



APPENDIX I: 3D Upper Limb analysis

1. UPPER LIMB MODEL

In this appendix, the results from the standardization committee of the International Society of Biomechanics (Wu et al. 2005) have been used as guidelines.

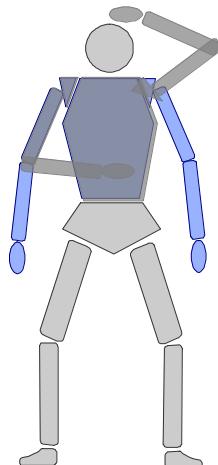
1.1 KINEMATIC MODEL

Five rigid segments represent the kinematic model of the upper limb:

1. Thorax (represented by the sternum)
2. Scapula
3. Upper arm (Humerus)
4. Forearm (Radius)
5. Hand (carpals & metacarpals 2-5)

Five joints are analyzed:

1. Trunk movement
2. Scapulathoracic movement
3. Shoulder
4. Elbow
5. Wrist



www.bodymech.nl

1.2 MEASUREMENT MODEL

Each segment is completely defined in space by a technical cluster of at least three non-collinear markers. Inter-marker motions are suppressed by fixing the markers in clusters on a common surface per segment. The markers have a diameter of 14mm and are attached to the cuffs using Velcro-straps (Fig. 1). Technical coordinate frames are calculated based on singular value decompositions (ref.).

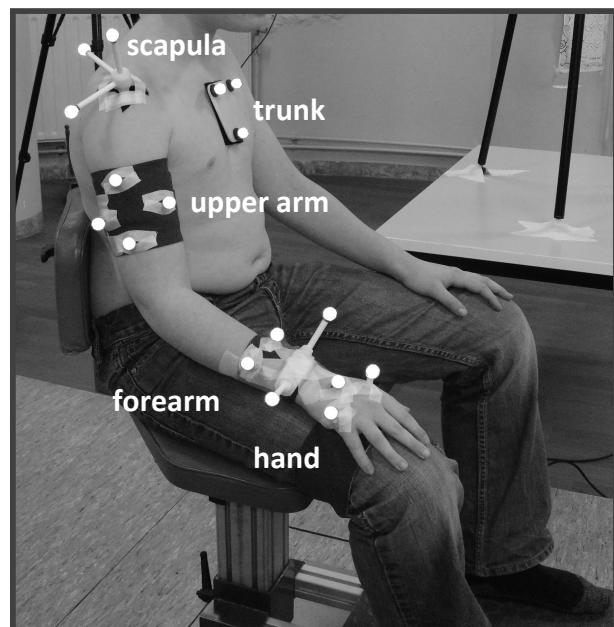


Fig. 1: Segmental marker clusters



1.3 ANATOMICAL FRAMES AND JOINT MOVEMENTS

The selection of bony landmarks for defining the anatomical frames, the calculation of the anatomical frames, as well as the rotation sequences for the joint angles all follow the ISB recommendations (Wu et al. 2005).

The anatomical landmarks are defined within their respective segmental technical coordinate systems using the CAST-procedure (ref).

The axes follow the convention for the global coordinate system, which is

X: the axis pointing forward

Y: the axis pointing upward

Z: the axis pointing lateral to the right

TABLE I: Upper limb joints and clinical definitions of rotations

JOINT	Joint Type	Segments	Degrees of Freedom
TRUNK	Trunk movement in three planes	Sternum relative to the global coordinate system	Extension/Flexion Lateral Flexion Axial Rotation
SCAPULO-THORACIC	Artificial joint	Scapula relative to the trunk	Protraction/Retroversion Lateral/Medial Rotation Anterior/Posterior Tilt
SHOULDER*	Ball and socket joint	Humerus relative to the trunk	GH Plane of elevation GH Elevation GH Axial Rotation
ELBOW	Rotating hinge joint	Forearm relative to the humerus	Flexion/Extension Pronation/Supination
WRIST	Universal joint	Hand relative to the forearm	Palmar/Dorsal Flexion Ulnar/Radial Flexion

See 3.1 for interpretation of joint angles

2. MEASUREMENT SET-UP

2.1 STANDARDIZATION

A thorough standardization of the set-up is provided, by means of a custom-made chair, to ensure maximum repeatability of the task performance (Figure 2).

