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# Analysis of Hemiparetic Gait by Using Mechanical Models

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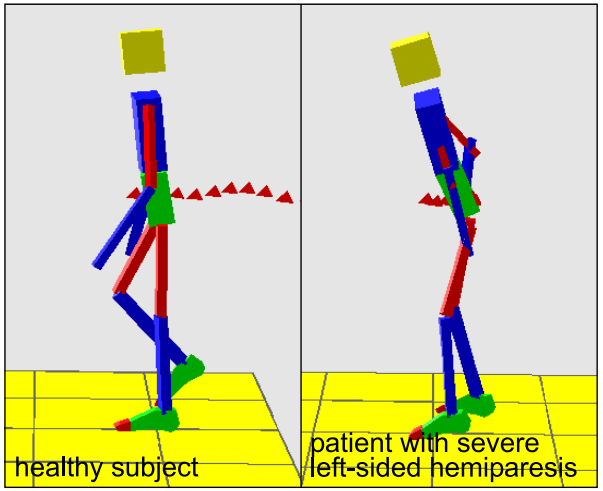
- Gait Analysis
- Mechanical Model of the Human Locomotor Apparatus
- Mathematical Formulation
- Measurements and Verification
- Results
- Future Work

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**Purpose: reduction of gait deviations**

- diagnosis of gait deviations
- definition of therapy
- control and quantization of outcome of therapy

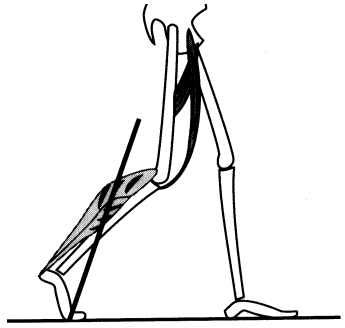
**Execution:**

- performed by a physical therapist or doctor
- simulation and measurements provide additional information:
  - cadence, step length
  - joint angles
  - forces, torques, ...
  - EMG profiles

