WIM GROOTEN
TRAMA project
Milano
November 2009

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DEVELOPMENT OF A NEW PROTOCOL FOR MEASURING TRUNK KINEMATICS IN REAL WORK SITUATION

COMPARISON OF TWO METHODS FOR MOVEMENT ANALYSIS IN LOAD LIFTING TASKS

2 weeks in Colombia

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- Experiments

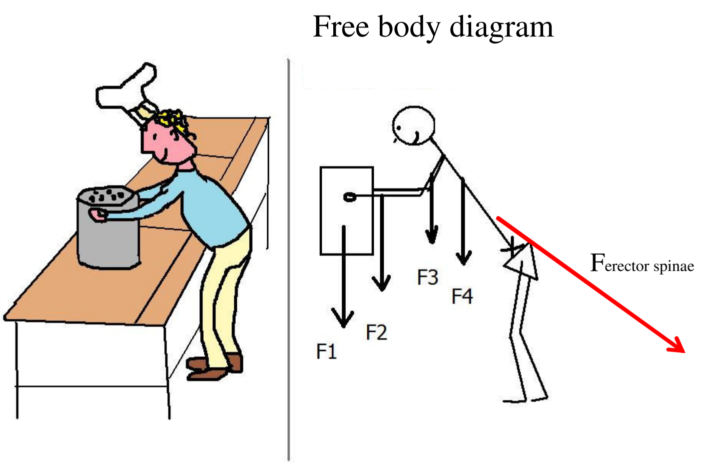
→ Javieriana	Inclinometer, goniometer, gyroscop
→ Roosenfeld	BTE, Inclinometer, goniometer, gyroscop
→ Hospital Central	BTE, Inclinometer, goniometer, gyroscop
→ Pavco (in field)	Inclinometer, goniometer, gyroscop

- Meetings
  - → Dean(s)
  - → PhD and undergraduate students
- Lectures
  - → Research group (20 persons)
  - → PT students (140 persons)
  - → Clinicians (80 persons)

PRESENTATION 1:
Research group at the Javierana University

- Biomechanics:
  - →External forces
  - →Internal forces
  - →Joint forces
    - Compression forces
    - Shear forces

BIOMECHANICAL MODEL THE FOR CALCULATION OF JOINT FORCES



BIOMECHANICAL MODEL THE FOR CALCULATION OF JOINT FORCES

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1. External Torque

Load from body weight and external loadings

2. Internal torque

Load from muscles and ligaments

3. Joint force

Load on joint surface

1. External Torque

M = F x *d*

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External forces (F)

Body segments

External forces

* boxes, patients, etc

* Ground reaction forces

Lever arm (*d*)

The shortest distance between the axis of rotation and the force vector

2. Internal Torque

M = F x *d*

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Internal forces (F)

Muscle forces

Ligaments

Lever arm (*d*)

The shortest distance between the axis of rotation and the force vector

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In slow movements: the external torque equals the internal torque!

In fast movements this is not totally true

Too complex due to forces caused by
- inertia
- acceleration (F = m x a)

So we can use these two equations for calucation of joint forces

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$$\Sigma M = 0 \quad \text{and} \quad \Sigma F = 0$$

External Torque Load from body weight and external loadings	=	**Internal torque** Load from muscles and ligaments

External forces + internal forces	=	**Joint force**

Example of calculation joint force in the local spine with the Axes of rotation at L5/S1

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External forces:

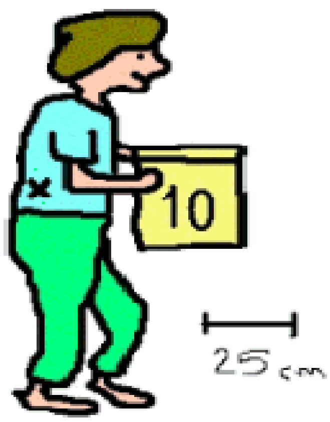
* Bodysegments: torso and head (F1) and two arms (F2)

* Box (F3)

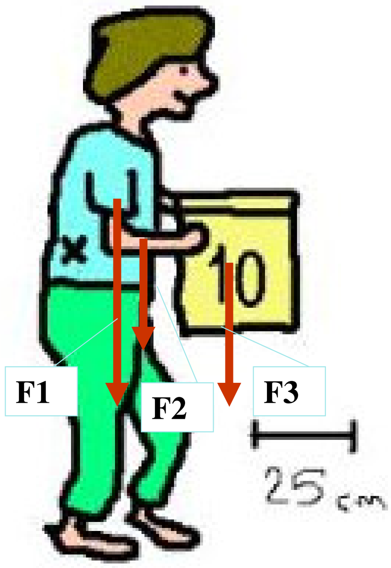
Internal forces:

Muscle force (FES)**?**

Joint force:
F1+F2+F3+FES **?**



External forces



F1 = 44% BW
F1 = 68 kg x 0.44 = 30 kg.
F1 = 300N

F2 = 10% BW
F2 = 6.8 kg. = 68N

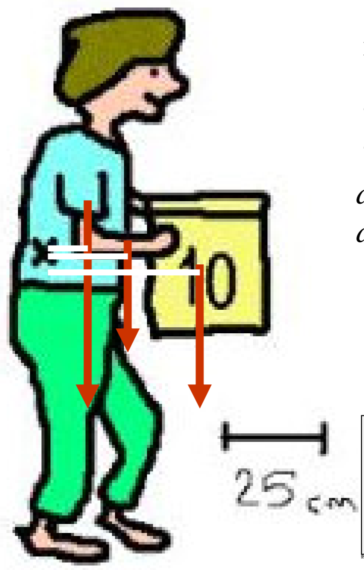
F3 = 10 kg. = 100N

Basic facts:

Bodyweight (BW) = 68 kg.

Box: 10 kg.

