Validity of Observational Job Analysis Methods

Brian D. Lowe, Ph.D., CPE,
National Institute for Occupational Safety & Health(NIOSH)

Validity of Observational Job Analysis Methods

Brian D. Lowe, Ph.D., CPE
National Institute for Occupational Safety and Health
Cincinnati, OH
USA

September 2, 2003

Presentation Outline

- Physical risk factors for work related musculoskeletal disorders (WMSDs) of the upper limbs
- Ergonomics job analysis methods to characterize exposure to WMSD risk factors
- NIOSH study of the validity of observational methods for exposure characterization (working posture)
- Validity considerations in ergonomic observational-based job analyses

Risk Factors in Physical Work

Exposure *"the presence of a substance (factor) in the environment external to the worker"*
Checkoway et al. (1989)

WMSD exposure variables/risk factors

- posture
- force
- repetition
- vibration

goals for exposure characterization

(Kilbom, 1994)

- *External Validity* - identify exposures associated with increased risk for WMSDs

Exposure ⟶ Response

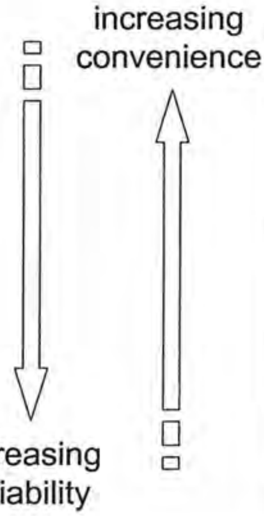
✓ **epidemiology**

☆ *Internal Validity* - exposure is classified accurately relative to a known standard

✓ **biomechanics**

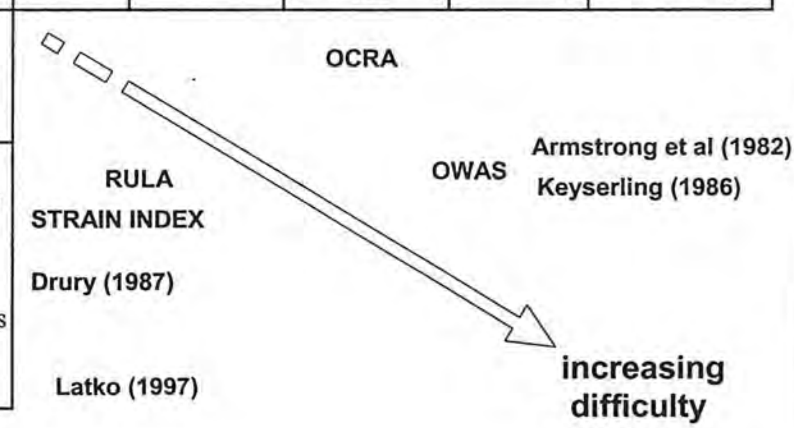
Methods for Assessing WMSD Risk Factors

- Job Titles/SIC code
- Worker Self Report
- **Systematic Observation**
- Instrumentation-Based Direct Measurement

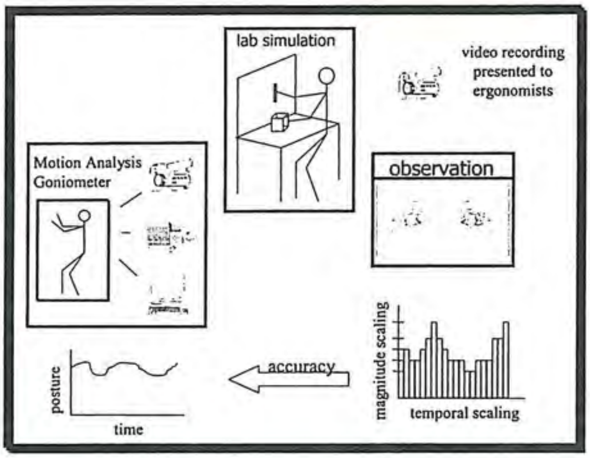


systematic observation of posture

Temporal → / Spatial ↓	peak (peak posture)	average (average posture)	mode (category with most frequently occurring posture)	work sampling (periodic observations)	near continuous (posture category vs. time recording)
low (2 - 3 categories)					
medium (4 - 6 categories)					
high (> 6 categories, VAS method or continuous scale)					

