Methods for biomechanical risk assessment within the context of occupational TLVs®

Italian Society of Occupational Medicine, Webinar

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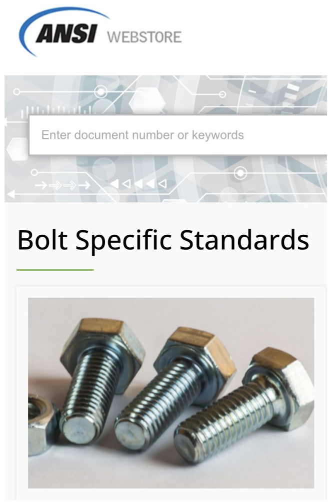
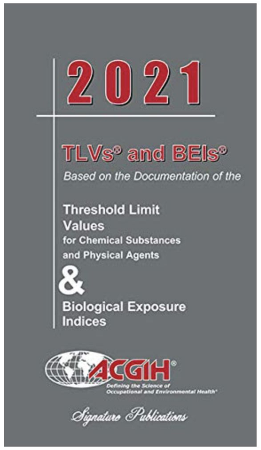
Recommendations, Standards, Regulations

1. Recommendations
   a. Individuals
   b. Groups
   c. Organizations
   d. Industry self regulation
   e. Professional/trade groups
2. Standards
   a. ANSI -- consensus
   b. ISO -- consensus
   c. ACGIH TLVs® -- best available science
3. Regulations -- subject to enforcement action
   a. OSHA (Federal & State) -- government
      i. Record keeping
      ii. General duty clause
   b. EU Directives -- government
   c. Workers' compensation -- Employer
   d. Product liability -- Manufacturers





OSHA (USA) -- regulatory

Injury or illness record keeping requirements

- Reportables:
  a. Any work-related injury or illness that results in loss of consciousness, days away from work, restricted work, or transfer to another job.
  b. Any work-related injury or illness requiring medical treatment beyond first aid.
- Proposal to require annual electronic reporting
- https://www.osha.gov/recordkeeping/

General Duty Clause (section 5a(1))

Each employer --

> shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees;

https://www.osha.gov/laws-regs/oshact/section5-duties

Published studies enabled OSHA to use record keeping to apply the general duty clause to address work-related musculoskeletal injuries in the absence of specific standards starting in 1978.

OSHA record keeping & general duty enforcement actions related to biomechanical loads

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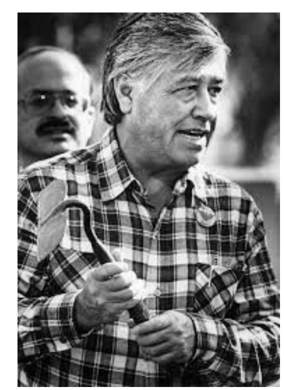
Date	Compliance Activity	OSHA Industry Guide/Standard
1978 1979	Eastman Kodak cited $4,300.00 ergonomic stresses. Samsonite cited $16,000..00 ergonomics violations.	
12-84 1-85	OSHA inspects plant at Institute, WV, records reviewed, no full inspection.	
4-85	John Morrell Co. records reviewed, no inspection.	
8-85	Institute plant experiences large toxic gas leak. OSHA inspects for 6 months, cites and fines $1.38 million, mostly for recordkeeping.	
1-86 6-86	OSHA responds to employee complaint at IBP. Review records, no inspection.	OSHA adds ergonomist Dr. R. Stephens to Office of Technical Support.
1-87 3-87	IBP inspected, fined $2.59 million for recordkeeping violations. Chrysler pays $295,000 settlement for recordkeeping.	
4-87 7-87	Morrell cited for 69 recordkeeping violations, fined $690,000. Ford Motor cited $476,000 for recordkeeping	Congressional testimony on exemptions, recordkeeping and ergonomics problems in meatpacking.
4-88	Morrell cited for ergonomic violations, fined $4.3 million.	
5-88	IBP cited for ergonomic violations, fined $3.1 million.	
11-88 12-88	OSHA settlement with IBP and UFCW, fines reduced to $970,000. Pepperidge Farm cited $1.4 million for ergonomics/records problems.	
10-89 11-89	OSHA cites U.S. Dept. of Agriculture for ergonomic violations.	NIOSH issues call for information on ergonomic hazards in the workplace. Recommendations to OSHA in 1992.
1-90 3-90	Pepperidge Farm cited $638,000 for recordkeeping and ergonomics hazards. Company contests.	OSHA indicates General Industry Ergonomics Guidelines may be available by July. OSHA begins ergonomics training for field offices.
7-90 12-90		OSHA- a general industry standard for ergonomics will be developed. Ergonomist Stephens- OSHA will assemble ergonomics advisory committee
7-91 9-91	OSHA cites U.S. Postal Service for ergonomics violations. Samsonite cited $1.6 million for ergonomics	
10-91	Testimony in Pepperidge Farm contest hearing for citations ends.	

Sources: BNA Occupational Safety and Health Reporter and other cited references.

Courtney TK, Smith GD, Armstrong TJ. Ergonomics and OHSA: A Chronological Review of Enforcement and Regulation Development. Advances in Industrial Ergonomics and Safety IV. Edited by S. Kumar. Taylor & Francis, 1992

Short handled hoes “el cortito”

- Short handle hoes were a cause of complaints and protest for 50 years
- Farmers argued that the short handle hoes were better than long handle hoes for digging. Also, they could see from a distance if workers were bent over working
- In a unanimous 1975 ruling, the California Supreme Court found that the tool was “unsafe” given that it “causes injury, immediate or cumulative, when used in the manner in which it was intended.”
- Once banned, farm workers’ back injuries decreased by 34%
- We weren’t listening to the users



César E. Chávez

OSHA (USA)

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1. **Ergonomics Program; Final Rule**
   (14 November 2000)
   - Extensive review of literature
   - Extensive public hearings and comments
   - 595 page document reviewing literature and detailing actions
   - https://www.federalregister.gov/documents/2000/11/14/00-28854/ergonomics-program

2. **Ergonomics Program Rule Removed**

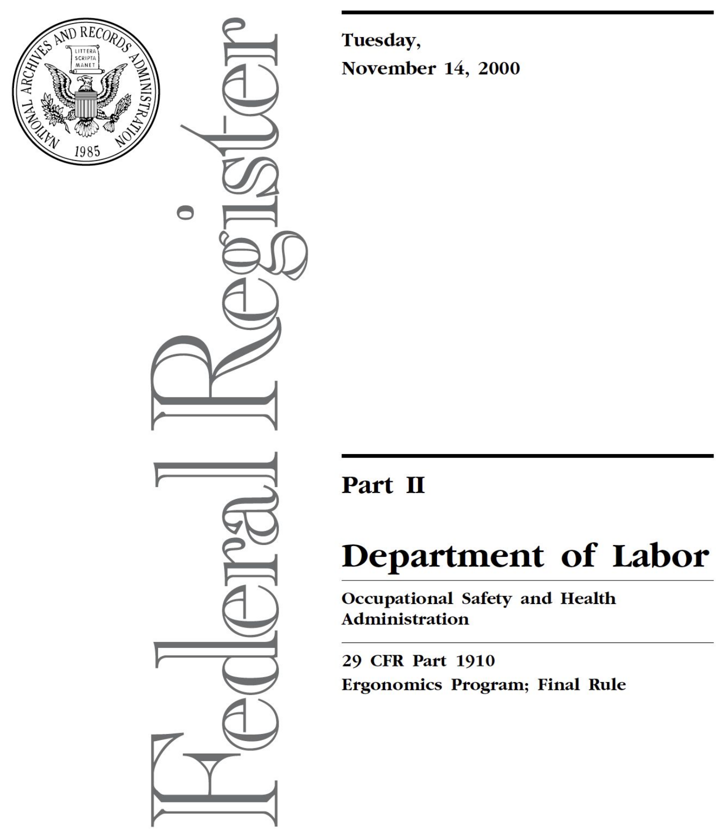
Under the Congressional Review Act, Congress has passed, and the President has signed, Public Law 107-5, a resolution of disapproval of OSHA's final Ergonomics Program Standard. OSHA published the ergonomics program standard on November 14, 2000 (65 FR 68262), and the standard became effective on January 16, 2001. Because Public Law 107-5 invalidates the standard, OSHA is hereby removing it from the Code of Federal Regulations.

DATES: This action is effective April 23, 200

https://www.osha.gov/laws-regs/federalregister/2001-04-23

People have a very high scientific standard for things they don't want to hear

3. **Continued use of record keeping and general duty**
4. **Don't overreach!**


Federal Register

Tuesday,
November 14, 2000

Part II

Department of Labor

Occupational Safety and Health Administration

29 CFR Part 1910
Ergonomics Program; Final Rule

Science is important, but not always sufficient

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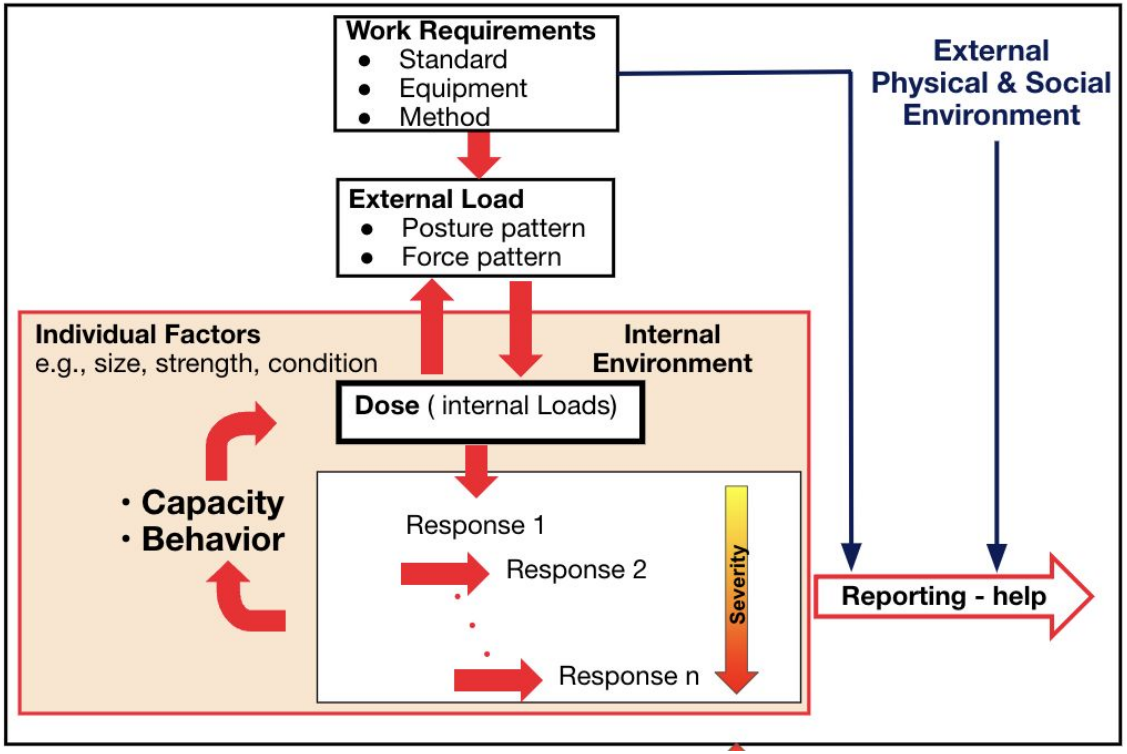
We aren't lacking for science:

Some key references for further reading:

- Armstrong TJ, Buckle P, Fine LJ, Hagberg M, Jonsson B, Kilbom A, Kuorinka IA, Silverstein BA, Sjogaard G, Viikari-Juntura ER. A conceptual model for work-related neck and upper-limb musculoskeletal disorders. Scandinavian journal of work, environment & health. 1993 Apr 1:73-84.
- National Research Council 1998. Work-Related Musculoskeletal Disorders: A Review of the Evidence. Washington, DC: The National Academies Press. https://doi.org/10.17226/6309.
- National Research Council and the Institute of Medicine (2001) Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities. Panel on Musculoskeletal Disorders and the Workplace. Commission on Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.National Academies of Sciences, Engineering, and Medicine. 2001. Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities. Washington, DC: The National Academies Press. https://doi.org/10.17226/10032.
- Armstrong TJ, Burdorf A, Descatha A, Farioli A, Graf M, Horie S, Marras WS, Potvin JR, Rempel D, Spatari G, Takala EP. Scientific basis of ISO standards on biomechanical risk factors. Scandinavian journal of work, environment & health. 2018 Jan 1;44(3):323-9.
- David, G. C. (2005). Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. *Occupational medicine*, *55*(3), 190-199.

Models are necessary to explain and apply both field and laboratory studies



Adapted from: Armstrong TJ, Buckle P, Fine LJ, Hagberg M, Jonsson B, Kilbom A, Kuorinka IA, Silverstein BA, Sjogaard G, Viikari-Juntura ER. A conceptual model for work-related neck and upper-limb musculoskeletal disorders. Scandinavian journal of work, environment & health. 1993 Apr 1:73-84.

