v 2.0

HANDPAK

An Integrated Software Package
for the Ergonomic Assessment
of Hand Intensive Tasks

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Introduction

HandPak is a software package designed to determine recommended acceptable forces and torques for a wide variety of manual, hand intensive tasks commonly found in the workplace. These guidelines will be very valuable to those interested in an evidence-based assessment of task designs and the determination of the injury risk associated with tasks with different grips, postures, frequencies, durations and effort requirements. This software was developed by integrating a large body of scientific research published in the literature.

For every analysis, there are a number of common inputs, including: 1) gender, 2) percentage of the population you wish to design for, 3) units (empirical or metric). In addition, HandPak has a number of modules for specific tasks demands. These include:

Torques

This module accounts for tasks that require the application of a torque or moment to some object that has been grasped with the hand.

Forearm Pronation or Supination: For a variety of grasp interfaces, elbow postures, forearm orientations and frequencies, the maximal acceptable torque can be determined for both the pronation and supination direction.

Wrist Flexion, Extension, Ulnar or Radial Deviation: The maximal acceptable torque can be determined for a number of grips, frequencies and wrist torque directions.

Grips and Pinches

This module accounts for tasks that are limited by the amount of force required to grip or pinch and object.

Power Grip: For power grips with one or two hands, different spans, wrist and elbow postures, durations and frequencies, the maximal acceptable power grip force can be determined.

Pinches: For different types of grips (chuck, lateral/key, pulp, tip), apertures, wrist postures, durations and frequencies, the maximal acceptable pinch forces can be determined.

Pushes and Pulls

This module accounts for tasks where the hand interfaces with an object so that it can be pushed or pulled.

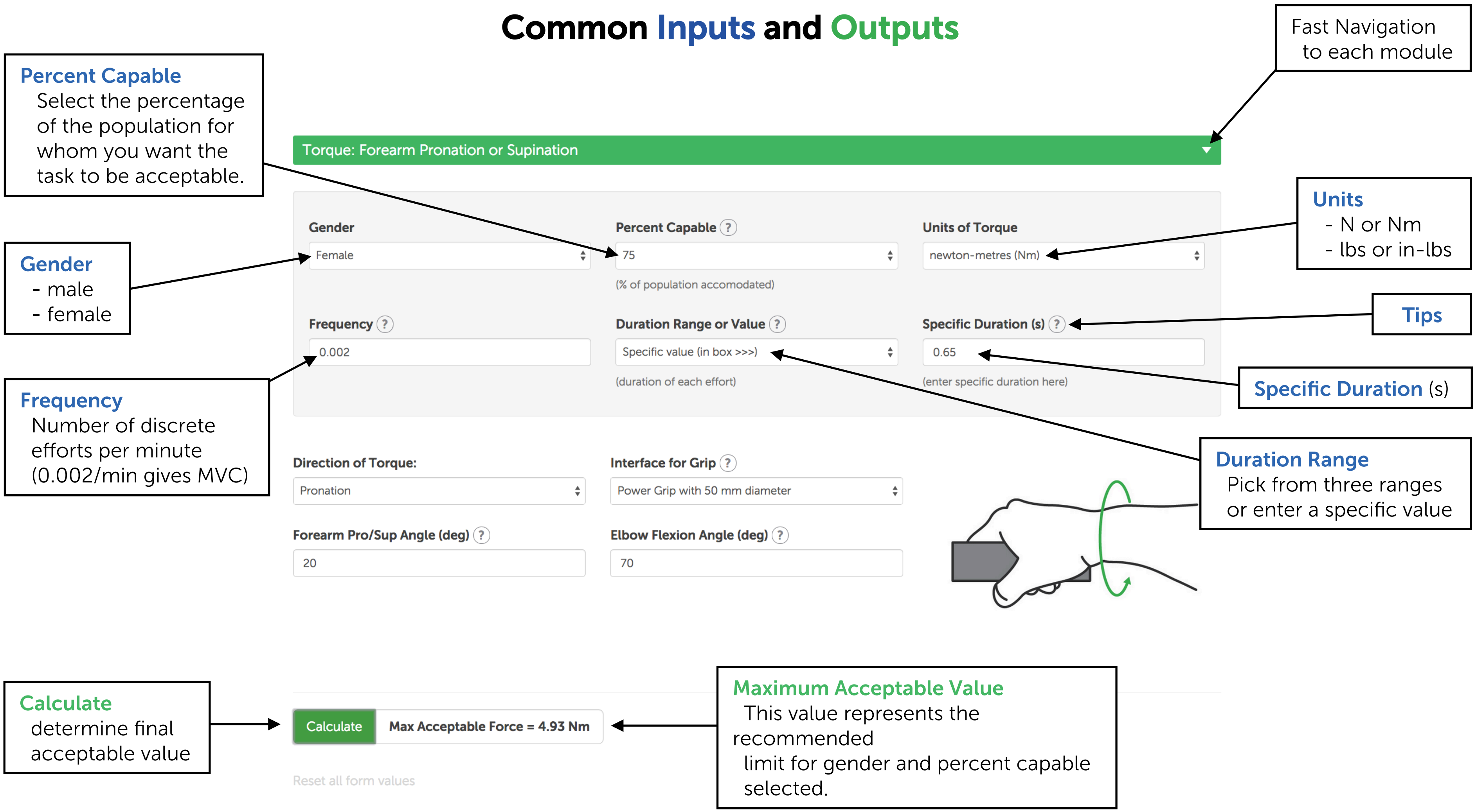
Finger Pulls: For pulls with various finger interface locations (tip or knuckle), glove use, finger clearance, object dimensions, effort durations and frequencies, the maximal acceptable finger pull force can be determined.

