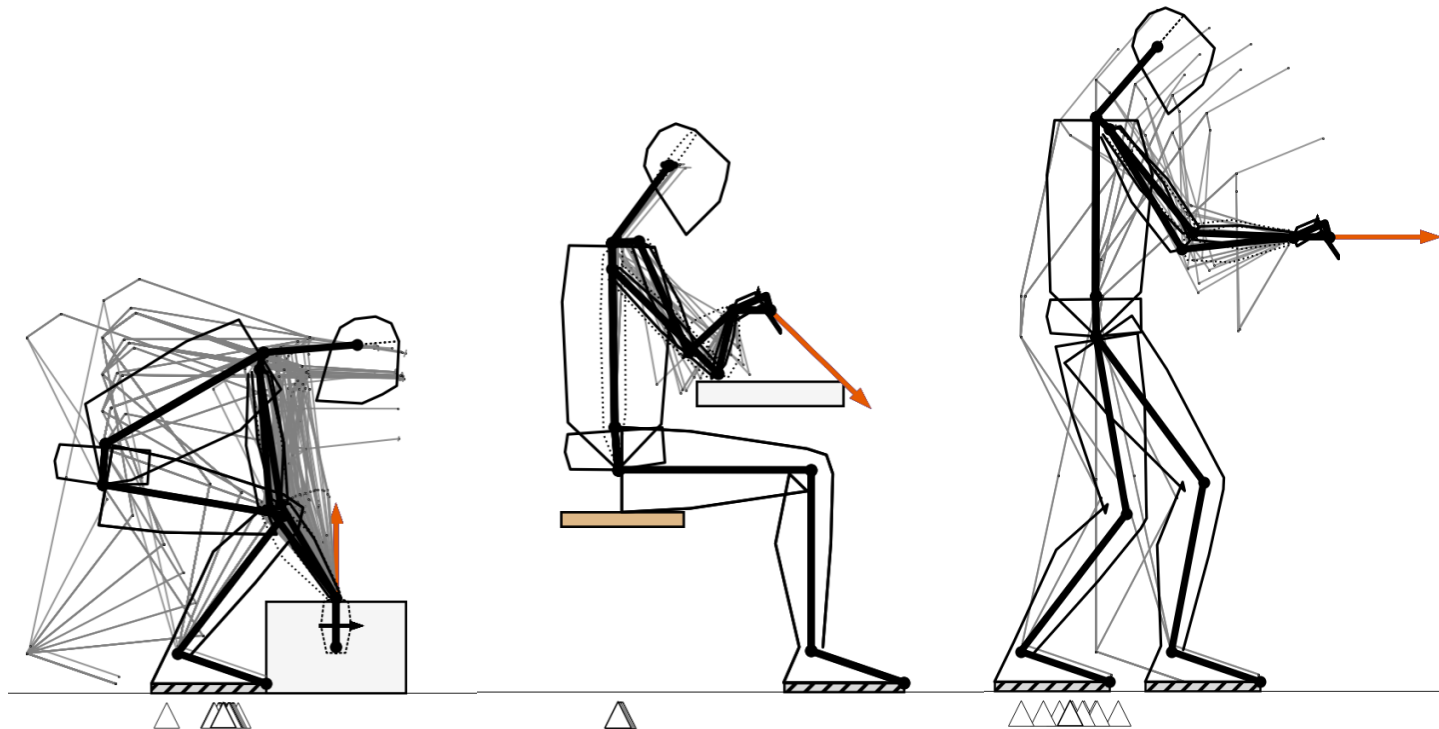


Work(s)

User Manual

Version 1.10

April 15, 2024



Copyright Notice

Copyright © 2023-2024 Work(s) Ergo Inc. All rights reserved.

Work(s)TM software and its accompanying documentation are protected by copyright laws and international copyright treaties, as well as other intellectual property laws and treaties. The software is licensed, not sold. The User is granted a limited, non-exclusive, non-transferable license to use the software for the purposes outlined in this User Manual. The User may not copy, modify, rent, lease, loan, sell, distribute, or create derivative works based on the software or any part thereof, except as expressly authorized in writing by the copyright owner. The User may not reverse engineer, decompile, or disassemble the software or otherwise attempt to discover the source code or trade secrets of the software. The User may not remove or alter any proprietary notices or marks on the software. The copyright owner reserves all rights not specifically granted in this agreement. Any unauthorized use may result in civil and/or criminal penalties. This copyright statement shall be governed by and construed in accordance with the laws of the jurisdiction in which the copyright owner is located. The User agrees to comply with all applicable laws regarding the use of the software. This copyright statement constitutes the entire agreement between the User and the copyright owner with respect to the use of the software and supersedes all prior or contemporaneous understandings, whether written or oral, between the User and the copyright owner.

Disclaimer of Warranties and Limitations on Liability

Work(s)TM software is provided "as is" without warranty of any kind, either express or implied, including but not limited to the implied warranties of merchantability, fitness for a particular purpose, and non-infringement. The company does not warrant that the software will meet the User's requirements or that the operation of the software will be uninterrupted or error-free. The User assumes the entire risk as to the quality and performance of the software.

In no event shall the company be liable for any direct, indirect, incidental, special, or consequential damages arising out of the use of or inability to use the software, even if the company has been advised of the possibility of such damages. The User acknowledges that the company shall not be responsible for any damages resulting from loss of data or from unauthorized access to the User's data. The User acknowledges that the company shall not be responsible for any damages resulting from the User's use of the software.

The User shall indemnify and hold harmless the company, its affiliates, and their respective officers, directors, employees, agents, and representatives, from and against all claims, demands, losses, damages, costs, and expenses, including reasonable attorney's fees, arising out of or in connection with the User's use of the software.

This agreement shall be governed by and construed in accordance with the laws of the jurisdiction in which the company is located.

This agreement constitutes the entire agreement between the User and the company with respect to the software and supersedes all prior or contemporaneous understandings, whether written or oral, between the User and the company.

The failure of the company to exercise or enforce any right or provision of this agreement shall not constitute a waiver of such right or provision.

If any provision of this agreement is found to be invalid or unenforceable, the remaining provisions shall remain in full force and effect.

Table of Contents

- Copyright Notice 2**
- Disclaimer of Warranties and Limitations on Liability 2**
- Introduction 6**
- Caution..... 6**
- Getting Started 6**
- Input Interface 7**
 - Load Inputs from a Work(s) Analysis Report 7**
 - Step 1: Target Population 7**
 - Sex..... 7
 - Unit of Measurement..... 7
 - Demand/Capacity Ratio Percentile 7
 - Body Mass Magnitude or Percentile 7
 - Stature Percentile 7
 - Percent Capable 7
 - Next Button 7
 - Step 2: Task Characteristics 8**
 - Task Type 8
 - Posture Location 8
 - Frequency 8
 - Effective Duration..... 8
 - Task Distance/Hip Height: 9
 - Step 3: Barrier Characteristics 9**
 - Depth 9
 - Top Edge 9
 - Bottom Edge 9
 - Left Edge..... 9
 - Right Edge 9
 - X Offset..... 9
 - Step 4: Hand Contact Locations 10**
 - Turn Off an Arm 10
 - Coordinates..... 10
 - Step 5: Force Parameters 13**
 - Hand Effort Directions..... 13

| | |
|---|-----------|
| Force Applied at Hands | 14 |
| Step 6: Hand Grip & Orientation | 15 |
| Hand Tasks..... | 15 |
| Knuckle Line | 16 |
| Palm Direction..... | 16 |
| Knuckle Line & Palm Direction | 17 |
| Span/Diameter | 18 |
| Gloves Used? | 18 |
| Surface Type..... | 18 |
| Step 7: Analysis Settings..... | 19 |
| Eye Gaze? | 19 |
| Above-Shoulder Correction? | 20 |
| Cumulative Compression Calculated?..... | 20 |
| Limit Trunk to Flexion/Extension?..... | 21 |
| Straight Legs?..... | 21 |
| Allow Body Bracing?..... | 22 |
| Task Name..... | 23 |
| Calculate Outputs | 23 |
| Feedback for Input Errors..... | 24 |
| Unavoidable Barriers | 24 |
| Center of Pressure Outside the Base of Support | 25 |
| No Feasible Wrist/Forearm Postures..... | 26 |
| Hand(s) Inside a Barrier..... | 27 |
| Hand(s) Placed Beyond the Reach Envelope | 28 |
| Outputs | 29 |
| Digital Human Models | 29 |
| Skeleton | 29 |
| Body Mass & Stature | 29 |
| Segment Anthropometry | 29 |
| Joint Range of Motion | 29 |
| Predicting a Full Range of Feasible Postures | 30 |
| Ergonomics Assessments..... | 31 |
| Hand, Wrist & Forearm Demands..... | 31 |
| Arm Demands | 31 |
| Neck Demands | 32 |
| Lumbar Joint Loading – Biomechanical Criterion | 32 |
| Manual Materials Handling – Psychophysical Criterion..... | 33 |

- Integrating Demand/Capacity Ratios 33
- Combining Multiple Subtasks 33
- Website Output Interface 34**
 - Composite View of Postures 34
 - Ranking of Demand/Capacity Ratios 35
 - Summary Table 36
 - Summary Table: Push & Pull 37
- Exported Excel Report 38**
 - DCR Graph 38
 - Summary Sheet 39
 - Cumulative Fatigue Analysis for Each Tasks 40
 - Cumulative Fatigue Analysis Across Subtasks 40
- References 41**
- Appendix A: Demand/Capacity Ratios 44**
- Appendix B: Effective Duration 47**
 - The Effective Durations of Manual Materials Handling Tasks 49**
 - Lift and Lower Tasks: 49
 - Push and Pull Tasks 49
 - Carry Tasks 49

Introduction

Work(s) Ergo Inc.™ is dedicated to producing task analysis software that is easy to use, while utilizing and fully integrating the most valid, science-based ergonomics assessment tools currently available. We believe that ergonomics must start to finally embrace the variability in task performance that we know exists (and is likely beneficial) both within and between workers.

Work(s)™ is a Software-as-a-Service (SaaS) application that represents the next quantum leap in the evolution of ergonomics assessment tools. Most current computerized ergonomics task analyses quantify work-related musculoskeletal disorders (WMSD) risk (1) from a single, user-defined posture, (2) often with outdated (and even unvalidated) analysis methods, and (3) require the user to integrate results obtained across the different metrics and methods.

Work(s) is unique because it assesses the full range of feasible postures for a task and integrates every assessment using the best ergonomics tools currently available to practitioners. We do this in the following ways for each task:

- 1) **Establish the full range of feasible postures:** Designed to assess a wide range of task types, Work(s) does not assume there is one posture but, instead, using our IntelliPose™ method it determines the full variety of postures that don't exceed joint range of motion, stability, and barrier constraints. No posturing is required by the user, and the inputs are simple, familiar, and easy to obtain.
- 2) **Perform ergonomics assessments on each posture:** For each of the postures determined (often thousands), Work(s) performs analyses with a full suite of the best existing, science-based ergonomics assessment tools.
- 3) **Integrate all assessments:** While each analysis tool has its own unique outputs, we convert the output from each into a common Demand/Capacity Ratio so the results can be fully integrated across assessment tools and easily interpreted, including the ability to combine subtasks to assess complex jobs.
- 4) **Export a detailed Excel report:** For each task assessment, all inputs, outputs, Demand/Capacity Ratios, and graphics are combined in an Excel report that can be exported to your computer. None of your task data are saved on our servers.

Caution

Work(s) should not be used as the sole determinant of the risk of WMSDs. The results from Work(s) should be combined with professional judgement, worker feedback, injury statistics and other criteria to evaluate occupational tasks. Before using Work(s), please read the Terms of Use at the beginning of this manual.

Getting Started

Work(s) can be accessed from the Work(s) Ergo Inc. [home page](#) by clicking "Work(s) Software" on the menu bar to get to the Work(s) software [landing page](#). Use the green "Log in to Work(s)™" button to access the [Login](#). Once logged in, you can go directly to the software with this [link](#), and that can be bookmarked. You will need a Work(s) account, Userid and password to access the software. If you have not obtained a license yet, please contact Work(s) Ergo at info@worksergo.com.

Input Interface

The Work(s) input interface sets the manikin anthropometry, task type, frequency, effective duration, grip/pinch types, hand orientations, force magnitudes & directions, and hand locations relative to the middle of the ankles. The user can also input the dimensions and locations of one or two barriers, set constraints for trunk and leg postures, indicate if there is body bracing, set if an above-shoulder correction will be used, and establish where the eyes will gaze. The inputs are done in the seven steps outlined below.

Load Inputs from a Work(s) Analysis Report

Each analysis results in an Excel Work(s) Report file summarizing all the inputs and outputs. This will be explained in more detail later. Previously saved Report files made after July 28, 2023 can be opened to populate all the Input fields.

Step 1: Target Population

Sex: Select a female or male manikin and capacities for analysis.

Unit of Measurement: Select metric or imperial units.

Demand/Capacity Ratio Percentile: The Demand/Capacity Ratio (ie. “D/C Ratio” or “DCR”) is simply the demand of the task relative to the assumed capacity to meet that demand, and it provides a unitless measure of WMSD risk based on the outputs from each of the ergonomics assessment tools used in Work(s). The DCR, and its percentile, are described in much more detail in Appendix A. We currently recommend that the 25th percentile D/C Ratio be used to represent the risk for each demand variable, across the many feasible postures for a given task.

Body Mass Magnitude or Percentile: One of three percentiles can be selected (5th, 50th and 95th) for the body mass of the digital human model, and these are associated with the Sex selected previously. Alternatively, the actual mass can be input, but must be within the range from the 1st to 99th female or male body mass. The ranges for Females are 45 to 138 kg (98 to 303 lbs), and for Males are 53 to 155 kg (or 117 to 341 lbs).

Stature Percentile: One of three percentiles can be selected (5th, 50th and 95th) to determine stature of the digital human model used in the analyses, and these are associated with the Sex selected earlier. More details are provided in the Outputs section.

Percent Capable: Within a population, there are a wide range of capacities for any type of demand. Further, for any specific demand, there will be a percentage of the population that is capable of meeting that demand, such that the remainder of the population would be incapable of meeting that demand. Most ergonomics analyses use the 75 percent capable value as the threshold for demand, meaning the acceptable demand is within the capabilities of 75% of the population but exceeds the capabilities of the “weakest” 25 percent of the population. The user can input any whole number from 5 to 95 percent.

Next Button: At the end of each step, clicking the “Next” button will engage the next step. You can also click on the down or up arrow on the right of the blue bar to open or close the next step, respectively.