NRC (1998) Another Model

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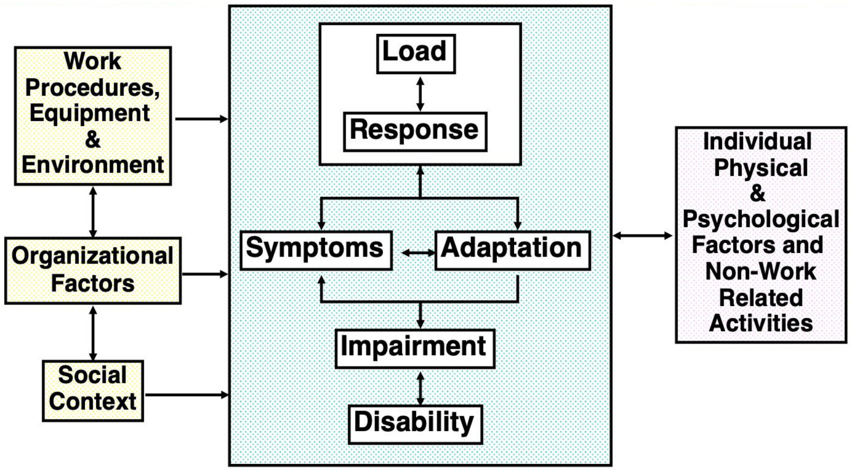

"to make sense of such a multifaceted body of research" the committee extended its analysis beyond the traditional criteria used in epidemiological studies:

1. soft tissue responses to physical stressors, covers material that corresponds to the load and responses
2. the biomechanics of the load-response relationship and examines the contributions of work procedures
3. equipment, and environment to this relationship
4. epidemiological evidence relating biomechanical factors at work to musculoskeletal disorders
5. the state of the evidence regarding the contributions of the non biomechanical factors -- organizational, social, and individual.
6. workplace interventions; this section covers material relevant to all factors

Conclusion: "The risk of musculoskeletal disorders depends on the interaction of person and task, as does the effectiveness of options for reducing those risks. A full specification would require much more detailed treatment of person-task combinations than is possible here. We have, instead, focused on the scientific principles that should guide the prediction and prevention of problems."

National Research Council 1998. Work-Related Musculoskeletal Disorders: A Review of the Evidence. Washington, DC: The National Academies Press. https://doi.org/10.17226/6309.

Risk Factors -- Primary & Secondary

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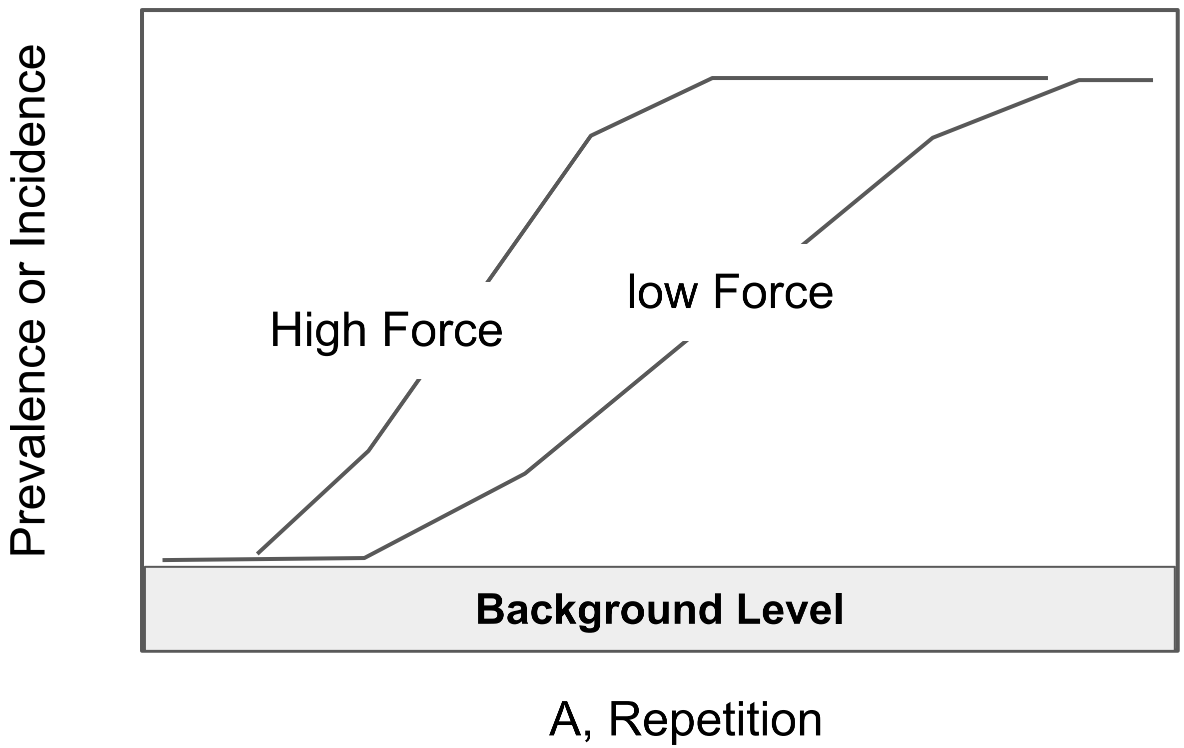
Occupational (direct & indirect)

1. Repetition
2. Force
3. Contact Stress
4. Posture
5. Low temperature
6. Vibration

Personal

1. Rheumatoid arthritis
2. Endocrinological disorders, e.g., diabetes
3. Acute trauma, e.g., bruises, burns, lacerations
4. Nutrition (e.g., Vitamin B-6 deficiency)
5. Wrist size and shape
6. Obesity
7. Gender
8. Pregnancy
9. Oral contraceptives
10. Gynecological surgery, e.g., oophorectomy, hysterectomy

Dose-response relationship between mechanical factors and MSDs



Work Activity v. Biomechanical Loads

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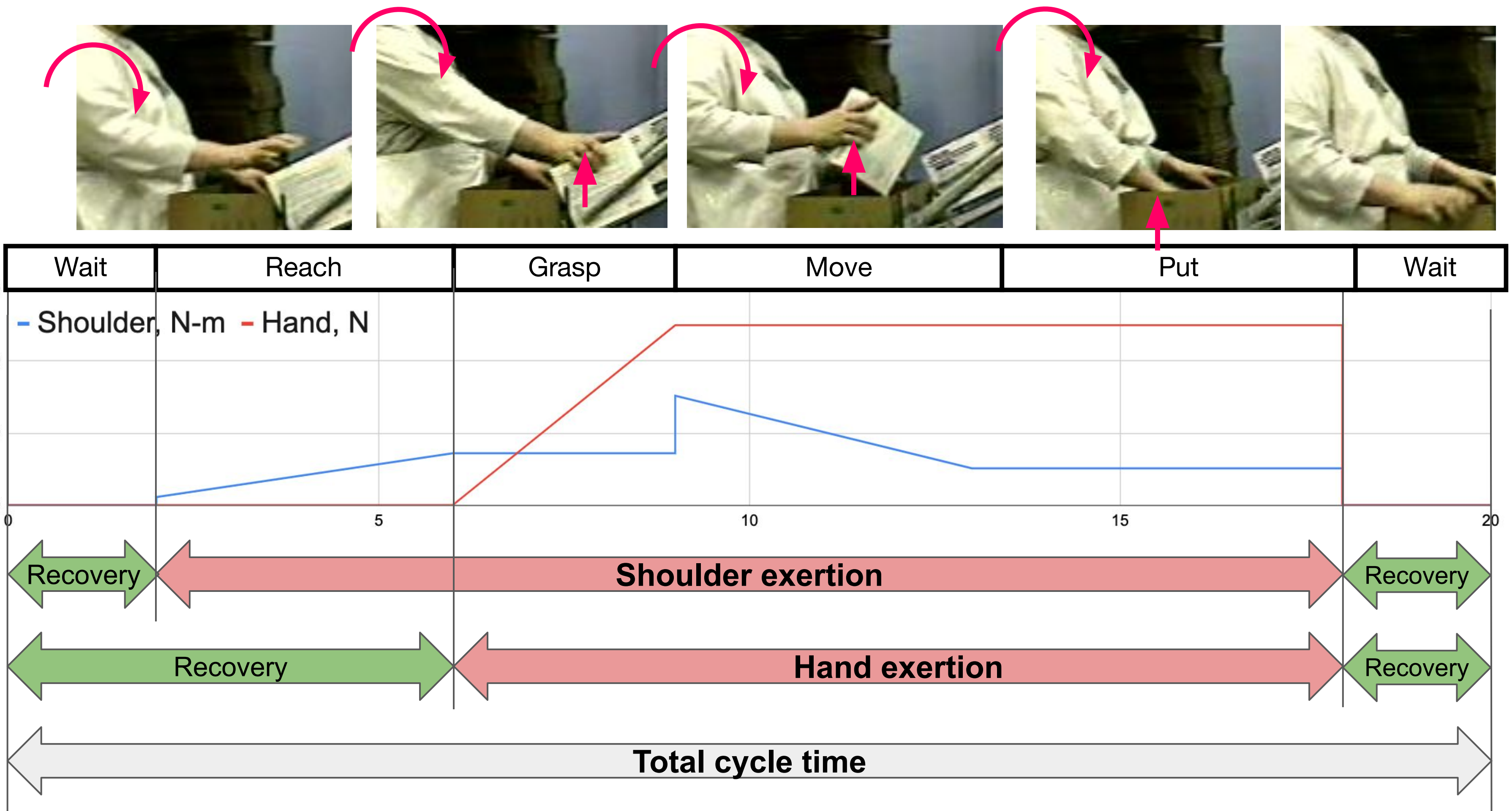

Shoulder Workload:	33%MVC max;	Hand Workload:	31%MVC max
	11% avg		27% Avg
	16 time units (89%)		12 time units (67%)
Rest:	2 time units (11%)	Rest:	6 time units (33%)
Cycle time:	18 time units	Cycle time:	18 time units

Source of Biomechanical Loads

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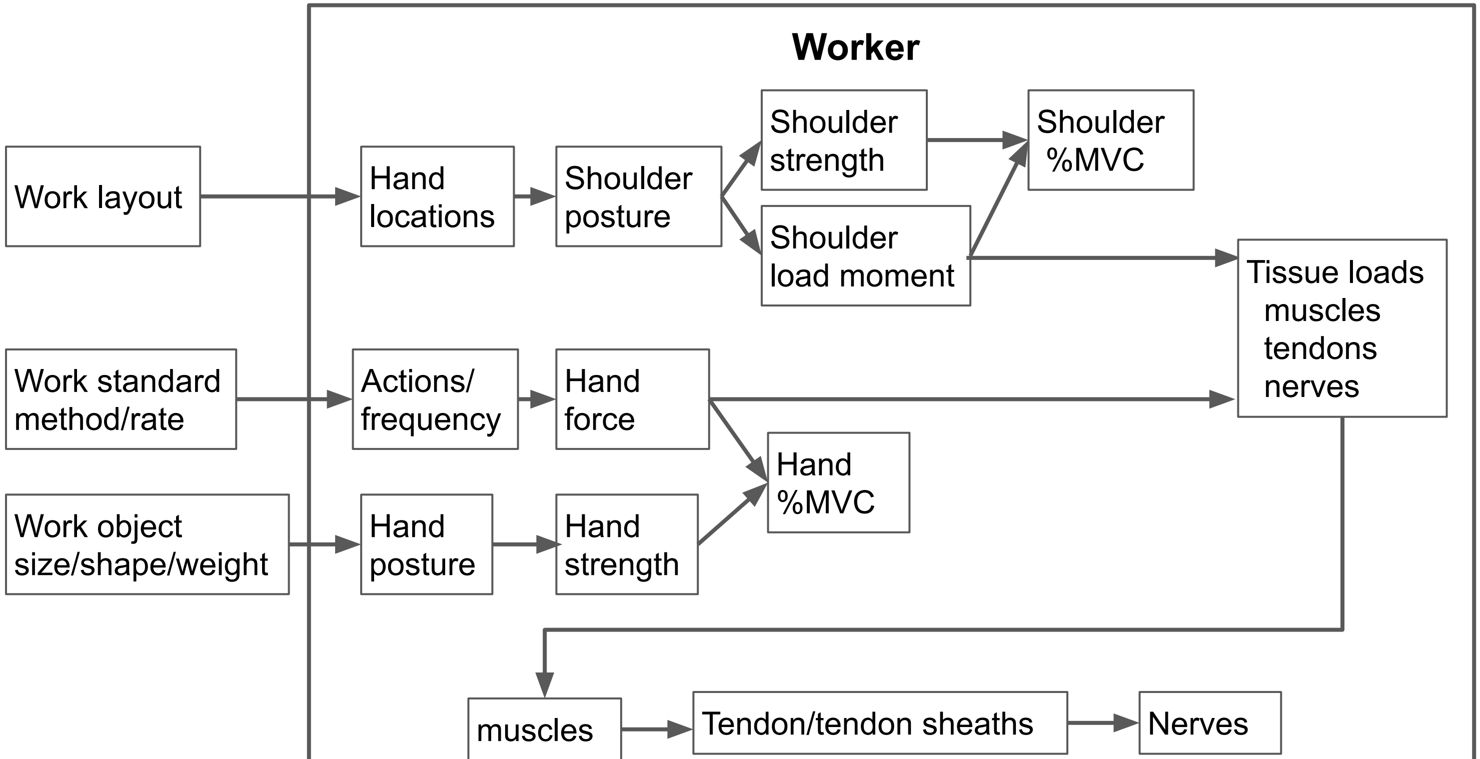

Biomechanical responses
-- tissue deformation, damage
Physiological responses
-- metabolic demand, recovery, tissue repair, adaptation

Occupational exposure limits

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1. ACGIH HAL TLV® ACGIH (2022)
2. ACGIH Localized Fatigue TLV® (2022)
3. EMG probability distribution -- Fatigue (Jonsson 1988)
4. OCRA (Occhipinti, Colombini 1996).
5. OWAS (Karhu, Kansi et al. 1977; Karhu, Harkonen et al. 1981)
6. Portable Posture Exposure, PEO (Fransson-Hall & Gloria 1995)
7. RULA (McAtamney & Corlett 1993)
8. REBA (Hignett and McAtamney 2000)
9. Strain Index (Moore & Garg 1995)
10. UAW-GM RFC Checklist (Keyserling et al. 1993)
11. Washington State Checklist (Washington State 2000)
12. Wrist velocity/ acceleration (Marras and Schonmarklin 1993)

Which one is best? It depends.