Finger and Thumb Pushes: For pushes with different numbers of fingers or thumbs, contact location (tip or pad), wrist postures, effort durations and frequencies, the maximal acceptable push forces can be determined.

Pushes or Pulls with Grips: For different types of pinches or grasps, wrist postures, object apertures or spans, surface coatings, effort durations and frequencies, the maximal acceptable push or pull forces can be determined.

HANDPAK

Common Inputs and Outputs



Torques

Wrist Flexion and Extension

HandPak v2.0 has now created separate modules for wrist flexion/extension and wrist ulnar/radial deviation.

Strength data were taken from a number of studies for both wrist flexion and extension for both males and females (see p. 9). These data were pooled within 3 different types of grips. Data for power grip, lateral pinch and pulp pinch came from the weighted averages of multiple studies.

Corrections for specific wrist flexion/extension angles came from Delp et al (1999).

The maximum torque strength values were assumed to be those acceptable for one second of efforts per day. For more frequency efforts, the maximum acceptable effort (MAE) equation from Potvin (2012) was used to correct for the combination of effort frequency and effort duration (ie. duty cycle). See Appendix A for details.

Table 1: Summary of the studies used for the extension and flexion maximum strengths, for males and females.

	Flexion		Extension	
	Female	Male	Female	Male
Backlund et al (1968)				■
Nordgren (1972)	■	■	■	
Vanswearingen (1983)	■	■		
Anderson et al (1990)		■		
Snook et al (1995)	■		■	
Al Eisawi (1998)		■		
Imrhan & Jenkins (1999)		■	■	■
Greig & Wells (2004)	■	■	■	■
Seo et al (2007)	■		■	■
Seo et al (2008)	■			■

Torques
Wrist Flexion or Extension

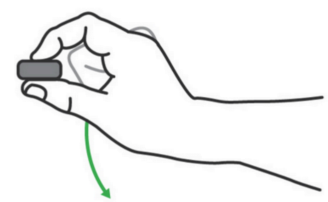
Torque: Wrist Flexion or Extension

Gender	Percent Capable (?)	Units of Torque
Female	75	newton-metres (Nm)

Frequency (?)	Duration Range or Value (?)	Specific Duration (s) (?)
0.002	under 0.2 seconds (ie. snap)	0

Direction of Torque
Flexion

Type of Grip (?)
Pulp Pinch
(Power Grip is optimal)



Wrist Ext/Flex Angle (deg) (?)
0
(-75 deg Ext to +75 deg Flex)
(-25: optimal for Ext, +37: optimal for Flex)

Calculate | **Max Acceptable Force = 1.10 Nm**

Direction of Torque
- Flexion
- Extension

Type of Grip
- Power Grip
- Lateral Grip
- Pulp Pinch Grip

Wrist Flexion/Extension Angle
0 deg is neutral.
- is extension, + is flexion

Ulnar and Radial Deviation

Strength data were taken from a number of studies for both wrist ulnar deviation and radial deviation for both males and females (see p. 11). These data were pooled within 3 different types of grips. Data for power grip, lateral pinch and pulp pinch came from the weighted averages of multiple studies.

Corrections for specific wrist ulnar/radial deviation angles came from Delp et al (1999).

The maximum torque strength values were assumed to be those acceptable for one second of efforts per day. For more frequency efforts, the maximum acceptable effort (MAE) equation from Potvin (2012) was used to correct for the combination of effort frequency and effort duration (ie. duty cycle). See Appendix A for details.

Table 2: Summary of the studies used for the radial and ulnar deviation maximum strengths, for males and females

	Ulnar Deviaion		Radial Deviaion	
	Female	Male	Female	Male
Vanswearingen (1983)	■	■	■	■
Snook et al (1997)	■			
Al Eisawi (1998)				■
Ciriello et al (2001)	■			
Ciriello et al (2002)	■			
Peebles & Norris (2003)	■	■	■	■
Greig & Wells (2004)	■	■	■	■

Torques

Wrist Ulnar or Radial Deviation

Torque: Wrist Ulnar or Radial Deviation

Gender
Female

Percent Capable (?)
75

Units of Torque
inch-pounds (in-lbs)

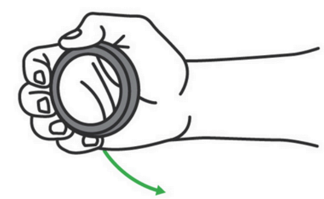
Frequency (?)
0.002

Duration Range or Value (?)
0.2 to 0.6 second range

Specific Duration (s) (?)
0

Direction of Torque
Ulnar Deviation

Type of Grip (?)
Grip Smooth 85mm Lid
(Power Grip is optimal)



Wrist Rad/Uln Angle (deg) (?)
0
(-25 deg Rad to +37 deg Uln, 0: optimal)

Calculate | **Max Acceptable Force = 35.67 in-lbs**

Direction of Torque
- Ulnar Deviation
- Radial Deviation

Type of Grip
- Power Grip
- Lateral Grip
- Pulp Pinch Grip
- Grip smooth 85 mm lid

Wrist Ulnar or Radial Deviation Angle
0 deg is neutral
- is radial, + is ulnar

Forearm Pronation and Supination

Male and female strength data were taken from a number of studies for both pronation and supination (see p. 7). These data w ere pooled within 8 different types of grips. Data for power grip, lateral pinch and pulp pinch came from the weighted averages of multiple studies. Corrections for circular knobs, butterfly nuts, ridged knobs and screwdrivers came from Peebles and Norris (2003). The data of O'Sullivan and Gallwey (2002) were used to determine corrections for specific pronation/supination angles of the forearm, and for specific elbow flexion angles.

