

**Dynamic Loading of the Upper Limb in Industrial Work**

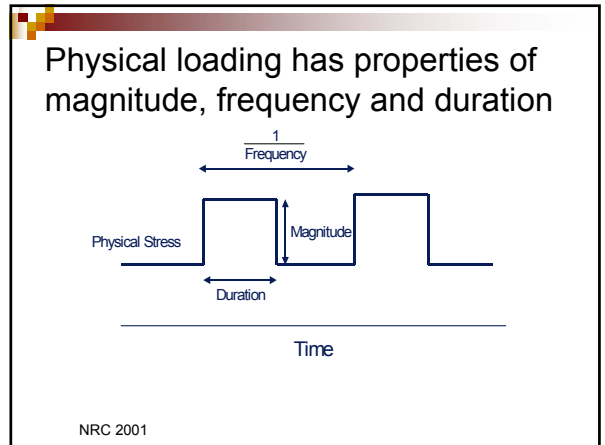
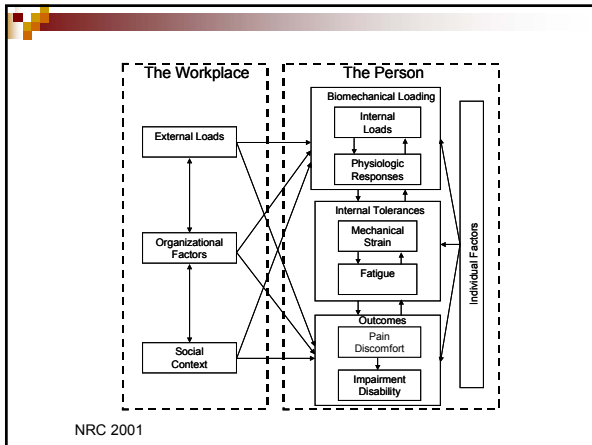
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THE UNIVERSITY OF WISCONSIN

**Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities**

National Research Council, 2001

<http://www.nap.edu/books/0309072840/html/>



**External Loads**

	Property		
Physical Stress	Magnitude	Repetition Rate	Duration
Force	Forceful exertions	Repetitive exertions	Sustained exertions
Motion	Extreme postures and motions	Repetitive motions	Sustained postures
Vibration	High vibration level	Repeated vibration exposure	Long vibration exposure
Cold	Cold temperatures	Repeated cold exposure	Long cold exposure

NRC 2001

**Measurement of external loads**

	Property		
Physical Stress	Magnitude	Repetition Rate	Duration
Force	Force generated or applied	Frequency that force is applied	Time that force is applied
Motion	Joint angle, velocity, acceleration	Frequency of motion	Time to complete motion
Vibration	Acceleration	Frequency that vibration occurs	Time of vibration exposure
Cold	Temperature	Frequency of cold exposure	Time of cold exposure

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### Measurement of internal loads

- Biomechanical models
- EMG
- Compartmental pressure

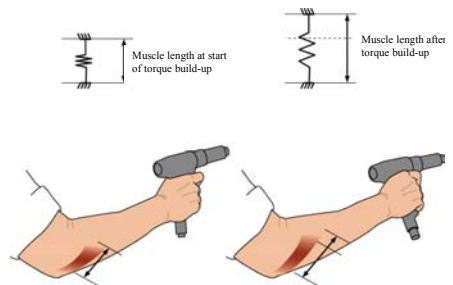
### Physiological responses

- Localized muscle fatigue
- Psychophysical studies

### External loading and hand tool use

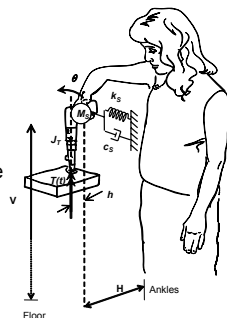
- EMG studies of reaction force and buildup time
  - Radwin et al. (1989)
- Kinematics (motion) of operator response
  - Oh and Radwin (1998)
  - Freivalds and Eklund (1993)
  - Kihlberg et al., (1993)
  - Kihlberg et al. (1994)

### Eccentric (lengthening) muscle exertions

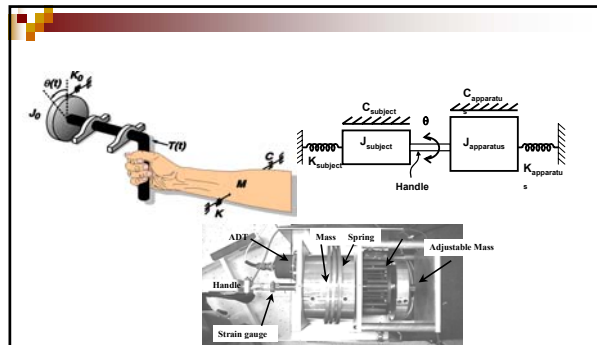


### Human operator mechanical model

- Mechanical parameters
  - Stiffness  $k_s$
  - Viscous damping  $c_s$
  - Inertial mass  $M_s$
- Mechanically describe operator eccentric response to tool reaction forces
- Dependent on location (H and V) and orientation