$\Rightarrow$ more precise gait analysis

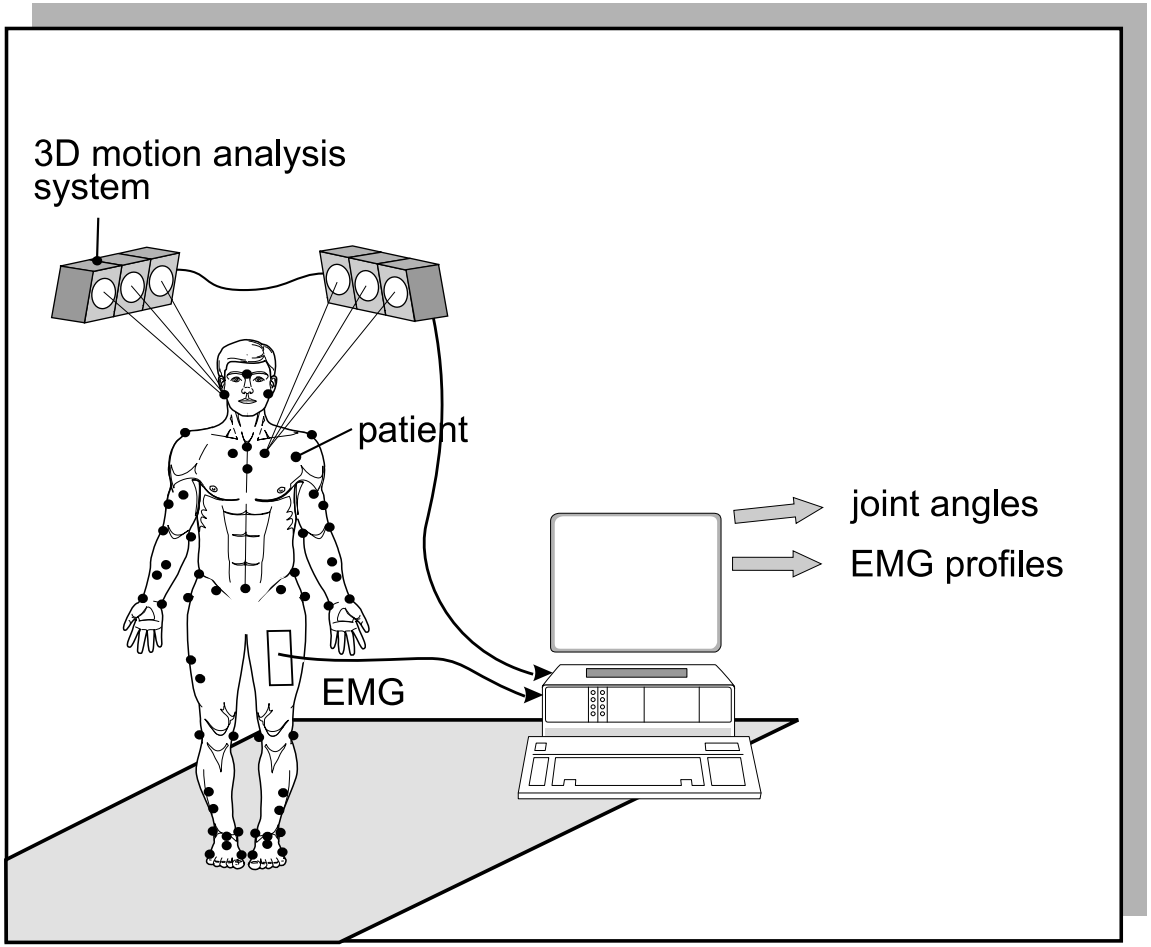
hemiparetic

normal



from Perry, J.: Gait Analysis

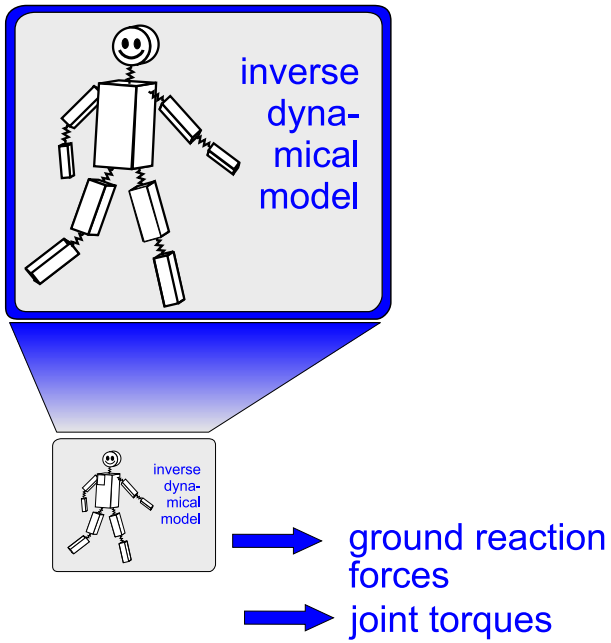
# Common Gait Analysis





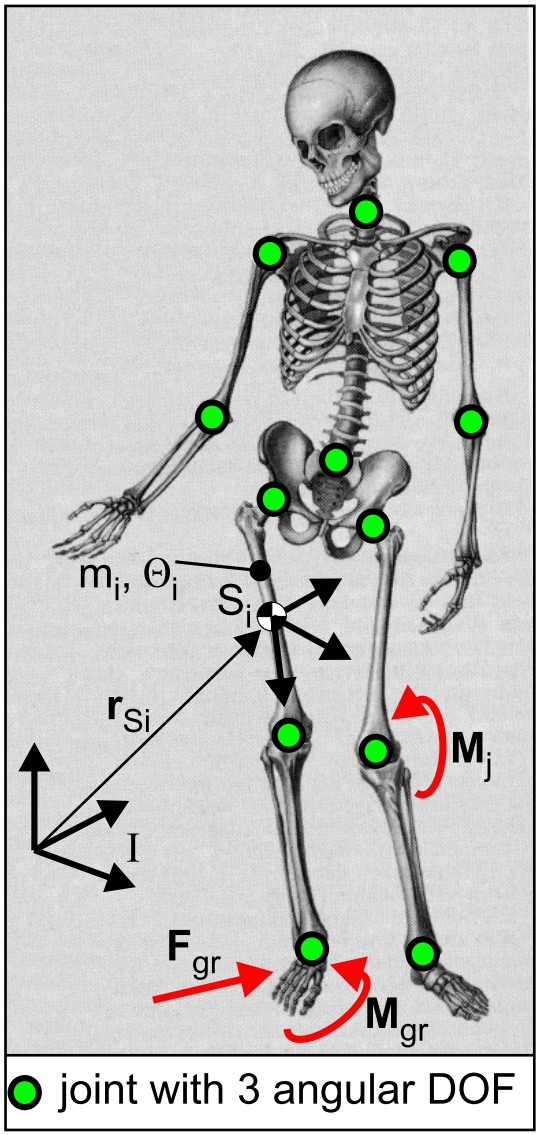

1. Gait Analysis

# and Extended




## Advantages of the extended approach:

- additional quantities for diagnosis
  - ground reaction forces
  - joint torques, power
- better understanding and therapy of gait deviations
- no force plates needed




**Model properties:**

- three-dimensional multibody-system
- 13 rigid bodies
- 12 joints with 3 degrees of freedom each
- 42 degrees of freedom at all
- joint torques $\boldsymbol{M}_j$
- ground reaction forces $\boldsymbol{F}_{gr}$ and torques $\boldsymbol{M}_{gr}$
- parameter scaling for each patient



2. Mechanical Model of the Human Locomotor Apparatus

- equations of motion for the single support phase

$$\boldsymbol{M}(\boldsymbol{q})\ddot{\boldsymbol{q}} - \boldsymbol{h}(\boldsymbol{q},\dot{\boldsymbol{q}}) = \boldsymbol{J}_T^T\boldsymbol{F}_{gr} + \boldsymbol{J}_R^T\boldsymbol{M}_{gr} + \sum_{k=1}^{12}\boldsymbol{J}_{R,k}^T\boldsymbol{M}_{j,k}$$