The maximum torque strength values were assumed to be those acceptable for second of efforts per day. For more frequency efforts, the maximum acceptable effort (MAE) equation from Potvin (2012) was used to correct for the combination of effort frequency and effort duration (ie. duty cycle). See Appendix A for details.

Table 3: Summary of the studies used for the pronation and supination maximum strengths, for males and females.

	Pronation		Supination	
	Female	Male	Female	Male
Backlund et al (1968)		■		■
Nordgren (1972)	■		■	
Kramer et al (1994)	■	■	■	■
Ciriello et al (2002)	■		■	
O'Sullivan & Gallwey (2002)		■		■
Peebles & Norris (2003)			■	■
Greig & Wells (2004)	■	■	■	■
O'Sullivan & Gallwey (2005)		■		■
Matsuoka et al (2006)	■	■		

Torques
Forearm Pronation or Supination

Interface for Grasp
- Power Grip (yoke) with 50 mm diameter
- Circular Knob with 40 mm diameter
- Butterfly Nut with 40 mm diameter
- Ridged Knob with 40 mm diameter
- Lateral Pinch Grip
- Pulp Pinch Grip
- Screwdriver with 30 mm handle
- Screwdriver with 40 mm handle

Direction of Forearm Rotation
- Pronation
- Supination

Forearm Rotation Angle
0 deg is neutral. Positive is supination, negative is pronation.

Elbow Flexion Angle
0 deg is fully extended, angles increase with flexion

Torque: Forearm Pronation or Supination

Gender: Female

Percent Capable (?): 75
(% of population accomodated)

Units of Torque: newton-metres (Nm)

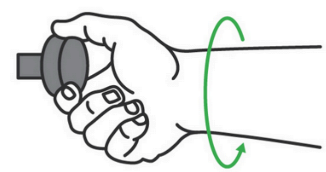
Frequency (?): 0.002

Duration Range or Value (?): Specific value (in box >>>)
(duration of each effort)

Specific Duration (s) (?): 1
(enter specific duration here)

Direction of Torque: Pronation

Interface for Grip (?): Circular Knob with 40 mm diameter
(Power Grip is optimal)



Forearm Pro/Sup Angle (deg) (?): 20
(-75 deg Pro to +90 deg Sup)
(+35: optimal for Pro, -75: optimal for Sup)

Elbow Flexion Angle (deg) (?): 70
(0 deg [fully extended] to 135 deg flexed)
(65: optimal for Pro, 80: optimal for Sup)

Calculate | Max Acceptable Force = 2.55 Nm

Grips & Pinches

Pinch Grips

The female maximum pinch strength values were determined with averages from a number of studies for each grip type (see Table 2).

Table 4: This table indicates which studies were averaged to determine maximum chuck, lateral, tip and pulp pinch strengths. Female data were used for each.

	Chuck (ie. Palmar)		Lateral (ie. Key)		Pulp (Thumb & Index)	
	Female	Male	Female	Male	Female	Male
Mathiowetz et al (1985)	■	■	■	■		
Berg et al (1988)	■	■	■	■	■	■
Imrhan & Loo (1989)	■	■	■	■	■	■
Fernandez et al (1991)		■		■		
Imrhan (1991)		■		■		■
Fernandez et al (1992)	■		■		■	
DiDomenico & Nussbaum (2003)	■	■	■	■	■	■
Greig & Wells (2004)			■			

Corrections for specific wrist flexion and extension postures were based on an integration of data from Fernandez et al (1991), Kamal et al (1992), Hallbeck et al (1992) and Fernandez et al (1992). Corrections for specific ulnar deviation and radial deviation postures were based on an integration of the results from Imrhan (1991) and Fernandez et al. (1992. Further, corrections for aperture were made based on the data of Imrhan & Rehman (1995).

Based on the data of Mathiowetz et al (1985), Imrhan & Loo (1989), Fernandez et al (1992), DiDomenico & Nussbaum (2003) and Greig & Wells (2004), it was assumed that male pinch strengths and MAT values are 47% higher than corresponding values for females.

The maximum torque strength values were assumed to be those acceptable for one second of efforts per day. For more frequency efforts, the maximum acceptable effort (MAE) equation from Potvin (2012) was used to correct for the combination of effort frequency and effort duration (ie. duty cycle). See Appendix A for details.

Hand Grips

The data of Mathiowetz et al. (1985), Imrhan & Loo (1989) and Peebles & Norris (2003) were averaged to determine maximum hand grip strengths, at a grip span of 50 mm, for females (312 N) and males (502 N). These values are corrected to account for the use of a second hand, and for grip spans above or below 50 mm, based on the data of Peebles & Norris (2003). Further corrections were made for specific wrist flexion, ulnar deviation, elbow flexion and shoulder flexion postures, based on the data of Kattel et al (1996).