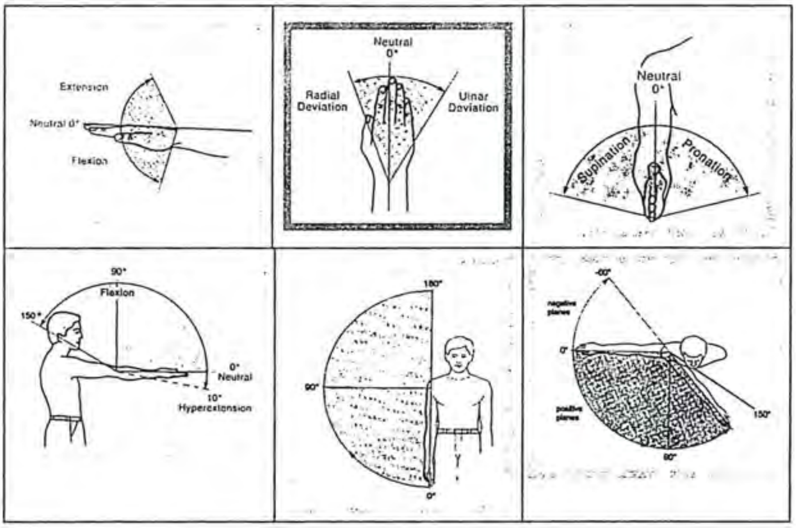


Validity of Observational Exposure Assessment

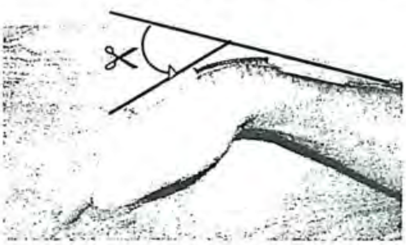


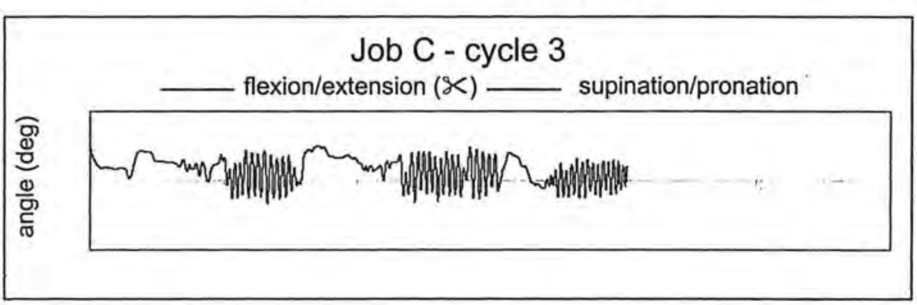
jobs simulated in the laboratory

Upper Limb Postures Evaluated

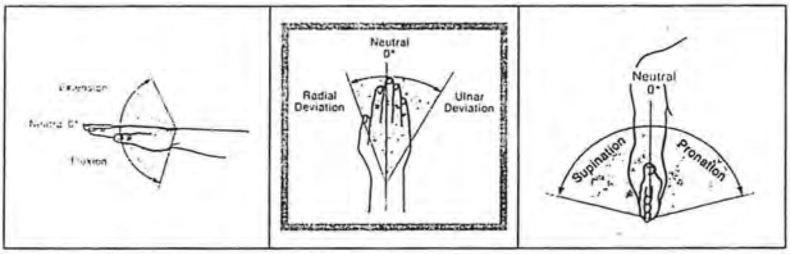


Electrogoniometer



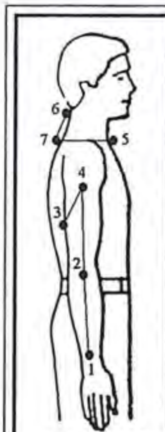


Electrogoniometer Calibration



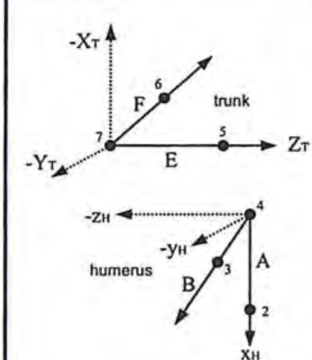
	R^2	maximum error
flex/ext	0.99	0.5° @ 45° flex
sup/pro	0.94	2.5° @ 45° pro
rad/uln	0.80	10° @ 30° uln

Optical/Video Motion Reconstruction



A: 4 – 2 HCS*x*
B: 4 – 3
C: A x B HCS*y*
D: A x C HCSz
E: 7 – 5 TCS*Z*
F: 7 – 6
G: F x E TCS*Y*
H: G x E TCS*X*

anatomical pod



Kinematics – Euler Angles

[rotation about x] [rotation about z'] [rotation about x'']

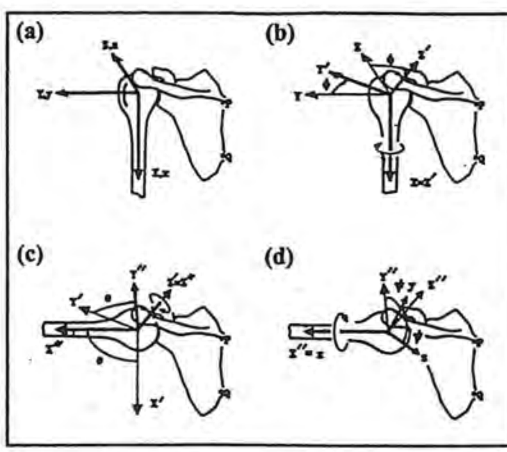
$$\begin{vmatrix} X\cdot x & X\cdot y & X\cdot z \\ Y\cdot x & Y\cdot y & Y\cdot z \\ Z\cdot x & Z\cdot y & Z\cdot z \end{vmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & -\sin\phi \\ 0 & \sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\psi & -\sin\psi \\ 0 & \sin\psi & \cos\psi \end{bmatrix}$$

