Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework**

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**Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

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Neuromorph Movement Control

(Neuromorf mozgás vezérlés)

Neuromorph Control of Human Movements: introduction

(Emberi mozgások neuromorf mozgás vezérlése:bevezetés)

József LACZKÓ PhD; Róbert TIBOLD

Table of Contents of the Course

1. Introduction
2. Direct (forward) kinematics
3. Inverse kinematics
4. Geometry and material features of muscles
5. Electromyography (recording, signal processing)
6. Neuro-biomechanical muscle characteristics
7. Synergy and redundancy of the motor system
8. Modeling and measurements in practice
9. Applying electrical stimulation in rehabilitation
10. Neural structures in the motor control
11. Optimalization in the motor control
12. Motor deiseases and rehabilitation

Main points of the lecture

- From definition of motor task to execution
- The relation between modeling and experimental methods
- Elementary definitions
    - Kinematics
    - EMG (electromyography)
- Types of data acquisition of 3D joint coordinates
    - Optical (Vicon)
    - Ultrasound (Zebris)
    - Case study of arm movements to show EMG’s

Main points of the lecture

- Overview of EMG measurements
- Sensation – Execution (relation between coordinate systems
- **Basic Issue:** a given motor task can be executed in an infinity of different ways
    - Redundancy problem
    - Overcompletness
    - Movement patterns - action patterns
    - Sensory systems and Motor systems
    - sensory-motor transformations
    - Extrinsic and intrinsic geometry

Movements of the upper extremity (human arm)

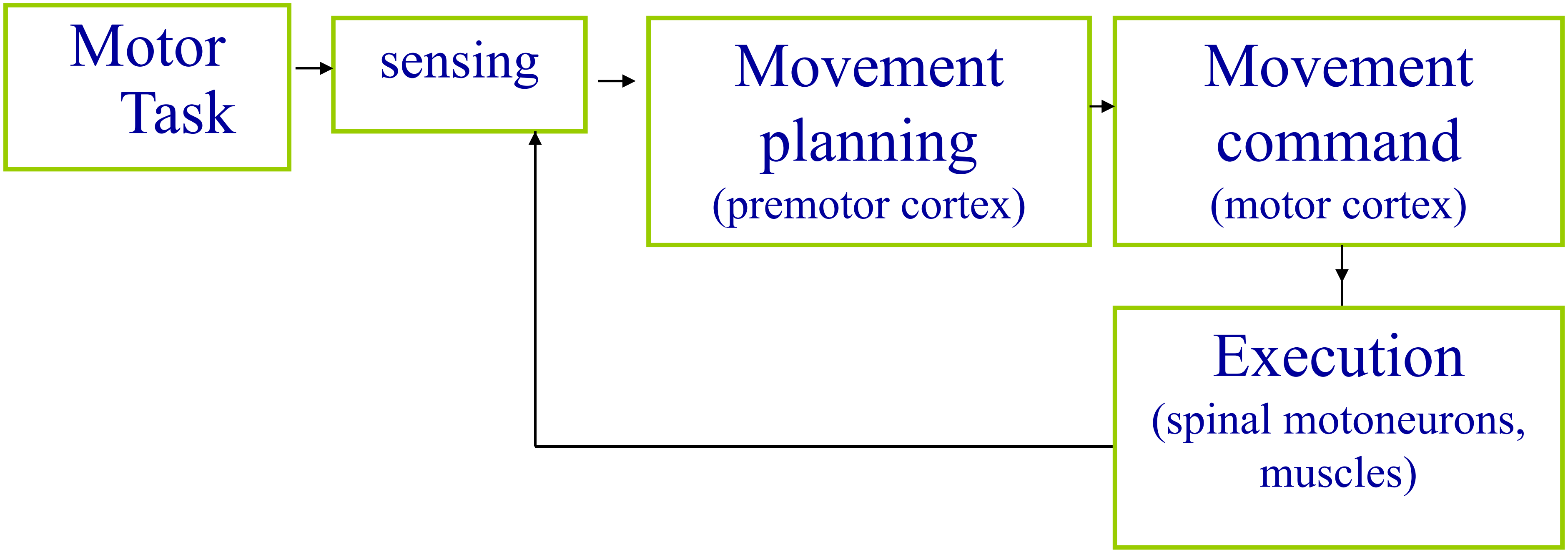
- Pointing movements (reaching)
- Tracking movements (moving the index finger along a trajectory)
- Grasping (grasping a given object)

Movements of the lower extremity (human leg)