- equations of motion for the double support phase

$$\boldsymbol{M}(\boldsymbol{q})\ddot{\boldsymbol{q}} - \boldsymbol{h}(\boldsymbol{q},\dot{\boldsymbol{q}}) = \sum_{i=1}^{2}\left\{\boldsymbol{J}_{T,i}^T\boldsymbol{F}_{gr,i} + \boldsymbol{J}_{R,i}^T\boldsymbol{M}_{gr,i}\right\} + \sum_{k=1}^{12}\boldsymbol{J}_{R,k}^T\boldsymbol{M}_{j,k}$$

optimization

$$C = \frac{1}{2}\boldsymbol{f}_{gr}^T\boldsymbol{C}_1\boldsymbol{f}_{gr} + \frac{1}{2}\boldsymbol{t}_{gr}^T\boldsymbol{C}_2\boldsymbol{t}_{gr} + \frac{1}{2}\boldsymbol{t}_j^T\boldsymbol{C}_3\boldsymbol{t}_j$$

Lagrangian function L

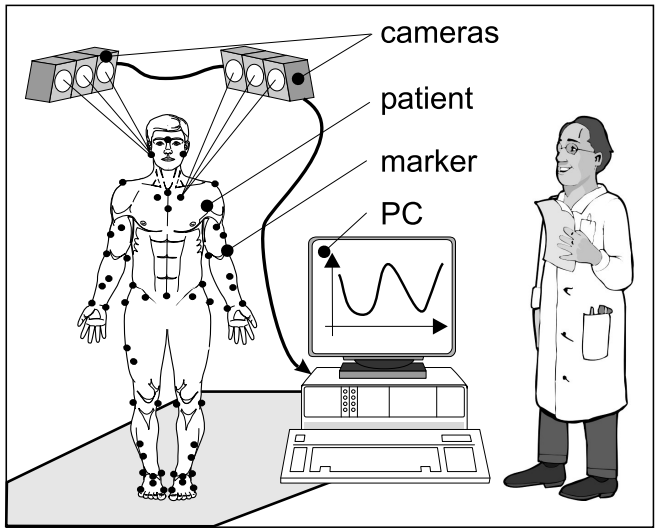
$$L = C + \boldsymbol{\lambda}^T\left\{\left[\boldsymbol{J}_{T,gr}^T \mid \boldsymbol{J}_{R,gr}^T\right]\begin{pmatrix}\boldsymbol{f}_{gr} & \boldsymbol{t}_{gr}\end{pmatrix} + \boldsymbol{J}_{R,j}^T\boldsymbol{t}_j - \boldsymbol{M}\ \ddot{\boldsymbol{q}} + \boldsymbol{h}\right\}$$

