	Diplegia	26 (25%)
	Hemiplegia	50 (49%)
	quadriplegia	26 (25%)
GMFCS (N=103)	I	78 (76%)
	II	7 (7%)
	III	5 (5%)
	IV	13 (13%)
	V	0 (0%)
MACS (N=83)	I	67 (81%)
	II	10 (12%)
	III	4 (5%)
	IV	1 (1%)
	V	1 (1%)

low = pre-vocational practical education or lower, moderate = pre-vocational theoretical education and upper secondary vocational education, high = secondary general education, higher educational institutes and university

GMFCS = gross motor function classification system

MACS = manual ability classification system

Table II shows the mean scores and standard deviations of the Melbourne assessment and the Abilhand Questionnaire for the whole group and three sub-groups regarding the limb distribution of the spastic paresis. For both measures there is a significant difference between diplegic and quadriplegic and between hemiplegic and quadriplegic participants. A small, but significant difference between diplegic and hemiplegic participants was present for the Abilhand Questionnaire.

Table II. Mean values (SD) of the measures of functional activities and participation for the total group and the sub-groups of participants, based on the different limb distributions of spastic paresis.

	all participants	diplegic participants	hemiplegic participants	quadriplegic participants	
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Difference[1]
Melbourne assessment (N=98)*	98.3% (3.1)	98.7% (1.7)	99.4% (1.2)	95.3% (5.0)	b, c
Abilhand Questionnaire (N=83)	40.7 (7.4)	42.0 (4.3)	43.3 (3.8)	33.9 (11.1)	a, b, c

1. Significant differences between sub groups of participants are indicated:
a = difference between hemiplegic and diplegic participants, $p < 0.05$
b = difference between hemiplegic and quadriplegic participants, $p < 0.05$
c = difference between diplegic and quadriplegic participants, $p < 0.05$
* from 5 participants the outcome of the Melbourne assessment was missing

Figures 1 and 2 show the median and ranges of scores on the Melbourne assessment and the Abilhand Questionnaire for the different sub-groups, indicating that especially quadriplegic persons greatly vary in their level of functional activities.

Figure 1. Relationship between the limb distribution of the spastic paresis and the scores on the Melbourne assessment. Box plots depict median score (▬), interquartile range (grey) and minimum and maximum values (whiskers); ◯ and * show outliers.

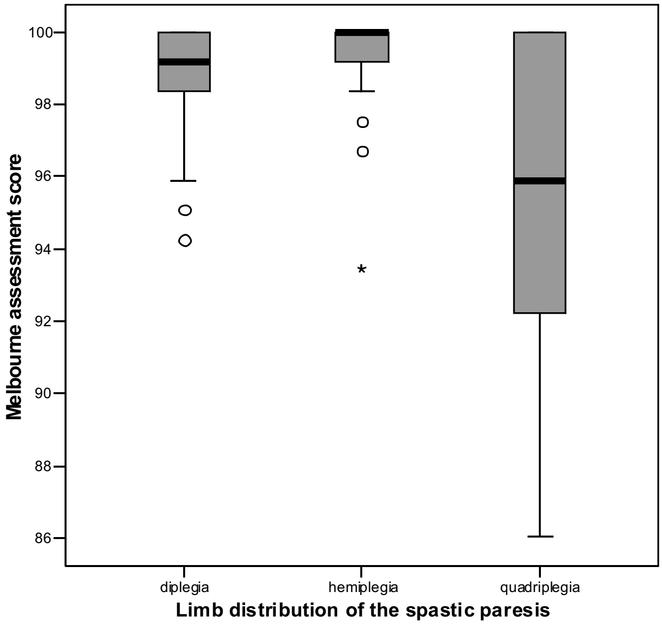
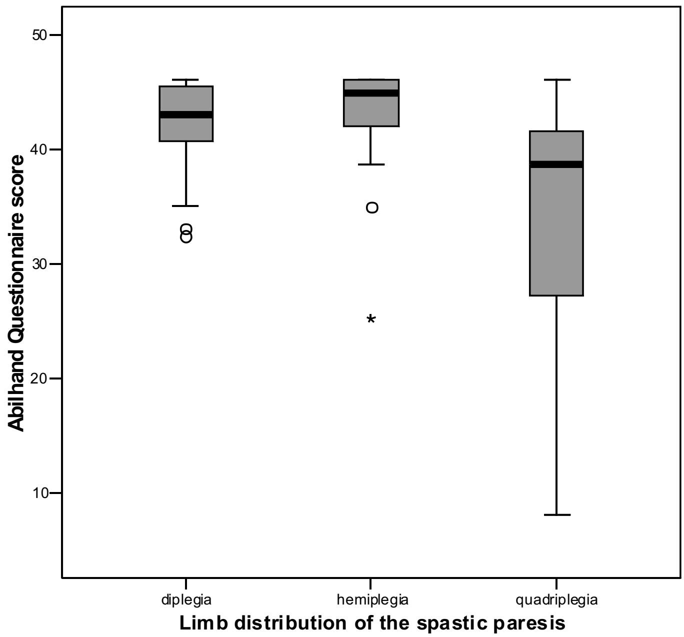


Figure 2. Relationship between the limb distribution of the spastic paresis and the scores on the Abilhand Questionnaire. Box plots depict median score (▬), interquartile range (grey) and minimum and maximum values (whiskers); ◯ and * show outliers.



There were no specific items of the Melbourne assessment, which were especially difficult for most participants or for specific sub-groups. The quadriplegic participants scored not maximal on many items in contrast to the diplegic and hemiplegic participants, in whom only some items do not have a maximal score. On the Abilhand questionnaire diplegic persons indicated activities such as skinning potatoes, putting a thread through a needle and wrapping up a present as most difficult, whereas in hemiplegic patients difficult activities were cutting and polishing nails and putting a thread through a needle. The quadriplegic participants showed difficulties in many items which varied over the participants.

Table III. Correlations (Pearson's R) between characteristics of the participants and functional activities of the upper extremity.

	Age	Limb distribution	Educational level	GMFCS	MACS	Melbourne assessment	Abilhand Questionnaire
Age	-	0.10	**0.25**	0.09	0.08	0.06	0.13
Limb distribution		-	**0.28**	**0.62**	**0.42**	**0.49**	**0.49**
Educational level			-	**0.26**	**0.29**	0.09	**0.28**
GMFCS				-	**0.55**	**0.39**	**0.61**
MACS					-	**0.45**	**0.76**
Melbourne assessment						-	**0.53**
Abilhand Questionnaire							-

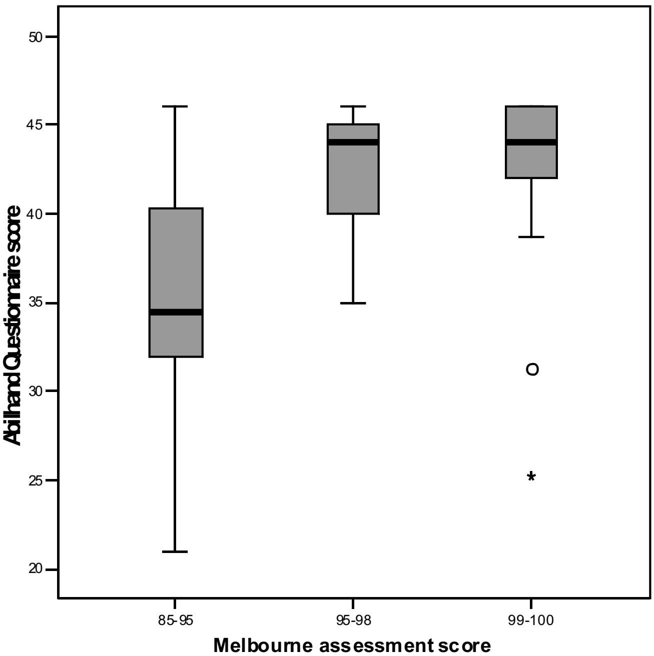
Bold = significant

GMFCS = Gross Motor Function Classification System

MACS = Manual Ability Classification System

Table III shows the correlations between participant characteristics and functional activities of the upper extremity. No correlations were found between the general participant characteristics, such as age and educational level, and functional activities of the upper extremity. In addition to limb distribution of spastic paresis (0.49), moderate but significant correlations (0.28 to 0.76) were found between GMFCS and MACS on the one hand and measures of functional activities of the upper extremity on the other hand. The Abilhand Questionnaire showed the strongest relation with the MACS, however, the relation with the GMFCS and limb distribution of the spastic paresis were also evident. Interrelationship between both measures of functional activities of the upper extremity was moderate (0.53).

Figure 3. Relationship between the scores on the Melbourne assessment and on the Abilhand Questionnaire. Box plots depict median score (▬), interquartile range (grey) and minimum and maximum values (whiskers); ○ and * show outliers.



This relationship is shown in figure 3, indicating that participants with a maximal score on the Melbourne assessment showed high scores on the Abilhand Questionnaire, whereas participants with sub-maximal scores on the Melbourne assessment varied in their Abilhand Questionnaire scores.

Table IV shows the regression models for functioning in daily activities and participation for both measures of functional activities of the upper extremity.

The regression models indicate that the limitations in daily activities and restrictions in participation, measured with the Life-H, are largely attributable to limitations in functional activities of the upper extremity as well as to limitations in gross motor function and a low educational level.

Categories of Life-H							
		Melbourne assessment			Abilhand Questionnaire		
	Mean (SD)	Model	β	R^2	Model	β	R^2
Daily activities	8.2 (1.2)	GMFCS	0.74	0.71	GMFCS	0.56	0.81
		Educational level	0.18		Abilhand	0.42	
		Melbourne	0.15		Educational level	0.11	
Participation	8.1 (1.1)	GMFCS	0.73	0.65	GMFCS	0.58	0.70
		Educational level	0.23		Abilhand	0.29	
					Educational level	0.18	

These models explain 71% and 81% of the total variance in daily activities, and 65% and 70% of the total variance in participation, including the Melbourne assessment and the Abilhand Questionnaire, respectively. An important predictor for participation seems to be especially the scores on the Abilhand Questionnaire, with a standardized regression coefficient () of 0.29.

DISCUSSION

In this study assessment of functional activities of the upper extremity in young adults with CP was described. Furthermore, relationships between functional activities of the upper extremity and characteristics of the participants and between functional activities of the upper extremity and participation were investigated.

Some limitations of the present study have to be mentioned. First, the study population consisted of young adults with CP, with rather good gross motor function, manual ability and educational level; also rather high levels of participation were reported. Twenty-five percent of the participants were classified as diplegic and 50% as hemiplegic; one could assume that in diplegic

participants both hands have a good function and in hemiplegic participants the uninvolved side has a good arm-hand function. Because of the characteristics of the study population, ceiling effects seemed to be present for both the Melbourne assessment and the Abilhand Questionnaire. Because of this skewed distribution we may not generalize the present relations to a broader population of young adults with CP, including patients with more severe functional and cognitive consequences of the lesion.
Second, the measures of functional activities of the upper extremity we used were not age-specific. We used one assessment developed for children (the Melbourne assessment) and the Abilhand Questionnaire was investigated in adults. The Melbourne assessment was developed for the age of 5 to 15 years; in the present study population the age ranged from 16 to 20 years and we assumed that the items assessed were also valid for these ages, because the items are general aspects of functioning of the upper extremity. For the Abilhand Questionnaire we assumed that the items in the version for chronic stroke patients were also valid for young adults with CP, since they refer to common bimanual activities.
Third, in this study we used the raw sum score of the Abilhand Questionnaire instead of logit scores, which were only available for stroke patients. Further research should focus on a Rasch analysis to determine an item hierarchy and to assess logit scores in young adults with CP.
Fourth, the MACS and Abilhand Questionnaire were assessed in the 2-years follow-up measurement of the CP Transition Study, resulting in missing data for participants that were lost to follow-up. Since these participants did not differ in main characteristics of CP, we assumed that these missing values did not influence the estimated scores of functional activities of the upper extremity and relationships with other characteristics. Furthermore, at this age we assumed no changes in functional activities of the upper extremity in the 2-years period between baseline and follow-up measurements.