Load inputs from a Work(s) Analysis Report

Step 1: Target Population

Sex, Units & Demand/Capacity Ratio Percentile

| | | |
|---|---|---------------------------------|
| Sex | Unit of Measurement | D/C Ratio %ile |
| <input checked="" type="radio"/> Female | <input checked="" type="radio"/> Metric | <input type="text" value="25"/> |
| <input type="radio"/> Male | <input type="radio"/> Imperial | |

Anthropometry & Percent Capable

| | | |
|--|-----------------------------------|---------------------------------|
| Body Mass Magnitude or %ile | Specify Body Mass (kg) | Stature %ile |
| <input type="text" value="Specific Mass"/> | <input type="text" value="75.0"/> | <input type="text" value="50"/> |
| 5th | | 1.62 (m) |
| 50th | | |
| 95th | | |
| <input type="text" value="Specific Mass"/> | % Capable | |
| | <input type="text" value="75"/> | |

Step 2: Task Characteristics

In this step, the user inputs variables like task typed, frequency, effort duration, and task distance (where applicable).

Task Type: The tasks in Work(s) are grouped as “Static Exertions”, including standing, seated or sit/stand efforts, or “Manual Materials Handling (MMH)”, including lift, lower, push, pull & carry tasks. MMH tasks will use the LM-MMH Equations, so must conform to their constraints (i.e. mostly in the sagittal plane, symmetrical bilateral hand forces and hand heights etc.). To assess MMH tasks with large trunk lateral bends and/or axial twists, and/or with asymmetrical hand forces, the Static Exertion Standing module should be used.

Posture Location: Currently, Work(s) will only perform a biomechanical analysis on the postures associated with one hand location. Now, for “Lift Load” and “Lower Load” task, the user must choose the Bottom or Top hand height for the posture analysis. This should be the hand height assumed to have the highest risk. If you are unsure, run Work(s) at both posture locations, and use highest Overall DCR. If both heights are run, the user will be able to use different hand orientations and/or barriers at each height.

Frequency: Work(s) uses the frequency of efforts per day, instead of frequency per minute, as it is easier to determine and does not depend on when the task efforts are performed. We use assessment tools that, where applicable, base their capacity limits on an 8-hour workday, assuming a total of 1 hour of breaks such that there are 7 hours (420 minutes) of work. Thus, work done for <7 hours will tend to have lower frequencies and higher limits, and work done for >7 hours will tend to have higher frequencies and lower limits.

Effective Duration: The fatigue caused by an effort will depend on the full-time history of the force or torque and can be approximated with the mechanical impulse, which is the area under the force-time curve. Since impulse = (force)(time), then time = (impulse)/(force). We define the effort by the peak force, so the “effective duration” is the impulse divided by the peak force. It is not sufficient to estimate the effective duration as the total duration the hand is in contact with the load. For manual materials handling tasks, the effective durations are now estimated for the user, based travel distance and data from the scientific literature and using either the horizontal or vertical distance travelled. More details about effective duration are provided in Appendix B.

Task Type Options: Standing, Seated (90° knee/hip), Sit/Stand, Lift Load, Lower Load, Push & Walk, Pull & Walk, Carry Load.

Form Fields:
 Task Type: Standing
 Posture Location: Bottom
 Frequency (efforts / day): 420.0
 Effective Duration (s / effort): 1.000
 Task Distance (ft): 10.0
 MMH Task Type: Push & Walk
 Hip Height (m): 0.7

Annotations:
 - Note: Frequency is per day, regardless of how long a shift may be.
 - This is the representative duration of each effort.
 - Used for Lifts or Lowers (referring to Posture Location).
 - Effective Durations are now estimated by Work(s) for all MMH Tasks.
 - If the Task Type in Step 1 is “Push & Walk”, “Pull & Walk” or “Carry Load”, the horizontal “Task Distance” must be entered.
 - If the Task Type in Step 1 is “Sit/Stand”, the vertical “Hip Height” must be entered.

Task Distance/Hip Height: For manual materials handling tasks where the worker is pushing, pulling, or carrying a load while walking, there is an additional input of average horizontal distance travelled each time the load is pushed, pulled or carried (in meters for metric, or inches for imperial). Similarly, when the task is “Sit/Stand”, the worker’s hip height must be entered.

Step 3: Barrier Characteristics

In this step, the user will define the dimensions of one or two rectangular physical barriers. All dimensions are in meters or inches.

Depth: The anterior length of the horizontal surfaces

Top Edge: Height of the vertical surfaces’ top edge

Bottom Edge: Height of the vertical surfaces’ bottom edge

Left Edge: Distance of the left side edge from the middle of the ankles. Negative is to the left and positive is to the right.

Right Edge: Distance of the right-side edge from the middle of the ankles. Negative is to the left and positive is to the right.

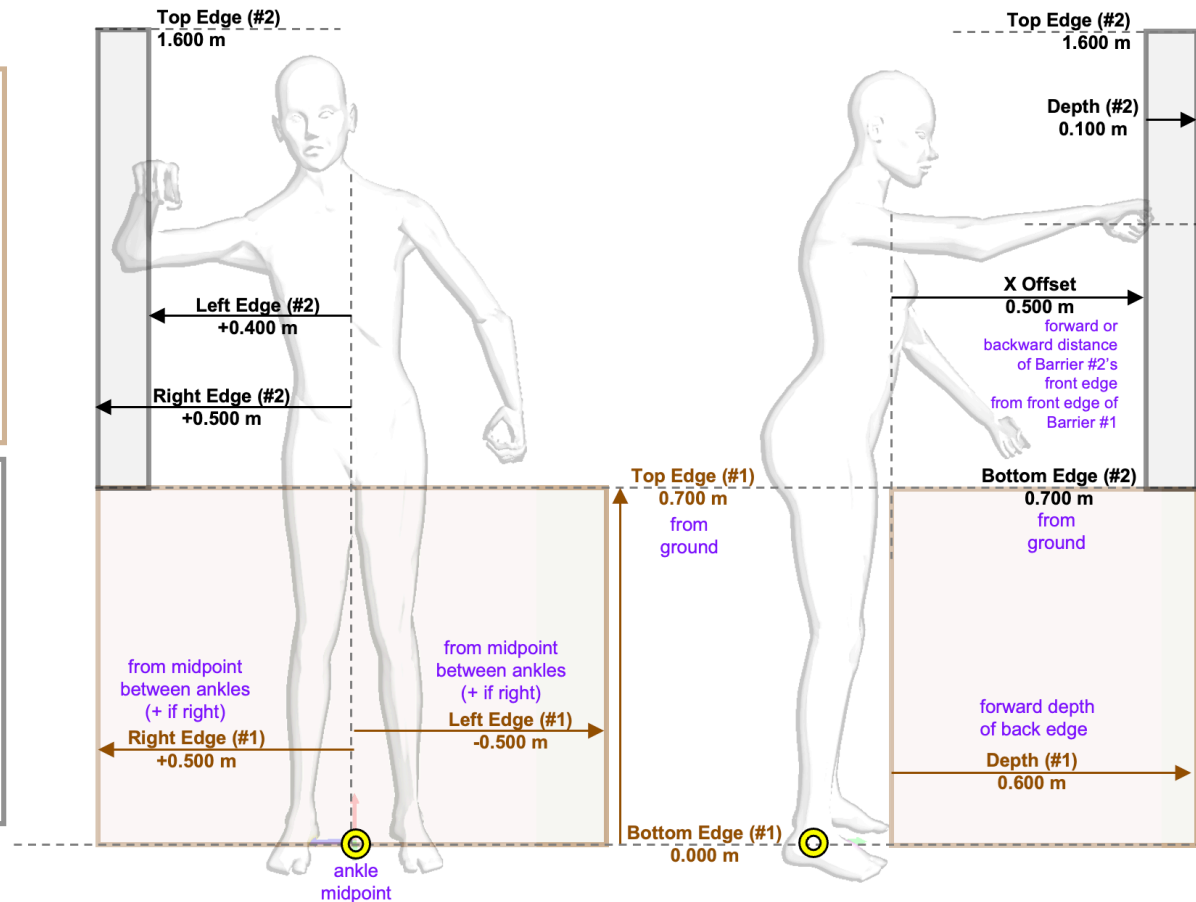
X Offset: For only Barrier #2 (if applicable), X Offset is the forward displacement of Barrier #2’s anterior vertical surface from Barrier #1’s anterior vertical surface. **Note: Barrier #2 cannot be posterior to Barrier #1.**

In the example below, Barrier #1 sits on the floor, with a height of 0.7 m, the left edge is 0.5 m to the left of the middle of the ankles and the right edge is 0.5 m to the right of the middle of the ankles. Barrier #2’s anterior vertical surface is 0.5 m forward of Barrier #1’s, and has a bottom height of 0.7 m and a top height of 1.6 m. It is located to the right of the middle of the ankles. Note that the manikin is only shown here (in a single posture) to provide a frame of reference. For each posture, we assume the manikin gets as close as possible to Barrier #1. When a barrier is present and Body Bracing (see below) is activated, v1.10 will add postures with the manikin standing further back and leaning forward on the barrier.

Step 3: Barrier Characteristics

| Barrier #1 | |
|---|---|
| Barrier #1 <input type="checkbox"/> | Depth (m) 0.600 <small>forward depth of back edge</small> |
| | Top Edge (m) 0.700 <small>from ground</small> |
| Left Edge (m) -0.500 <small>from midpoint between ankles (+ if right)</small> | Right Edge (m) 0.500 |
| | Bottom Edge (m) 0.000 <small>from ground</small> |

| Barrier #2 | |
|--|---|
| Barrier #2 <input type="checkbox"/> | Depth (m) 0.100 <small>forward depth of back edge</small> |
| X Offset (m) 0.500 <small>forward distance of front edge of Barrier #2 from front edge of Barrier #1</small> | Top Edge (m) 1.600 <small>from ground</small> |
| Left Edge (m) 0.400 <small>from midpoint between ankles (+ if right)</small> | Right Edge (m) 0.500 |
| | Bottom Edge (m) 0.700 <small>from ground</small> |



Step 4: Hand Contact Locations

In this step, the user defines the locations of the contact points of the hands, which depend on the hand grips/pinches that will be defined in Step 6. All units are in meters (metric) or inches (imperial).

Turn Off an Arm: Either the left or right arm can be turned off (but not both). If turned off, all relevant inputs for that arm are greyed out and Work(s) assumes that arm is placed at the side of the body.

Coordinates:

X: The X-axis is defined with Forward being positive and Backward being negative (in meters or inches). With no barriers, the forward locations of the hand contact points are taken with respect to the middle of the ankles. With at least one barrier, the forward locations are taken with respect to the anterior vertical surface of Barrier #1.

Y: The Y-axis is defined with Up being positive with respect to the ground

Z: The Z-axis is defined as Right being positive and Left being negative.

Step 4: Hand Contact Locations ^

Turning an arm off greys out the inputs and places its hand at the side

Turn Left Arm Off

Turn Right Arm Off

Left

Right

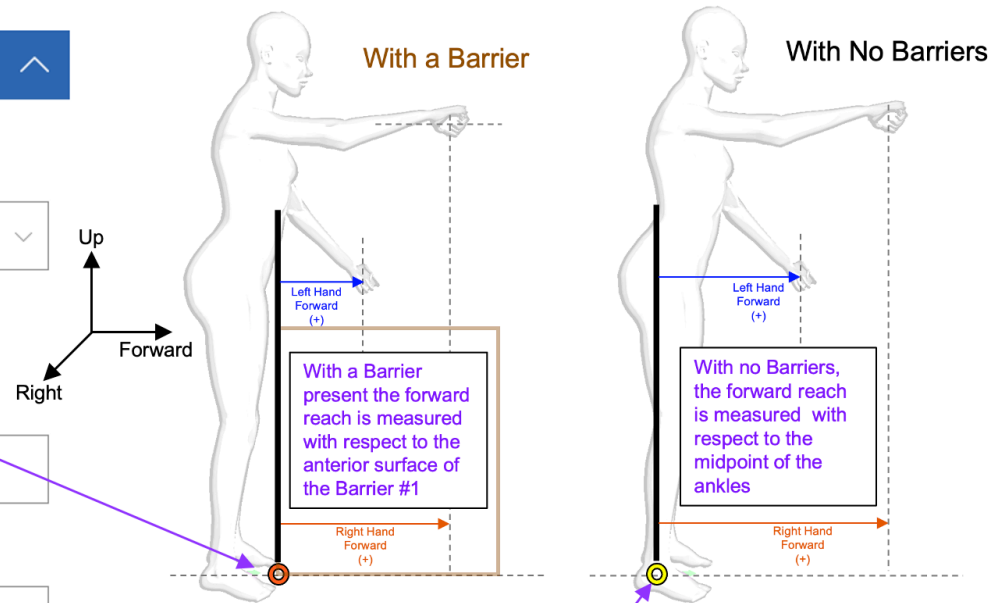
X (m): +Forward / -Backward

wrt Barrier #1 Front Edge

Y (m): +Up wrt the Ground

Z (m): +Right / -Left wrt the Middle of the Ankles

The forward distance from the ankle to the toe is assumed to be 0.20 m (Females) & 0.25 m (Males)



With no Barriers

X (m): +Forward

wrt Middle of Ankles

Y (m): +Up wrt the Ground

Z (m): +Right / -Left wrt the Middle of the Ankles

Step 4: Hand Contact Locations (continued)

Note 1: For Lift and Lower tasks only, the user must define the hand contact locations at the “Bottom” height (ie. the lower of the two heights, so the origin of lift or destination of lower) and the “Top” height (i.e.. the higher of the two heights, so the destination of lift or origin of lower). For Lifts and Lowers, the direction of the forces on the left and right hand (Step 5) are always assumed to be Up.

Note 2: For push, pull and carry tasks, only one hand height (Y) can be input. Also, for push and pull tasks, it is difficult to estimate what reaches would be used, so we’ve estimated the reach distances (X) based on data from Chaffin, Andres & Garg (1983). To use these modules, the tasks should occur mainly in the sagittal plane, with both arms applying the same force (so arms cannot be turned off in the MMH modules). In addition, for push, pull and carry tasks, the hand heights are limited to the ranges studied in the Liberty Mutual psychophysical studies.