- inverse dynamics

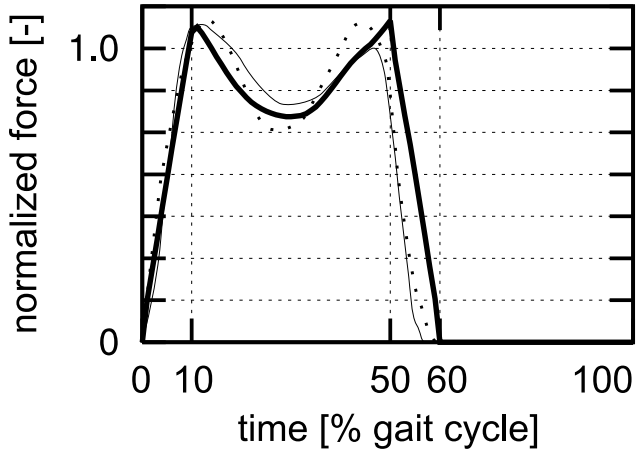
$$\boldsymbol{q}(t), \dot{\boldsymbol{q}}(t), \ddot{\boldsymbol{q}}(t) \rightarrow \boldsymbol{F}_{gr,j}(t), \boldsymbol{M}_{gr,j}(t), \boldsymbol{M}_{j,i}(t)$$

## Measurements

- performed in the neurological clinic in Bad Aibling, Germany
- contactless 3D motion analysis system with 58 markers (Optotrak)
- measurement of joint angles
- computation of joint angular velocities and accelerations by differentiation




## Verification of the Model

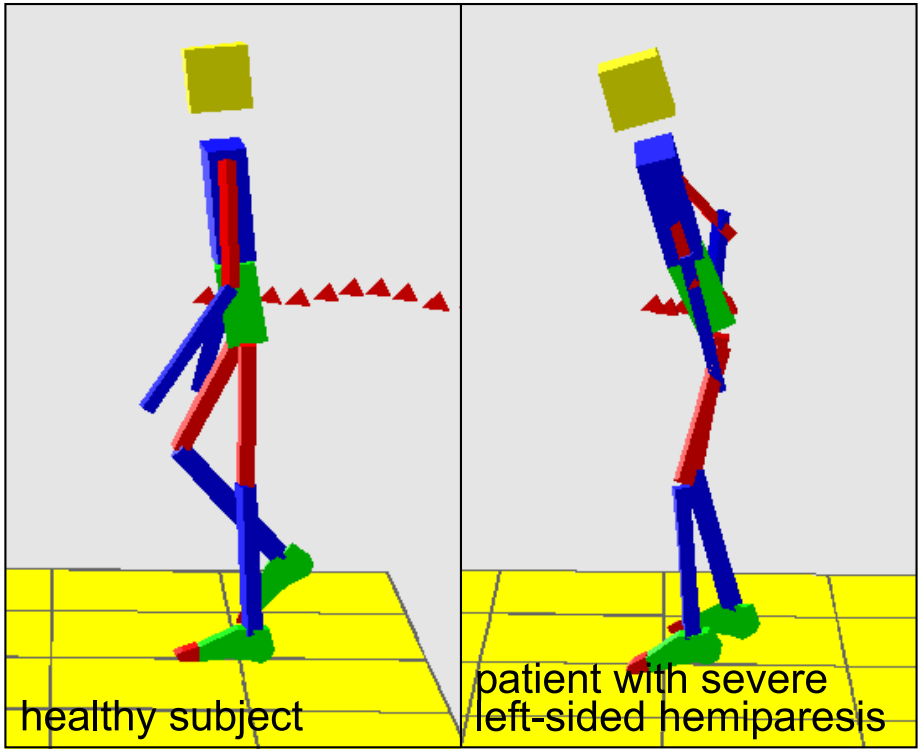



$\Rightarrow$ good agreement of simulation results (bold solid line) with measurements (dotted line) and calculations (solid line) from literature