The Melbourne assessment showed no significant difference between the diplegic and hemiplegic participants. This measurement instrument assesses unilateral upper-limb motor function; in diplegic participants one could expect a good

arm-hand function at both sides and the hemiplegic participants will use their uninvolved side, which is supposed to have a good motor function. So, no difference in unilateral activities of the upper extremity between these sub-groups could be expected. However, both sub-groups did not obtain maximal scores, which may be explained by the presence of slight impairment in arm-hand function and slight limitations in functional activities of the upper extremity. An earlier study showed that in hemiplegic CP patients the uninvolved hand has also an impaired function, when maximal grip strength, muscle coordination and muscle endurance are assessed (28). Furthermore, one could conclude that diplegic participants also have a slightly impaired arm-hand function. This corresponds with clinical experience, from which we know that impairment of the lower extremities is in many cases combined with some impairment of the upper extremity, although patients are classified as diplegic. Because of this phenomenon, Colver (29) pleaded for abandoning the term diplegia.
The Abilhand Questionnaire showed significant differences between all sub-groups. The scores on the Melbourne assessment as well as on the Abilhand Questionnaire show that the quadriplegic participants differ significantly from the diplegic and the hemiplegic participants, which could be expected, because the arm-hand function is more impaired in the quadriplegic participants.

Limb distribution of the spastic paresis showed a moderate correlation with functional activities of the upper extremity. The limb distribution of the spastic paresis, in this study based on the Swedish classification (23), might have a direct relation with arm-hand function. In diplegia it is assumed that only the lower extremities have an impaired function. In hemiplegia it is assumed that predominantly one side of the body has an impaired function. In quadriplegia all four extremities show an impaired function, sometimes with asymmetry between both sides and between the upper and lower extremities. Although it is known that this topographical classification is not very reliable (29,30), the present results showed that a distinction between diplegic, hemiplegic and quadriplegic patients might be useful with respect to arm-hand function.
Besides the limb distribution of the spastic paresis, also the GMFCS and the

MACS showed moderate correlations with the measures of functional activities of the upper extremity. Earlier studies report that GMFCS and the MACS are interrelated, addressing different aspects of the consequences of CP, i.e. impaired gross motor and fine motor function, even though the severity may differ between the upper and lower extremities (21,22).

From the results of the multiple regression analysis we may conclude that, in addition to the GMFCS and educational level, functional activities of the upper extremity, assessed by the Abilhand Questionnaire are an important predictor for limitations in daily activities and restrictions in participation. The Melbourne assessment, performed for the least affected side, achieved less as a predictor for restrictions in participation in this study. Reasons can be that this assessment addressed capacity and dexterity instead of actual performance of functional activities of the upper extremity, or that not the least affected side, as we assumed, but the most affected side might be more critical for functioning and participation. Another reason, already mentioned, could be related to the of the study population, with a high percentage of hemiplegic CP participants for whom the Melbourne assessment is not standardized (11).
In a previous analysis we showed that also manual ability, classified according to the MACS, was an additional determinant for participation besides gross motor function (22). A direct comparison between both models including the MACS versus the Abilhand Questionnaire as an additional determinant for participation is not allowed, since the first model applied to the 2-year follow-up measurements and the present to the baseline measurements of young adults with CP. Both models, however, did affirm the importance of functioning of the upper extremity for daily activities and social participation.

In conclusion, limitations in functional activities of the upper extremity are present in young adults with CP, especially in the quadriplegic participants. This aspect of functioning is related to other aspects of CP, such as limb distribution of the spastic paresis and gross motor function. We found evidence that limitations in functional activities of the upper extremity are an important predictor for restrictions in daily activities and participation. Based on these findings it is recommended to include a measure of functional activities of the upper extremity in the assessment of patients with CP and to incorporate this aspect in goal setting for rehabilitation treatment, aiming to improve daily activities and participation.

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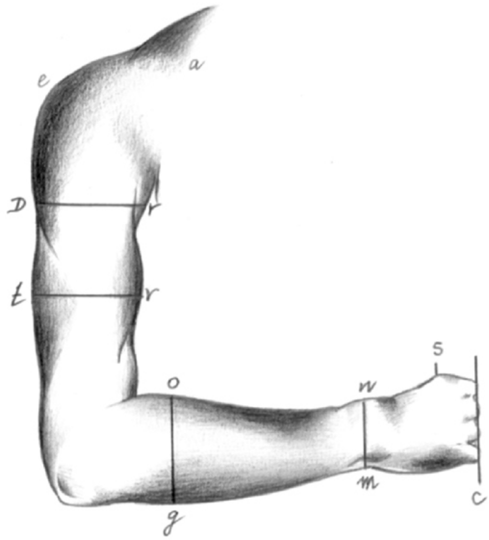
CHAPTER 7

Is the Manual Ability Classification System (MACS) a valid classification system of manual ability in young adults with cerebral palsy?



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Submitted.

ABSTRACT

Purpose The study aimed to establish whether the MACS, a valid classification system for manual ability of children with cerebral palsy (CP), is also valid in young adults with CP.

Method In this study validity was investigated by determining relationships with patient characteristics (such as the GMFCS and limb distribution of the spastic paresis) and with outcome measures of functional activities related to arm-hand function (such as the Melbourne assessment, the Abilhand Questionnaire and the domain self-care of the FIM). Furthermore, with a linear regression analysis it was determined whether the MACS could be used as a determinant of limitations in activities and participation. The participants (n=83) had a mean age of 19 years and 11 months (range 17 to 24 years) and 49 of them were male.

Results The Spearman correlation coefficients with the GMFCS and the limb distribution of the spastic paresis were 0.53 and 0.46, respectively. The Spearman correlation coefficients with the outcome measures of arm-hand function were moderate (ranging from -0.38 to -0.55). The MACS is, in addition to the GMFCS, an important determinant for limitations in activities and restrictions in participation.

Conclusion We conclude that the MACS is a valid method to classify manual ability in young adults with CP.

INTRODUCTION

Cerebral palsy (CP) is an umbrella term for multiple aetiologies and clinical manifestations. The usual definition of CP is: a persistent disorder of posture and movement caused by a non-progressive pathological lesion of the immature brain (1,2). Thus, this disorder is developed in early childhood; the lesion is non-progressive but its symptoms persist in adulthood and can have consequences for functions, activities and participation while growing up. Little is known about the consequences of this disorder in adolescence and adulthood (3-5). The prevalence of CP in western countries ranges from 1.5 to 2.5 per 1000 living births (6). The prevalence of CP has been increasing since the 1980s, mainly due to lower mortality rates in very-low-birth-weight children (6,7).

Besides motor impairments such as spastic paresis, sensory disturbances, cognitive impairments, visual and auditory problems, and epilepsy are frequently present (7,8). In nearly 50% of the patients with CP the arm-hand function is impaired (7-10).

The purpose of the Manual Ability Classification System (MACS) is to provide a systematic method to classify how children aged 4-18 years with CP actually use their hands when handling objects in daily activities (11). In this age range the MACS is proven to be a valid and reliable classification system using five levels (11). Validation in that study was based on the opinion of experienced professionals within paediatric rehabilitation and parents of children with CP. The MACS is not an assessment tool, and someone who knows the child well must do determining the MACS level. Its aim is not to determine what a child can do (the best capacity), but what the child does do (performance) in daily activities.

For young adults with CP the validity of the MACS has not yet been studied. Because no gold standard is available to determine the validity of the MACS in an older age group, we assessed the relationship between the MACS and relevant patient characteristics, such as the Gross Motor Function Classification System (GMFCS) and limb distribution of the spastic paresis. The GMFCS is a classification system focusing on the ambulatory function and gross motor function (12). We assume that there is a moderate relationship between the

MACS and the GMFCS, because the underlying disorder can affect both manual ability and gross motor function, although the paresis of the upper extremity can differ from that of the lower extremity. Additionally, the arm-hand function is expected to be correlated with the limb distribution of the spastic paresis, as there are hemiplegia, diplegia and quadriplegia, described in the Swedish classification (13).
In addition, addressing concurrent validity, the relationship of the MACS with outcome measures of functional activities of the upper extremity is assessed. The MACS is expected to be related to more detailed outcome measures of functional activities of the upper extremity, such as the Melbourne assessment, the Abilhand Questionnaire and the domain self-care of the Functional Independence Measure (FIM-ADL). These outcome measures are used to assess capacity or performance of arm-hand function.

In a previous study in young adults with CP we found that the GMFCS is an important determinant of limitations in activities and restrictions in participation (5). From the literature there is no evidence that impairments in arm-hand function are related to performance in activities and participation of persons with CP. Based on clinical experience, we assume that (besides gross motor function such as ambulation), arm-hand function might be a determinant of limitations in functional activities and restrictions in participation. Therefore, we expect that, in addition to the GMFCS, the MACS might be an important determinant.

This study aimed to assess the validity of the MACS in young adults with CP by investigating: 1) relationships with relevant characteristics of CP, i.e. the GMFCS and limb distribution of paresis, and 2) relationships with the outcome measures of functional activities of the upper extremity. Furthermore, we investigated whether the MACS is a determinant of limitations in activities and restrictions in participation, in addition to other determinants such as gross motor function.

METHOD

Participants

In this study 83 young adults with CP (aged 18-22 years) were assessed with respect to activities and participation. These subjects participated in the 2-year follow-up measurements (2004) of the CP Transition study in the South West Netherlands, a prospective cohort study. At the start of the study they were recruited from eight participating rehabilitation centres and rehabilitation departments in the region. Inclusion criteria were diagnosis of CP, and born in the years 1982-1986. Exclusion criteria were severe learning disabilities (IQ below 70), additional diagnosis with lasting effects on motor functioning, and insufficient knowledge of the Dutch language. With a response rate of 56%, 103 participants were included at baseline. They did not differ from non-responders with respect to gender, age, type of CP and limb distribution of the spastic paresis (5). At present, 16% of the participants have been lost to follow-up; loss to follow-up was not selective with respect to age, gender, gross motor function, limb distribution and educational level (14). Participants received verbal and written information about the study and filled in a written informed consent. The Medical Ethics Committee of Erasmus MC Rotterdam approved this study.

Procedure

Two teams, comprising one trained physical therapist and one researcher, performed all the measurements. The physical therapist performed a functional assessment, including a test (Melbourne assessment) and a questionnaire on manual activities (Abilhand Questionnnaire), and then classified the participant according to the MACS. The researcher conducted an interview (including the domain self-care according to the FIM) and assessed activities and participation with the Life-Habits Questionnaire (Life-H).

Measurement instruments

Patient characteristics

The following characteristics were recorded: age, gender, limb distribution of spastic paresis, GMFCS level and educational level. Limb distribution of spastic paresis was subdivided into diplegia, hemiplegia and quadriplegia according to the Swedish classification (13). Educational level was divided into 3 levels; low is pre-vocational practical education or lower, moderate is pre-vocational theoretical education and upper secondary vocational education, and high is secondary general education, higher educational institutes and university.