Step 4: Hand Contact Locations

Lift & Lower Tasks are assumed to be 2-handed

| | |
|--|---|
| Turn Left Arm Off <input type="text" value="No"/> | Turn Right Arm Off <input type="text" value="No"/> |
|--|---|

| | |
|------|-------|
| Left | Right |
|------|-------|

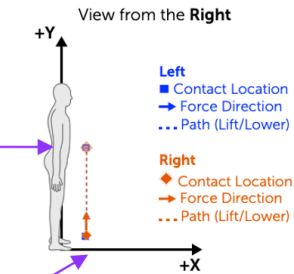
Top

| | |
|---|--|
| X (m): +Forward wrt Middle of Ankles <input style="width: 90%;" type="text" value="0.250"/> | <input style="width: 90%;" type="text" value="0.250"/> |
| Y (m): +Up wrt the Ground <input style="width: 90%;" type="text" value="1.000"/> | <input style="width: 90%;" type="text" value="1.000"/> |
| Z (m): +Right / -Left wrt the Middle of the Ankles <input style="width: 90%;" type="text" value="-0.200"/> | <input style="width: 90%;" type="text" value="0.200"/> |

Bottom

| | |
|---|--|
| X (m): +Forward wrt Middle of Ankles <input style="width: 90%;" type="text" value="0.250"/> | <input style="width: 90%;" type="text" value="0.250"/> |
| Y (m): +Up wrt the Ground <input style="width: 90%;" type="text" value="0.150"/> | <input style="width: 90%;" type="text" value="0.150"/> |
| Z (m): +Right / -Left wrt the Middle of the Ankles <input style="width: 90%;" type="text" value="-0.200"/> | <input style="width: 90%;" type="text" value="0.200"/> |

Hand Contact Locations & Force Directions



This graphic provides a visual verification of the input of the locations of the left and right hands

This is an example from a Lift or Lower task where the hand locations from the Top and Bottom of the movement are input

For Push & Pull tasks, the forward reach is estimated, and for Push, Pull & Carry both hands are assumed to be at the same height

| | |
|---|--|
| Left | Right |
| X (in): +Forward wrt Middle of Ankles <input style="width: 90%;" type="text" value="0.000"/> | <input style="width: 90%;" type="text" value="0.000"/> |
| Y (in): +Up wrt the Ground <input style="width: 90%;" type="text" value="0.000"/> | <input style="width: 90%;" type="text" value="0.000"/> |
| Z (in): +Right / -Left wrt the Middle of the Ankles <input style="width: 90%;" type="text" value="0.000"/> | <input style="width: 90%;" type="text" value="0.000"/> |

Step 5: Force Parameters

In this step, the user defines the hand effort directions and magnitudes. Currently, Work(s) only supports the input of linear forces (not moments/torques).

Hand Effort Directions: Force directions represent the direction that the force is applied by the hand, and can be entered as the absolute or relative magnitudes in each direction. As with hand contact locations, the X-axis is Forward (positive) and Backward (negative), the Y-axis is Up (positive) and Down (negative) and the Z-axis is Right (positive) and Left (negative). If an arm is turned off, the inputs are greyed out. Any combination of Forward/Back, Up/Down and Right/Left direction can be entered, though users will often enter simple combinations of -1.000 or 1.000 for 1, 2 or 3 axes. In the example inputs below, the force is equal parts Forward and Up for the left hand (blue arrow) and only Left for the right hand (orange arrow). Additional examples are provided in the table below on the right for the six primary directions and then some combinations of directions.

Force directions are assumed to be Up for Lift, Lower and Carry tasks, Forward for Push tasks and Backward for Pull tasks.

Step 5: Force Parameters

Hand Effort Directions

Left

Right

X: +Forward / -Backward

1.000

0.000

0.707

Forward & Up (Equally)

Y: +Up / -Down

1.000

0.000

0.707

Note: the unit vectors are shown below the box

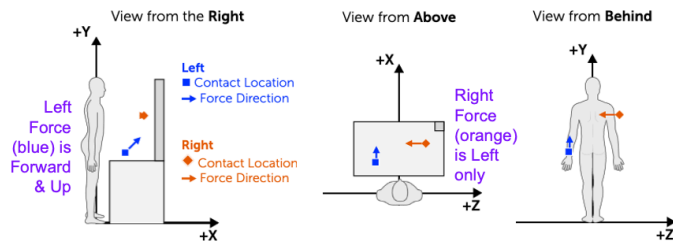
Z: +Right / -Left

0.000

-1.000 Left only

0

-1



Note: For previous users of Jack, Process Simulate, 3DSSPP and/or Santos, note that those packages require input of the direction of the force acting ON the hand(s) (ie. reaction forces), but Work(s) requires input of the direction of the forces applied BY the hand(s).

| Example | X | Y | Z |
|--------------------------------|----------|--------|--------|
| | Fwd/Back | Up/Dwn | Rt/Lft |
| Forward | +1.000 | 0 | 0 |
| Backward | -1.000 | 0 | 0 |
| Up | 0 | +1.000 | 0 |
| Down | 0 | -1.000 | 0 |
| Right | 0 | 0 | +1.000 |
| Left | 0 | 0 | -1.000 |
| Forward & Down (equally) | +1.000 | -1.000 | 0 |
| More Forward, some Up | +3.000 | -1.000 | 0 |
| Forward, Up and Left (Equally) | +1.000 | +1.000 | -1.000 |
| | +0.577 | +0.577 | -0.577 |
| | +27.5 | +27.5 | +27.5 |

Unit Vector
Actual Force

For the last example, equal forces in the Forward, Up and Right directions can be input as (1) the unit vector of +0.577 in each direction, or (2) as +1.000 in each direction, or (3) the actual force of +27.5 N in each direction.

Regardless of how the force combinations are input, the unit vectors are determined and used in any further calculations (and shown below the boxes).

Step 5: Force Parameters (continued)

Force Applied at Hands: The user must enter the force magnitudes in newtons (for metric) or pounds (for imperial).

For all manual materials handling modules, symmetry is assumed for the forces on the right and left hands, so only one total force is entered.

If the “Push & Walk” or “Pull & Walk” task is selected, the user must enter the total Initial force and total Sustained force.

Step 5: Force Parameters
^

Hand Effort Directions ⓘ

| Left | Right |
|-------------------------|--------|
| X: +Forward / -Backward | |
| 1.000 | 0.000 |
| 0.707 | 0 |
| Y: +Up / -Down | |
| 1.000 | 0.000 |
| 0.707 | 0 |
| Z: +Right / -Left | |
| 0.000 | -1.000 |
| 0 | -1 |

Force Applied at Hands

| Left (N) | Right (N) |
|----------|-----------|
| 35 | 30 |

Total Initial & Total Sustained Forces are required for “Push & Walk” & “Pull & Walk” Tasks

Force Applied at Hands

Total

| Initial Force (lbs) | Sustained Force (lbs) |
|---------------------|-----------------------|
| 150.0 | 0.000 |

Total Forces are required for “Lift Load”, “Lower Load” and “Carry Load” Tasks

Force Applied at Hands

Total (lbs)

150.0

This is where the magnitude of the forces are input (Newtons for Metric units, Pounds of force for Imperial units)

Step 6: Hand Grip & Orientation

In this step, the user defines the hand tasks, orientation of the hands (via the direction of the knuckles and the palms) and, where relevant, the span/diameter of the object, whether gloves are used and the surface type. Step 6 is where you enter the inputs for the HandPak™ assessment tool (Potvin Biomechanics Inc., Tecumseh, Ontario, Canada) embedded within Work(s) for the fingers, hands, wrists, and forearms. More details about HandPak™ are provided in the Outputs section.

Hand Tasks: The first step is to define the hand posture and grip used each hand. If one hand is turned off, it's column will be greyed out. The 23 interfaces are the same as in HandPak and include power grips, pinches, and finger and thumb interfaces to push or pull on an object. Graphics of the grip/pinch are provided as feedback above the input box after the hand task is selected. Each grip and pinch are shown below in the bottom right. **Note: HandPak is not invoked for the Power Grip or Flat Hand postures.**

Step 6: Hand Grip & Orientation

Left

Right

The grips/tasks for the left and right hand

| | |
|---------------------------------------|---------------------------------------|
| Hand Task | Hand Task |
| Push along cylinder: Oblique Grasp | Push along cylinder: Oblique Grasp |
| Knuckle Line (To Thumb Side) | Knuckle Line (To Thumb Side) |
| Forward & Up | Left |
| Palm Direction | Palm Direction |
| Right | Down |
| Span/Diameter (mm) | Span/Diameter (mm) |
| 30.000 | 30.000 |
| Gloves Used | Gloves Used |
| No | No |
| Surface Type | Surface Type |
| Rubber | Rubber |

Grip/pinch options

| | | |
|----------------------|--|------------------------------------|
| Generic (No HandPak) | Power Grip (Medial Grasp) Flat Hand | |
| Pinch | Lateral Pinch | |
| | Pulp Pinch | |
| | Chuck Pinch | |
| Push | Finger(s) | |
| | Tip of Index Finger | |
| | Pad of Index Finger | |
| | Tips of Two Fingers | |
| Thumb | Pad of Two Fingers | |
| | Tip of Thumb | |
| Cylinder | Pad of Thumb | |
| | Along cylinder/hose: Oblique Grasp | |
| Pull | Along cylinder/hose: Medial Grasp | |
| | Pinch | |
| | Lateral Pinch | |
| | Pulp Pinch | |
| | Chuck Pinch | |
| | Finger | 1 Finger - Tip |
| | | 1 Finger - Last Knuckle |
| | | 2 Fingers - Tips |
| | | 2 Fingers - Last Knuckles |
| | | 3 Fingers - Tip |
| | 3 Fingers - Last Knuckle | |
| | Cylinder | Along cylinder/hose: Oblique Grasp |
| | | Along cylinder/hose: Medial Grasp |

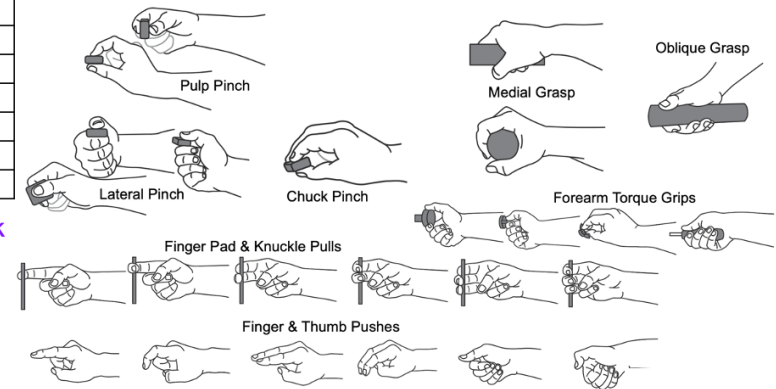
All grips associated with the HandPak linear force tasks are available for selection.

Currently, wrist and forearm torque tasks must be assessed in HandPak

Push or Pull: with Hand Grips

| | | |
|-----------------------------|---|-------------------------------|
| 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) |
| Direction of Effort Push | Type of Grip Oblique Grasp (thumb forward) | |
| Grip Span (mm) 24 | Surface Type Rubber | |

Integrating HandPak™




Step 6: Hand Grip & Orientation (continued)

Knuckle Line: The knuckle line direction is defined by the line through the knuckles towards the thumb side. This can be in the six primary directions (e.g. Forward) and the 12 directions between two of the orthogonal directions (e.g. Forward & Up, Right & Down, etc.). The table in the bottom left shows the 18 directions that can be selected. On the input interface, the three views under “Knuckle Line” show the selected knuckle direction as a dark black arrow, for visual verification.


Palm Direction: Once the knuckle line direction is selected, the user will be provided with four options for the Palm Direction. In the example below, the right knuckle line was input as “Forward & Up”, such that the four options for palm direction were “Forward & Down”, “Backward & Up”, “Right” and “Left”, of which “Right” was selected. Four examples of combinations of knuckle line and palm direction are shown below in the graphics on the right. More examples are provided on the next page.

Step 6: Hand Grips & Orientations

Left



Right



Hand Task

Push along cylinder:
Oblique Grasp

Push along
Oblique

Knuckle Line (To Thumb Side)

Forward & Up

Left

Palm Direction


Right

Down

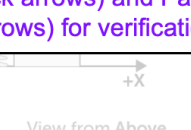
| Knuckle/Thumb Directions | Palm Directions | | | |
|--------------------------|-----------------|-----------------|-----------------|------------------|
| Forward | Up | Down | Right | Left |
| Backward | Up | Down | Right | Left |
| Up | Forward | Backward | Right | Left |
| Down | Forward | Backward | Right | Left |
| Right | Forward | Backward | Up | Down |
| Left | Forward | Backward | Up | Down |
| Forward & Up | Forward & Down | Backward & Up | Right | Left |
| Forward & Down | Forward & Up | Backward & Down | Right | Left |
| Forward & Right | Up | Down | Forward & Left | Backward & Right |
| Forward & Left | Up | Down | Forward & Right | Backward & Left |
| Back & Up | Forward & Up | Backward & Down | Right | Left |
| Back & Down | Forward & Down | Backward & Up | Right | Left |
| Back & Right | Up | Down | Forward & Right | Backward & Left |
| Back & Left | Up | Down | Forward & Left | Backward & Right |
| Up & Right | Forward | Backward | Up & Left | Down & Right |
| Up & Left | Forward | Backward | Up & Right | Down & Left |
| Down & Right | Forward | Backward | Up & Right | Down & Left |
| Down & Left | Forward | Backward | Up & Left | Down & Right |

Hand Contact Locations & Force Directions

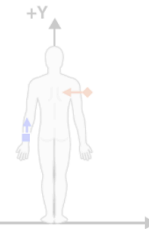
View from the Right



View from Above



View from Behind




When you get to Step 6, this graphic on the right appears, showing the input Knuckle Lines (black arrows) and Palm Directions (short blue and orange arrows) for verification

There are 4 Palm Direction options for each Knuckle Direction

Knuckle Line (To Thumb Side)

