The aim is to present an integrated multidisciplinary approach for spasticity assessment, by providing information about accurate and valid methods that are suitable for the clinic.

An instrumented assessment of spasticity developed for routine clinical practice can assist clinicians to make more goal directed decisions about the treatment pathways for their patients, to choose the most efficient and cost effective management option for the individual patient and to verify the efficacy of various procedures. Crucial in the instrumented spasticity assessment is the multidisciplinary approach to the problem by aiming for an optimal combination of the biomechanical, neurophysiological and clinical aspects of the problem. Three groups of signals during standardised passive isolated movements in different lower limb joints, which are (1) stretch characteristics (joint angle parameters), (2) reactive resistance and (3) muscle activity, are integrated to provide objective spasticity parameters. Clinically meaningful parameters for spasticity assessment are described and relations between biomechanical and neurophysiological characters of the reflex responses and velocity of lengthening are highlighted. These associations between parameters, as well as innovative parameters describing additional phenomena of spasticity, can be used to unify all multidisciplinary knowledge in an integrated clinical spasticity assessment, illustrated by clinical cases.
A velocity dependent increase in tonic stretch reflex (muscle tone) with exaggerated tendon jerks, Resulting from hyper excitability of the stretch reflex, As one component of the upper motor neurone syndrome

Lance 1980

Scoring the resistance felt in a specific muscle group by passively moving a limb at one velocity

Bohannon and Smith 1987
Clinical grading of spasticity

- Related to muscle activity
  - E.g. Spasticity
  - Increased resistance to passive motion

- Related to passive structures
  - Stiffness
  - Viscosity
  - Inertia

Outline

- Introduction
- Instrumented Spasticity Assessment
  - Protocol
  - Spasticity parameters
  - Angle Of Catch (AOC)
  - Treatment
- Advanced data-analysis for treatment fine-tuning

Instrumented Spasticity Assessment (ISA)

A clinical measurement to quantify spasticity in children with cerebral palsy by integration of multidimensional signals

- Desloovere Kaat

Instrumented spasticity assessment
Spasticity assessment

- Muscle length/lengthening velocity
- Joint angles/velocity (muscle length/lengthening velocity)
- EMG (Tonic stretch reflex)
- Torque (reactive Resistance)

Reactive resistance

Tonic stretch reflex

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Signals measured simultaneously

Angles and angular velocity

Torque

Electromyography (EMG)

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Protocol: Instrumented Spasticity assessment (ISA)

• Manually performed passive stretches
• Three stretch velocities:
  • Low (5sec), Medium (1s), High (as fast as possible)
• 3 good repetitions
• 7 seconds rest between stretches

Data acquisition and sensor processing Overview

Sensing → Acquisition → Calibration & Processing → Presentation & Data analysis

Desloovere Kaat
Data acquisition and sensor processing
Overview

Sensing
Motion
Force
EMG

Measuring the Velocity of Stretch

Inertial Measurement Units (IMU) sensors
- Gyroscope: angular velocity
- Accelerometer: gravity and acceleration

1. placed arbitrarily
2. joint motions/positions calibrated during measurement protocol

Measuring the torque

Force/Torque-sensor
Interaction force therapist-patient
- 3 forces
- 3 torques

Specific adaptors to attach sensor to limb.

Foot-piece: Triceps
Calf-piece: Hamstrings
Knee extensors

Measuring Muscle Activity

Wireless EMG
1. Standard electrode placement (SENIAM) (Hermens et al. 2000)
2. Maximal Voluntary Contraction (MVC)
3. EMG in rest
Data acquisition and sensor processing

Overview

Sensing
Motion
Force
EMG

Acquisition
Compact Rio
Acquisition GUI
Clinical information

Calibration & Processing

Presentation & Data analysis

Presentation
Analysis
Exploration group analysis

Synchronous acquisition and
Grafical User Interface (GUI)

Motion capturing system

Interaction force

sEMG
Synchronous
Clinical information

and context.