Melbourne assessment

The Melbourne assessment is a simple, easy-to-administer test of a child's unilateral upper-limb motor function. It provides general information about levels of ability and disability and, by measuring change, can evaluate the effectiveness of various treatments or interventions (15). The assessment is developed for use in children aged 5 to 15 years. The assessment evaluates the capacity of arm-hand function and consists of 16 items addressing 37 sub-scores (16). Each component is scored on a 3, 4 or 5-point scale. The total score is the sum of all sub-scores, converted to a percentage score (0-100). The Melbourne assessment is a reliable tool for measuring the quality of unilateral upper-limb function (15), but has not been standardized in children with hemiplegic CP (9). Because in our study population half of the participants had a hemiplegic paresis and in this study we focused primarily on handling objects, we selected four items of the Melbourne assessment concerning fine motor hand functions (e.g. grasping, manipulation and dexterity) performed with both the right and left hand. From the 5 sub-scores of both hands we computed an adapted total score, ranging from 0 to 36.

Abilhand Questionnaire

The Abilhand Questionnaire is a questionnaire about manual activities. The Abilhand Questionnaire measures the patient's perceived difficulty in performing everyday manual activities (17). It has been studied in patients with chronic stroke and in patients with rheumatoid arthritis with wrist arthrodesis (17,18). Rasch analysis in chronic stroke patients led to a hierarchical list of 23 bimanual items, 3-level scaled (17). For children with CP a different questionnaire, i.e. Abilhand-Kids, has been developed (19). Because the Abilhand-Kids is intended for younger children (mean age in that study was 10 years), in the present study we used the Abilhand for chronic stroke patients (17,19), because we assumed that young adults with CP were comparable to this patient group. An explorative Rasch analysis on own data, collected in the CP Transition study cohort confirmed the unidimensionality of the scale, but not the item hierarchy found in chronic stroke patients. Therefore, in the present study we used the raw sum score of the Abilhand Questionnaire, with a maximum score of 46.

Functional Independence Measure (FIM)

The FIM originally is an observational instrument to evaluate limitations in activities by professionals in a rehabilitation setting (20). The FIM assesses the amount of assistance required for a person with a disability to perform basic life activities safely and effectively (20). In this study we performed a semi-structured interview based on the 18 items of the FIM. The domains of the FIM are self-care, sphincter control, transfers, locomotion, communication, and social cognition. In the present analysis we only used the domain self-care (FIM-ADL), because in performance of self-care activities arm-hand function is important (21). Inter-rater reliability of the domain self-care was excellent, with an ICC of 0.93 (20). Items were scored on a 7-point scale ranging from 1 (total assistance required) to 7 (complete independence); the domain self-care consists of 6 items with a minimum total score of 6 and a maximum total score of 42.

Life-Habits Questionnaire (Life H)

The Life-H was designed to assess the handicap situations observed in the daily life of individuals with disabilities (22). Life habits were defined as “daily activities and social roles that ensure the survival and development of a person in society throughout his or her life” (23). The questionnaire assesses the difficulty of performance, and the need of assistance in activities. The Life-H produces a mean continuous score ranging from 0 to 9, by combining sub-scores addressing the degree of difficulty and type of assistance; 0 indicates total dependence and 9 indicates optimal social participation (24). In this study the short version of 69 items in 12 categories has been used. The first 6 categories refer to daily activities while the other 6 are associated with social roles, i.e. participation according to the International Classification of Functioning, Disability and Health (ICF) (25). The Life-H total performance score has a good reliability; the different categories have a moderate reliability. Construct validity of the Life-H was supported by a study in older adults (24).

Statistical analysis

Because in the present study a limited number of participants is classified as GMFCS levels III, IV and V and as MACS levels III, IV and V, for both classifications we combined these 3 levels into one group with levels III-V. Relationships between the MACS and relevant patient characteristics and outcome measures of arm-hand function were assessed with Spearman's correlation coefficients (R_S).

Multivariate analysis was done to fit models predicting outcome on activities and participation, using a stepwise multiple regression analysis. Dependent variables were the Life-H categories and domains scores. The independent variables (MACS, GMFCS, limb distribution of spastic paresis, educational level, age, gender) were entered stepwise (5). The standardised regression coefficients (Beta, β) and explained variance (R^2) of the regression models are presented.

RESULTS

Table I presents the characteristics of the participants; from the GMFCS and educational level one could conclude that most participants had only mild impairments in gross motor function and cognitive functions with 86% classified as GMFCS level I or II, and 74% followed secondary theoretical or higher education. Half of the participants had a hemiplegic paresis, in which we expected a relatively good arm-hand function.

Table I. Characteristics of the study population (n=83).

Participants characteristics		
Age	years	19.9 (1.5)
Gender	M	49 (59%)
	F	34 (41%)
Distribution of spastic paresis	hemi	42 (51%)
	di	31 (37%)
	quadri	10 (12%)
GMFCS	I	65 (78%)
	II	7 (8%)
	III-V	11 (13%)
Educational level	low	21 (25%)
	moderate	35 (42%)
	high	27 (32%)

M = male, F = female

hemi = hemiplegia, di = diplegia, quadri = quadriplegia.

GMFCS = gross motor function classification system

low = pre-vocational practical education or lower, moderate = pre-vocational theoretical education and upper secondary vocational education, high = secondary general education, higher educational institutes and university.

Most of the 83 participants (81%) were classified as MACS level I, 12% were classified as level II, and the remainder (7%) were classified as levels III, IV or V. Figure 1 shows the distribution of the MACS levels over the GMFCS levels. It appears that most participants with GMFCS level I can be classified as MACS level I, whereas MACS levels I and II and III-V are equally distributed over GMFCS level III-V.

Figure 1. Distribution of the MACS levels over the GMFCS levels

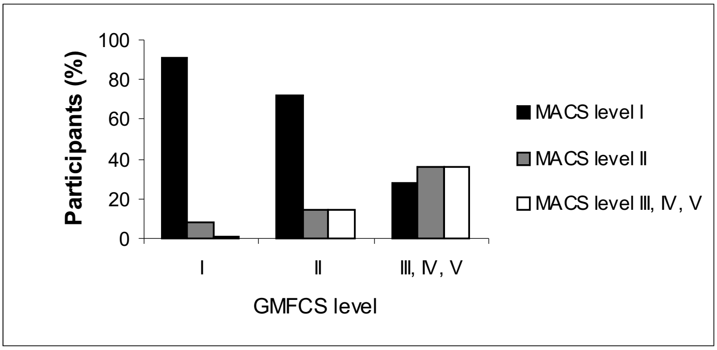
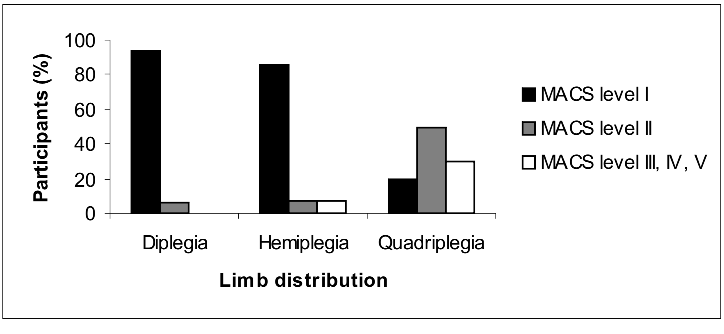


Figure 2 shows how the MACS levels are distributed over the limb distribution of spastic paresis. Only a few participants with diplegia and hemiplegia have restrictions in arm-hand function. However, 80% of the participants with a quadriplegia are classified as MACS levels II or III-V, indicating moderate to severe limitations in manual ability.

The correlation coefficients between GMFCS and MACS, and between the limb distribution of spastic paresis and the MACS are 0.53 ($p < 0.01$) and 0.46 ($p < 0.01$), respectively.

Figure 2. Distribution of the MACS levels in relation to the limb distribution of the spastic paresis



Figures 3, 4 and 5 show the relationships between the MACS and the adapted Melbourne assessment, the Abilhand Questionnaire, and the domain self-care of the FIM, with the median and interquartile ranges of scores on these measures of arm-hand function for MACS levels I, II and III-V. The figures indicate a relationship between manual ability classified according to the MACS and capacity of hand function (adapted Melbourne assessment), perceived difficulty in performing manual abilities (Abilhand), and amount of assistance in self-care (FIM-ADL). The correlation coefficients between the MACS levels and the adapted Melbourne assessment, the Abilhand Questionnaire and the FIM-ADL are 0.38 ($p < 0.01$), 0.53 ($p < 0.01$) and 0.55 ($p < 0.01$), respectively.

Figure 3. Box plots of the relation between the MACS and the four items of the Melbourne assessment; median and 25 and 75 percentile of the total score of the Melbourne assessment are for level I 34 [31;36], for level II 32 [24;35] and for level III-V 24 [16;33]

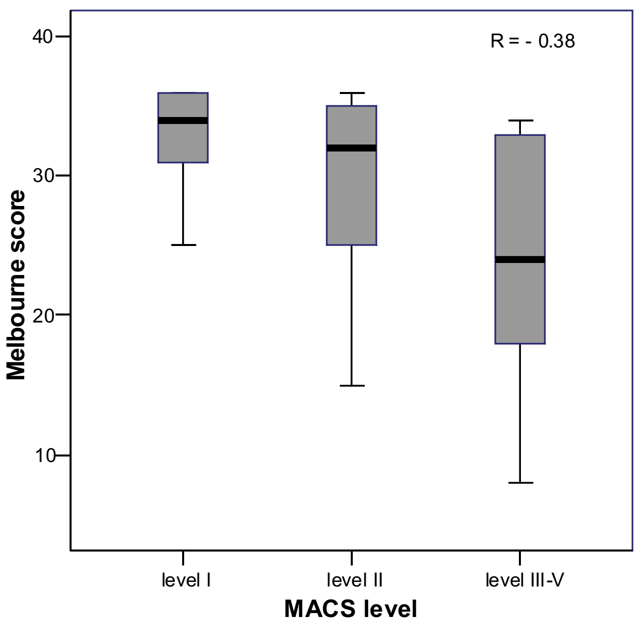


Figure 4. Box plots of the relation between the MACS and the Abilhand Questionnaire; median and 25 and 75 percentile of the logits score of the Abilhand Questionnaire are for level I 3.8 [3.1;6.0], for level II 1.9 [1.3;3.0] and for level III-V -0.3 [-1.2;3.6]

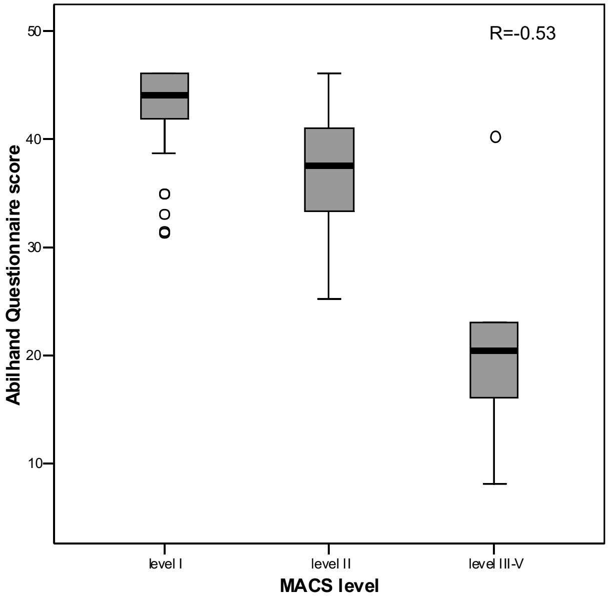


Figure 5. Box plots of the relation between the MACS and the domain self-care of the FIM (FIM-ADL); median and 25 and 75 percentile of the total score of the FIM-ADL are for level I 42 [42;42], for level II 41 [36;42] and for level III-V 26 [6;39]

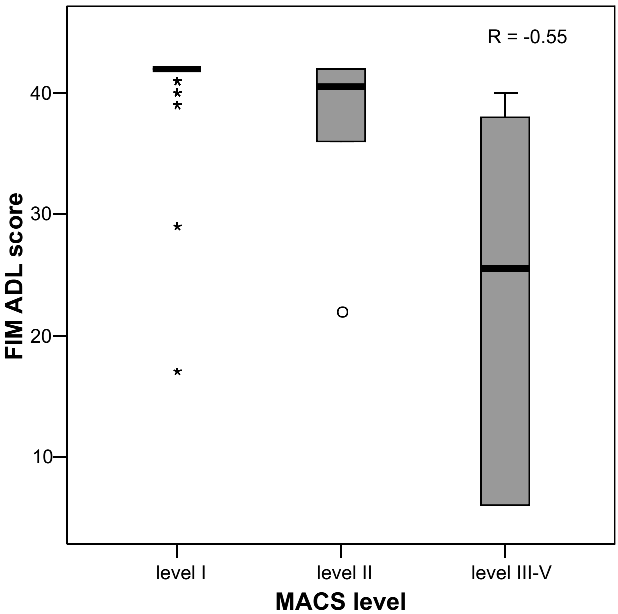


Table II gives the mean scores with standard deviation (SD) of the different categories of the Life-H. The most difficulties are experienced in the categories mobility, self-care, employment and leisure. The mean score of the first 6 categories addressing daily activities is 8.3, indicating that participants experience some difficulty in functional activities; the other 6 categories addressing participation have a similar mean score of 8.4.