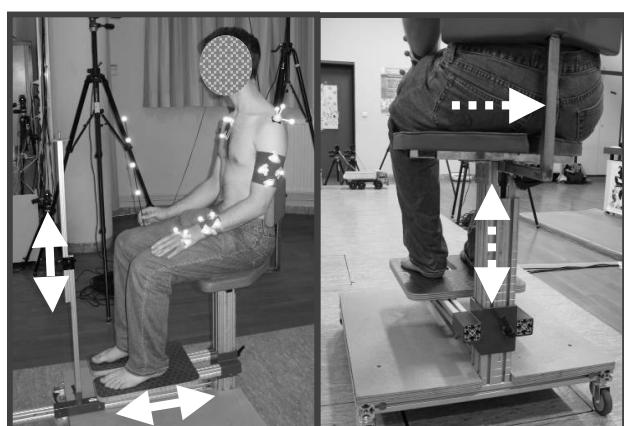


Fig. 2: children are seated in a custom-made chair that allows adjusting foot and back support (dotted arrows) and reaching distance and height (full arrows) to the individual anthropometric measures of each child



2.2 MOVEMENT PROTOCOL

All upper limb tasks are executed with the non-preferred (i.e. affected) arm at self-selected speed. Two trials are collected for every task and children are asked to repeat every task 4 times per trial.

REACH FORWARDS



REACH SIDEWAYS



REACH UPWARDS



REACH TO GRASP SPHERICALLY



REACH TO GRASP VERTICALLY



HAND TO MOUTH



HAND TO HEAD



HAND TO SHOULDER





3. DATA ANALYSIS TOOL

U.L.E.M.A. (Upper limb Evaluation in Motion Analysis) runs on MATLAB version 7.3 and higher, including the Signal Processing Toolbox, and has adopted the underlying structure of BodyMech to store data (ref).

ISB guidelines (Wu et al. 2005) are implemented to compute anatomical coordinate systems and joint angles (trunk, scapulathoracic, shoulder, elbow, wrist). U.L.E.M.A. is offered as a graphical user interface and has been created to ensure maximum applicability in clinical practice and research (Fig. 3).

It allows processing multiple trials, sessions and subjects at once. The required conditions for each trial under analysis are highly modifiable and can be defined by the users, e.g.:

- side analysed (left, right, or bilateral)
- segments/joints to include
- definition of the coordinate system (ISB or Grood & Suntay)
- calculation of the shoulder joint centre, i.e. regression (Meskers et al. 1997) or functional (ref).

U.L.E.M.A. allows the calculation of

- Spatiotemporal parameters
- Joint angles
- Arm Movement Analysis Profile (Jaspers et al. 2011)

Processed data is stored in a structured array (.mat), though multiple exportation options are available: C3D (BT-K tools [ref]), CSV, PDF (MAPs) or XML.

Finally, U.L.E.M.A. allows computing a reference data set. Depending on the exportation format, reports can be made in Polygon®, excel or using a standalone Python application (developed as part of U.L.E.M.A.). The latter permits the transformation of custom OpenOffice templates into reports. The software will be made available online (GitHub page).