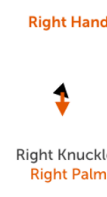
View from the Right

Left Hand




Left Hand
Knuckle Line
Forward & Up

Right Hand




Right Hand
Knuckle Line
Up & Left

View from Above




Left Hand
Knuckle Line
Up & Left




Right Hand
Knuckle Line
Down & Left

View from Behind




Left Hand
Knuckle Line
Up




Right Hand
Knuckle Line
Left

Left Hand



Left Hand
Palm
Right

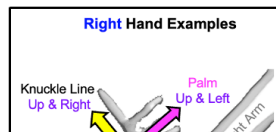
Right Hand




Right Hand
Palm
Down

Right Hand Examples

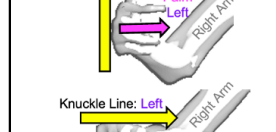
Knuckle Line Up & Right




Knuckle Line Up & Left



Knuckle Line Up

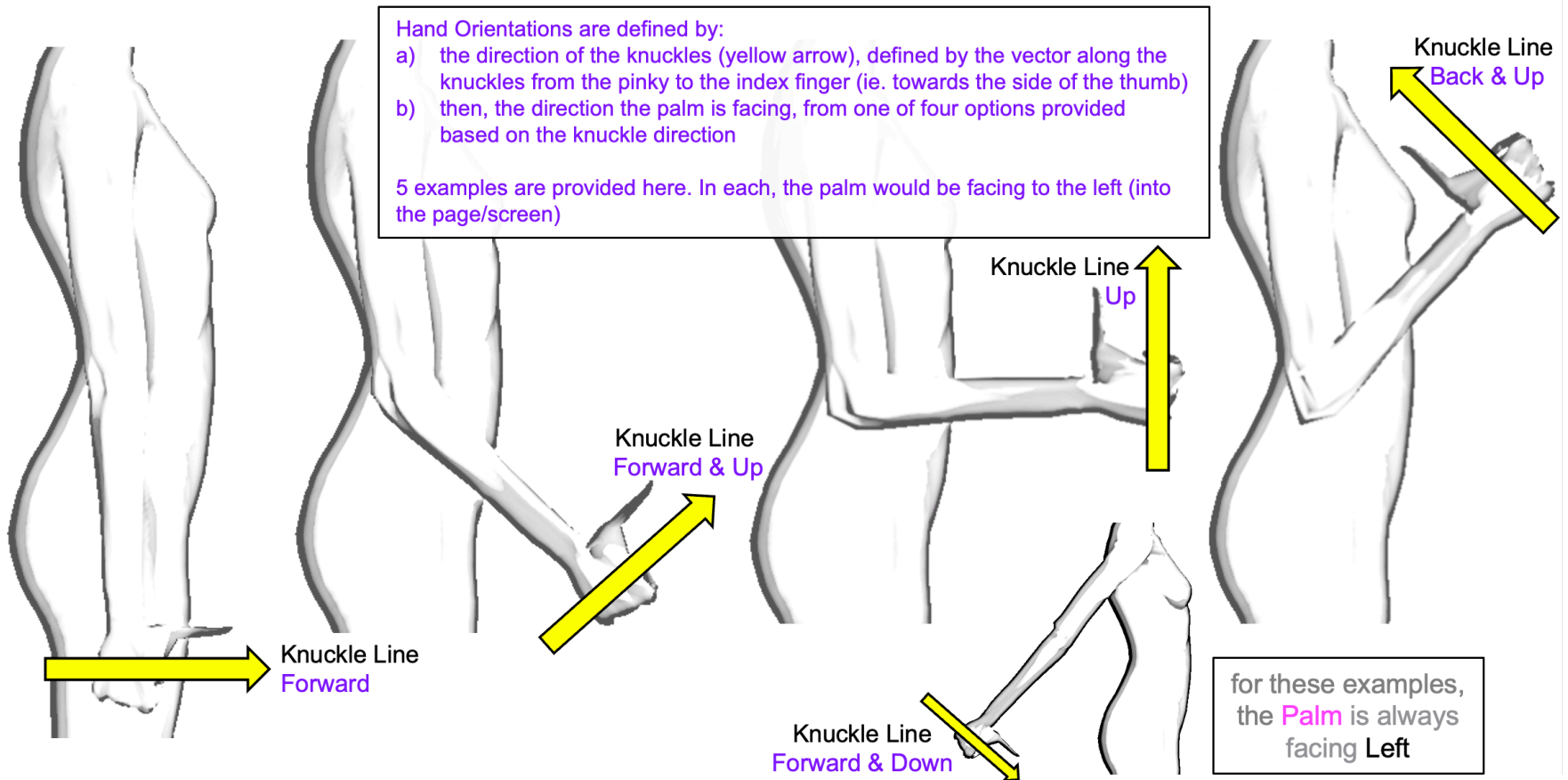


Knuckle Line: Left



Step 6: Hand Grip & Orientation (continued)

Knuckle Line & Palm Direction (continued)



Step 6: Hand Grip & Orientation (continued)


Span/Diameter: For some hand grips or pinches, the user will be asked to enter the span or diameter of the object being gripped or pinched. This represents the diameter of a power grip or the distance between the fingers for pinches (in mm for metric or inches for imperial).

Gloves Used?: For tasks involving pulling with the fingers, the user will indicate if gloves are worn.


Surface Type: For tasks involving pushing or pulling with a medial grip or oblique grasp, the user will input whether the surface is rubber (e.g. pushing along a hose) or plastic (e.g. pulling along a wire harness).

Step 6: Hand Grip & Orientation
^

Left



Right



| | |
|--|--|
| Hand Task | |
| <div style="border: 1px solid #ccc; padding: 5px; display: flex; justify-content: space-between;"> Push along cylinder: Oblique Grasp ▼ </div> | <div style="border: 1px solid #ccc; padding: 5px; display: flex; justify-content: space-between;"> Push along cylinder: Oblique Grasp ▼ </div> |
| Knuckle Line (To Thumb Side) | |
| <div style="border: 1px solid #ccc; padding: 5px; display: flex; justify-content: space-between;"> Forward & Up ▼ </div> | <div style="border: 1px solid #ccc; padding: 5px; display: flex; justify-content: space-between;"> Left ▼ </div> |
| Palm Direction | |
| <div style="border: 1px solid #ccc; padding: 5px; display: flex; justify-content: space-between;"> Right ▼ </div> | <div style="border: 1px solid #ccc; padding: 5px; display: flex; justify-content: space-between;"> Down ▼ </div> |
| Span/Diameter (mm) ⓘ | |
| <div style="border: 1px solid #ccc; padding: 5px; display: flex; justify-content: space-between;"> 30.000 ▼ </div> | <div style="border: 1px solid #ccc; padding: 5px; display: flex; justify-content: space-between;"> 30.000 ▼ </div> |
| Gloves Used | |
| <div style="border: 1px solid #ccc; padding: 5px; display: flex; justify-content: space-between;"> No ▼ </div> | <div style="border: 1px solid #ccc; padding: 5px; display: flex; justify-content: space-between;"> No ▼ </div> |
| Surface Type | |
| <div style="border: 1px solid #ccc; padding: 5px; display: flex; justify-content: space-between;"> Rubber ▼ </div> | <div style="border: 1px solid #ccc; padding: 5px; display: flex; justify-content: space-between;"> Rubber ▼ </div> |

Some hand grips/pinches require the input of some combination of the following:

- Span/Diameter (mm or inches)
- Are Gloves used (Yes or No)
- Type of Surface (Rubber or Plastic)

Step 7: Analysis Settings

In this step, the user indicates some additional analysis settings including the direction of the eye gaze, whether the above-shoulder correction will be used, if the body is bracing against a barrier, if the trunk posture will be limited to flexion/extension rotations, if the legs will be straight, and if the new cumulative compression variable will be used in the DCR scores (details about this below).

Eye Gaze?: The user can indicate if there is eye gaze directed towards (1) the hands, (2) an external target XYZ location, (3) the horizon, or (3) none. If the “Hands” are selected, the focal point will be between the hand contact locations, weighted to the force on each hand. If an “External” focal point is selected the user must indicate the XYZ coordinates, using the same reference system as used for the hand contact locations. If “Horizon” is selected, the head will remain upright, and if “None” is selected, the neck remains in a neutral posture with respect to the trunk.

Step 7: Analysis Settings

| | | | |
|---|--|---|-------------------------|
| Eye Gaze? Hands ▾ Hands External Horizon None | X (m) ⓘ 0.500 | Y (m) ⓘ 1.000 | Z (m) ⓘ 0.000 |
| ▾ | Cumul. Comp. Calculated? ⓘ Yes ▾ | Limit Trunk To Flex/Ext? No ▾ | |
| Body Bracing? None ▾ | Straight Legs? No ▾ | | |
| Task Name Task Name | | | |

Step 7: Analysis Settings (continued)

Above-Shoulder Correction?: Select “Yes” to turn on the above-shoulder correction using the method of Rempel & Potvin (2022), which calculates the manual arm strength from the Arm Force Field method of La Delfa & Potvin (2017), then estimates the glenohumeral angle based on the humerothoracic angle, and corrects the arm strength down as the glenohumeral angle increases from 60 to 90 deg. More detail is provided in the Outputs section.

Cumulative Compression Calculated?: We’ve recently developed a method to calculate the cumulative compression associated with repetitive peak lumbar compression forces. These can be used to assess isolated tasks or to combine the risk from multiple subtasks. More detail is provided in the Outputs section. If you don’t wish to incorporate this new measure into the DCR values calculated in the Work(s) output, then select “No” for this option.

Step 7: Analysis Settings

| | | | |
|----------------------------|----------------------------|--------------------------|---------|
| Eye Gaze? | X (m) ⓘ | Y (m) ⓘ | Z (m) ⓘ |
| External ▾ | 0.500 | 1.000 | 0.000 |
| Above-Shoulder Correction? | Cumul. Comp. Calculated? ⓘ | Limit Trunk To Flex/Ext? | |
| Yes ▾ | Yes ▾ | No ▾ | |
| Body Bracing? | Straight Legs? | | |
| None ▾ | No ▾ | | |
| Task Name | | | |
| Task Name | | | |

Step 7: Analysis Settings (continued)

Limit Trunk to Flexion/Extension?: It is not likely that there would be noticeable trunk axial twisting or lateral bending during tasks that have the following two characteristics;

- 1) symmetrical hand locations, on either side of the sagittal plane (ie. midline of the body.)
- 2) forces in the same direction with the same magnitudes.





In such cases, those off-axis rotations can be turned off so only trunk flexion/extension postures are evaluated. This is only suggested in cases where the hand locations and forces are mirrored on the sagittal plane. This will have two benefits:

- 1) reduce the processing time
- 2) eliminate feasible, but unlikely, asymmetrical postures with high risk from the DCR distributions.

Straight Legs?: The user can set the legs to be straight for tasks where they don't expect knee flexion or anterior/posterior spreading of the feet (eg. work done above the shoulder). As with limiting trunk rotations to flexion/extension, this will speed up the processing and eliminate postures deemed to be highly unlikely.

Step 7: Analysis Settings

| | | | |
|--|---|---|--|
| Eye Gaze? | X (m)  | Y (m)  | Z (m)  |
| External  | 0.500 | 1.000 | 0.000 |

| | | |
|---|--|--|
| Above-Shoulder Correction? | Cumul. Comp. Calculated?  | Limit Trunk To Flex/Ext? |
| Yes  | Yes  | No  |

| | |
|--|--|
| Body Bracing? | Straight Legs? |
| None  | No  |

Task Name

Step 7: Analysis Settings (continued)

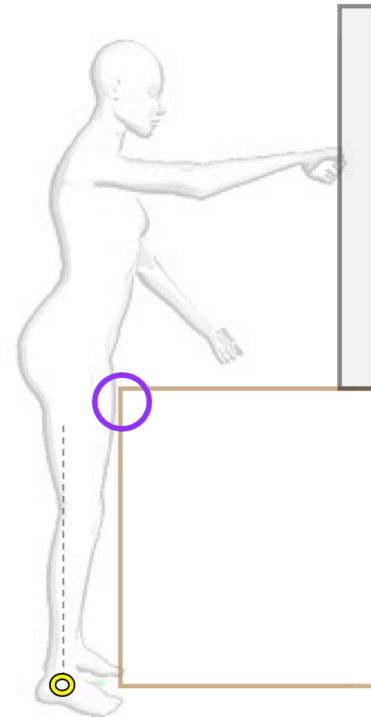
All Body Bracing?: “Bracing” occurs when the lower extremity or torso can come in contact with a barrier. Without body bracing, postures can be eliminated if the center of pressure moves forward of the base of the support. With body bracing, this constraint is removed as it is assumed that the barrier is providing sufficient support and stability. Bracing can be on the lower extremities (shown below) or the torso (in which case, the low back loading cannot be solved). Bracing should only be used when barriers are present.

Step 7: Analysis Settings ^

| | | | |
|---|--|--|--|
| Eye Gaze? | X (m) i | Y (m) i | Z (m) i |
| External v | 0.500 | 1.000 | 0.000 |

| | | |
|--|---|---|
| Above-Shoulder Correction? | Cumul. Comp. Calculated? i | Limit Trunk To Flex/Ext? |
| Yes v | Yes v | No v |

| | |
|---|---|
| Body Bracing? | Straight Legs? |
| None v | No v |
| None | |
| On Lower Extremities | |
| On Torso | |



Step 7: Analysis Settings (continued)

Task Name: Enter the Task Name as a code identifying the analysis. This code will appear in the Summary sheet of the Excel Work(s) report (described later). If the code is left blank, the Excel report file will be named “Work(s) Report” and will still be available for download at the Output interface (more details later).

Calculate Outputs: Once the inputs are finalized, click this button to calculate all outputs. After clicking, the window in the bottom right will appear indicating the progress during each step of the analysis. Once completed, the user can click on “View Outputs” and be taken to the Output page.

Step 7: Analysis Settings

^

Eye Gaze?

External
▼

X (m) ⓘ

0.500

Y (m) ⓘ

1.000

Z (m) ⓘ

0.000

Above-Shoulder Correction?

Yes
▼

Cumul. Comp. Calculated? ⓘ

Yes
▼

Limit Trunk To Flex/Ext?

No
▼

Body Bracing?

None
▼

Straight Legs?

No
▼

Task Name

Task Name

Calculate Outputs

Calculating Outputs

✕

Please wait. This may take several minutes. Do not refresh the page.

Task input parameters are valid. Maximum force solver is ENABLED.

Applying IntelliPose™ Methodology

Phase 1 of 5

Completed 0 percent of tasks

Phase 1 Completed

Phase 2 of 5

Completed 32 percent of tasks

Completed 64 percent of tasks

Completed 96 percent of tasks

Phase 2 Completed

Phase 3 of 5

Cancel

Feedback for Input Errors

The following examples illustrate the modes of feedback provided by Work(s) if input combinations are deemed to be unfeasible. The feedback is intended to identify potential input errors. In v1.1, if the hands are inside a barrier or beyond the reach envelope, the analysis will be stopped immediately, with feedback provided in the analysis window. For other input issues, Work(s) will provide input issue feedback on the “Output” screen and the user will have the option to save the Report file for future reference and troubleshooting.

Unavoidable Barriers

Outputs

Issues

Input Issue: The hand locations cannot be achieved without a collision with the barrier(s), given their size and/or location. Graphics provide a frame of reference for what the issue might be.