Table II. Multivariate regression analysis of several determinants of outcome on participation. Educ = educational level

Life-Habits categories	Mean (SD)	Model	β	R^2
Communication	8.8 (0.7)	educ	0.28	*0.15*
		MACS	0.22	
Mobility	7.9 (1.6)	GMFCS	0.58	*0.61*
		educ	0.14	
		MACS	0.19	
		age	0.16	
Self-care	8.1 (1.7)	GMFCS	0.60	*0.66*
		MACS	0.31	
Fitness	8.6 (0.8)	GMFCS	0.44	*0.18*
Domestic life	8.7 (0.8)	GMFCS	0.54	*0.45*
		MACS	0.21	
Nutrition	8.4 (1.6)	MACS	0.46	*0.52*
		GMFCS	0.36	
Daily activities total	8.3 (1.1)	GMFCS	0.58	*0.73*
		MACS	0.32	
		educ	0.14	
Relationships	8.8 (0.7)	MACS	0.26	*0.06*
Major life areas				
- education	8.6 (1.0)	MACS	0.43	*0.17*
- employment	8.2 (1.2)	educ	0.46	*0.20*
Community, social & civic life				
- responsibility	8.5 (1.4)	MACS	0.38	*0.34*
		educ	0.35	
- community	8.3 (1.6)	GMFCS	0.46	*0.44*
		MACS	0.25	
		age	0.18	
- leisure	8.2 (1.0)	GMFCS	0.56	*0.54*
		MACS	0.23	
		age	0.19	
Participation total	8.4 (1.0)	GMFCS	0.44	*0.49*
		MACS	0.31	
		age	0.19	

The multiple regression analysis (see also Table II) shows that the GMFCS and the MACS are both important determinants of nearly all categories of daily activities and participation. These determinants explain 73% of the variance in daily activities and 49% of the variance in participation.

DISCUSSION

The aim of this study was to determine whether the MACS is a valid classification system of manual ability in young adults with CP by investigating relationships with relevant characteristics of CP and relationships with the outcome measures of functional activities of the upper extremity. Furthermore, we investigated whether the MACS is a determinant of functional activities and participation.

The correlation coefficient between the MACS and GMFCS was 0.53. This moderate correlation was expected, since both impaired fine motor function and impaired gross motor function are consequences of the underlying disorder. A high correlation was not expected because the impairments, mainly due to spastic paresis, may differ between the upper and lower extremities, globally addressing fine motor and gross motor functioning.

The distribution of the MACS levels over the different types of CP, represented by the limb distribution of spastic paresis, was as expected. In diplegic participants the arm-hand function will be good and most participants will be classified in level I, because the lower extremities are mainly involved. In hemiplegic participants several MACS levels were involved. Hemiplegic patients might have limitations in manual ability, even though only one side of the body is involved. Therefore, especially in bimanual tasks, they may encounter problems. In quadriplegic participants both the upper and lower extremities are involved bilaterally and moderate to severe impaired arm-hand function might be present. Therefore, participants with a quadriplegia are classified over all levels of the MACS.

A limitation of the study is that most of the young adults with CP are classified in the higher levels of GMFCS and MACS. In the analysis we combined levels III, IV and V because a few participants were classified as these levels. Because of this skewed distribution over the levels, the present results predominantly address validity of the upper part of the classification. For further insight in the validity of the MACS in young adults with severe limitations in hand use, additional data are needed, including more participants with MACS levels III to V.

We found moderate correlations between the MACS and the outcome measures of functional activities of the upper extremity. Similar to the MACS, these outcome measures focused on activity level according to the ICF. The correlation coefficient between the MACS and the adapted Melbourne assessment was 0.38, the lowest correlation of these three outcome measures. The Melbourne assessment focused on capacity in functional activities and which may differ from actual performance in handling objects in daily activities. Therefore, a somewhat lower correlation than with performance scales could be expected and was indeed found.

The correlation coefficient between the MACS and the Abilhand Questionnaire was 0.53. In both measures usual performance of and perceived difficulty with functional activities were assessed. Both methods used different types of assessment which were indirectly or directly patient based. The MACS classification was made by a professional based on information that a participant provided in the interview and during the functional assessment, whereas participants themselves assessed the items of the Abilhand Questionnaire.

The correlation coefficient between the MACS and the FIM-ADL was 0.55. Participants with MACS level I and II had a higher FIM-ADL score than participants with levels III-V, but in this group there was a large variety of scores (Figure 5). This implies that participants with moderate or severe limitations in manual ability may vary in the level of assistance they use in self-care activities. Overall, the strongest correlations were found between the MACS and the Abilhand Questionnaire and the FIM-ADL, both assessing performance of manual activities in daily life. The present results contribute to the evidence that the MACS is a valid classification system of manual ability in young adults with CP, which is in line with results found in children (11).

Similar to previous assessments in the same cohort of young adults with CP (5) we found that some of them reported problems in participation, according to the results of the Life-H. Young adults with CP had most problems in participation regarding employment (10% of the participants had a paid job in contrast to 32% of the Dutch population of this age) and participation in community, social and civic life. We found that, in addition to the GMFCS, the MACS is an important determinant for these restrictions in participation. These results support that the distinctions between either the MACS or the GMFCS levels are clinically meaningful. Thus, information on a patient's MACS level may be valuable for clinicians to identify patients with CP who are at risk for developing limitations in activities and restrictions in participation. Furthermore, adequate treatment regimes during childhood should focus on treatment goals to diminish the consequences of impaired arm-hand function, in addition to gross motor function.

We found some evidence that the MACS, a valid classification system of manual ability in children with CP (11), is also valid for young adults with CP. The MACS is similar to the GMFCS. Both classification systems are based on subjective performance and consist of five levels with a clinically meaningful discrimination between the levels. In addition to the GMFCS, the MACS is an important determinant for limitations in activities and restrictions in participation.

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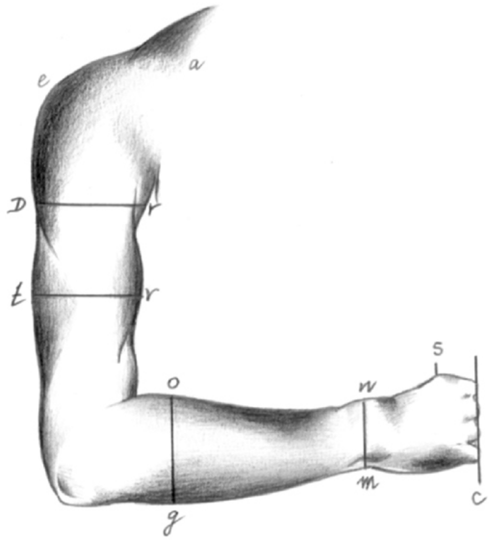
CHAPTER 8

General discussion



The main purpose of this thesis was to describe the assessment of arm-hand function according to the three perspectives described by the International Classification of Functioning, Disability and Health (ICF), i.e. body function, functional activities, and participation (1).
In rehabilitation medicine, temporary as well as chronic disorders are treated. For temporary disorders, treatment of impaired functions is mainly performed with the aim to diminish limitations in functional activities. In chronic disorders, impaired functions (sometimes progressive) are present which are generally not curable. Thus, interventions need to focus not only on impaired functions but also on minimizing limitations in functional activities and, finally, resulting in an optimal social participation.
The results of this thesis offer outcome measures to assess the upper extremity additional to the usual arsenal of clinical measures. In patients with CP, especially the relationship with social participation emphasizes the importance of paying adequate attention to assessment of the upper extremity, including both function and functional activities.

Isokinetic dynamometry and shoulder disorders

One of the reasons to investigate isokinetic dynamometry of the shoulder is that shoulder disorders are a frequently occurring problem in medical practice and a variety of treatment modalities are applied (2). No effective controlled studies have been performed to determine the outcome of interventions (3,4). Clinicians need measurement methods that they can use to assess patients, both in terms of a patient's initial status and how the patient is affected by treatment. Isokinetic dynamometry, an objective outcome measure, could be added to the more routinely used outcome measures, such as range of motion and pain; therefore, isokinetic dynamometry might be useful for clinical decision-making in shoulder disorders.

The reliability of isokinetic dynamometry of the shoulder is the first main issue addressed in this thesis. The study on test-retest reliability (**chapter 2**) performed in healthy subjects shows a good to excellent reliability of the measurements on the group level (ICCs ranged from 0.62 to 0.92) (5) and can be used as an outcome measure for research in groups. For reliability at the individual level the standard error of measurement (SEM) and the smallest detectable difference (SDD) were determined. The SDDs ranged from 21% to 43%. Comparison with other studies on the reliability of isokinetic measurements of the shoulder is not possible. The relatively large SDDs may hamper the detection of clinically relevant changes that may be within the range of measurement error. The SDDs in our study are larger than those found in isokinetic dynamometry of the knee joint (6,7). One has to conclude that isokinetic dynamometry of the knee joint is more reliable in individual measurements than that of the shoulder. This might be explained by the complexity of the shoulder joint and function; the aspects that we evaluate provide no answer regarding a specific cause.

To evaluate the clinical applicability of isokinetic strength measurements, we investigated whether the outcome measure is discriminative between healthy subjects and patients. In this thesis (**chapter 3**) it is concluded that the ratio of peak torques of the dominant and non-dominant shoulder in healthy subjects, or the involved and uninvolved side in patients, is the most discriminative parameter of isokinetic dynamometry. The 90% normal distribution of the dominant/non-dominant ratio ranges from 0.9 to 1.2 in healthy subjects. One concludes from this study that when the ratio is lower than 0.9 or higher than 1.2, there is a considerable chance that there is an imbalance of muscle strength of the rotator cuff and, possibly, a shoulder disorder. Other studies (8-16) often used maximal peak torques or agonist/antagonist ratios. In this study, however, no evidence was found to show that the maximal peak torques or agonist/antagonist ratio of healthy subjects and patients with a capsulitis are discriminative, although there was a significant difference between the maximal peak torques of healthy subjects and patients. Therefore, we suggest that bilateral comparison of peak torques is appropriate in clinical use.

In patients with a unilateral capsulitis there is good responsiveness of the involved/uninvolved ratio of peak torques, range of motion, pain and functional activities (**chapter 4**). All outcome measures have a large standard response mean (>0.8) (17). Further analysis showed no significant differences between the standardized response means of the different outcome measures. The parameters of isokinetic dynamometry may provide additional information in patients with a capsulitis of the shoulder as compared to the more routinely used outcome measures of pain and functional activities, and can be used to evaluate the effectiveness of the intervention.