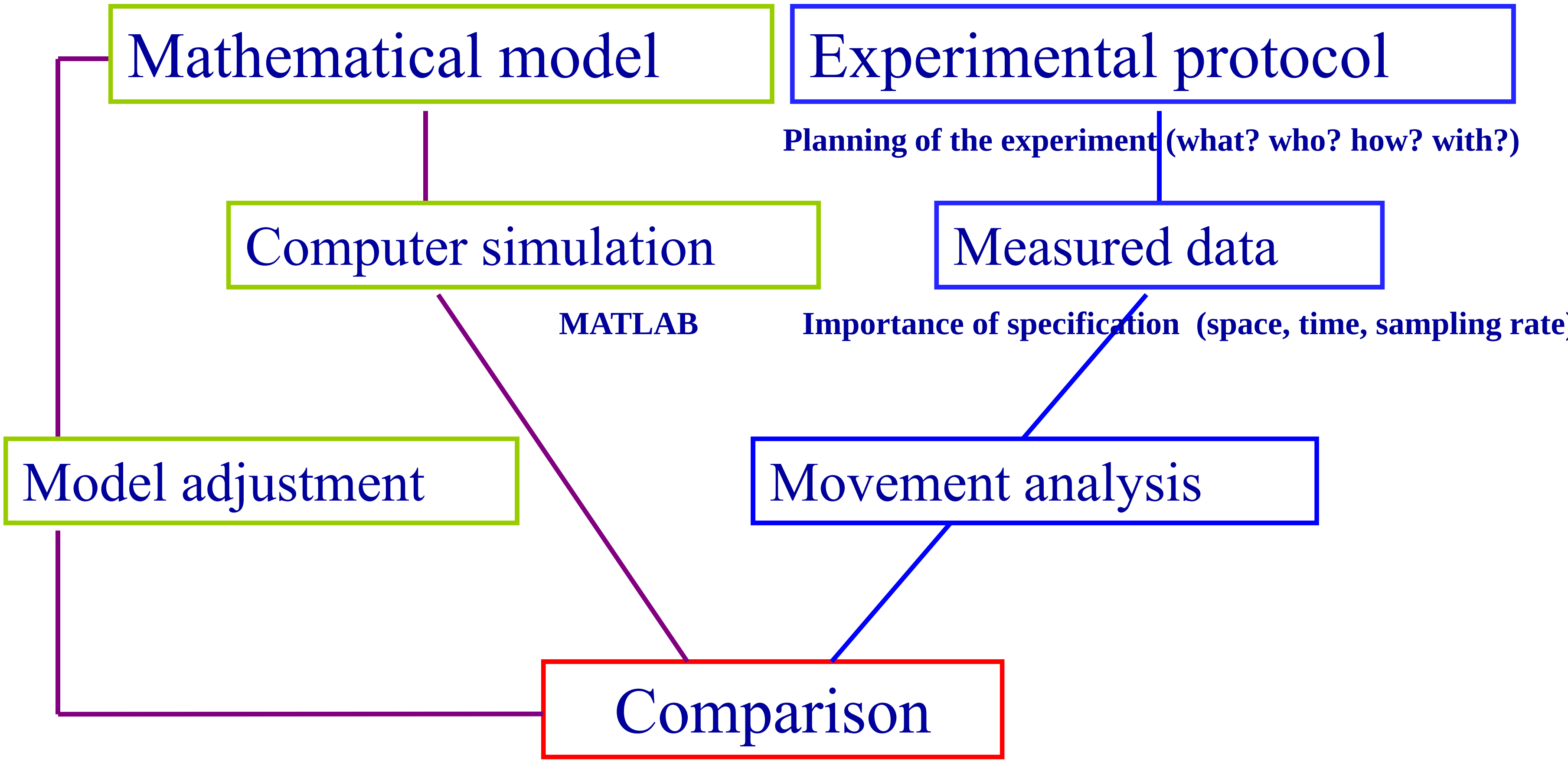
- Walking
- Cycling

Others

- Eye movements („ one joint system”)
- Head-Neck movements



Cooperation of sensory and motor systems


Mathematical model
Experimental protocol
Planning of the experiment (what? who? how? with?)
Computer simulation
Measured data
MATLAB
Importance of specification (space, time, sampling rate)
Model adjustment
Movement analysis
Comparison

- Mathematical models and algorithms are developed to predict how a given motor task could be executed by a given musculo-skeletal structure.

- Based on neuro-mechanical models computer programs are developed to calculate virtual (predicted) trajectory of the joints and the activities of muscles (e.g. forces).

- Then measured data can be compared to theoretically predicted ones. If the measured and theoretically predicted movement patterns confine than we may assume that an adequate model has been offered to discern hidden processes.

- If the measured and predicted data deviate than using the result of their comparison, either the model can be modified or the measurement can be repeated employing a modified protocol.

Which parameters are controlled and what can be measured experimentally?

- From physical point of view (POV):
  - Dynamics
  - Kinematics
- From biological -biomechanical POV:
  - Firing frequency of neurons in the central nervous system (CNS)
  - Muscle activity patterns, Electromyogram (EMG)
  - Joint rotations (Torques)

AIM: to investigate the relation between kinematical movement patterns and neurobiological processes

Neuromorph movement control

Kinematics

(study of geometric properties of motion as function of time)

- Definition of an object's position according to a reference frame at a certain instant
- Linear algebric processing of measured coordinates (vector algebra)

- MEASUREMENT (recording the coordinates of a moving point):
  - Computer controlled movement analyzer
- Sampling Frequency: depends on the motor task (velocity of motion) and on number of measured points

EMG (ElektroMyoGram)

- the CNS send commands
  - *To invoke muscle force:*
  - Electronic potential on muscle fibers (mV,uV)

- MEASUREMENT (EMG):
  - Invasive and non-invasive (surface or implanted electrodes)
  - Minimalization of artefacts
    - Depilation
    - Cleaning and shaving the surface of the skin

HOW?

placing markers on anatomical landmarks (joints)

Different marker types:

- **Active** = Transmitter (transmits a given signal)
- **Passive** = Receiver (receives the transmitted signal)

Movement Analyzer (MA) systems:

- Optical markers (active markers as lightsource)
- Digital video markers (APAS)
- Infrared (selspot, elite, vicon)
- Ultrasonic markers(ZEBRIS)