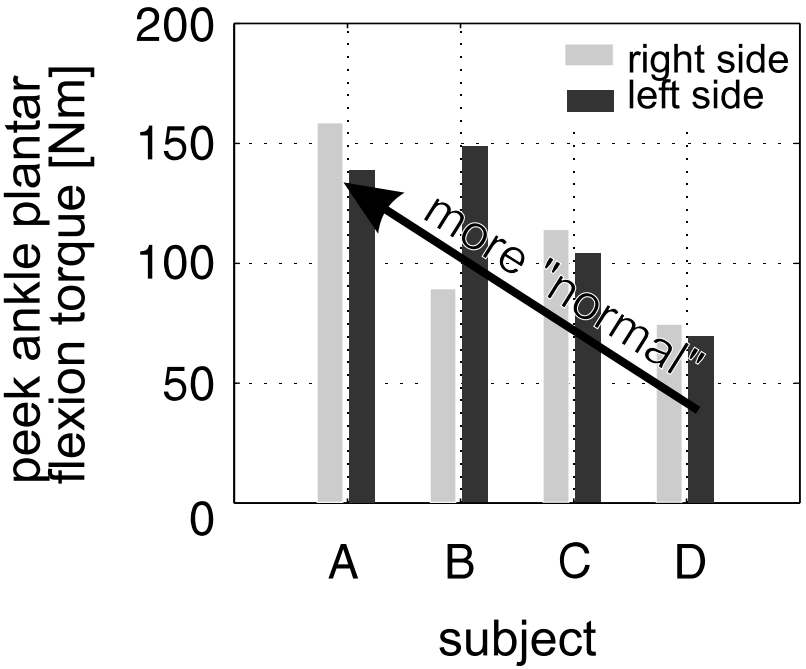
# Animation

Advantages compared to common recording techniques:

- view the disturbed gait pattern under different angles
- zoom on details
- oppose the impaired to a healthy gait pattern
- facil storage