Limitations of the studies on isokinetic dynamometry

Some limitations of the presented studies need to be addressed. These studies were performed with a Biodex® dynamometer; comparison with other studies is difficult because many of them use another type of isokinetic dynamometer, i.e. the Cybex®. Although the Biodex® has more technical features (e.g. more angular velocities, greater maximal torque and the option of measuring the active range of motion), comparison of the peak torques of healthy subjects found in our study with those in other studies performed with a Cybex® showed comparable data (8-10,18).

We did not investigate all possible outcome parameters of isokinetic dynamometry in order to determine its clinical applicability. We selected maximal peak torque and ratios of the agonists and antagonists, because these parameters are the most frequently used in other studies. Based on the results of our study, we also investigated the ratio of maximal peak torques of both shoulders and this ratio appears to be discriminative between healthy subjects and patients with a capsulitis.

In the study on responsiveness, because the population was very small (n=9) the results must be interpreted with caution. Despite the small number of patients, we found significant differences between healthy subjects and patients as well as within the patients for the period of the follow-up measurements, suggesting that the sample size was sufficient for the purpose of this study.

In this thesis only one kind of shoulder disorder is investigated, therefore generalization to patients with other shoulder disorders (especially those that are not characterized by pain) is not possible.

Clinical implications

Previous studies on isokinetic dynamometry of the shoulder interpreted the results without knowledge on the reliability and responsiveness, and without knowing whether discrimination between normal shoulder function and pathology was possible. The work in this thesis allows to conclude that isokinetic dynamometry of the shoulder can be used for group studies rather than for individual measurements.

Isokinetic dynamometry apparently can discriminate between healthy subjects and patients with a unilateral capsulitis. The most discriminative parameter of isokinetic dynamometry is the ratio of the peak torques of both shoulders; in healthy subjects the dominant/non-dominant ratio and in patients the involved/uninvolved ratio.

Although the test-retest reliability in individual measurements might hamper detection of clinically relevant changes, from the study on responsiveness one can conclude that isokinetic dynamometry can be used to follow-up spontaneous recovery or to determine the effectiveness of treatment in patients with a capsulitis. In this respect, isokinetic dynamometry could be complementary to measurements of pain and functional activities.

Future research

A first priority for future research is to collect normative data on the muscles of the rotator cuff in a large number of healthy subjects. This would enable comparison with normative data, because bilateral measurements are not always possible in all situations.

Measuring a large population of healthy subjects would also refine the 90% normal distribution of the ratio of peak torques of both shoulders for each muscle group. Discrimination between healthy subjects and patients would then be easier and more precisely.

Furthermore, we recommend to investigate whether the test-retest reliability can be improved, so that long-term follow-up in individual patients is possible.

Finally, test-retest reliability and responsiveness must be studied in other shoulder disorders, such as inflammation of the tendons or bursae, and instability of the rotator cuff, and after surgical repair of the rotator cuff.

Function and functional activities of the upper extremity in young adults with cerebral palsy

The transition from child to adult, especially in persons with a chronic disorder, is a vulnerable period. The CP Transition Study in the South West Netherlands aimed to gain more insight into the course of cerebral palsy (CP) and in determinants of functioning of young adults with CP during this period. Since functional decline is reported by adult patients with CP, attention must be paid to impaired functions, limitations in functional activities and restrictions in social participation (19-21). We need to know why and when the deterioration occurs and whether rehabilitation interventions can prevent such deterioration of functional skills. Insight into the determinants of participation might elucidate the processes involved.

In patients with CP, gross motor function, educational level and age are important determinants for restrictions in participation (22-24). This thesis confirms the assumption that arm-hand functioning is also an important determinant of participation.

From the grip strength measured in young adults with hemiplegic or unilateral CP we concluded that, besides the involved hand, the uninvolved hand also has impaired function (**chapter 5**). A non-linear relation between maximal grip strength or muscle coordination and functional activities was found. With a good function (maximal grip strength and coordination) the patients had only a few limitations in functional activities. Patients with low maximal grip strength or muscle coordination sometimes had many and sometimes a few limitations in functional activities. This non-linear relation indicates that limitations in functional activities cannot be estimated directly from grip strength parameters. There is no consensus about the relation between grip strength and functional activities. In contrast to our study, grip strength was reported to be an accurate indicator for upper limb ability in patients with early rheumatoid arthritis (25). Other studies performed in patients with peripheral nerve injuries reported that, besides grip strength, other functions (such as sensory disturbance) also had a relation with functional activities (26,27); since these authors did not describe this relation in detail, a direct comparison with our results is not possible.

The assumption that assessment of functional activities with the Melbourne assessment (developed for children) and the Abilhand Questionnaire (investigated in adult chronic stroke patients) could also be used in young adults with CP was confirmed in this study (**chapter 6**). In all three sub-groups, based on the limb distribution of spastic paresis, some limitations in functional activities of the upper extremity were found, but especially in the quadriplegic participants. There are relations with other patient characteristics such as gross motor function, manual ability and limb distribution of the spastic paresis. Limitations in functional activities of the upper extremity, measured by the Abilhand Questionnaire, are an important determinant for restrictions in participation. We recommend to include measurement of functional activities of the upper extremity in the assessment of patients with CP.

The classification of patients with CP has received much attention from, for example, the Surveillance of Cerebral Palsy in Europe (SCPE) (28). Although, the classification into hemiplegia, diplegia and quadriplegia (based on the Swedish classification) has been used for a long time (29), the SCPE has recently recommended classifying patients in unilateral and bilateral CP. Additionally, classification of ability of the lower and upper extremity has been recommended, representing gross motor function and fine motor function, respectively. For the gross motor function the Gross Motor Function Classification System (GMFCS) is internationally accepted (30). A Swedish group recently developed the Manual Ability Classification System (MACS) to assess manual ability in children aged 4 to 18 years (31). Our study has contributed to the evidence that the MACS is also a valid classification system for young adults with CP (**chapter 7**).
The five MACS levels have meaningful clinical discrimination (31). However, there is no level that describes the situation in which there are no impairments. MACS level I implies the ability to handle objects easily and successfully with independence in daily activities, but does not mean that there is a complete normal function. Our study shows, however, that the patients classified as level I might experience limitations in functional activities and social participation (**chapter 7**).

Besides gross motor function, educational level and age, manual ability and limitations in functional activities of the upper extremity are important determinants for restrictions in participation of young adults with CP. The classification of manual ability and a more detailed assessment of functional activities of the upper extremity might be used to complement each other. The MACS can be used to indicate the level of manual ability, for example, in communication between professionals. One advantage is that the MACS does not require special training; familiarity with the patient with CP is sufficient and it is not time consuming. The Abilhand Questionnaire more specifically focuses on difficulty in performing functional activities of the upper extremity and may be used for evaluative purposes. Whether the Abilhand Questionnaire is responsive enough to detect changes after interventions in patients with CP is not yet known.

Limitations of the studies on young adults with CP

Some limitations of these studies should be mentioned. In accordance with the inclusion criteria, the study population with CP had a high educational level, as well as a high level of gross motor function and fine motor function. There is a relation between the severity of impairment of motor function, associated impairments and cognitive level. Notwithstanding this high level of functioning, our participants reported several limitations in functional activities and participation, thus allowing us to study prognostic factors of functioning. The study population consists of participants who are known within a rehabilitation setting, this might imply we missed a subgroup of patients. Finally, because the study population is Dutch, generalization to other cultures or countries is not possible.

In these studies we used the limb distribution of spastic paresis based on the Swedish topographical classification (i.e. hemiplegia, diplegia and quadriplegia) which is known to have a poor reliability (29,32). Nowadays, the SPCE recommends classifying CP in unilateral and bilateral CP. It is not yet known whether this classification is more reliable than the Swedish one, and we discuss here a few aspects related to upper extremity functioning. Based on our

conclusion that even in patients with hemiplegic (or unilateral) CP the uninvolved hand has an impaired function, we think that both classifications have their limitations. The Swedish classification might be even more obvious when one wishes to describe the manual ability, because in diplegic and hemiplegic patients a relatively good arm-hand function is considered in contrast to the quadriplegic patients.
Regarding the use of the Abilhand Questionnaire in this study, we had to focus on its raw sum scores instead of the logit scores, since explorative Rasch analysis did not confirm the item hierarchy found in chronic stroke patients for young adults with CP (33). Raw sum scores lack the precision regarding assessed difficulty of individual items and corresponding logit scores on an interval scale. Further research in a larger sample will establish an item hierarchy in adults with CP.

Clinical implications

Until now studies on patient with CP reported the use of different classification systems, often based on the distribution of the spastic paresis. Our study shows that manual ability can be assessed adequately with the MACS. Therefore, we propose that patients with CP, children and (young) adults, be classified for gross motor function as well as for manual ability, according to the GMFCS and the MACS. Distinction between unilateral and bilateral CP in combination with classification according to the GMFCS and MACS gives a more complete description of the motor disorder and functional consequences (32).
It appeared that the uninvolved side of hemiplegic patients also has an impaired function, such as maximal grip strength and muscle coordination. Therefore, we advise that diagnosis and rehabilitation treatment aim at both hands instead of only the involved side.
Although there is a relation between the impaired functions and limitations in functional activities of the upper extremity, this relation is not linear. Thus, the question remains whether interventions predominantly focusing on impaired functions may decrease limitations in functional activities and participation. Further research may provide an answer and thus better advice for rehabilitation treatment.

Future research

In collaboration with the Swedish authors we have translated the MACS into Dutch (www.macs.nu). For clinical use of the MACS a Dutch version is important because parents, or the (young) adult patients, can perform the classification themselves. For further validation of the MACS in adults with CP it is necessary that all five levels of the MACS be represented in a study population. It would be interesting to determine whether the MACS can be used for a more detailed prognosis regarding social participation in adult life.

For the Abilhand Questionnaire a Rasch analysis would determine the hierarchy of the items in patients with CP. It would be interesting to establish whether the logit scores of the Abilhand Questionnaire are be more predictive for participation than the raw sum scores.

Because in chronic disorders such as CP it is necessary to evaluate the effect of interventions on functional activities, it is recommended to investigate the responsiveness of the Abilhand Questionnaire, so that it can be used to detect changes after interventions in patients with CP.

The underlying mechanism of the impaired function of the uninvolved arm and hand of patients with hemiplegic CP is not yet known. One explanation might be that there is also a dysfunction between agonists and antagonists in the uninvolved side. Investigation of the concerted action between the agonists and antagonists of the arm and hand muscles with surface EMG may provide more insight into this mechanism.

There is some evidence that team-based approaches for adolescents and young adults with a disability may help to achieve optimal social participation (34). In the Netherlands special rehabilitation treatment programs for adolescents and young adults are now in progress. In the evaluation of the effectiveness of these programs we strongly advise to incorporate measurements of the upper extremity.

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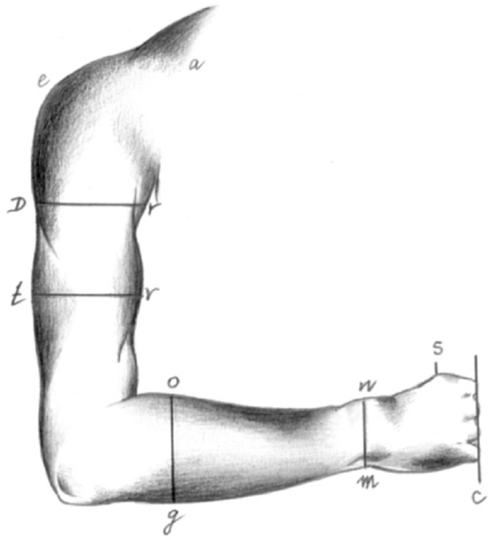
CHAPTER 9

SUMMARY/SAMENVATTING



This thesis describes different methods used to measure of functions and functional activities of the upper extremity. In rehabilitation medicine, treatment aims to improve functions, to diminish limitations in functional activities, and to achieve an optimal level of social participation. The International Classification of Functioning, Disability and Health (ICF) published in 2001 by the World Health Organization (WHO) describes the terms functions, functional activities and participation.
This thesis is divided into two parts; the first part presents studies investigating measurement of the function of the shoulder and the relation with functional activities. The second part consists of studies that determine relationships between measurements of functions, functional activities of the upper extremity, and participation in young adults with cerebral palsy (CP).

