

Ergonomic Risk Factors and Characteristics of Hand Tool Design

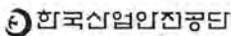
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Ergonomic Risk Factors and Characteristics of Hand Tool Design

*Evaluation of Ergonomic Risk Factors on Work-related
Musculoskeletal Disorders*

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National Institute for Occupational
Safety and Health



Overview

- Hand Tool Related Injury
- Hand Tool Design Characteristics
- Applications of Hand Tool Designs
- Checklist for the Ergonomic Evaluation of Hand Tools
- NIOSH Research – Handle Size Study

Hand Tool Related Injury

- Injured Body Parts by Hand Tools

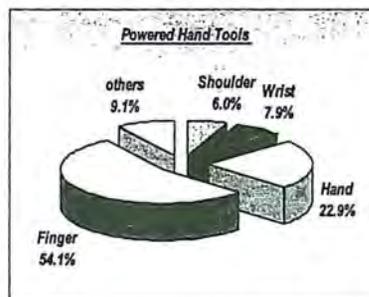
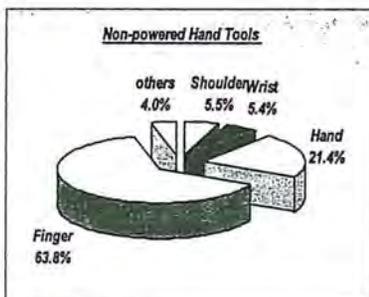
- (Aghazadeh and Mital, 1987)

- 22% of occupational disorders are related with hand tools
 - Non-powered hand tools
 - upper extremities (59.3%); trunk, back (8.5%, 16.7%)
 - Powered hand tools
 - upper extremities (51.0%); lower extremities, back (22.1%, 15.4%)
 - In both types of hand tools
 - 30% of all body parts are fingers
 - 56% of all upper extremities are fingers

Hand Tool Related Injury (Cont.)

- Injured Body Parts of Upper Extremities

- (1995~2001, BLS)



- Injured body parts of upper extremities associated with hand tools - (1995~2001, BLS)

<u>Non-Powered</u>	Finger	Hand	Wrist	Shoulder	Other
Hammers	64%	21%	6%	8%	1%
Screwdrivers	31%	44%	15%	10%	-
Wrench	35%	19%	14%	32%	-
Saws	42%	37%	21%	-	-
Pliers	66%	24%	10%	-	-

<u>Powered</u>	Finger	Hand	Wrist	Shoulder	Other
Drills	40%	35%	15%	4%	6%
Screwdrivers	35%	37%	20%	8%	-
Sanders	67%	19%	5%	7%	2%
Saws	59%	28%	8%	5%	-
Pliers	72%	15%	4%	3%	6%

Risk Factors

(Dababneh and Waters, 1999)

- Exerting high muscle force
- High level of repetition of task
- Awkward posture
- Working in cold, hot, vibration and/or high noise places
- Unbalanced work-rest cycle or inadequate recovery from fatigue

Risk Factors (Cont.)

- Repetitive and forceful hand motions (w/ awkward posture)
 - When the forearm flexor muscles contract to hold/grasp an object, the tendons of these muscles pull the four fingers and flex them,
 - Repetitive and forceful uses of the wrist deviations affect the gripping capability and can cause inflammation, and chronic pain, and injury to the tendons, synovial sheaths or median nerve, because the tendons pass through the carpal tunnel and insert into the phalanges of the finger
 - Tool handles should be designed in such a way that the hand can be kept in line with the forearm to minimize tendon forces

- Cross-sectional configuration:

- Handle shape and size can directly affect the operator's performance and health



Figure 1 (Armstrong, 1985)

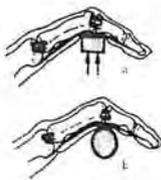


Figure 2 (Greenburg and Chaffin, 1977)

- Figure1: high forces are created against the palmar side of the fingers, when squeezing on the pliers; another factor of tendon disorders is contact with hard sharp edges of handle
- Figure2: the finger flexors are tight due to the required tool squeezing action, and hence the forces can easily pinch the nerves, veins and arteries against the tendon sheaths; the flat, short handle with a high curvature causes pressure on the center of palm

Hand Tool Design Characteristics

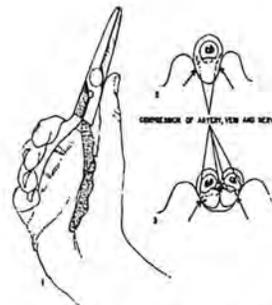
- Handle Size:

Handles	Analysis Method	Task Type	Optimal Handle Size
Cylindrical	Subjective Rating	Up & down stair	45-51mm (Hall & Bennett, 1956)
		Max. Gripping	30-40mm (female: 10% less, Yakou, 1997)
	EMG	Static loading (torque)	32mm (Khalil, 1973)
	Grip Dyn. & EMG	Max. Gripping	38mm (Ayoub & LoPresti, 1971); 41.4 or 50.9mm (Blackwell, 1999)
		Force sensor, Grip Dynamometer	Max. Gripping
	Torque meter	Torque	50mm (Replogle, 1983)
Thrust, push, & pull		35-41mm (29-35, Cochran & Riley, 1982)	
Palmar	Jarmar Grip Dynamometer	Max. Gripping	48, small hand & 58, large hand (Cotton & Johnson, 1971); 45-55mm (Pheasant & Scriven, 1983); 55-65, male & 50-60, female (Fransson & Winkel, 1991)

Hand Tool Design Characteristics

- Handle Shape:

- A handle shape directly affects a user's ability to firmly grasp
 - (Greenburg and Chaffin, 1977)
- The handle should be designed to distribute the force over as large an area on the palm as possible
- Recesses can be used to prevent slippage, but deep recesses are not recommended because hand sizes vary



(Greenburg and Chaffin, 1977)

Hand Tool Design Characteristics

- Handle Length
 - 100-125mm (hand breadth: 71mm-97mm for a 5th %ile female - 95th %ile male: Konz, 1990)
- Hand tool Weight (Freivalds, 1996)
 - Hand tool should be designed to minimize the weight because heavy weight tools can cause fatigue in muscles
 - Hand tool should be well balanced, with its center of gravity as close as possible to the center of gravity of the hand
 - Hand tool should be designed to use of both hands.

Hand Tool Design Characteristics

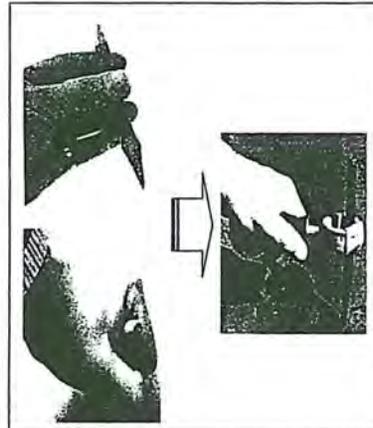
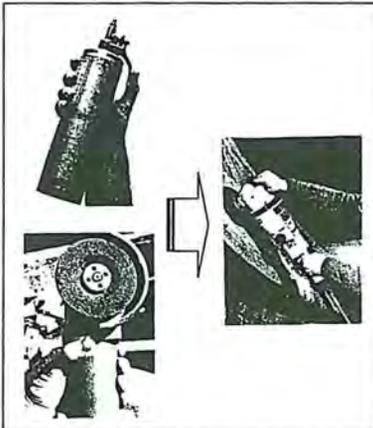
- Handle Edges and Corners
 - a radius of at least 1/8 inch
 - preferably 1/4inch~3/8inch (Greenburg and Chaffin, 1977)
- Handle Temperature and Vibration
 - Vibration and particularly localized vibration of the hand has been cited as a potential hazard such as white finger syndrome (Ayoub, Purswell, and Hoag, 1975)
 - Hot, cold and vibrating tools may lead to a loss of sensory feedback and decreased performance (Silverstein, Fine, and Armstrong, 1987)
 - Range of 2-200 Hz should be avoided (Lundstrom and Johansson, 1986)

Hand Tool Design Characteristics

- Hand tools should be selected to:
(Proceedings of a NIOSH Workshop, 1994)
 - Maximize performance
 - Enhance work quality
 - Maximize comfortable for use
 - Minimize physical stress / local stress
 - Prevent operator fatigue

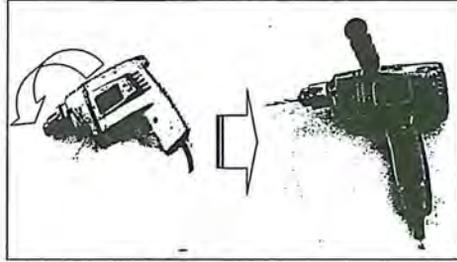
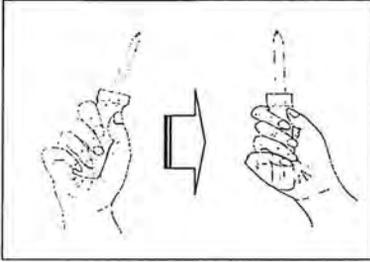
Applications of Hand Tool Designs

