Clinical Gait Analysis

dr. ir. Jaap Harlaar

j.harlaar@vumc.nl

www.vumc.nl/revalidatie

VU University Medical Center
Amsterdam The Netherlands

Human Movement Laboratory

Department of
Rehabilitation Medicine

VU University
Medical Center

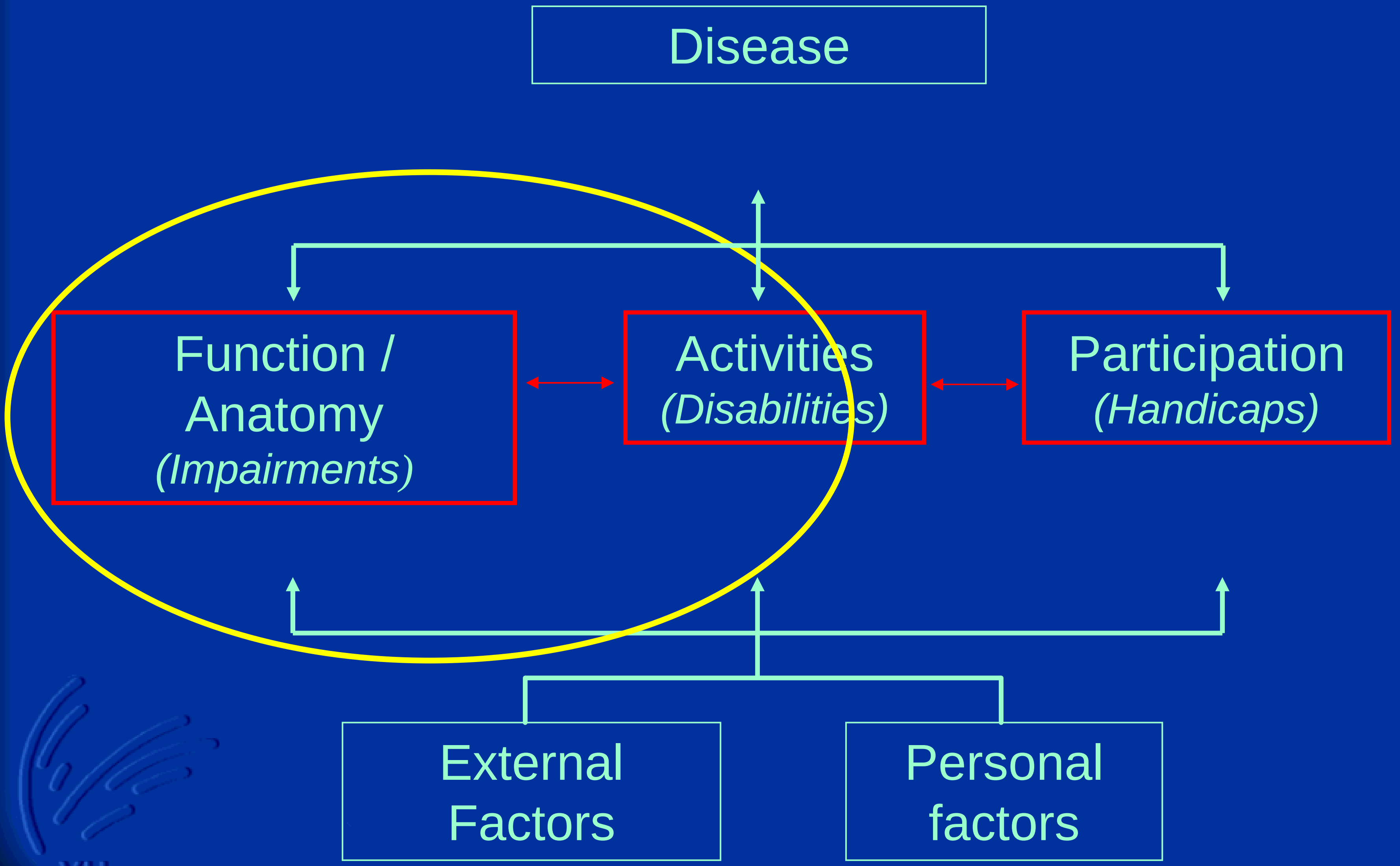
Amsterdam

casus

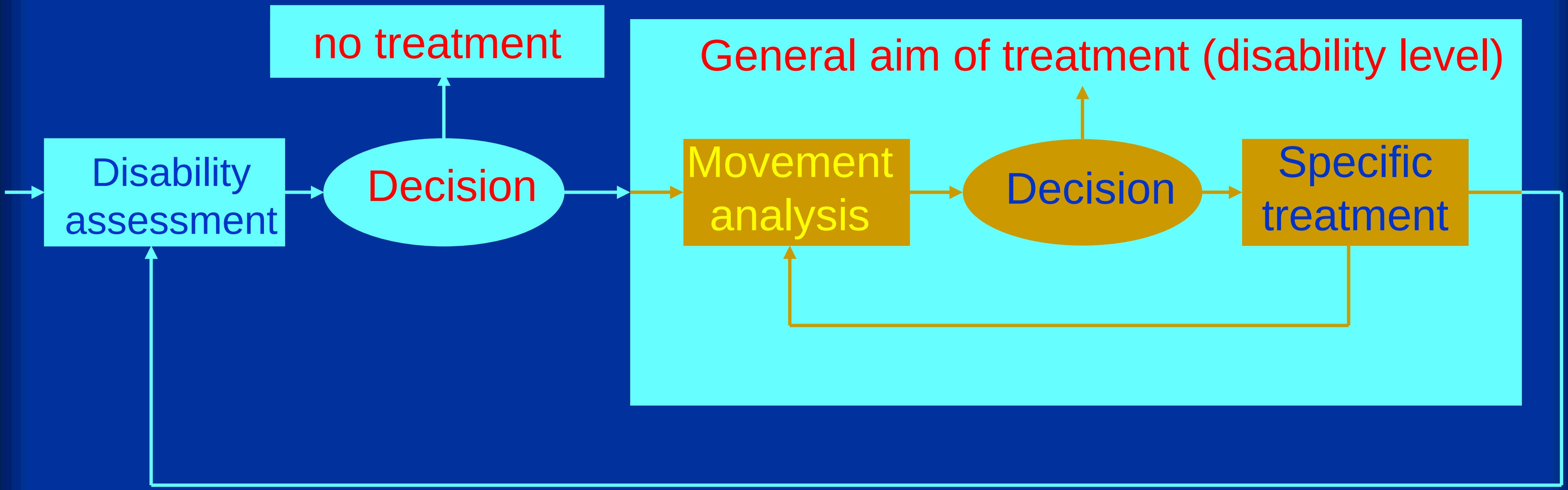
Goal setting vs. tools

- problems with specific activities
- >> goal setting at this level
- specific interventions might work
- movement analysis: biomechanics

International Classification of Functions (ICF)



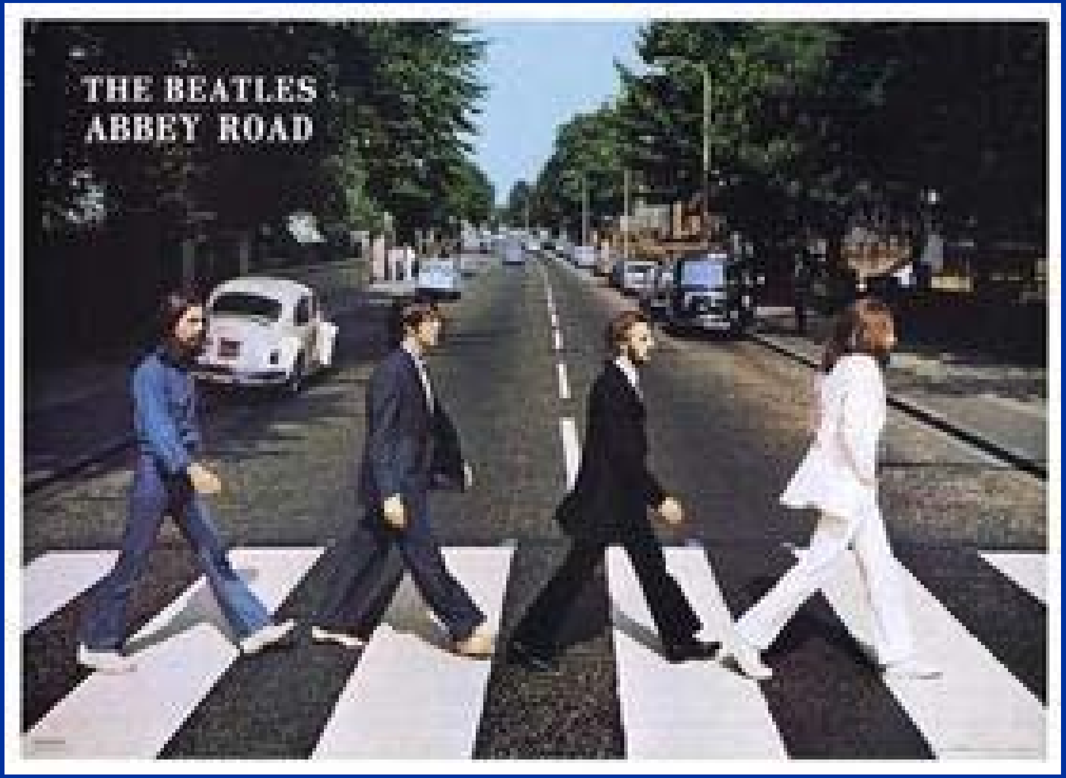
Complete nested decision scheme



casus

Gait and movement analysis in clinical practice of rehabilitation medicine

GAIT



VU University Medical Center

Goal of walking

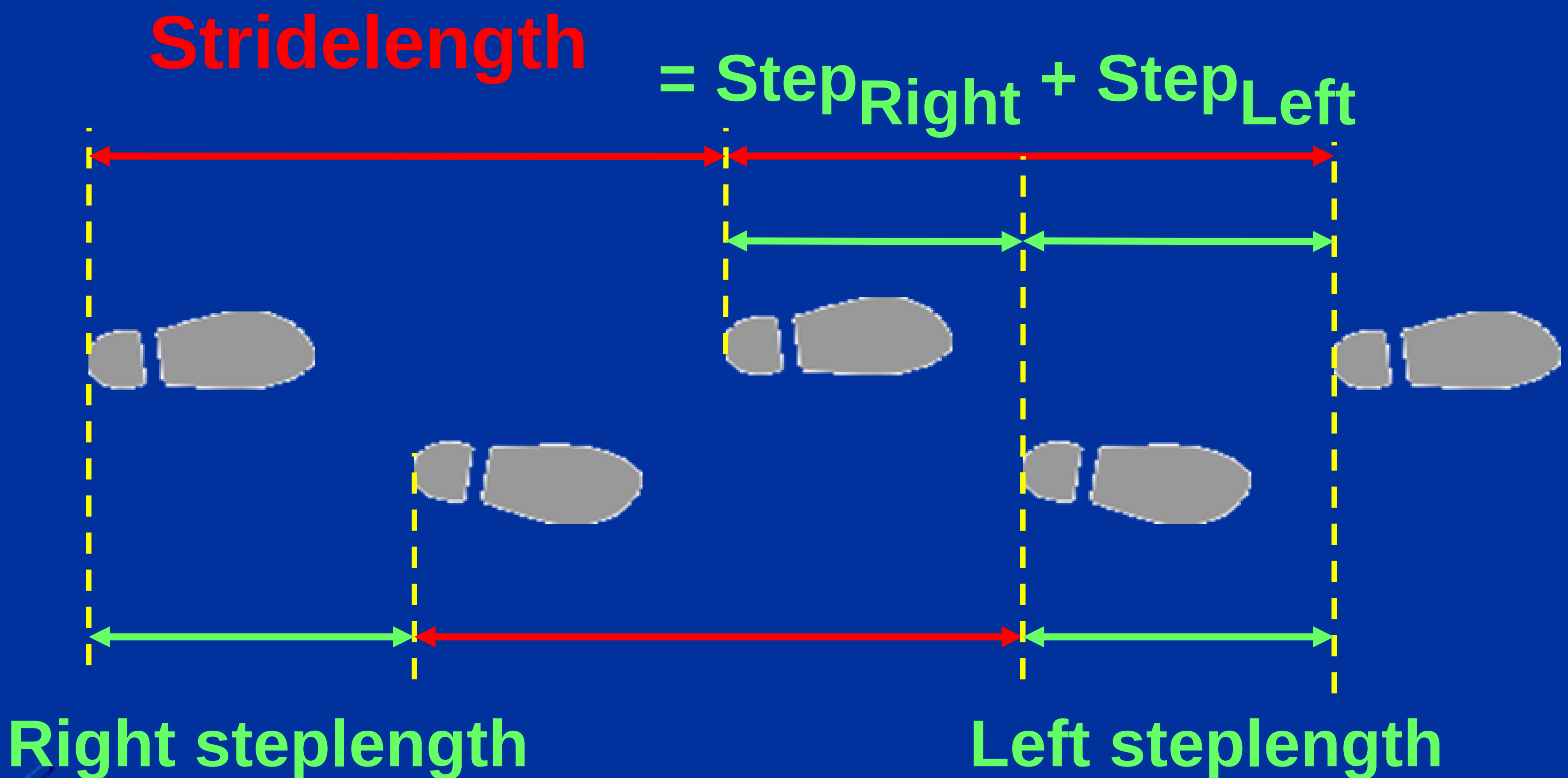
- To go from one place to another
- Walking speed, Energy & Safety

HOW ?

By repeatedly placing one foot in front of the other

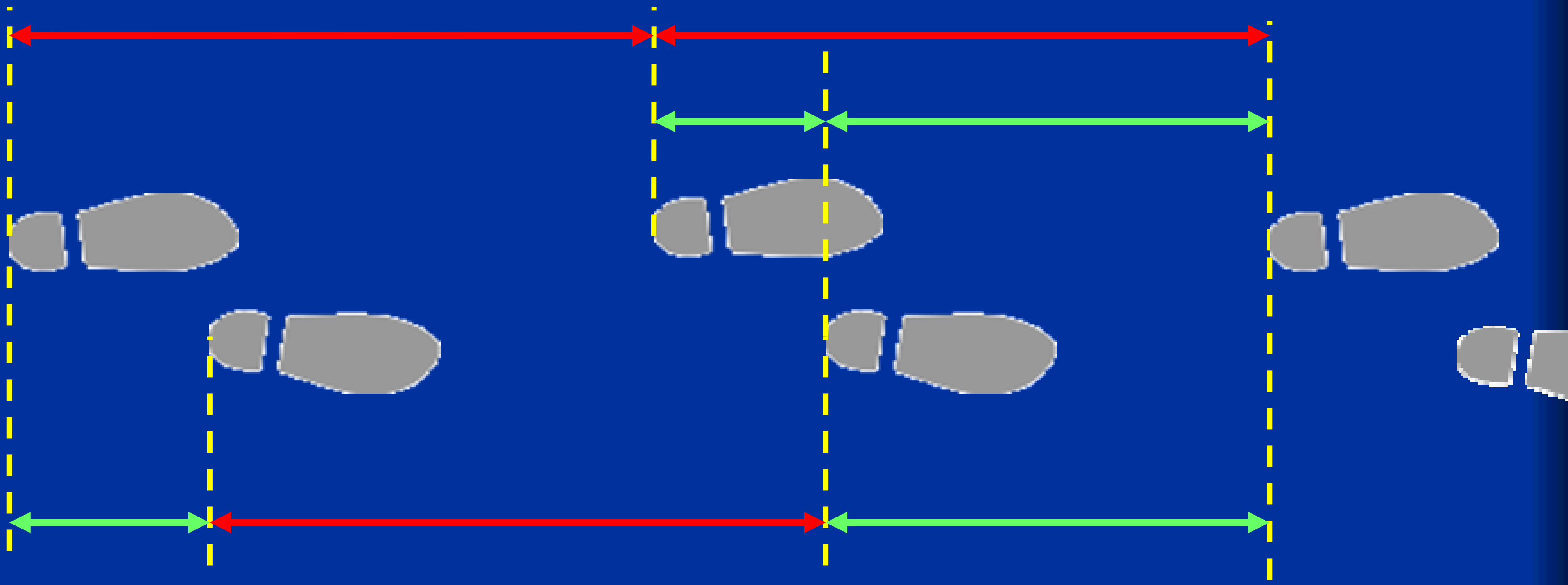
VU University Medical Center

Footsteps


Stridelength
= Step Right + Step Left
Right steplength
Left steplength

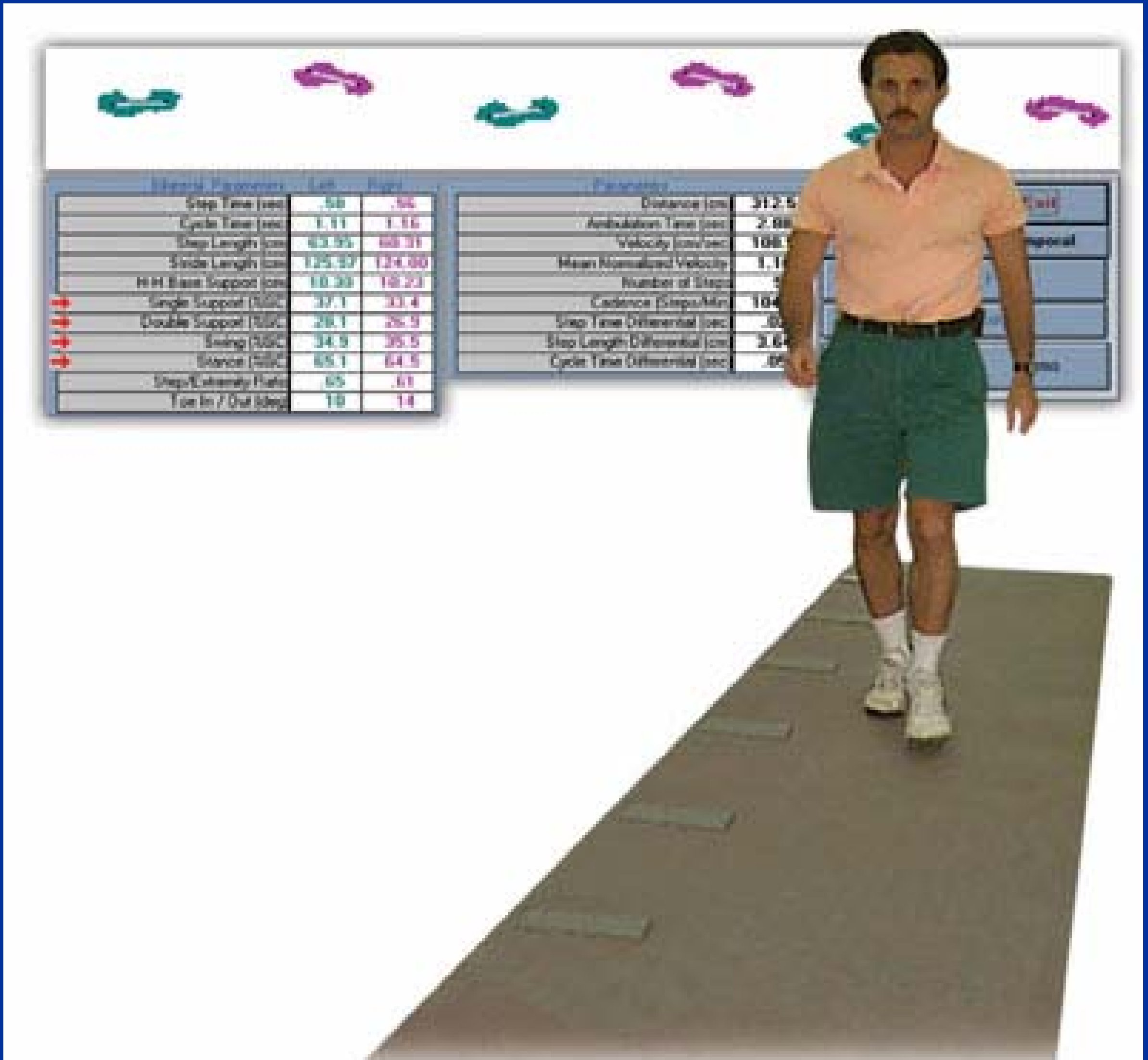
Footsteps (asymmetric)

Stridelength = Right step + Left step



Right steplength **Left steplength**

Measure footsteps

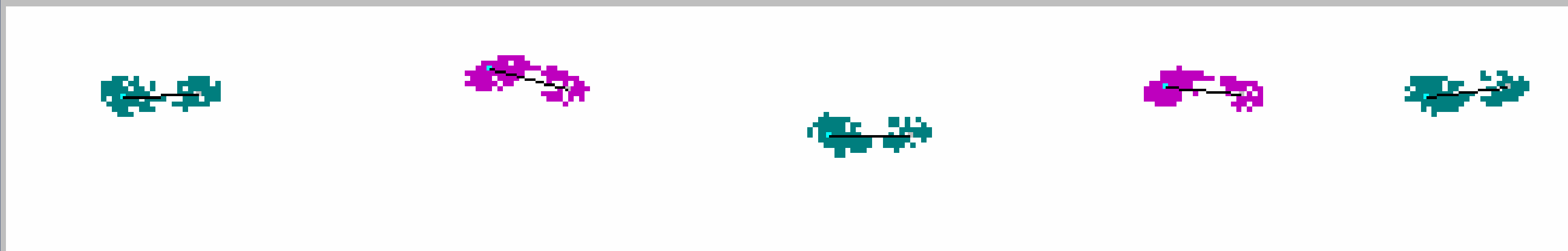


www.gaitrite.com

Measure footsteps

Gender: M | Age: 38 | Left - Leg - Right: 89 | 89

Long Gap 2 (Toe In/Out) | Pattern | Unassisted | FAP 68



Bilateral Parameters	Left	Right
Step Time (sec)	.69	.95
Cycle Time (sec)	1.64	1.32
Step Length (cm)	81.92	71.02
Stride Length (cm)	153.34	157.92
H-H Base Support (cm)	10.52	5.09
Single Support (%GC)	27.4	36.1
Double Support (%GC)	20.4	27.6
Swing (%GC)	29.1	34.1
Stance (%GC)	70.9	65.9
Step/Extremity Ratio	.92	.80
Toe In / Out (deg)	2	12

Parameters	
Distance (cm)	305.9
Ambulation Time (sec)	3.27
Velocity (cm/sec)	93.5
Mean Normalized Velocity	1.05
Number of Steps	4
Cadence (Steps/Min)	73.4
Step Time Differential (sec)	.26
Step Length Differential (cm)	10.90
Cycle Time Differential (sec)	.32

Prim Dr: Johnson | Problem: L hip pain | Samp

www.gaitrite.com

Goal of walking

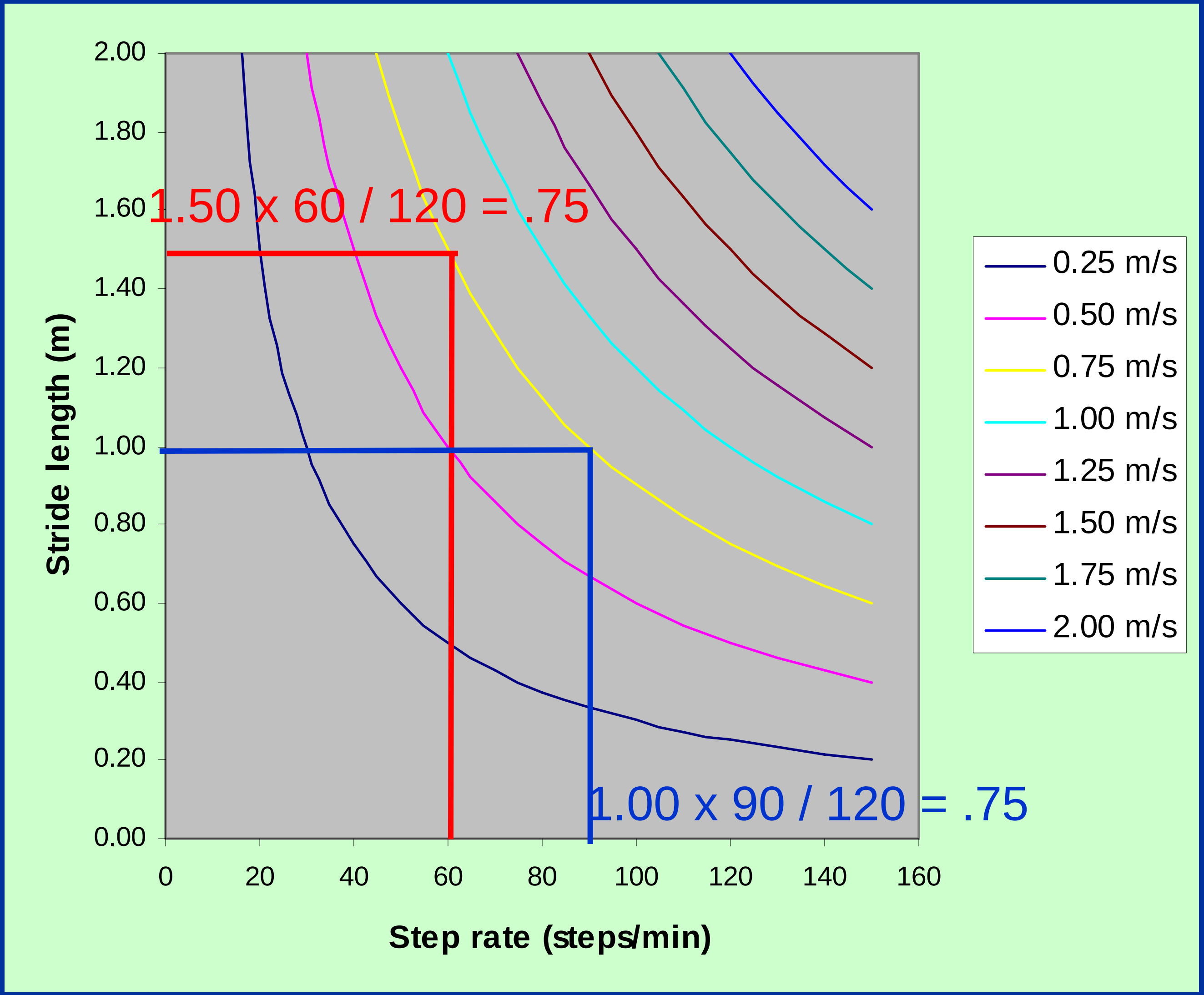
Stridelength [m]

x → / 120 = Walking speed [m/s]

Cadence [steps/min]