Biomechanical load indices

	Body parts	Repetition	Duty Cycle (% Recovery)	Dynamics	Work Duration	Force	Posture	Contact stress	Low Temp	Vibration
ACGIH HAL TLV® ACGIH (2022)	Hand, wrist, forearm	Observe & rate (0-10) or calc freq & duty cycle	0-100%	Speed considered in rating	>4hrs	Score 0-10; rate, biomech calcs, psychophysics, instrumentation	Professional judgment	Professional judgment	Professional judgment	Professional judgment
ACGIH Fatigue TLV® ACGIH (2022)	Hand, elbow, shoulder		Duty cycle calculated from force patter			Score %MVC; rate, biomech calcs, psychophysics, instrumentation				
EMG probability distribution (Jonsson 1988)	Any muscle group	No	Amplitude probability distribution	No	No	RMS EMG normalized 0-100%	No	No	No	No
OCRA (Occhipinti 1998)	Upper limb	30 actions/min ✕ force, posture & other factors				Yes	Yes			
OWAS (Karhu, Kansi et al. 1977; Karhu, Harkonen et al. 1981)	Shoulders, neck, back, lower limb	No	% time in various posture categories	No	No	Yes	% time in various posture groups	No	No	No
RULA (McAtamney & Corlett 1993)	Upper limb & torso	Static >1 min or Repeated >4/min	No	Static/ dynamic	No	Loads <2kg, 2-10Kg (intermittent or static/repeated), >10Kg	Wrist, lower arm, upper arm, neck, trunk categories	No	No	No
REBA (Hignett and McAtamney 2000)	Whole body	Activity score increased if static >1 minute, repeated >4 times/min or very large moves	No	No	No	Load/Force <5Kg, 5-10Kg, >10Kg, shock	Wrist, lower arm, upper arm, neck, trunk, leg variable cats.	No	No	No

Adapted from: David, G. C. (2005). Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. *Occupational medicine*, *55*(3), 190-199.

Biomechanical load indices (cont)

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	Body parts	**Repetition**	**Duty Cycle (% Recovery)**	**Dynamics**	**Work Duration**	**Force**	**Posture**	**Contact stress**	**Low Temp**	**Vibration**
Strain Index, (Moore & Garg 1995)	Hand, wrist, forearm	<4; 4-8; 9-14; 15-20; >=20 efforts/min	<10, 10-29, 30-49, 50-79, >80%	Very slow; Slow, Fair, Fast, Very fast	<1; 1-2; 2-4 4-8; ≥8 hr/day	Light; Somewhat hard; Hard; Very hard; Near maximal	Hand/wrist 5 categories	No	No	No
UAW-GM RFC (Keyserling et al. 1993)	Upper limb & back	RFC I: Low >30s; Hi <30s RFCII: Low, Medium High (Latko 1997)	Included in repetition	Included in repetition	No	Selected factors yes/no	Wrist, elbow, shoulder 3 categories	Selected factors yes/no	Selected factors yes/no	Yes; 3 categories
Washington State Checklist (Washington State 2000)	Upper limb & back	Repeating the same motion … >2hr/da Intensive keying >4hr/da				Pinching an unsupported object >2 pounds >2hr/da; Gripping an unsupported object >10 pounds > 2hr/da	Working with hands over head, neck or back bent>30°, Squatting or Kneeling >2hr/da			Using impact wrenches, carpet strippers, chain saws percussive tools> 30min/da Using grinders, sanders, jig saws, etc. >2hr/da
Wrist velocity/ acceleration (Marras & Schonmarklin 1993)	Wrist	Angular velocity, angular acceleration	Posture frequency distribution	Velocity & acceleratio n	No	No	Wrist flexion/extension , Radial/ulnar dev			
Computer vision tools (Rawin et al. 2016)	Various body parts	Angular velocity, angular acceleration	indirectly	yes	yes	t.b.d.	yes	indirectly		indirectly

Adapted from: David, G. C. (2005). Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. *Occupational medicine*, *55*(3), 190-199.

Transcriptionist

Exposure (Dose)-Response Studies

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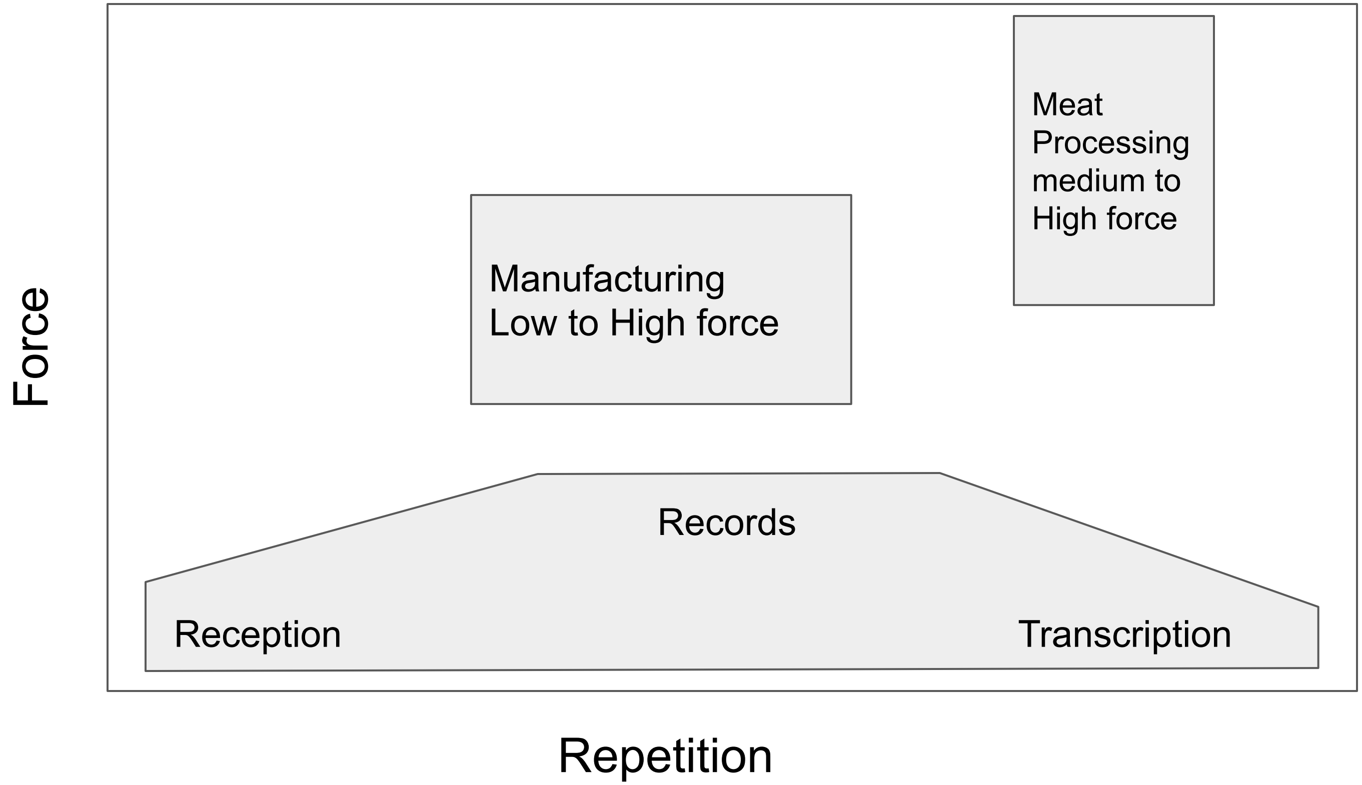
The range of exposures in a given industry affects the statistical power of the study -- Δ/s



Which is best?

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1. The indices have more in common than differences, e.g., Repetition, Force, Posture, etc.

2. Some differences
   a. **Data** used to develop and evaluate indices

   b. **Repetition**
      i. ACGIH: HAL (exertion frequency & duty cycle)
      ii. Strain Index: (exertion frequency, duty cycle, speed)
      iii. OCRA: exertions per minute
      iv. RULA: static or dynamic etc.

   c. **Force**
      i. ACGIH, Strain index, OCRA scores are normalized 0-10 or 0-100%
      ii. RULA: Absolute force in Kg
      iii. Josson (

   d. **Posture**
      i. ACGIH: Posture included to the extent it affects force and expert judgement
      ii. Strain index: integrates posture scores
      iii. RULA, Strain index, OCRA: posture scored on basis of joint angles

   e. **Combining & interpreting factors**
      i. ACGIH: equation/graph for determining acceptable Force or HAL score
      ii. Strain index and OCRA: factor scores are multiplied to get final score
      iii. RULA: factor scores are added and compared with

3. **David (2005) Review of various ergonomic assessment tools.**

"The more general, observation based assessments appear to be best matched to the needs of occupational safety and health practitioners (or those from related professions) who have limited time and resources at their disposal and need a basis for establishing priorities for intervention. Even so, this user group would benefit from the development of a decision aid that would allow them to make an informed choice about which techniques are most suited to which practical situations they are called upon to assess."

Advanced and direct assessment tools useful for detailed analysis in conjunction with further investigation of biomechanical loads and design of interventions

David, G. C. (2005). Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. *Occupational medicine*, *55*(3), 190-199.