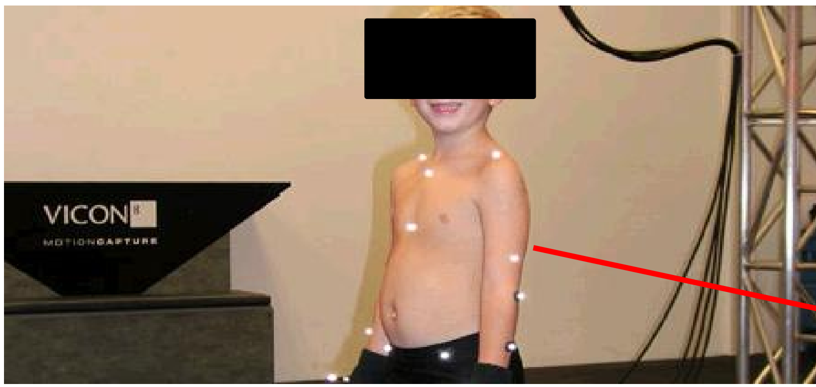
Optical Markers

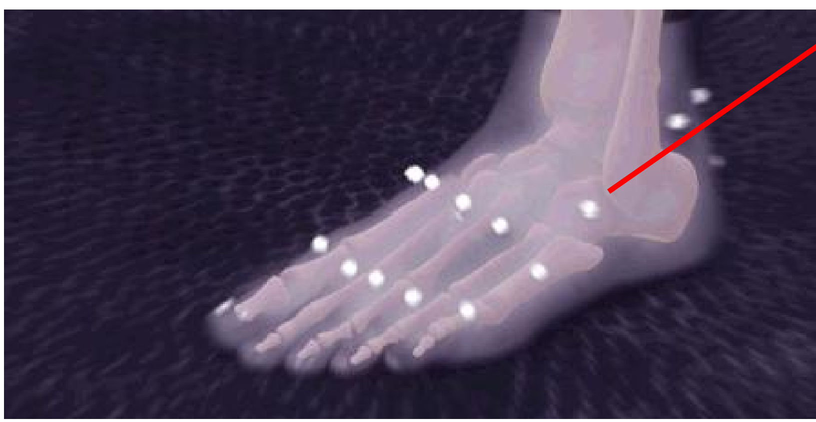
Reflective markers with base

Reflective markers without base

An application of Optical Markers (Vicon System)

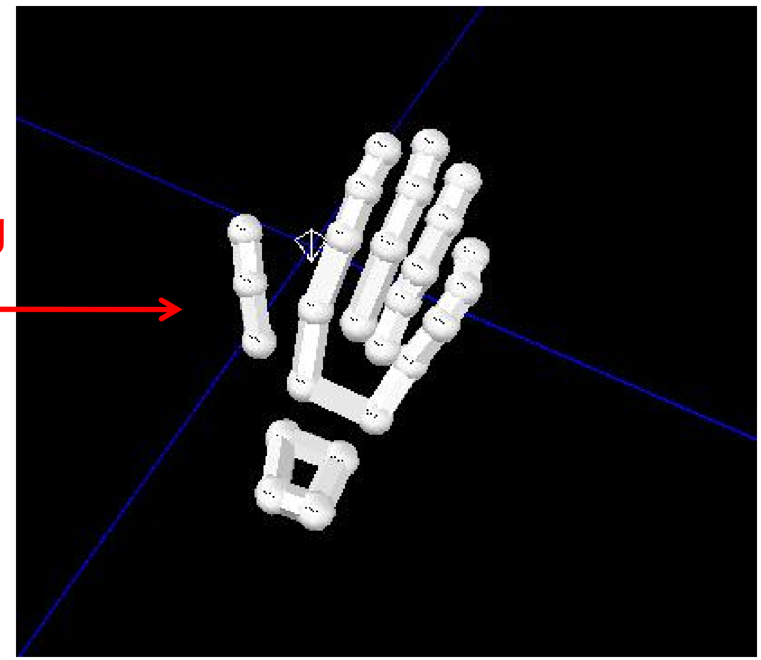
Measurement Configuration





3D mapping

Visual feedback of the limb



Ultrasound Based System (Zebris)

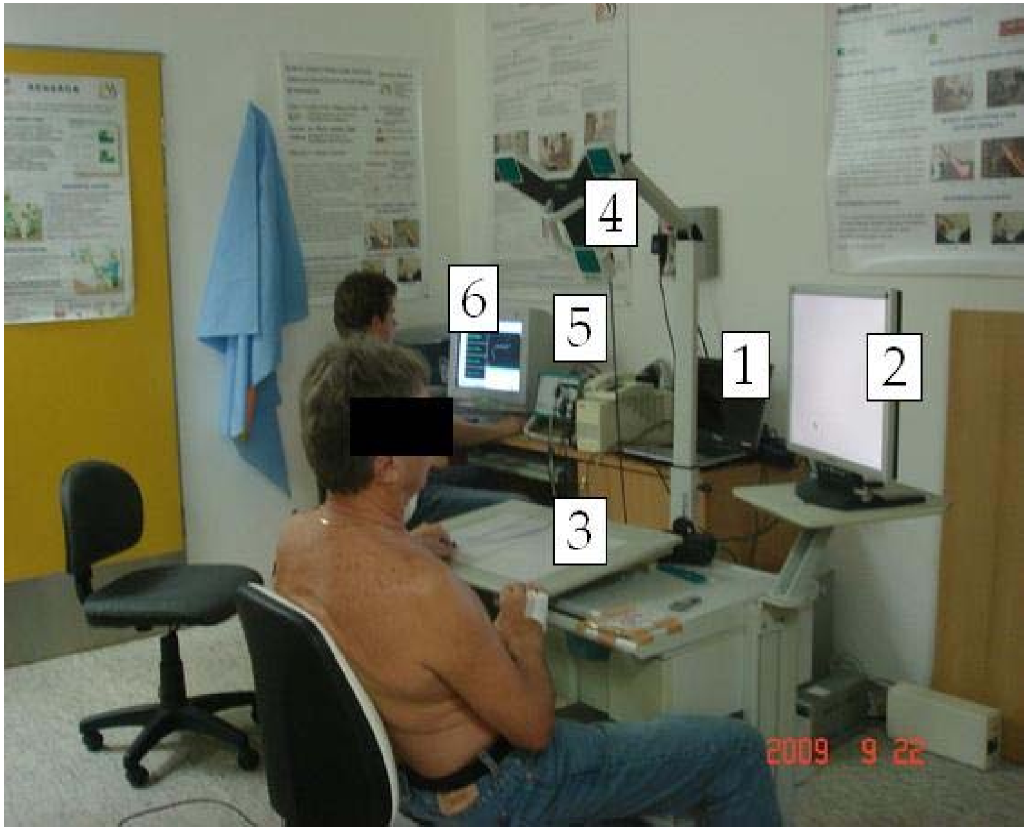
1. **Receiver**
   Receives transmitted signals
2. **Central Unit**
   Signal processing
3. **Signal Generator**
   Generates ultrasound signals

SummaSketch III Professional digitizer table (GTCO CalComp Inc.)