$$\begin{vmatrix} X\cdot x & X\cdot y & X\cdot z \\ Y\cdot x & Y\cdot y & Y\cdot z \\ Z\cdot x & Z\cdot y & Z\cdot z \end{vmatrix} = \begin{vmatrix} c(\theta) & -c(\psi)s(\theta) & s(\psi)s(\theta) \\ s(\theta)c(\phi) & c(\psi)c(\theta)c(\phi) -s(\psi)s(\theta) & -s(\psi)c(\theta)c(\phi) -c(\psi)s(\phi) \\ s(\theta)s(\phi) & c(\psi)c(\theta)s(\phi) +s(\psi)c(\phi) & -s(\psi)c(\theta)s(\phi) +c(\psi)c(\phi) \end{vmatrix}$$

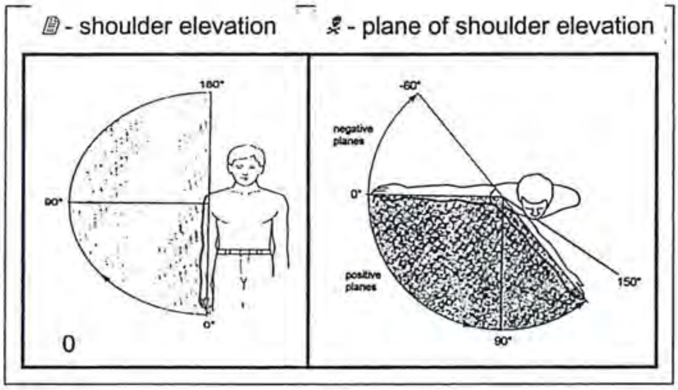
Shoulder Posture

Euler angle rotation sequence of
x – z' – x"
☠: Rotation about x
θ: Rotation about z'
ψ: Rotation about x"

$\theta = \cos^{-1} (X \cdot x)$
$\phi = \cos^{-1} [(Y \cdot x)/\sin(\theta)]$
$\psi = \cos^{-1} [-(X \cdot y)/\sin(\theta)]$



motion capture – shoulder kinematics



participants and procedure

Participants

- 28 professional ergonomists
- 14 from academia, 14 from industry/consulting
- 12 - Ph.D./M.D., 13 - M.S., 3 - B.S.
- Years experience in ergonomics (1 – 30 yrs.)

Procedure

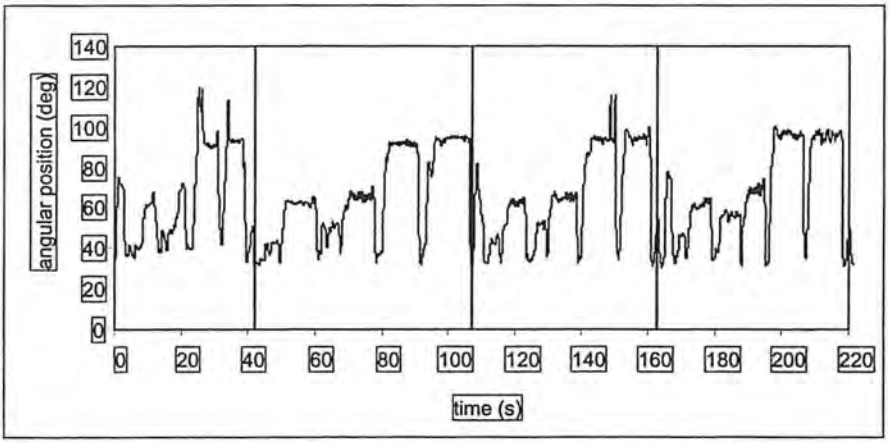
- Assigned one method for posture analysis
- Estimated posture from video recording of jobs
- Analyses were unguided

Posture Measures

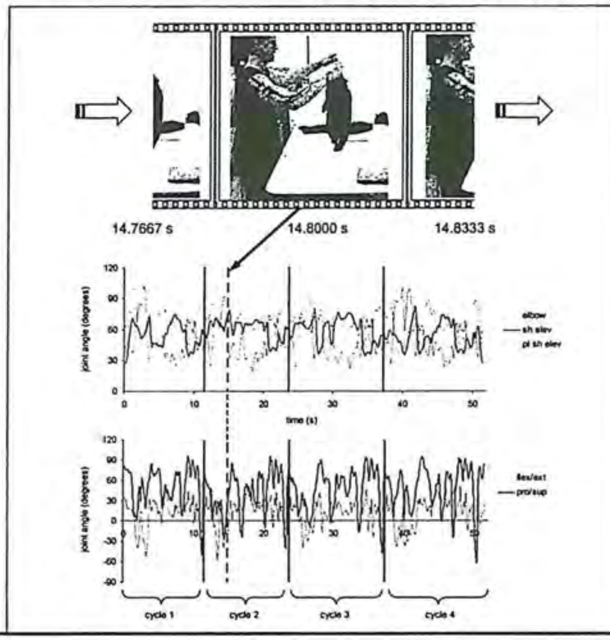
Precision →	Low (3 categories)	Medium (6 categories)	High (continuous)
Most frequently observed posture (mode)	✓	✓	
Peak observed posture (peak)	✓	✓	✓
Average posture (average)			✓
Temporal distribution of posture	✓	✓	