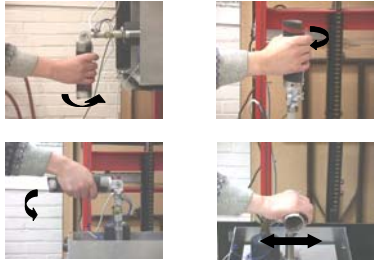


Lin, Radwin and Richard, *Ergonomics* 44(3):295-312, 2001



Lin, Radwin and Richard, *Ergonomics* 44(3):295-312, 2001

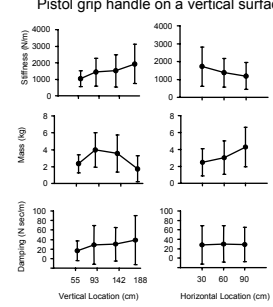
### Parameter identification for tool shape, location and orientation



25 student subjects

### Dynamic operator mechanical model parameters

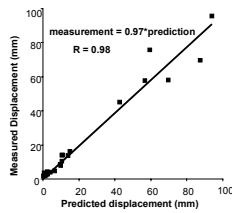
Pistol grip handle on a vertical surface



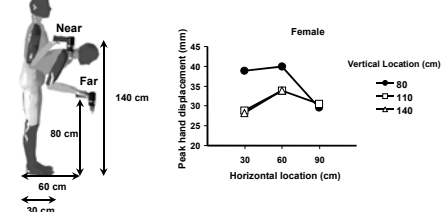
Parameter	Location	55 cm	93 cm	142 cm	188 cm
Stiffness (N/m)	Vertical	~1000	~1500	~2000	~2500
	Horizontal	~2000	~1500	~1000	~500
Mass (kg)	Vertical	~2	~4	~3	~1
	Horizontal	~2	~3	~4	~5
Damping (N sec/cm)	Vertical	~30	~40	~45	~50
	Horizontal	~30	~35	~40	~45

### Handle displacement predictions for actual tool operation

- Six different pneumatic screwdrivers
- Nine subjects (3 male, 6 female)
- Tool motion recorded in 3D using Northern Digital OptoTRAK 3020 motion analysis system
- Stiffness adjusted proportionally to EMG