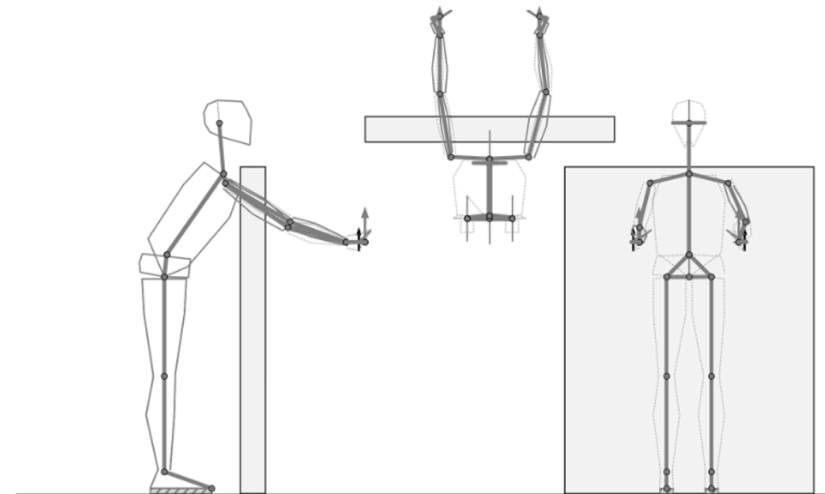
Solution: Check the accuracy of the barrier dimensions and/or the hand contact locations. Is the person really positioned in such a way that their hands contact directly behind the barrier.

Issue: Barrier Collision. It is not possible to avoid the Barrier(s) as defined. The arms, or head, have passed into or collided with one of the Barriers, as indicated in the image.

Most likely cause(s): Hand Grips and Orientations, Hand Contact Locations, Barrier Dimensions, Anthropometry

Additional potential cause(s): Straight Legs (if set to Yes), Limit Trunk to Flex/Ext (if set to Yes)

Download and consult the Report File to help determine the source(s) of the issue.



Center of Pressure Outside the Base of Support

Outputs

Issues

Input Issue: In this example, the combination of the hand locations and the very high push force demands, place the center of pressure (COP) behind the feet, such that there is no feasible stable posture. Specifically, given the high push forces input, the COP is at least 0.597 m behind the foot.

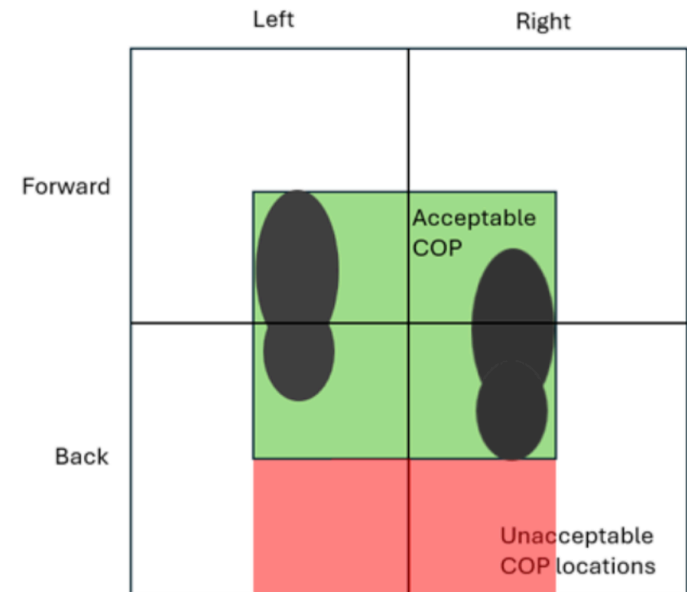
Solution: Check if the hands need to be that far forward for the push, and/or if the force magnitudes are really that high.

Issue: Center of Pressure. The estimated COP is behind the base of support by a minimum of 0.597 meters. The force on the hands may be rotating the body too far backward.

Most likely cause(s): Hand Contact Locations, Force Direction/Magnitude, Anthropometry

Additional potential cause(s): Straight Legs (if set to Yes)

Download and consult the Report File to help determine the source(s) of the issue.



No Feasible Wrist/Forearm Postures

Outputs

Issues

Input Issue: The left hand's orientation is not feasible for the hand contact location (i.e. the thumb side is pointing up and the palm is facing forward. Specifically, 100% of the postures violate both the wrist "Flx/Ext" and "Uln/Rad" ranges of motion (ROM).

Solution: Check the left hand's orientation. Should the left thumb really be pointing up (light blue arrow) with the palm facing forward (pink arrow)?

Issue: Range of Motion. At least one wrist and/or forearm ROM was violated for the right and/or left arm. The percentages of postures where the violation occurred about each wrist/forearm axis, are shown below:

Left Hand: Sup/Pro - 100 %, Uln/Rad - 100 %, Flx/Ext - 0 %

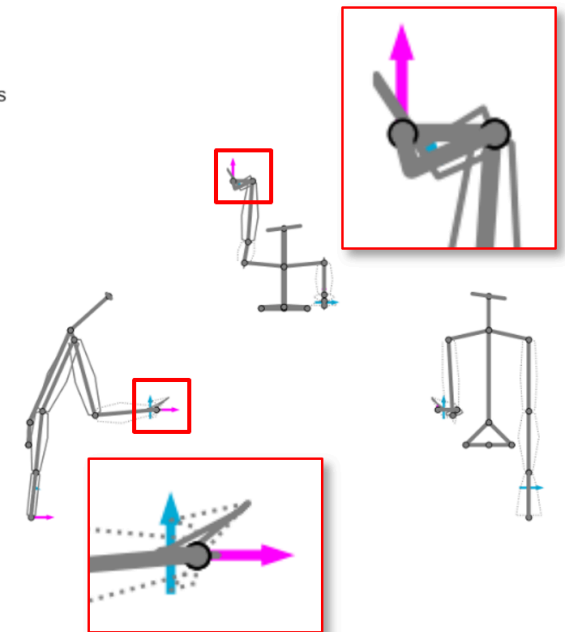
Right Hand: Feasible

Most likely cause(s): Hand Grips and Orientations, Hand Contact Locations, Barrier Dimensions, Anthropometry

Additional potential cause(s): Straight Legs (if set to Yes), Limit Trunk to Flex/Ext (if set to Yes)

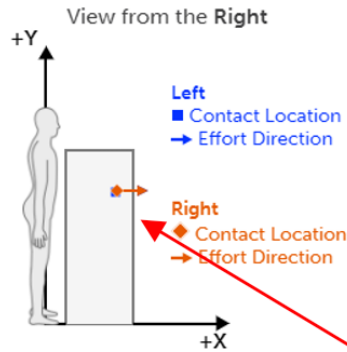
Download and consult the Report File to help determine the source(s) of the issue.

Knuckle Lines
Palm Directions

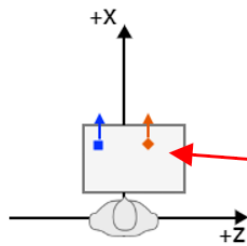


Hand(s) Inside a Barrier

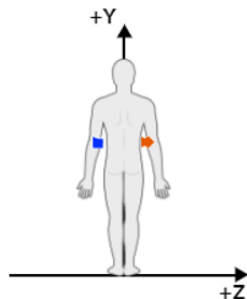
Hand Contact Locations & Effort Directions



View from Above



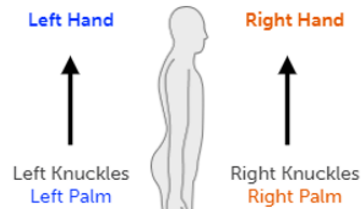
View from Behind



Knuckle Line

(To Thumb Side)

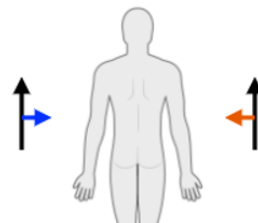
View from the Right



View from Above



View from Behind



Calculating Outputs

Work(s) Analysis Update

Work(s) could not finish processing. Please try again.

One, or Both of the Hands are located inside Barrier 1

There was an issue with the inputs used and Work(s) found no feasible solutions.

Cause: User Input Error. One, or Both of the Hands are located inside Barrier 1

Consider the following suggestions and constraint settings. Adjust where applicable to try and rectify the issue:

Primary Cause(s): Hand Contact Locations, Barrier Dimensions

Additional Factors: Hand Grips and Orientations

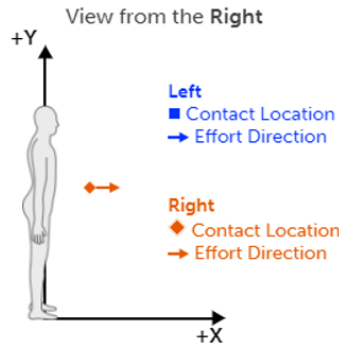
Please check/modify input settings, verify the changes in the graphical interface, and re-run the analysis.

Input Issue: In this example, both hands are located within a barrier, which is not possible.

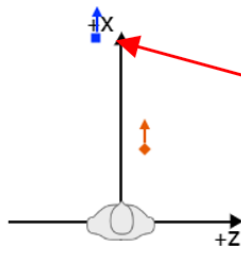
Solutions: Check the accuracy of the barrier dimensions & locations, and/or the hand contact locations.

Hand(s) Placed Beyond the Reach Envelope

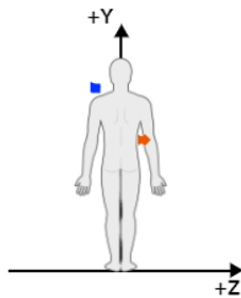
Hand Contact Locations & Effort Directions



View from Above



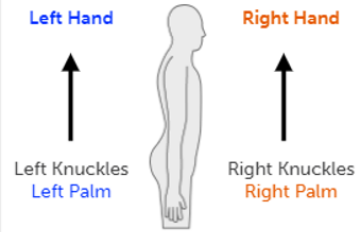
View from Behind



Knuckle Line

(To Thumb Side)

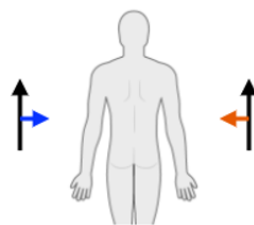
View from the Right



View from Above



View from Behind



Calculating Outputs

Work(s) Analysis Update

There was an issue with the inputs used and Work(s) found no feasible solutions.

Cause: Reach. The reach distances are exceeded by at least (in meters):

Left Hand: 0.137

Right Hand: OK

Consider the following suggestions and constraint settings. Adjust where applicable to try and rectify the issue:

Primary Cause(s): Hand Contact Locations, Barrier Dimensions, Anthropometry

Additional Factors: Hand Grips and Orientations, Straight Legs (if set to yes), Trunk (if limited to Flex/Ext only)

Input Issue:

In this example, the reach for the left hand is outside the feasible reach envelope. Specifically, the reach of the left hand is at least 0.137 m beyond its reach envelope.

Solutions:

check the accuracy of the left-hand contact locations. Is the left hand's forward distance really that high?

Outputs

Work(s) was designed to assess every posture and integrate every assessment for those performing ergonomics analyses of occupational tasks and jobs. To summarize, given hand locations, orientations, postures, interfaces and forces, Work(s) predicts the full range of feasible postures within the constraints of any physical barriers, all joint ranges of motion, and postural stability and balance. Then, a comprehensive ergonomics analysis is performed on a representative random sample of postures and the full distribution of risk scores, across postures, is fully integrated and summarized for the user. The following will briefly explain the process used by Work(s) to obtain its outputs.

Note: once every feasible posture is determined (sometimes >80,000 postures), a representative, randomly selected subset of those postures is selected for a full analysis with each assessment tool. This is necessary to substantially decrease the analysis time, but results in slightly different summary DCR values and graphics each time you run Work(s) with a particular set of inputs.

Digital Human Models

Skeleton

Work(s) uses a digital human model (DHM) with 15 rigid-linked segments, including bilateral feet, lower legs, thighs, hands, forearms, and upper arms, as well as a pelvis, trunk (from the L5/S1 to C7/T1 joints) and head/neck segments. The assumptions and data used for whole-body, segment and joint anthropometries are explained below.

Body Mass & Stature

The NHANES database from 2015-2018 (Fryar et al, 2021) was used to calculate average body masses and statures across the age groups from 20 to 69. Those values are summarized in metric and imperial units in the table below.

| | | Female | | | Male | | |
|-----------|-----|--------|-------|-------|-------|-------|-------|
| | | 5th | 50th | 95th | 5th | 50th | 95th |
| Body Mass | kg | 50.4 | 73.5 | 120.7 | 63.0 | 88.1 | 132.0 |
| | lbs | 111.1 | 162.0 | 266.1 | 138.9 | 194.2 | 291.0 |
| Stature | m | 1.506 | 1.619 | 1.727 | 1.634 | 1.758 | 1.874 |
| | in | 59.3 | 63.7 | 68.0 | 64.3 | 69.2 | 73.8 |

Segment Anthropometry

Values for segment masses (as a ratio of body mass), lengths (as a ratio of stature), shapes and centers of mass (as a ratio of segment length) are based on a compilation of data from the literature (Grenier, 1991; Buchholtz et al., 1992; Tilley, 1993; DeLeva, 1996; Durkin & Dowling, 2003; Chaffin et al., 2006). Unique forearm and upper arm segment length ratios were used for the 5th, 50th and 95th females and males, based on data from Fromuth & Parkinson (2008)

Joint Range of Motion

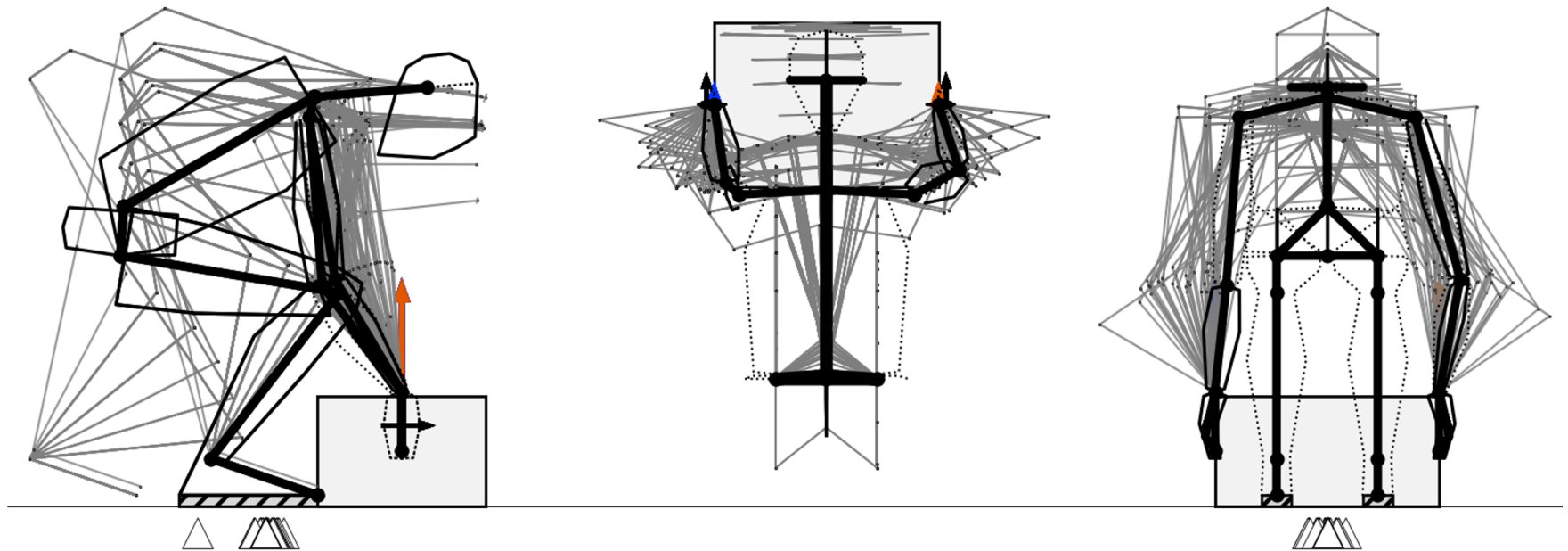
The range of motion of the ankle, knee, hip, lower back, neck, shoulder (including protraction during reaches), elbow, forearm and wrist joints were determined based on a compilation of data from 72 published studies.