The first three studies deal with isokinetic dynamometry of the shoulder. The shoulder joint is a complex joint with many directions of movement. The dynamic stability provided by the muscles of the rotator cuff is of great importance for shoulder function. Imbalance of the agonist and antagonist muscle can cause complaints and pathology.
Shoulder disorders are a frequently occurring problem which are generally temporary but can also be longstanding. The impairments can cause limitations in functional activities.
Although various conservative treatments are available, their effectiveness is not well established. Generally, outcome measures in studies on the effectiveness of treatment are pain and range of motion (ROM); however, the reliability, validity and responsiveness of these two outcome measures are limited. It is advisable to include an objective outcome measure that has sufficient reliability, validity and responsiveness.
Measuring muscle strength with isokinetic dynamometry is well established, primarily in testing the knee; isokinetic dynamometry of the knee joint is a reliable technique. Studies on isokinetic dynamometry of the shoulder are available, but data on the reliability, validity and responsiveness are scarce.

Chapter 2 describes a study on the test-retest reliability of isokinetic dynamometry of the abduction/adduction and external/internal rotation of the shoulder in healthy subjects. Both shoulders were measured with a two-week interval. The test-retest reliability on the group level is determined with Intraclass Correlation Coefficients (ICC). The ICCs ranged from 0.69 to 0.92, indicating a good to excellent reliability. The test-retest reliability on the individual level is determined with the Smallest Detectable Difference (SDD). The SDDs ranged from 21% to 43% in the different muscle groups. These relatively large SDDs may hamper the detection of clinically relevant changes in individual follow-up measurements.

Chapter 3 presents a study that investigated which parameter of isokinetic dynamometry is clinically applicable. It explores which parameter is most discriminative between healthy subjects and patients with a unilateral capsulitis. In other studies, maximal peak torques and ratios of peak torques of the agonists and antagonists are often used; our study concludes that these parameters are not discriminative enough. It is concluded that the ratio of peak torques of the dominant and non-dominant shoulder in healthy subjects, or the involved and uninvolved shoulder of patients, is the most discriminative parameter. In healthy subjects the 90% normal distribution is from 0.9 to 1.2; when the ratio is lower than 0.9 or higher than 1.2 there is a considerable chance that there is an imbalance of muscle strength of the rotator cuff and possibly a shoulder disorder.

Patients with a shoulder disorder may have pain, limited ROM, decreased muscle strength or an imbalance between the muscle groups. **Chapter 4** describes a study which investigates whether measurement of muscle strength with isokinetic dynamometry can be a useful addition to measures of pain and ROM. The Shoulder Disability Questionnaire (a questionnaire addressing functional activities of the upper extremity) was also completed. It is known that there is no linear relationship between muscle strength and the performance of functional activities. Measurements were made in patients with a unilateral capsulitis of the shoulder during treatment with a well-known and often used method. The responsiveness of all outcome measures was determined and all outcome measures showed a good responsiveness without significant differences between the outcome measures. It is concluded that isokinetic dynamometry is an additional outcome measure to measures of pain, ROM, and functional activities. Generalization to patients with other types of shoulder disorders is, however, not possible.

The second part of this thesis presents studies on the measurement of function and functional activities of the upper extremity, and the relation with social participation, in young adults with CP. A working definition of CP is: a persistent disorder of posture and movement caused by a non-progressive pathological lesion in the immature brain. Besides motor impairments such as spastic paresis, also sensory disturbances, cognitive impairments, visual and auditory problems, and epilepsy are frequently present. Although the lesion is non-progressive, symptoms persist in adulthood and can have consequences for functions, functional activities and participation while growing up, and functional skills can deteriorate. For these reasons, the CP Transition study in the South West Netherlands, a prospective cohort study into the course and determinants of functioning of young adults with CP, was started. Within this CP study, the studies of this thesis concentrate on the arm-hand function and functional activities of the upper extremity.

Chapter 5 describes a study on the measurement of maximal grip strength, muscle coordination and muscle endurance in young adults with hemiplegic CP. Both hands of the patients with CP are compared with that of healthy subjects. It is concluded that the uninvolved hand of the patients with CP also has an impaired function, in maximal grip strength, muscle coordination as well as muscle endurance. Relationships with the outcome measure of functional activities are determined. Functional activities are measured with the (modified) Melbourne assessment and the Abilhand Questionnaire. There is a non-linear relation between the maximal grip strength and muscle coordination on the one hand and the Abilhand Questionnaire on the other hand. With a good function there are few limitations in functional activities, but with less function sometimes a few and sometimes many limitations in functional activities are present. Limitations in functional activities cannot be estimated directly from maximal grip strength or muscle coordination.

Chapter 6 describes a study on the measurement of functional activities of the upper extremity, including the Melbourne assessment and the Abilhand Questionnaire. The Melbourne assessment measures especially capacity, i.e. what a person can do. The Abilhand Questionnaire measures performance of activities, i.e. what a person actually does and with how much difficulty. Relationships with patient characteristics, such as the classification of gross motor and manual ability, the limb distribution of the spastic paresis, the age and educational level are determined. Correlations exist between the gross motor function, manual ability and the limb distribution on the one hand and the measures of functional activities of the upper extremity on the other. Subsequently, it is determined whether the limitations in functional activities are a determinant for participation. It is concluded that limitations in functional activities of the upper extremity measured with the Abilhand Questionnaire are a determinant for restrictions in participation.

Chapter 7 presents a study exploring whether the Manual Ability Classification System (MACS) can be used in young adults with CP. The MACS was developed in Sweden for children (age 4-18 years) with CP and is a reliable classification system. There are 5 levels with a clinically meaningful discrimination between the levels. The classification is based on handling age-specific objects and what the child actually does; it is not a tool to assess or determine what a child can do. Relationships with patient characteristics (gross motor function and limb distribution of the spastic paresis) and outcome measures of functional activities (Melbourne assessment, Abilhand Questionnaire and Functional Independence Measure (FIM), the domain activities of daily life) are determined. It is concluded that the MACS is a valid classification system for manual ability in young adults. Furthermore, the MACS is a determinant for restrictions in participation.

Chapter 8 discusses the conclusions of the studies; their limitations and clinical implications, and presents directions for future research.
From the studies on reliability, clinical applicability and responsiveness one can conclude that isokinetic dynamometry of the shoulder can be used to evaluate, for example, interventions. The most discriminative parameter of isokinetic dynamometry of the shoulder is the ratio of peak torques of both shoulders.
From the studies on young adults with CP it is concluded that the uninvolved hand of hemiplegic CP patients also has an impaired function. Furthermore, there is no linear relation between function and functional activities.
Measurement (especially with the Abilhand Questionnaire) of functional activities of the upper extremity and classification of manual ability is important, because these are determinants for restrictions in participation.

NEDERLANDSE SAMENVATTING

Dit proefschrift beschrijft verschillende meetmethoden van functies en functionele activiteiten van de bovenste extremiteit. In de revalidatiegeneeskunde behandelen we patiënten met de bedoeling om functies te verbeteren, mensen minder beperkingen in activiteiten van het dagelijks leven te laten ervaren en zodoende een optimale participatie in de maatschappij te bewerkstelligen. In de International Classification of Functioning, Disability and Health (ICF) (2001), opgesteld door de World Health Organisation (WHO), worden de begrippen functie, functionele activiteit en participatie beschreven. Dit proefschrift is in twee delen op te splitsen, waarbij in het eerste deel metingen van functies van het schoudergewricht en de relaties met functionele activiteiten worden onderzocht. Het tweede deel richt zich op het bepalen van relaties tussen metingen van functies en functionele activiteiten van de bovenste extremiteit enerzijds en participatie anderzijds bij jong volwassenen met een cerebrale parese (CP).

Het eerste deel omvat studies aangaande isokinetische dynamometrie van de schouder. Het schoudergewricht is een complex gewricht met vele bewegingsmogelijkheden. De dynamische stabiliteit, geboden door de spieren, ook wel rotator cuff genaamd, is van groot belang. Disbalans tussen de spieren van de rotator cuff zou kunnen leiden tot klachten en pathologie van de schouder. Schouderaandoeningen komen veel voor, zijn in het algemeen tijdelijk, echter soms langdurig en kunnen voor de patiënt klachten en beperkingen in het uitvoeren van activiteiten opleveren. Er zijn vele behandelmogelijkheden bekend, die worden toegepast in de algemene en specialistische medische praktijk; echter goede interventiestudies zijn schaars. Veel gebruikte uitkomstmaten in interventiestudies zijn pijn en range of motion (ROM); van beide is bekend dat de betrouwbaarheid, validiteit en responsiviteit matig zijn. Het zou nuttig zijn om een objectieve uitkomstmaat toe te kunnen voegen aan de reeds bestaande uitkomstmaten, die dan tevens voldoende betrouwbaar, valide en responsief moet zijn.

Spierkracht meten met behulp van isokinetische dynamometrie is reeds lange tijd bekend, in eerste instantie vooral van metingen van de knie. Isokinetische dynamometrie van de knie blijkt betrouwbaar te zijn. Er zijn veel studies bekend waarin isokinetische dynamometrie van de schouder als meting gebruikt wordt. Echter studies naar betrouwbaarheid, validiteit en responsiviteit zijn vrijwel niet gedaan.

Hoofdstuk 2 beschrijft een studie naar de test-hertest betrouwbaarheid van isokinetische dynamometrie van de ab- en adductoren en de exo- en endorotatoren van de schouder bij gezonde proefpersonen. Beide schouders zijn met een interval van 2 weken gemeten. De test-hertest betrouwbaarheid is op groepsniveau bepaald met de Intraclass Correlation Coefficient (ICC). De ICCs variëren van 0.69 tot 0.92 en zijn goed tot excellent te noemen. Daarnaast is voor de betrouwbaarheid van metingen op individueel niveau het kleinst te meten verschil (ook wel Smallest Detectable Difference, SDD) bepaald. Deze kleinst te meten verschillen variëren van 21% tot 43% voor de verschillende spiergroepen. Hieruit blijkt dat bij follow-up metingen bij individuen alleen relatief grote veranderingen in spierkracht met zekerheid kunnen worden vastgesteld. Of klinisch relevante verschillen gemeten kunnen worden kan niet geconcludeerd worden uit deze studie.

In **hoofdstuk 3** wordt een studie beschreven waarin we gekeken hebben welke parameter van isokinetische dynamometrie klinisch relevant is. Onderzocht is welke parameter het beste onderscheid maakt tussen gezonde proefpersonen en patiënten met een capsulitis van de schouder oftewel het beste discriminerend vermogen heeft. De, in de literatuur, meest gebruikte parameters zijn de piekmomenten en de ratio's van de piekmomenten van agonisten en antagonisten; in onze studie bleken deze parameters onvoldoende discriminerend te zijn. Het beste onderscheid maakt de ratio van de piekmomenten van de dominante en niet-dominante schouder (of bij patiënten van de aangedane en niet-aangedane schouder). Bij de gezonde proefpersonen is een 90% normale verdeling tussen 0.9 en 1.2 vastgesteld; wanneer een persoon een ratio van de piekmomenten van beide schouders heeft die buiten deze verdeling valt moet men bedacht zijn op een disbalans van de spierkracht en mogelijk op een schouderaandoening.