Work Cycle Analysis

shoulder elevation – Job C



video and instrumentation synchronization



posture scaling
method 1 – 3 categories

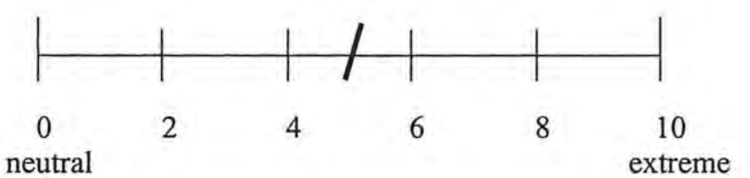
			1	2	3
mode	peak	wrist flex (deg)	>20°	20°-0°	
	peak	wrist ext (deg)		0°-20°	>20°
mode	peak	forearm sup (deg)	>40°	40°-0°	
	peak	forearm pro (deg)		0°-40°	>40°

	1	2	3
elbow flex (deg)	<40°	40°-80°	>80°
shoulder elev (deg)	0°-40°	40°-80°	>80°
plane of sh elev (deg)	<30°	30°-90°	>90°

posture scaling
method 2 – 6 categories

	1	2	3	4	5	6
wrist flex	>45	45-20	20 -0			
wrist ext				0-20	20-45	>45
forearm sup	>60	60-30	30-0			
forearm pro				0-30	30-60	>60
elbow flex	<20	20-40	40-60	60-80	80-100	>100
shoulder elev	<20	20-40	40-60	60-80	80-100	>100
plane of sh elev	<0	0-30	30-60	60-90	90-120	>120

posture scaling
method 3 - visual analog scale (VAS)



0°	wrist flexion	95°
0°	wrist extension	85°
0°	forearm supination	145°
0°	forearm pronation	135°
0°	elbow flexion	150°
0°	shoulder elevation	180°
0°	plane of shoulder elevation	150°

Results

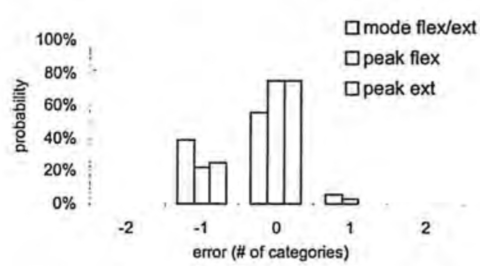
wrist/forearm

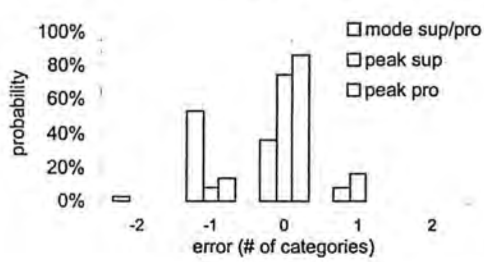
			estimated >40° sup >20° flex	estimated neut (±40°) neut (±20°)	estimated >40° pro >20° ext	
			1	2	3	
measured	>40° sup / >20° flex	1	0.0	0.0	0.0	0.0
	neut (±40°) / neut (±20°)	2	1.4	30.6	6.9	38.9
	>40° pro / >20° ext	3	1.4	44.4	15.3	61.1
			2.8	75.0	22.2	100

shoulder

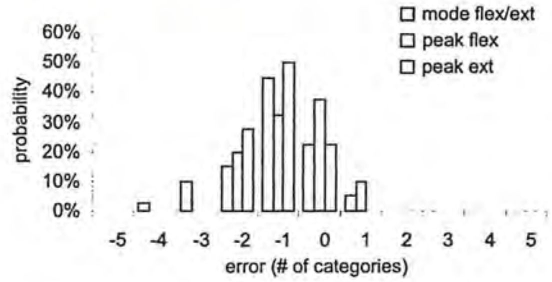
			estimated < 30° 0° - 40° 0° - 40°	estimated 30° - 90° 40° - 80° 40° - 80°	estimated > 90° > 80° > 80°	
			1	2	3	
measured	< 30° / 0° - 40° / 0° - 40°	1	7.4	0.9	0.0	8.3
	30° - 90° / 40° - 80° / 40° - 80°	2	20.4	65.7	5.6	91.7
	> 90° / > 80° / > 80°	3	0.0	0.0	0.0	0.0
			27.8	66.7	5.6	100