### Tool reaction force acting against operator is dependent on location and orientation




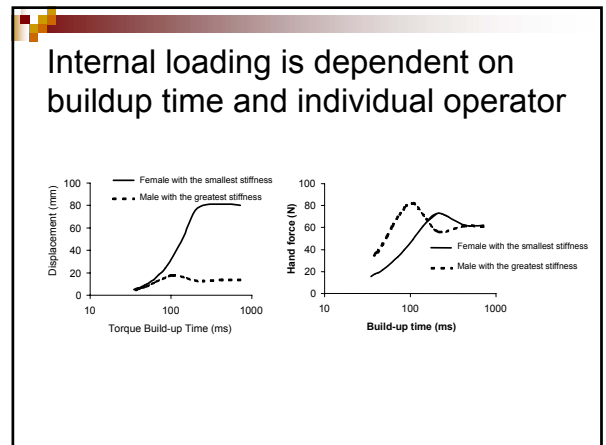
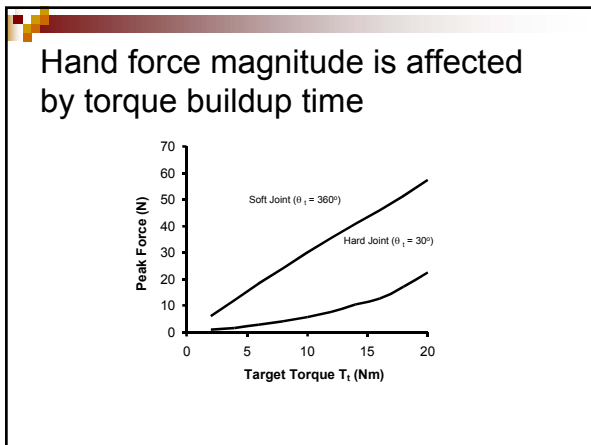
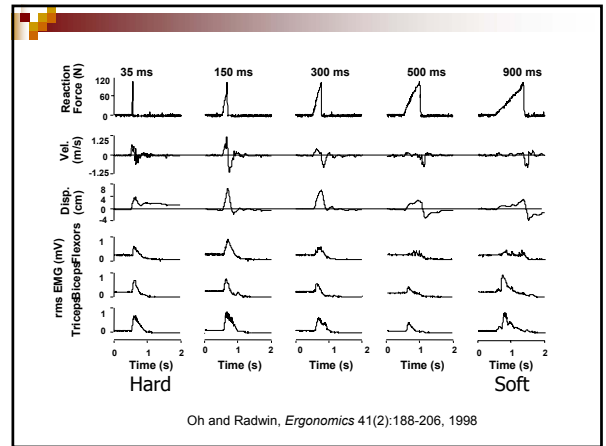
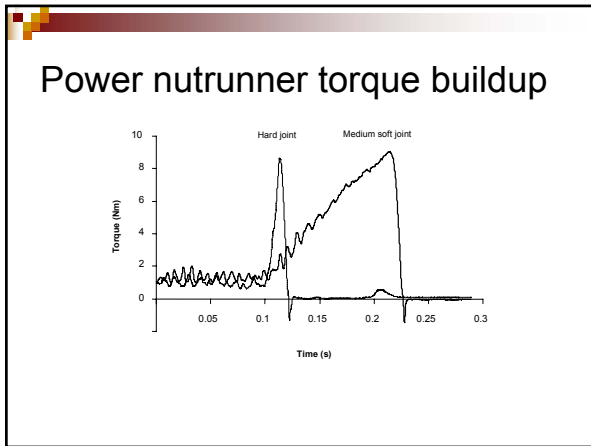
Vertical Location (cm)	Horizontal location (cm)	Peak hand displacement (mm)
80	30	~35
80	60	~40
80	90	~30
110	30	~25
110	60	~35
110	90	~30
140	30	~25
140	60	~35
140	90	~30

### Perceived exertion and discomfort are related to work location

- Ulin et al., *Appl Occup Environ Hyg* 7(5):327-337, 1992
- Ulin, et al., *Am. Ind Hyg Assoc J* 54(7):383-391, 1993
- Ulin et al., *Ergonomics* 36(7):833-846, 1993

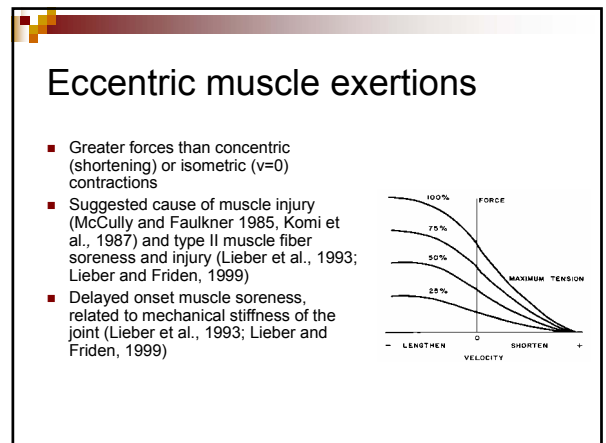
### Torque buildup time is related to threaded fastener characteristics





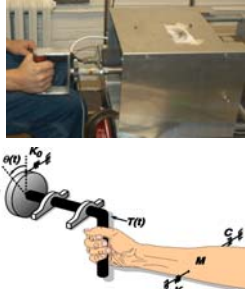
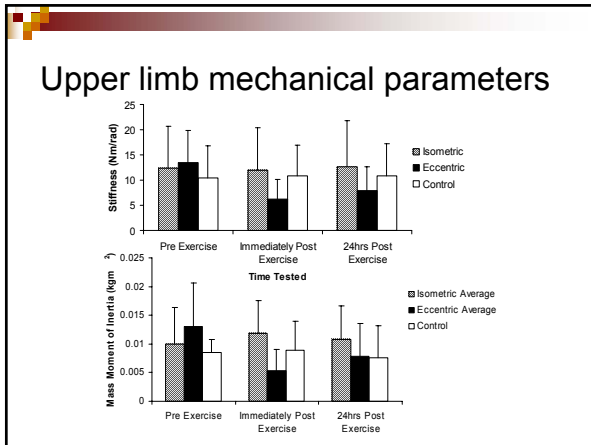
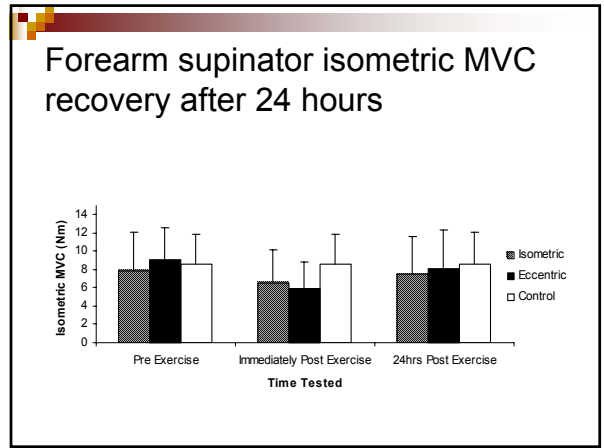
### Power hand tool displacement response and perceived discomfort