Predicting a Full Range of Feasible Postures

Work(s) uses our IntelliPose™ method to determine a full range of feasible postures for each task, given the selected body mass percentile and stature percentile. The range of postures is determined by the hands' orientation, grip/pinch interface, and location relative to the middle of the ankles and that is combined with the hand force magnitudes and directions. All posture analyses are performed first with the pelvis height associated with upright, straight legs and then with additional combinations of lower pelvis heights and knee flexions, as well as anterior/posterior spreads of the right and left feet. We also evaluate postures with anterior and posterior displacement of the body. Once the pelvis location is established, we eliminate upper body postures that do not allow for the hands to reach the specified contact locations, then simulate a full range of combinations of low back, shoulder, elbow, forearm, and wrist postures. For each posture, once the trunk orientation and location are established, the neck posture is defined by the focal target (if defined by the user).

Posture and force combinations are eliminated if they result in (1) the overall center of pressure being outside the base of support, and/or (2) at least one segment surface marker that penetrates one of the barriers, and/or (3) at least one joint posture that exceeds a joint's range of motion constraints. For each task, what results from our IntelliPose™ method is often a set of tens of thousands of feasible postures - even with the constraints in place - highlighting the potential validity and reliability issues with most current ergonomics processes that typically rely on only one (or sometimes two) postures to solely represent the risk associated with a task.

The figure below illustrates a sample of 50 postures, out of a total of 26,653 feasible postures, for a task where a box lift is initiated from the ground. Note that a barrier was created to represent the box. Views are from the right (left), above (middle) and behind (right). Most postures are shown in grey, but one posture is shown with thicker black lines and the full segment shapes.



Ergonomics Assessments

Based on the total number of feasible postures for a task, we randomly sample a subset of postures for analysis with the ergonomics assessment tools according to the Dvoretzky–Kieffer–Wolfowitz inequality (Dvoretzky et al., 1956). The size of the posture subset considers the trade-off between speed and accuracy, but we use enough postures to ensure the accuracy of the calculated DCR values. It should be noted that multiple runs of the same inputs will result in the same total number of feasible postures, but with the random sampling method used, there will be slight differences in the DCR values and images with each run. With each sampled posture, Work(s) performs ergonomics assessments with a wide variety of the most current, science-based tools described below.

Hand, Wrist & Forearm Demands

For the distal upper extremities, Work(s) fully integrates the four push and pull modules of the HandPak™ software package (Potvin Biomechanics Inc., Tecumseh, Ontario, Canada). HandPak™ quantifies acceptable forces for occupational tasks placing demands on the forearms, wrists, hands and fingers, based on an integration of data from 32 published studies. The HandPak™ modules incorporated into Work(s) are (1) pulls with finger(s), (2) pushes with the finger(s) or thumbs, (3) pushes or pulls with pinch grips, and (4) pushes or pull with hand grips. Strengths are predicted based on factors such as location of contact on the finger(s)/thumb(s), glove use, finger clearance, interface characteristics, types of pinch/grip, aperture/span, surface type, direction of effort, wrist posture, elbow posture and shoulder posture. Those maximum strengths are further corrected using the duty cycle, from the frequency and duration of efforts, as input for the Maximum Acceptable Effort (MAE) Equation (Potvin, 2012) to calculate the maximum acceptable forces. In v1.1, we've now included HandPak analyses for power grip strength when the force is acting along the palm towards the wrist (eg. when the hands are hanging down and lifting up on a handle, or are horizontal and pulling).

The Hand/Wrist/Forearm Demand/Capacity Ratios (DCRs) are calculated for the left and right sides by dividing the linear forces applied at each hand by their maximum acceptable forces from HandPak™. Use this link to access the [HandPak™ web page](#), a Demo version of the software and the user manual for more details.

Arm Demands

To predict manual arm strength, Work(s) uses the Arm Force Field (AFF) method of La Delfa & Potvin (2017). To develop the AFF, female manual arm strengths were measured directly for up to 26 directions in 36 unique hand locations relative to the shoulder (536 conditions, 13,460 experimental trials). The resulting artificial neural network required only inputs of trunk and arm posture, hand location, force magnitude and force direction to predict manual arm strength and resulted in an overall RMS of only 6.4 N (1.4 lbs). The strengths from the AFF are further corrected using the duty cycle as input to the MAE Equation (Potvin, 2012) to calculate the maximum acceptable forces.

The Arm DCRs are calculated for the left and right sides by dividing the linear forces applied by each arm by their maximum acceptable forces from the AFF. Use this link to download the [La Delfa & Potvin \(2017\)](#) publication describing the AFF method in much more detail.

While the AFF accounts for maximum manual arm strength and the MAE Equation accounts for the fatiguing effects of duty cycle, the Above-Shoulder correction was developed by Rempel & Potvin (2022) to account for the additional risk factor of subacromial impingements of the supraspinatus muscle tendon when the upper arm rotates up above the shoulder. Since this is a new method, Work(s) includes it as an option in Step 7. Download [Rempel & Potvin \(2022\)](#) for more details.

Neck Demands

Flexion and extension neck strengths were estimated from a compilation of data from 5 published studies (Harms-Ringdahl & Schuldt, 1988; Jordan et al. 1999; Queisser et al. 1994; Seng et al., 2002; Vasavada et al., 2001) and corrected using the duty cycle input in the MAE Equation (Potvin, 2012) to calculate the maximum acceptable neck moment.

The Neck DCR is then calculated by dividing the neck flexion or extension strength demand by the maximum acceptable neck flexion or extension moment. Note that a more comprehensive neck analysis package is in the “work(s)”, including head-mounted loading and postural effects on strength, fatigue and discomfort.

Lumbar Joint Loading – Biomechanical Criterion

L5/S1 Peak Compression and Shear Force Demand: Peak lumbar compression and shear forces are important risk factors for WMSDs (Waters et al., 1991; Dempsey, 1998; Gallagher & Marras, 2012). For Work(s), the reaction forces (directly caused by the body segment weights and forces at the hands) are calculated at the L5/S1 joint then partitioned into shear and compression force components, assuming that the L5/S1 surface is rotated 34 deg forward of the anterior line perpendicular to the trunk (Gelb set al, 1995). The internal contribution of muscle forces to L5/S1 compression force are estimated with a method developed to estimate the single-equivalent moment arm with a 3rd order polynomial regression equation using the L5/S1 flexion/extension, lateral bend and axial twist moments as inputs ($r^2 = 0.87$, RMS error = 0.004 m, $n = 89$). The muscle compression is calculated with the resultant moment of force at L5/S1 divided by the single-equivalent moment arm estimate, and this is added to the compression component of the reaction force to calculate the total bone-on-bone compression force at L5/S1 ($r^2 = 0.95$, RMS error = 342 N, $n = 89$).

Lumbar Peak Compression Force Limits: Jäger (2023) summarized the raw compression strength data from 510 lumbar spine specimens (205 female, 305 male) (see his Table 5.12 on p 547–569). We analyzed these data to estimate the mean and standard deviation of the ultimate strength (US) for the L5/S1 joint of females and males for any age from 20 to 70 years. The calculations in Work(s) are based designing for 42 years of age, as that is the mean age of North American labourers. The yield point was set at 82% of the compression ultimate strength based on Yoganandan et al. (1989), such that the peak compression force limits were 3,500 and 4,364 N for females and males, respectively. The Peak Lumbar Compression DCR is calculated by dividing the peak lumbar compression force by the relevant peak compression force limit.

Lumbar Cumulative Compression Force: In v1.1, we’ve added a calculation of cumulative compression for each task based on a new method developed by Work(s) Ergo Inc., using on the raw data of Brinckmann et al. (1988). Brinckmann and colleagues tested a total of 70 joints (from 35 specimens) with repetitive loads up to 5,000 cycles. Load magnitudes were set based on assumptions of ultimate stress (US). A Weibull analysis was used to determine representative C2F values for the following four ranges: 50-60, 60-70, 70-80, 80-90 %US. A function was created to transform the average of the peak %US values from each range (~55, ~65, ~75 and ~85%) so that, when multiplied by the C2F, the product was 1.00, which was set to be the threshold limit value (TLV). The resulting equation estimates the cumulative compression for any combination of (1) frequency (F), and (2) peak lumbar compression force represented as a percentage of the relevant ultimate strength (%US). Values >1.00 are unacceptable and cumulative compression values can be summated across tasks to calculate an overall cumulative compression. The overall lumbar compression DCR is calculated as the maximum of the peak compression DCR and cumulative compression DCR.

Manual Materials Handling – Psychophysical Criterion

The Liberty Mutual Insurance psychophysical data of Snook (1978) was an important foundation of the original NIOSH Lifting Equation (NIOSH, 1981). After the tables were updated by Snook & Ciriello (1991), they were incorporated into the Revised NIOSH Lifting Equation (Waters et al., 1993). After 1991, there were no more published updates to the Snook & Ciriello Tables, but manual materials handling research continued at the Liberty Mutual Center for Safety & Health and Vince Ciriello published 12 more studies, with the last in 2011. These data were combined with that from the previous 7 publications used for the Snook & Ciriello Tables (19 publications, 388 unique conditions, 1,788 trials) to create the Liberty Mutual Manual Materials Handling (LM-MMH) Equations published in Potvin, Ciriello, Snook, Maynard, Brogmus, (2021). The resulting 14 equations (7 each for females and males) are integrated into Work(s) to calculate maximum acceptable loads for lift, lower, push (initiate and sustained), pull (initiate and sustained) and carry tasks. Download [Potvin et al., \(2021\)](#) for more details.

The LM-MMH Equation DCR is calculated by dividing the total force at the hands by the maximum acceptable load. For push and pull tasks, the DCR is calculated as the higher of the initiate DCR and sustained DCR.

Integrating Demand/Capacity Ratios

For each feasible posture determined for a given task, Work(s) calculates 7 DCRs, including the lumbar compression force, neck demands, LM-MMH Equation, as well as the left and right hand/wrist/forearm and manual arm demands. An Overall DCR is also calculated for each posture, representing the highest (ie. weakest link) of the 7 DCRs. This provides a single value to represent the risk for each posture and, using the DCR Percentile cutoff set by the user, this can also provide a single value to represent the risk for all feasible postures for a given task. Appendix 1 provides an example of how the Overall DCR would be calculated from 2 of the 7 variables (right arm and lumbar compression force), to illustrate this concept.

Combining Multiple Subtasks

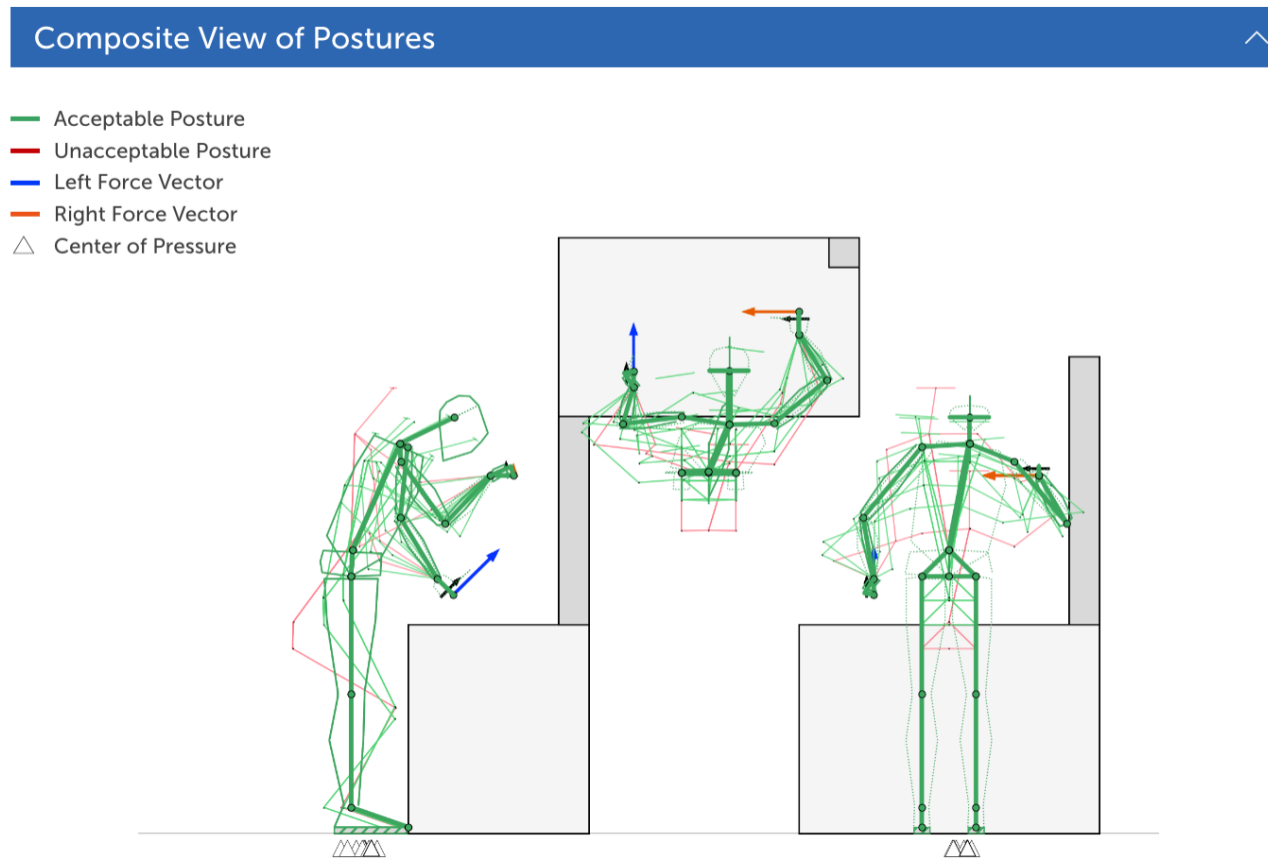
Work(s) is designed to assess individual tasks, with specific hand locations, force characteristics, frequency, and effort duration. However, many jobs include multiple subtasks and confirming that each task is acceptable in isolation does not confirm that the combination of all subtasks is also acceptable. Gibson & Potvin (2016) developed the Recommended Cumulative Recovery Allowance (RCRA) method to allow for the combination of risk across tasks placing demands on similar muscle groups. They rearranged the MAE Equation to solve for recovery allowance, when effort, frequency and effort duration are known, such that the recovery allowance from each subtask can be summated across task to ensure that the total recovery duration needed is not greater than the recovery duration provided (after the total effort duration is accounted for). We've replaced the RCRA method with a new variable to calculate "Cumulative Fatigue", which has a TLV of 1.00 and is easier to interpret and more intuitive than the RCRA, but results in the same decision of acceptable/unacceptable within isolated tasks and across multiple subtasks. In addition, the Cumulative Compression values are compiled in the Report so they can be combined in a "Work(s) Cumulative Task Analysis Template.xlsx" file which can be obtained on request. This is explained in more detail in the "Exported Excel Report" section.