- Handle Diameter: (sources: Greenburg and Chaffin, 1977)



Applications of Hand Tool Designs

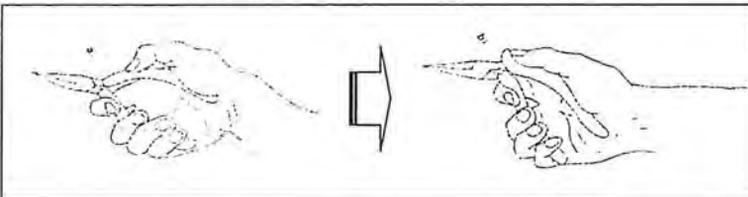
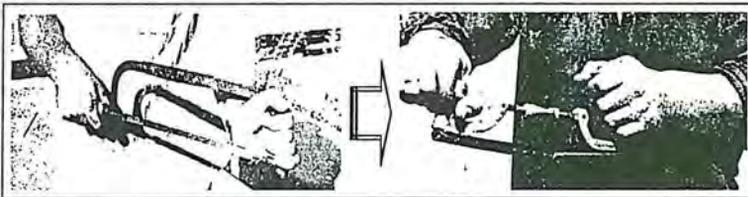
- Handle Length and Balance:



(sources: Freivalds, 1996; Greenburg and Chaffin, 1977)

Applications of Hand Tool Designs

- Wrist Posture: (sources: Freivalds, 1996; Greenburg and Chaffin, 1977)



Checklist for the Ergonomic Evaluation of Hand Tools



- 16 items
- Simple (yes/no)
- Qualitative to Semi-quantitative
- Item weights assigned based on importance

Checklist for the Ergonomic Evaluation of Hand Tools

- (NIOSH, Dababneh and Waters, 1999)

#	Ergonomic Feature	Yes	NA	No
1	Grip surface is non-slippery.			
2	Grip surface does not have sharp edges, under cuts, deep ribs and/or finger groves.			
3	Grip surface is electrically insulated; tool handle is either made of wood, or coated with rubber.			
4	Grip surface is thermally insulated, it will not get hot or cold fast when working in hot or cold environment.			
5	Handle is made of wood or grip surface is coated with semi-pliable material; not too hard and not too soft, similar to the rubber used in the soles of sport shoes.			
6	Grip length is 4-6"; given handle does not end inside the palm of the hand.			

#	Ergonomic Feature	Yes	NA	No
7	For one handle tools; size of handle cross section is not too small or too large. The index finger and the thumb is allowed to overlap by 3/8" when gripping.			
8	For one handle tools other than screw driver; shape of handle cross section is oval or rounded-edge rectangular.			
9	For screw drivers; the basic shape of handle cross section is circular, hexagonal, square or triangular.			
10	For two-handle tools (Plier-like); grip span is greater or equal than 2" when fully closed and less or equal than 3.5" when fully open			
11	Angle of the handle is formed in a way that will allow work to be done keeping a straight wrist.			
12	The tool weight is less than 5 lbs.			
13	The tool can be used with either hands.			
14	The tool can be used with the workers dominant hand.			
15	The tool will allow a two-handed operation; using both hands at the same time.			
16	The tool and accessories are clearly marked and/or color coded that are easy to identify; its colors are bright and it contrasts with the surroundings at the work area			

Handle Size Study

- Purpose:
 - To obtain the optimal handle sizes according to the user's hand length in various tasks
 - To validate quantitatively the "Checklist for the ergonomic evaluation of hand tools"

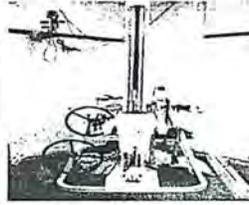
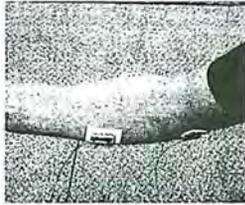
- Handles:
 - Six cylindrical experimental handles
 - (25, 30, 35, 40, 45, 50mm)

- Subject:
 - 24 subjects



Handle Size Study (Cont.)

- Measurement System:
 - 1. Force Glove (16 sensors)
 - 2. Surface EMG (2 channels)
 - 3. LIDO WorkSET II (torque/pushing)



Handle Size Study (Cont.)

- Normalized Handle Size
 - To obtain the optimal NHS ratios based on subjective comfort rating and/or performance, a quadratic regression model was employed

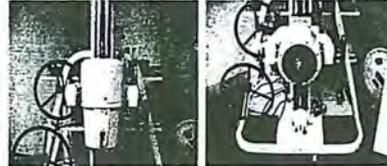
Handle Size Study (Cont.)