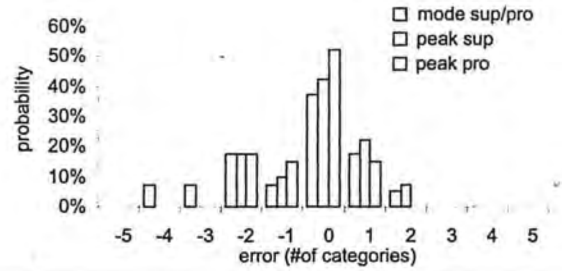
wrist/forearm – 3 categories



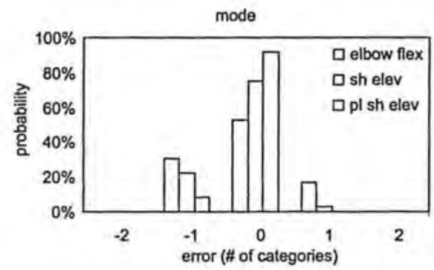


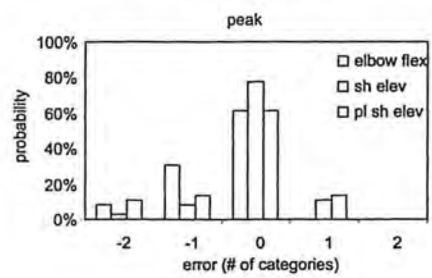
wrist/forearm – 6 categories



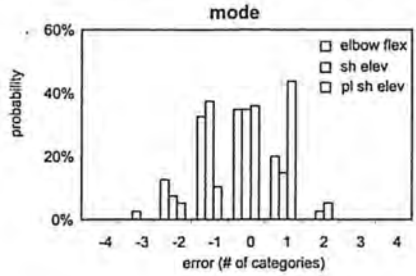


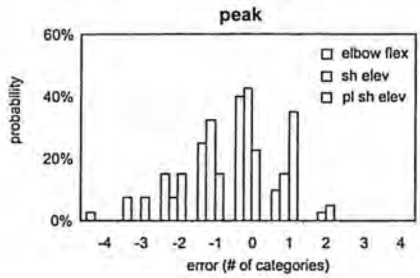
elbow/shoulder – 3 categories





elbow/shoulder – 6 categories





Observation vs. Chance

ergonomists' estimates

p(correct) = 0.375

		estimated						
		> 60 sup	30 - 60 sup	0 - 30 sup	0 - 30 pro	30 - 60 pro	> 60 pro	marginal
	> 60 sup	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	30 - 60 sup	0.000	0.000	0.000	0.000	0.000	0.000	0.000
measured	0 - 30 sup	0.000	0.000	0.025	0.075	0.000	0.000	0.100
	0 - 30 pro	0.000	0.000	0.025	0.150	0.075	0.050	0.300
	30 - 60 pro	0.000	0.000	0.000	0.050	0.000	0.025	0.075
	> 60 pro	0.000	0.075	0.075	0.175	0.000	0.200	0.525
	marginal	0.000	0.075	0.125	0.450	0.075	0.275	1.000

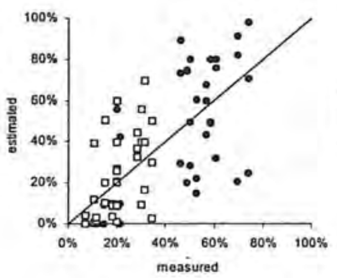
chance

p(correct) = 0.168

		> 60 sup	30 - 60 sup	0 - 30 sup	0 - 30 pro	30 - 60 pro	> 60 pro	marginal
	> 60 sup	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	30 - 60 sup	0.000	0.000	0.000	0.000	0.000	0.000	0.000
measured	0 - 30 sup	0.017	0.017	0.017	0.017	0.017	0.017	0.100
	0 - 30 pro	0.050	0.050	0.050	0.050	0.050	0.050	0.300
	30 - 60 pro	0.013	0.013	0.013	0.013	0.013	0.013	0.075
	> 60 pro	0.088	0.088	0.088	0.088	0.088	0.088	0.525
	marginal	0.167	0.167	0.167	0.167	0.167	0.167	1.000