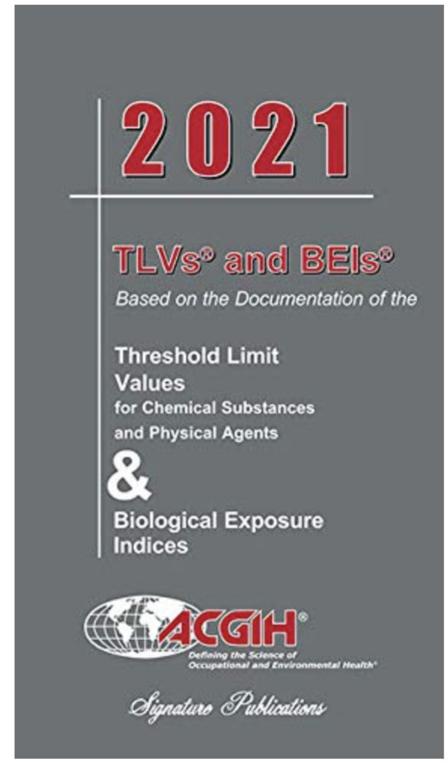
Occupational TLVs®

ACGIH Statement on Work-related Musculoskeletal disorders, circa 1998

ACGIH TLV® for Hand Activity Level, HAL (hand, wrist, and forearm) 2001

ACGIH TLV® for Manual Materials Handling (back) 2003

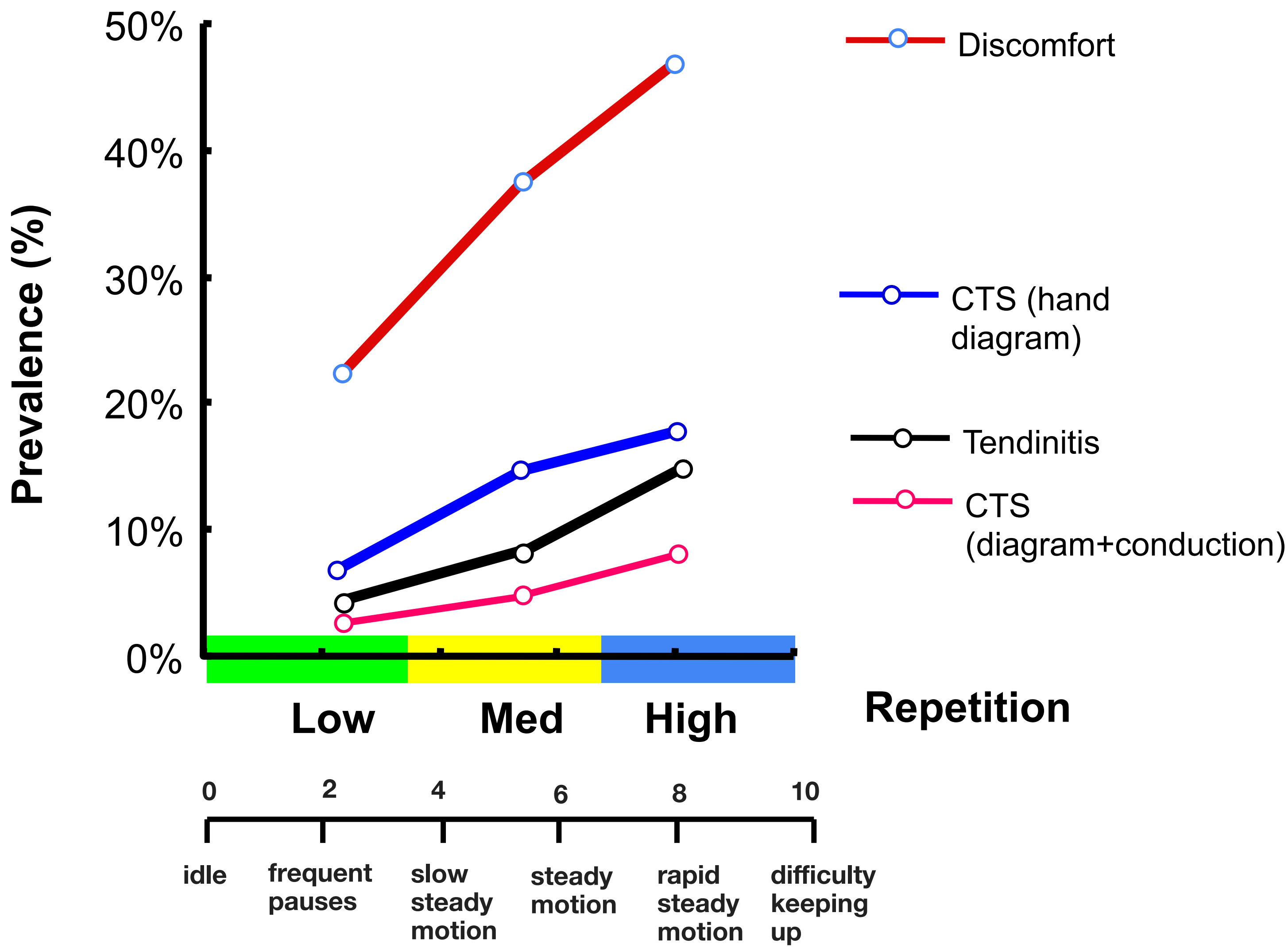
ACGIH TLV® for Localized Fatigue (hand, elbow, & shoulder) 2018



ACGIH TLV® for Hand Activity Level, HAL

- Hand, wrist & forearm
- 4 or more hours per day
- Mono task job involves repeating similar motions or exertions
- Hand Activity Level, HAL (Repetition)
- Peak finger force (90^{th} percentile)
- Defers other factors to professional judgment

Epidemiological data providing basis for dose-response relationship between mechanical factors and MSDs



Latko W, Armstrong T, Franzblau A, Ulin S, Werner R, Albers J. A cross-sectional study of the relationship between repetitive work and the prevalence of upper limb musculoskeletal disorders. Am J. Ind. Med. (1999) Aug;36(2):248-59.

ACGIH TLV® for Hand Activity Level

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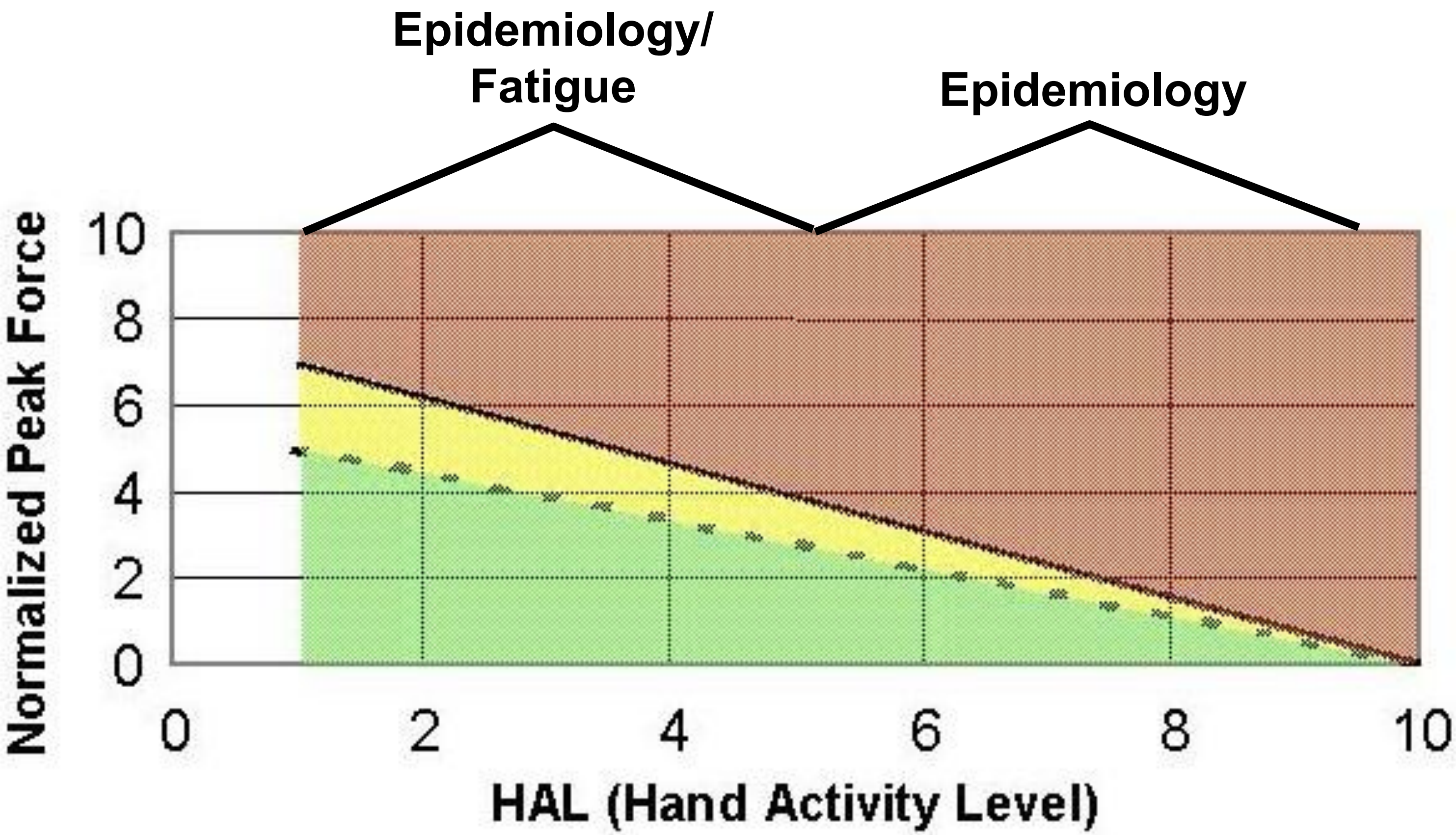

Action Limit -- Training, health and risk factor surveillance

TLV® -- Training, health and risk factor surveillance, appropriate engineering controls, medical management

HAL & Peak Force Ratings -- Quick Assessments

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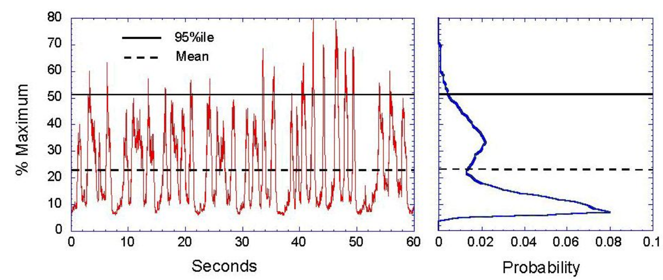
0	2	4	6	8	10
Hands idle most of the time; no regular exertions	consistent, conspicuous long pauses; or very slow motions	slow steady motion/ exertion; frequent brief pauses	steady motion/ exertion; infrequent pauses	rapid steady motion/ exertion; infrequent pauses	rapid steady motion or continuous exertion, difficulty keeping up

0	2	4	6	8	10
None					Greatest Imaginable

[90th %tile]

- highest force occurring during each cycle or task

- disregard random elements



Calculating HAL from exertion frequency and duty Cycle

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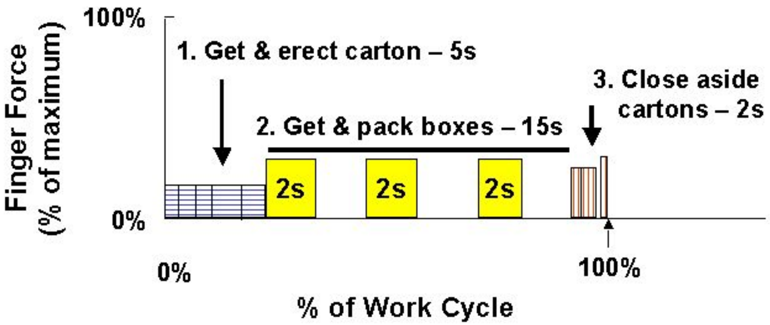

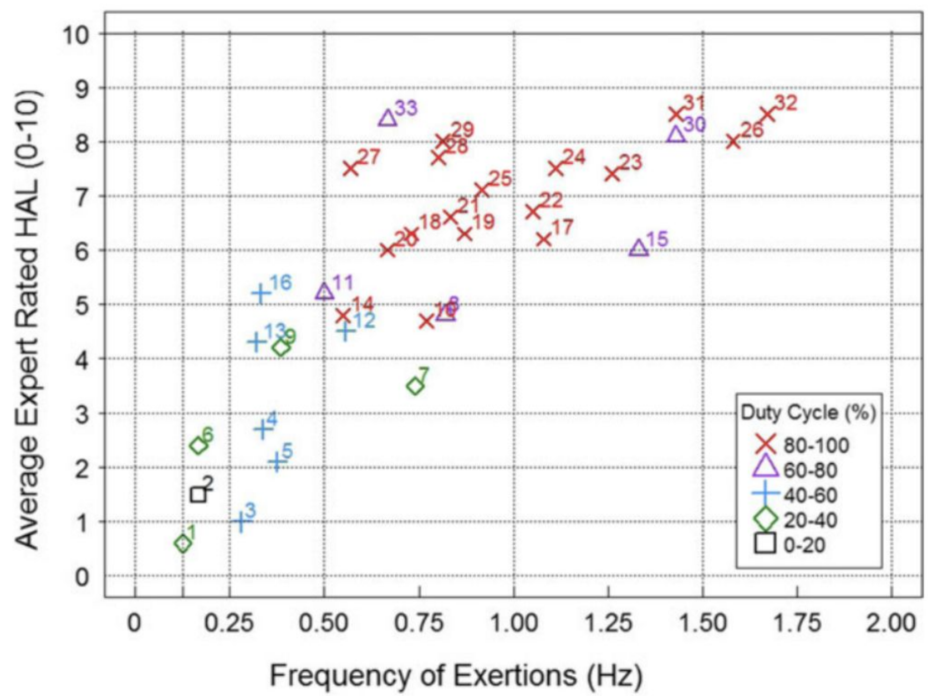

Freq = 10 exertions / 22s = 0.45 ex/sec
Duty cycle = (5s+2s+2s+2s+2s)/22s = 60%
HAL = 4.4

These factors may vary over time from one worker to another.

$$\mathrm{HAL} = 6.56 \ln D \left[\frac{F^{1.31}}{1 + 3.18 F^{1.31}} \right]$$

Latko WA, Armstrong TJ, Foulke JA, Herrin GD, Rabourn RA, Ulin SS. Development and evaluation of an observational method for assessing repetition in hand tasks. American Industrial Hygiene Association Journal. 1997 Apr 1;58(4):278-85.

Radwin RG, Azari DP, Lindstrom MJ, Ulin SS, Armstrong TJ, Rempel D. A frequency–duty cycle equation for the ACGIH hand activity level. Ergonomics. 2015 Feb 1;58(2):173-83.