- Freivalds and Eklund, *Applied Ergonomics*, 24: 158-164, 1993
- Kihlberg, Kjellberg and Lindbeck, *Applied Ergonomics*, 24:165-173, 1993
- Kihlberg, Lindbeck and Kjellberg, *Applied Ergonomics*, 25, 242-247, 1994
- Kihlberg, et al. *Int J Indust Ergon*, 15: 417-426, 1995



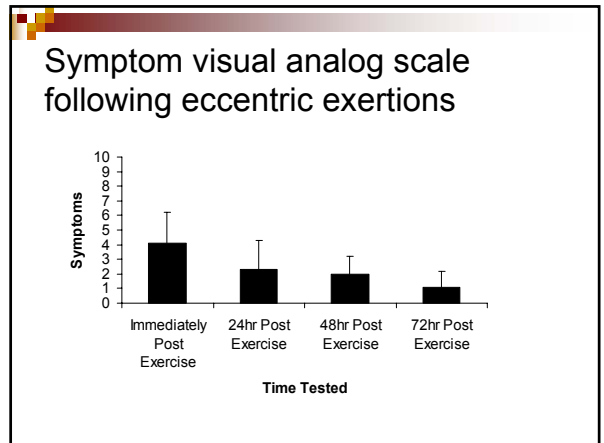
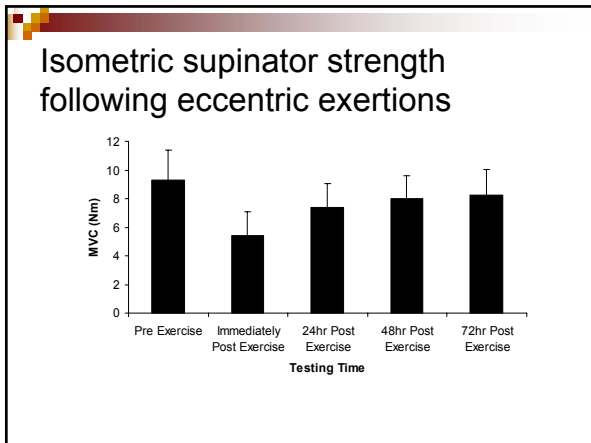
### Operator dynamic parameters following repetitive eccentric exertions

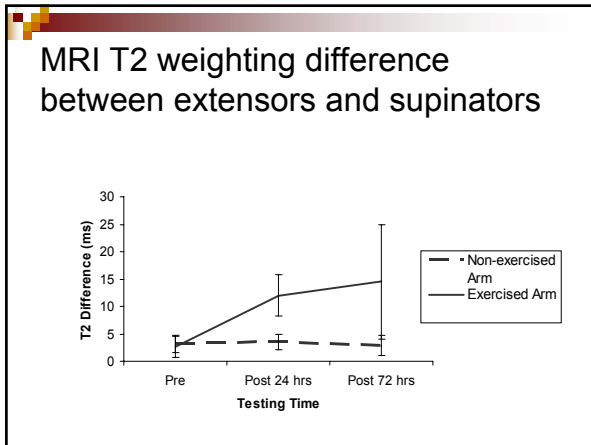
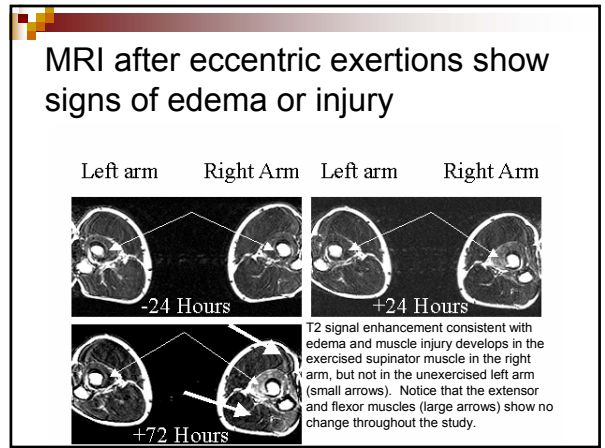
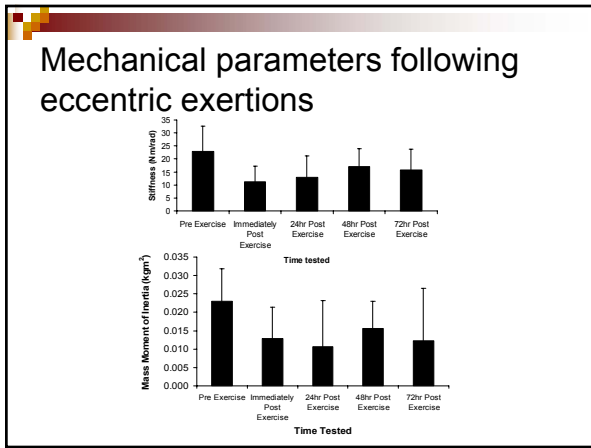
- 18 subjects (12 males, 6 females)
- randomly assigned to: (1) isometric exercise, (2) eccentric exercise at 30°/s pronation, and (3) control subjects who performed no exercise
- Isometric supinator strength test and mechanical parameters before, after and 24 hours later
- three second contraction followed by a three second rest at 50% MVC for 10 min with a 1 min rest break after 5 min