SummaSketch III Professional

Az eszköz egy hozzávetőlegesen A/3 aktív felületű, elektromágneses csatolási elv alapján működő digitalizáló tábla, melyen egy erre a célra kialakított egérrel lehet mozgásokat végezni

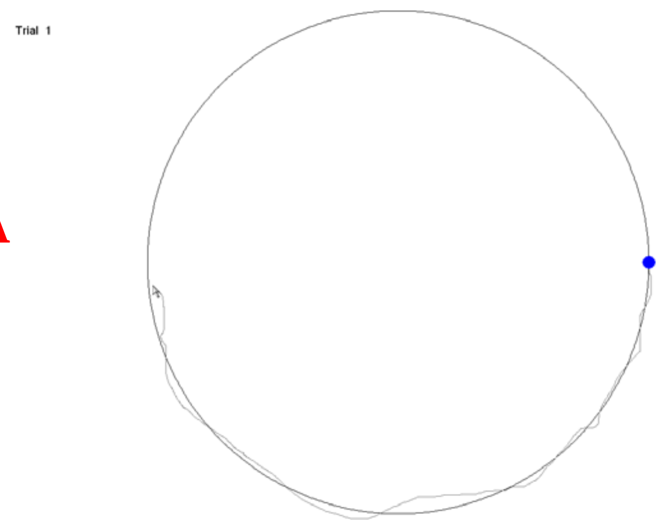
Applying a compact measurement system (Modified Ultrasound based system)



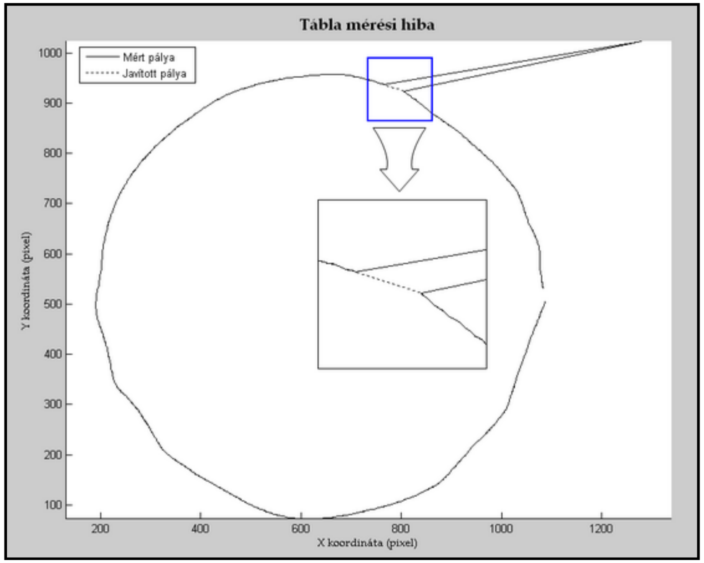
1. Controlling Notebook
2. Monitor (visual signal)
3. Tablet digitizer
4. Zebris receiver
5. Zebris central unit
6. Visual FB of the measurement

Applying a compact measurement system (Measured trajectory & Matlab)