TLVs® reviewed annually & adjusted based on new data

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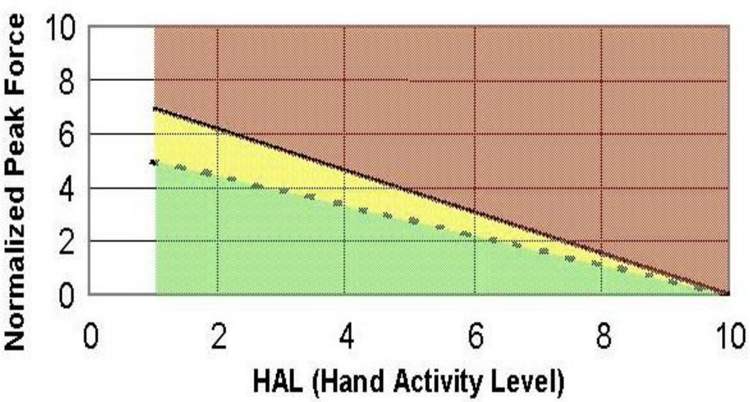
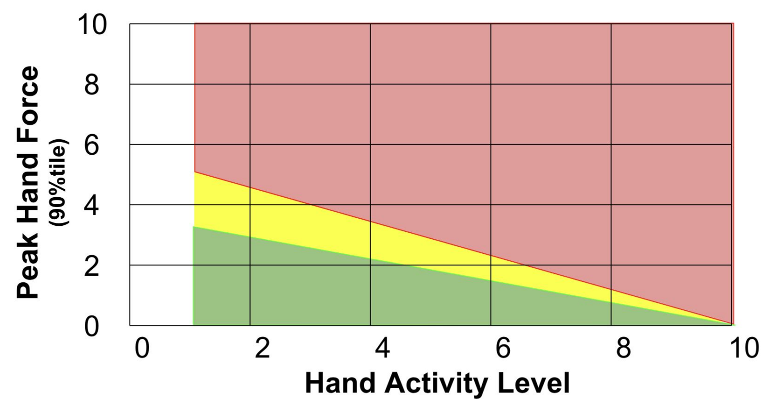
The original HAL TLV was revised as new epidemiological data became available

Bonfiglioli, R., Mattioli, S., Armstrong, T. J., Graziosi, F., Marinelli, F., Farioli, A., & Violante, F. S. (2013). Validation of the ACGIH TLV for hand activity level in the OCTOPUS cohort: a two-year longitudinal study of carpal tunnel syndrome. *Scandinavian journal of work, environment & health*, 155-163.

Kapellusch, J. M., Gerr, F. E., Malloy, E. J., Garg, A., Harris-Adamson, C., Bao, S. S., ... & Rempel, D. M. (2014). Exposure–response relationships for the ACGIH threshold limit value for hand-activity level: results from a pooled data study of carpal tunnel syndrome. *Scandinavian journal of work, environment & health*, *40*(6), 610.

Harris-Adamson, C., Eisen, E. A., Kapellusch, J., Garg, A., Hegmann, K. T., Thiese, M. S., ... & Rempel, D. (2015). Biomechanical risk factors for carpal tunnel syndrome: a pooled study of 2474 workers. *Occupational and environmental medicine*, *72*(1), 33-41.





Fatigue

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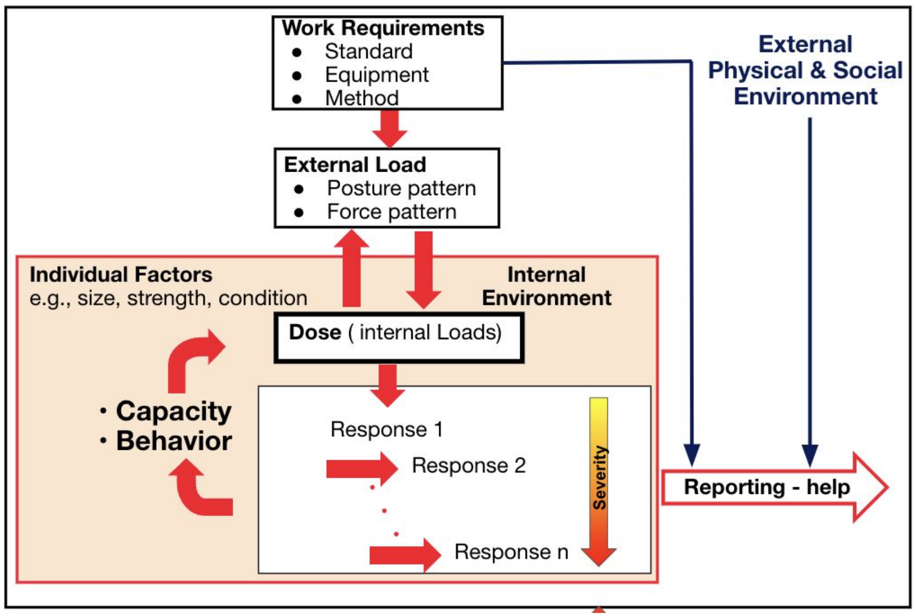
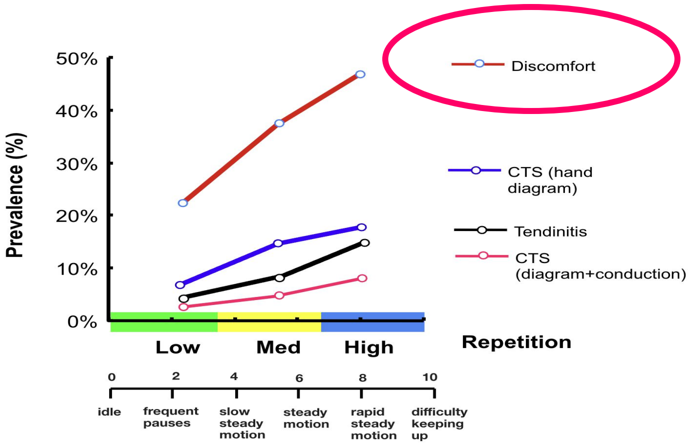
http://www-personal.umich.edu/~tja//fatigue/localizedFatigue.html
http://www-personal.umich.edu/~tja/strength/strnDemands.html#main

Discomfort associate with objective MSD symptoms

- Many common physiological, mechanical, and psychological factors in fatigue and chronic musculoskeletal injuries
- Discomfort is a common result of both fatigue and musculoskeletal injuries
- The time in which fatigue develops and recovers distinguished fatigue from musculoskeletal injuries
- Evidences suggest: prevent fatigue -- prevent chronic musculoskeletal injuries





Muscle Fatigue Literature

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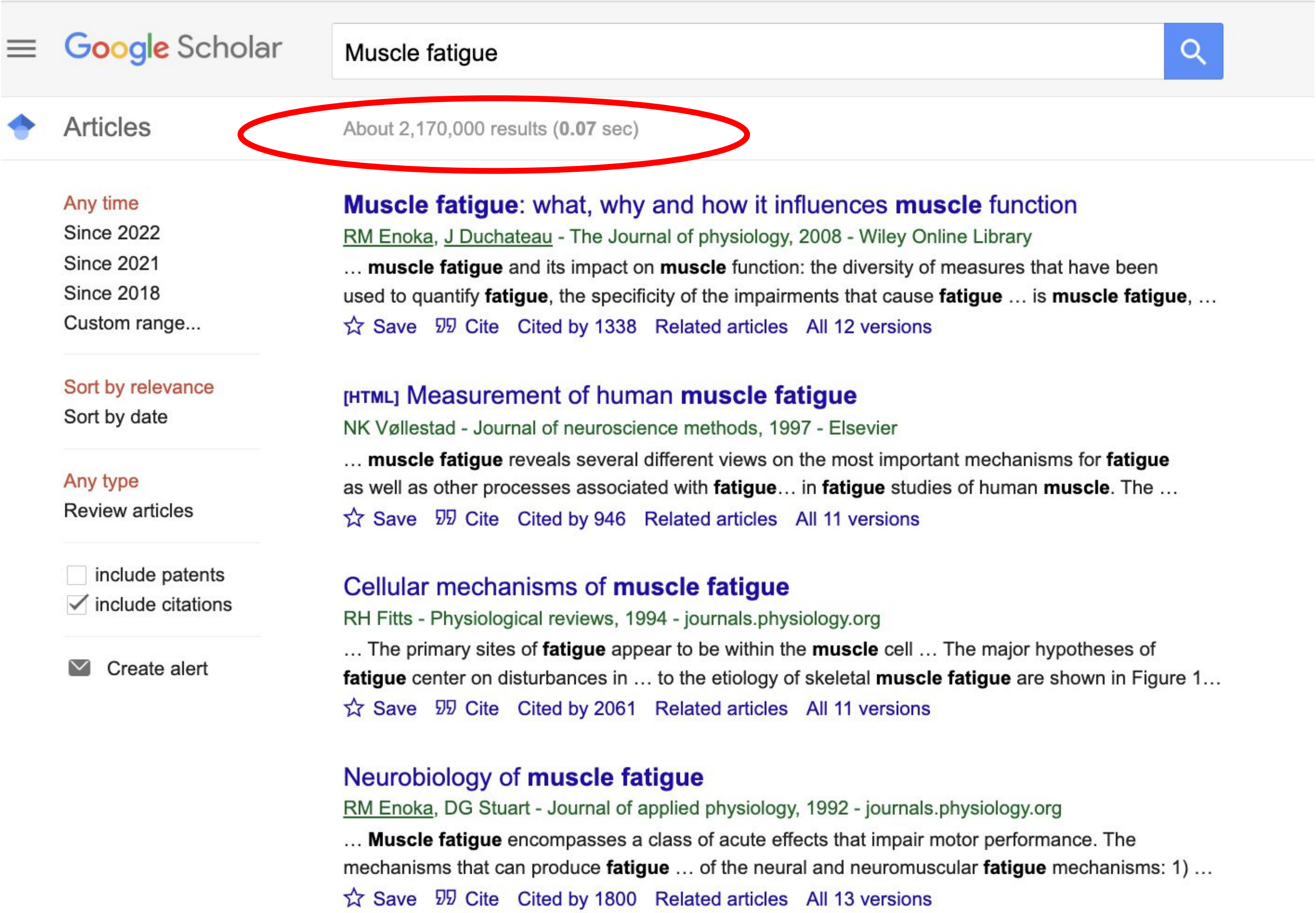
2,170,000 references -- to the nearest 10,000



In the beginning …

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Thus the heavens and the earth were finished, and all the host of them. And on the seventh day God ended his work which he had made; and he rested on the seventh day from all his work which he had made. And God blessed the seventh day, and sanctified it: because that in it he had rested from all his work which God created and made.

-- Genesis 22

That is a rest allowance of 14% or 8.5 minutes of every hour.

Would stakeholders accept this datum?

Taylor Shovel Studies

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For a first-class shoveler there is a given shovel load at which he will do his biggest day's work. What is this shovel load? Will a first-class man do more work per day with a shovel load of 5 pounds, 10 pounds, 15 pounds, 20, 25, 30, or 40 pounds? Now this is a question which can be answered only through carefully made experiments. By first selecting two or three first-class shovelers, and paying them extra wages for doing trustworthy work, and then gradually varying the shovel load and having all the conditions accompanying the work carefully observed for several weeks by men who were used to experimenting, **it was found that a first-class man would do his biggest day's work with a shovel load of about 21 pounds**.

THE PRINCIPLES OF SCIENTIFIC MANAGEMENT By Frederick Winslow Taylor, M.E., Sc.D. 1911

Maximum acceptable weight of lift studies

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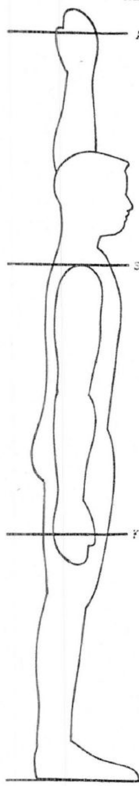
Snook, S. H., and C. H. Irvine. "Maximum acceptable weight of lift." _American Industrial Hygiene Association Journal_ 28, no. 4 (1967): 322-329.