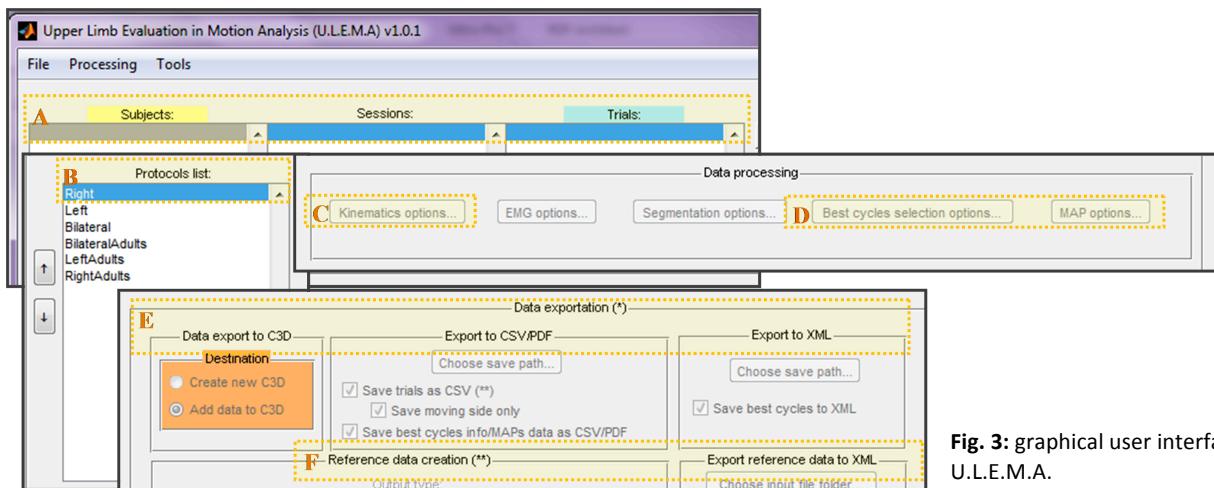
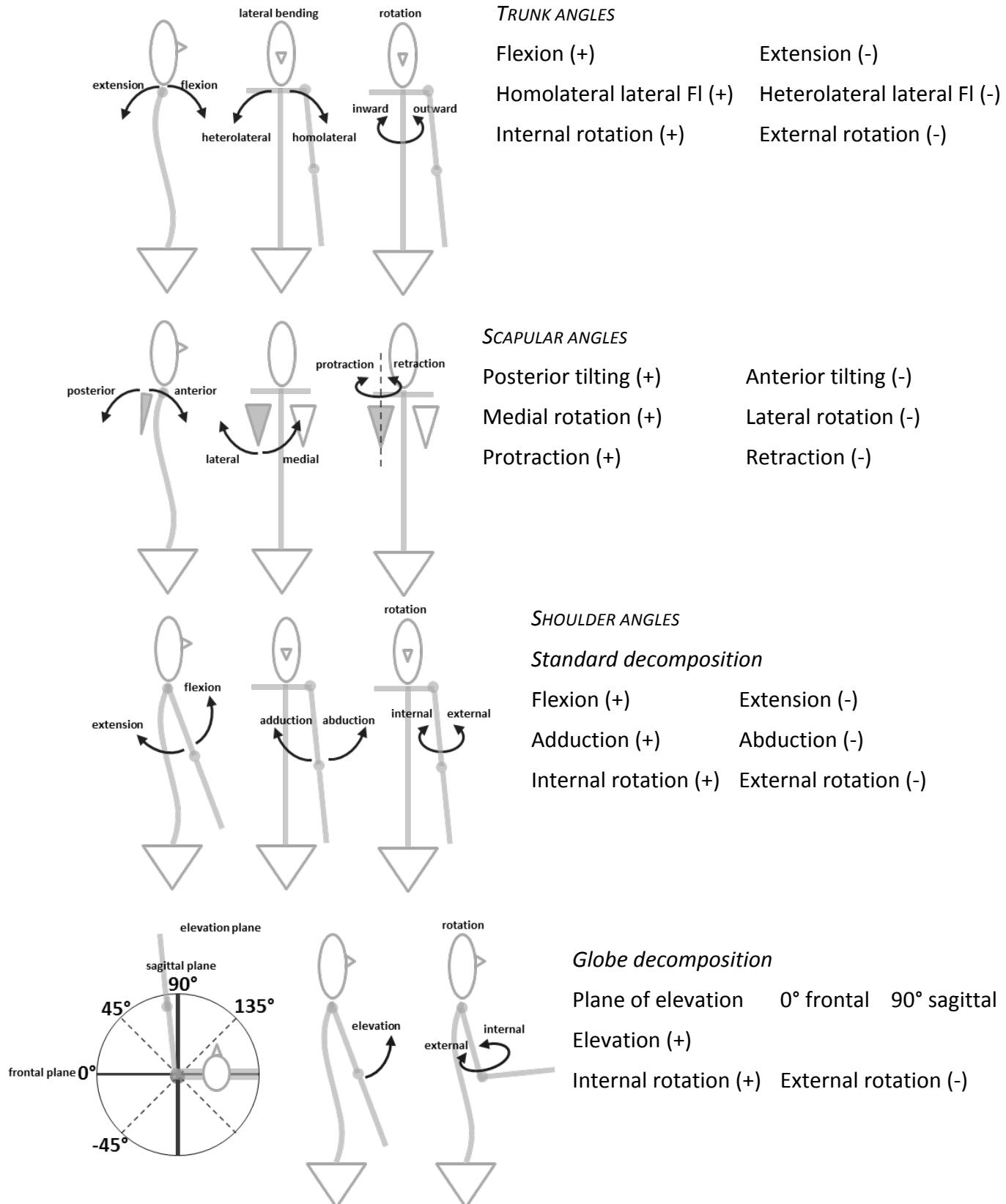