The maximum torque strength values were assumed to be those acceptable for one second of efforts per day. For more frequency efforts, the maximum acceptable effort (MAE) equation from Potvin (2012) was used to correct for the combination of effort frequency and effort duration (ie. duty cycle). See Appendix A for details.

Grips & Pinches

Pinch Grips

Type of Pinch
- Chuck (thumb vs index & 2nd finger)
- Lateral (thumb vs side of index finger)
- Pulp Pinch (thumb vs index finger pad)

Distance Between Fingers
- this is the aperture between the fingers and the specific value can be entered (mm)

Wrist Flexion or Extension Angle
0 deg is neutral.
- is extension, + is flexion

Wrist Ulnar or Radial Deviation Angle
0 deg is neutral
- is radial, + is ulnar

Grip Force: with Pinches

Gender	Percent Capable ?	Units of Force
Male	50	newtons (N)

Frequency ?	Duration Range or Value ?	Specific Duration (s) ?
2	Specific value (in box >>>)	3

Type of Pinch: Lateral Pinch

Distance Between Fingers (mm) ?: 30
(150: max for Chuck & Pulp, 110: max for Lateral)
(35: optimal for Chuck & Pulp, 27: optimal for Lateral)

Wrist Flex/Ext Angle ?: -10
(-75 deg Ext to +75 deg Flex, -10: optimal)

Wrist Uln/Rad Angle ?: 0
(-25 deg Rad to +37 deg Uln, 0: optimal)

Calculate | Max Acceptable Force = 42.1 N

Grips & Pinches
Hand Grips

Grip Span
- the specific value can be entered here

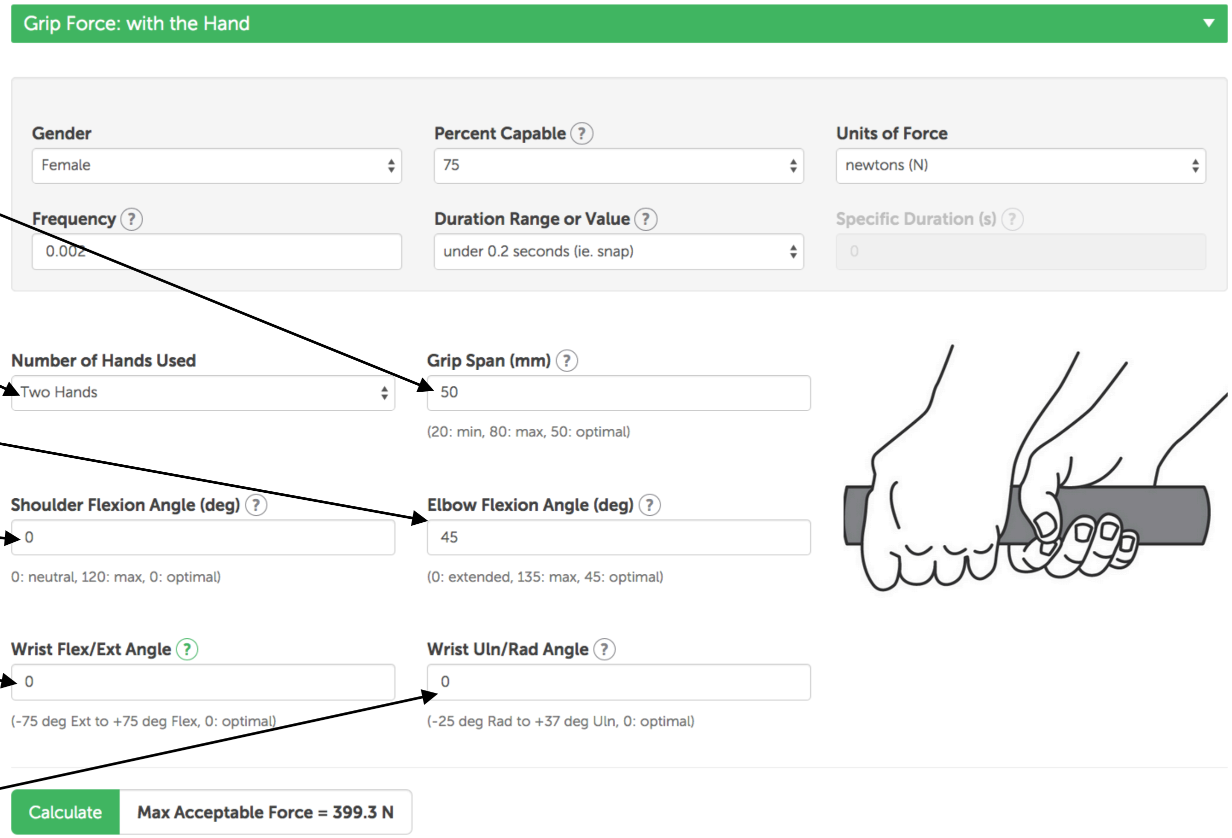
Number of Hands Used
- One Hand
- Two Hands

Elbow Flexion Angle
- 0 deg is fully extended

Shoulder Flexion Angle
- 0 deg is neutral

Wrist Flexion or Extension Angle
0 deg is neutral.
- is extension, + is flexion

Wrist Ulnar or Radial Deviation Angle
0 deg is neutral
- is radial, + is ulnar



Pushes & Pulls

Finger Pulls

The female data of Cort et al. (2011) was used to determine all maximum finger pull strengths. Based on the data of DiDomenico & Nussbaum (2003), it was assumed that male finger pull capabilities are 44% higher than corresponding values for females.