TABLE II: LIFTING EVALUATION TABLE (LIFTS/MINUTE)
(20 inch lift; 90% group work capacity;
moderate environment; males 20-50 years)



ARM REACH — Average 82.5"

	10#	15#	20#	25#	30#	35#	40#	45#	50#
10%	0.78	0.72	0.65	0.58	0.52	0.45	0.39	0.33	0.27
20%	1.57	1.43	1.30	1.17	1.03	0.90	0.78	0.66	0.53
30%	2.35	2.15	1.95	1.75	1.55	1.35	1.17	0.98	0.80
40%	3.13	2.87	2.60	2.33	2.07	1.80	1.56	1.31	1.07
50%	3.92	3.59	3.25	2.92	2.59	2.25	1.95	1.64	1.34
60%	4.70	4.30	3.90	3.50	3.10	2.70	2.33	1.97	1.60
70%	5.48	5.02	4.55	4.08	3.62	3.15	2.72	2.30	1.87
80%	6.26	5.74	5.20	4.66	4.14	3.60	3.11	2.62	2.14
90%	7.05	6.45	5.85	5.25	4.65	4.05	3.50	2.95	2.40
100%	7.83	7.17	6.50	5.83	5.17	4.50	3.89	3.28	2.67

SHOULDER HEIGHT — Average 55.9"

	10#	15#	20#	25#	30#	35#	40#	45#	50#
10%	1.13	1.02	0.90	0.78	0.67	0.55	0.49	0.43	0.38
20%	2.27	2.03	1.80	1.57	1.33	1.10	0.98	0.87	0.75
30%	3.40	3.05	2.70	2.35	2.00	1.65	1.48	1.30	1.13
40%	4.53	4.07	3.60	3.13	2.67	2.20	1.97	1.73	1.50
50%	5.67	5.09	4.50	3.92	3.34	2.75	2.46	2.17	1.88
60%	6.80	6.10	5.40	4.70	4.00	3.30	2.95	2.60	2.25
70%	7.93	7.12	6.30	5.48	4.67	3.85	3.44	3.03	2.63
80%	9.06	8.14	7.20	6.26	5.34	4.40	3.94	3.46	3.00
90%	10.20	9.15	8.10	7.05	6.00	4.95	4.43	3.90	3.38
100%	11.33	10.17	9.00	7.83	6.67	5.50	4.92	4.33	3.75

KNUCKLE HEIGHT — Average 30.0"

	up to 50#	55#	60#	65#	70#	75#	80#	85#
10%	0.25	0.23	0.22	0.20	0.18	0.17	0.15	0.13
20%	0.50	0.47	0.43	0.40	0.37	0.33	0.30	0.27
30%	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40
40%	1.00	0.93	0.87	0.80	0.73	0.67	0.60	0.53
50%	1.25	1.17	1.09	1.00	0.92	0.84	0.75	0.67
60%	1.50	1.40	1.30	1.20	1.10	1.00	0.90	0.80
70%	1.75	1.63	1.52	1.40	1.28	1.17	1.05	0.93
80%	2.00	1.86	1.74	1.60	1.46	1.34	1.20	1.06
90%	2.25	2.10	1.95	1.80	1.65	1.50	1.35	1.20
100%	2.50	2.33	2.17	2.00	1.83	1.67	1.50	1.33

FIGURE 4. Lifting evaluation chart for calculation of maximum number of lifts per minute. (Based on 20-inch lift; 90% group work capacity; moderate environment; males 20-50 years.) Average heights are in inches; # = lb.

What is Fatigue?

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It's complicated!

As far back as 1921 Muscio (1921) argued that the current interpretation of fatigue was too general in meaning for scientific use and should be abandoned.

B. Musico, "Is a Fatigue Test Possible?" British Journal of Psychology, XII (June, 1921), Part I, pp. 31-46.
Gomberg, W. (1947). Measuring the fatigue factor. *ILR Review*, *1*(1), 80-93.

In 1943 Bills suggested that fatigue should be divided into three categories:

1. Subjective fatigue; diminished alertness, mental concentration, motivation
2. Objective fatigue: diminished work output
3. Physiological fatigue:

Gomberg, W. (1947). Measuring the fatigue factor. *ILR Review*, *1*(1), 80-93.
De Luca, CJ, Basmajian, JV. Muscles alive: their functions revealed by electromyography. Wiliams & Wilkins: Philadelphia, PA, USA, 1985

What distinguishes fatigue from other musculoskeletal disorders?

Rohmert (1960) Fatigue Curves

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ROHMERT,W.(1960)ErmittlungvonErholungspausenfurstatischeArbeitdesMenschen.InternationaleZeitschriftfurangewandtePhvsiologie,18,123.

Edwards, R. H. T. (1975). Muscle fatigue. *Postgraduate Medical Journal*, *51*(593), 137-143.

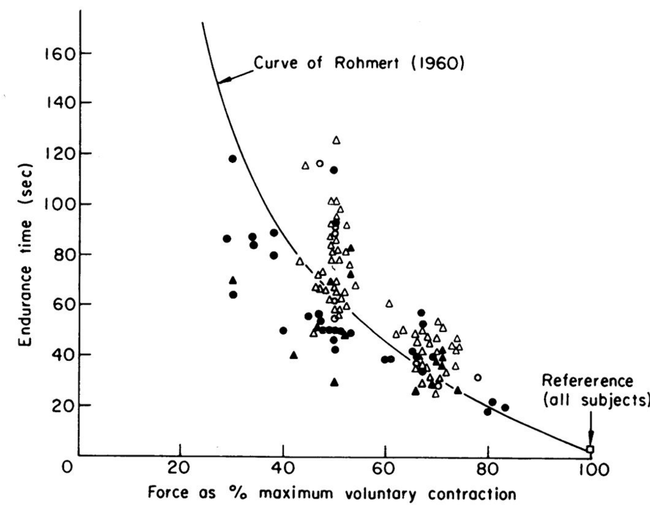
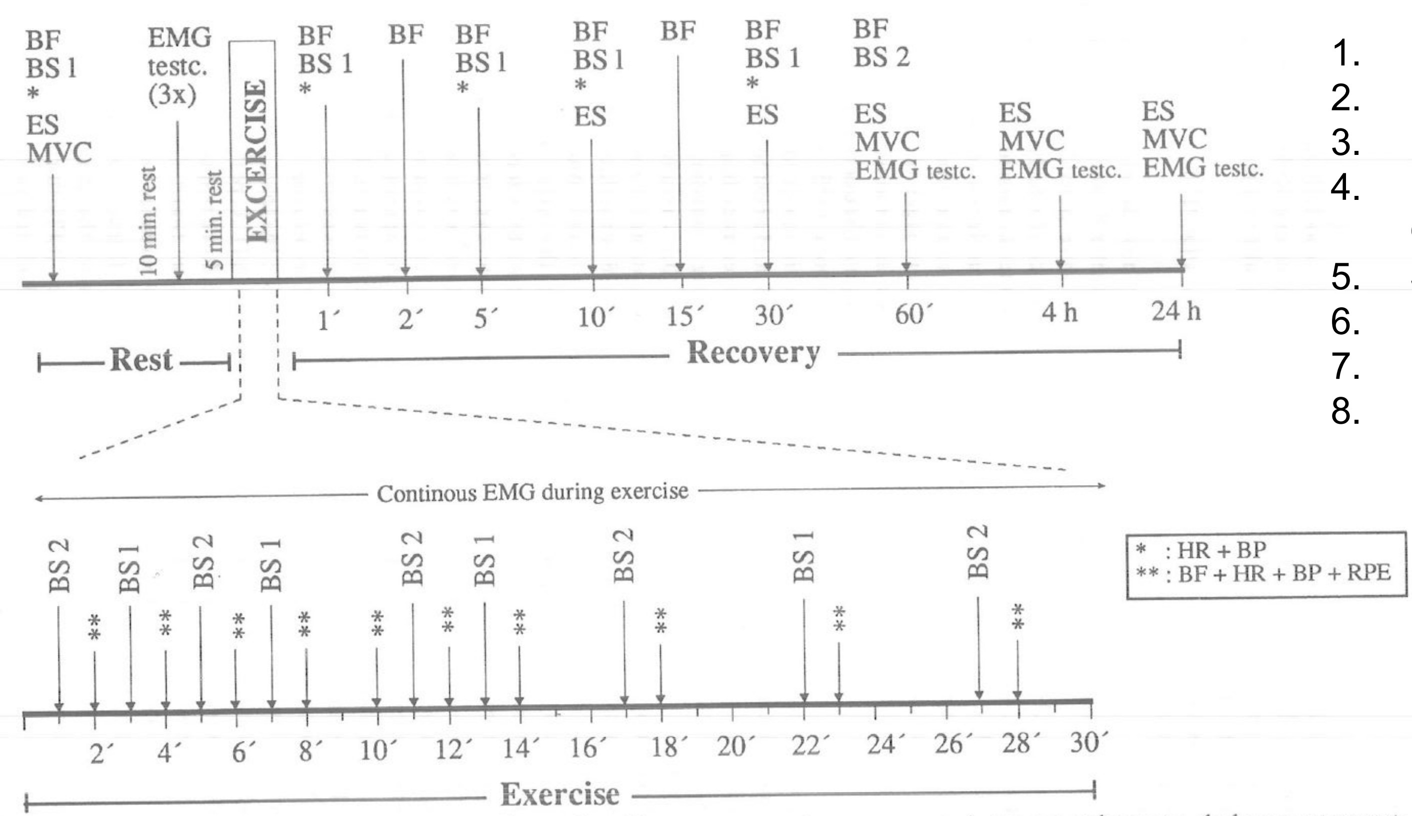


FIG. 2. Relationship between force of contraction and endurance time for isometric contractions of the quadriceps muscle, sustained to fatigue. Symbols indicate results in individual subjects studied at Hammersmith. The curve, redrawn from Rohmert (1960) is based on measurements in thirteen different muscle groups, including the quadriceps. Sedentary males, ● (n = 10); female subjects, ▲ (n = 5); male athletes, O (n = 5); female athletes, △ (n = 11).

Fatigue Studies (Byström & Fransson-Hall 1994)



1. Blood flow
2. EMG
3. Electrical stimulation
4. $[K^+]$ & $[Lactate^-]$ Concentrations
5. Strength
6. Perceived Exertion
7. Blood Pressure
8. Heart Rate

Based on these physiological criteria:

- intermittent hand grip contractions ≥ 17%MVC mean contraction intensity &
- continuous handgrip contractions ≥ 10%MVC

were considered unacceptable.

Byström S, Fransson-Hall C. Acceptability of intermittent handgrip contractions based on physiological response. Human Factors. 1994 Mar;36(1):158-71.

ACGIH Model -- fatigue →WMSDs

Exertion/force → joint forces/moments (loads)

- ➔ Muscle Tendon Loads
- ➔ Tissue deformation
- ➔ Discomfort - slow down
- ➔ Ischemia

} Localized fatigue

- ➔ Mechanical Damage
- ➔ Pain & impaired performance
- ➔ Tissue repair & adaptation

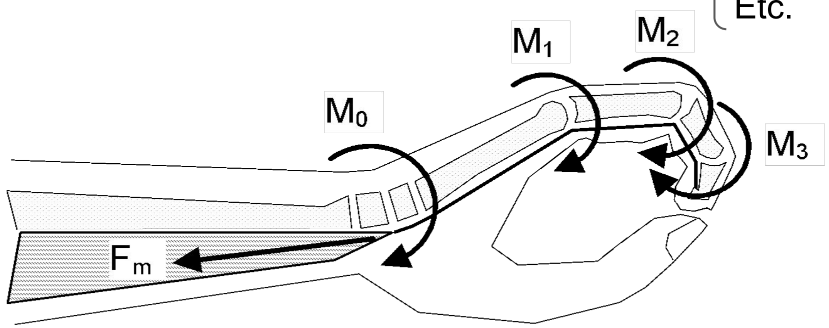
} WMSD

- ➔ Consumption of metabolic substrates, Production of metabolite & Increased blood flow
- ➔ Impaired strength & control
- ➔ **Discomfort -- slowdown/stop**
- ➔ Physiological damage
- ➔ Pain
- ➔ Tissue repair & adaptation

} Localized fatigue

- Tendonitis
- Carpal tunnel syndrome
- Etc.

} WMSD



- WMSD: Work-related Musculoskeletal Disorder;
  - May require medical attention
- Localized fatigue may be a precursor or harbinger of chronic musculoskeletal pain and injury

ACGIH Fatigue TLV®

1. Recommended for upper limb work (hands, elbow, shoulder)
2. Healthy workers can sustain day-after-day without adverse effects
3. Work performance: repeated/sustained reach, grasp, hold, manipulate work objects
4. May not protect persons with pre-existing conditions
5. Fatigue symptoms should not persist > 24 hours (one day to next)
6. Some fatigue is normal and may contribute to adaptation
7. Several days more weeks may be required to adapt
8. Work loads are expressed in terms of %MVC = load/strengthx100%
9. Hand loads: force exerted with fingers
10. Elbow & shoulder loads: Moments about joint
11. Quasi static loads
12. Loads based on worker or observer ratings, biomechanics, instrumentation

Characterization of Intermittent work

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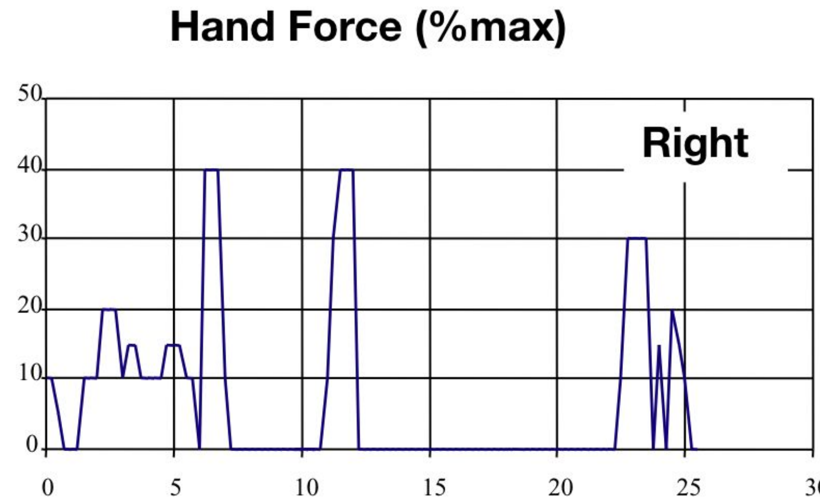