Moment arms



Scaling
1 cm in the picture means 10 cm in real life (0.1 m)

*d*1 = 1 cm picture
*d*1 = 0.1 m real life

*d*2 = 2.5 cm picture
*d*2 = 0.25 m real life

*d*3 = 5 cm picture
*d*3 = 0.5 m i real life

Reference line is 25 cm in real life but only 2,5 cm in the picture
⇒ Each cm in the picture correspond with10 cm in real life

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EXTERNAL TORQUE

$M_1 = F_1 \times d_1$
$M_1 = 300\ N \times 0{,}1\ m$
$M_1 = 30\ Nm$

$M_2 = F_2 \times d_2$
$M_2 = 68\ N \times 0{,}25\ m$
$M_2 = 17\ Nm$

$M_3 = F_3 \times d_3$
$M_3 = 100\ N \times 0{,}5\ m$
$M_3 = 50\ Nm$

$M_{total} = M_1 + M_2 + M_3$

$M_{total} = 30\ Nm + 17\ Nm + 50\ Nm$

$M_{total} = 97\ Nm$

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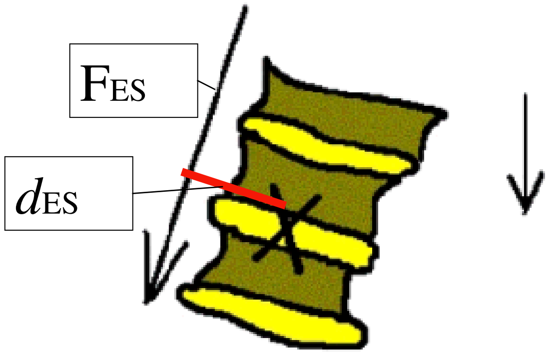
Internal Torque

M = F x *d*

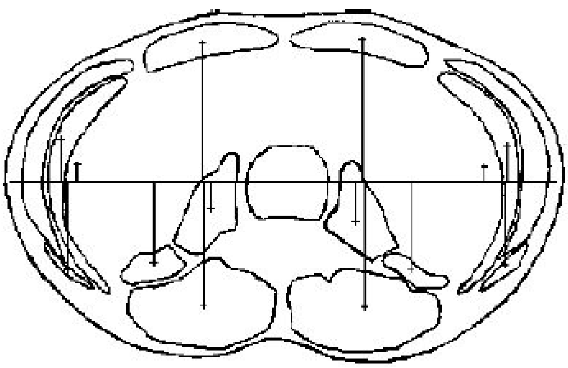
Internal forces (F)	Muscle forces Ligaments
Lever arm (*d*)	The shortest distance between the axis of rotation and the force vector

Erector Spinae (F_{ES}) is anatomically aligned to the vertebrae.



The moment arm is the perpendicular line
from the axes of rotation to the muscle force vector
For F_E this is 6,1 cm (parallell to the discs)

INTERNAL moment arms for different trunk muscles



M.J. Jorgensen et al. / Clinical Biomechanics 16 (2001) 182–193

Table 4
Mean (SD) *sagittal plane* moment-arms (cm), for each muscle and gender[a]

Muscle	Gender	T_8	T_9	T_{10}	T_{11}	T_{12}	L_1	L_2	L_3	L_4	L_5	S_1
R. Lat. Dorsi	F	−1.6 (10.2)	−1.9 (1.1)	−2.3 (0.9)	−2.6 (0.8)	−2.9 (0.8)	−3.2 (1.0)	−3.4 (1.1)	−3.1 (1.2)			
	M	−1.8 (0.9)	−2.2 (1.0)	−2.4 (0.9)	−2.7 (0.8)	−2.9 (0.7)	−3.8 (0.9)	−4.1 (0.7)	−4.2 (0.8)			
L. Lat. Dorsi	F	−0.7 (1.0)	−1.1 (0.9)	−1.6 (0.9)	−2.0 (0.8)	−2.6 (0.8)	−3.1 (1.0)	−3.9 (1.1)	−4.0 (1.2)			
	M	−0.7 (1.1)	−0.9 (1.1)	−1.3 (1.1)	−1.6 (1.0)	−2.2 (1.0)	−3.0 (1.2)	−4.0 (1.1)	−3.9 (1.1)			
R. Er. Spinae	F	−4.4 (0.3)	−4.5 (0.4)	−4.4 (0.4)	−4.4 (0.4)	−4.4 (0.4)	−4.7 (0.5)	−4.8 (0.4)	−5.0 (0.5)	−4.9 (0.4)	−5.4 (0.5)	−5.4 (0.5)
	M	−5.2 (0.4)	−5.3 (0.4)	−5.2 (0.4)	−5.1 (0.4)	−5.0 (0.4)	−5.2 (0.5)	−5.4 (0.7)	−5.7 (0.7)	−5.6 (0.6)	−6.1 (0.7)	−6.2 (0.7)
L. Er. Spinae	F	−4.2 (0.3)	−4.3 (0.3)	−4.2 (0.3)	−4.2 (0.4)	−4.3 (0.4)	−4.7 (0.5)	−5.1 (0.6)	−5.3 (0.6)	−5.3 (0.5)	−5.7 (0.6)	−5.6 (0.5)
	M	−4.9 (0.5)	−4.9 (0.6)	−4.8 (0.5)	−4.7 (0.5)	−4.8 (0.5)	−5.0 (0.6)	−5.4 (0.6)	−5.6 (0.6)	−5.7 (0.5)	−6.1 (0.7)	−6.3 (0.8)
R. Rect. Abd.	F					10.4 (0.9)	9.6 (1.0)	8.5 (0.9)	7.0 (0.9)	6.1 (0.9)	6.5 (1.0)	7.5 (1.3)
	M					13.5 (1.7)	12.4 (1.2)	10.7 (1.2)	8.9 (1.3)	7.7 (1.5)	7.6 (1.4)	8.4 (1.2)
L. Rect. Abd.	F					10.5 (1.0)	9.7 (1.1)	8.5 (1.1)	6.9 (1.1)	6.0 (0.9)	6.1 (1.0)	7.3 (1.2)
	M					13.7 (1.7)	12.7 (1.1)	10.8 (1.3)	9.2 (1.3)	7.8 (1.4)	7.6 (1.5)	8.2 (1.2)