A



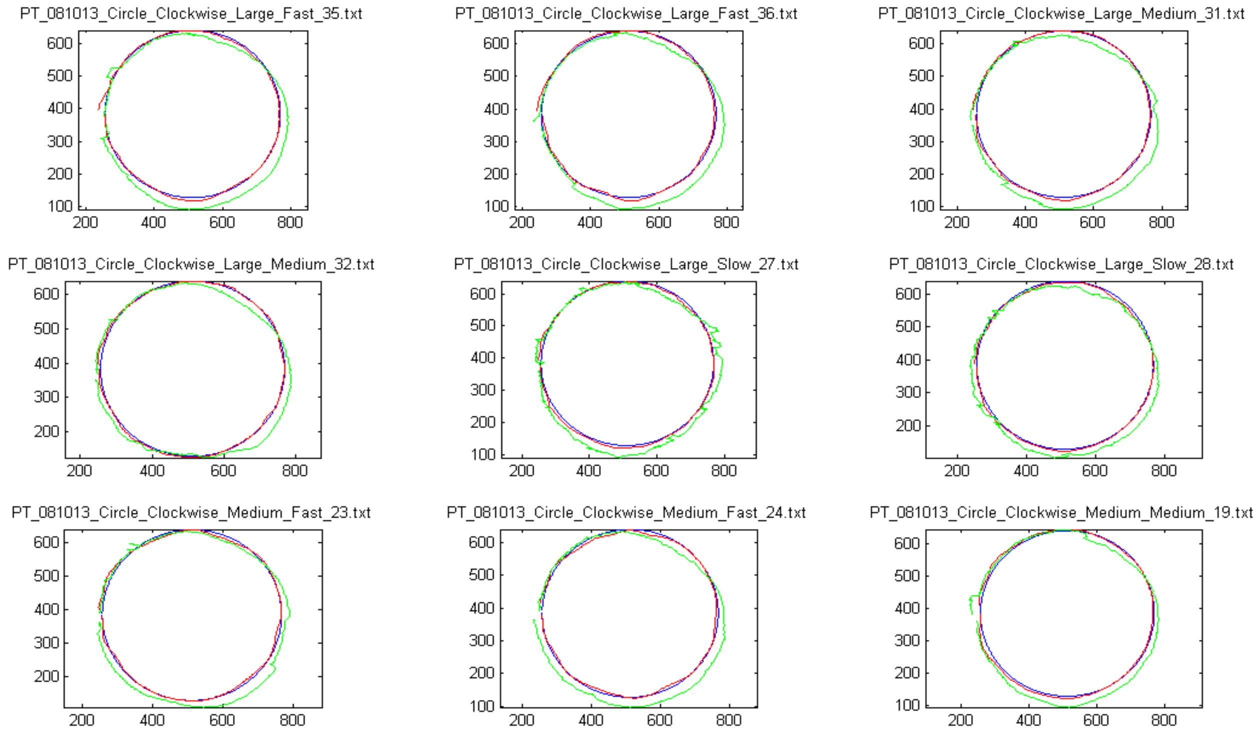
B



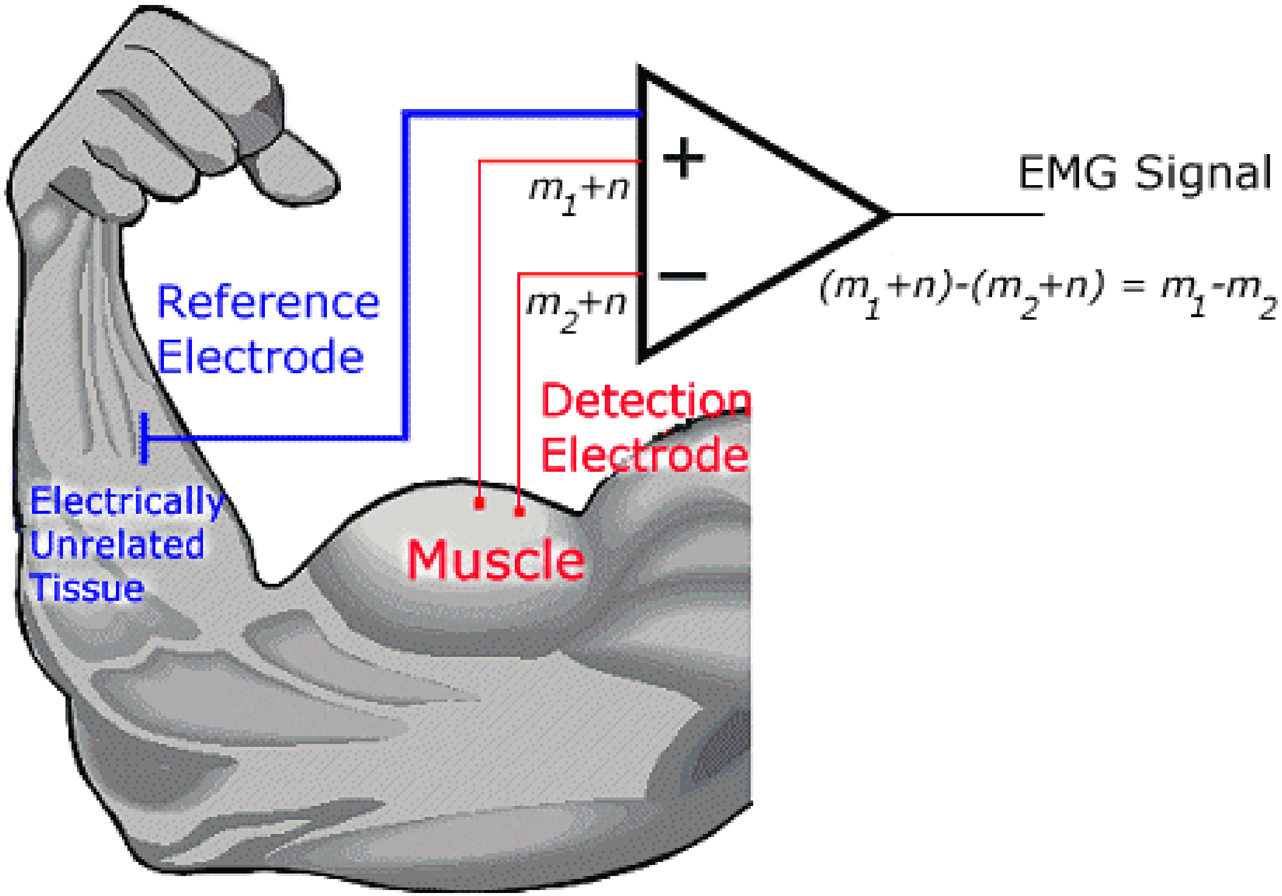
Visual input (trajectory to be followed by the mouse pointer of the tablet digitizer) (A)

Measured trajectory and measurement inaccuracy **(B)**

Applying a compact measurement system (Different measurement conditions)

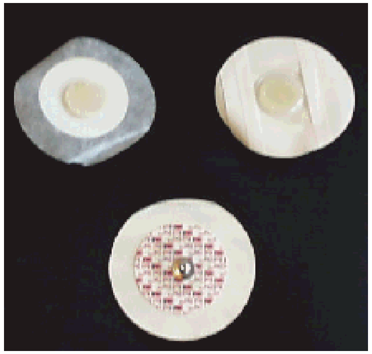


The measuring process of EMG



Measurements of electromyogram by electrodes:

– Surface (*non-invasive*)



monopolar

bipolar

– Implanted electrodes (*invasive*)

The analsys of movements: investigation of kinematics and EMG’s

Kinematics: based on visible parameters

- Changes of coordinates as a function of time
- Joint angles
- Joint angular velocity (1st time derivative) and acceleration (2nd time derivative)