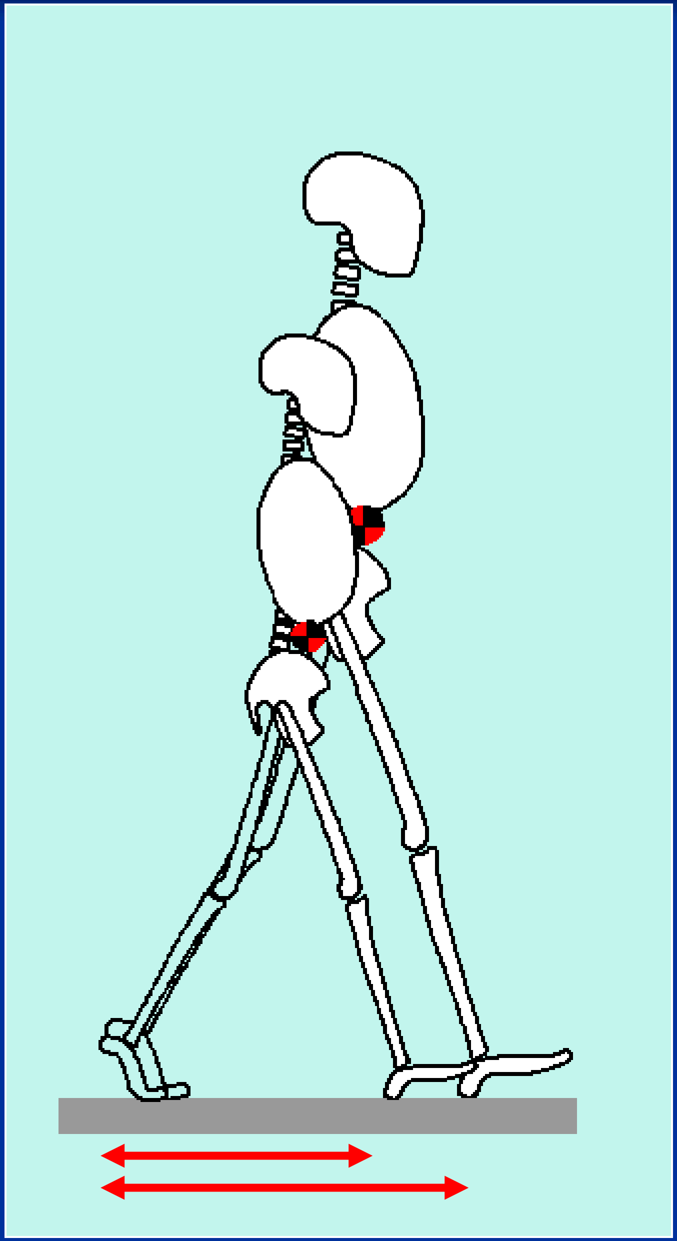
3.6 km/h = 1 m/s

Walking speed=stride length*cadence

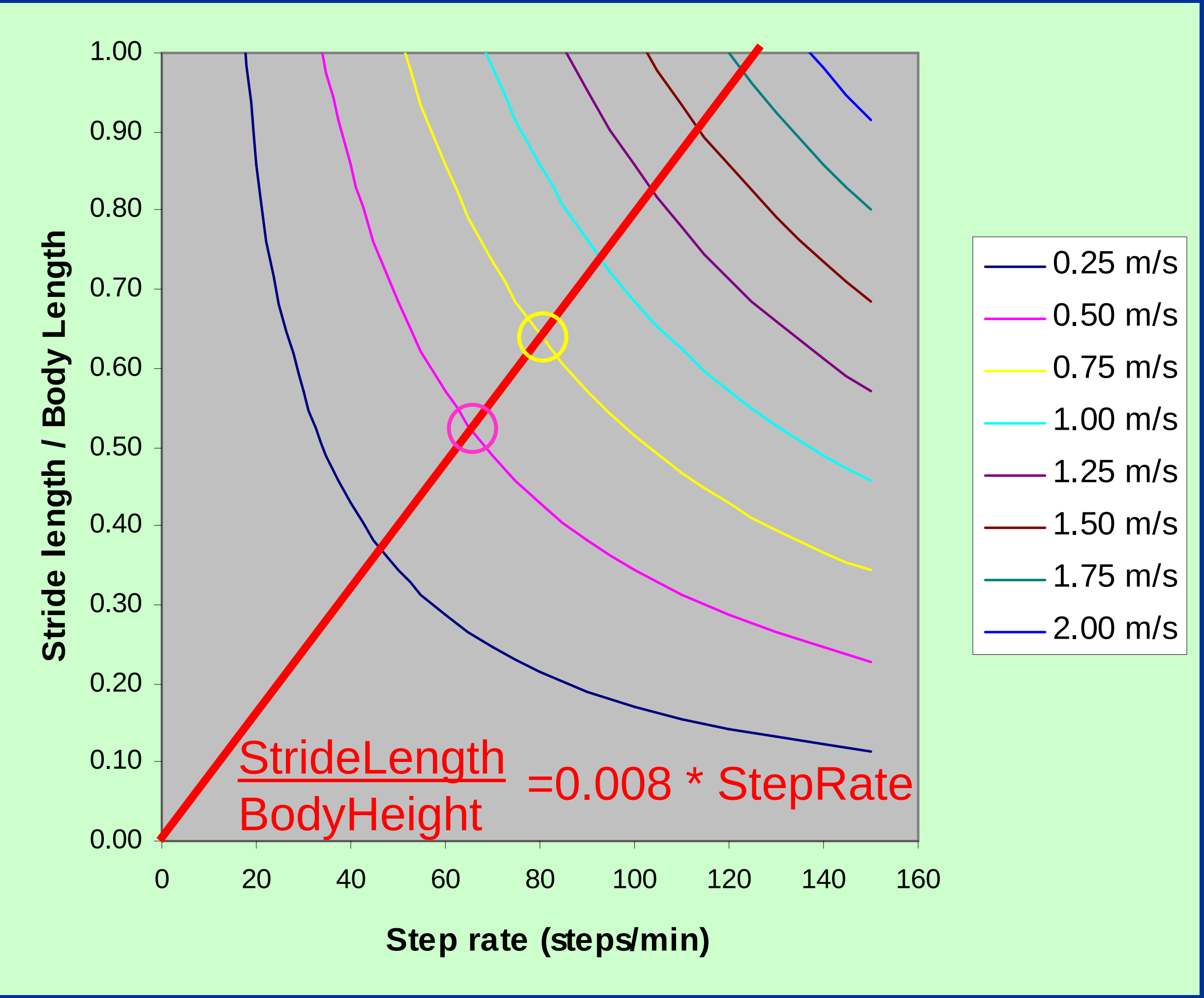


VU University Medical Center

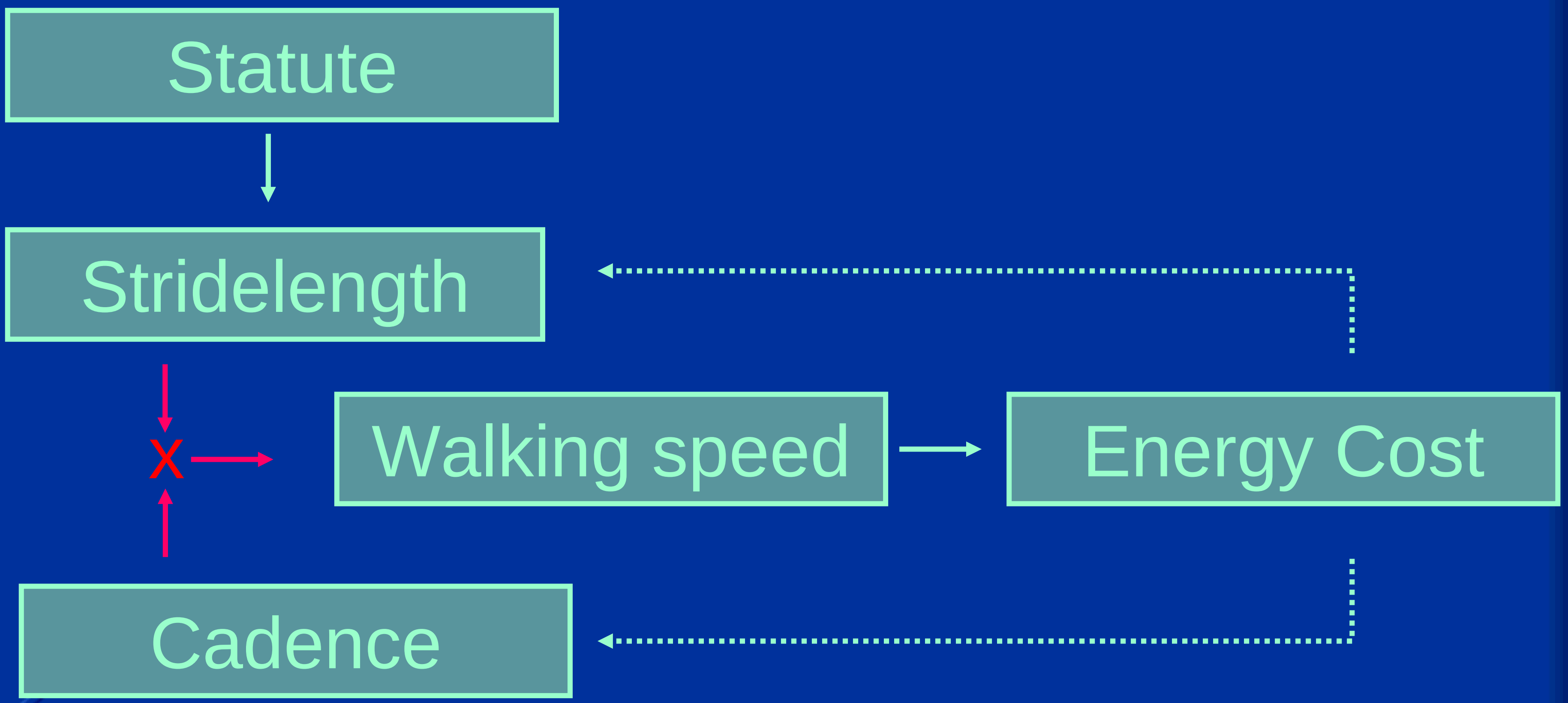
Body length and stride length



What is the optimal stridelength ?



Energy

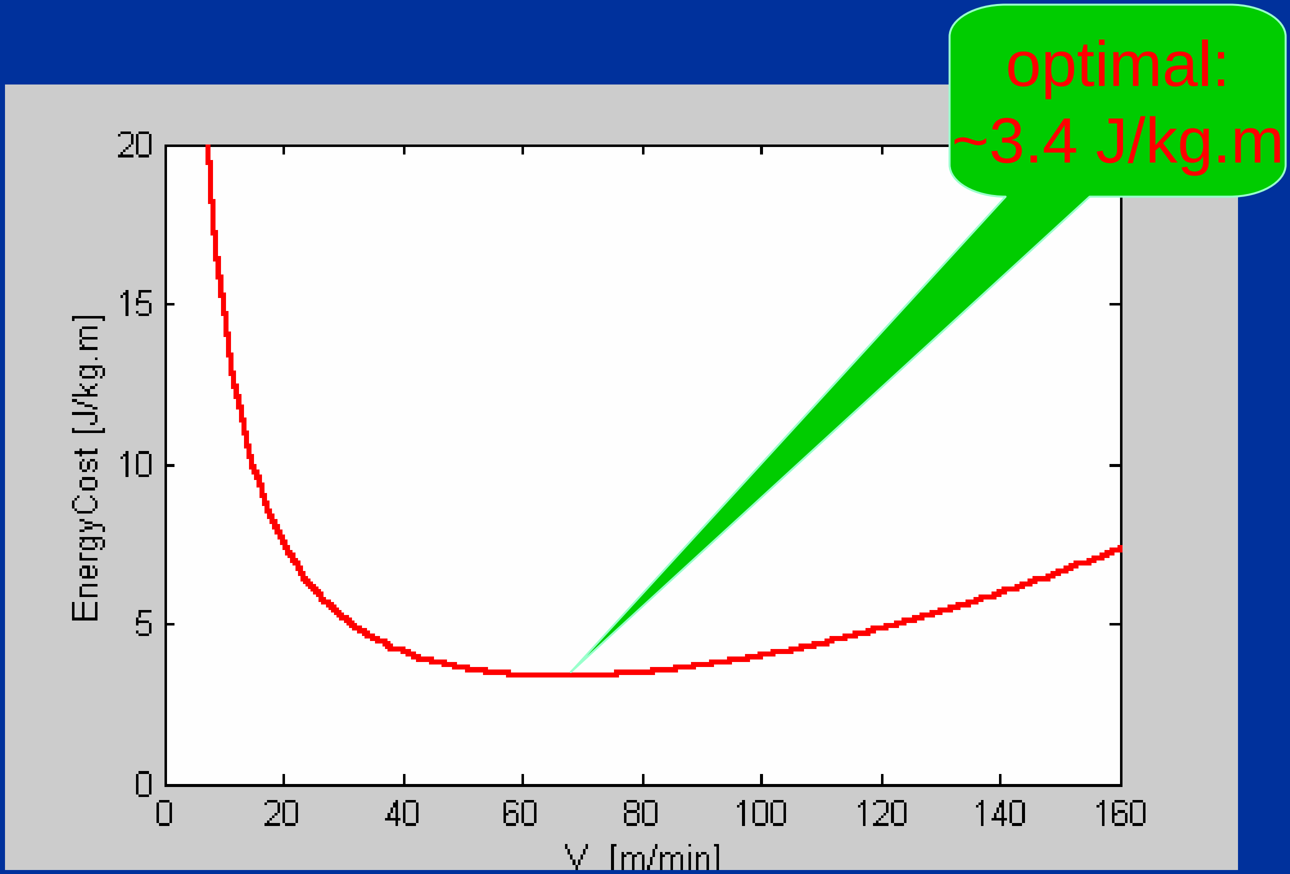


Energy measurements during gait

- (ambulatory) oxygen recording
- one ml O2 / min
  - = 5 cal / min
  - = 20 J/min

VU University Medical Center

Human gait is very efficient...



How far can you walk on a pastry ?

250 kcal

Energy cost at optimal speed
= 0.8 cal/kg.meter

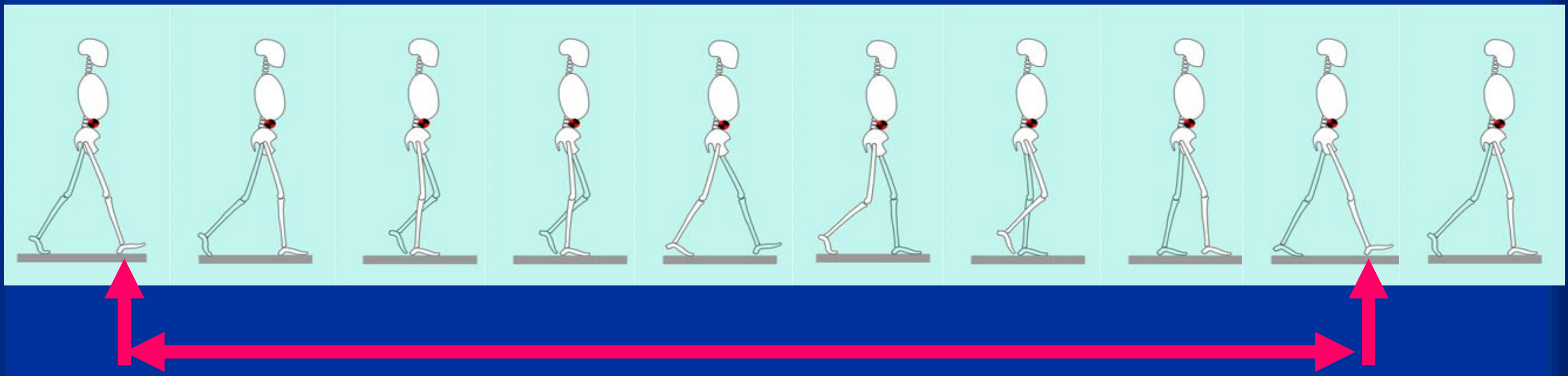
250.000/(0.8*70)=4,5 km

Metabolic Energy Measurement

VU University Medical Center

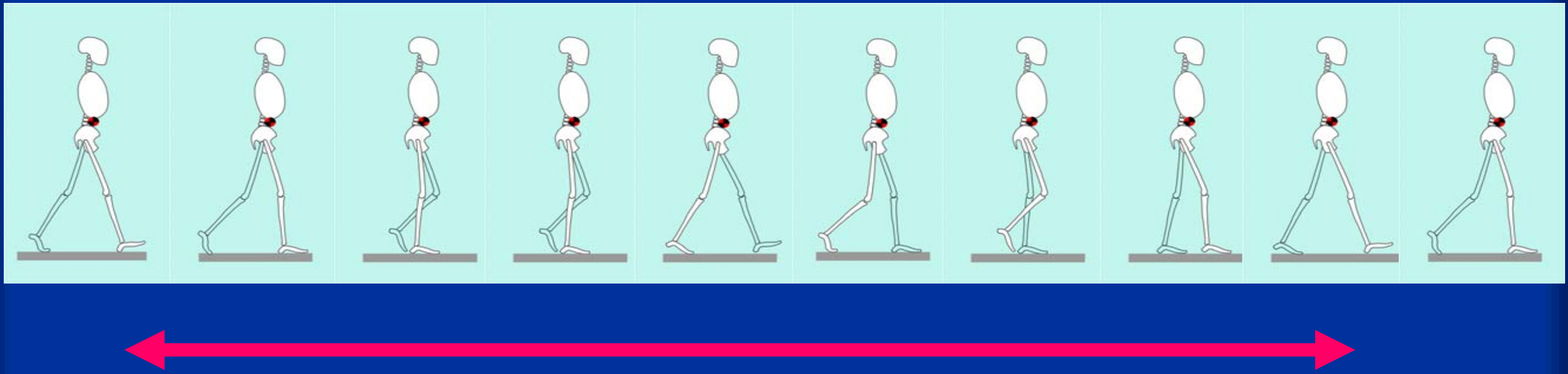
casus

the gaitcycle



One stride lasts from initial foot contact until the next *ipsilateral* initial foot contact

the gaitcycle (2)



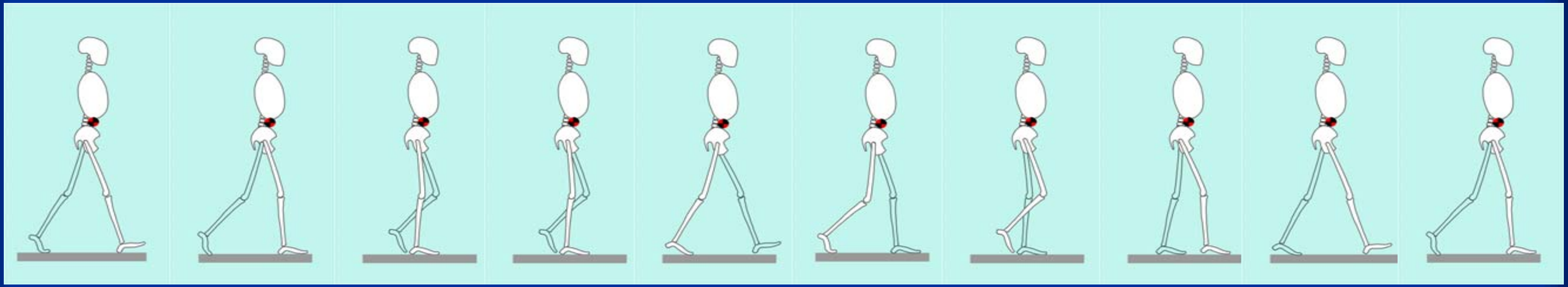
normalized time: 0 % - 100 %

VU University Medical Center

Heelstrike & Toe-off

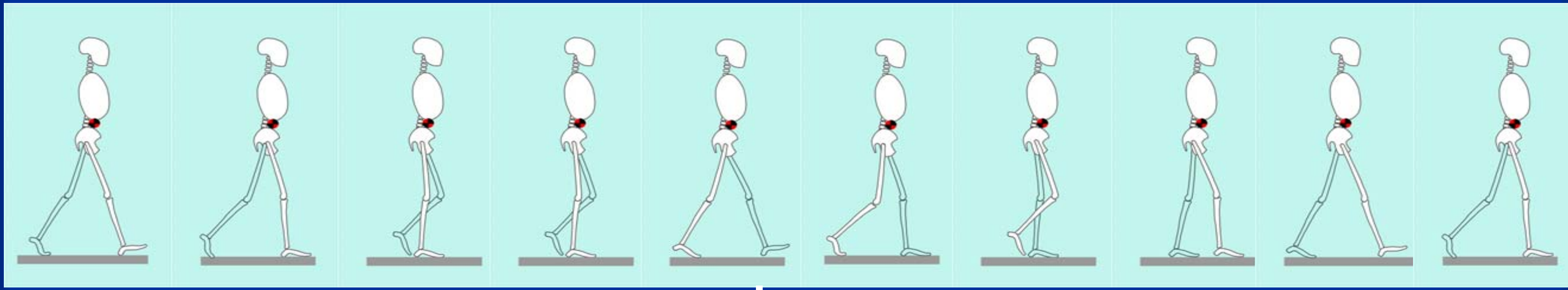
VU University Medical Center

the gaitcycle (3)



0 % -- stance -- 60 % -swing- 100%

the gaitcycle (4)

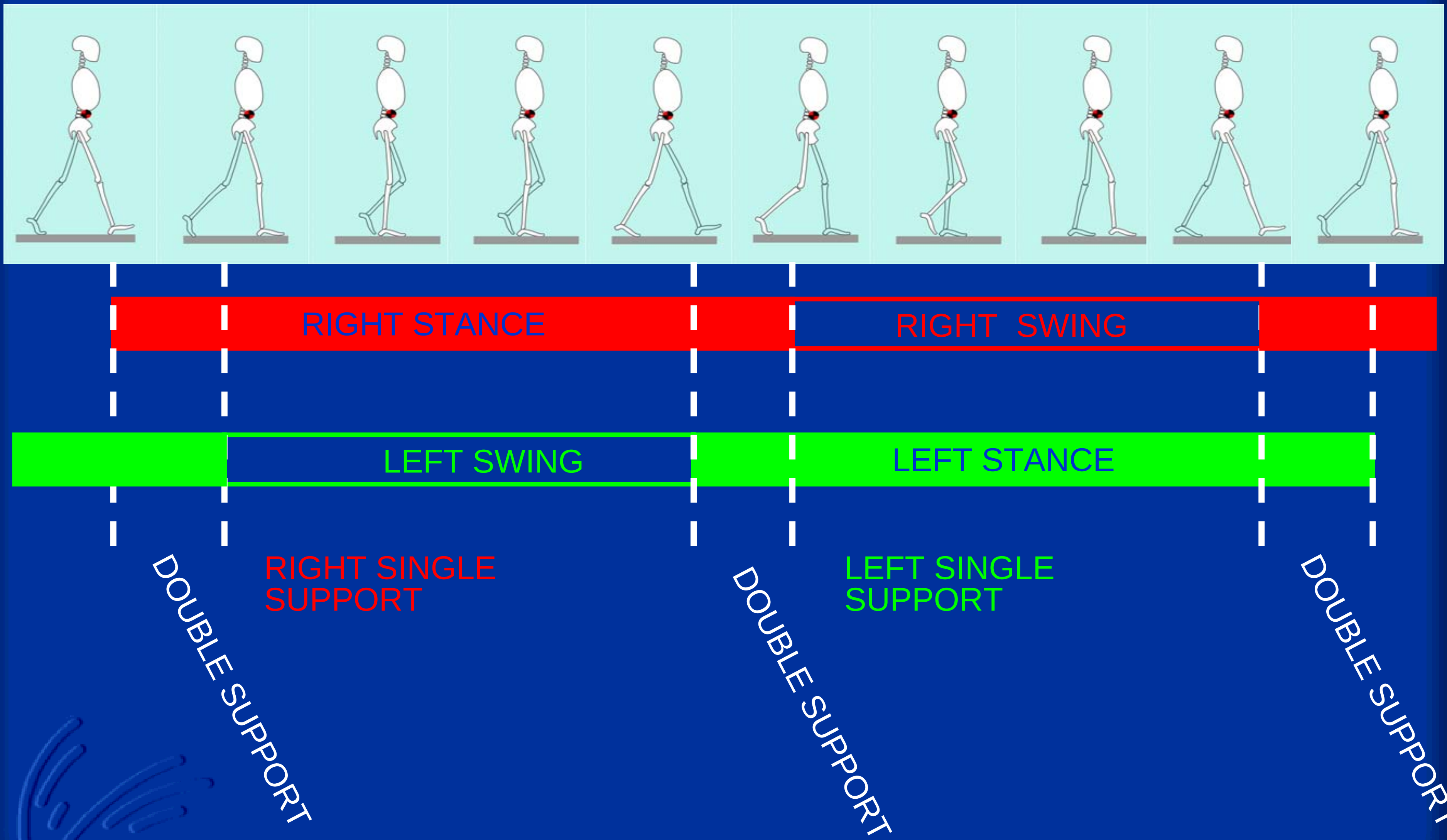


RIGHT STANCE | RIGHT SWING

LEFT SWING | LEFT STANCE

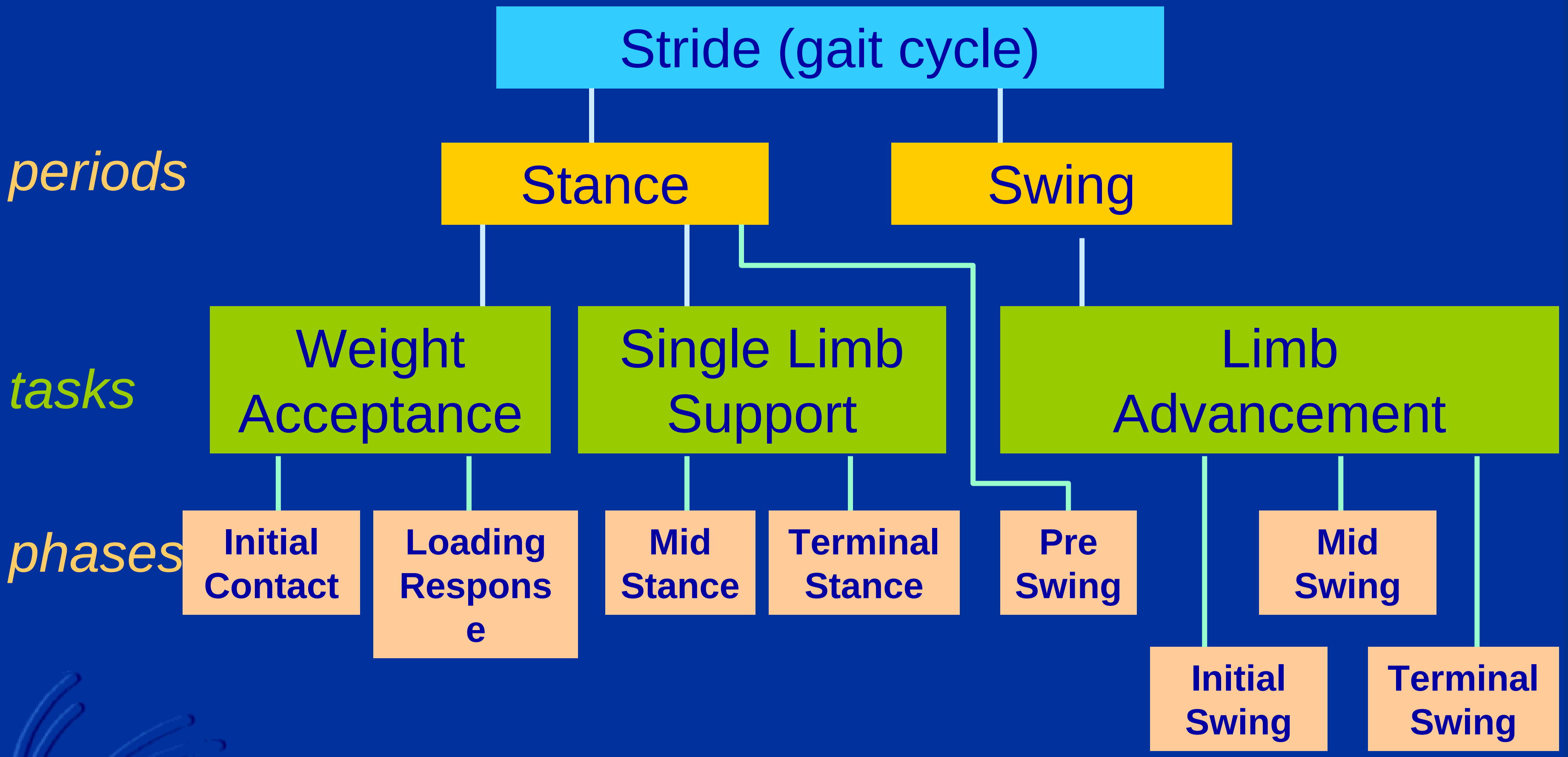
-- 50 % --

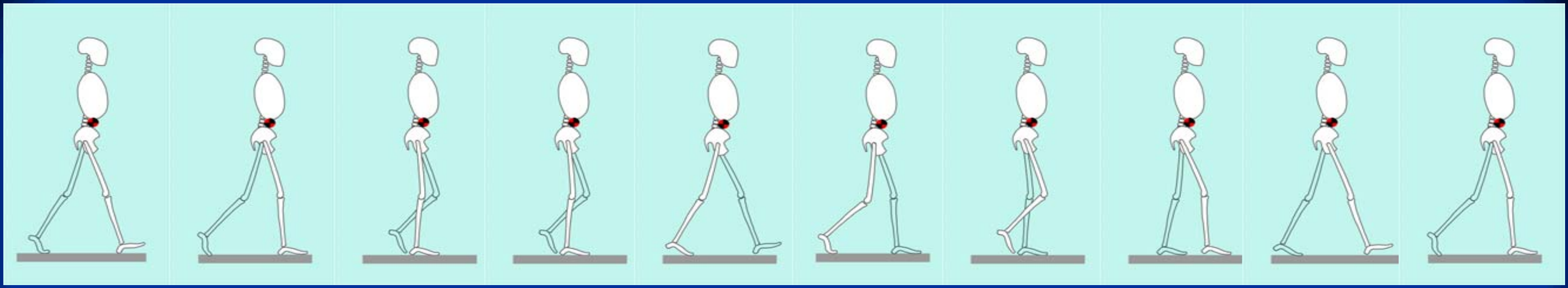
the gaitcycle (5)