# Evaluation of Degree of Hemiparesis

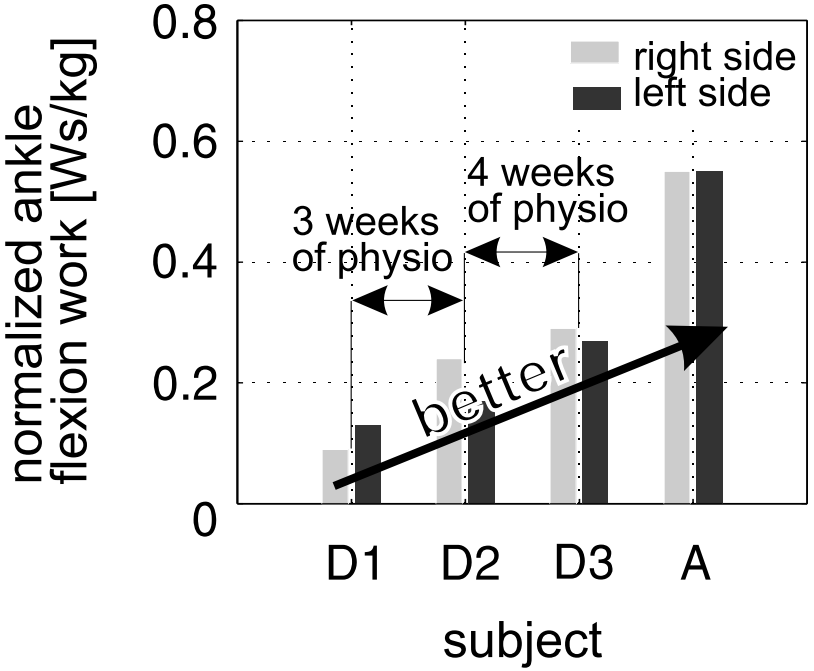



A: healthy subject

B: patient with moderate hemiparesis

C, D: patients with severe hemiparesis

# Outcome of Therapy




A: healthy subject

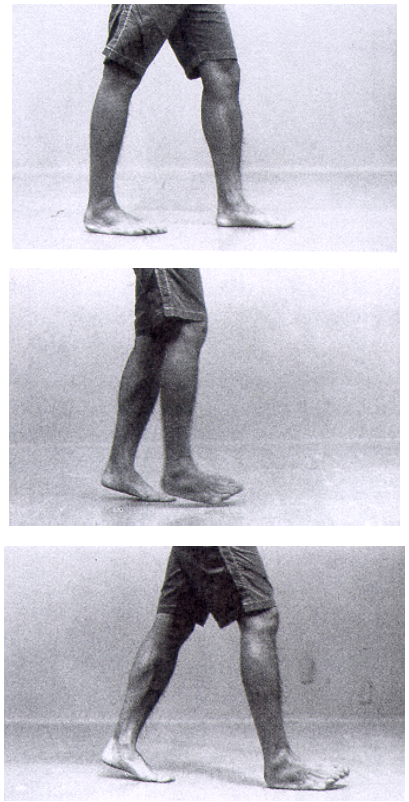
D1, D2, D3: patient D in different stages of physiotherapy (physio)



5. Results

# Kinematic Characteristics of Hemiparetic Gait

- excessive lateral movement of body's center of mass
- high lateral ground reaction forces on the affected side
- low peak torques in all joints of the lower limb
- lower peak torques on the affected than on the unaffected side
- energy for propulsion results mainly from the unaffected side



from Perry, J.: Gait Analysis

# Model-based Functional Electrical Stimulation (FES) for Therapy of Hemiparesis

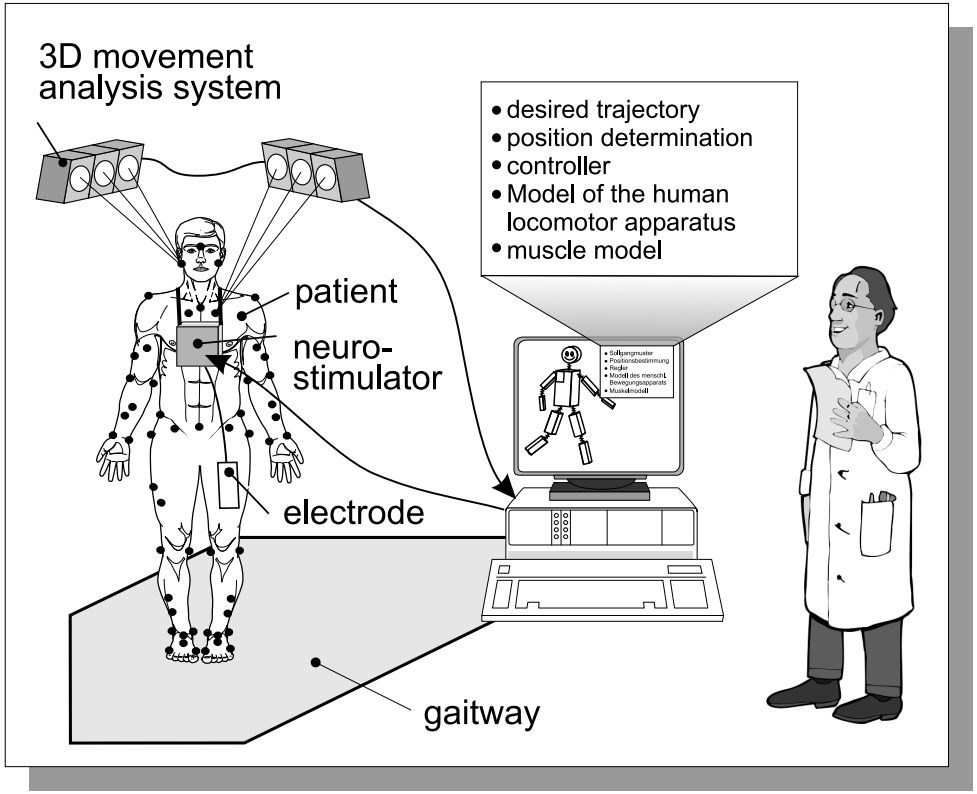
## Therapy of hemiparetics

- physiotherapy
- treadmill walking
- new treatment: **FES**

**FES:**
artificial stimulation of muscles on the affected side of the patient

**Advantage:**
significant improvement of therapy

**Goal:**
correct the impaired gait pattern






6. Future Work