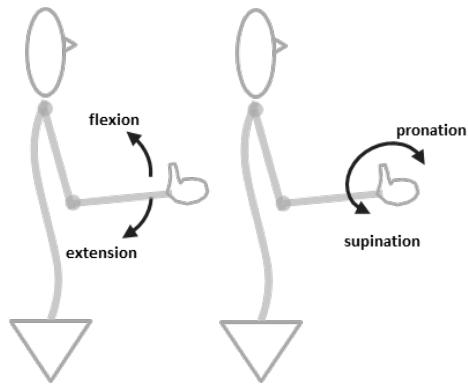
Fig. 3: graphical user interface of U.L.E.M.A.



4. DATA INTERPRETATION

4.1 KINEMATICS

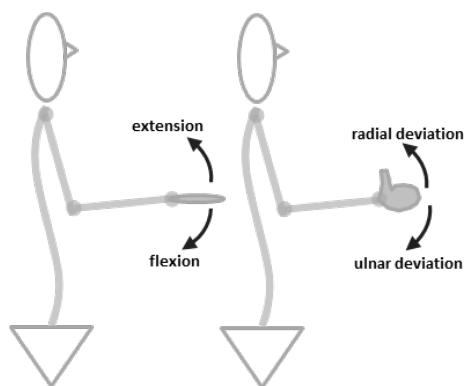




ELBOW ANGLES

Flexion (+)
Pronation (+)

Extension (-)
Supination (-)



WRIST ANGLES

Flexion (+)
Ulnar deviation (+)

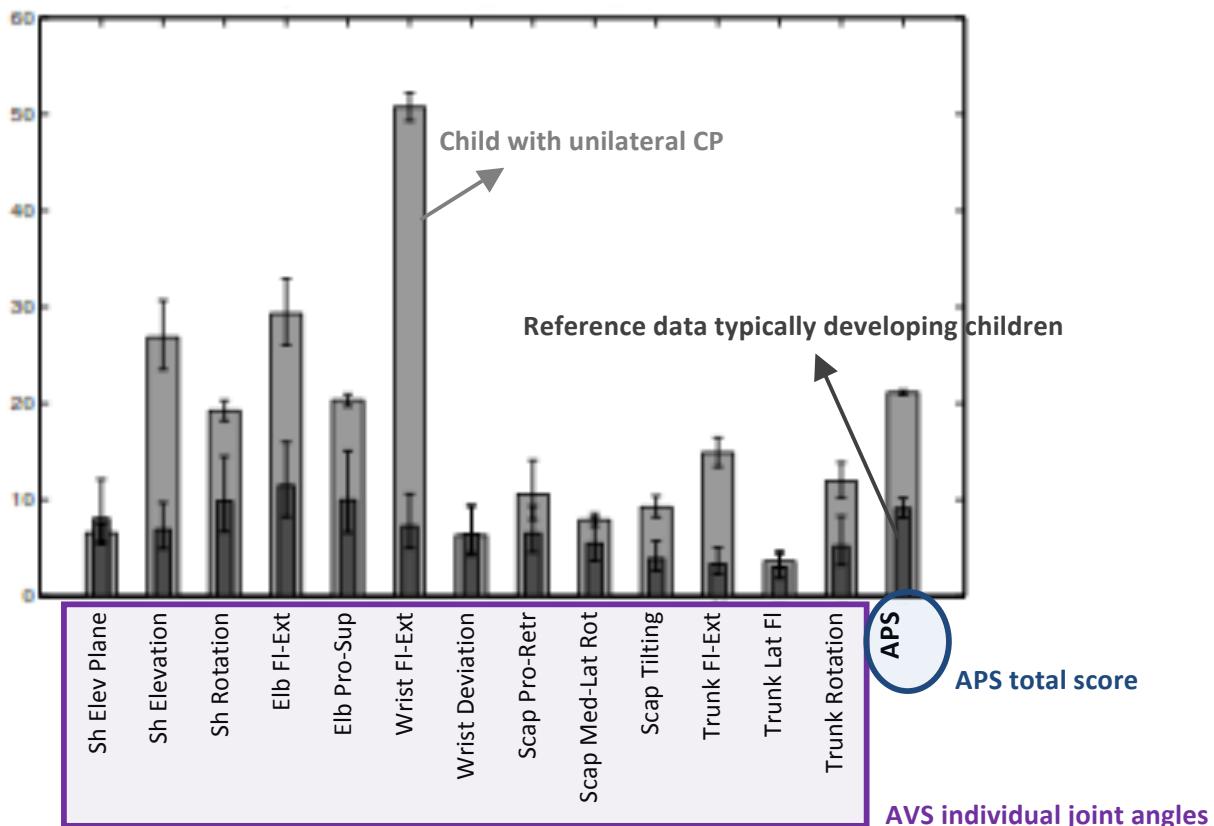
Extension (-)
Radial deviation (-)