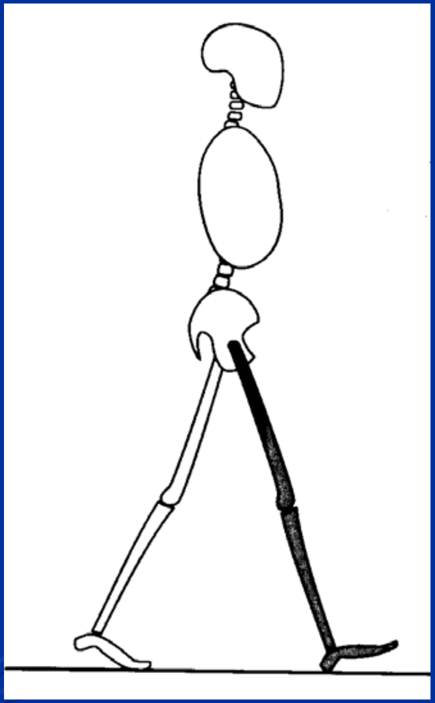
VU University Medical Center

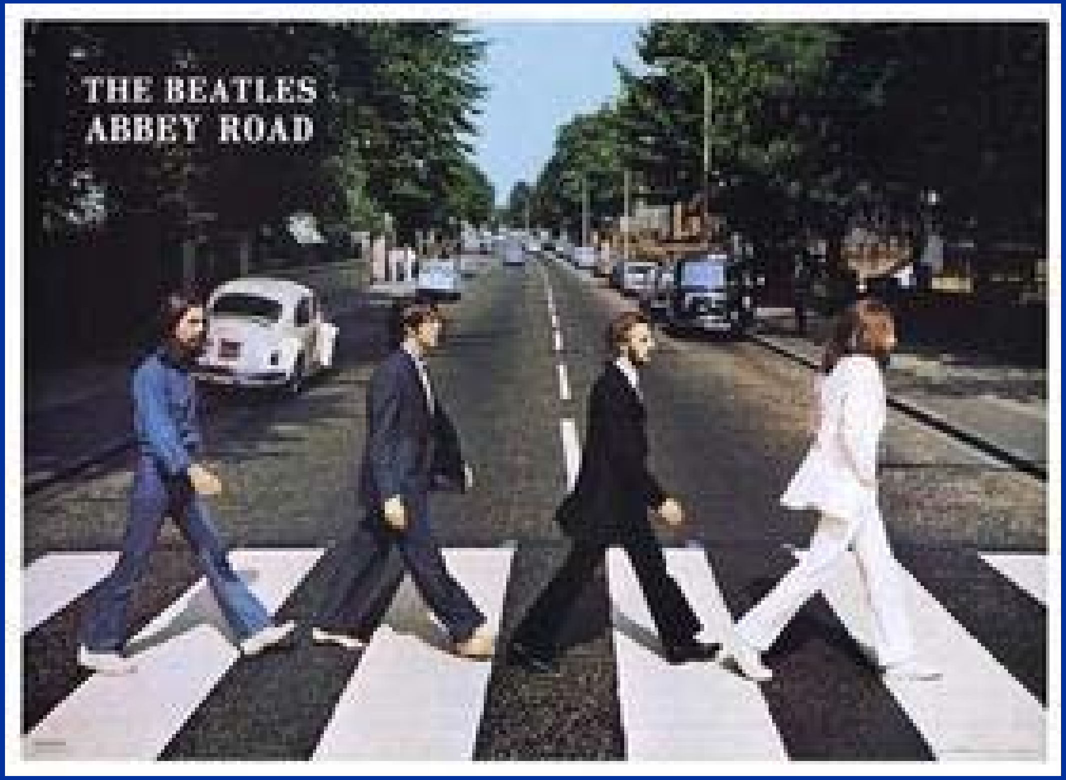
Functional division of gait phases (after J. Perry)

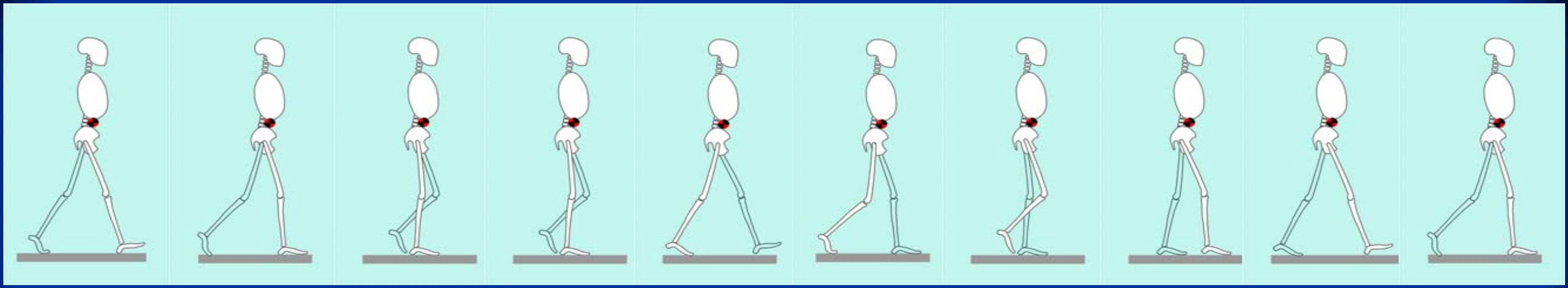




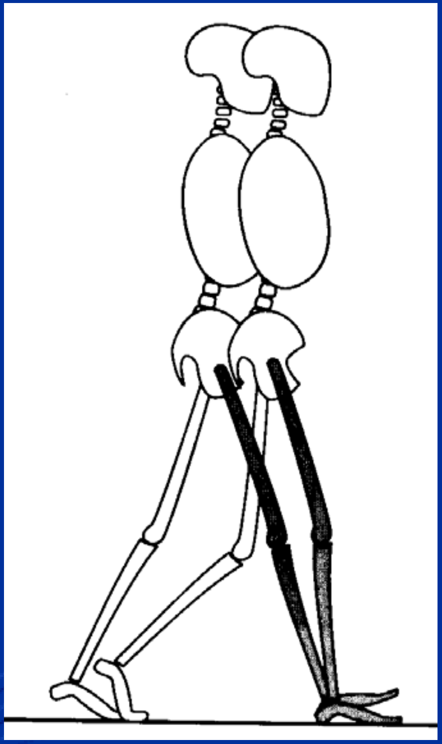
Initial Contact 0 %



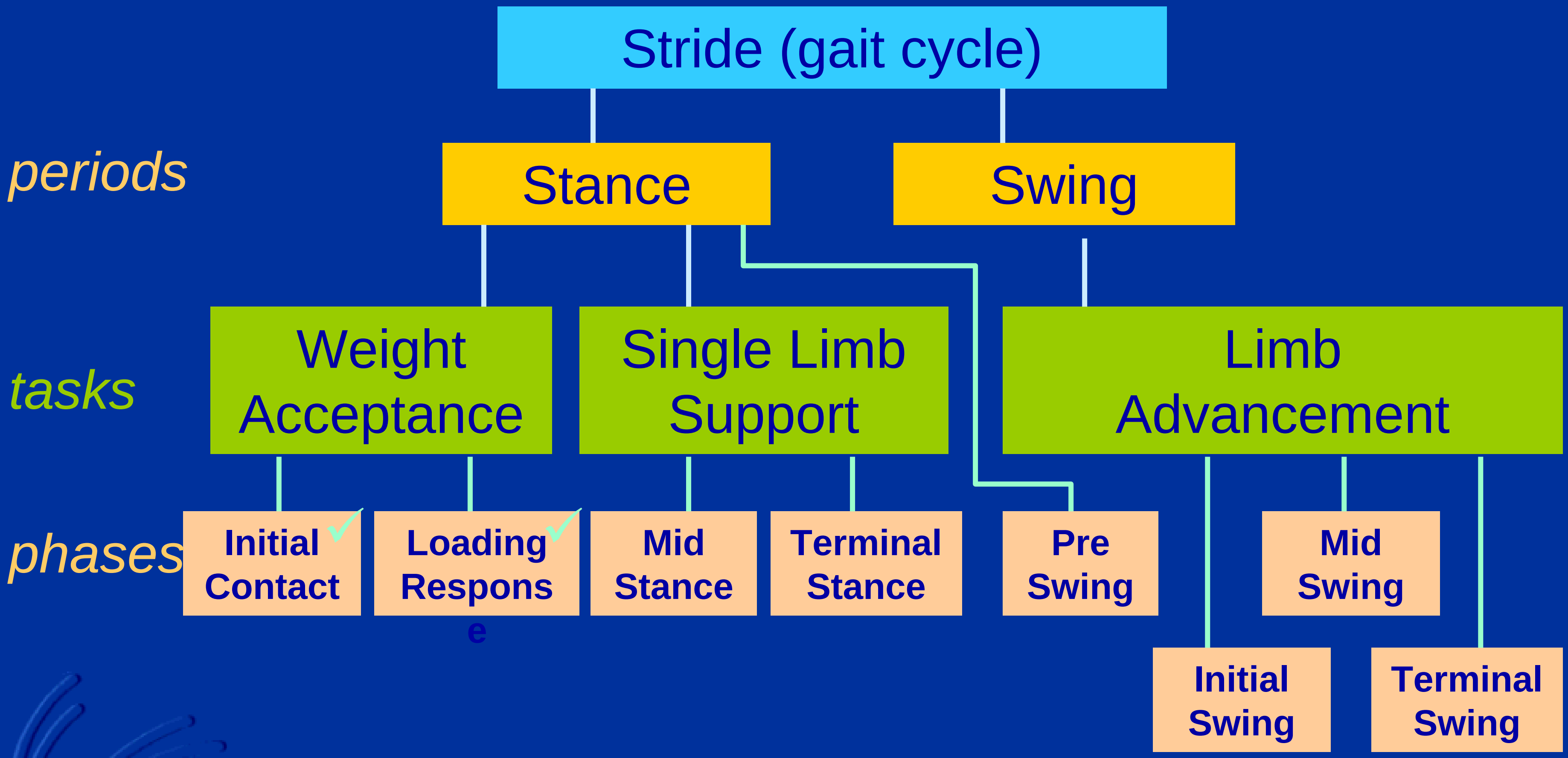


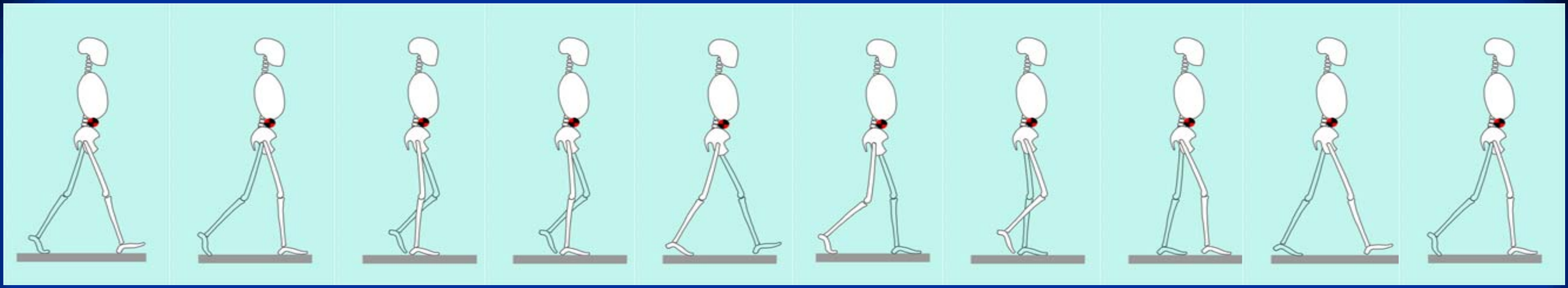


Loading Response 0-10 %



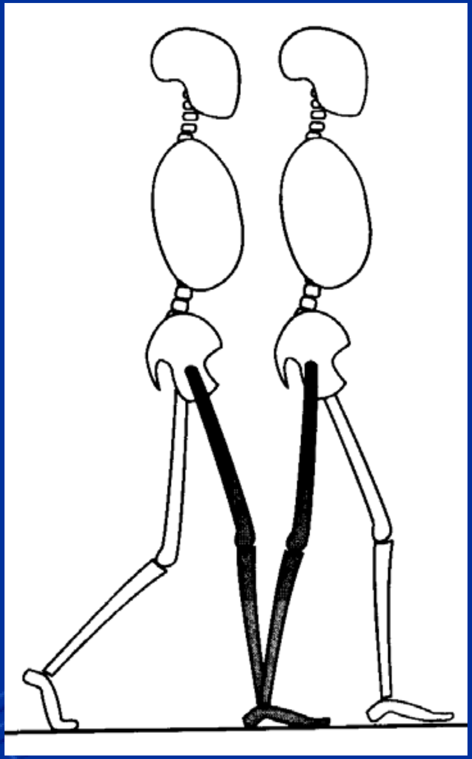
Functional division of gait phases (after J. Perry)

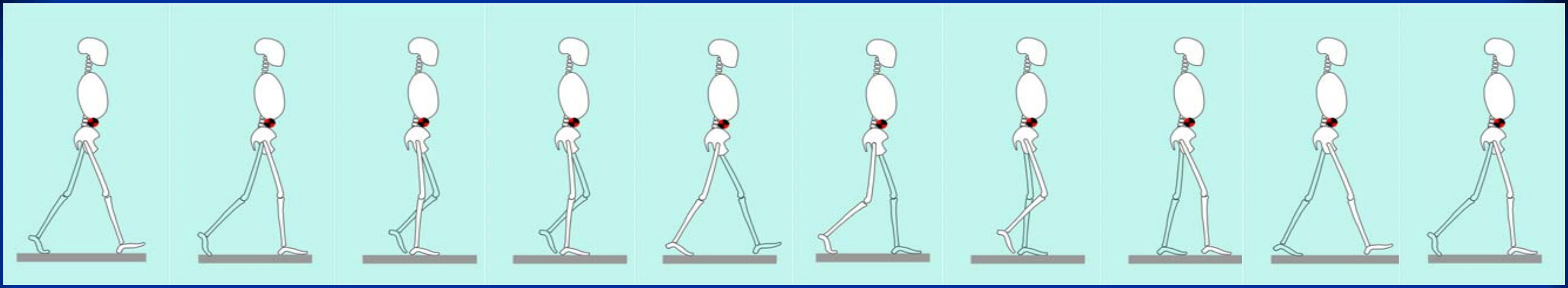




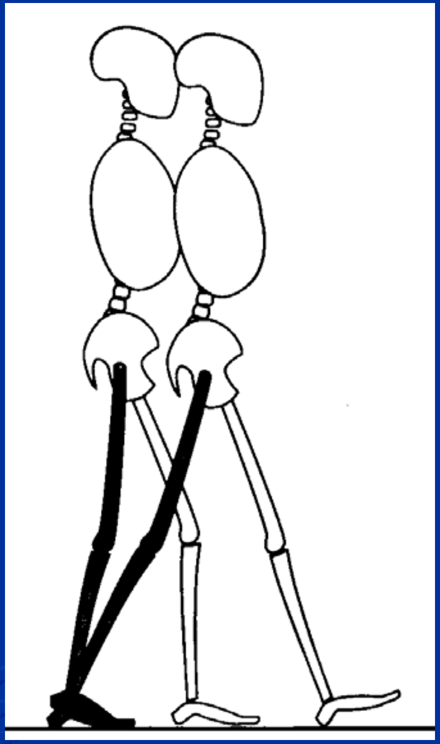
Midstance

10 - 30 %

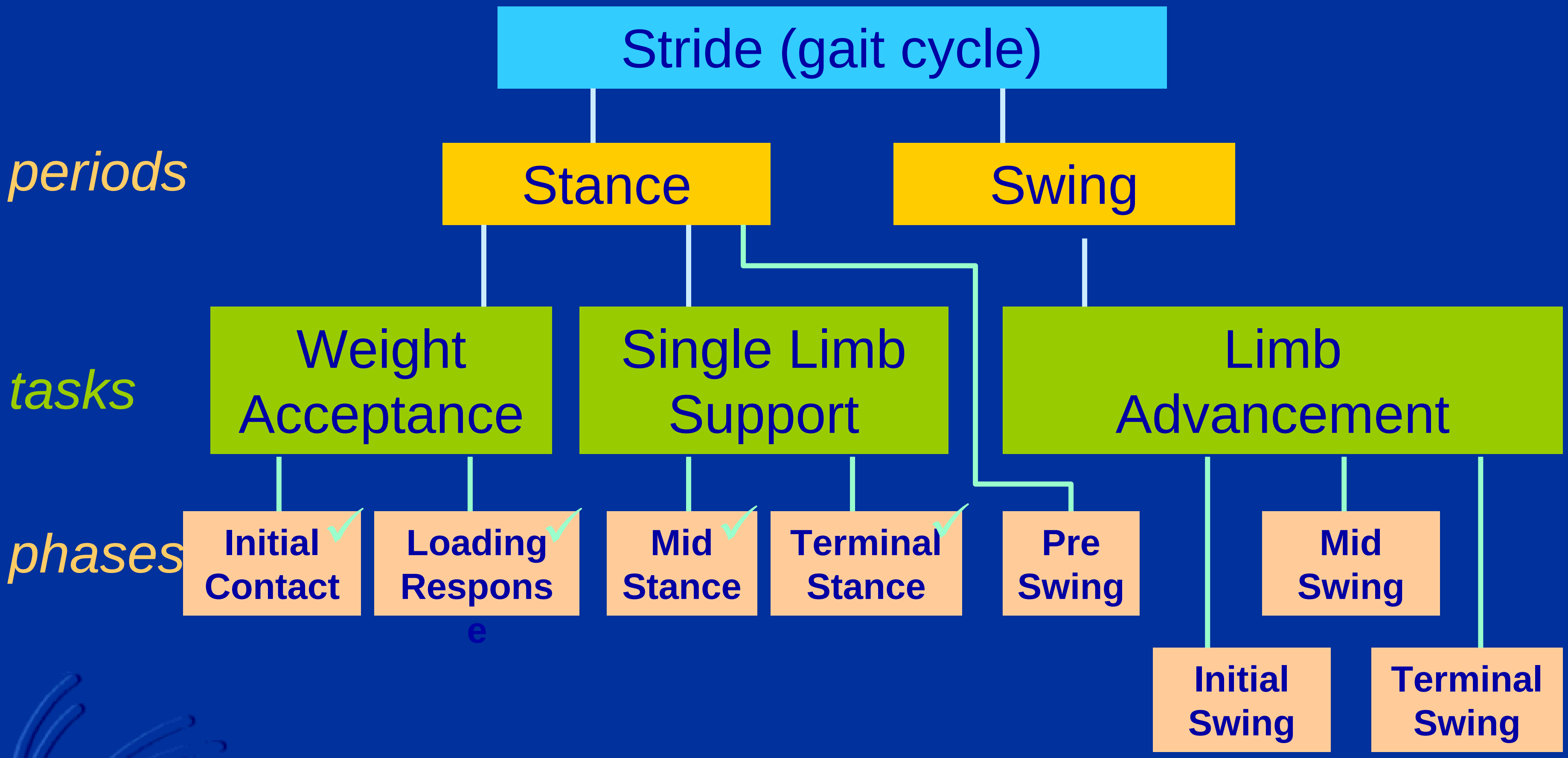


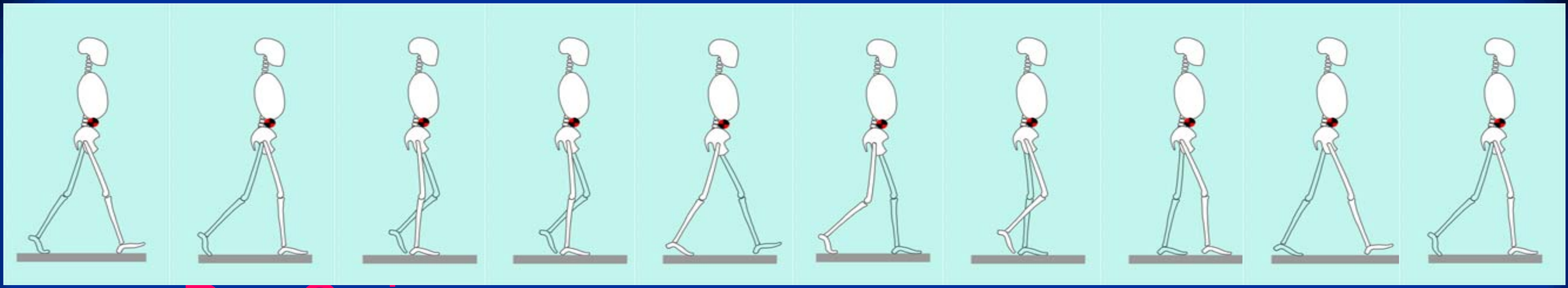


Terminal Stance 30 - 50 %

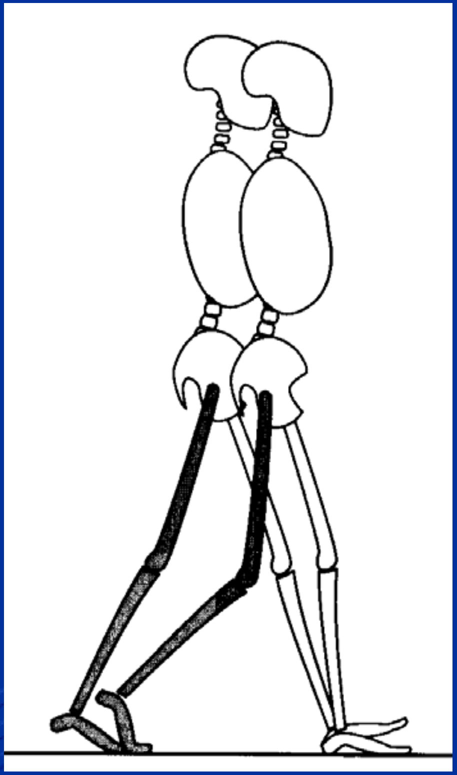


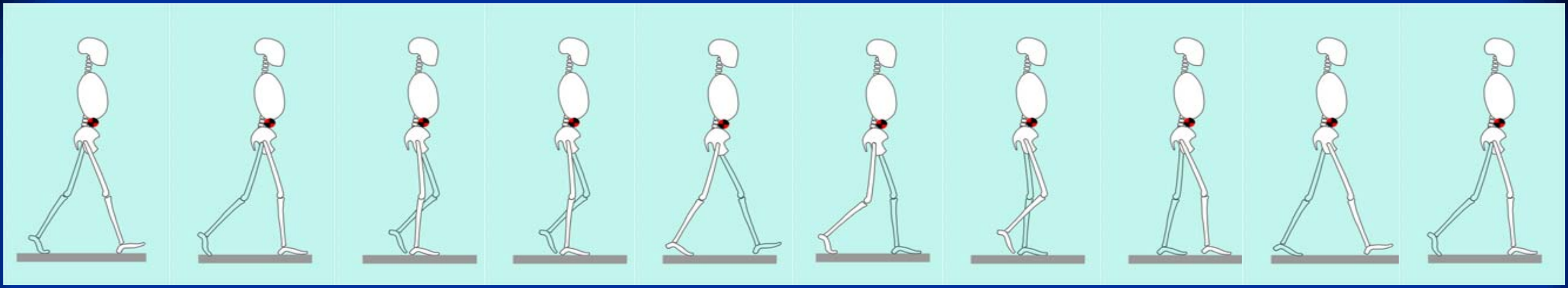
Functional division of gait phases (after J. Perry)