EQUILIBRIUM

$\sum M = 0$

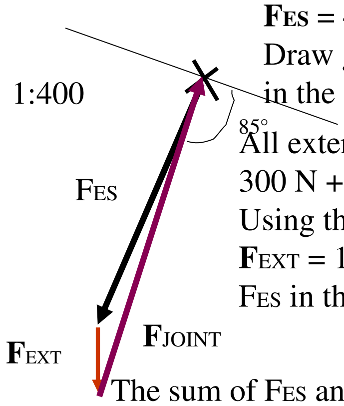
EXTERNAL TORQUE = INTERNAL TORQUE

Calculation of internal forces

External torque	=	internal torque
97 Nm	=	internal torque
97 Nm	=	F_{ES} X d_{ES}
97 Nm	=	F_{ES} x 0,061 m
F_{ES}	=	97 Nm / 0,061 m
F_{ES}	=	1590N

Jointforce – Direction and Magnitude

F_{ES} =1590 N and using a scale of 1:400
F_{ES} = 4 cm
Draw graphical a line
in the direction of the force



All external forces together (**F_{EXT}**):
300 N + 68 N + 100 N = 468 N
Using the same scale 1:400
F_{EXT} = 1,2 cm lång draw it on endpoint of F_{ES} in the direction of the force (downward).

The sum of F_{ES} and **F_{EXT}** is F_{JOINT}
Draw graphical **F_{JOINT}** back to the startpoint of F_{ES}
measure the length of **F_{JOINT}**
F_{JOINT} is 6,6 cm and equals to 2640N
F_{JOINT} ”hits” the joint with an angle of 85°

11. JOINT FORCES – COMPRESSION & SHEAR FORCES

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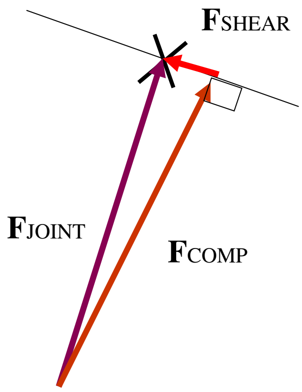

The compression force vector is 6.5 cm and this equals to 2600 N.

The shear force vector is 1.1 cm and this equals to 440 N.

What does it mean?

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Cadaver studies :

Damage of vertebrae tissue, cartilage and discs occur with:

Compression 4360N

Compression 1334N, flexion 7^{o} and rotation 3^{o}

- lower values with repetitive movements!

LOW BACK PAIN AND LIFTING TECHNIQUE - A REVIEW

Hsiang, 1997

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PRESENTATION 2
Physiotherapy students
- undergraduate level

- APPLIED BIOMECHANICS, the concept of moment arms
- STRENGTH TRAINING
  → External forces
  → Internal forces
- ERGONOMICS

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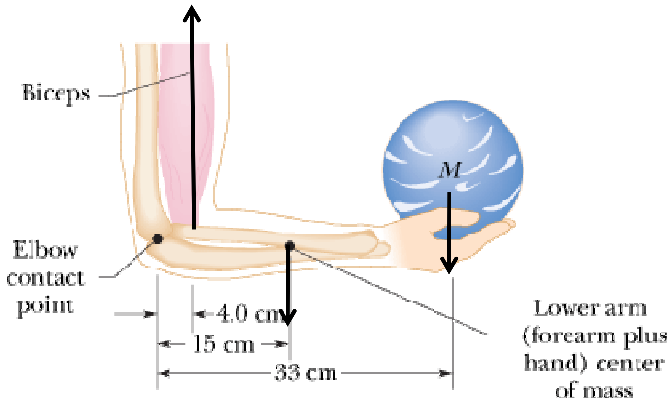
External torque = Internal torque

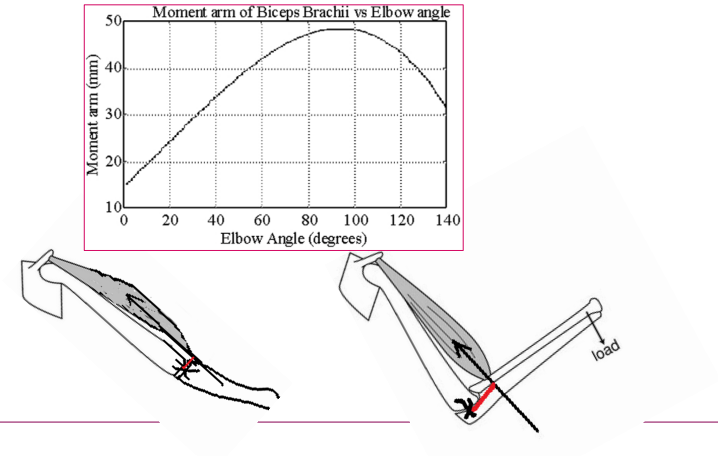
39Nm = Muscle force x 0.04m

Muscle force = 39N/0,04m = 975N



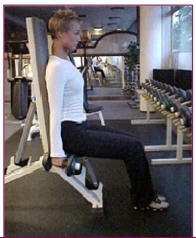
Muscle strength is dependent on joint angles

- Internal moment arms



Different ways of loading muscles

- Free weights
  → Cheap
  → Functional
- Pulley systems
  → Flexible
- Machines
  → Ready to use
- Theraband
  → Increased force during motion
- Body segments
  → Easy?