Data acquisition and sensor processing

Acquisition set-up

Clinical Protocol
Calibration motion sensors

• Ankle
  • Neutral position
  • Move to plantar flexion

• Knee
  • Full extension
  • Move to knee flexion

• Hip
  • Neutral ab/adduction
  • No motion

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Calculating the net internal joint torque

Taking into account:

• Forces in non-perpendicular directions
• Moments exerted by the therapist
• Inertia
• Gravity

\[ M_{\text{net}} = -F_\theta \ddot{\theta} + F_\theta \dot{\theta} + M_d - mg \cos(\alpha_{\text{kinz}}) \gamma_{\text{pess}} - I_{\text{arm}} \alpha_{\text{arm}} \]

(with \( I_{\text{arm}} = \alpha_{\text{arm}}^2 \))

(Anthropometric models of Drillis 1964, and Jensen 1986)

---

Four lower-limb muscles

Adductors
Gastrocnemius
Hamstrings
Rectus Femoris

---

Data acquisition and sensor processing

Overview

Presentation & Data analysis

Presentation
Analysis
Exploration group analysis

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Comparison between velocities

**Low velocity**

- Position
- Velocity
- RMS-EMG
- Torque

**High velocity**

- Position
- Velocity
- RMS-EMG
- Torque

Muscle Activity

**Raw EMG**

- Example of patient
  - Stretch at low velocity
  - Stretch at high velocity

- Example of typical subject
Muscle Activity

**Raw EMG**

**rms EMG**

Stretch at high velocity

- **Start:** 200 msec prior to the time of max velocity
- **End:** at 90% of total range of motion

- **Average of EMG**
  - Area under rms EMG-time curve divided by time and expressed as % of MVC
- **Knee angle and angular velocity at EMG onset**

Three stretch velocities

1. Slow (ROM)
2. Medium (Ashworth-like)
3. High (Tardieu-like)

- **Period of interest**

Compare between velocities

- **Position**
- **Velocity**
- **RMS-EMG**
- **Torque**

**Change between velocities**

- **Time (s)**

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Torque at 70° knee flexion

Low velocity

High velocity

Change between Low and High

Work

From maximum velocity until 90% of the ROM

\[ W = \int_{p_{\text{start}}}^{p_{\text{end}}} \tau \, d\theta \]
Change between High and Low Work
From maximum velocity until 90% of the ROM

Three stretch velocities
1. Slow (ROM)
2. Medium (Ashworth-like)
3. High (Tardieu-like)

Work

Change between velocities

Instrumented spasticity assessment

- Spasticity parameters are reliable
- Instrumented spasticity has discriminative validity (between CP and TD)
- Parameters can distinguish different levels of spasticity
• Introduction

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Modified Tardieu Scale

- Subjective
- Inaccurate

Quantification of the spastic catch

Quantitative definitions

Maximum change in torque (dT/dt)
AOC 1

Maximum deceleration
AOC 2

ISOLATED BIOMECHANICAL SIGNALS
Velocity dependence of the catch angle

Wu et al. 2010

The faster the stretch, the later the catch?!

We assume that the earlier the catch, the more severe the spasticity

BUT

Problem with the AOC!

Angle of catch (AOC)

Joint angular velocity

EMG

Torque

Joint angular position

Integration of signals

TORQUE (T)

VELOCITY (ω)

POWER (ω*T)

INTEGRATED SIGNAL

AOC 3 = min. (ω*T)

Integration

Quantification of signals

Quantification of the spastic catch

Spastic Catch conclusions

- The AOC depends on the velocity of stretch.
- AOC best defined by integrating signals.
- The intensity at which the catch occurs should additionally be considered.
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Sensitivity to BTX-A treatment

**CP (n=31), Hamstrings muscles (n=40)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pre Ashworth</th>
<th>Post Ashworth</th>
<th>Pre Tardieu</th>
<th>Post Tardieu</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMS-EMG (mV)</strong></td>
<td>1+</td>
<td>1+</td>
<td>-15°</td>
<td>-15°</td>
</tr>
<tr>
<td><strong>Torque at 70˚ (Nm)</strong></td>
<td>1+</td>
<td>1+</td>
<td>-50°</td>
<td>-50°</td>
</tr>
<tr>
<td><strong>Torque at Vmax (Nm)</strong></td>
<td>1+</td>
<td>1+</td>
<td>-15°</td>
<td>-15°</td>
</tr>
<tr>
<td><strong>Work (J)</strong></td>
<td>1+</td>
<td>1+</td>
<td>-50°</td>
<td>-50°</td>
</tr>
<tr>
<td><strong>AOC (%)</strong></td>
<td>1+</td>
<td>1+</td>
<td>-15°</td>
<td>-15°</td>
</tr>
<tr>
<td><strong>AOC power (W)</strong></td>
<td>1+</td>
<td>1+</td>
<td>-50°</td>
<td>-50°</td>
</tr>
</tbody>
</table>