4.2 SPATIOTEMPORAL PARAMETERS

Maximum speed (mm/sec)	maximum speed in movement cycle
Timing maximum speed (%)	time-point in movement cycle when max speed is reached
Duration (sec)	duration of movement cycle
Index of curvature	ratio between straight line and travelled hand path between start and endpoint of movement

4.3 MOVEMENT ANALYSIS PROFILE (MAP)





APPENDIX II: Clinical Evaluation

1. CLASSIFICATION SYSTEMS

House Classification

- 0= does not use
- 1= poor passive assist / uses as stabilizing weight only
- 2= fair passive assist / can hold object placed in hand
- 3= good passive assist / can hold object and stabilize it for use by other hand
- 4= poor active assist / can actively grasp object and hold it weakly
- 5= fair active assist / can actively grasp object and stabilize it well
- 6= good active assist / can actively grasp object and manipulate it against other hand
- 7= spontaneous use partial / can perform bimanual activities easily and occasionally uses the hand spontaneously
- 8= spontaneous use complete / uses hand completely independently without reference to the other hand

House Thumb Classification

- (0 = no thumb contracture)
- 1= Simple metacarpal adduction
- 2= Metacarpal adduction and metacarpal phalangeal flexion
- 3= Metacarpal adduction and phalangeal extension/instability
- 4= Metacarpal adduction and phalangeal flexion, interphalangeal flexion

Zancolli classification

- 1= Can completely extend the fingers with a neutral position of the wrist or with less than 20° of flexion
- 2= Fingers can be actively extended but only with more than 20° of wrist flexion
 - 2a= can actively extend, partially or totally, the wrist with the fingers flexed
 - 2b= can not actively extend the wrist with the fingers flexed
- 3= Cannot extend the fingers even with maximal flexion of the wrist, due to severe flexion spasticity

Manual Ability Classification System (MACS)

- 1 = Handles objects easily and successfully
- 2 = Handles most objects but with somewhat reduced quality and/or speed of achievement
- 3 = Handles objects with difficulty; needs help to prepare and/or modify activities
- 4 = Handles a limited selection of easily managed objects in adapted situations
- 5 = Does not handle objects and has severely limited ability to perform even simple actions



2. RANGE OF MOTION (ROM)

shoulder

forward flexion:	0° = neutral, neutral shoulder position, degrees forward flexion is noted, 180° = normal
abduction:	0° = neutral, degrees abduction is noted, follow the spontaneous shoulder rotation, remain in the horizontal plane, 180° = normal
external rotation:	0° = neutral (starting from 90° shoulder abduction & elbow flexion), degrees external rotation is noted, 90° = normal
internal rotation:	0° = neutral (starting from 90° shoulder abduction & elbow flexion), degrees internal rotation is noted, 70° = normal

elbow

extension:	position the forearm to allow maximum ROM 0° = normal, extension deficit is noted negatively, hyperextension is also noted
------------	--

forearm

supination:	90° elbow flexion, degrees supination is noted, place the goniometer on dorsal side of the wrist, 90° = normal
-------------	--

wrist

extension with fingers flexed:	wrist in neutral position (no ulnar-radial deviation), degrees extension is noted, place the goniometer laterally, 85° = normal
extension with fingers extended:	wrist in neutral position (no ulnar-radial deviation), degrees extension is noted, place goniometer laterally, 85° = normal

fingers

extension PIP with wrist and MCP neutral:	ordinal scale
extension DIP with wrist, MCP and PIP neutral:	ordinal scale

thumb

abduction (in the plane of the hand):	ordinal scale
---------------------------------------	---------------

ordinale scale limitation passive ROM

- 0 = normal
- 1 = discrete limitation
- 2 = severe limitation
- h = hyperextension