- Task 1: Maximum Torque Task

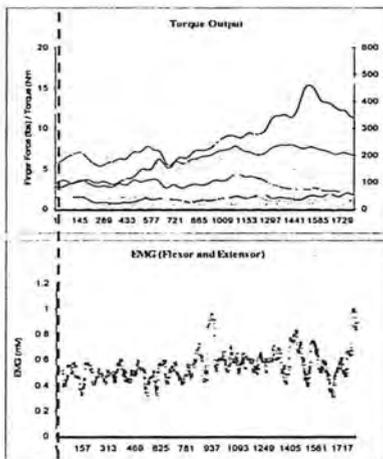
- Two positions (vertical & horizontal)
- 6 handles with two repetitions

- Dependent variables:

- Torque output
- Subjective comfort rating (SCR):
 - 7-point scale
- Finger force capability (FCC):
 - Summing of all 16 sensors
- Individual finger / phalange force distribution
- Muscle activity
 - [flexor digitorum superficialis (FDS) and extensor digitorum (ED)]



Handle Size Study (Cont.)



Handle Size Study (Cont.)

- Task 2: Maximum Gripping Task

- 6 handles with two repetitions
- Dependent variables:
 - Subjective comfort rating (SCR):
 - 7-point scale
 - Finger force capability (FCC):
 - Summing of all 16 sensors
 - Individual finger / phalange force distributions
 - Muscle activity
 - [flexor digitorum superficialis (FDS) & extensor digitorum (ED)]



Handle Size Study (Cont.)

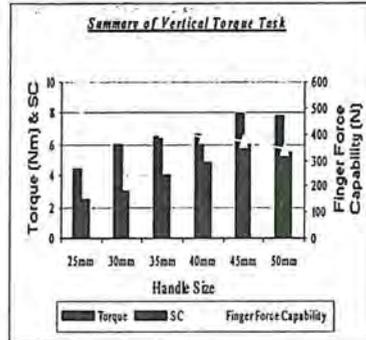
- Task 3: Maximum Pushing Task

- Two positions (45degree & Horizontal)
- 6 handles with two repetitions
- Dependent variables:
 - Pushing force
 - Subjective comfort rating (SCR):
 - 7-point scale
 - Finger force capability (FCC):
 - Summing of all 16 sensors
 - Individual finger / phalange force distribution
 - Muscle activity
 - [flexor digitorum superficialis (FDS) and extensor digitorum (ED)]



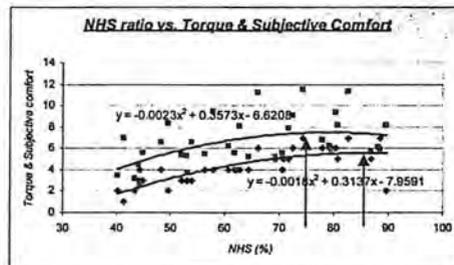
Results

- Maximum Torque Task
 - (preliminary results)
 - Subjective Comfort Ratings (SCR)
 - 45mm handle: the most comfortable
 - 25mm handle: the least comfortable
 - Torque Output (Torque)
 - The larger the handle diameter, the larger the torque, except between the 45 and 50mm
 - 45mm handle: the largest torque
 - 25mm handle: the lowest torque
 - Finger Force Capability (FFC)
 - As handle diameter increased, the finger force capability decreased
 - Finger force capability of the large handles were 71-78% of that for the smallest handle



Results (Cont.)

- Normalized Handle Size (NHS)
 - NHS vs. Subjective Comfort Rating: 87.1% [$NHS\% = 0.3137 / (2 * .0018)$]
 - ex.) hand length of 191.0mm (50%ile male): $191 * .871 / \pi = 52.9\text{mm}$
 - NHS vs. Torque Output: 77.7% [$NHS\% = 0.3573 / (2 * .0023)$]
 - ex.) hand length of 191.0mm (50%ile male): $191 * .777 / \pi = 47.2\text{mm}$



Results (Cont.)