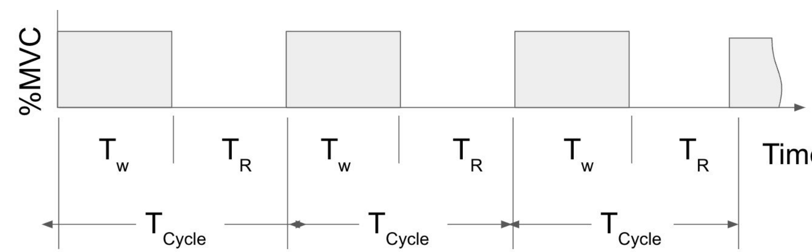

T_w = Work time

T_R = Rest (Recovery) time

T_{Cycle} = Cycle time = $T_w + T_R$

DC = Duty Cycle = (T_w / T_T) (* 100%)

Selected studies of acceptable force-frequency patterns

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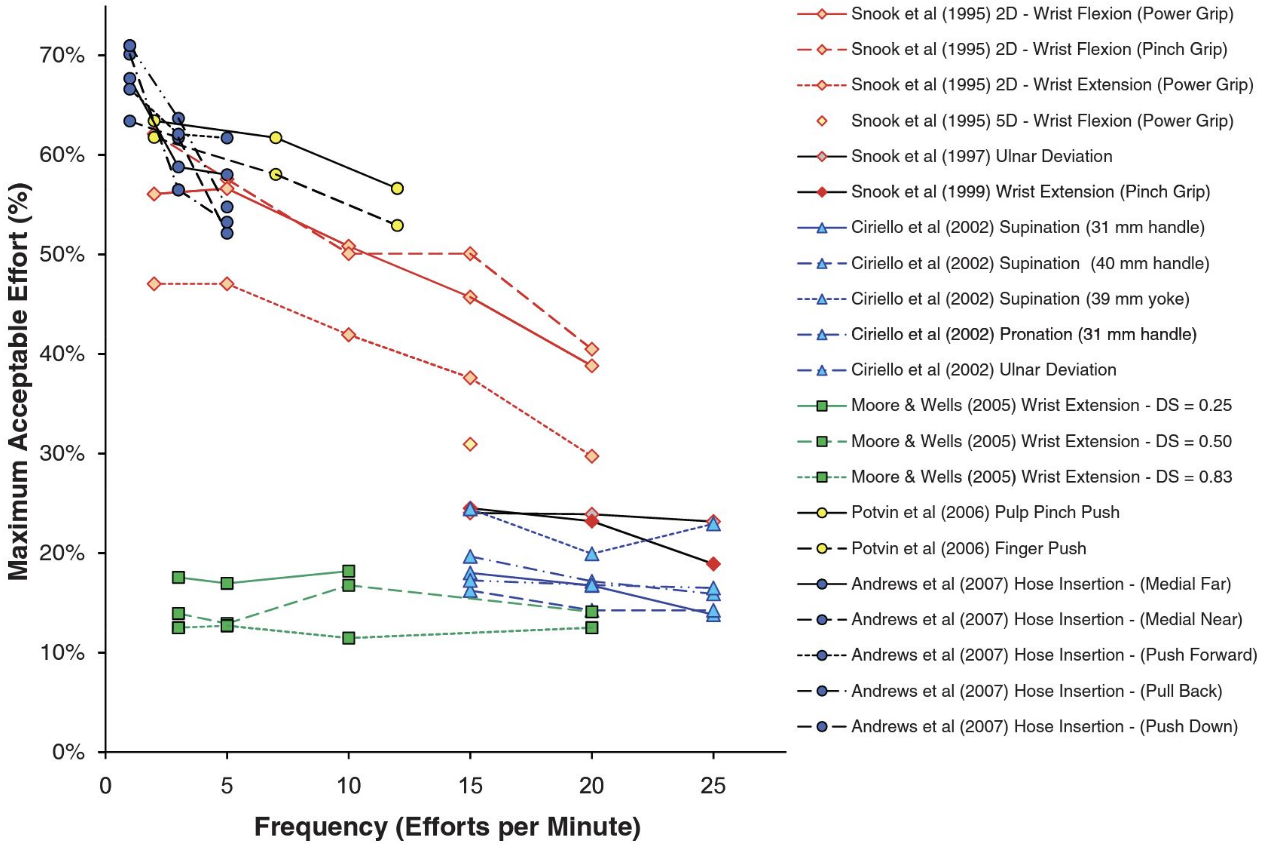
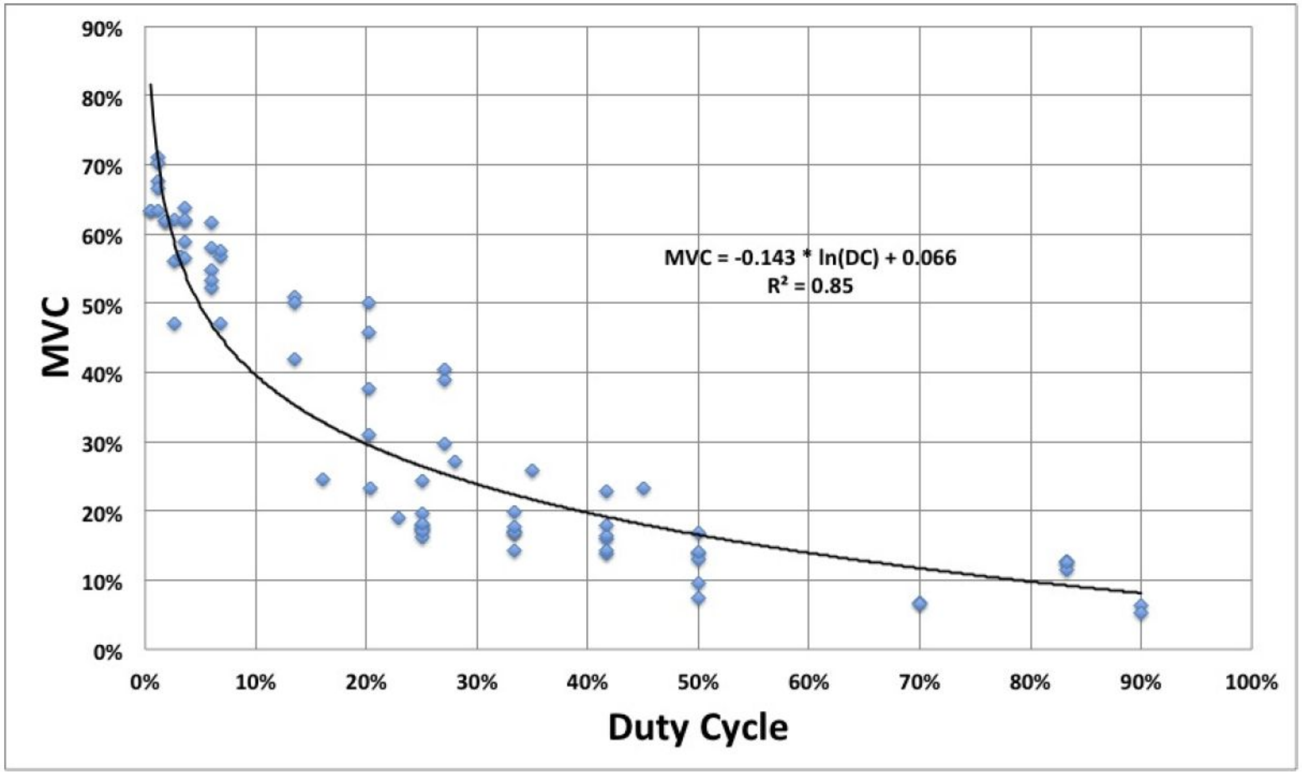
(%MVC)



Maximum acceptable effort (as a percentage of maximum voluntary effort) versus frequency of effort. Mean data are shown for the upper extremity psychophysical studies meeting the inclusion criteria

Potvin, J. R. (2012). Predicting maximum acceptable efforts for repetitive tasks: an equation based on duty cycle. *Human factors*, *54*(2), 175-188.

Curve fitted for data from 0.5-90%MVC*

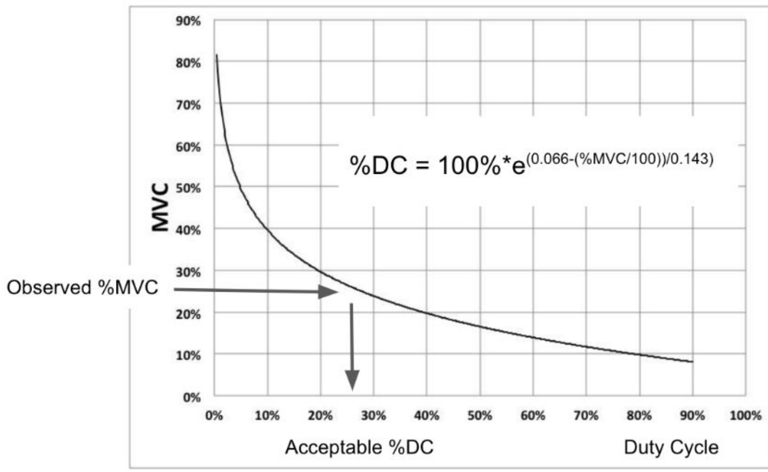


*TLV® Limits

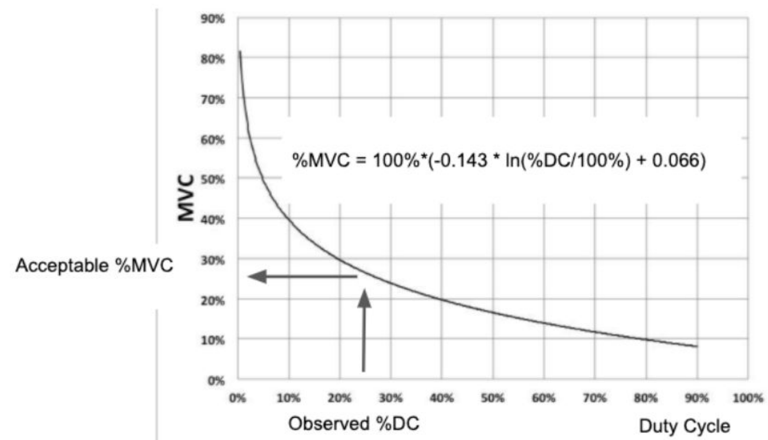
Application of TLV

Observed %MVC → Acceptable %DC or

Observed %DC → Acceptable %MVC



(a)



(b)

See:

Localized (peripheral) fatigue

Task strength demands and capacities

Measuring biomechanical load factors

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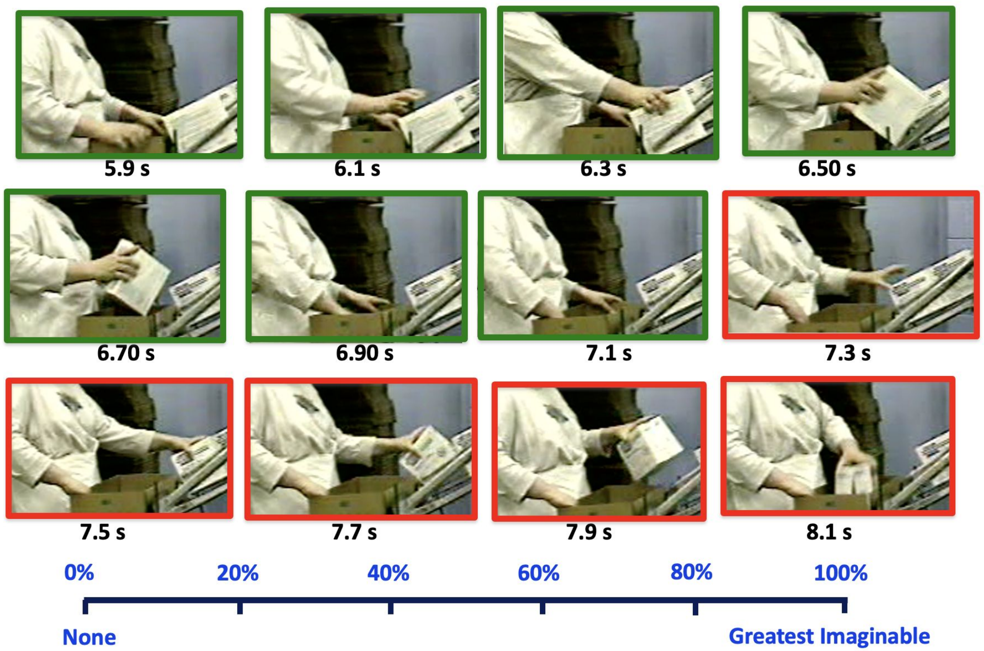
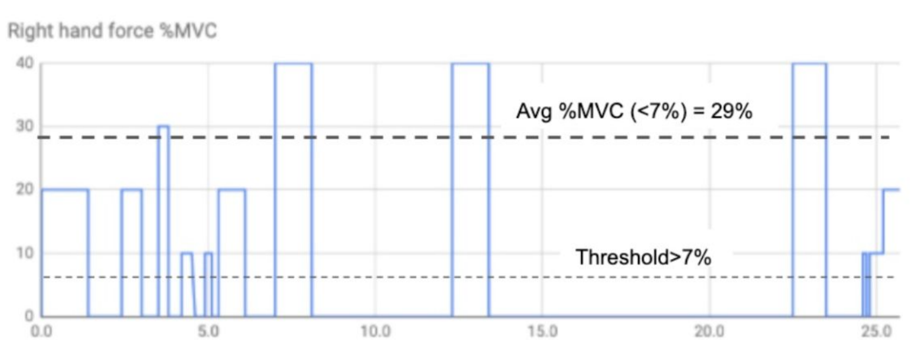
Determining Duty Cycle Based on Observations





Observe job at fixed or random time intervals
Estimate %MVC for each observation

Duty cycle = $\Sigma\Delta ti_{(\%MVC>7\%)} / \Sigma\Delta ti \times 100\%$

Avg %MVC = $\Sigma\%MVC_{(\%MVC>7\%)} \times \Delta ti_{(\%MVC>7\%)} / \Sigma\Delta ti$

Time Study	Right	Left
Duty Cycle	30%	29%
$\%MVC_{avg}(>7\%)$	27%	29%

https://www.youtube.com/watch?v=WBnCsiWZc90

Armstrong, et al. "Time based job analysis for control of work related musculoskeletal disorders." *15th Triennial Congress of the International Ergonomics Association, Seoul, Korea*. 2003.