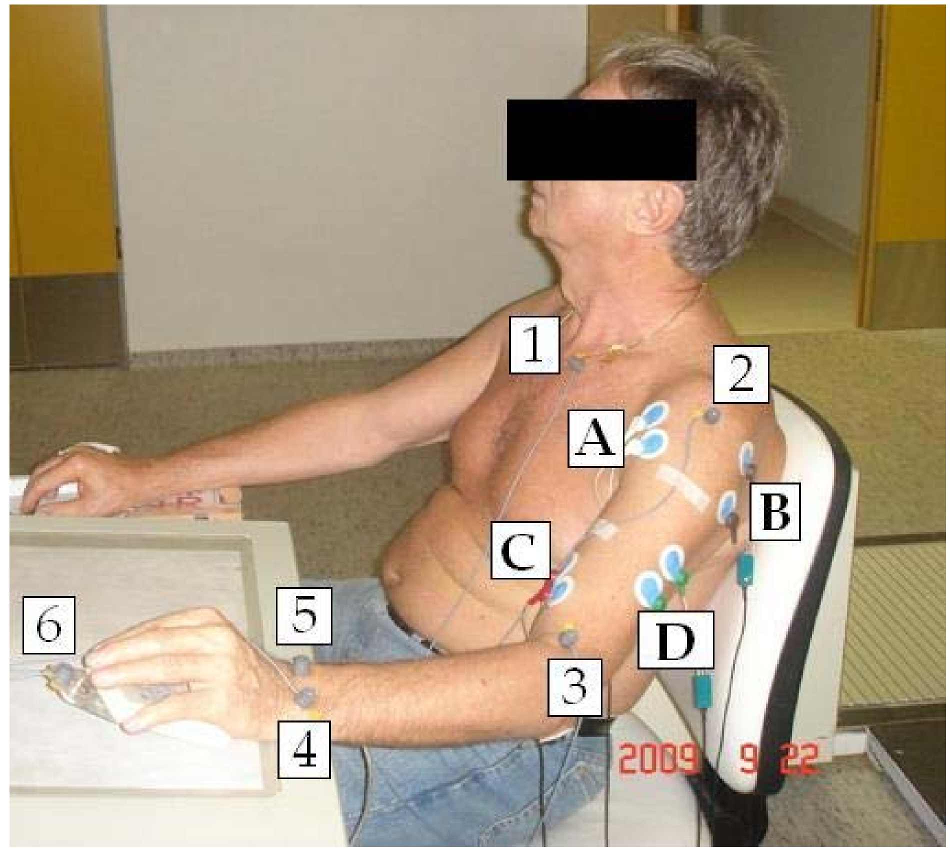
RESULT:

- Measured data can be compared with the output of model based computer simulation (prediction) of a motor task.

Placing ultrasonic markers and EMG electrodes on the participant

Markerek:
Clavicula
Shoulder
Elbow
Wrist (ulna)
Wrist (radius)
Index finger

EMG:
Delta anterior
Delta posterior
Biceps
Triceps



High coherence during implementation

- Between modeling and simulation

Model improvement

- Processing of measured data
- Mathematical and physical algorithms
- Programming of algorithms
  - MATLAB, EXCEL …

Algorithms

- To make the model more realistic the algorithms employed
  - To compute Inertia, Torque, Gravity, Muscle force
  - Biomechanical parameters (attachment sites, muscle length and contraction)
- Error correction
- Time normalization

Differential kinematics

Position (of a point) → velocity → acceleration → jerk

Time derivative Time derivative Time derivative

Trigonometrics (3D mathematics)

Joint angle → Angular velocity → Angular acceleration → Angular jerk

Linear algebra – coordinate transformation
Calculating variances – optimal movement execution

Levels of motor control and execution

CNS (central nervous system)

↓ electric signal

Muscle

↓ contraction

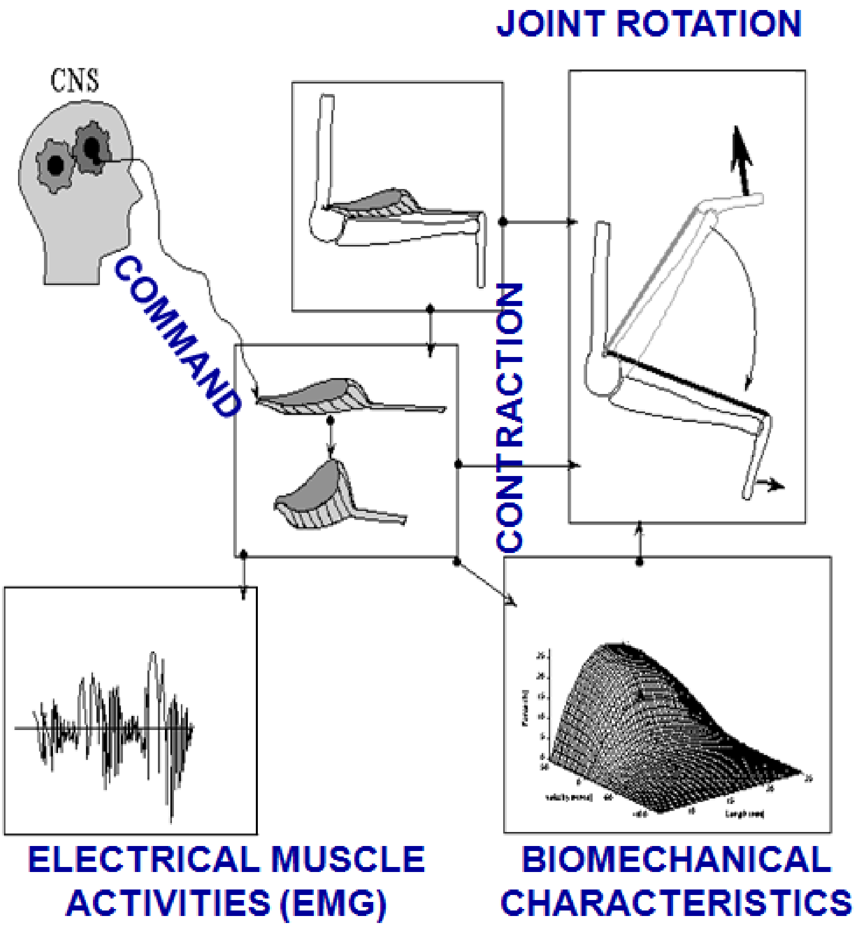
Joint

↓ rotation

Limb

excursion, displacement

Overview


JOINT ROTATION
CNS
COMMAND
CONTRACTION
ELECTRICAL MUSCLE ACTIVITIES (EMG)
BIOMECHANICAL CHARACTERISTICS

The Software of the Movement Analysing System saves and stores measured data in text files

- Post processing in:
  - MATLAB
  - Excel

Development of algorithms by

- MATLAB

Why MATLAB and not C or C++?