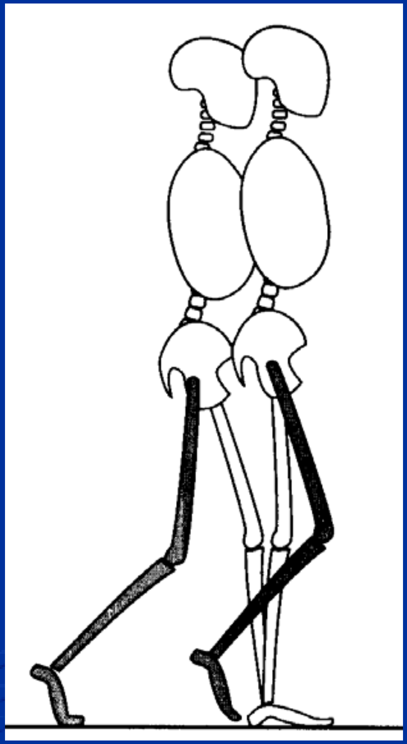


Pre-Swing 50 - 60 %

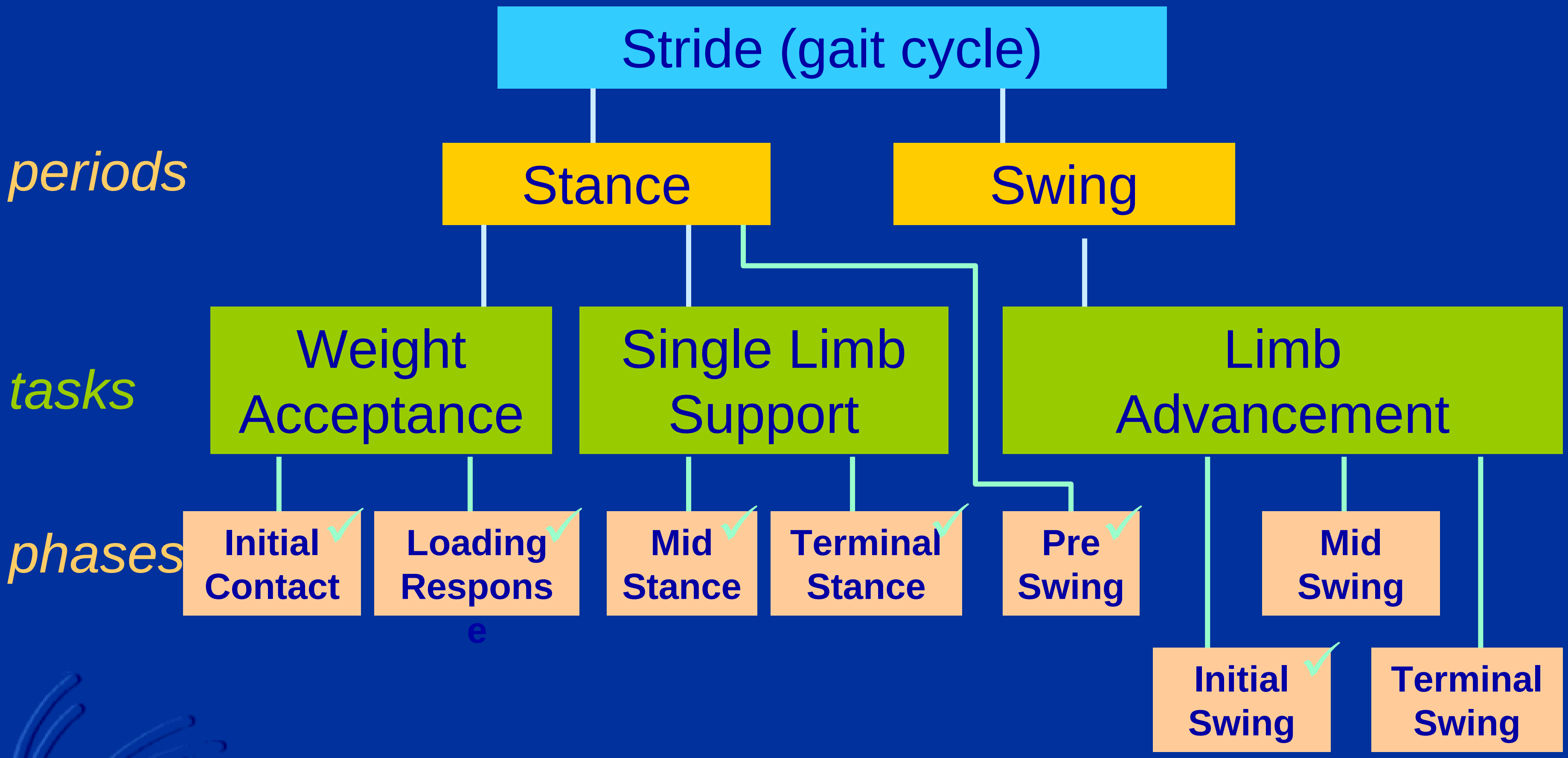


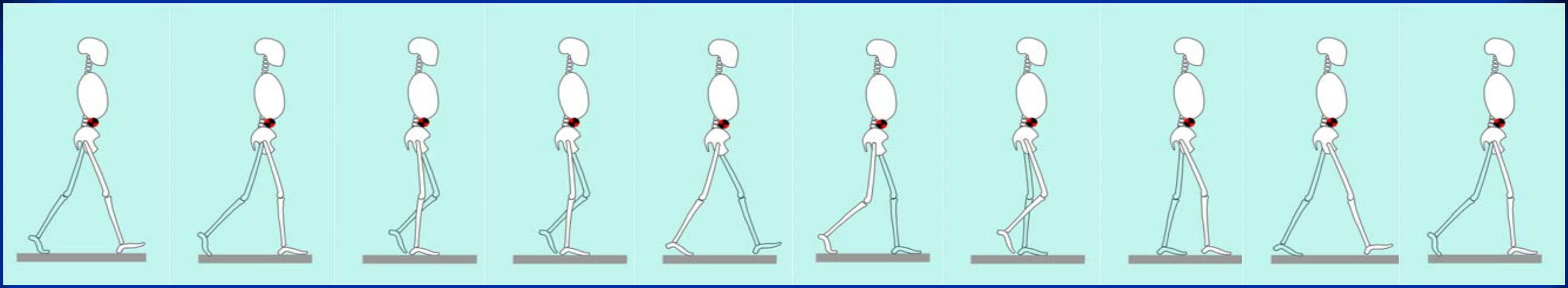


Initial-Swing 60 - 73 %



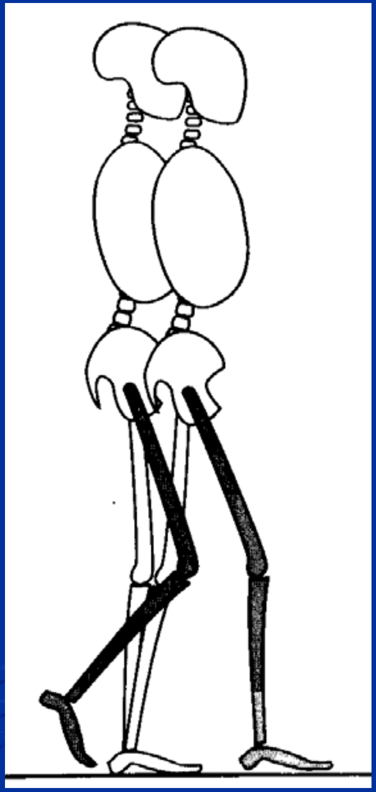
Functional division of gait phases (after J. Perry)

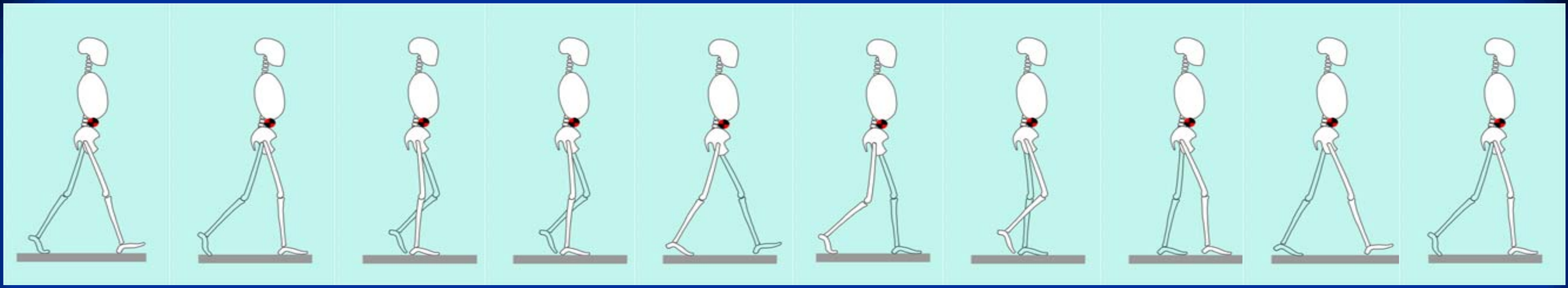




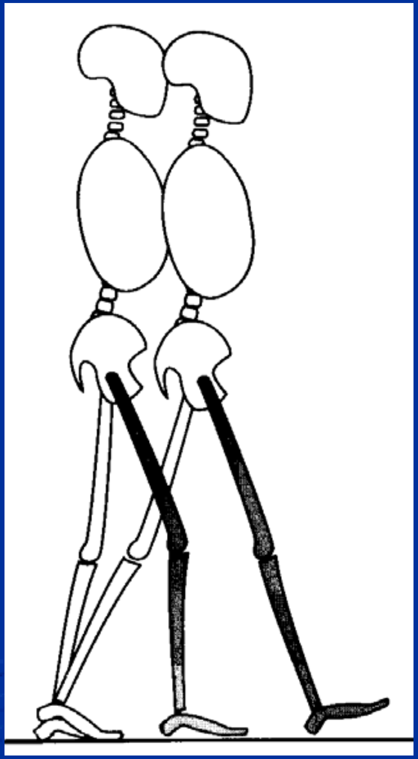
Mid-Swing

73 - 87 %

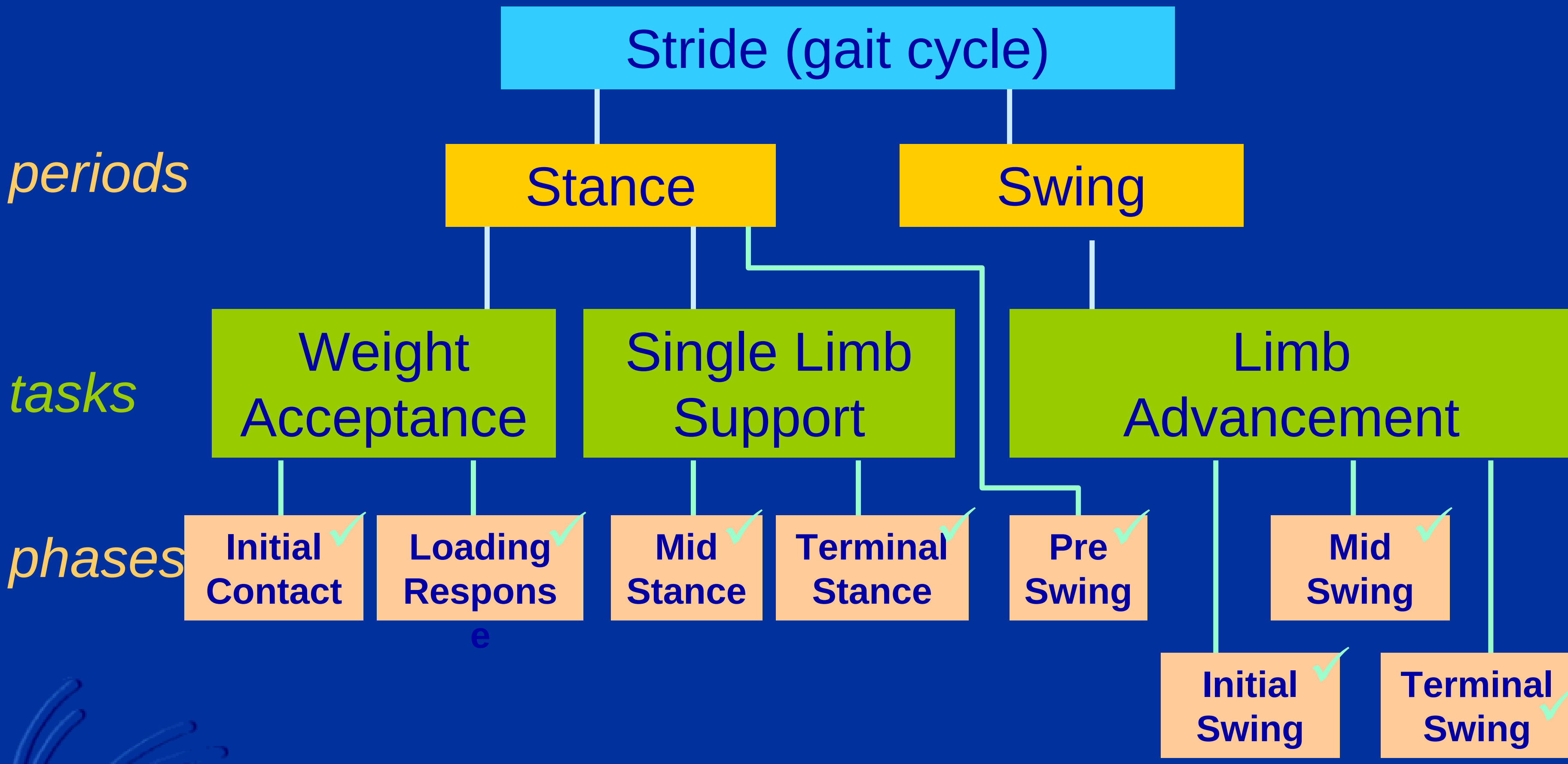




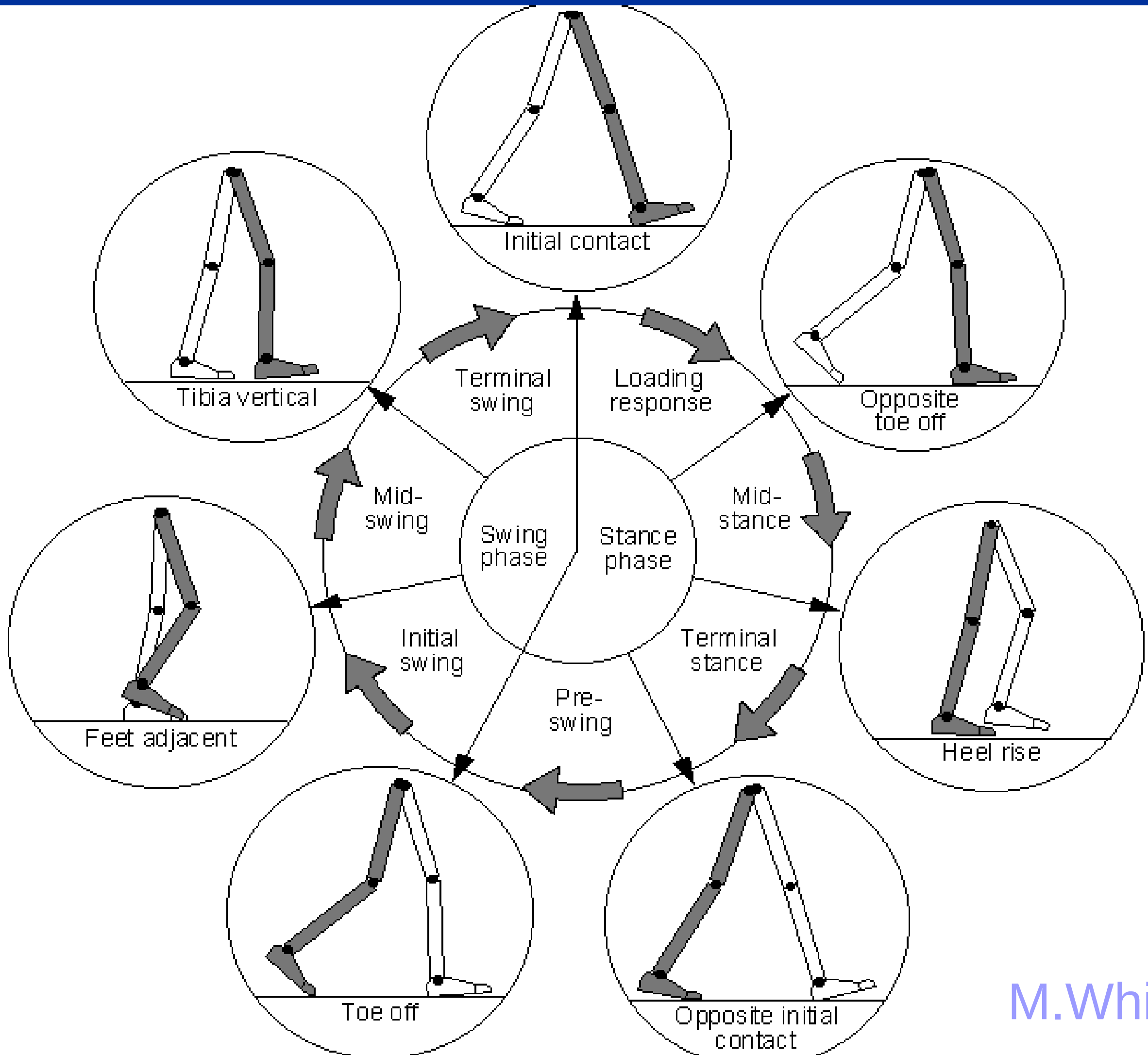
Terminal-Swing 87 - 100 %



Functional division of gait phases (after J. Perry)



The gait cycle



M.Whittle

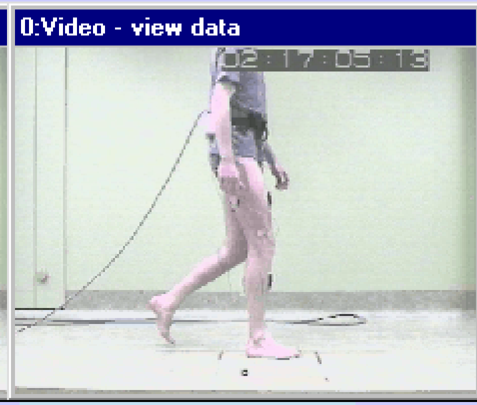
videorapport loopanalyse

datum opname: / /

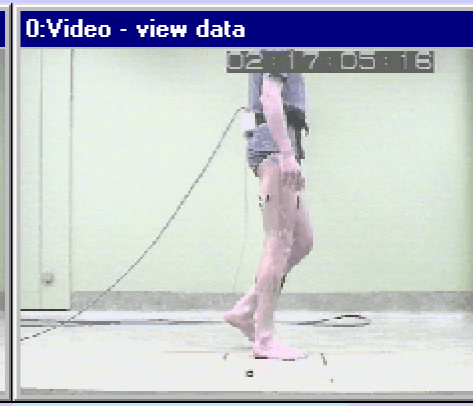
filenaam STUDY: `xxxSYxxx.sty`

❒ rechts
❒ links

1. initial contact

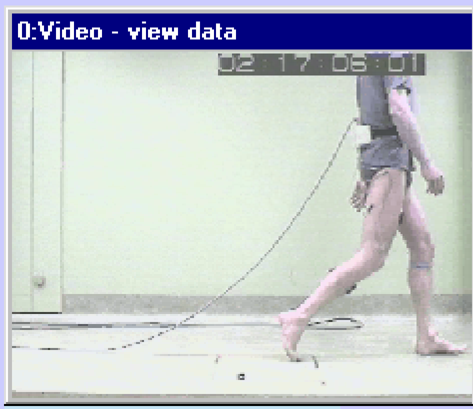


2. load response



3. midstance

4. terminal stance



5. preswing

6. initial swing

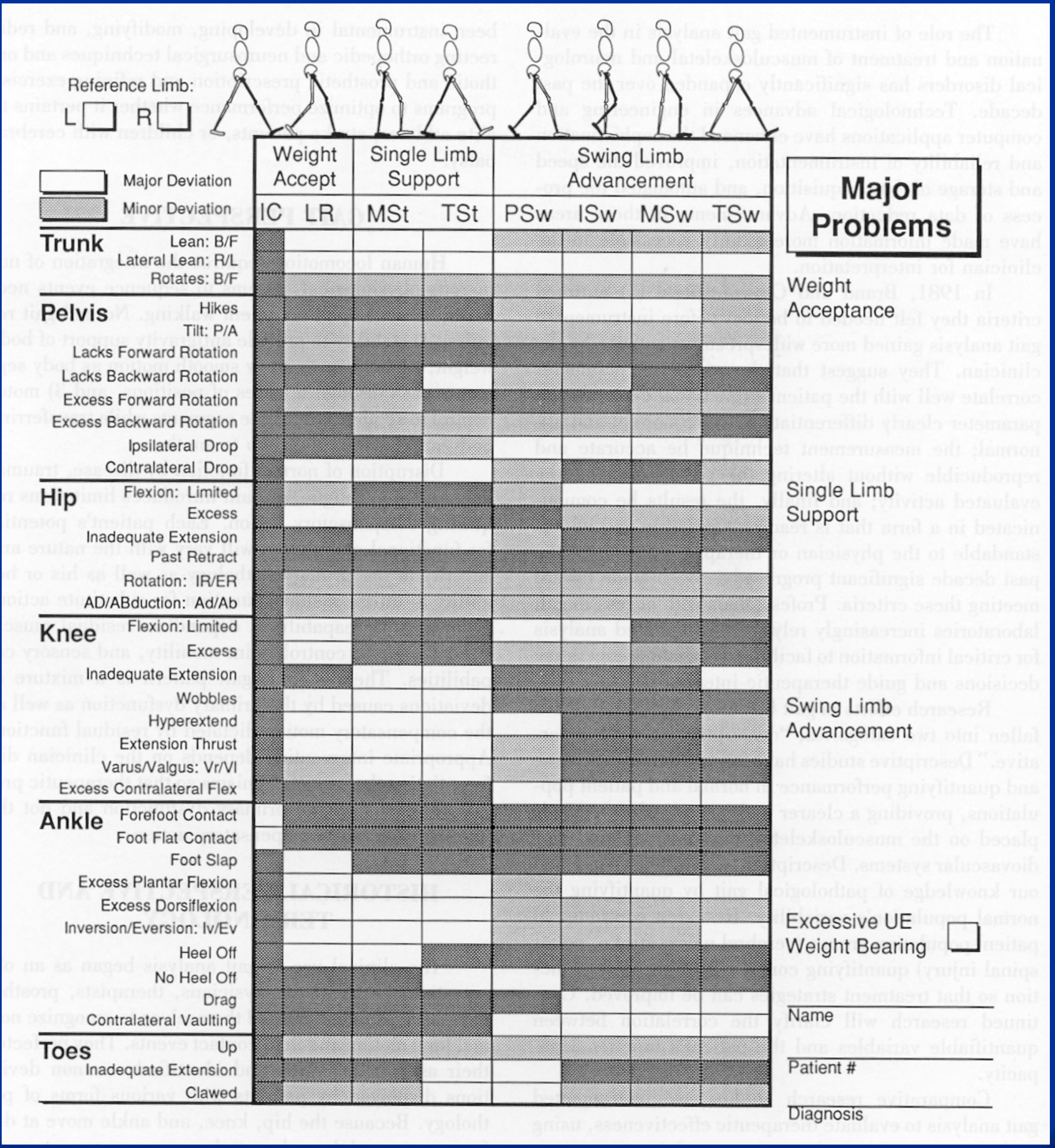
7. midswing

8. terminal swing

VU academisch ziekenhuis

Observational Gait Analysis form

Rancho Los Amigos Medical Centre



Reference Limb: L R

Major Deviation

Minor Deviation

Weight Accept | Single Limb Support | Swing Limb Advancement

IC LR MSt TSt PSw ISw MSw TSw

Trunk
Lean: B/F
Lateral Lean: R/L
Rotates: B/F

Pelvis
Hikes
Tilt: P/A
Lacks Forward Rotation
Lacks Backward Rotation
Excess Forward Rotation
Excess Backward Rotation
Ipsilateral Drop
Contralateral Drop

Hip
Flexion: Limited
Excess
Inadequate Extension
Past Retract
Rotation: IR/ER
AD/ABduction: Ad/Ab

Knee
Flexion: Limited
Excess
Inadequate Extension
Wobbles
Hyperextend
Extension Thrust
Varus/Valgus: Vr/Vl
Excess Contralateral Flex

Ankle
Forefoot Contact
Foot Flat Contact
Foot Slap
Excess Plantar Flexion
Excess Dorsiflexion
Inversion/Eversion: Iv/Ev
Heel Off
No Heel Off
Drag
Contralateral Vaulting