Bij patiënten met een schouderaandoening kunnen, naast pijn en een beperkte gewrichtsmobiliteit, spierkrachtvermindering en/of een disbalans tussen spiergroepen optreden. In **hoofdstuk 4** hebben we onderzocht of de meting van spierkracht van de rotator cuff met behulp van isokinetische dynamometrie iets kan toevoegen aan de metingen van pijn en range of motion. Daarnaast is de Shoulder Disability Questionnaire (SDQ), een vragenlijst over beperkingen in functionele activiteiten van de bovenste extremiteit, afgenomen. Uit de literatuur is bekend dat er geen directe relatie bestaat tussen spierkracht en het kunnen uitvoeren van functionele activiteiten. Patiënten met een enkelzijdige capsulitis, een aandoening waarbij pijn op de voorgrond staat gecombineerd met een mobiliteitsbeperking, zijn geïncludeerd. Van alle uitkomstmaten is de responsiviteit bepaald aan de hand van metingen tijdens een bekende, en vaak gebruikte behandeling van een capsulitis, i.e. een intra-articualire injectie. Alle uitkomstmaten zijn responsief, maar er is geen significant verschil tussen de uitkomstmaten onderling. Geconcludeerd wordt dat isokinetische dynamometrie iets kan toevoegen het meten van pijn en functionele activiteiten. Generalisatie naar patiënten met andere schouderaandoeningen is niet mogelijk.

Het tweede deel van dit proefschrift gaat over het meten van functies en functionele activiteiten van de bovenste extremiteit, en de relatie met participatie, bij jong volwassenen met CP. CP wordt gedefinieerd als een stoornis in houding en motoriek ten gevolge van een niet-progressieve hersenaandoening in het nog niet volgroeide brein. Naast motorische stoornissen zijn er vaak andere stoornissen, zoals sensibiliteitsstoornissen, visuele en auditieve stoornissen en epilepsie. De aandoening ontstaat voor, tijdens of niet lang na de geboorte en de stoornissen blijven levenslang aanwezig. Het is inmiddels bekend dat beperkingen in functionele activiteiten en in participatie in de loop van het leven zelfs kunnen toenemen. In Zuid West Nederland vindt er een prospectief cohort onderzoek bij jong volwassenen met CP naar determinanten en prognostische factoren voor het functioneren plaats. Als deel van dit onderzoek concentreren we ons in dit proefschrift op de arm-hand functie en functionele activiteiten van de bovenste extremiteit.

In **hoofdstuk 5** wordt een studie beschreven naar metingen van knijpkracht, spiercoördinatie en duurvermogen bij jong volwassenen met een hemiparese. Naast de vergelijking van beide handen van de patiënten is er ook vergeleken met gezonde proefpersonen. Het blijkt dat de niet aangedane hand eveneens een gestoorde functie heeft, zowel wat betreft de knijpkracht als de coördinatie en duurvermogen. Er is ook gekeken naar de relatie van de metingen van functies met die van functionele activiteiten. Functionele activiteiten zijn gemeten met de (gemodificeerde) Melbourne assessment en de Abilhand Questionnaire. Het blijkt dat er een relatie bestaat tussen maximale knijpkracht en spiercoördinatie enerzijds en de Melbourne assessment en Abilhand Questionnaire anderzijds. Dit is geen lineaire relatie, bij een goede functie blijkt dat er weinig beperkingen in functionele activiteiten zijn, maar bij een minder goede functie kan de persoon zowel veel als weinig beperkingen hebben. Een rechtstreekse prognose van beperkingen in functionele activiteiten is vanuit de knijpkracht en spiercoördinatie dan ook niet mogelijk.

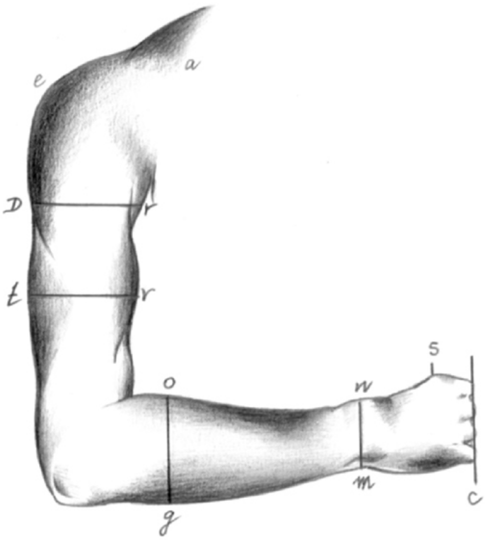
Hoofdstuk 6 beschrijft een studie waarin functionele activiteiten van de bovenste extremiteit bij jong volwassenen met CP gemeten worden met de Melbourne assessment en de Abilhand Questionnaire. De Melbourne assessment meet vooral capaciteit, d.w.z. wat een persoon kan en de Abilhand Questionnaire meet uitvoering van activiteiten, d.w.z. wat een persoon doet en welke moeite het kost. Relaties met patiënt karakteristieken zoals de classificatie van de grove motoriek en de handvaardigheid, de verdeling van de spastische parese, de leeftijd en het opleidingsniveau zijn bepaald. Er zijn relaties tussen de grove motoriek, handvaardigheid en verdeling van de parese enerzijds en de functionele activiteiten anderzijds. Daarnaast werd beoordeeld of de gemeten beperkingen in functionele activiteiten een determinant zijn voor beperkingen in participatie. Het blijkt dat functionele activiteiten van de bovenste extremiteit gemeten met de Abilhand Questionnaire een determinant zijn voor beperkingen in participatie.

Tenslotte wordt in **hoofdstuk 7** onderzocht of een classificatiesysteem voor handvaardigheid bij jong volwassenen met CP gebruikt kan worden. De MACS (Manual Ability Classification System) is in Zweden ontwikkeld voor kinderen met CP (leeftijd 4-18 jaar) en is gebleken valide en betrouwbaar te zijn. Het is een classificatiesysteem met 5 klinisch onderscheidende niveaus. Het gaat bij het classificeren om het hanteren van leeftijdsspecifieke objecten en om wat een kind doet; het is geen test om te beoordelen wat het kind kan. Relaties met patiënt karakteristieken en uitkomstmaten op activiteiten niveau (Melbourne assessment, Abilhand Questionnaire en Functional Independence Measure, het domein activiteiten van het dagelijks leven (FIM-ADL)) zijn geanalyseerd. Geconcludeerd kan worden dat de MACS ook een valide classificatie voor handvaardigheid is op deze leeftijd. Daarnaast is de MACS een determinant voor beperkingen in participatie.

In **hoofdstuk 8** worden de conclusies van de uitgevoerde studies bediscussieerd, daarnaast worden beperkingen van de studies en klinische implicaties, aanbevelingen voor toekomstige onderzoek worden gedaan. Naar aanleiding van de studies betreffende betrouwbaarheid, klinische relevantie en responsiviteit kan geconcludeerd worden dat, aanvullend aan uitkomstmaten als pijn, beweeglijkheid en functionele activiteiten, isokinetische dynamometrie van de schouder gebruikt kan worden om bijvoorbeeld effectiviteit van interventies te onderzoeken.
Uit de studies verricht bij jong volwassenen met CP kan geconcludeerd worden dat de niet aangedane hand bij hemiplegische patiënten toch ook een gestoorde functie heeft, zowel in knijpkracht als in coördinatie en duurvermogen. Veder bestaat er geen lineaire relatie tussen de mate van gestoorde functies en beperkingen in functionele activiteiten. Het meten van functionele activiteiten van de bovenste extremiteit en classificeren van de handvaardigheid is van belang, mede omdat deze voorspellende factoren zijn voor beperkingen in participatie.

APPENDIX A

MACS (English version)



Introduction and User Information

The purpose of the ***Manual Ability Classification System*** **(MACS)** is to provide a systematic method to classify how children with cerebral palsy use their hands **when handling objects in daily activities**. MACS is based upon self-initiated manual ability, with a particular emphasis on handling objects in an individual's personal space (the space immediately close to one's body, as distinct from objects that are not within reach).

The focus of MACS is on determining which level best represents the **child's usual performance** in home, school and community settings. Accordingly, the level must be determined by asking someone who knows the child well and not by conducting a specific assessment. MACS is not designed to classify best capacity and does not mean to distinguish different capacities between the two hands. MACS does not intend to explain the underlying reasons for limitations of performance or to classify types of cerebral palsy.

Distinctions between the levels are based on the child's **ability to handle objects** and their **need for assistance or adaptations** to perform manual tasks in everyday life. The objects in question are those that are relevant and age appropriate for the child, used for example in eating, dressing, playing, writing, as distinct from objects used in advanced specially skilled activities, like playing a musical instrument.

MACS can be used for children of different ages, but some interpretation is needed regarding the age of the child. Obviously, children handle **different objects** at four years of age, compared to when they are adolescents. The same point concerns **independence**, as a young child needs more help and supervision than an older child. Classification of a child should be made with reference to children of the same age.

A child's motivation and cognitive ability influence their ability to handle objects and thereby their MACS level. If the child's motivation to perform activities is low, if they do not understand the task or continuously ask for help and support from adults, they should be classified based on their actual performance, even if they are thought to have a higher capacity.

As a general principle, if a child's manual ability fits within a particular level the child will probably be classified either at or above that level. Children who do not perform the functions of a particular level will almost certainly be classified below that level. Level I includes children with cerebral palsy with, at most, minor limitations compared to typically developing children, and where the limitations, if any, barely influence their performance of daily life tasks.

In MACS five levels are described. Distinctions between each pair of levels are also provided to assist in determining the level that most closely resembles a child's manual abilities.

The scale is ordinal, with no intent that the distances between levels should be considered equal, or that children with cerebral palsy are equally distributed across the five levels.

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Eliasson AC, Krumlinde Sundholm L, Rösblad B, Beckung E, Arner M, Öhrvall AM , Rosenbaum P. The Manual Ability Classification System (MACS) for children with cerebral palsy: scale development and evidence of validity and reliability Developmental Medicine and Child Neurology 2006 48:549-554

Manual Ability Classification System for Children with Cerebral Palsy 4-18 years

March 2005

MACS is a system to classify children's ability to handle objects in daily activities

- **MACS** intends to describe which level best represents the child's usual performance in home, school and community settings.
- **MACS** level must be determined based on knowledge about the child's actual performance in daily life. It should not be done by conducting a specific assessment but by asking someone who knows the child and how that child performs typically.
- To determine the level of **MACS**, the child's ability to handle objects needs to be considered from an age-related perspective.
- **MACS** intends to report the participation of both hands in activities, not an assessment of each hand separately.

MACS

What do you need to know to use MACS?

The child's ability to handle objects in important daily activities, for example during play and leisure, eating and dressing.

In which situation is the child independent and to what extent do they need support and adaptation?

I. **Handles objects easily and successfully.** At most, limitations in the ease of performing manual tasks requiring speed and accuracy. However, any limitations in manual abilities do not restrict independence in daily activities.

II. **Handles most objects but with somewhat reduced quality and/or speed of achievement.** Certain activities may be avoided or be achieved with some difficulty; alternative ways of performance might be used but manual abilities do not usually restrict independence in daily activities.

III. **Handles objects with difficulty; needs help to prepare and/or modify activities.** The performance is slow and achieved with limited success regarding quality and quantity. Activities are performed independently if they have been set up or adapted.

IV. **Handles a limited selection of easily managed objects in adapted situations.** Performs parts of activities with effort and with limited success. Requires continuous support and assistance and/or adapted equipment, for even partial achievement of the activity.

V. **Does not handle objects and has severely limited ability to perform even simple actions.** Requires total assistance.