Three different positions (free weights) – which one is the best?

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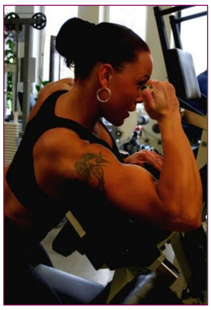
- Standing
- Sitting straight
- Leaning backwards



Calculations of external torque during elbow flexion with free weights

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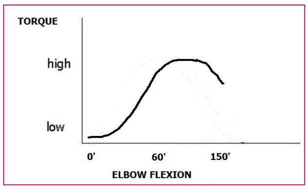
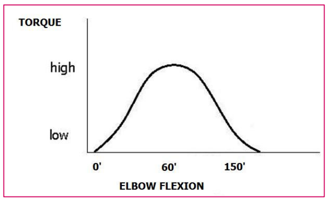
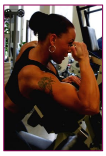
- Standing

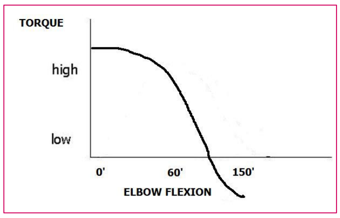


- Leaning backwards



- Sitting straight





PRESENTATION 3
Clinicians at a hospital

- Movement analyzes
  - → History
  - → Current measurement systems
    - KINEMATICS
    - KINETICS
    - EMG
    - GAIT (BTE/GAIT-RITE)
  - → Clinical research
    - Single case studies

Thesis

- INTRODUCTION
  - → Litterature
  - → Aims
- METHODS

THESIS WORK INTRODUCTION

- Low back pain in society
- Ergonomics – model
  → Exposures and Outcomes
- RISK FACTORS
  → Load lifting / manual handling as main risk factor
- Exposure assessment
  → Questionnaires
  → Observation scales
  → Reliable measurements (!?)

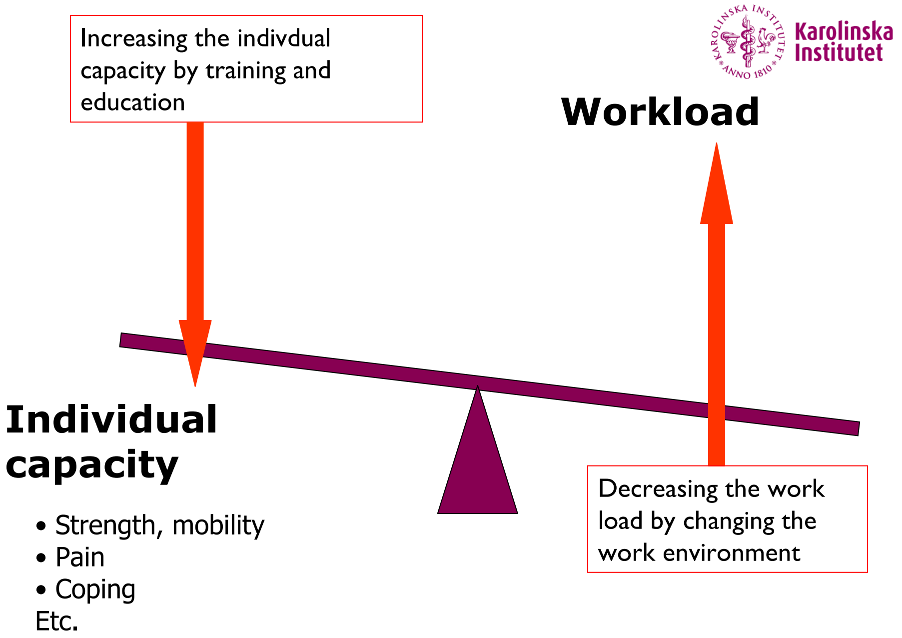
LOW BACK PAIN

Low back pain (LBP) has a tremendous impact on society both financially and physically. Over **80% of the working population will experience LBP** at some point in time during their lives [Waddell, 1998].

LBP is more prevalent for individuals who work in physically demanding jobs where it is the leading cause of disability (up to 47% of the workers are affected) [Statistics Sweden, 2006].

Estimates of the total cost of low back injuries and related pain (both direct and indirect costs) in Sweden are between **6000 and 19000 euros per person/year** [Hansson & Hansson, 2005; Liwing, Grooten et al, 2009].

Thus, there is a tremendous incentive to understand how individuals become injured in the low back while at work in order to work on prevention.



EXPOSURE

= What ***work load*** exist at the work site

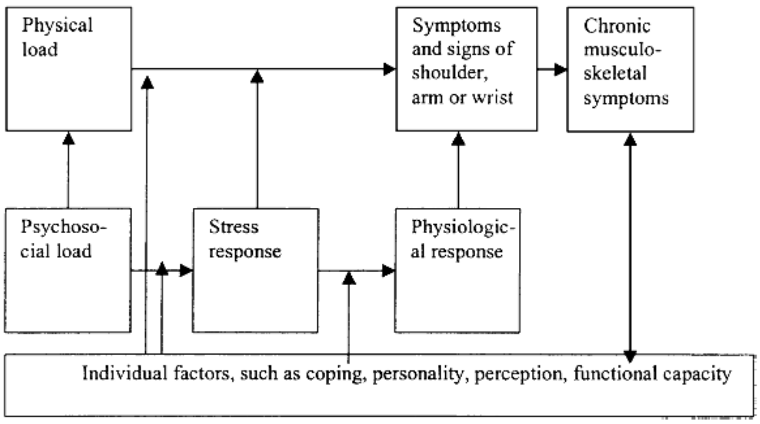
Biomechanical load and psychosocial load

OUTCOME

= Which ***consequence*** for the worker

E.g pain/disability medical care seeking health economics

Bongers, et al (2002)