Toes
Up
Inadequate Extension
Clawed

Major Problems

Weight Acceptance

Single Limb Support

Swing Limb Advancement

Excessive UE Weight Bearing

Name

Patient #

Diagnosis

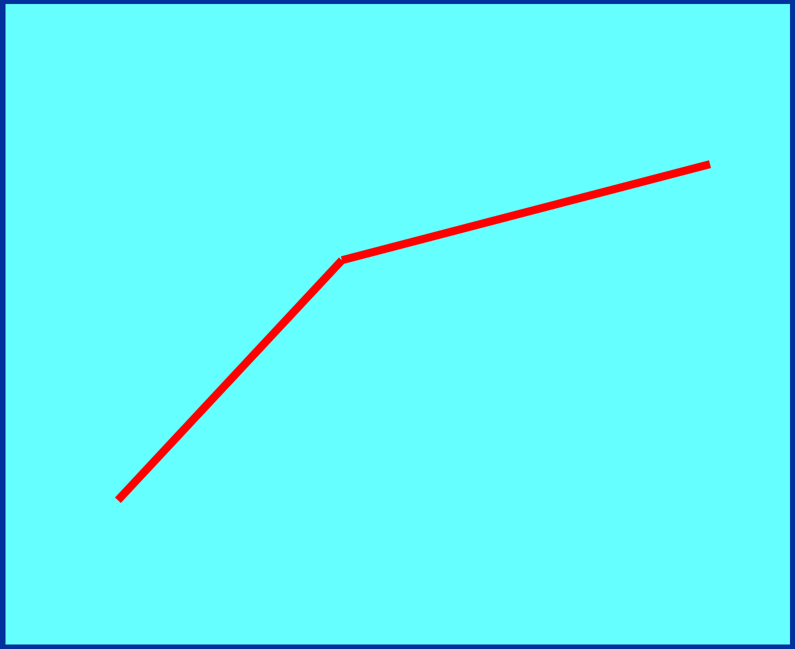
Edinburgh GAIT Scoring Table

Movement SAGITTAL	2	1	0	1	2		Movement CORONAL/TRANSV	2	1	0	1	2
FOOT							FOOT					
1 Foot clearance	None	Reduced	Full	N/A	N/A		5 Stance position hindfoot in load	>15 Valgus	6-15 Valgus	5-0-5 Neutral	6-15 Varus	>15 Varus
2 Initial Contact	Toe	Flatfoot	Heel	N/A	N/A		6 Foot progression angle	>15 IR	6-15 IR	5-0-5 Neutral	6-15 ER	>15 ER
3 Heel lift	None	Early	Normal	Delayed	N/A							
4 Max dorsiflexion hindfoot in stance	>10 Plantar	10-0-9 Plan/Dors	10-20 Dorsifl	21-30 Dorsifl	>30 Dorsifl							
KNEE							KNEE					
7 Terminal swing	>30 Flexion	15-30 Flexion	0-15 Flexion	>0 Hypext	N/A		10 Knee progression angle mid-stance	part cap IR	all cap IR	Neutral	all cap ER	part cap ER
8 Peak stance knee ext	>30 Flexion	15-30 Flexion	0-15 Flexion	1-10 Hypext	>10 Hypext							
9 Peak knee flex in swing	>80 Flexion	65-80 Flexion	60-64 Flexion	30-59 Flexion	<30 Flexion							
HIP							HIP					
11 Peak hip ext in stance	>30 Flexion	16-30 Flexion	15-0-15 Flex/Ext	N/A	N/A		13 Position in swing	>15 Adduct	5-15 Adduct	4-0-9 Add/Abd	10-20 Abduct	>20 Abduct
12 Peak hip flex in swing	>75 Flexion	51-75 Flexion	30-50 Flexion	15-29 Flexion	<15 Flexion							
PELVIS (Trans)							PELVIS					
14 Pelvic rotation i midstance	>15 Fwd	6-15 Fwd	5-0-5 Neutral	6-15 Bwd	>15 Bwd		15Contralat drop in stance	Marked	Mod	Normal	N/A	N/A
TRUNK							TRUNK					
16 Peak sagittal position in stance	>15 Fwd	6-15 Fwd	5-0-5 Neutral	>5 Bwds			17 Maximal lat shift in stance	Marked	Mod	Normal	N/A	N/A
TOTAL												

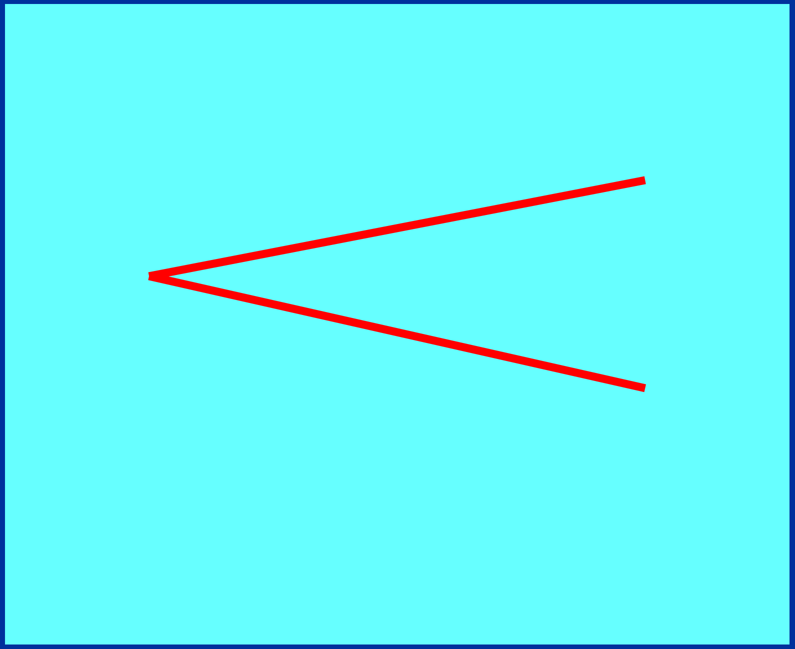
Error sources in observational kinematic analysis

- Subjective
- estimation error
- out of plane (2D vs. 3D)

How well do we perform ?



148 º



24 º

VU University Medical Center

Estimation of joint angles

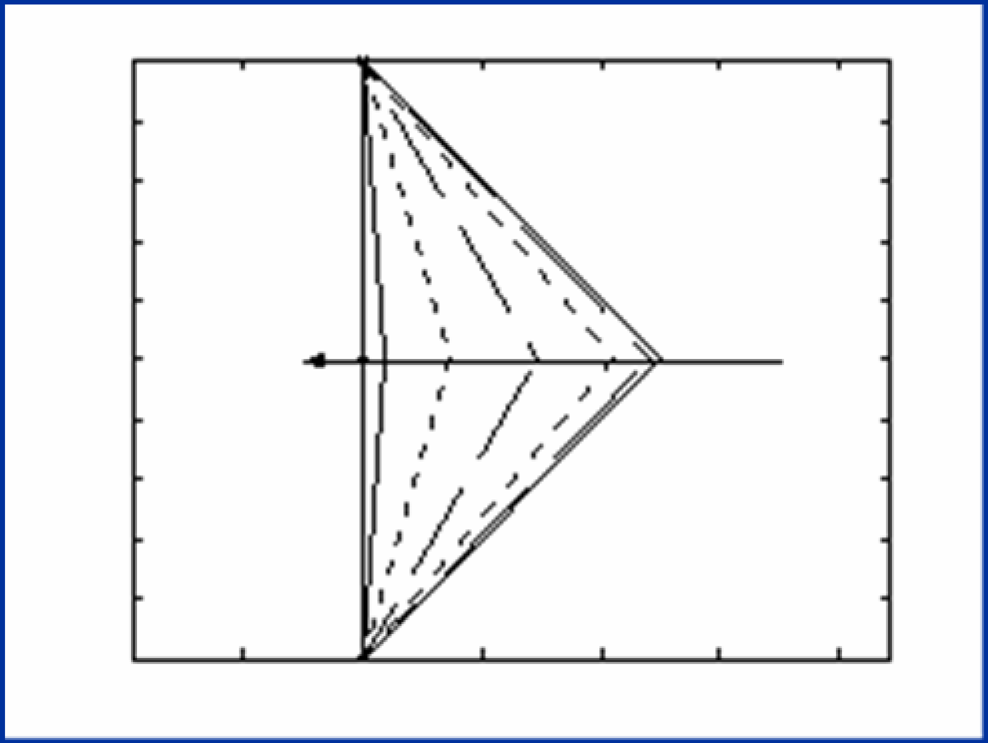
How well do we perform ?

148 º 24 º

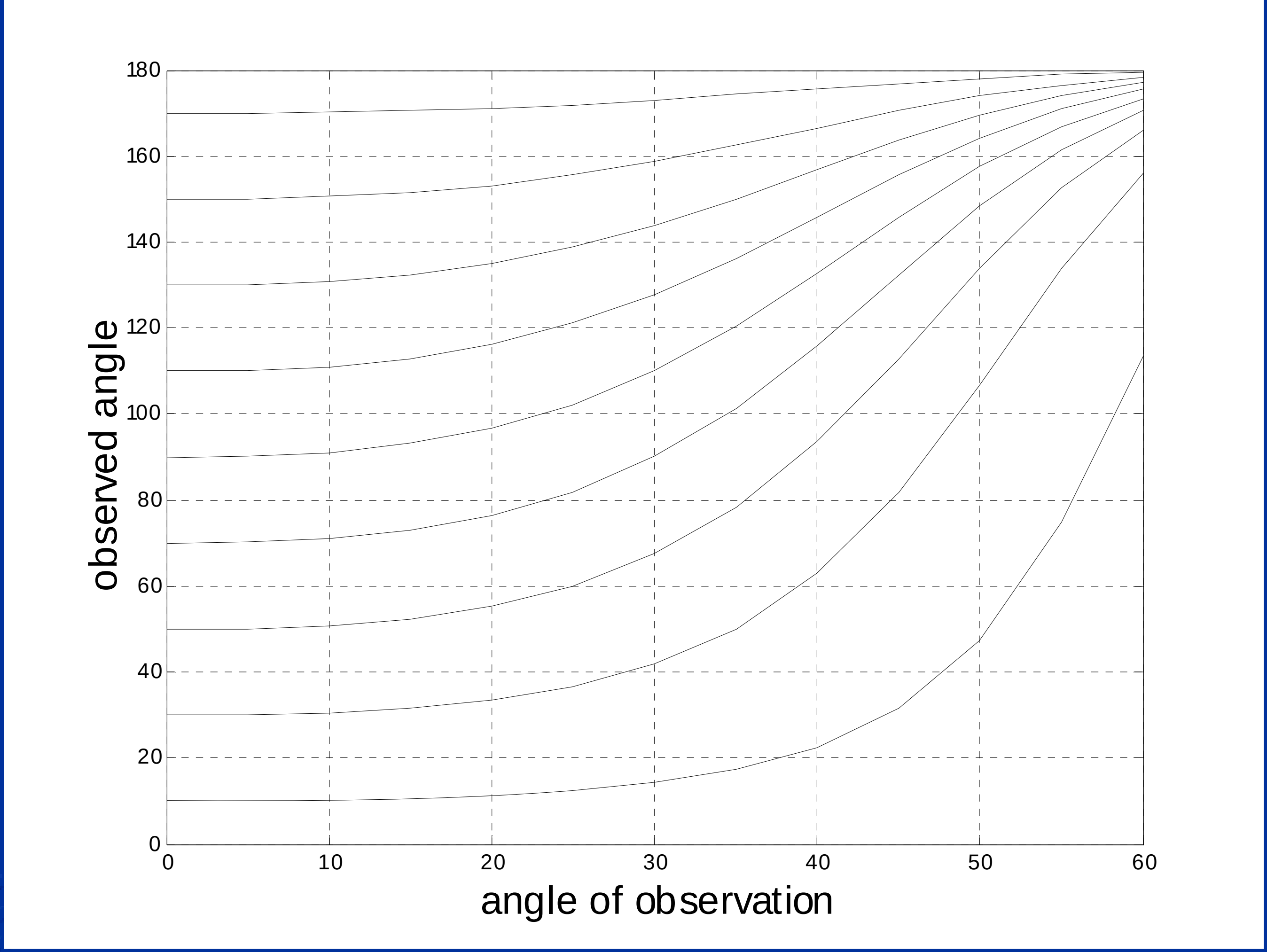
VU University Medical Center

Projection error

Projection error

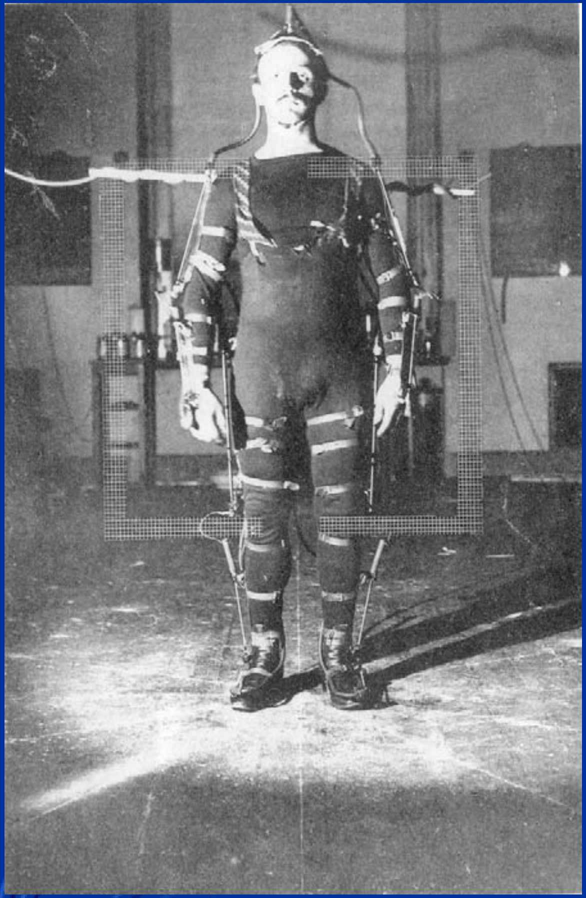


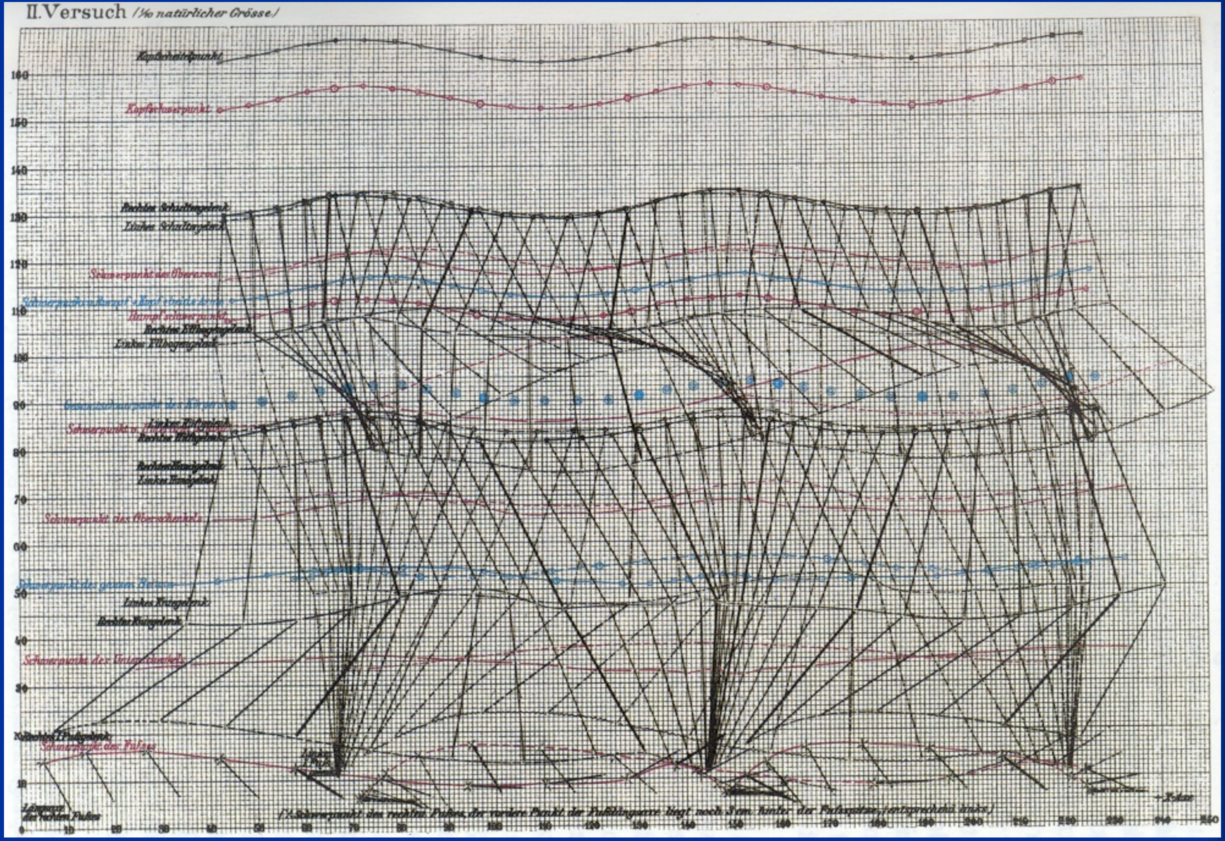
Projectionerror (2)



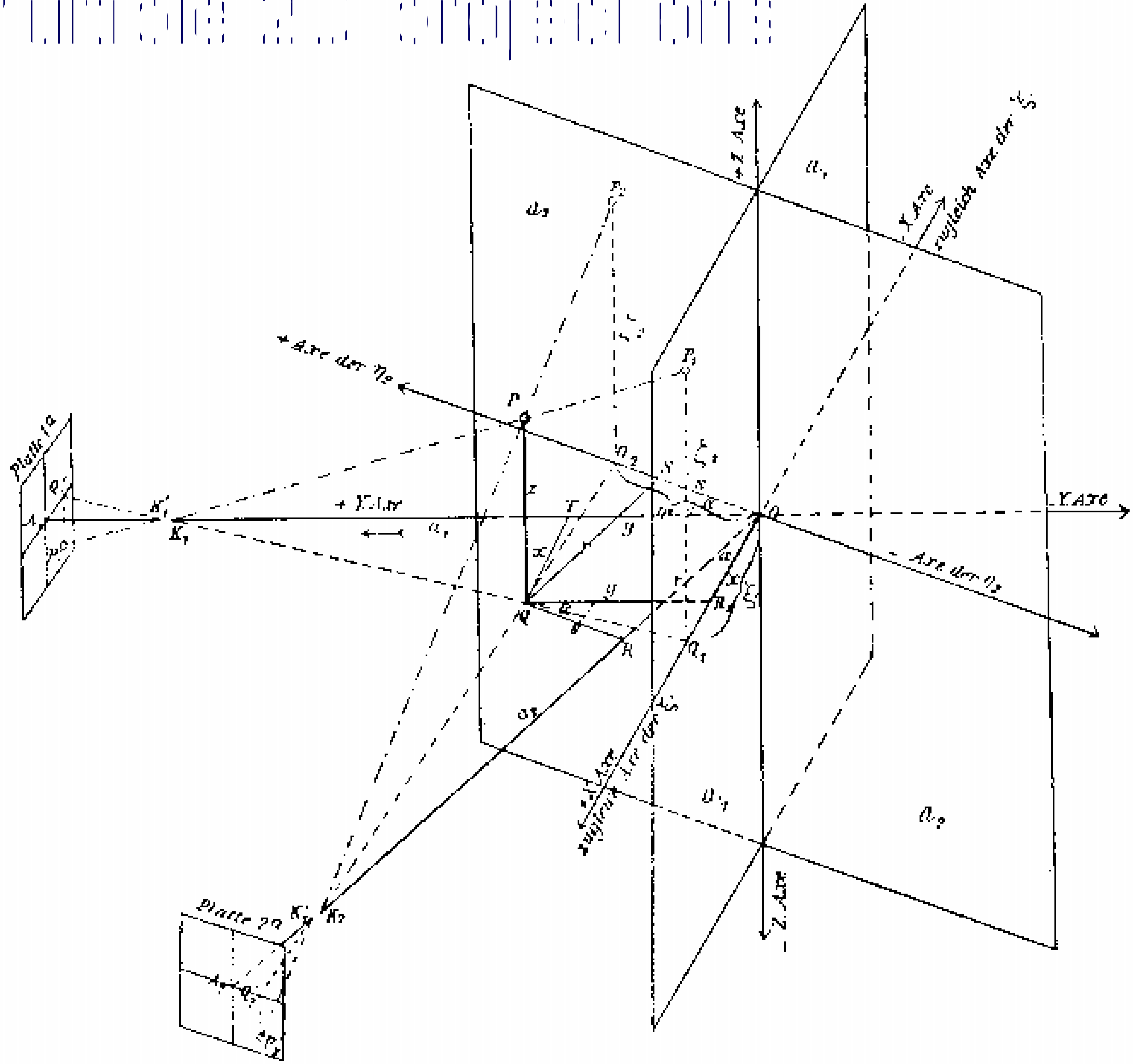
Earliest 3D movement analysis

Braun & Fischer 1895





Multiple 2D projections



Calibrate the projection

calibration frame

Direct
Linear
Transformation

15 points are known in the real (3D) world

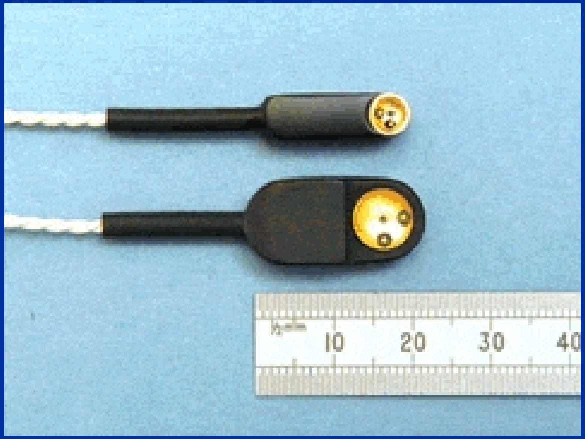
Videobased systems: SYBAR, SIMI, PEAK, ...

Automated marker tracking and 3D reconstruction of marker position

Multiple (2+) stroboscopic InfraRed camera's using reflective markers on the body

Vicon, MotionAnalysis, Elite, Qualysis,. . .

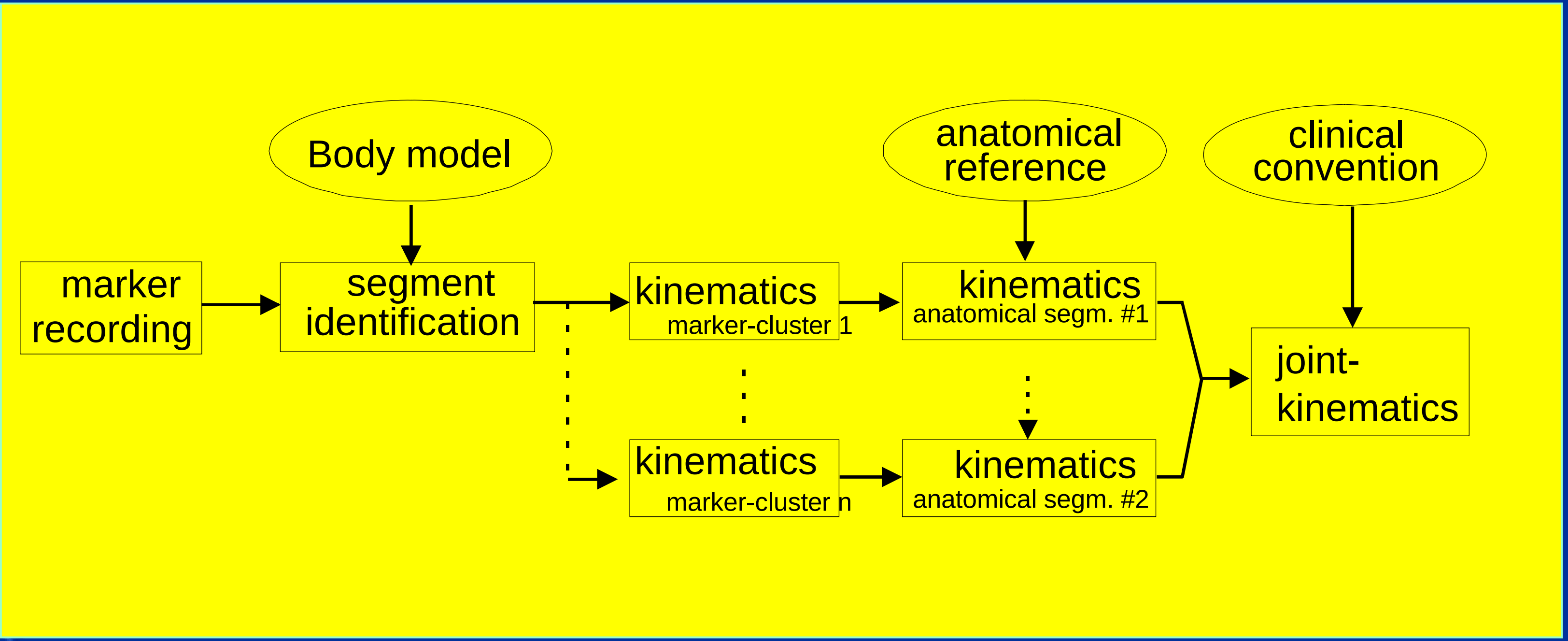
Automated marker tracking and 3D reconstruction of marker position (2)



Active InfraRed markers

3D camera ('s)

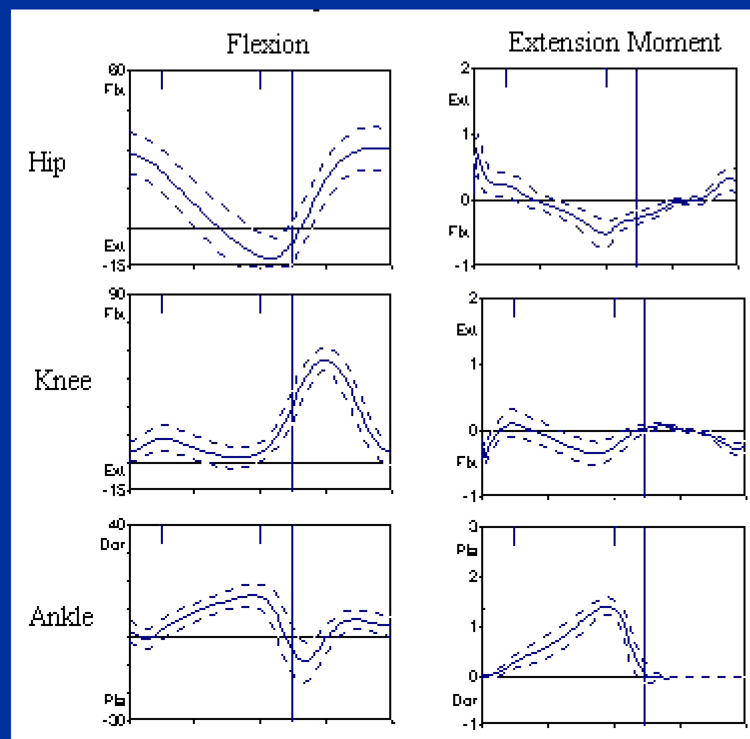
CODAmotion, OptoTrak, . . .