The maximum torque strength values were assumed to be those acceptable for one second of efforts per day. For more frequency efforts, the maximum acceptable effort (MAE) equation from Potvin (2012) was used to correct for the combination of effort frequency and effort duration (ie. duty cycle). See Appendix A for details.

Finger or Thumb Pushes

The female data from a number of studies were used to determine the maximum strengths for pushes with the thumb pad (133.5 N from Peebles & Norris, 2003), thumb tip (99.9 N from Longo et al., 2002), finger pad (86.6 N from Peebles & Norris, 2003) and finger tip (61.8 N from Potvin et al., 2006), The use of a second finger, on the same hand, was assumed to add 70% to the acceptable force. Using the index finger from the second hand was assumed to double the acceptable force. Similarly, the acceptable force for two thumbs was assumed to be double that for one. Corrections were made for neutral, extended, flexed or ulnar deviated wrist postures, based on Potvin et al. (2006). Based on the data of DiDomenico & Nussbaum (2003), and Peebles & Norris (2003) it was assumed that male finger pull capabilities are 43% higher than corresponding values for females.

The maximum torque strength values were assumed to be those acceptable for one second of efforts per day. For more frequency efforts, the maximum acceptable effort (MAE) equation from Potvin (2012) was used to correct for the combination of effort frequency and effort duration (ie. duty cycle). See Appendix A for details.

Pushes & Pulls
Finger Pulls

Location on Finger point of contact
- Finger Tip Pad
- Last/Distal Knuckle

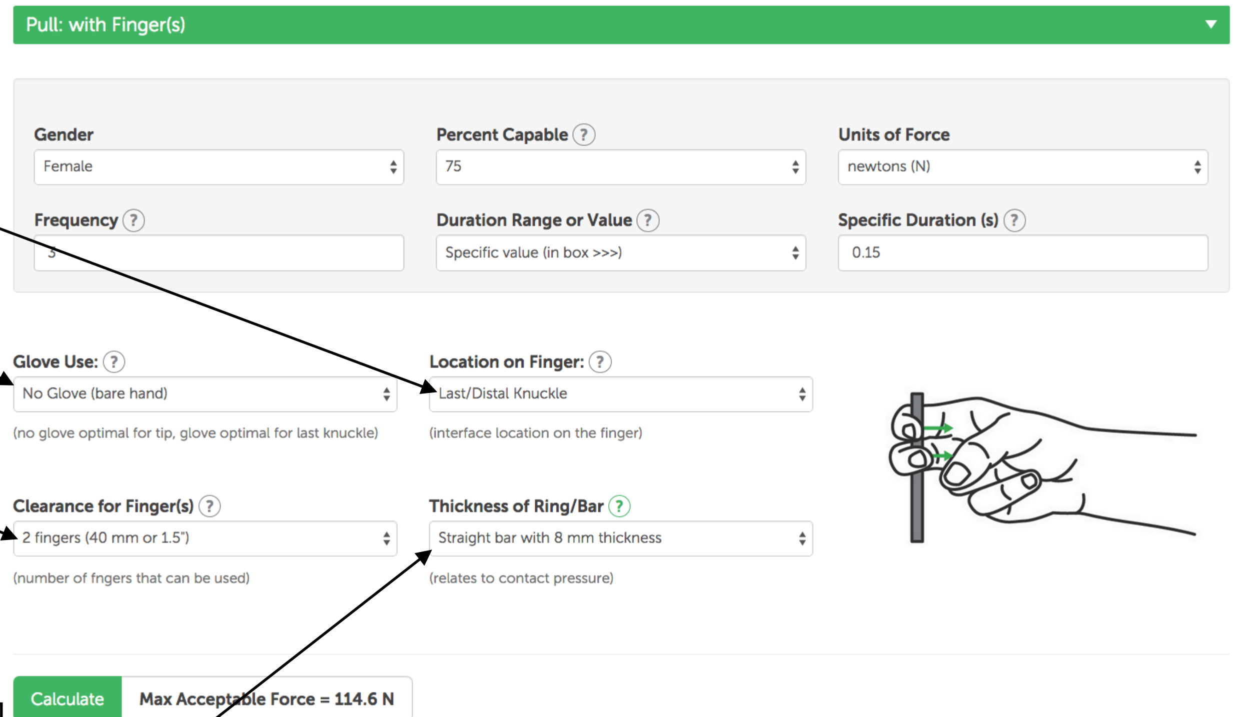
Glove Use
- With Glove
- No Glove (Bare Hand)

Clearance for Finger(s)

This indicates the diameter or width of the opening and will determine the number of fingers that can be used
- 25 mm (~1") allowing for 1 finger
- 40 mm (~ 1.5") allowing for 2 fingers
- > 60 mm (~2.25") allowing for >2 fingers