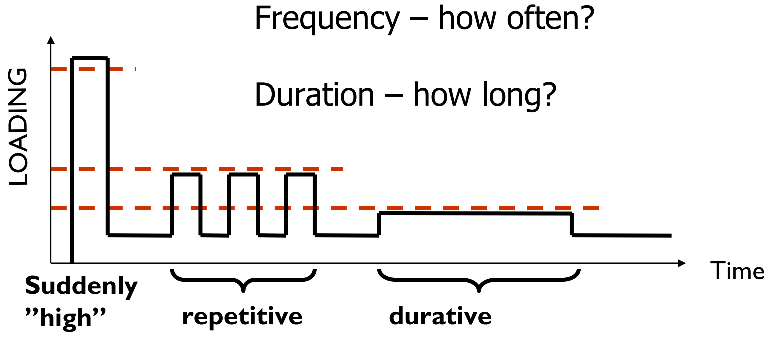


Biomechanical work load is dependent on three parameters:

Intensity – how heavy?

Frequency – how often?

Duration – how long?



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BIOMECHANICAL RISK FACTORS FOR LBP

described in Swedish law:

- Static work
- Repetitive work
- Awkward positions
- Manual handling
- Vibration

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BIOMECHANICAL RISK FACTORS FOR LBP

Evidence (Bongers, 2009: keynote at IEA)

- Manual handling (heavy lifting; lifting)
- Awkward positions (trunk flexion)
- Whole Body vibration

Exposure assessment
– what to measure?

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External forces

Intensity

Frequency

Duration

Awkward positions

measuring the (lack of) changes in body postures (angles)

Revised NIOSH Lifting Equation

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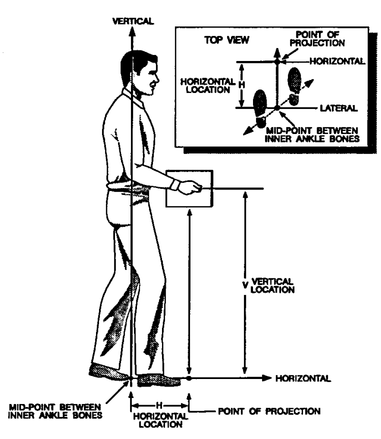
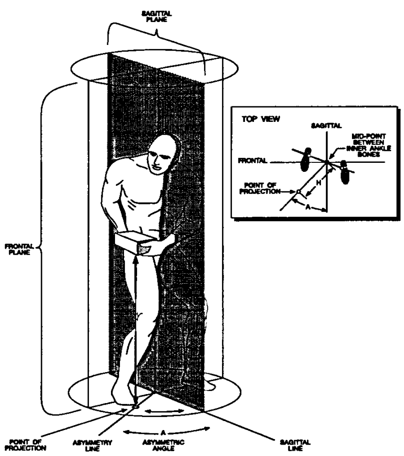


Figure 1 Graphic Representation of Hand Location



http://www.cdc.gov/niosh/docs/94-110/

http://www.ccohs.ca/oshanswers/ergonomics/niosh/calculating_rwl.html

What is the Revised NIOSH lifting equation?

The equation is: LC x HM x VM x DM x AM x FM x CM = RWL

Where

- LC is the load constant (23 kg),
- HM, the "Horizontal Multiplier" factor, — horizontal distance(start)
- VM, the "Vertical Multiplier" factor, — vertical distance (start)
- DM, the "Distance Multiplier" factor, — vertical traject
- FM, the "Frequency Multiplier" factor, — time between lifts
- AM, the "Asymmetric Multiplier"factor, — assymetri
- CM, the "Coupling Multiplier" factor, — good/bad handles
- RWL, the "Recommended Weight Limit".

Cadaver studies :

Damage of vertebrae tissue, cartilage and discs occur with:

Compression 4360N

Compression 1334N, flexion 7^{o} and rotation 3^{o}

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LOW BACK PAIN AND LIFTING TECHNIQUE - A REVIEW
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Exposure assessment

– what to measure?

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External forces

Intensity

Frequency

Duration

Awkward positions
measuring the (lack of) changes in body postures (angles)

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EXPOSURE ASSESSMENT

How to identify / measure these exposures in field measurements?

- easy
- cheap
- correct

Questionnaires
Interview
Portable measurement systems

A. Registration methods for working positions

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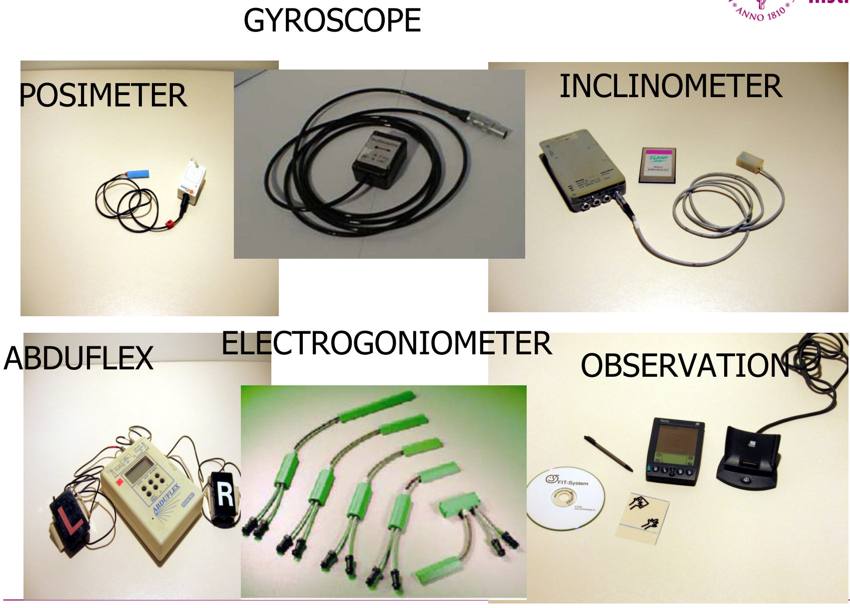

Inclinometer

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- Angle between upperarm and vertical (y-axes)
- Frequency, how often the arm is lifted
- Duration, duration of time an arm has been lifted above a specific angle
- Velocity, acceleration of movements

Accelerometers – largely used in ergonomics and measurements of physical activity.