Body model
anatomical reference
clinical convention
marker recording
segment identification
kinematics marker-cluster 1
kinematics anatomical segm. #1
kinematics marker-cluster n
kinematics anatomical segm. #2
joint-kinematics

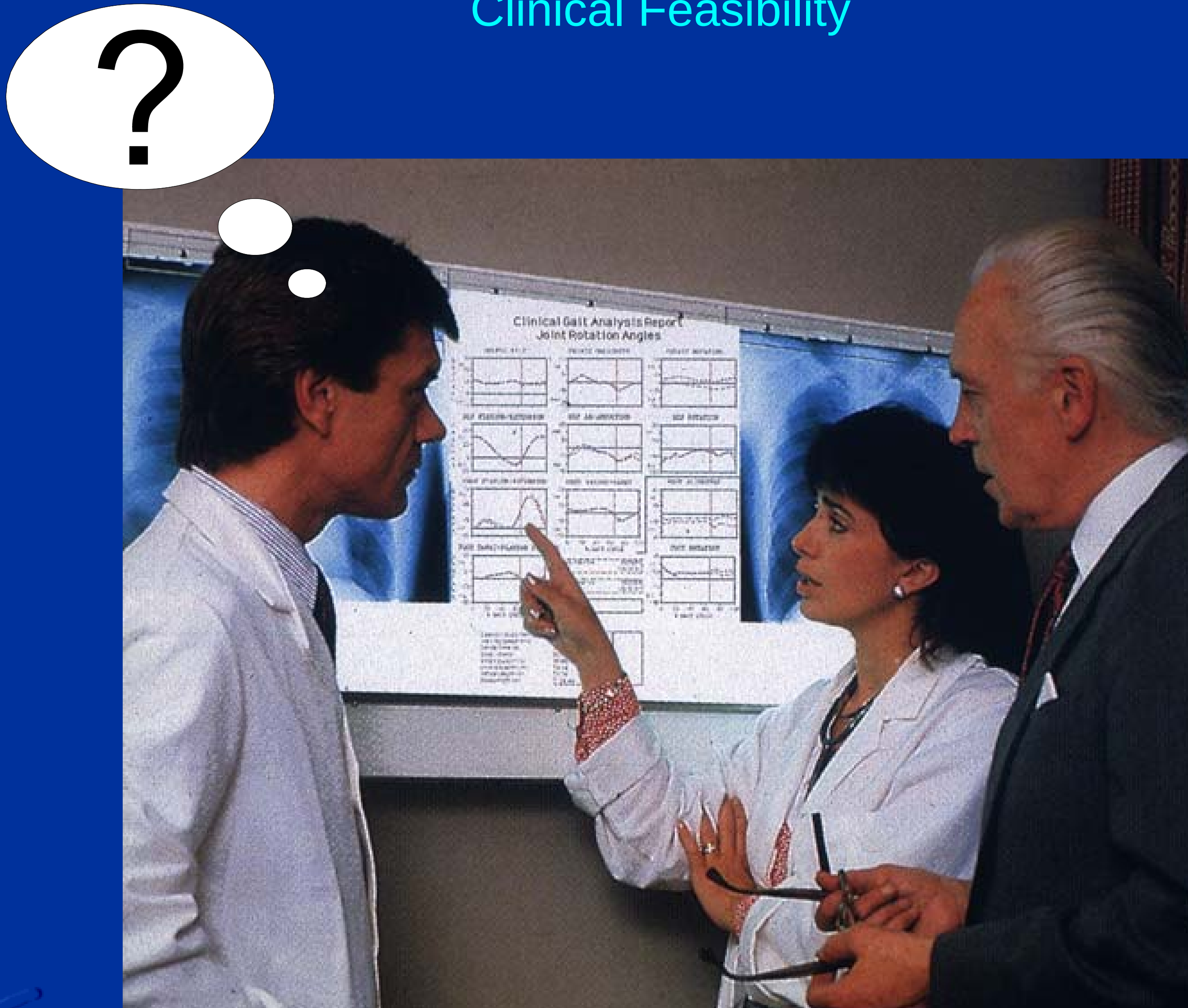
3D Kinematics software

Matlab

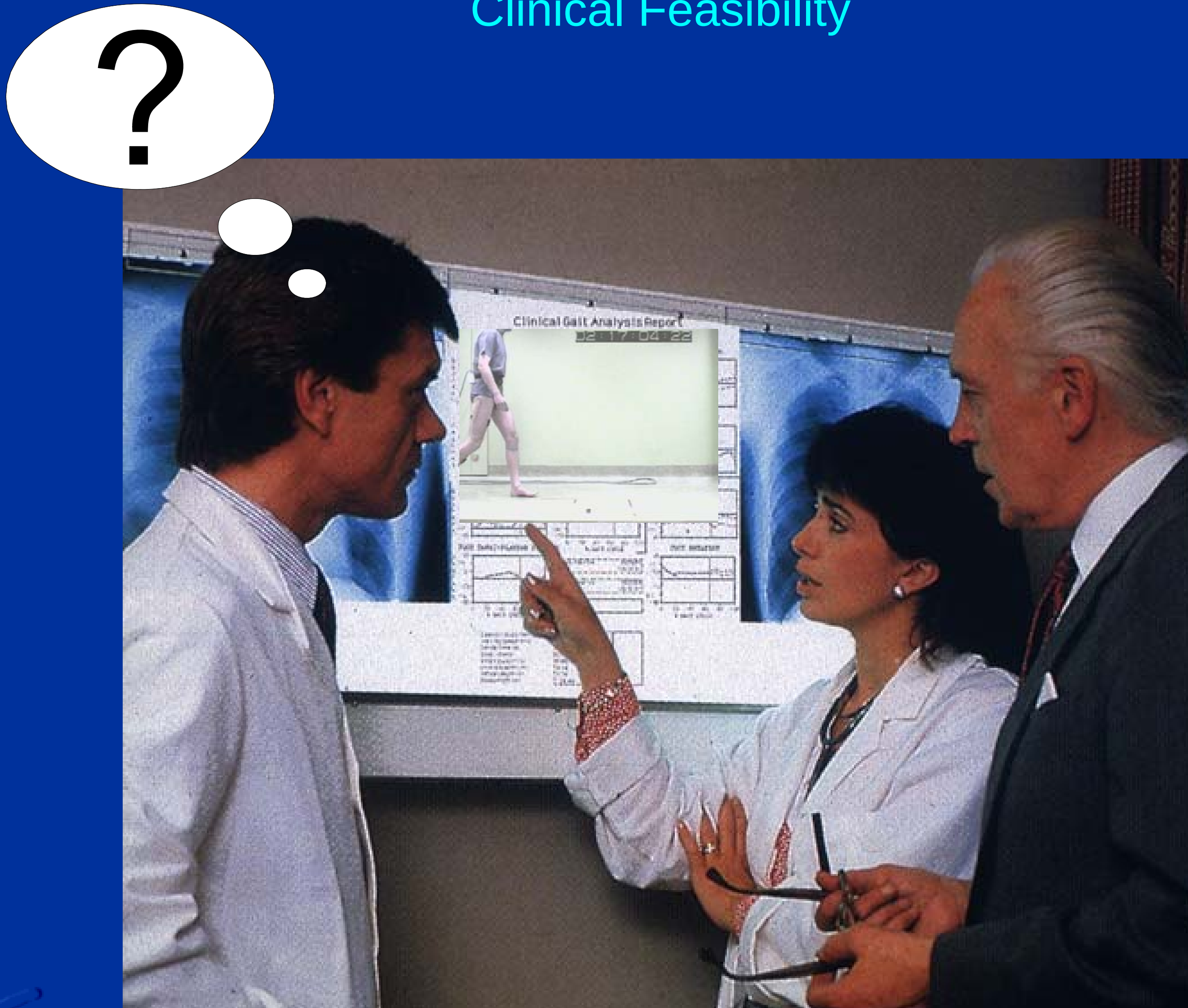
www.bodymech.nl


Flexion
Extension Moment
Hip
Knee
Ankle
60
Flx
Ext
-15
90
40
Dor
Plt
-30
2
1
0
-1
3

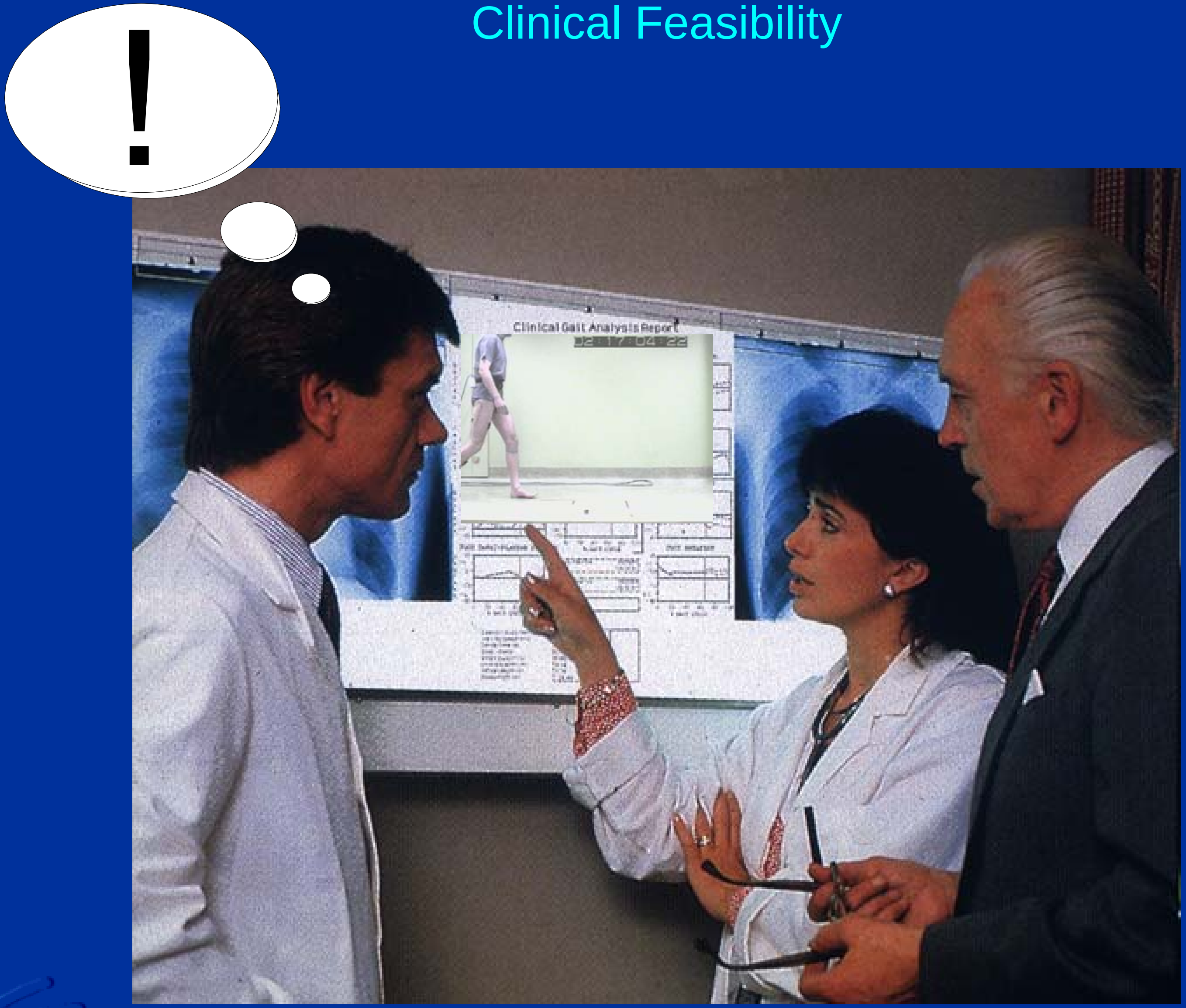
Clinical Feasibility



Clinical Feasibility



Clinical Feasibility



INFORMATION

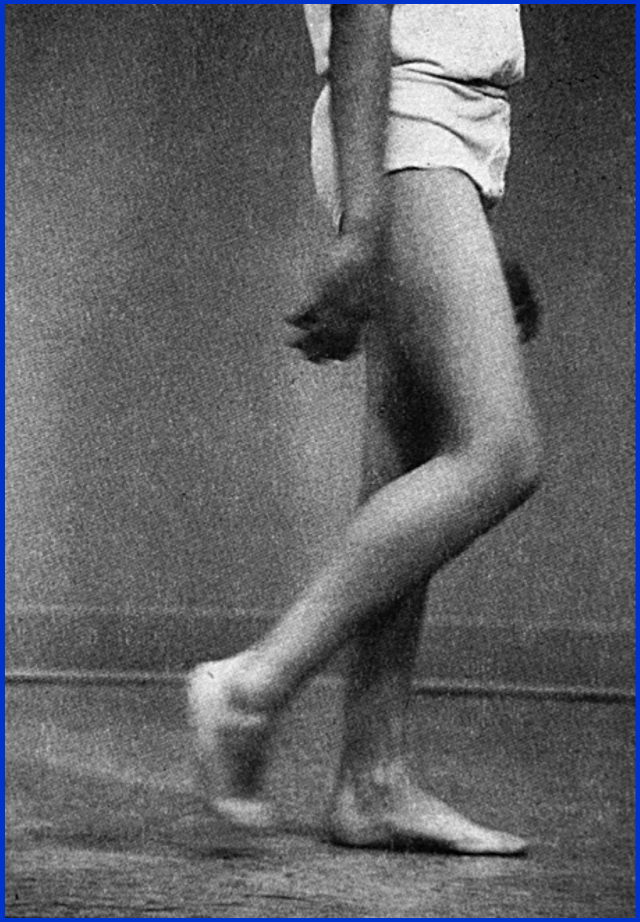
?

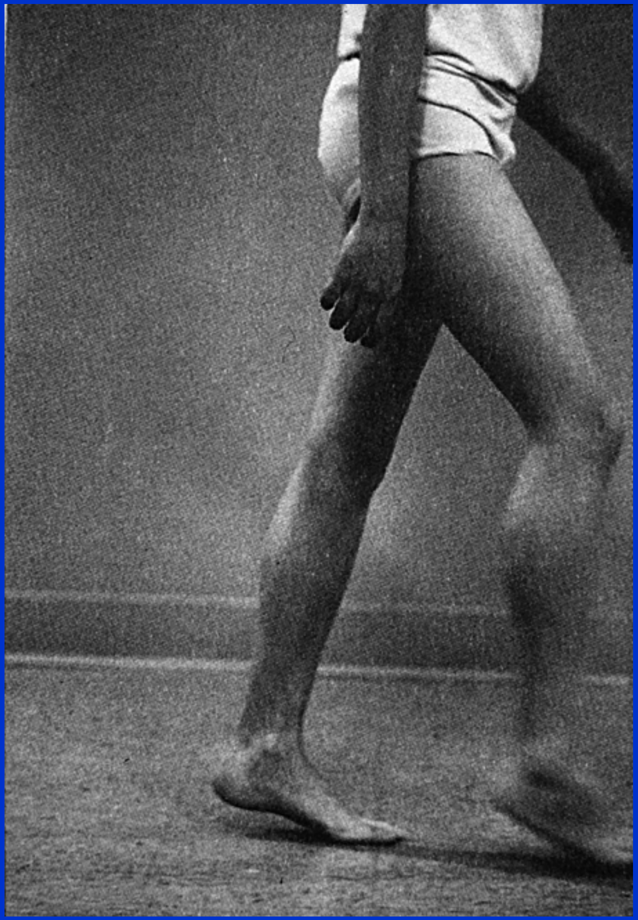
=

KNOWLEDGE

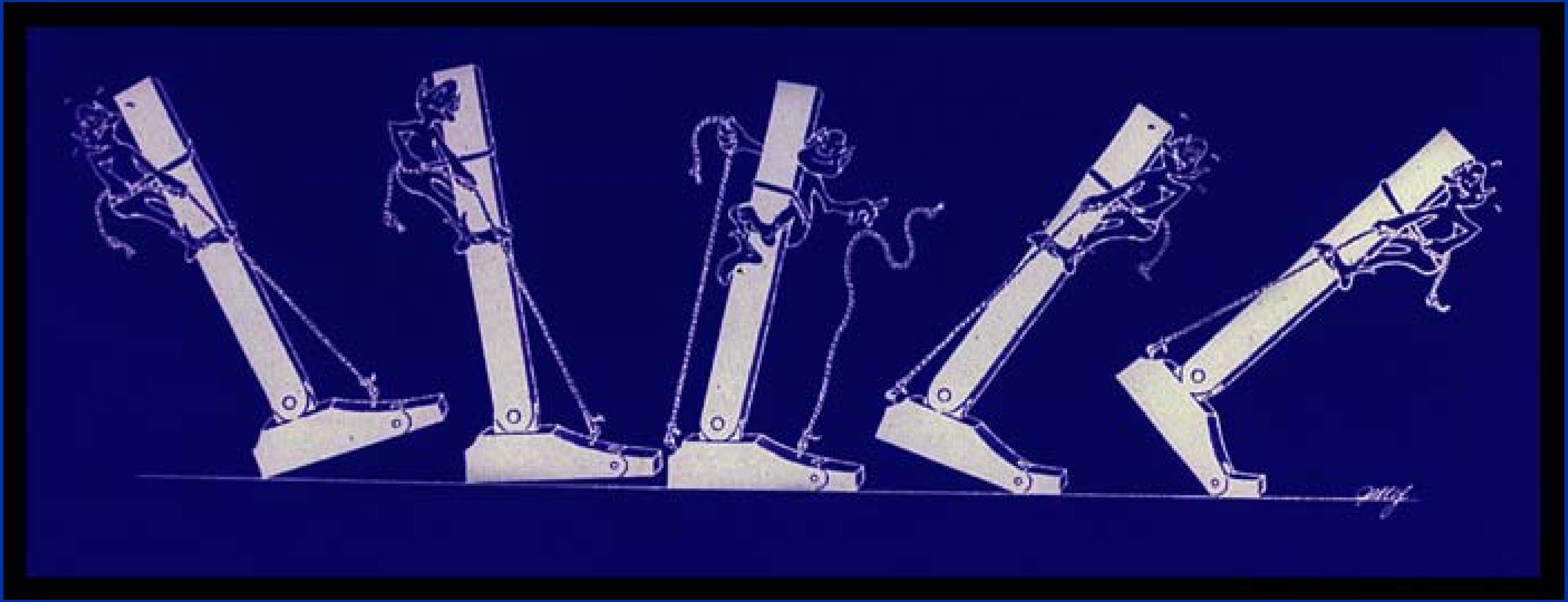
VU University Medical Center

Observational analysis of pathological movement



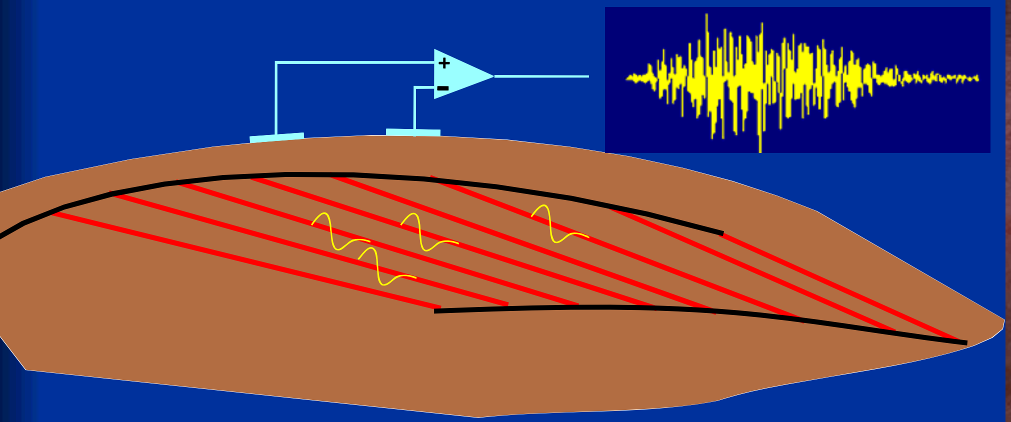


Muscle function during movement



Reprinted from: Inman et al. (1981)

Electro Myo Gram (EMG)