Thickness of Ring or Bar

This indicates the thickness of the object being pulled and will determine the contact area with the finger(s) and the contract pressure
- Ring with 4 mm thickness
- Ring with 8 mm thickness
- Straight Bar with 8 mm thickness



Pushes & Pulls
Finger or Thumb Pushes

Contact Point(s)
interface location(s)
- One Finger
- 2 Fingers from 1 Hand
- 1 Finger from Both Hands
- 2 Fingers from Both Hands
- One Thumb
- Two Thumbs

Tip(s) or Pad(s) Used?
This indicates whether the contact is with the tip (end) of the finger/thumb or with the pad
- Pad
- Tip

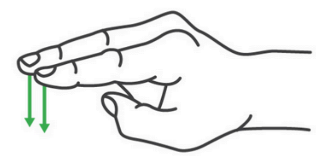
Wrist Posture
- Neutral
- Extended
- Flexed
- Ulnar Deviated

Push: with Finger(s) or Thumb(s)

Gender: Female
Percent Capable (?): 75
Units of Force: newtons (N)
Frequency (?): 0.002
Duration Range or Value (?): under 0.2 seconds (ie. snap)
Specific Duration (s) (?): 0

Contact Point(s) (?): One Hand: Index and 2nd Finger
(interface with hand(s))

Tip(s) or Pad(s) Used? (?): Pad
(contact location on digit(s))



Wrist Posture (?): Neutral
(best description of wrist posture)

Calculate | **Max Acceptable Force = 103.5 N**

Pushes or Pulls with Pinch Grips

The data from Potvin et al (2006), and the unpublished MVC data of Potvin et al (2005), were combined to determine female maximum strength and maximum acceptable forces for pulp pinch and lateral pinch pushes with neutral, extended, ulnar deviated and flexed wrist postures. Potvin et al (2005) studied 24 female subjects and determined maximum push strengths with pulp and lateral pinches in neutral and flexed postures. The ratios of pulp versus lateral push strength and flexed versus neutral wrist posture strength were used to estimate lateral pinch and/or flexed wrist MAFs based on the pulp pinch and/or neutral wrist MAFs of Potvin et al (2006). The data of Peebles & Norris (2003) and Greig & Wells (2004) were combined to allow for estimates of chuck pinch MAFs based on pulp pinch MAFs.

Pull values were estimated based on push versus pull strength ratios from Greig & Wells (2004) for pulp pinch and lateral pinch. Chuck pinches were assumed to have the same push versus pull ratios as pulp pinch.

Corrections were made for pinch aperture (distance between opposing fingers) based on Imrhan & Rehman (1995). Male values were estimated based on female versus male strength ratios from Peebles & Norris (2003) for chuck pinches, from Greig & Wells (2004) for lateral pinches and from an integration of Peebles & Norris (2003) and Greig & Wells (2004) for pulp pinches, including different ratios with different apertures.

Corrections for specific wrist flexion and extension posture were based on an integration of data from Fernandez et al (1991), Kamal et al (1992), Hallbeck et al (1992) and Fernandez et al (1992). Corrections for specific ulnar deviation and radial deviation postures were based on an integration of the results from Imrhan (1991) and Fernandez et al. (1992).

The maximum torque strength values were assumed to be those acceptable for one second of efforts per day. For more frequency efforts, the maximum acceptable effort (MAE) equation from Potvin (2012) was used to correct for the combination of effort frequency and effort duration (ie. duty cycle). See Appendix A for details.

Pushes & Pulls

Pushes or Pulls with Pinch Grips

Type of Pinch
- Chuck (thumb vs index & 2nd finger)
- Lateral (thumb vs side of index finger)
- Pulp Pinch (thumb vs index finger pad)

Direction of Effort
- Push
- Pull

Wrist Flexion or Extension Angle
0 deg is neutral.
- is extension, + is flexion

Distance Between Fingers
- this is the distance between the fingers and the specific value can be entered

Wrist Ulnar or Radial Deviation Angle
0 deg is neutral
- is radial, + is ulnar

Push or Pull: with Pinch Grips

Gender	Percent Capable ?	Units of Force
Female	75	newtons (N)

Frequency ?	Duration Range or Value ?	Specific Duration (s) ?
0.002	under 0.2 seconds (ie. snap)	0

Direction of Effort: Push

Type of Pinch: Chuck

Distance Between Fingers (mm) ?: 30
(150: max for Chuck & Pulp, 110: max for Lateral)
(35: optimal for Chuck & Pulp, 27: optimal for Lateral)

Wrist Flex/Ext Angle ?: -12
(-75 deg Ext to +75 deg Flex, -12: optimal)

Wrist Uln/Rad Angle ?: 0
(-25 deg Rad to +37 deg Uln, 0: optimal)

Calculate | **Max Acceptable Force = 62.3 N**

Pushes or Pulls with Oblique or Medial Grasps

The data of Cort et al (2006) were used to determine maximum forces for pushes with oblique grasps. That study measured strengths while pushing with the line of force directed through the elbow and shoulder, so that values would be limited by the ability of the hand to sustain a grip while pushing. As such, strength was not limited by shoulder or elbow joint strength. Consequently, the HandPak values, while acceptable to the hands, will often exceed the strength capacity of other joints. Thus, it is recommended that this software be used to determine the hand capacity, and other biomechanics software (eg. 3DSSPP) be used to evaluate the effect of the recommended force on other joints. In many cases, the final acceptable forces will be based on those other joints, and will be substantially lower than the HandPak value. Cort et all (2006) was also used to correct for surface (rubber or plastic) and for the aperture/diameter of the object interfacing with the hand. Diameter was found to have no effect on maximum push forces with a rubber coating, but corrections are made for diameter with a plastic coating. Maximum hand pushes can only be achieved with no moment arm at the shoulder and, to do this, the wrist has to be ulnar deviated. With any other wrist posture, there is a moment arm to the shoulder and the maximum force will undoubtedly be limited by the shoulder or elbow. Thus, no wrist posture effect was incorporated into the software.