- Easy handling of difficult matrices and geometric transformations
- Object oriented programming
- Good tools for proper analysis

Sensori-motor trnsformations

Sensation

vision, audition
posture
vestibular system
muscle spindle
proprioception

Execution

motoneurons,
muscles
joints
limbs

Sensori-Motor
Transformation

Extrinsic and intrinsic geometry

external world

(x,y,z) Cartesian (orthogonal) coordinate systems

3D vectors (e.g. position, velocity)

internal representation

„intrinsic" coordinate-systems not orthogonal

High dimensional vectors (n > 3)

Transformation

The representation of external variables in internal coordinate systems

sensory
coordinate- systems

the coordinates
are independent
from each other

defined by the structure
of sensory organs

motor
coordinate-systems.

coordinates are interdependent
dimensions are high:
number of joints,
number of muscles,
number of neurons

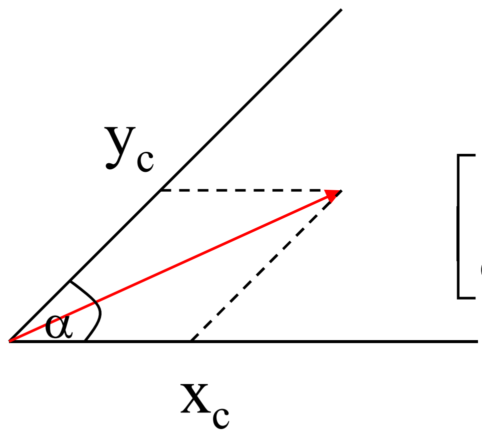
defined by the geometry of
limbs, muscles, neural systems

sensory-motor transformation

Tensor network theory

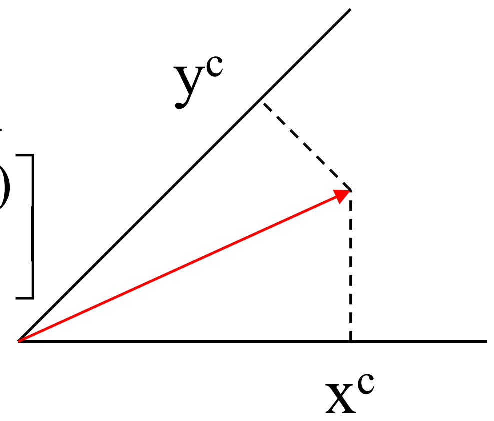
Contravariant coordinates
The coordinates are interdependent
e.g. motor coordinate sytems

Covariant coordinates
The coordinates are independent
e.g. sensory coordinate systems



Metric tensor

$$\begin{bmatrix} 1 & \cos(\alpha) \\ \cos(\alpha) & 1 \end{bmatrix}$$



In orthogonal coordinate systems the two types of coordinates aligned

Vestibulo-Ocular Reflex (example for sensori-motor transformation)

Biologically:

Vestibular information (sensation)

transformed into

Eye muscle activity (execution)

Physically:

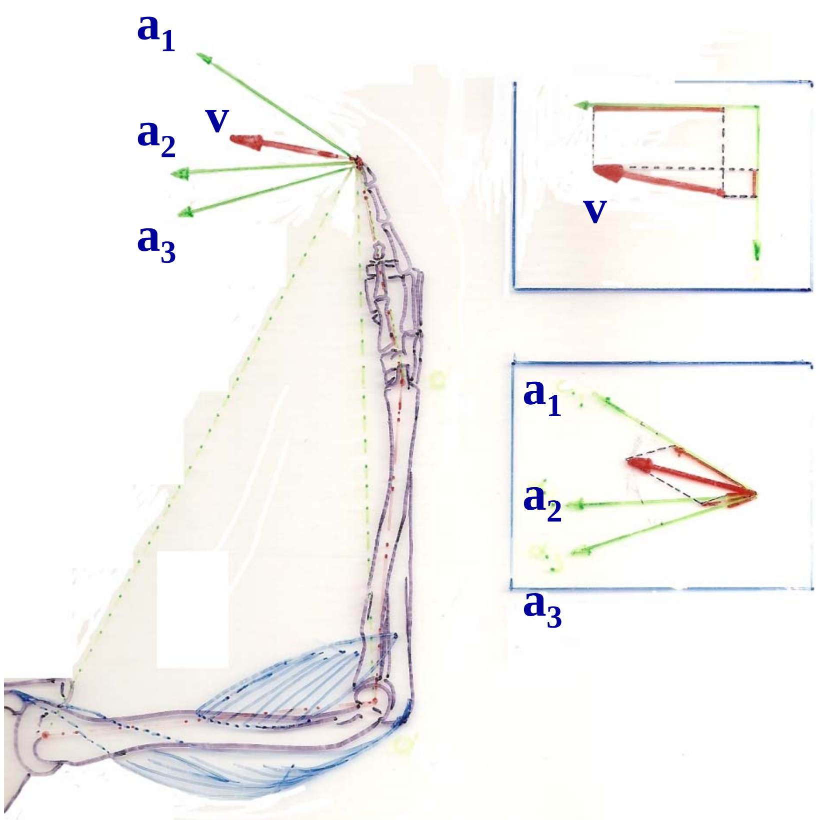
Angular velocity vector of head rotation

transformed into

Compensatory Eye rotation

Sensory representation is transformed into motor execution.