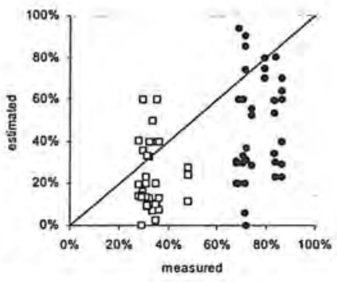
Visual Analog Scaling

wrist flexion



$r^2 = 0.31$*
$r^2 = 0.28$*

wrist extension

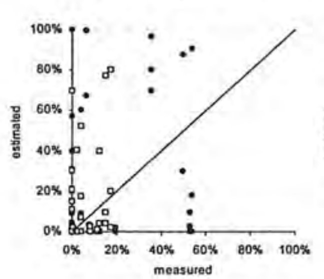


$r^2 = 0.02$
$r^2 = 0.00$

• peak
□ average

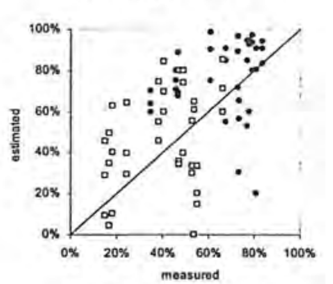
Visual Analog Scaling

forearm supination



$r^2 = 0.02$
$r^2 = 0.03$

forearm pronation

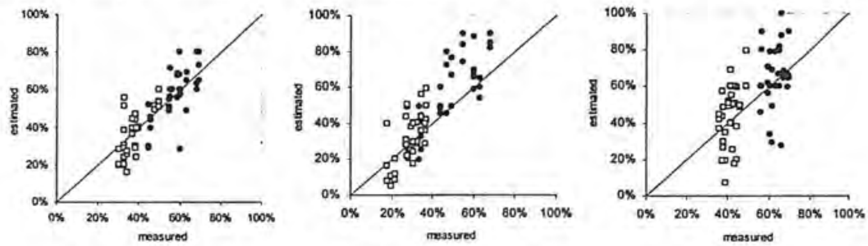


$r^2 = 0.02$
$r^2 = 0.09$

• peak
□ average

Visual Analog Scaling

elbow flexion | shoulder elevation | plane of shoulder elev

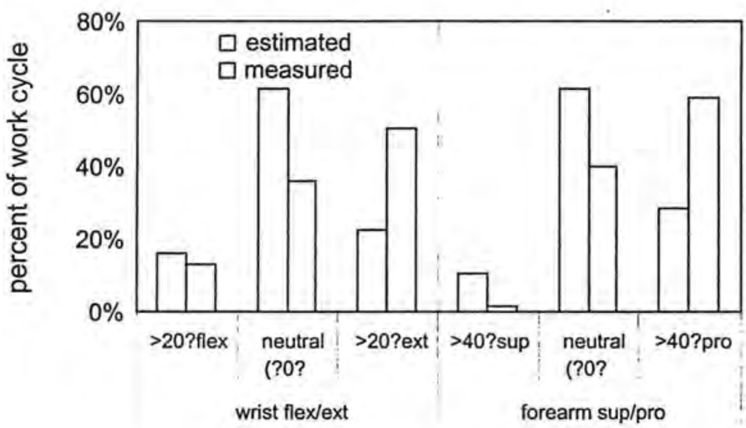


elbow flexion	shoulder elevation	plane of shoulder elev
$r^2 = 0.47^*$	$r^2 = 0.66^*$	$r^2 = 0.03$
$r^2 = 0.49^*$	$r^2 = 0.46^*$	$r^2 = 0.18^*$

● peak
□ average

temporal distribution of posture

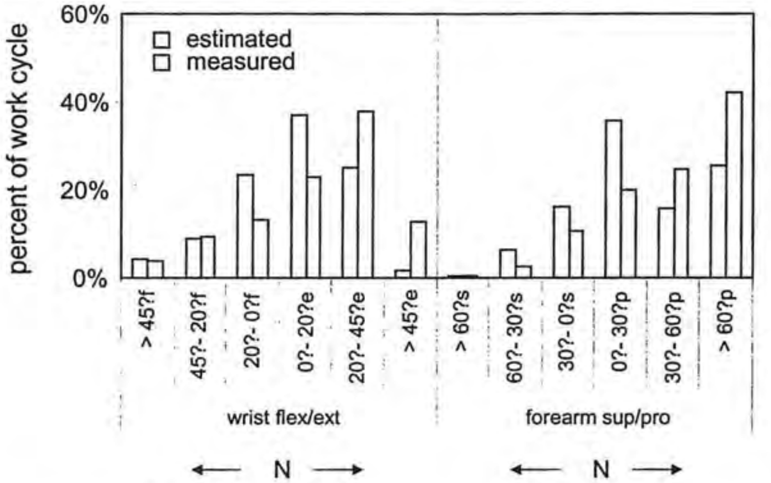
(wrist/forearm – 3 category)