- Normalized Handle Size (*NHS*): The preliminary findings can be used to derive handle diameter for maximizing comfort or torque output based on the user's hand size:

$$[\text{Handle Diameter} = \text{Hand Length} * (0.871 \text{ or } 0.777) / \pi]$$

Hand length (mm)	Handle Diameter (mm)
167.1-178.2	46-49mm*; 41-44mm**
178.3-183.0	49-51mm*; 44-45mm**
183.1-187.8	51-52mm*; 45-46mm**
187.9-198.9	52-55mm*; 47-49mm**

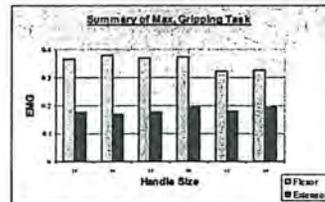
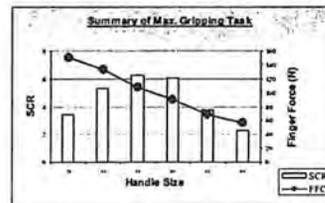
*: handle diameters for subjective comfort rating; **: for torque output

Results (Cont.)

- Maximum Gripping Task

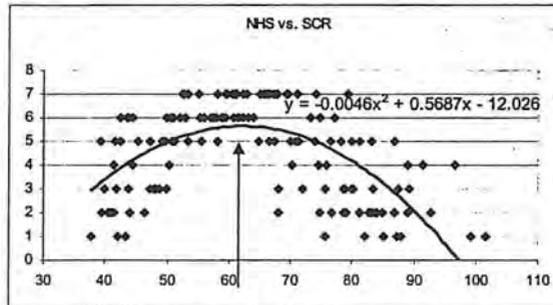
(preliminary results)

- Subjective Comfort Ratings (*SCR*)
 - 35mm and 40mm handles were the best comfortable handles
 - 25mm and 50mm handles were the least comfortable handles
- Finger Force Capability (*FFC*)
 - Finger force capabilities of small handles were higher than those of larger handles
- Flexor and Extensor (*EMG*)
 - Flexor muscle was a prominent role in the maximum gripping task than the extensor muscle



Results (Cont.)

- Normalized Handle Size (*NHS*)
 - *NHS* vs. Subjective Comfort Rating: 61.8% [$NHS\% = 0.5887 / (2 * 0.0046)$]
 - ex.) hand length of 191.0mm (50%ile male): $191 * 0.618 / \pi = 37.6\text{mm}$



Results (Cont.)

- Normalized Handle Size (*NHS*): The preliminary findings can be used to derive handle diameter for maximizing comfort based on the user's hand size:

$$[\text{Handle Diameter} = \text{Hand Length} * (0.618) / \pi]$$

Hand length (mm)	Handle Diameter (mm)
167.1-178.2	32.9-35.1mm
178.3-183.0	35.1-36.0mm
183.1-187.8	36.0-36.9mm
187.9-198.9	36.9-39.1mm

Discussion

- Maximum Torque Task
 - The effects of handle size on torque output
 - The larger the handle diameter, the greater the torque output
 - (Pheasant and O'Neill, 1975; Shih and Wang, 1996)
 - The relationship is not simply linear (non-linear) due to the reduction of finger force capability as handle diameter increases
 - Torque (T)=G*R*u, (i.e., a function of the shear force [total normal grip force (G)*coefficient of friction (u) between glove and handle surface] and radius of the handle (R))
 - The effects of handle size on subjective comfort rating
 - Participant preferred the large handles over the small handles
 - Subjective comfort ratings are often dominated by impressions of operational performance (torque output)- Strasser, 1991

Discussion (Cont.)

- Maximum Gripping Task
 - Finger force capability showed a decreasing trend as the fingers were extended to grasp larger handles
 - The number of cross-bridges between the thick and thin filaments are minimize at the large handles
 - If the hand does not completely encircle the handle, there is an area on which no force is exerted. Thus, it can not be fully developed in the area opposite the open area, because there is "nothing to squeeze against" (Replogle, 1983)
 - Subjective comfort ratings did not appear to be influenced by impressions of gripping performance

Summary

- Maximum Torque Task
 - 45mm handle: "most comfortable"
 - 25mm handle: "uncomfortable"
 - Torque: 45 and 50mm handles= 1.78~1.8 * 25mm handle
 - Finger force capability: 45 and 50mm handles= 72~78% of 25mm handle
 - 87% and 78% NHS ratios are the best for maximizing subjective comfort and torque, respectively.
- Maximum Gripping Task
 - 35mm handle: "most comfortable"
 - Smaller handles showed high finger force capability.
 - Small handles: high flexor muscle activities vs. Large handles: low flexor muscle activities
 - A 61.8 % NHS ratio is the best for subjective comfort ratings

Further Study

- Quantitative evaluation of other design characteristics (such as shape, surface, texture, etc.) with various construction hand tools
- Application of the quantitative evaluation study to the *"NIOSH Checklist for Ergonomic Evaluation of Hand Tools"*

THANK YOU !!

 한국산업안전공단

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