Force Assessment

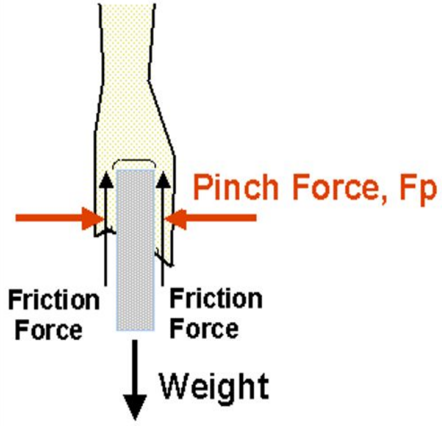
Observations

See: Ebersole M, Armstrong T (2006). Analysis of an observational rating scale for repetition, posture, and force in selected manufacturing settings. *Human factors*, *48*(3), 487-498.

0% 20% 40% 60% 80% 100%

None — Greatest Imaginable

Biomechanical Calculations:



Weight: 6.7 N (1.5 pounds)

CoF: 0.42 (moist skin); 0.27 (dry skin)

Pinch Force, $F_p \geq$ Weight / (2 x CoF*

Moist skin: $F_p \geq 6.7N / (2 \times .42) = 16$ N

Dry skin: $F_p \geq 6.7N / (2 \times .27) = 25$ N

*CoF=Coefficient of Friction

Force exerted to transfer part from one location to another

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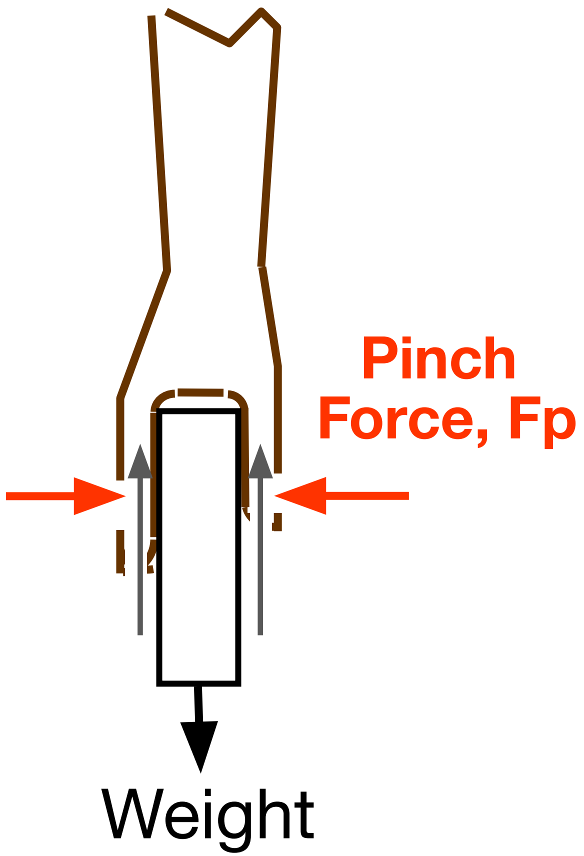
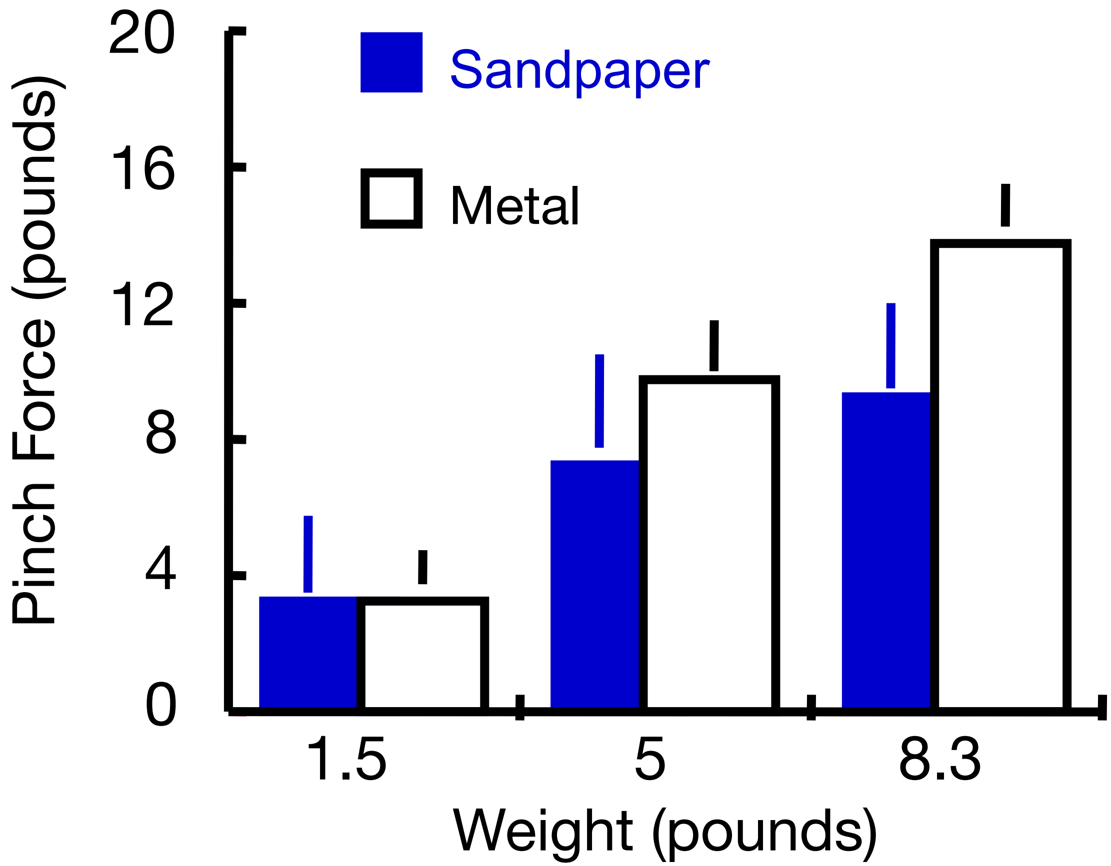


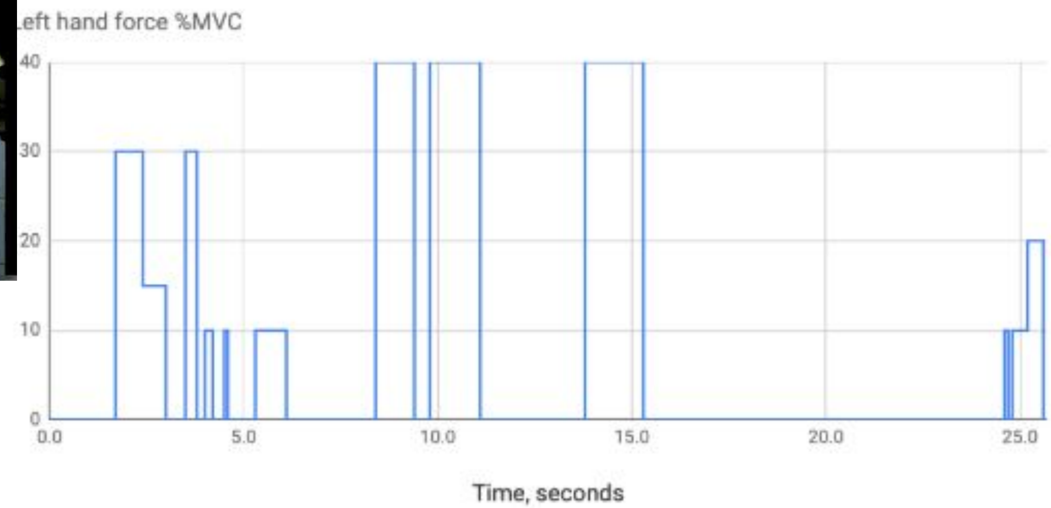


*From: Frederick, L. J. and T. J. Armstrong (1995). "Effect of friction and load on pinch force in a hand transfer task." Ergonomics **38**(12): 2447-54.*

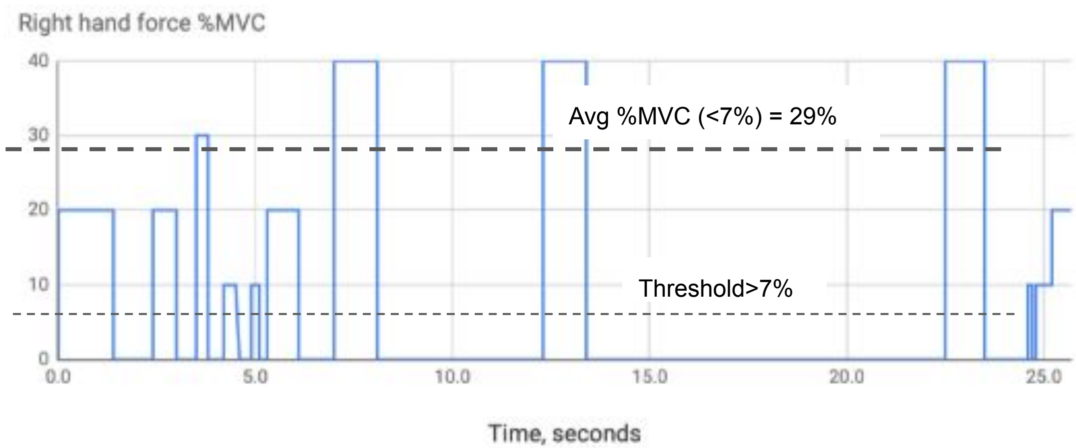
Bobjer, O., Johansson, S. E., & Piguet, S. (1993). Friction between hand and handle. Effects of oil and lard on textured and non-textured surfaces; perception of discomfort. Applied Ergonomics, 24(3), 190-202.

Buchholz, B., Frederick, L. J., & Armstrong, T. J. (1988). An investigation of human palmar skin friction and the effects of materials, pinch force and moisture. *Ergonomics*, *31*(3), 317-325.

Hand force %MVC versus Time



Tcycle	25.7s
Tw	7.7s
Trest	18.0s
Duty Cycle	30%
%MVC (>7)	27%MVC



Tcycle	25.7s
Tw	7.4s
Trest	18.3s
Duty Cycle	29%
%MVC (>7)	29%MVC

Summary

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1. There are many good indices for characterizing biomechanical risk, e.g., ACGIH TLVs®, OCRA, RULA, REBA, Strain Index, etc.
2. Conceptual models provide
   a. A framework for integrating and interpreting laboratory and epidemiological studies &
   b. A foundation for various exposure indices
3. Common elements of risk indices repetition, force, posture
4. Difference among tools include how biomechanical risk factors are defined and combined
5. A index suitable for one type of work may not be suitable for anther,
   e.g., office work versus foundry work
6. Indices can be determined using:
   a. **Observations** -- good for quick cursory assessments -- results may vary from observer to observe and observation to observation
   b. **Task and workspace analysis** -- requires more time than observations, but provides insight into causes of various risk factors and into the development of interventions
   c. **Instrumentation**,
      i. Provides objective measurements, but there can be significant sampling issues.
      ii. Most useful when problem is well defined, e.g., comparing one tool with another in specific work setting
      iii. Emerging tools: wearable sensors and computer vision for surveillance
7. User training is important -- you will probably get the best results using the tool you know how to use