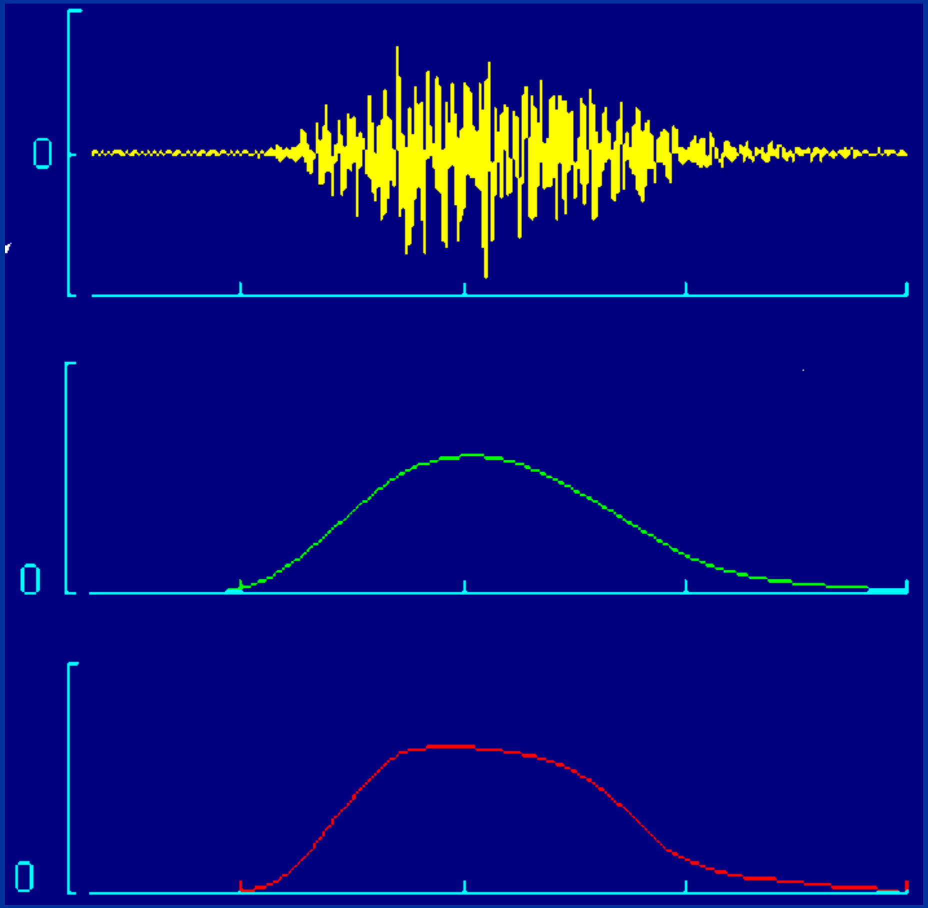


EMG is the summation of many asynchronous Motor Unit Action Potentials

Electrode mounted amplifier

differential lead-off

Relation EMG and Muscle Force

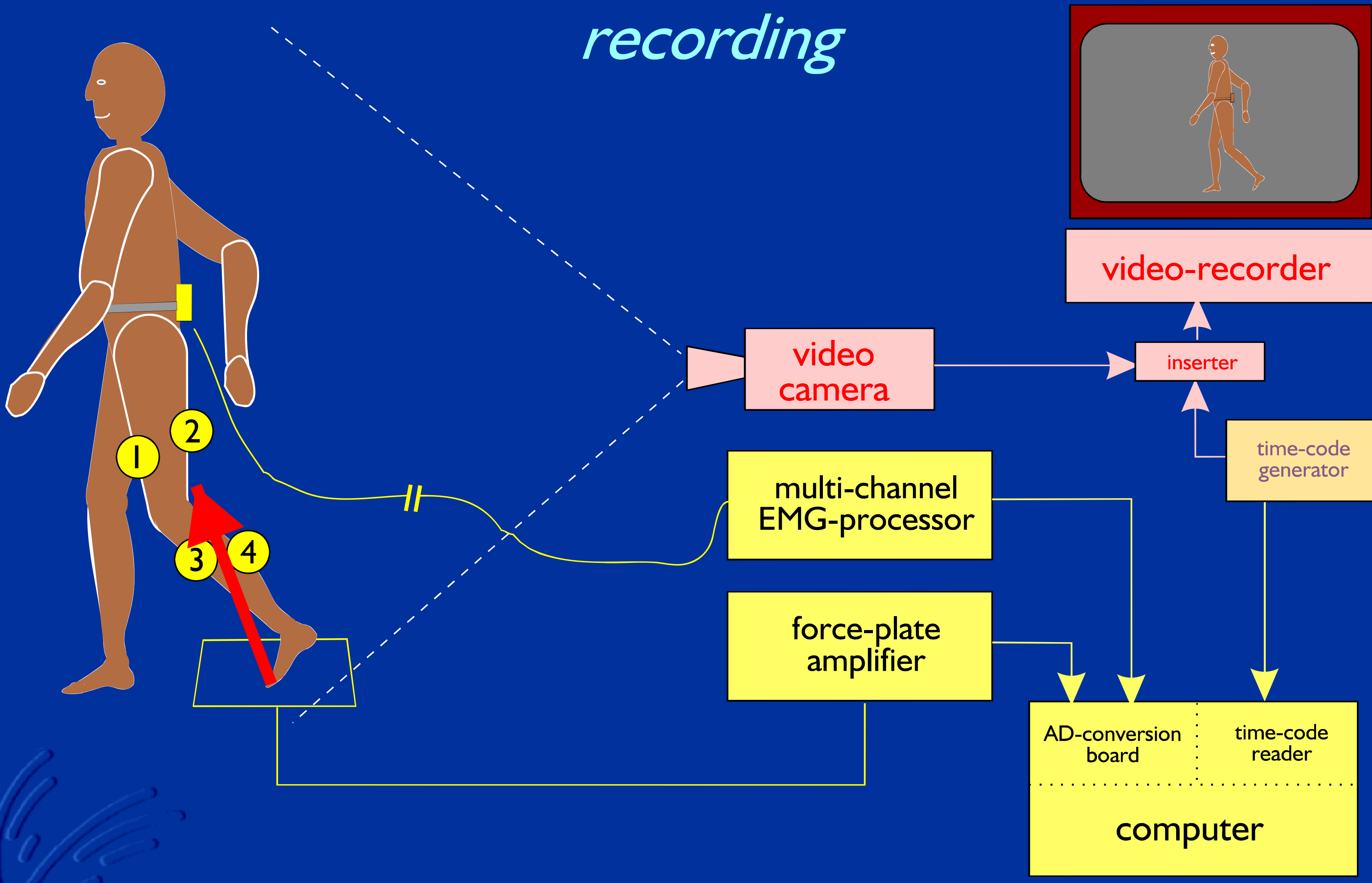


Raw EMG

Smoothed Rectified EMG @ 2 Hz

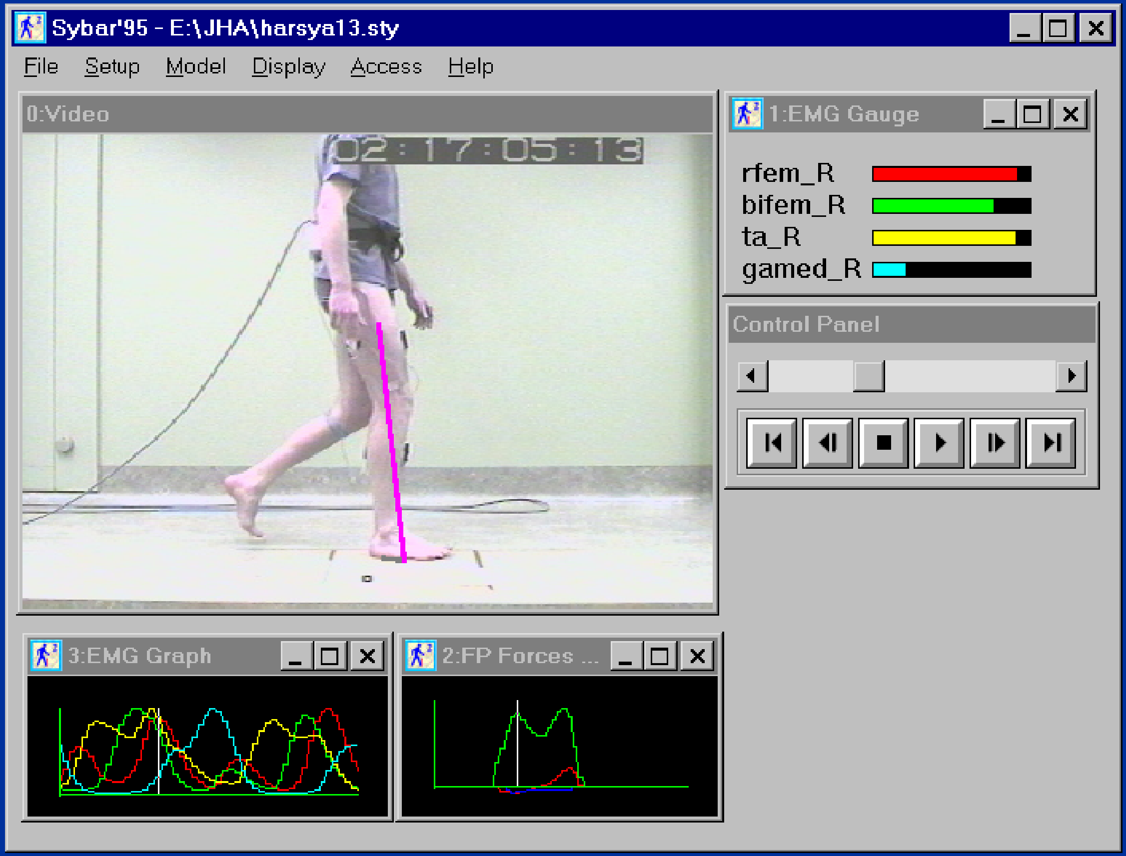
Isometric muscle force

the SYBAR system



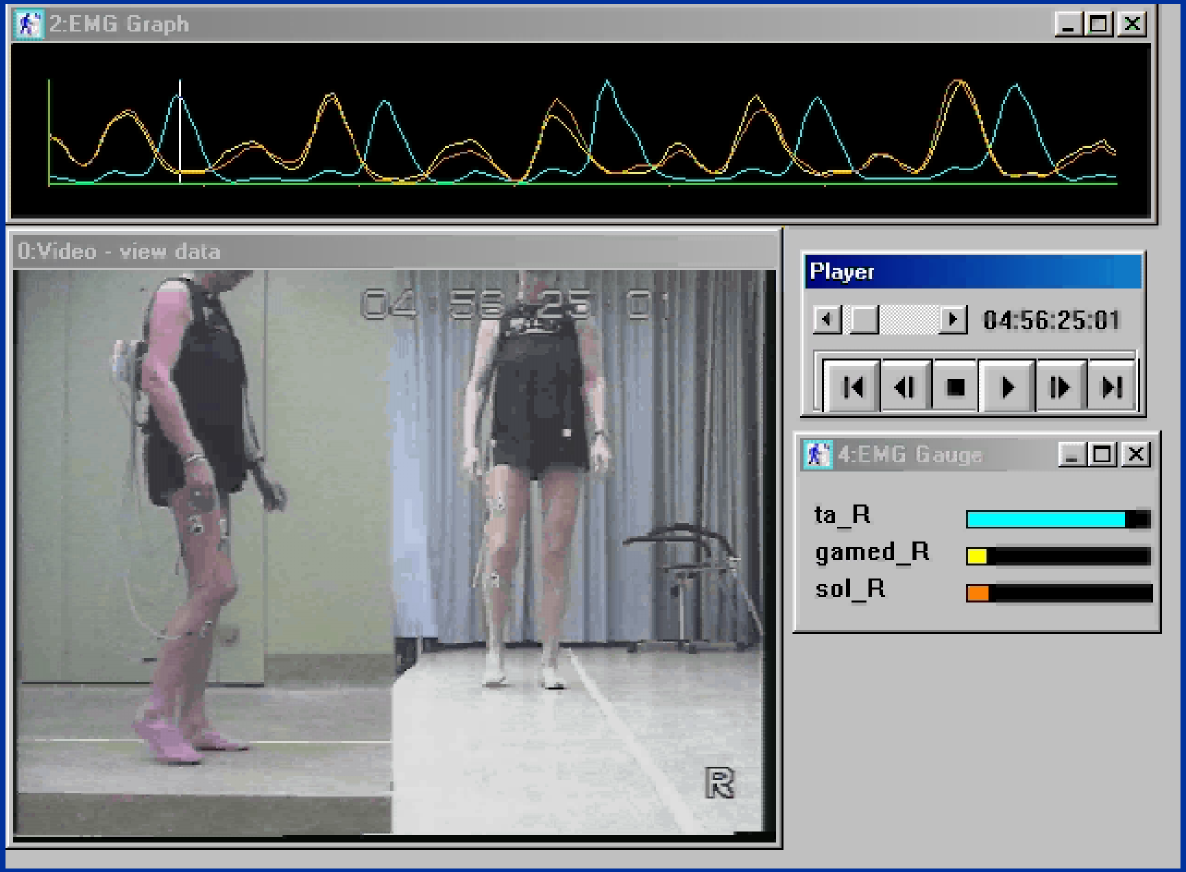
the SYBAR system

display

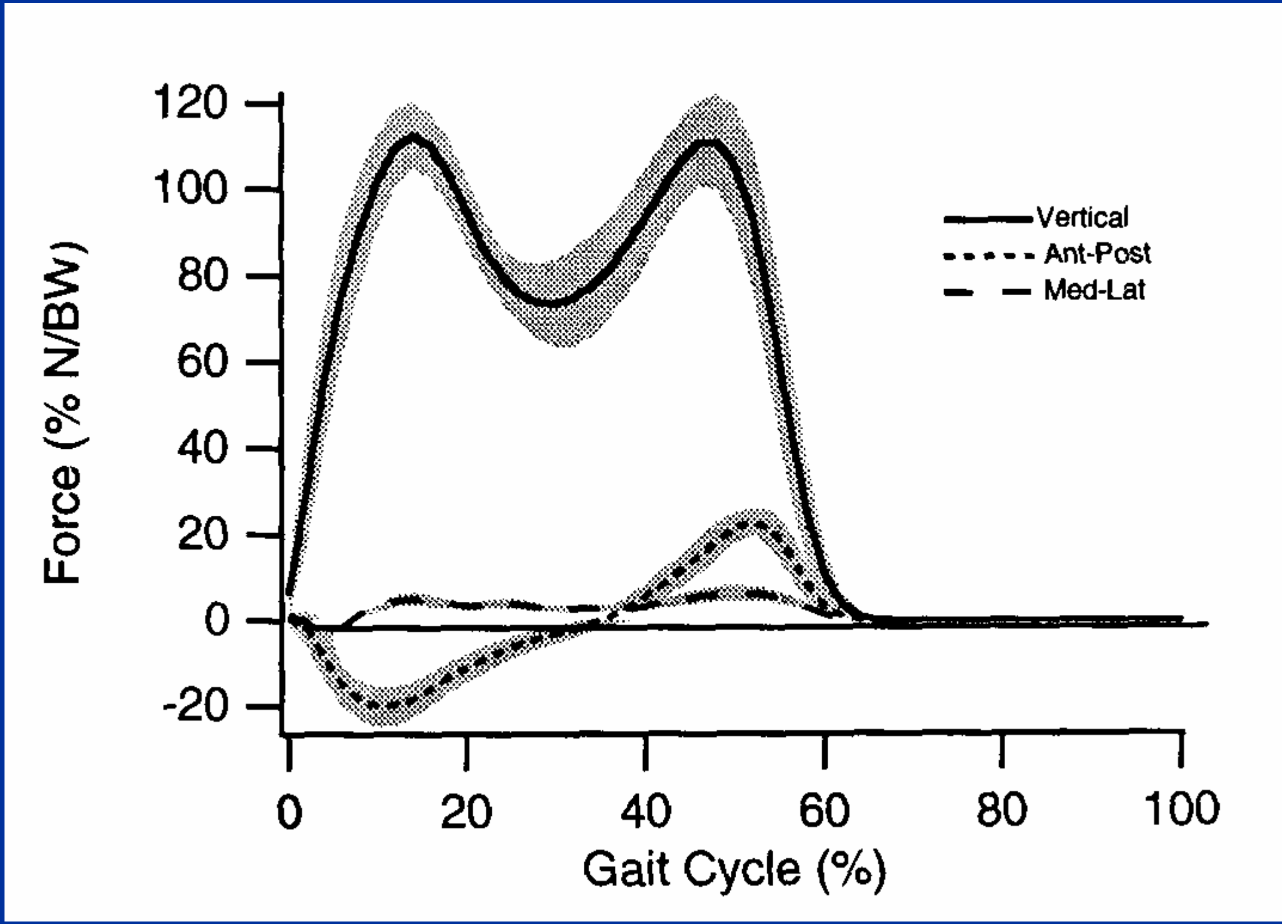


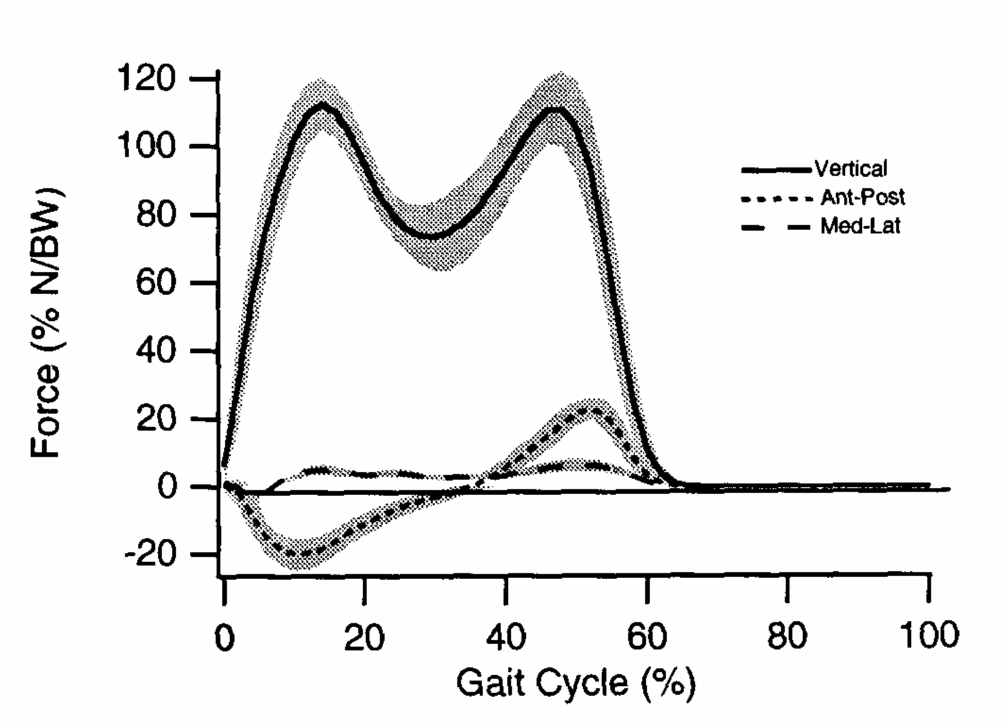
VU University Medical Center

casus


2:EMG Graph
0:Video - view data
Player
04:56:25:01
4:EMG Gauge
ta_R
gamed_R
sol_R

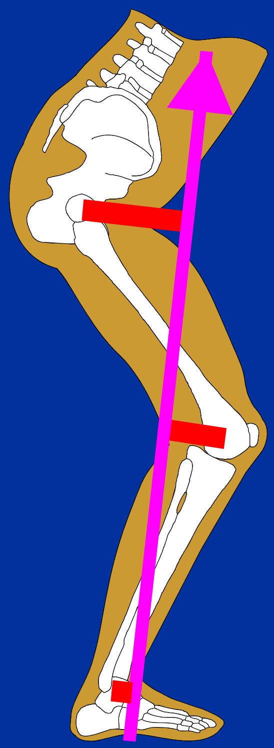
Groundreaction force





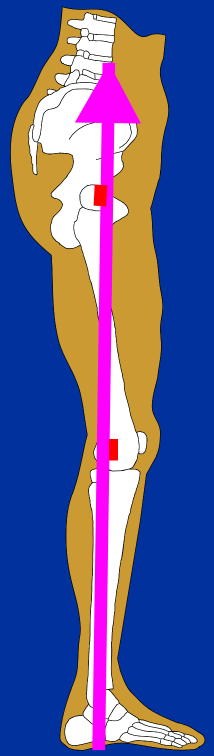
Force (% N/BW)
120
100
80
60
40
20
0
-20
0
20
40
60
80
100
Gait Cycle (%)
Vertical
Ant-Post
Med-Lat

Net joint moment

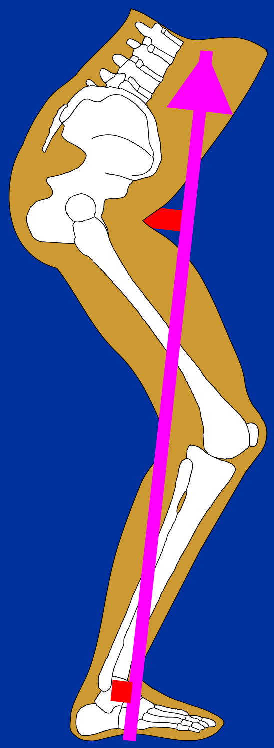


Moment =

F x r



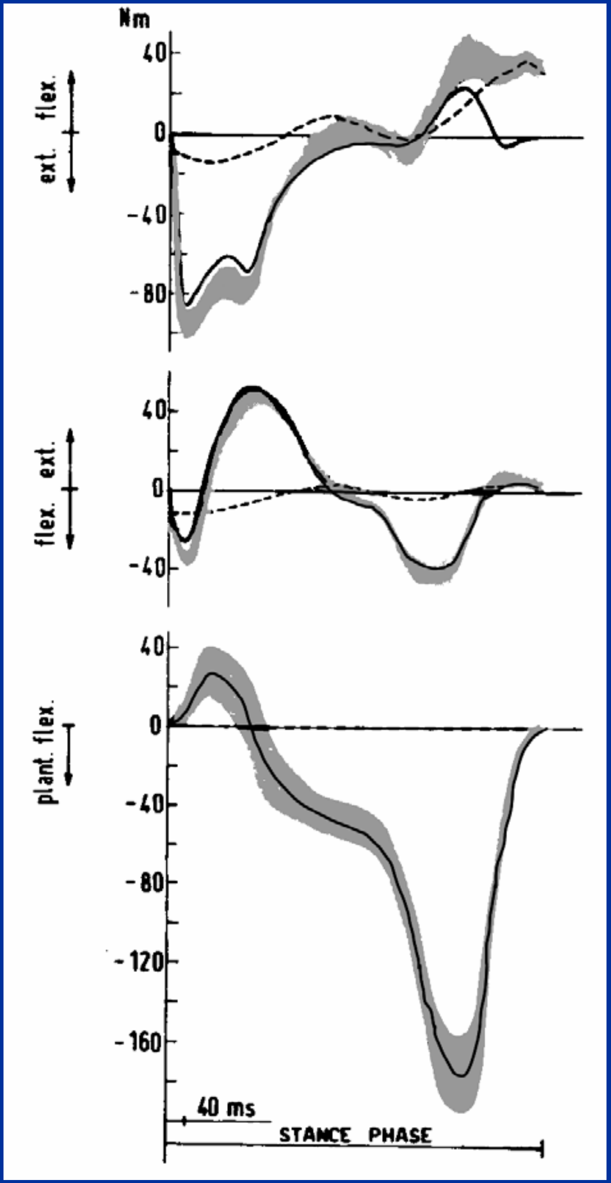
Estimated net joint moment versus inverse dynamics



Moment =

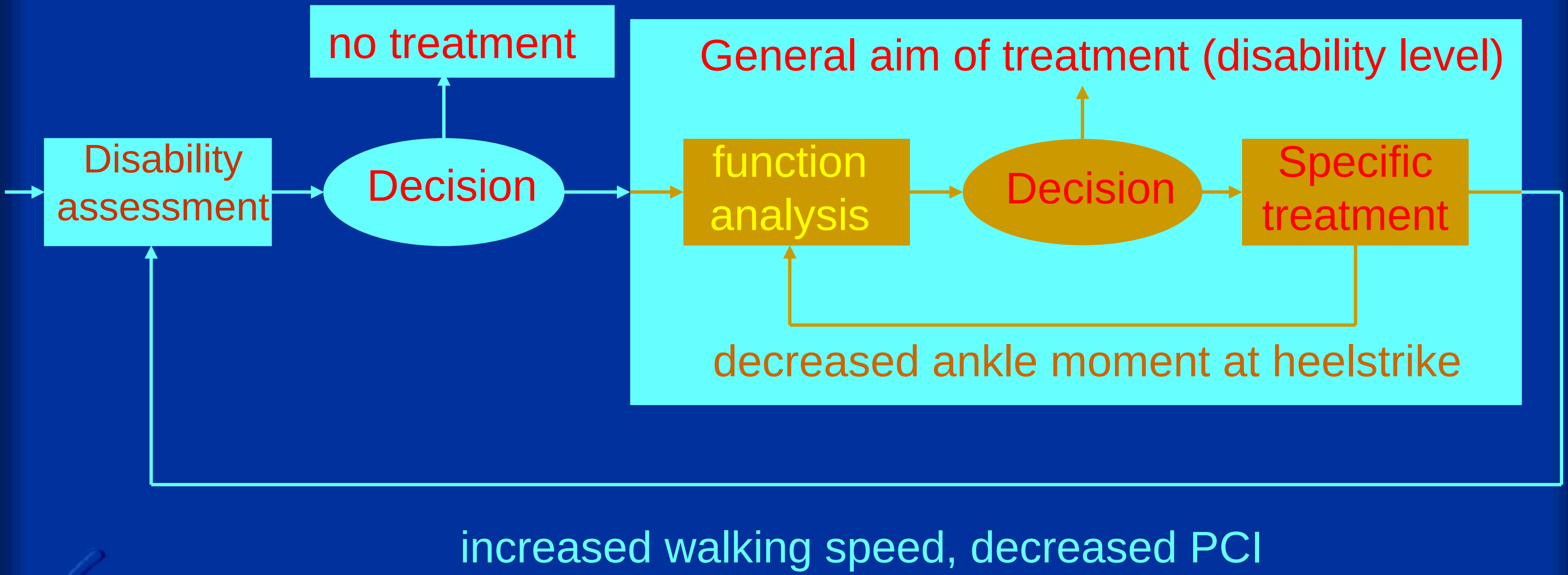
F x r

Boccardi et al. (1981)



What therapeutic intervention is needed ?

Evaluation of treatment at two (nested) levels



What therapeutic intervention is needed ?

Complex Clinical Cases

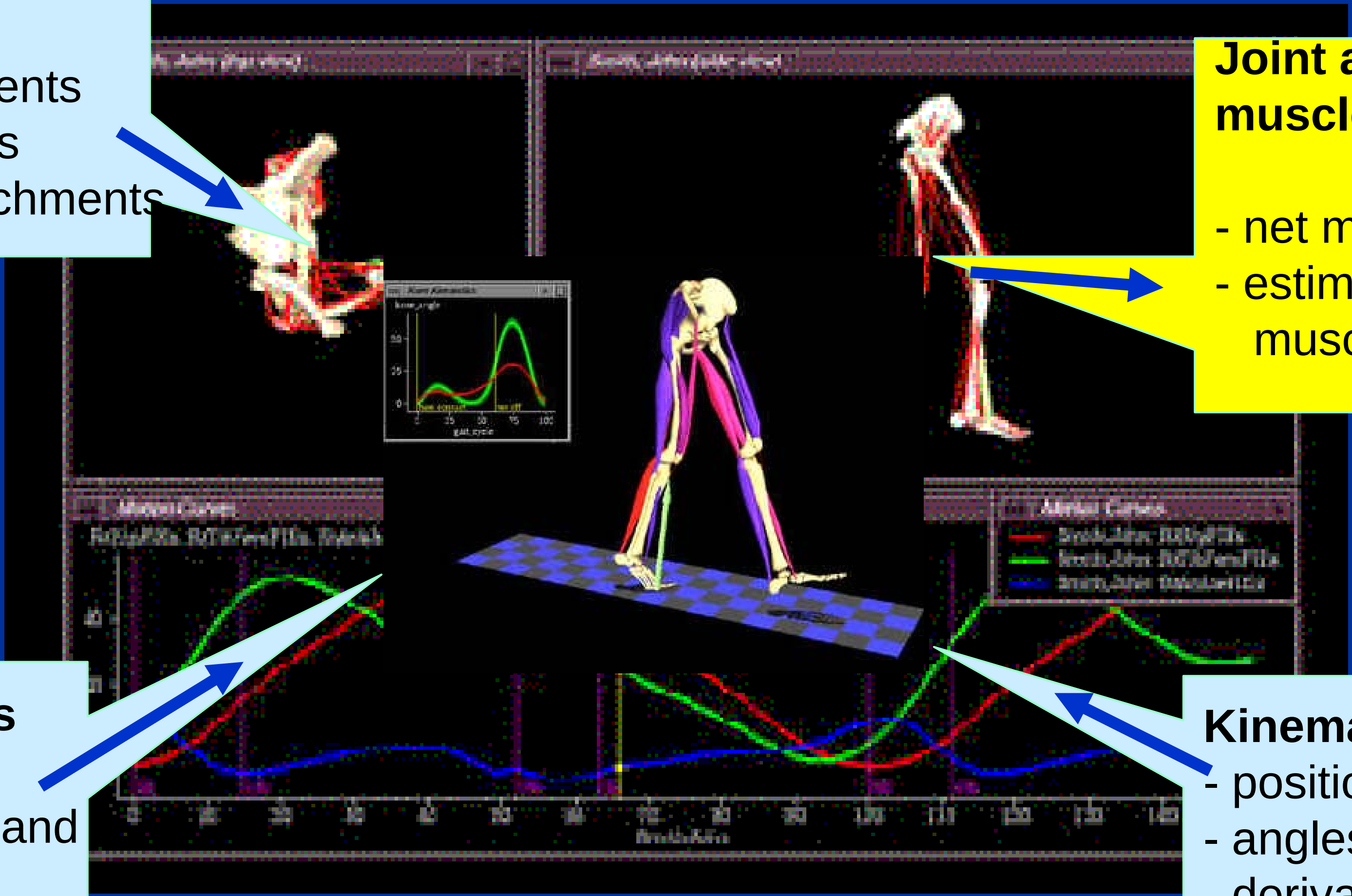
VU University Medical Center

Inverse dynamics model

Antropometrics:
•mass
•inertal moments
•jointlocations
•muscle attachments

Joint and muscle function

- net moments
- estimated muscle forces



Dynamics
external moments and forces

Kinematics
- positions
- angles
- derivatives

Problem statement

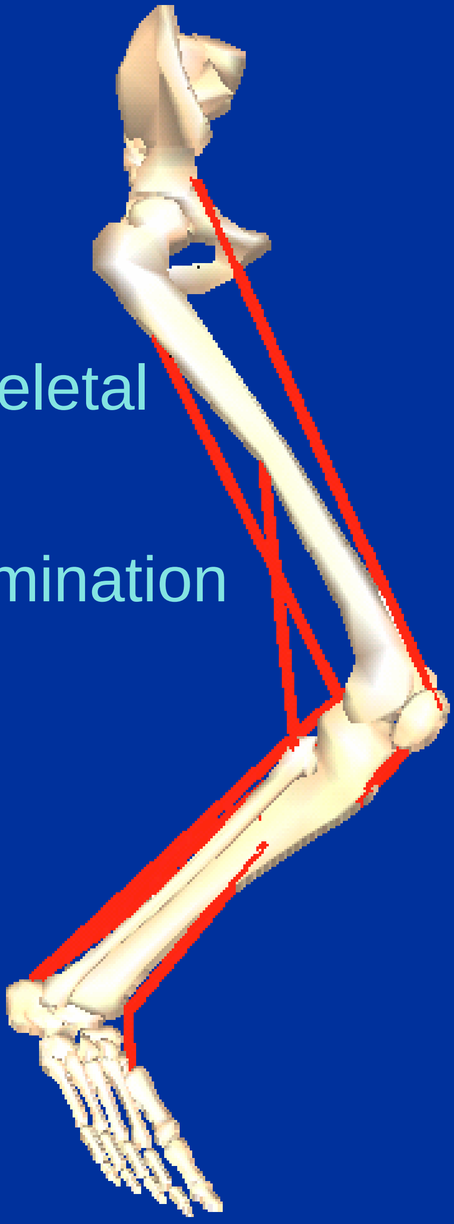
Physical examination yields angles

The measure should address muscle length

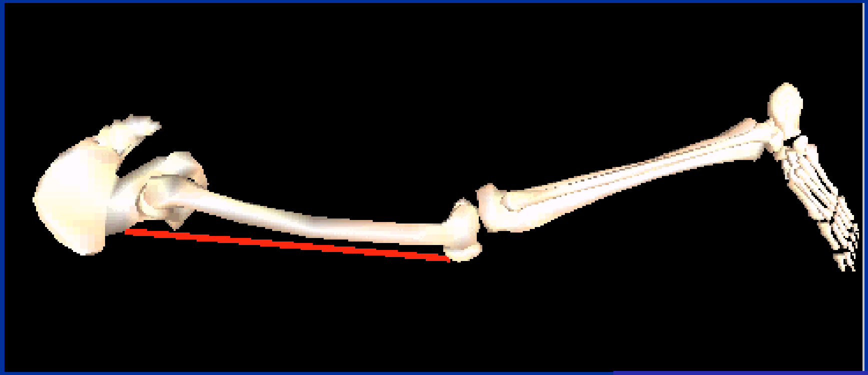
The reference values are based on normal gait