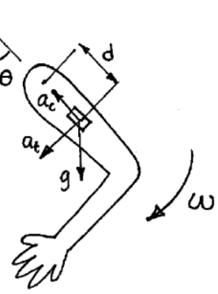
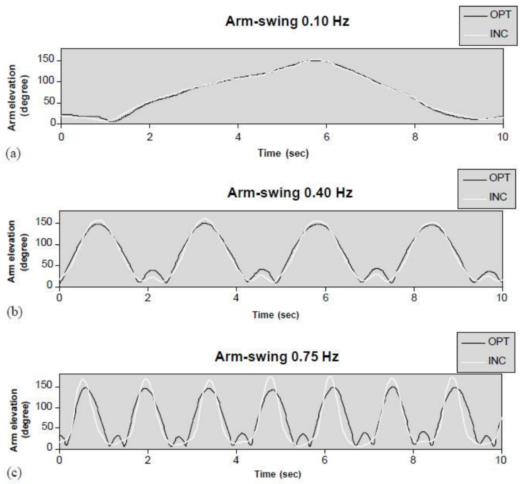


Fig. 5. The total acceleration acting on the inclinometer sensor can be divided into three accelerations, centripetal acceleration (ac), tangential acceleration (at) and, gravity (g). Degree of arm elevation (θ), angular velocity (ω) and, distance between movement centre and the inclinometer sensor (d) are also presented.

A triaxial accelerometer for measuring arm movements. Bernmark E, Wiktorin C. Appl Ergon. 2002 Nov;33(6):541-7

Figure 1



Comparison with the VICON system

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Working with the hands above shoulder level

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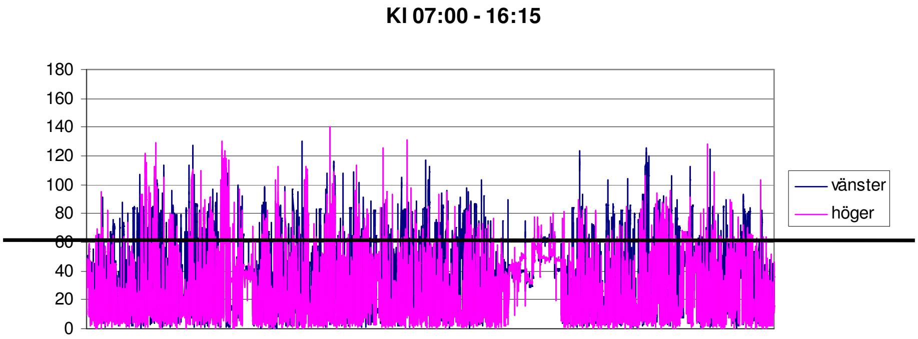
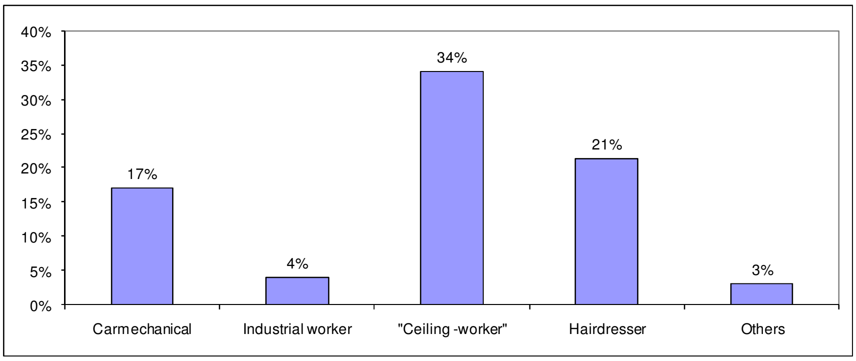
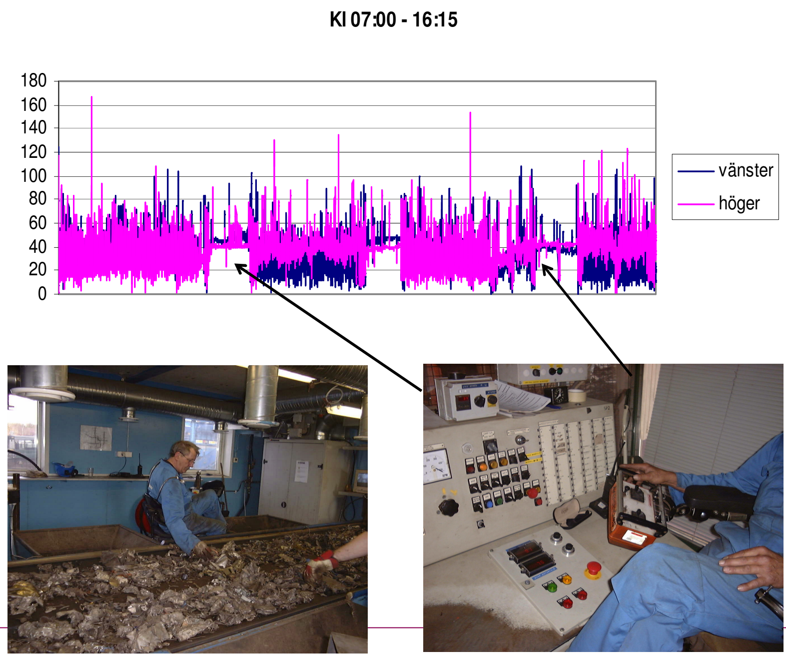


At least one hand above shoulder level
(≥ 60° abuction in the shoulders)
17% of the working time

Working with hands above shoulder level





Litterature

- In the Ergonomic field, the load lifting has been related to:
  - → the relation between **external and internal loads** at lumbar spine level. (NIOSH)
  - → the **influence of fatigue processes** in upper limbs (Chen, 2003)
  - → the effects of the **load mass distribution** (Dennis and Barrett, 2003)
  - → the different **lifting techniques**.