The human arm and an intrinsic coordinate system

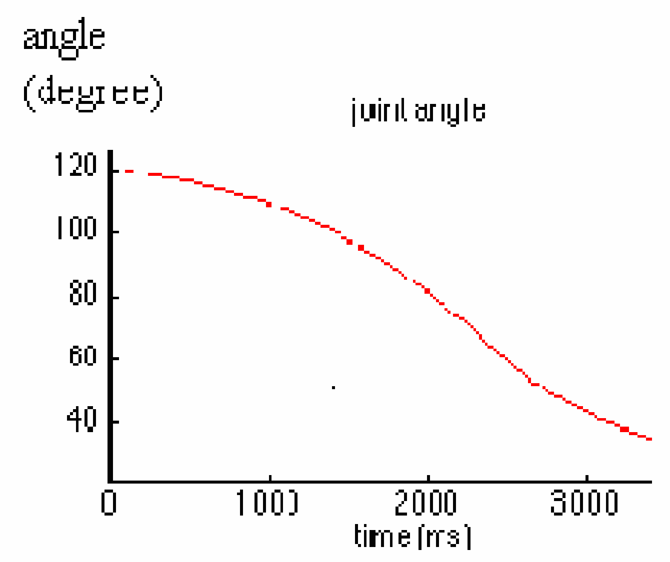


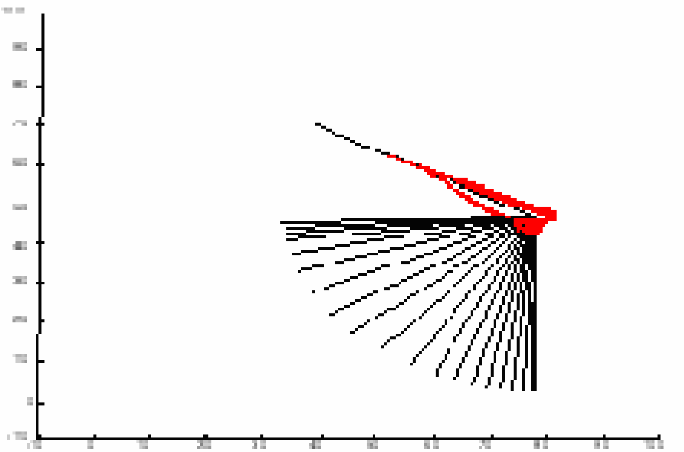
- **Each joint defines a coordinate axis**
  - Orthogonal to the line that connects the joint and the finger
- **Rotations in**:
  - Shoulder (**a_1**)
  - Elbow (**a_2**)
  - Wrist (**a_3**)

Moves the finger along the correspondig axis

- **Displacement vector** (**v**) is:
  - Represented in a 2D orthogonal coordinate-system and in a 3D generalized joint-coordinate-system

Modeling of Rotations in single joint systems





The time course of the angular change in the joint, and a stick-figure representation of the movement of a single-joint system while the joint angle decreased from 120 degrees to 30 degrees.

The angular velocity is the smallest at the beginning and at the end of the movement and largest at the middle of the movement. This can be seen on the stick figure representation where black lines represent the positions of the rotated segment at discrete points of time with equal intervals between them.

Summary

- **An important goal of movement control:**
  - To produce methods for restoring lost motor functions based on different movement disorders (*if it is possible*)
  - To help people suffering from the after effect of Parkinson desease, stroke, dystonia, spine injury, etc.
- **How can we do this?**
  - Measurements have to be done to get information on how healthy people solve different movement tasks
  - Based on these measurements (kinematics, EMG) a model is to be defined
  - Outputs of the model are used to generate different control strategies

Summary

- **Human motor control can be regarded as a complex control system with different levels of controlling (sensory-motor system)**
  - Sensing the changes of the environment
  - Execution of motor commands generated by higher levels

- **From the point of view of the models applied by motor control:**
  - Sensing: external world
  - Execution: internal representation

- **Therefore: the main issue of motor control is to find a proper solution to transform the sensation of the external world to commands accepted („interpreted") by the levels of execution**

Suggested literature

•Schaaf T, Hartmann J, Seidel EJ; (2010) Comparison of measurements devices zebris (R) CMS 70 P and Varilux Essilor VisionPrint System (TM) for identification of Neuro-muscular patterns „Head-or-Eye-Mover”, PHYSIKALISCHE MEDIZIN REHABILITATIONS MEDIZIN KURORT MEDIZIN Vol. 20(1);pp: 20-26

•Tibold R, Poka A, Borbely B, Laczko J. (2009). The effect of load on joint- and muscle synergies in reaching arm movements. Accepted at VII. Conference on Progress in Motor Control, Marseille, France 2009. July

•Wu, J. J. (1987). "Clinical-Application of Vicon System to Evaluate the Gait Pattern after Toe-to-Thumb Reconstruction.,,, Journal of Biomechanics 20(9): 910-910.

Suggested literature

•Nair, S. P., S. Gibbs, et al. (2010). "A method to calculate the centre of the ankle joint: A comparison with the Vicon Plug-in-Gait model." Clinical Biomechanics, 25(6): 582-587.

•Gordon, C. R., A. Caspi, et al. (2008). "Mechanisms of vestibulo-ocular reflex (VOR) cancellation in spinocerebellar ataxia type 3 (SCA-3) and episodic ataxia type 2 (EA-2)." Using Eye Movements as an Experimental Probe of Brain Function - a Symposium in Honor of Jean Buttner-Ennever 171: 519-525.

•Louie, J. K., C. Y. Kuo, et al. (1984). "Surface Emg and Torsion Measurements during Snow Skiing - Laboratory and Field-Tests." Journal of Biomechanics 17(10): 713-&.