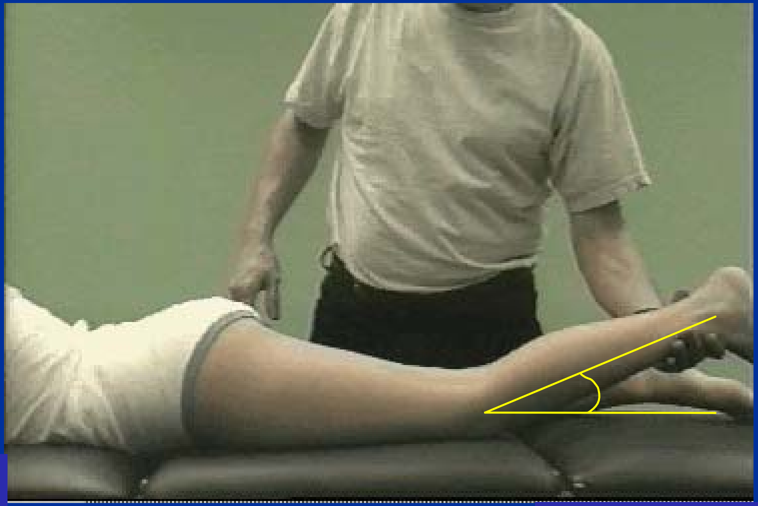
Method

- Application of a geometrical musculo-skeletal model SIMM (Delp et.al 1995)
- input 1: joint angles during physical examination
- input 2: joint angles during normal gait
- output: muscle length (origo-insertion)
- all lengths are normalized to anatomical position(=100 %)

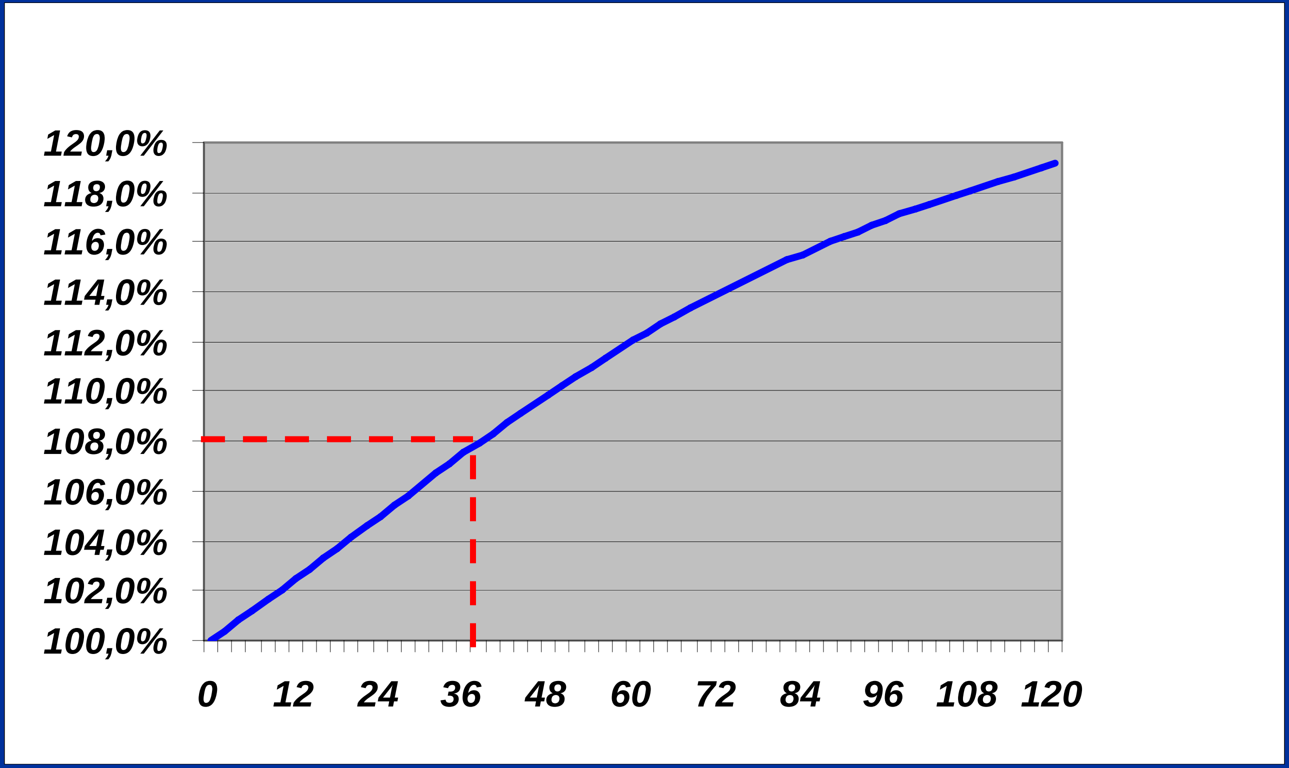


Results: m. Rectus Femoris (1)

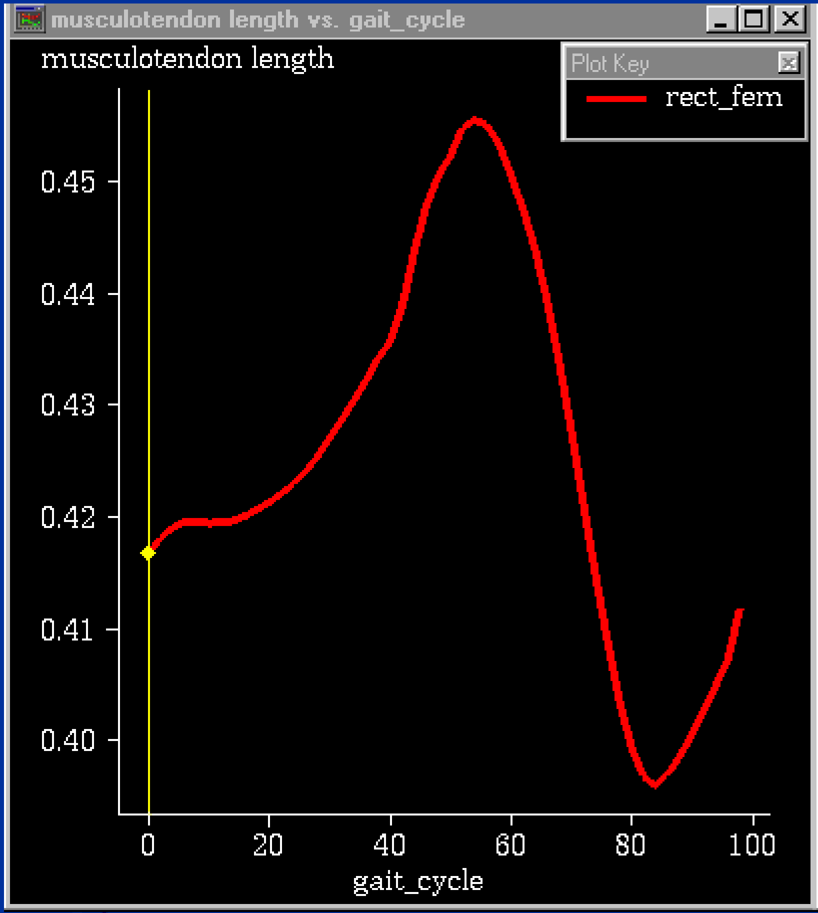




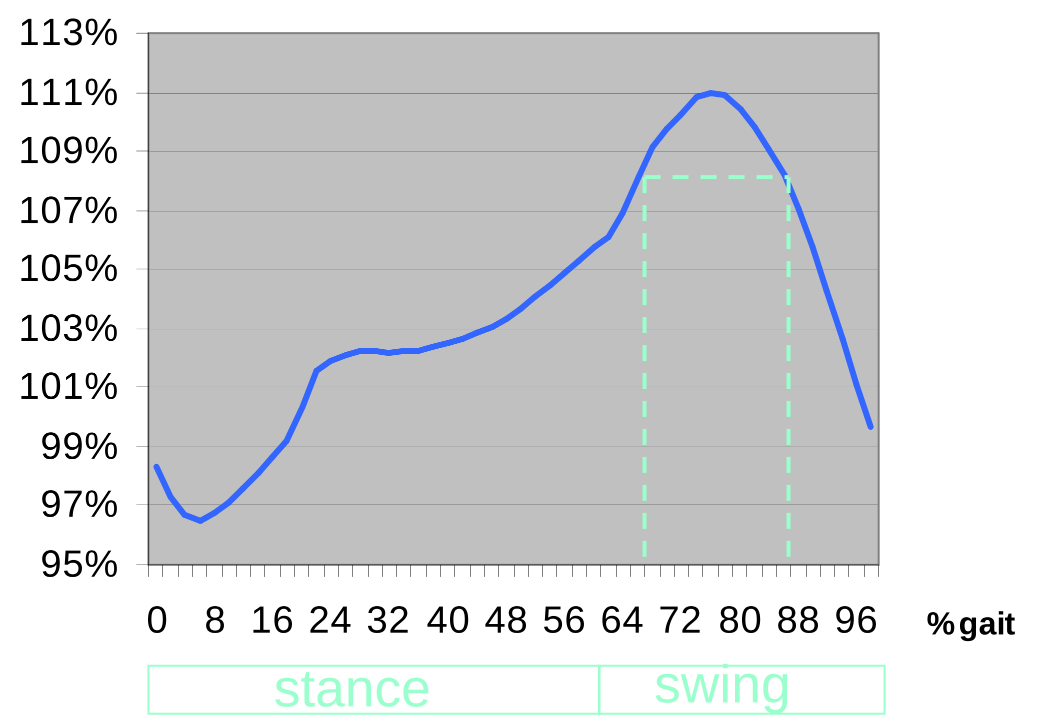
Results: m. Rectus Femoris (2)



Length m. Rectus Femoris during gait



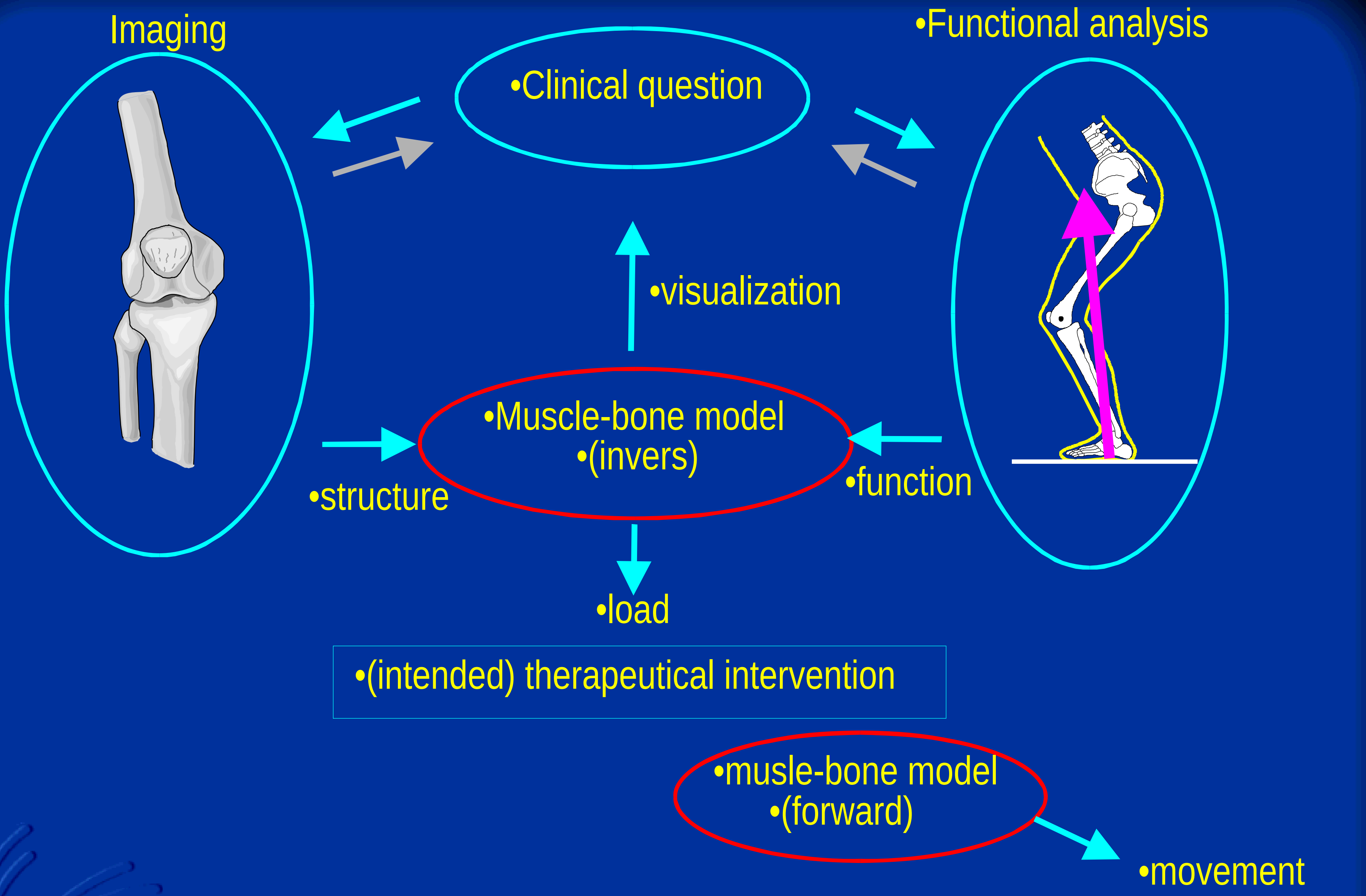
Results: m. Rectus Femoris (3)



Discussion

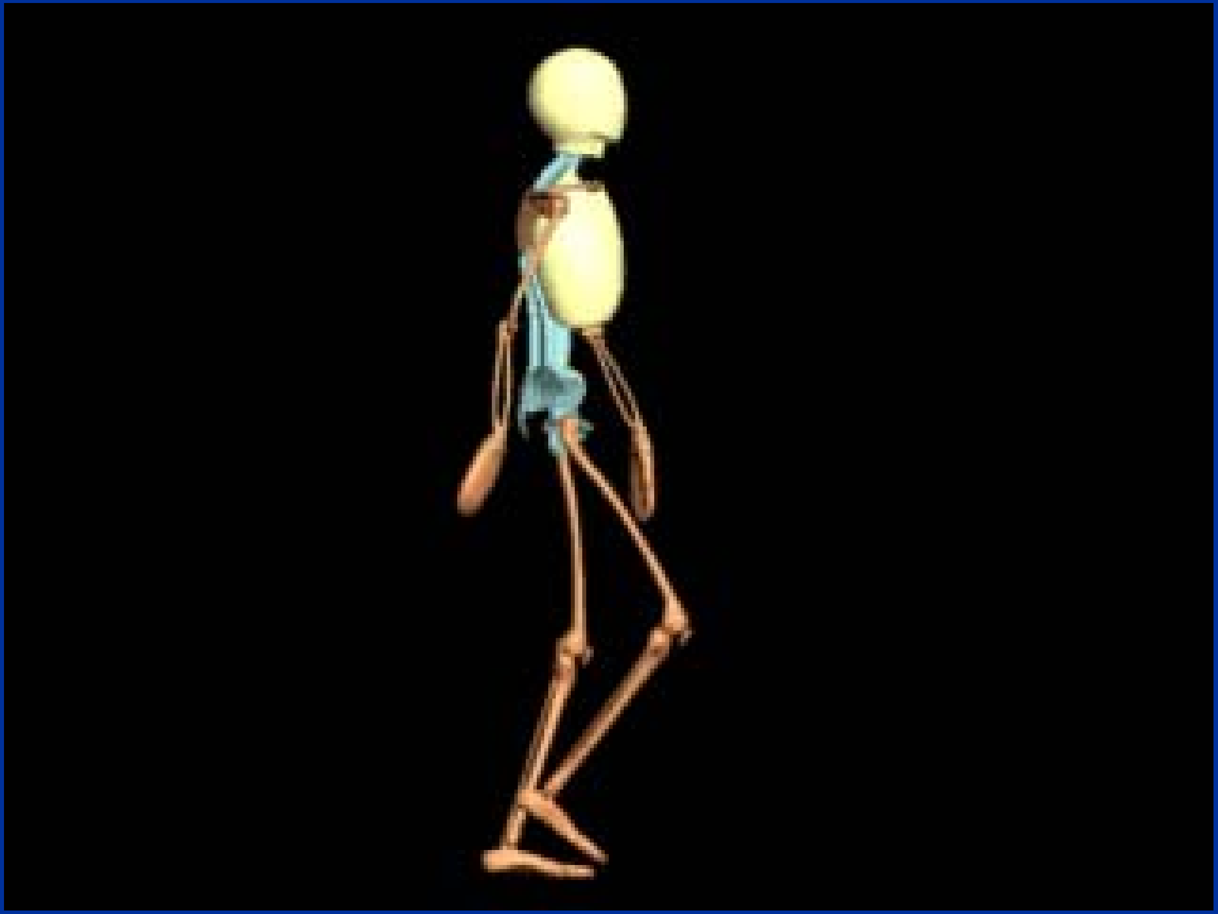
- “Passive” muscle length is not the sole cause to contractures during gait
- Muscle length during movement and EMG should be considered
- Warning: validity of the model
- Documentation of examination protocols (standardisation) using modeling software animations creates awareness of muscle length testing

VU University Medical Center

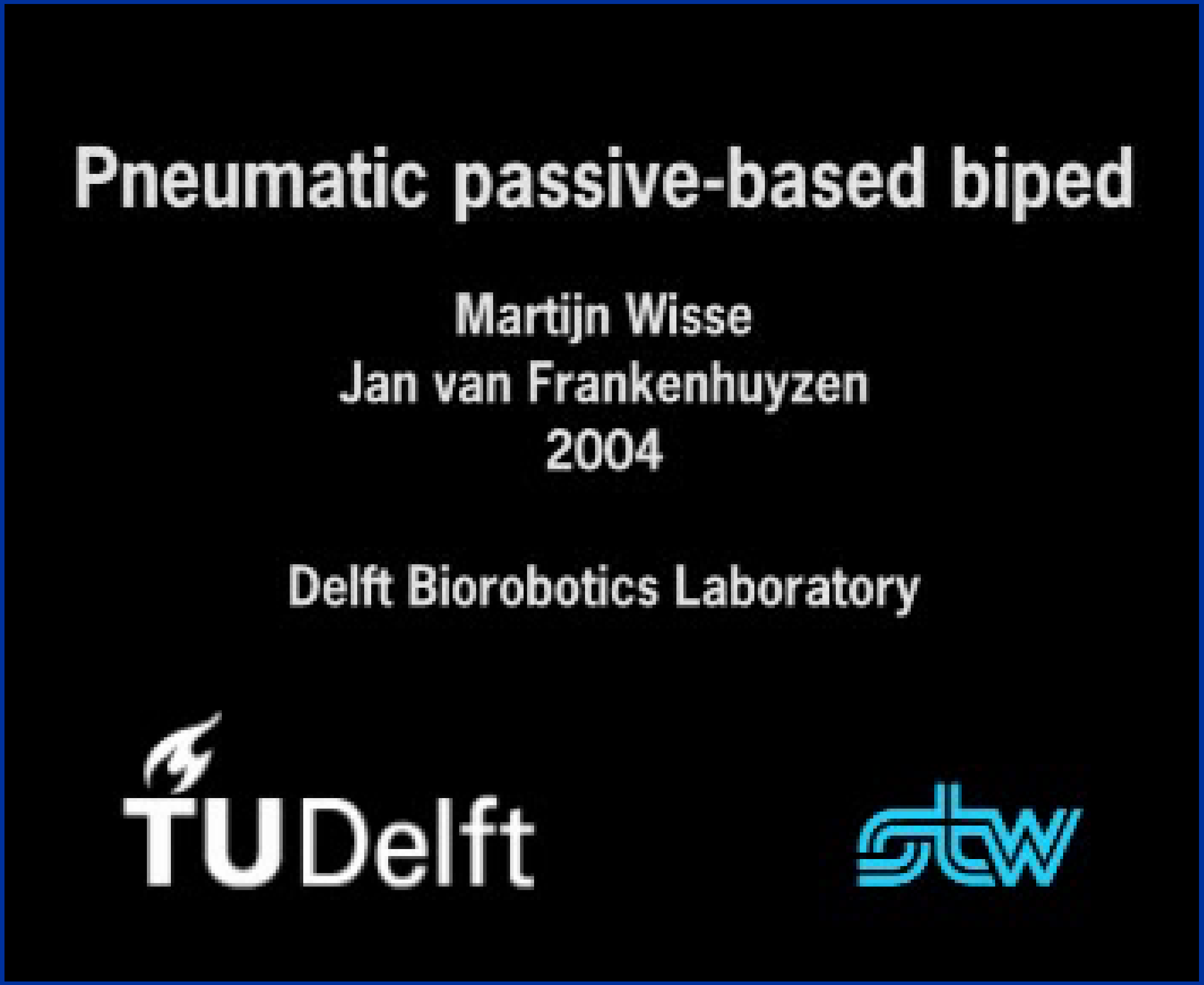

Imaging
•Clinical question
•Functional analysis
•visualization
•Muscle-bone model
•(invers)
•structure
•function
•load
•(intended) therapeutical intervention
•musle-bone model
•(forward)
•movement

casus

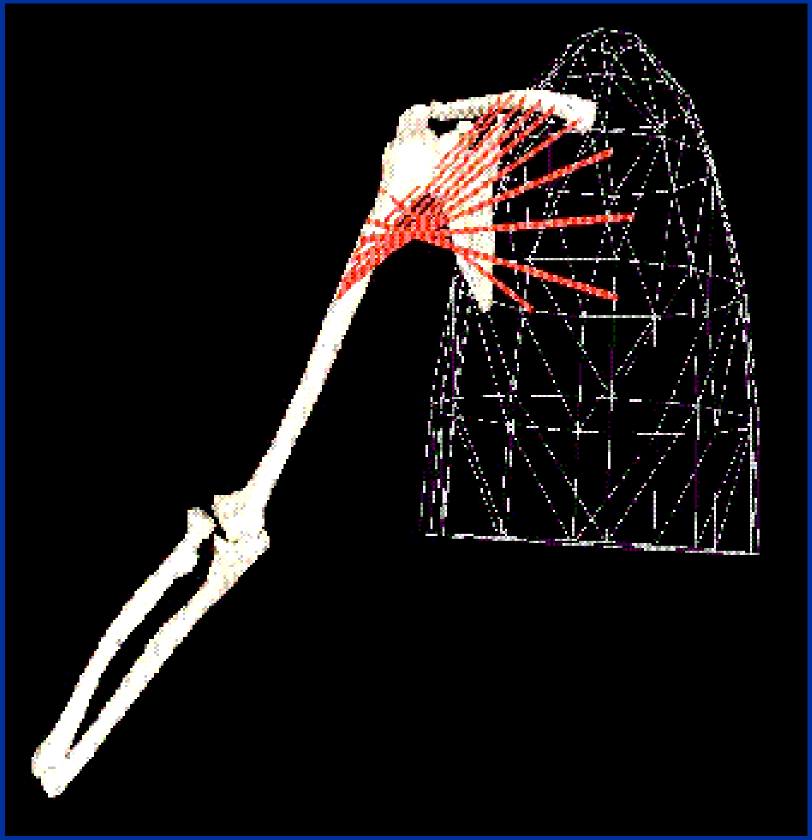
Models (1)



Models (1)


Pneumatic passive-based biped
Martijn Wisse
Jan van Frankenhuyzen
2004
Delft Biorobotics Laboratory
TU Delft
stw

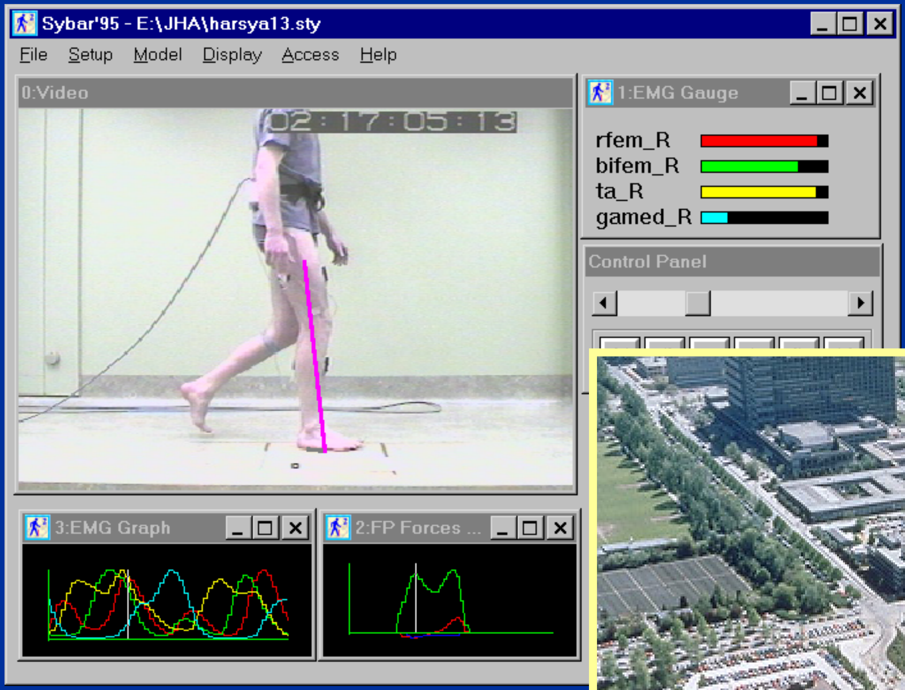
functional load and loading capability of the upper extremity

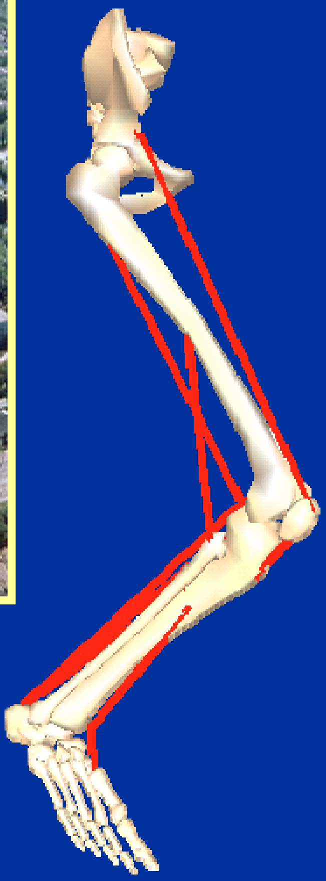


Upper extremity

Upper extremity (2)

VU University Medical Center





j.harlaar@vumc.nl

VU University Medical Center