Website Output Interface

There are two modes of output when a task assessment is run in Work(s). The first is the website output pages and the second is an Excel Work(s) Report file that can be exported to the user's hard drive (explained below). The following website outputs are presented for each assessment.

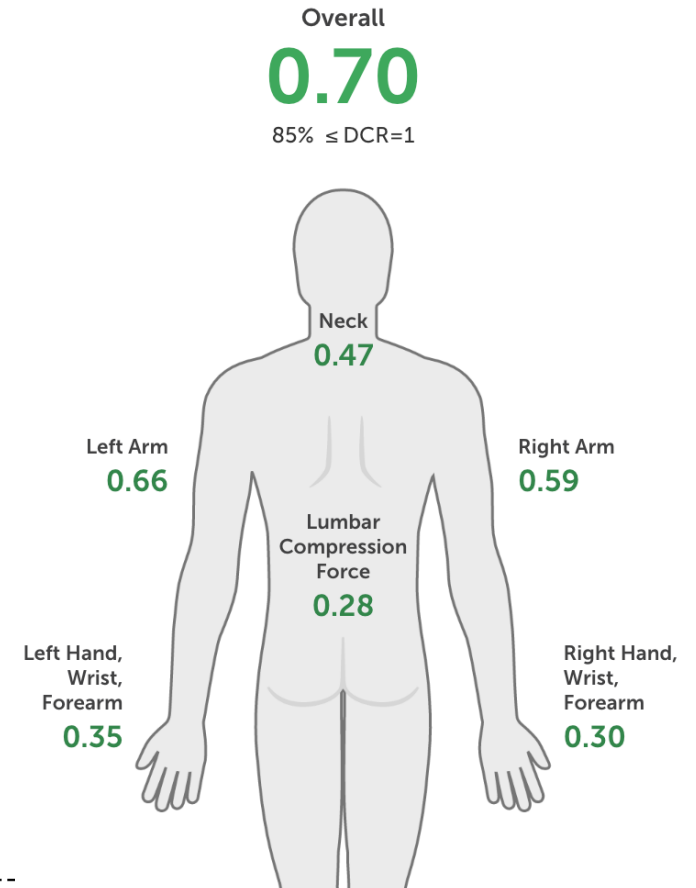
Composite View of Postures

After clicking the "View Outputs" button, the Work(s) Outputs page is presented on the website. The first section shows three views of postures associated with Overall DCRs at the 10th to 90th percentile (in increments of 10%) and at the DCR Percentile selected by the user in Step 1 (25th in this example), shown with segment shapes and thicker lines. Postures with an Overall DCR ≤ 1.0 are shown with green lines and those with an Overall DCR > 1.0 are shown with red lines. A view from the right is shown on the bottom left, a view from above is shown in the middle and a view from behind is shown on the right. The black arrows on the hands indicate the knuckle line directions, the blue arrow indicates the left hand's force direction, and the orange arrow indicates the right hand's force direction. The centers of pressure are shown as triangles under the feet. Barrier #1 is shaded in lighter grey and Barrier #2 is shaded in darker grey.



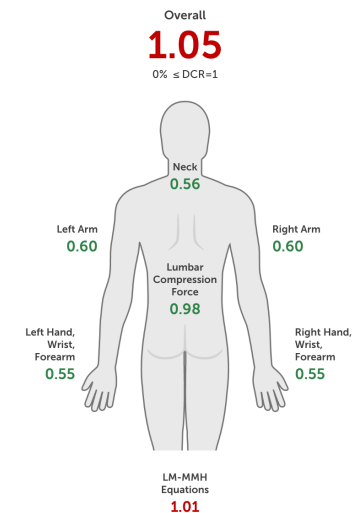
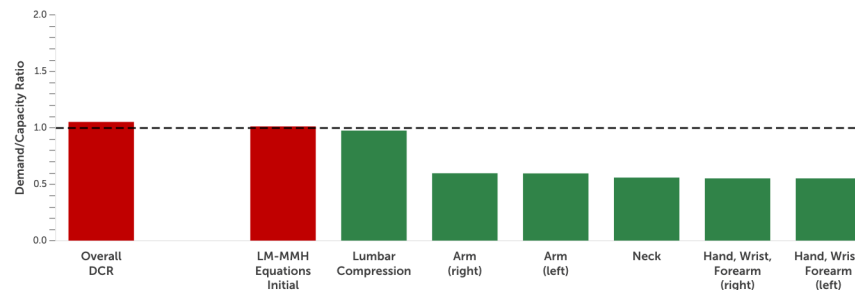
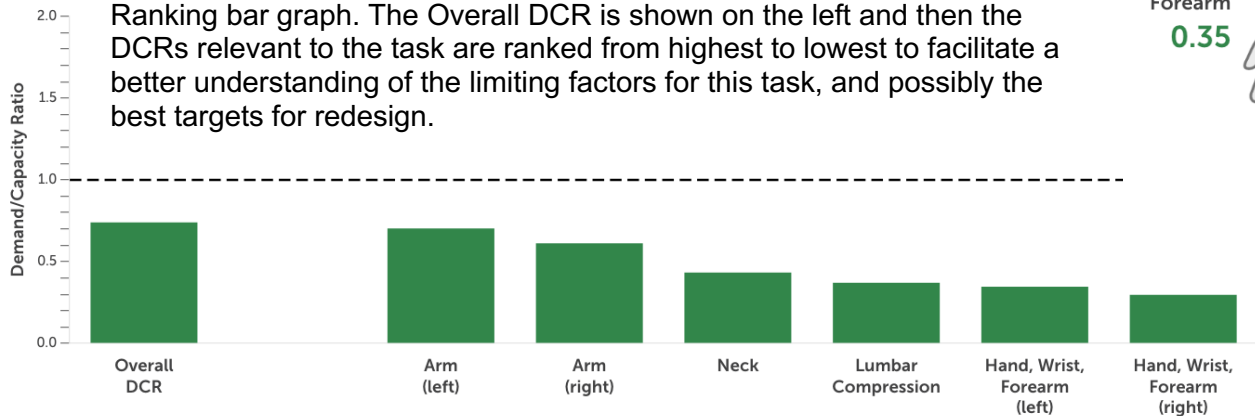
Body Map of Demand/Capacity Ratios (DCRs)

For each task, there will be a range of DCR values for each risk variable. The DCR Percentile cutoff set in Step 1 determines the DCR value that will represent each risk variable. We recommend that the 25th percentile be used as the and that is what is used in this example. The DCRs at the percentile cutoff are then presented on the body map shown to the right. As explained in Appendix A, the Overall DCR at the DCR Percentile cutoff will often be higher than the highest of the DCRs across the risk variables. In this case, the highest individual DCR is 0.66 for the Left Arm, but the 25th percentile Overall DCR is higher at 0.70. In addition, Work(s) determined that 85% of the 84,319 postures assessed for this task had Overall DCR values ≤ 1.0 , and this variable may prove to be a valuable metric for assessing the risk for tasks across the full range of feasible postures. Note that this sample task was a static exertion. Manual materials handling tasks (lift, lower, push, pull and carry) will also have a LM-MMH Equation DCR value below the legs. An example for lifting, with some DCRs > 1.0 and the LM-MMH Equation DCR is shown in the bottom right.



Ranking of Demand/Capacity Ratios

The same data shown on the DCR body map are also shown in the DCR Ranking bar graph. The Overall DCR is shown on the left and then the DCRs relevant to the task are ranked from highest to lowest to facilitate a better understanding of the limiting factors for this task, and possibly the best targets for redesign.



Summary Table

The Summary tab of the Output interface presents the demands for each risk variable (associated with to the DCR Percentile cutoff selected in Step 1), the maximum strength capacities (for a single effort) and the maximum acceptable forces (based on the duty cycle) for Hand/Wrist/Forearm (from HandPak™), the Arm (from the AFF), and Neck. All demands are calculated based on the “D/C Ratio %ile” selected in Step 1 of the Inputs.

Near the bottom of the table, the “Max. Acceptable Total Force” is presented, but only for tasks where the force magnitudes and directions are the same on the right and left hands.

The number of feasible solutions is shown at the bottom of the first column and the joint axis strength demands are shown on the right.

| Summary | | Results | |
|---|-------------|--------------|--------------|
| Analysis Tool Results | | | |
| Arm (N) | Left | Right | |
| Demand | 35.0 | 30.0 | |
| Strength | 84.8 | 77.8 | |
| Max. Acceptable Forces | 53.0 | 49.7 | |
| Hand, Wrist & Forearm (N) | | | |
| Demand | 35.0 | 30.0 | |
| Strength | 161.5 | 161.5 | |
| Max. Acceptable Forces | 101.1 | 101.1 | |
| Low Back (L5S1 Joint) (N) | | | |
| Shear Force Resultant Demand | | | 183 |
| Compression Force Demand | | | 1,086 |
| Max. Compression Strength | | | 3,856 |
| Cumulative Compression Demand | | | 0 |
| Cumulative Compression TLV | | | 1 |
| Neck (Nm) | | | |
| Resultant Demand | | | 7.2 |
| Max. Resultant Strength | | | 25.9 |
| Max. Acceptable Torque | | | 16.2 |
| Liberty Mutual MMH Equations (N) | | | |
| Demand | | | 65.0 |
| Max. Acceptable Load | | | NA |
| Total Force (N) | | | |
| Total Force | | | 65.0 |
| Max. Acceptable Total Force | | | NA |
| Feasible Simulated Postures | | | 84,319 |
| Joint Strength Demands (Nm) | | | |
| Joint | -/+ | Left | Right |
| Wrist | Ext / Flex | -0.1 | -0.2 |
| | RD / UD | -2.6 | -2.1 |
| | Sup / Pro | -1.1 | -0.9 |
| Elbow | Ext / Flex | 3.6 | 1.9 |
| Shoulder | Ext / Flex | -3.8 | 9.1 |
| | AD / AB | 5.8 | -2.7 |
| | Int / Ext | 3.1 | -1.6 |
| Neck | Ext / Flex | | -6.8 |
| | L / R Lat | | -1.1 |
| | R / L Twist | | 0.1 |
| L5S1 | Ext / Flex | | -43.0 |
| | L / R Lat | | 6.9 |
| | R / L Twist | | 3.7 |

Summary Table: Push & Pull

The Summary tab for “Push & Walk” and “Pull & Walk” tasks is shown, and now includes a more complete assessment of both the Initial and Sustained phases. Only the total demands, strengths and acceptable forces are shown, combining the right and left arms.

| Summary | | | Results | | |
|---|-------------|----------------|------------------|-----------------|--|
| Analysis Tool Results | | | | | |
| Arm (N) | | Initial | Sustained | | |
| Demand | | 150.0 | 100.0 | | |
| Manual Arm Strength | | 374.5 | 374.5 | | |
| Max. Acceptable Force | | 239.0 | 134.6 | | |
| Hand, Wrist & Forearm (N) | | Initial | Sustained | | |
| Demand | | 150.0 | 100.0 | | |
| Maximum Strength | | 312.1 | 312.1 | | |
| Max. Acceptable Force | | 195.4 | 105.7 | | |
| Low Back (L5S1 Joint) (N) | | | | | |
| Shear Force Resultant Demand | | | 318 | | |
| Compression Force Demand | | | 1,135 | | |
| Max. Compression Strength | | | 3,856 | | |
| Cumulative Compression Demand | | | 0 | | |
| Cumulative Compression TLV | | | 1 | | |
| Neck (Nm) | | | | | |
| Resultant Demand | | | 0.8 | | |
| Max. Resultant Strength | | | 26.1 | | |
| Max. Acceptable Torque | | | 8.1 | | |
| Liberty Mutual MMH Equations (N) | | Initial | Sustained | | |
| Demand | | 150.0 | 100.0 | | |
| Max. Acceptable Load | | 197.4 | 103.8 | | |
| Total Force (N) | | | | | |
| Total Force | | | 150.0 | | |
| Max. Acceptable Total Force | | | 197.4 | | |
| Feasible Simulated Postures | | | | | |
| | | | 3,704 | | |
| Joint Strength Demands (Nm) | | | | | |
| Joint | -/+ | | | L/R Mean | |
| Wrist | Ext / Flex | | | -0.2 | |
| | RD / UD | | | 0.0 | |
| | Sup / Pro | | | 0.0 | |
| Elbow | Ext / Flex | | | 1.2 | |
| Shoulder | Ext / Flex | | | -5.1 | |
| | AD / AB | | | -1.5 | |
| | Int / Ext | | | -0.7 | |
| Neck | Ext / Flex | | | -0.8 | |
| | L / R Lat | | | 0.0 | |
| | R / L Twist | | | 0.0 | |
| L5S1 | Ext / Flex | | | -58.9 | |
| | L / R Lat | | | 0.2 | |
| | R / L Twist | | | 0.1 | |

Exported Excel Report

On the Outputs interface page, there is an option to export and Excel Report file. This report file contains a summary of the inputs and the outputs from the website, but also includes a graph of all DCRs for each risk variable and a Summary sheet containing a table with all inputs and outputs.