Potvin et al (2005) studied 24 female subjects and determined maximum push strengths with oblique and medial grasps. These data were used to determine that medial grasp push forces are 94.3% of that for oblique grasp pushes. The data of Greig & Wells (2004) were used to estimate that male push and pull capacity was 60% higher than that for females.

The maximum strength values were assumed to be those acceptable for one second of effort per 8-hour work day. For more frequency efforts, the maximum acceptable effort (MAE) equation from Potvin (2012) was used to correct for the combination of effort frequency and effort duration (ie. duty cycle). See Appendix A for details.

Pushes & Pulls

Pushes or Pulls with Hand Grips

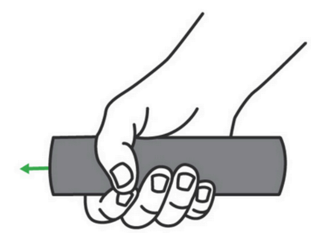
Push or Pull: with Hand Grips

Gender	Percent Capable ?	Units of Force
Female	75	pounds (lbs)

Frequency ?	Duration Range or Value ?	Specific Duration (s) ?
0.002	under 0.2 seconds (ie. snap)	0

Direction of Effort	Type of Grip
Push	Medial Grasp (power grip)

Grip Span (mm) ?	Surface Type ?
24	Rubber



Calculate | Max Acceptable Force = 34.3 lbs

Type of Grip
- Oblique Grasp
  - Thumb points in forward direction
- Medial Grasp
  - Thumb wrapped with other fingers

Direction of Effort
- Push
- Pull

Grip Span
- the specific value can be entered here in millimeters

Surface Type
Indicates the frictional properties of the object being pushed
- Rubber
- Plastic

Warning
The recommended forces from HandPak only indicate hand capabilities.
It is possible that this force may not be acceptable to some other joint.
Thus, biomechanical software should be used in conjunction with this module.

Appendix

Duty Cycle Effects

Generally, the maximum strength, or maximum voluntary contraction (MVC), values were used to represent acceptable forces for efforts performed for less than one second per day. For efforts with total durations greater than 1 second per 8 hour work day, further corrections were made based on an equation developed by Potvin (2012) fitted to a variety of psychophysical studies of the upper extremities.

Duty cycle (DC) refers to the total of effort durations divided by the cycle time. Based on 69 tasks from seven psychophysical studies of the upper extremities, Potvin (2012) calculated maximum acceptable efforts (MAE) by dividing average acceptable loads by single-effort maximum strength values for each task. An equation was developed to fit the relationship between MAE and DC and this took the form: $MAE = 1 - [DC - 01/28{,}800)^{0.24}$ ($r2 = 0.87\%$, RMS difference = 7.2% of the maximum). There are 28,800 seconds in 8 hours, so the equation allows for 1 second of 100% effort per day.

With psychophysical data available for only few upper extremity tasks, it is difficult for ergonomists to determine acceptable forces and torques for the large variety of repetitive tasks that exist in the workplace. The Potvin (2012) equation now allows for a scaling of the much more prevalent strength database to estimate acceptable load limits for repetitive occupational tasks, and it will have wide applications for ergonomic practitioners. For example, if an effort is performed 5 times per minute and each effort has an average duration of 0.75 seconds, this would have a duty cycle of (5 x 0.75) / 60 = 0.0625 such that:

$$MAE = 1 - [0.0625 - (1/28{,}800)]^{0.24} = 0.482 \text{ or } 48.2\% \text{ of maximum strength.}$$