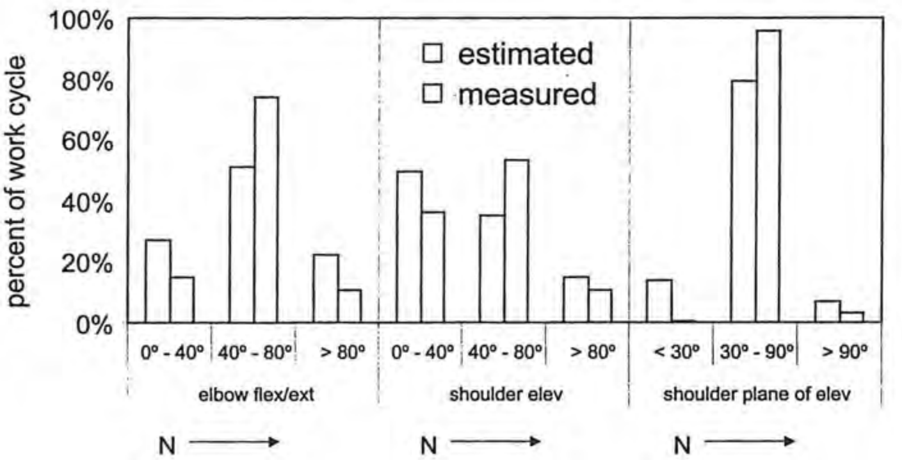
← N → ← N →

N = neutral posture

temporal distribution of posture
(wrist/forearm – 6 category)

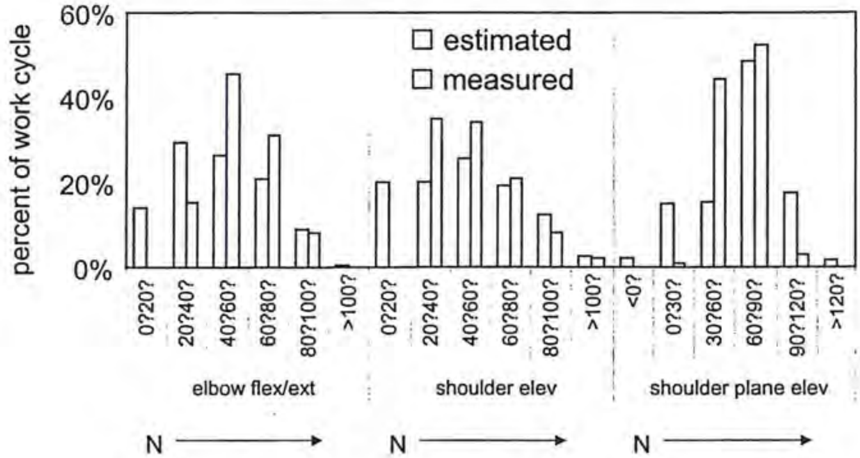


temporal distribution of posture
(elbow/shoulder – 3 category)



temporal distribution of posture

(elbow/shoulder – 6 category)

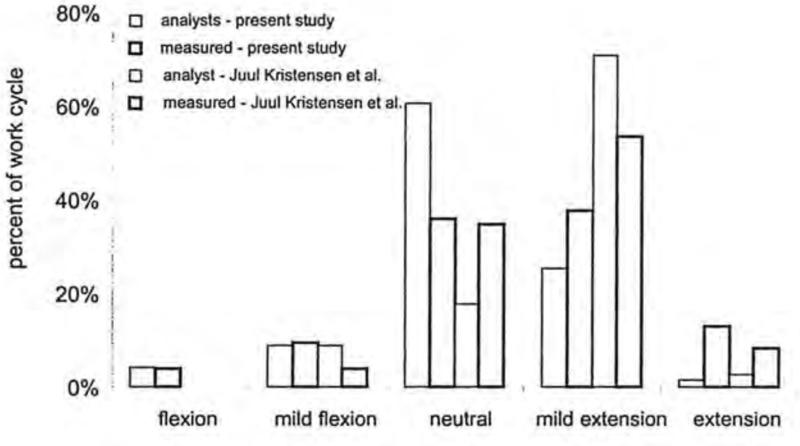


radial/ulnar deviation

- Inter-rater agreement statistics
- Intraclass correlation coefficient (ICC) among raters (ergonomists) slightly less than for flex/ext, sup/pro

	3-category	6-category
flex/ext	0.229	0.342
pro/sup	0.215	0.308
rad/uln	0.217	0.123

Juul-Kristensen *et al* (2001)



Discussion

- Performance does not necessarily reflect **best** case

  <u>Limitations of the Study</u>
  - Single video view
  - Simulated job tasks (laboratory study)
  - Analysts had no familiarity with jobs
  - Methods may not have been familiar to analysts
  - Little information regarding the strategy analysts used

- Intended to reflect performance in the **typical** case

summary of findings

- Posture classification accuracy related to the size of the joint/limb segments (Genaidy *et al*, 1993; Baluyut *et al*, 1995)
- Posture classification accuracy related to the number of scale categories
  - p(correct classification) = 73% for most frequent shoulder/elbow posture w/3 categories
  - p(correct classification) = 30% for most frequent wrist/forearm posture w/6 categories

summary of other findings

- Time to completion of the analyses was not related to the accuracy of the analyses
- No relationship between analysts' years experience and accuracy of observational estimates of risk factor exposure
- No relationship between work cycle variability and accuracy of observational estimates

validity considerations in job analysis

- Misclassification of working posture occurred in job analyses even when using a small number of posture categories
- Posture misclassifications with higher precision scale are more frequent, but their effect is less