- In movement analyses the important analyses variables are:
  - → **trunk displacement** (Van Dieën and De Looze, 1999; Givens *et al*, 2002; Dennis and Barrett, 2003; Hansen *et al*, 2007; Anderson *et al,* 2007; Arjmand *et al*, 2006; Bazrgaria *et al*, 2008;)
  - → **trunk angular velocity and acceleration** (Khalaf *et al*, 1999; Givens *et al*, 2002; Bazrgaria *et al*, 2008),
  - → **range of motion** (Andreoni *et al*, 2005; Arjmand *et al*, 2006),
  - → **moments and compression forces** (Hsiang, S and Mcgorry, 1997; Gallagher *et al*, 2001; Chen, 2003; Dennis and Barrett, 2003; Bazrgaria *et al*, 2007; Gallagher *et al*, 2009).

CONCLUSIONS FROM INTRODUCTION

- There is a need for better exposure assessment methods that can cover all three dimensions of biomechanical risk factors:
  - intensity
  - frequency
  - duration

- These exposure assessment methods should be able to be used in field measurements

- In ergonomics, lifting tasks are mostly studied regarding the external weights, and not on variables common in motion analyses: angles, velocity, acc.

AIMS

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To validate measures of angular displacement, velocity and acceleration of the trunk during load-lifting tasks measured with portable ergonomic measurement systems against optoelectronic laboratory systems.

To test whether measures of angular displacement, velocity and acceleration of the trunk during load-lifting tasks measured with portable ergonomic measurement systems are reliable and if worksite measurements are comparable with measurements under experimental laboratory conditions.

Set-up of the project

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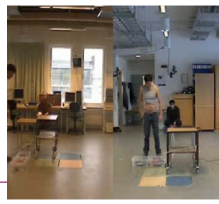
Work site measurements | Laboratory measurements

Inclinometer
Goniometer
Accelerometer

BTS



Specific research questions

The specific research questions for this project are:

- 1.Are the angular displacement, velocity and acceleration of the trunk measured with the CAPTIVE L3000 system under laboratory conditions comparable with measurements performed by BTS system?
- 2.Are the angular displacement, velocity and acceleration of the trunk measured with the portable systems under laboratory conditions reliable in terms of inter- and intra-trial variability?
- 3.Are the angular displacement, velocity and acceleration of the trunk measured with the CAPTIVE L3000 system during worksite measurements comparable with measurements of these variables under laboratory conditions?

METHODS

- Description of the lifting task
- Four different labs: INCLINOMETER/ GONIOMETER/ GYROSCOPE/ BTE (COLOMBIA + SWEDEN)
- Field measurements INCLINOMETER/ GONIOMETER/ GYROSCOPE
- Validity: comparison between the “golden standard (BTS)” and field measurement systems
- Reliability: comparison between different trials of the field measurement systems in different laboratories
- Comparison between field measurements and laboratory experiments.
- Statistics

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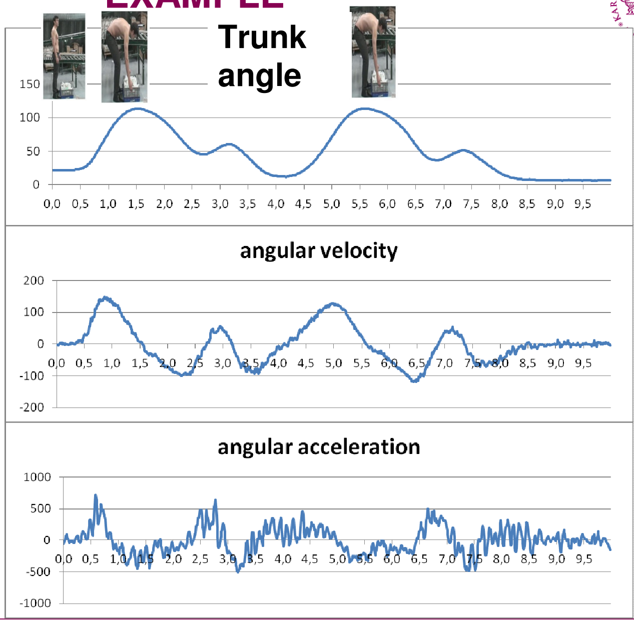
EXAMPLE



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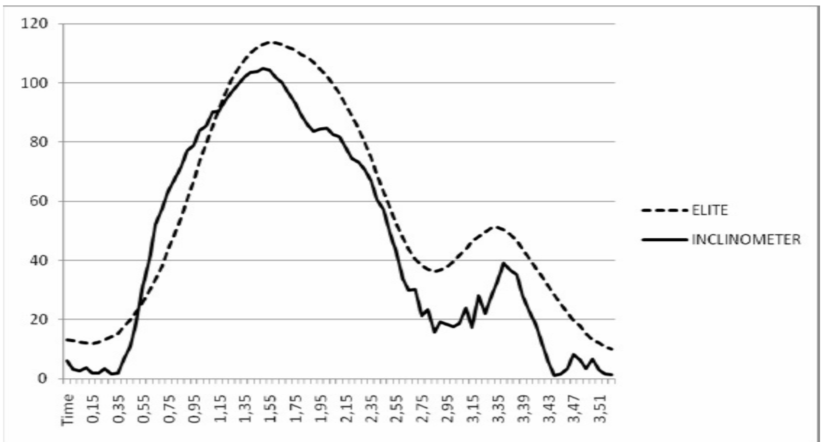
Example comparison BTS and Inclinometer