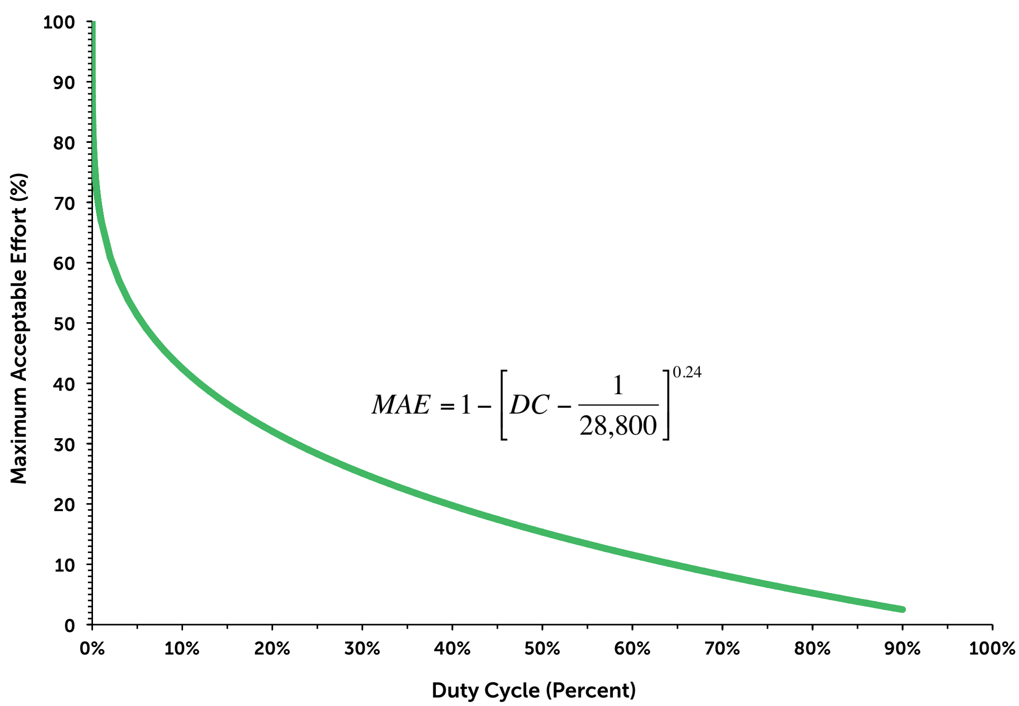
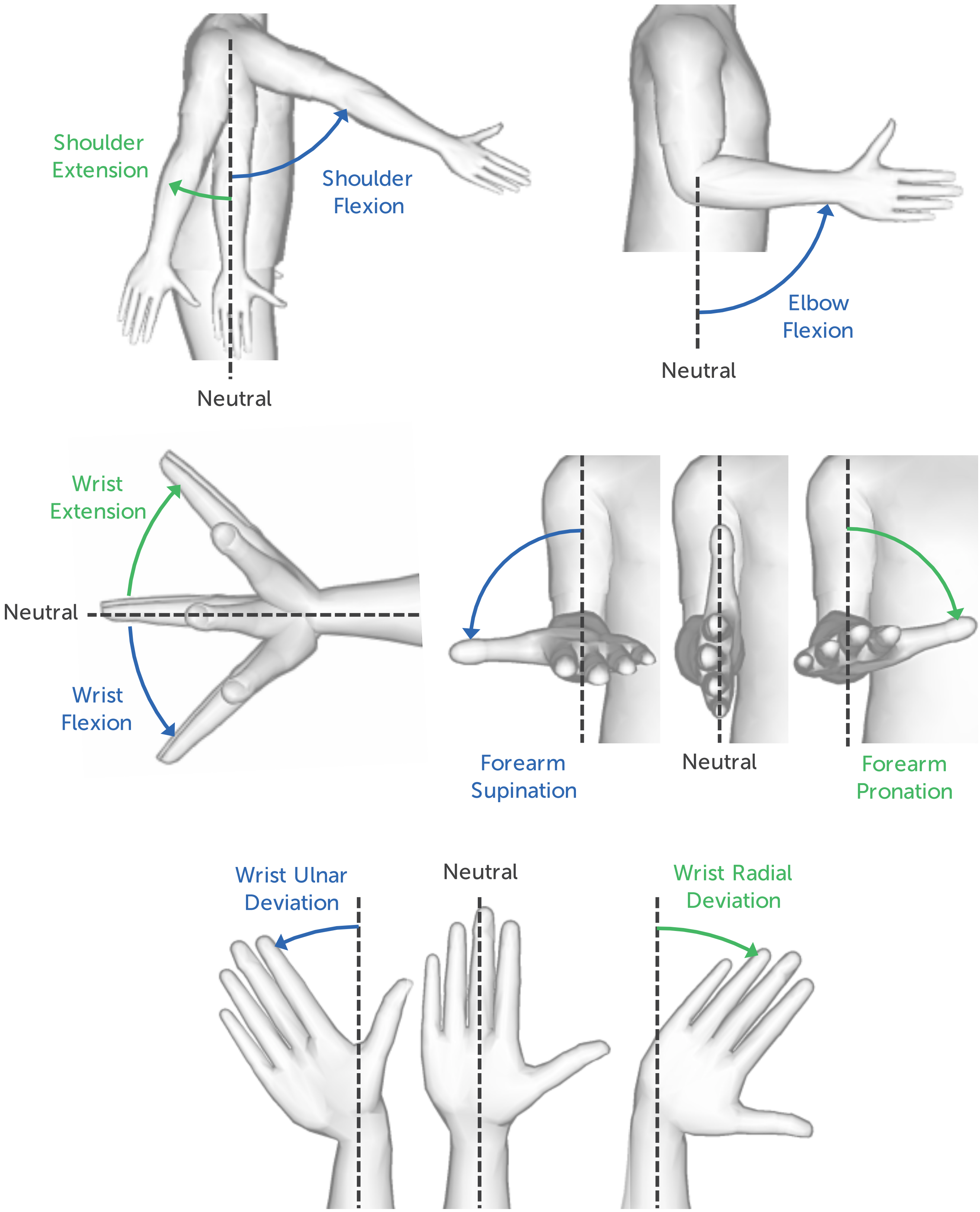


Figure 1: Summary of corrections for efforts with increasing duty cycles. Note the rapid decrease in MAE in the low duty cycle range.

Joint Posture Conventions



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