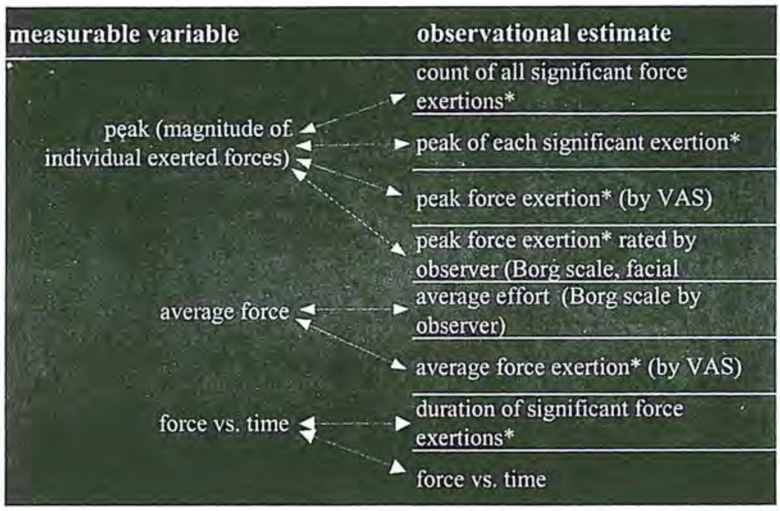
  ↑ number of categories
  ↑ precision
  ↑ probability of misclassification

- Duration severity of posture tended to be underestimated

Observational Assessment of Force

Method	Reference
count of all significant force exertions*	Stetson et al (1991)
duration of significant force exertions*	Stetson et al (1991)
peak of each significant exertion*	Seth et al. (1999)
average effort (Borg scale by observer)	OCRA Occhipinti (1998)
peak force exertion* rated by observer (Borg scale, facial expressions, etc.)	Strain Index - Moore and Garg (1995)
peak force exertion* (by VAS)	Latko (1997)
average force exertion* (by VAS)	Latko (1997)
force vs. time	ARBAN Holzmann (1982)

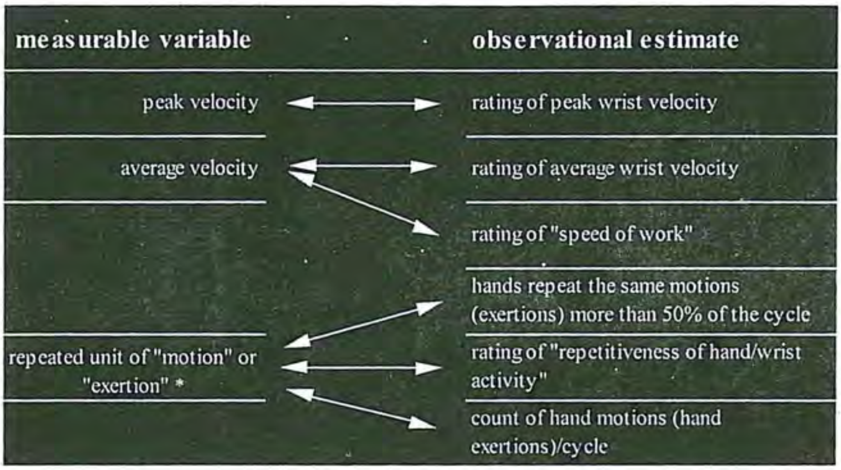
Force - Measurable Gold Standards



Observational Assessment of Repetition

Method	Reference
cycle time	Armstrong et al. (1982)
hands repeat the same motions*/ exertions more than 50% of the cycle (y/n)	Keyserling et al. (1993)
count of motions*/unit time	Stetson et al. (1991), Drury (1987), Seth et al. (1999)
count of exertions#/time	Stetson et al. (1991), Strain Index, Drury (1987)
VAS scale rating "repetitiveness of hand/wrist activity"	Latko (1997)
Peak movement speed of wrist (VAS)	Latko (1997)
Average movement speed of wrist (VAS)	Latko (1997)
speed of work (velocity)	Strain Index Moore and Garg (1995)

Repetition - Measurable Gold Standards



Conclusion

- Posture classification accuracy related to the size of the joint/limb segments (Genaidy *et al*, 1993; Baluyut *et al*, 1995)
- Misclassification of posture occurs even with few posture categories
- Posture misclassification with higher precision scale is more frequent, but the effect is less
- Posture exposure was more often *underestimated* than *overestimated*

Disclaimer

Mention of any company name or product, or inclusion of any reference, does not constitute endorsement by the National Institute for Occupational Safety and Health.

보건분야-교육자료
연구원 2003-42-362

OSHRI

직업성 근골격계질환의 인간공학적 위험성 평가

한국산업안전공단
산업안전보건연구원

한국산업안전공단
KOREA OCCUPATIONAL SAFETY & HEALTH AGENCY