Example comparison goniometer / gyro in LAB

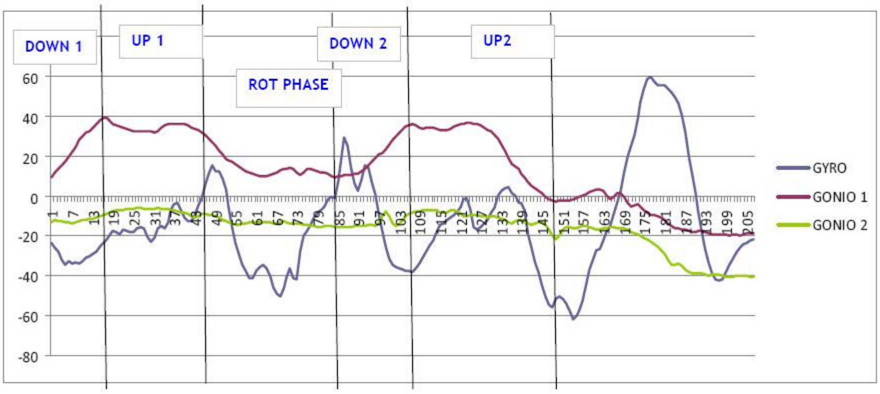


Figure 3. The three parameters of importance:
In red the trunk flexion angle,
In green the trunk lateral deviation
In blue the rotation of the trunk,
measured with the CAPTIV system at 25Hz at the movement science laboratory in Colombia

Field measurement

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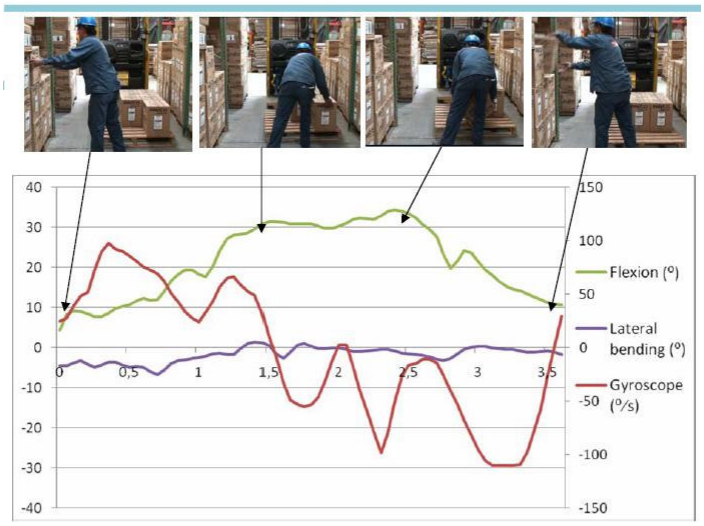

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EXPERIMENTS

- Experiments

→ Movement lab (Sweden)	Inclinometer, BTS
→ Javieriana	Inclinometer, goniometer, gyroscop
→ Roosenfeld	BTS, Inclinometer, goniometer, gyroscop
→ Hospital Central	BTS, Inclinometer, goniometer, gyroscop
→ Pavco (in field)	Accelerometer, goniometer, gyroscop

- Experiments

		number of lifts
→ Movement lab (Sweden)	5 trials (2 lifts each trial)	10
→ Javieriana	3 trials (2 lifts each trial)	6
→ Roosenfeld	2 x 5 trials (2 lifts each trial)	20
→ Hospital Central	3 trials (2 lifts each trial)	6
→ Pavco (in field)	4 trials (5-6 lifts each trial)	20-24

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VALIDITY - comparison inclinometer and BTS

	DOWN 1 angles	DOWN 2 angles	DOWN 1 velocity	DOWN 2 velocity	DOWN acc 1	DOWN acc 2
SWEDEN INC trial 12	102,4	104,2	366,8	248	320	251
SWEDEN ELITE trial 12	105,4	111,4	146,6	128,5	679,2	425,4

RELIABILITY – LAB MEASUREMENTS

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	Box 1	Box 2	Mean
JV -trial 2	35,6	36,6	36.1
ROOS 1-1	39	36	37.5
ROOS 1-2	40,5	37,7	39.1
ROOS 1-3	41,7	38,8	40.3
ROOS 1-4	35,8	38,8	37.3
ROOS 2-1	52,3	43,8	48.1
ROOS 2-2	46,9	50,6	48.8
ROOS 2-3	47,6	49,5	48.6
ROOS 2-4	46,5	48,9	47.7
ROOS 2-5	45,8	48,6	47.2
MEAN	43,17	42,93	43.1

GONIOMETER

RELIABILITY – FIELD MEASURES

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INTRA-TRIAL RELIABILITY

INTER-TRIAL RELIABILITY

	Box 1	Box 2	Box 3	Box 4	Box 5	Box 6	mean
Trial 1	36,1	31,4	34,9	32,1	29,8	37,2	34
Trial 2	41,4	48,9	65,9	87,5			61
Trial 3	32,7	31,5	36,6	41,9	43,5	38,6	37

Statistics

- Descriptive statistics
  → Mean (SD) or Median (range)
  → SEM (Standard error)

- Analytic statistics
  → T-test (ANOVA)
  → ICC[1,2] (Reliability coefficient)

[3]The formula $(BMS - EMS)/(BMS + EMS + k(JMS - EMS)/n)$ was used, where BMS is the mean square of variation between subjects, JMS is the mean square of variation within subjects, EMS is the residual mean square, k is the number of repetitions, and n is the number of subjects.