Distinctions between Levels I and II

Children in Level I may have limitations in handling very small, heavy or fragile objects which demand detailed fine motor control, or efficient coordination between hands. Limitations may also involve performance in new and unfamiliar situations. Children in Level II perform almost the same activities as children in Level I but the quality of performance is decreased, or the performance is slower. Functional differences between hands can limit effectiveness of performance. Children in Level II commonly try to simplify handling of objects, for example by using a surface for support instead of handling objects with both hands.

Distinctions between Levels II and III

Children in Level II handle most objects, although slowly or with reduced quality of performance. Children in Level III commonly need help to prepare the activity and/or require adjustments to be made to the environment since their ability to reach or handle objects is limited. They cannot perform certain activities and their degree of independence is related to the supportiveness of the environmental context.

Distinctions between Levels III and IV

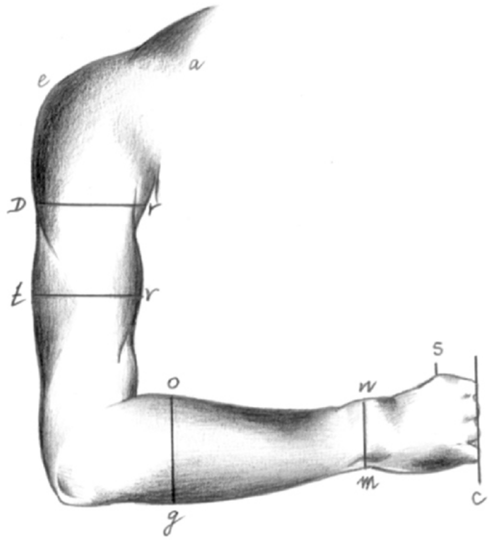
Children in Level III can perform selected activities if the situation is prearranged and if they get supervision and plenty of time. Children in Level IV need continuous help during the activity and can at best participate meaningfully in only parts of an activity.

Distinctions between Levels IV and V

Children in Level IV perform part of an activity, however, they need help continuously. Children in Level V might at best participate with a simple movement in special situations, e.g. by pushing a simple button.

APPENDIX B

MACS (Dutch version)



Introductie en gebruikersinformatie

Het doel van de MACS is om te voorzien in een systematische methode om te classificeren hoe kinderen met cerebrale parese (CP) hun handen gebruiken wanneer ze objecten hanteren in dagelijkse activiteiten. De MACS is gebaseerd op spontaan uitgevoerde hand-vaardigheid, met in het bijzonder nadruk op het hanteren van objecten in de persoonlijke ruimte van het individu (de ruimte direct rond iemands lichaam, in tegenstelling tot objecten die niet binnen bereik zijn).

Het doel van de MACS is te bepalen welk niveau het best de gebruikelijke uitvoering door het kind thuis, op school en in de maatschappij weergeeft. Het bepalen van het niveau moet gedaan worden door iemand te vragen die het kind goed kent en niet door het afnemen van een specifieke test. De MACS is niet ontwikkeld om het beste vermogen te classificeren en is niet bedoeld om verschillen in vermogen tussen beide handen te onderscheiden. De MACS heeft niet de bedoeling om de onderliggende redenen voor beperkingen in uitvoering te verklaren of types cerebrale parese te classificeren.

Onderscheid tussen de niveaus is gebaseerd op de vaardigheid van het kind om objecten te hanteren en hun behoefte aan hulp of aanpassingen om hand-vaardigheidstaken in het dagelijks leven uit te voeren. Het gaat om objecten, die relevant en leeftijdsspecifiek zijn voor het kind, inclusief bijvoorbeeld die voor eten, kleden, spelen, schrijven, te onderscheiden van objecten die gebruikt worden voor meer gevorderde speciaal getrainde activiteiten zoals het bespelen van een muziekinstrument.

De MACS kan gebruikt worden voor kinderen van verschillende leeftijden, maar sommige termen moeten gerelateerd worden aan de leeftijd van het kind. Het ligt voor de hand dat kinderen op de leeftijd van 4 jaar andere objecten hanteren dan adolescenten. Hetzelfde geldt voor onafhankelijkheid, een jong kind heeft meer hulp en toezicht nodig dan een ouder kind.

De motivatie en cognitieve vaardigheden van een kind beïnvloeden zijn vaardigheid om objecten te hanteren en daarmee het MACS niveau. Als de motivatie van het kind om activiteiten uit te voeren laag is, als zij de taak niet begrijpen of continu om hulp en ondersteuning van volwassenen vragen, zullen ze geclassificeerd worden op basis van hun feitelijke uitvoering, zelfs al wordt er gedacht dat ze een beter vermogen hebben.

In het algemeen zal, als de hand-vaardigheid van een kind past binnen een bepaald niveau, het kind waarschijnlijk geclassificeerd zal worden op of boven dat niveau. Als kinderen objecten passend bij een bepaald niveau niet kunnen hanteren zullen zij vrijwel zeker geclassificeerd worden onder dat niveau. Niveau I bevat kinderen met cerebrale parese met hooguit minimale beperkingen vergeleken met zich normaal ontwikkelende kinderen, en waarbij de beperkingen, indien aanwezig, nauwelijks de uitvoering van taken in het dagelijks leven beïnvloeden.

In de MACS zijn vijf niveaus beschreven. Ook het onderscheid tussen elk van de niveaus is weergegeven om te helpen bij het bepalen van het niveau dat het meest nauwkeurig de hand-vaardigheid van een kind weergeeft.

De schaal is ordinaal, zonder de intentie dat de afstanden tussen de niveaus als gelijk moeten worden beschouwd, of dat kinderen met cerebrale parese evenredig verdeeld zijn over de vijf niveaus.

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Eliasson AC, Krumlinde Sundholm L, Rösblad B, Beckung E, Arner M, Öhrvall AM , Rosenbaum P. The Manual Ability Classification System (MACS) for children with cerebral palsy: scale development and evidence of validity and reliability Developmental Medicine and Child Neurology 2006 48:549-554

Manual Ability Classification System

Classificatiesysteem voor hand-vaardigheid voor kinderen met cerebrale parese, 4-18 jaar

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MACS is een systeem om bij kinderen de vaardigheid om objecten te hanteren in dagelijkse activiteiten te classificeren

- **MACS** heeft de bedoeling te beschrijven welk niveau het best de gebruikelijke uitvoering door het kind in huiselijke, schoolse en maatschappelijke omgeving representeert.
- Het **MACS** niveau moet bepaald worden gebaseerd op kennis over de actuele uitvoering door het kind in het dagelijks leven. Het moet niet bepaald worden door het afnemen van een specifieke test maar door het iemand te vragen die het kind kent en precies weet hoe dat kind activiteiten gewoonlijk uitvoert.
- Om het niveau van de **MACS** te bepalen, is het nodig het te hanteren object te bezien vanuit een leeftijdsafhankelijk perspectief.
- **MACS** heeft de bedoeling de inzet van beide handen tijdens activiteiten weer te geven en is niet een test van beide handen afzonderlijk.

MACS

Wat moet u weten om de MACS te gebruiken?

De vaardigheid van het kind om objecten te hanteren in belangrijke dagelijkse activiteiten, bijvoorbeeld tijdens spelen en vrije tijd, eten en kleden.

In welke situatie is het kind onafhankelijk en in welke mate heeft het hulp en aanpassingen nodig.

I. Hanteert objecten gemakkelijk en met succes. Hooguit beperkingen in het gemak van uitvoering van handvaardigheden of manuele taken die snelheid en nauwkeurigheid vereisen. Echter, eventuele beperkingen in hand-vaardigheid beperken niet de onafhankelijkheid in de dagelijkse activiteiten.

II. Hanteert meeste objecten, maar met iets verminderde kwaliteit en/of snelheid van uitvoering. Bepaalde activiteiten worden mogelijk vermeden of worden uitgevoerd met enige moeite; alternatieve manieren van uitvoering kunnen gebruikt worden maar de hand-vaardigheid beperkt de onafhankelijkheid in de dagelijkse activiteiten meestal niet.

III. Hanteert objecten met moeite; heeft hulp nodig bij het voorbereiden en/of aanpassen van activiteiten. De uitvoering is langzaam en wordt met beperkt succes volbracht wat betreft kwaliteit en kwantiteit. Activiteiten worden onafhankelijk uitgevoerd als ze voorbereid of aangepast zijn.

IV. Hanteert een beperkte selectie van makkelijk hanteerbare objecten in aangepaste situaties. Voert een deel van de activiteiten uit met moeite en met beperkt succes. Vereist continue ondersteuning en assistentie en/of aanpassingen, zelfs voor het gedeeltelijke volbrengen van de activiteit.

V. Hanteert objecten niet en heeft een ernstig beperkte vaardigheid om zelfs simpele acties uit te voeren. Vereist totale assistentie.

Onderscheid tussen niveau I en II

Kinderen in niveau I mogen beperkingen hebben in het hanteren van erg kleine, zware of fragiele objecten die gedetailleerde fijn motorische controle of efficiënte coördinatie tussen de handen vereisen. Beperkingen mogen ook de uitvoering in nieuwe en onbekende situaties betreffen. Kinderen in niveau II voeren bijna dezelfde activiteiten uit als kinderen in niveau I, maar de kwaliteit van uitvoering is minder, of de uitvoering is langzamer. Functionele verschillen tussen handen kunnen de effectiviteit van uitvoering beperken. Kinderen in niveau II proberen meestal het hanteren van objecten te vereenvoudigen, maken bijvoorbeeld gebruik van een oppervlakte ter ondersteuning in plaats van objecten met beide handen te hanteren

Onderscheid tussen niveau II en III

Kinderen in niveau II hanteren de meeste objecten, alhoewel langzamer of met verminderde kwaliteit van uitvoering. Kinderen in niveau III hebben meestal hulp nodig om de activiteit voor te bereiden en/of de omgeving aan te passen omdat hun mogelijkheid om naar objecten te reiken of het hanteren ervan beperkt is. Ze kunnen bepaalde activiteiten niet uitvoeren en hun onafhankelijkheid is gerelateerd aan de ondersteuning van de omgeving.

Onderscheid tussen niveau III en IV

Kinderen in niveau III kunnen geselecteerde activiteiten uitvoeren als de situatie is voorbereid en als ze supervisie en genoeg tijd krijgen. Kinderen in niveau IV hebben continu hulp nodig tijdens de activiteit en kunnen hooguit zinvol deelnemen aan gedeelten van de activiteit.

Onderscheid tussen niveau IV en V

Kinderen in niveau IV voeren een deel van een activiteit uit, maar hebben continu hulp nodig. Kinderen in niveau V kunnen hooguit deelnemen aan een simpele beweging in speciale situaties, bijvoorbeeld op een simpele knop drukken.

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"I'm everything I am, because you love me"

Curriculum vitae

The author was born in Rotterdam on the 21st of July 1963 and spent her childhood in Breda and Dordrecht. From 1975 to 1981 she attended *Het Christelijk Lyceum* (VWO) in Dordrecht.

In 1981 she started medical studies at the Erasmus University Rotterdam and obtained her medical degree in 1988.

After this she worked as a resident in the departments of Surgery, Neurology and Rehabilitation Medicine for children.

Three years later, in 1992, she started her residency in the department of Rehabilitation Medicine at the University Hospital Rotterdam *Dijkzigt*; head of the department and trainer Prof.dr. H.J. Stam. The residency consisted of 3 years rehabilitation in the university hospital and 1 year in the rehabilitation centre *de Hoogstraat* in Utrecht; trainer drs. W. van Haselen.

From 1996 onwards, she has been a member of staff of the department of Rehabilitation Medicine at the Erasmus Medical Centre Rotterdam and has also worked, for several years, in the children's hospital *Sophia*, part of the Erasmus MC.

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Jetty van Meeteren is married to Paul de Graaff and they have two daughters Anouk (1999) and Kyra (2003).