Spasticity parameters are sensitive to the effect of BTX

Clinical cases: Eline and Yana

**Eline**

- BTX: GAS 3U/Kg, MEH 4U/Kg
- Pre Ashworth: 1+
- Post Ashworth: 1+
- Pre Tardieu: -15°
- Post Tardieu: -50°

**Yana**

- BTX: GAS 3U/Kg, MEH 1U/Kg
- Pre Ashworth: 1+
- Post Ashworth: 1+
- Pre Tardieu: -15°
- Post Tardieu: -50°
Instrumented spasticity assessment
Effect of botulinum toxin

• Spasticity parameters are sensitive in measuring the effect of BTX-A in the hamstrings
• Instrumented spasticity is more responsive than clinical scales
• Torque is less sensitive to BTX than EMG

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How can we explain the variation in response to treatment?

• Advanced analysis of EMG
• Advanced analysis of torque
### EMG

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>RMS-EMG (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLOW</td>
<td>Fast</td>
</tr>
</tbody>
</table>

**Gastrocnemius**

- SLOW stretch
- FAST stretch

**Hamstrings**

- SLOW stretch
- FAST stretch

### Position zones

- Position Zone 1

### Study Results (N = 54 children with CP)

**Visual classification of EMG patterns**

- **Gastrocnemius**
  - Velocity dependent
- **Adductors**
  - Mixed pattern
- **Low velocity dependent**
- **Rectus Femoris**
  - Mixed more velocity
- **Medial Hamstrings**
  - Mixed more low velocity dependent
Parameter development

EMG parameters

Study Results

Pilot study

Conclusions

- Differences between muscles
  - Hamstrings and adductors => low velocity-dependent
  - Gastrocnemius and Rectus femoris => velocity dependent

- Differences between patients

  Pattern definition may help to fine-tune patient specific treatment
Advanced analysis of torque

Is it stiff or is it spastic?

Increased joint torque

ASSESS

Stiff or Spastic?

Non-neural causes
Muscle and joint structure
Inertia
Stiffness
Viscosity

Neural causes
Hyper-active stretch reflex
Muscle activation

Stiff or Spastic?

Computational models

Motor-driven systems

Clinical reality?
Not clinically applicable for children
Mostly validated for upper limb and ankle

Torque decomposition

Related to passive structures

\[ T = \left( 1 + b \frac{d\theta}{dt} \right)^2 (\theta - \theta_0) + T_0 \]

(De Vlugt et al. 2012)

Joint angle (°)

Torque (Nm)

Time (s)
What part in the curve is not explained by stiffness or viscosity?

\[ T = \left( 1 + \frac{d}{dt} \right) e^{k(\theta - \theta_0)} + T_0 \]

Anthropometric parameters measured and estimated (Drillis 1964 and Jensen 1986)

- **Non-neural**
  - Stiffness
  - Viscosity

\[ T = \left( 1 + \frac{d}{dt} \right) e^{k(\theta - \theta_0)} + T_0 \]

Joint angle (°)  Torque (Nm)

Fast stretch

**Fitting error** = 0.44 Nm

Model deviation

Large deviation from stiffness during fast stretch

**Fitting error** > 0.04 Nm

Slow stretch is well explained by stiffness curve

Searching for maximum fitting error

Deviation from the model

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**Conclusions**

- Neural component of torque is sensitive to treatment
- Non-neural component of torque is not sensitive to treatment

Torque decomposition may help to fine-tune patient specific treatment.
Quantify and assess: Bar De Huenaerts, Bar doi:10.1371/journal.pone.0091759.

Developmental Desloovere, (2013). with Bar Boha Jensen

References