3. MUSCLE TONE

Modified Ashworth Scale (MAS) for grading spasticity

- | | |
|----|---|
| 0 | no increase in muscle tone |
| 1 | minor increase in muscle tone, manifested by a catch & release or by a minor resistance at the end of the ROM |
| 1+ | minor increase in muscle tone, manifested by a catch, followed by a minor resistance at the end of the ROM (2nd half of movement range) |
| 2 | notable increase in muscle tone in main part of ROM, though extremity is still easy to move |
| 3 | very clear increase in muscle tone, passive movement of the extremity is difficult |
| 4 | no movement of the extremity possible, fixed in flexion or extension |

shoulder

adductors- abductors	remain in the horizontal plane
extensors	
internal rotators	same starting position as for ROM-testing
external rotators	same starting position as for ROM-testing

elbow

flexors	forearm neutral Tardieu is noted as an extension deficit (negative, 0° ext = normal)
extensors	forearm neutral Tardieu is noted as degrees between horizontal plane and the forearm

forearm

pronators	90° elbow flexion, wrist neutral
-----------	----------------------------------

wrist

flexors	Tardieu is noted as degrees of extension from neutral position (e.g. -5° or 10°)
extensors	Tardieu is noted as degrees of flexion from neutral position (e.g. -5° or 10°)

fingers

flexors	wrist in neutral position
---------	---------------------------



4. STRENGTH

Double scoring system: active ROM & manual muscle testing

Active range of motion

- 0 = normal
- 1 = discrete limitation (less than half the passive ROM)
- 2 = marked limitation (more than half the passive ROM)
- 3 = no movement

Strength score

- 0 no contraction
- 1 no movement, though contraction present
- 2- movement initiation, though not possible against gravity
- 2 full range of movement without gravity possible, against gravity only movement initiation possible
- 3 full passive range of movement is achieved against gravity, though not possible against resistance
- 3+ first part of the active range movement against minor resistance, second part only against gravity
full active range of movement against minor resistance (possibly first part of movement against larger
- 4 resistance compared to second part of movement)
- 5 full active range of movement against full resistance

! Do not allow shoulder rotation during forward flexion or ab/adduction of the shoulder

Elbow pro/supination is tested with 90° elbow flexion



5. SENSORY FUNCTION

exteroception (tactile sensibility)

touch with finger

test thumb, index and hand palm in random order, when possible also test left-right randomly

thumb and index: touch distal phalanx

3 attempts per site

scoring: 0 exteroception absent

 1 reduced (1 or 2 attempts wrongly answered)

 2 normal

proprioception (motion sensibility)

1 hand fixes MCP, 1 hand moves the distal index in both directions, response should be given immediately

test index , child is given 3 attempts

if not felt within small movement amplitude, try again with larger amplitude (if all answered correctly within larger amplitude, score "1")

scoring: 0 proprioception absent

 1 reduced (1 or 2 attempts wrongly answered)

 2 normal

two-point discrimination

parallel to finger

test at the distal phalanx of the index finger

scoring: the distance in mm at which 5 consecutive trials are answered correctly

stereognosis

12 objects are presented to the child at forehand (child is not allowed to touch the objects):

6 objects are used to test stereognosis, of which 3 objects from the similar group and 3 objects from the dissimilar group

first test the hemiplegic side, if not answered correctly, present object to non-hemiplegic side

child should try to manipulate the object by his/herself

if not possible, the therapist moves the object

if still not possible, the therapist moves the child's fingers around the object

12 objects pencil and pen; coin and button; safety pin and paperclip
 coomb - key - pellet -washing pin - spoon - bal

scoring: number of correctly identified objects (max. 6)