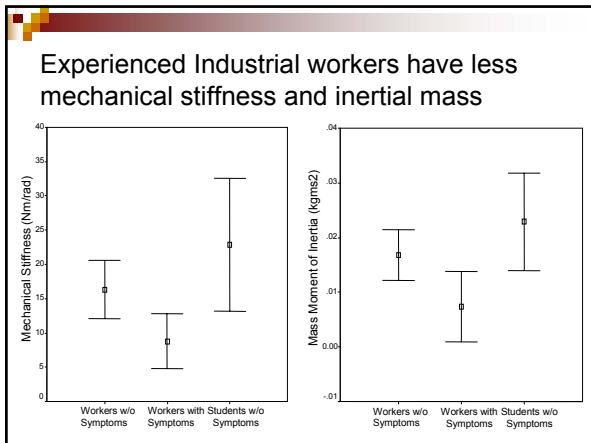
### Biomechanical changes in eccentric exertions

- Eight male subjects
- No upper extremity symptoms or participation in weight lifting program in previous six months
- Repetitive 3 second contractions followed by a 3 second rest on a BIODEX™ at a velocity of 30°/s
- 30 minutes of eccentric exercise at 50% MVC with one minute rest break after every 5 minutes
- Mechanical parameter identification and MRI on 1.5 T GE CVi scanner before, 24 h and 72 h after exercise





- ### Industrial workers
- 14 healthy male employee volunteers from a Midwestern US kitchen appliance manufacturer with at least 6 months experience
  - 8 healthy male students
  - Symptom survey, supinator isometric strength test and upper limb mechanical parameters

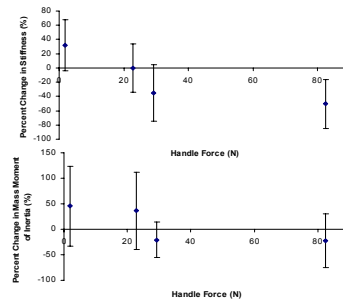


- ### Simulated threaded fastener operation in the laboratory
- 29 student subjects
  - Repetitively operate tool for one hour
  - 50 ms and 250 ms buildup time
  - 3 Nm and 9 Nm torque
-

### Handle force and displacement predicted for 95th percentile male

Experimental Condition	Force (N)	Displacement (mm)
3 Nm Peak Torque 50ms Build Up Time	1.93 N	0.24 mm
9 Nm Peak Torque 250 ms Build Up Time	22.87 N	5.64 mm
3 Nm Peak Torque 50 ms Build Up Tim	29.14 N	13.22 mm
9 Nm Peak Torque 250 ms Build Up Time	82.48 N	49.15 mm

### Mechanical parameters changes and predicted hand force



### Conclusions

- External upper limb loads are affected by tool, workplace, and individual factors, and therefore can be controlled through work design
- Biomechanical properties are affected by repetitive external loading
- Internal mechanical properties affect external loading
- Physiological responses are affected by external loading

### Future studies of dynamic loading

- Need to use more dynamic biomechanical models
- Need to use new methodologies to measure physiological response (e.g. imaging)
- Need to investigate how short-term physiological effects may lead to long-term outcomes (pain, discomfort, impairment, disability)

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