DCR Graph

This graph shows the distribution of DCR values from 0 to the 100th percentile for the sample task used above. DCRs for each of the 6 relevant variables, in addition to the Overall DCR (in yellow), are shown ranked from lowest on the left (0 percentile) to highest on the right (100th percentile). LM-MMH Equation DCRs are not calculated for static exertions.

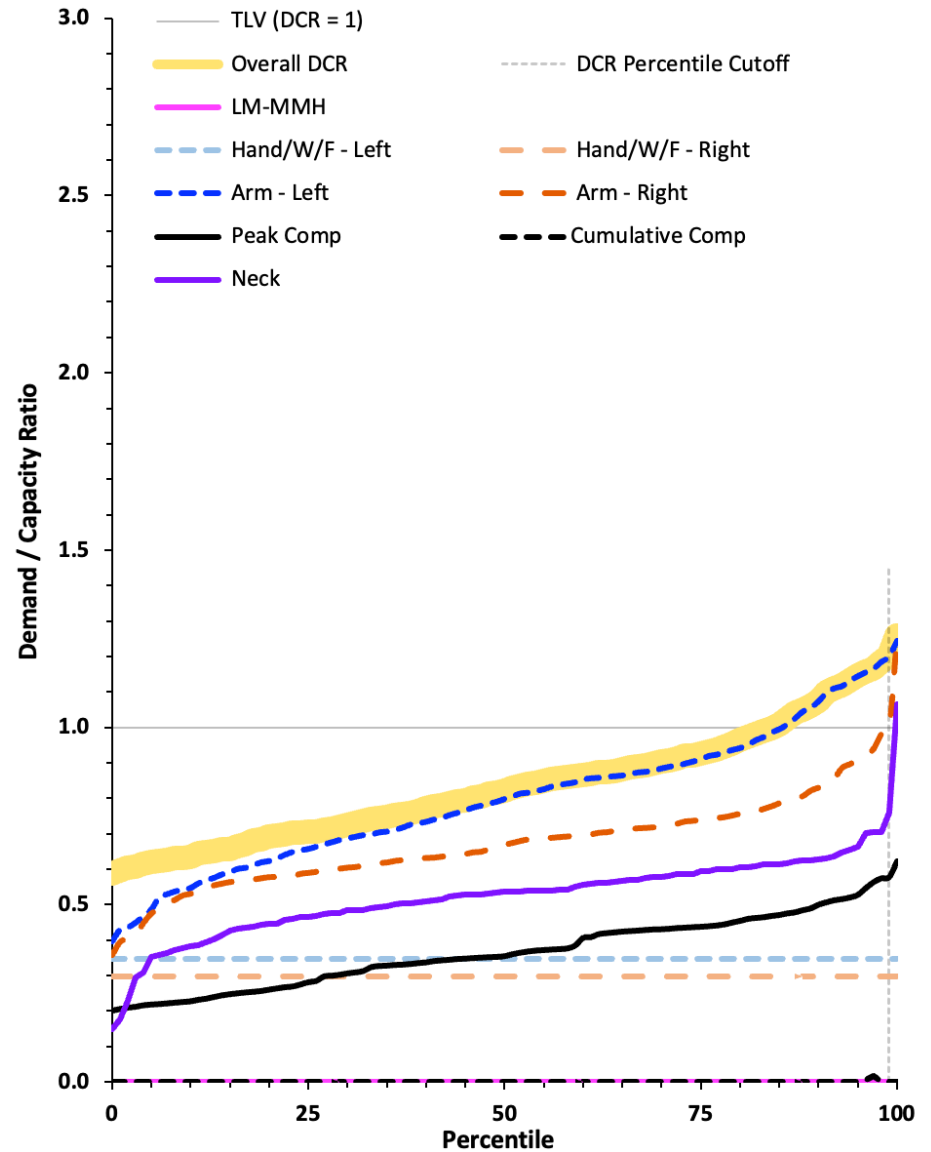
The TLV line is horizontal and set at a threshold of DCR = 1.0.

The DCR Percentile cutoff set in Step 1 is shown as a vertical dotted line. The values in the body map are based on where each DCR curve crosses this line.

The table below shows the 0 (minimum), 25th (cutoff) and 100th (maximum) DCR values for each risk variable.

| | Percentile | | |
|----------------------------|-------------|-------------|-------------|
| | 0 (Min) | 25 | 100 (Max) |
| Hand/Wrist/Forearm - Left | 0.35 | 0.35 | 0.35 |
| Arm - Left | 0.40 | 0.66 | 1.25 |
| Hand/Wrist/Forearm - Right | 0.30 | 0.30 | 0.30 |
| Arm - Right | 0.36 | 0.59 | 1.26 |
| Lumbar Compression | 0.20 | 0.28 | 0.62 |
| Neck | 0.15 | 0.47 | 1.06 |
| Overall DCR | 0.59 | 0.70 | 1.26 |

For this sample task, the right arm has the highest DCRs at the lowest percentiles, but the left arm has the highest DCRs after that. At the 25th percentile, the Overall DCR is **0.70** (acceptable) and the left arm DCR is 0.66 (as shown above on the body map). The Overall DCR is acceptable at the 25th percentile cutoff but does get as high as 1.26 at its maximum.



Summary Sheet

In the exported Excel Work(s) report file, there is a Summary sheet that compiles all the inputs and outputs into one column. An example from the sample task is shown below (but as two columns so they can be included on one page). First there is a summary of all Inputs, then all the calculated Demands, then Capacities, then DCRs, then some other information from the analysis at the bottom. The data from multiple tasks can be compiled into a "Work(s) Summary Template v1.1.xlsx" file available on request. Codes are provided in case pivot tables will be used with the compiled data.

Variables shaded in green are new to the Summary table in v1.1. Note that we've created a worksheet to align the rows of the Summary Table from the v1.0 reports to that of the new v1.1 reports, if you wish to continue to compile are results in one file. That worksheet is available from us on request.

| Category | Variable | Code | Units | Values | |
|--------------------------|----------------------------|-------------------|----------|------------------------------------|--------|
| Inputs | Target Population | Task ID | TaskID | Sample Task - 50F - 2024-04-05a | |
| | Sex | Sex | | Female | |
| | Units | Units | | Metric | |
| | DCR %ile | DCR%ile | | 25 | |
| | Body Mass %ile | BodyMass%ile | | 50 | |
| | Body Mass | BodyMass | kg | 73.5 | |
| | Stature %ile | Stature%ile | | 50 | |
| | Stature | Stature | m | 1.6 | |
| | Percent Capable | %Cap | % | 75 | |
| | Age | Age | years | 42 | |
| Task Type | Task Type | TaskType | | Static Exertion | |
| | Frequency per Day | Freq | /day | 420.0 | |
| | Effective Duration Entered | EEffect-Dur-Input | s | 1,000 | |
| | Task Distance | TaskDist | m | 0.000 | |
| | Hip Height | Height | m | 0.000 | |
| | Shift Duration | ShiftDur | hours | 1 | |
| | Barriers | Barrier #1? | B1 | Yes | |
| | | Depth | B1-Depth | m | 0.600 |
| | | Top Edge | B1-Top | m | 0.700 |
| | | Left Edge | B1-Left | m | -0.500 |
| Right Edge | | B1-Right | m | 0.500 | |
| Bottom Edge | | B1-Bottom | m | 0.000 | |
| Barrier #2? | | B2 | Yes | | |
| X Offset | | B2-Offset | m | 0.500 | |
| Depth | | B2-Depth | m | 0.100 | |
| Top Edge | | B2-Top | m | 1.600 | |
| Contact Locations | Left Edge | B2-Left | m | 0.400 | |
| | Right Edge | B2-Right | m | 0.500 | |
| | Bottom Edge | B2-Bottom | m | 0.700 | |
| | Left Arm Off? | LArmOff | No | | |
| | Left X Location | HCL-T-X-L | m | 0.150 | |
| | Y | HCL-T-Y-L | m | 0.800 | |
| | Z | HCL-T-Z-L | m | -0.250 | |
| | Left X Bottom | HCL-B-X-L | m | N/A | |
| | Y | HCL-B-Y-L | m | N/A | |
| | Z | HCL-B-Z-L | m | N/A | |
| Force Parameters | Right Arm Off? | RArmOff | No | | |
| | Right X Location | HCL-T-X-R | m | 0.350 | |
| | Y | HCL-T-Y-R | m | 1.200 | |
| | Z | HCL-T-Z-R | m | 0.300 | |
| | Right X Bottom | HCL-B-X-R | m | N/A | |
| | Y | HCL-B-Y-R | m | N/A | |
| | Z | HCL-B-Z-R | m | N/A | |
| | Left Direction: X | ForceDir-X-L | | 1,000 | |
| | Y | ForceDir-Y-L | | 1,000 | |
| | Z | ForceDir-Z-L | | 0.000 | |
| Hand Grip & Orientations | Left Force | Force-L | N | 35.0 | |
| | Left Sustained | Force-L-S | N | N/A | |
| | Right Direction: X | ForceDir-X-R | | 0.000 | |
| | Y | ForceDir-Y-R | | 0.000 | |
| | Z | ForceDir-Z-R | | -1,000 | |
| | Right Force | Force-R | N | 30.00 | |
| | Right Sustained | Force-R-S | N | N/A | |
| | Left Hand Task | Task-L | | Push along cylinder, Oblique Grasp | |
| | Knuckle Line | Knuckle-L | | Forward_and_Up | |
| | Palm Direction | Palm-L | | Right | |
| Analys Settings | Span/Diameter | Span-L | mm | 30.00 | |
| | Gloves Used? | Glove-L | N/A | | |
| | Surface Type | Surface-L | | Rubber | |
| | Right Hand Task | Task-R | | Push along cylinder, Oblique Grasp | |
| | Knuckle Line | Knuckle-R | | Left | |
| | Palm Direction | Palm-R | | Down | |
| | Span/Diameter | Span-R | mm | 30.00 | |
| | Gloves Used? | Glove-R | N/A | | |
| | Surface Type | Surface-R | | Rubber | |
| | Above-Shoulder? | AboveShld | No | | |
| Demands | Limit Trunk? | Limt-Trunk | No | | |
| | Body Bracing? | Body-Brace | None | | |
| | Straight Legs? | Strait-Leg | No | | |
| | Cumulative Compression? | CumulComp | Yes | | |
| | Task Name | TaskID | | Sample Task - 50F - 2024-04-05a | |
| | Gate? | Gate | Hands | | |
| | X | GateX | m | N/A | |
| | Y | GateY | m | N/A | |
| | Z | GateZ | m | N/A | |
| | Effective Duration | EEffect-Dur | s | 1,000 | |
| Left Upper Extremity | Effective Duration-Sust | EEffect-Dur-S | s | N/A | |
| | Total Duration | Total-Duration | s | 420.0 | |
| | Total Duration-Sust | Total-Duration-S | s | N/A | |
| | Duty Cycle | DESS-DC | | 0.0167 | |
| | Duty Cycle-Sust | DESS-ESS | | N/A | |
| | Wrist -Ext/+Flex | Wrist-Ext-L | Nm | -0.07 | |
| | -Rad/+Uln | Wrist-Uln-L | Nm | -2.61 | |
| | -Sup/+Pro | Wrist-PS-L | Nm | -1.10 | |
| | Elbow + Flex | Elbow-L | Nm | 3.62 | |
| | Shld -Ext/+ Flex | Shld-Ext-L | Nm | -3.81 | |
| Other | -Ad/+Ab | Shld-ABAD-L | Nm | 5.77 | |
| | Int/+Ext | Shld-El-L | Nm | 3.10 | |
| | Arm Force | Arm-Force-L | N | 35.0 | |
| | Arm Force-Sust | Arm-Force-L-S | N | N/A | |
| | Arm Effort | Arm-Effort-L | | 0.412 | |
| | Arm Effort-Sust | Arm-Effort-L-S | | N/A | |
| | Hand Force | Hand-Force-L | N | 35.0 | |
| | Hand Force-Sust | Hand-Force-L-S | N | N/A | |
| | Hand Effort | Hand-Effort-L | | 0.217 | |
| | Hand Effort-Sust | Hand-Effort-L-S | | N/A | |

| | | | | |
|--------------------------------|--------------------------|------------------|-----|------------|
| Right Upper Extremity | Wrist -Ext/+ Flex | Wrist-Ext-R | Nm | -0.23 |
| | -Rad/+Uln | Wrist-Uln-R | Nm | -2.08 |
| | -Sup/+Pro | Wrist-PS-R | Nm | -0.94 |
| | Elbow + Flex | Elbow-R | Nm | 1.87 |
| | Shld -Ext/+ Flex | Shld-Ext-R | Nm | 9.11 |
| | -Ad/+Ab | Shld-ABAD-R | Nm | -2.68 |
| | Int/+Ext | Shld-El-R | Nm | -1.61 |
| | Arm Force | Arm-R | N | 30.0 |
| | Arm Force-Sust | Arm-Force-R-S | N | N/A |
| | Arm Effort | Arm-Effort-R | | 0.369 |
| Neck (C7/T1 Joint) | Arm Effort-Sust | Arm-Effort-R-S | | N/A |
| | Hand Force | Hand-Force-R | N | 30.0 |
| | Hand Force-Sust | Hand-Force-R-S | N | N/A |
| | Hand Effort | Hand-Effort-R | | 0.186 |
| | Hand Effort-Sust | Hand-Effort-R-S | | N/A |
| | Total Duration | Neck-Total-Dur | s | 420.0 |
| | Total Duration-Sust | Neck-Total-Dur-S | s | N/A |
| | Total Duty Cycle | Neck-DC | | 0.017 |
| | Neck Fix/Ext | Neck-Fix | Nm | -6.78 |
| | Lateral | Neck-Lat | Nm | -1.13 |
| Lumbar Spine (L5/S1 Joint) | Axial | Neck-Ax | Nm | 0.09 |
| | Neck Result Mo | Neck-Res-Mo | Nm | 7.22 |
| | Neck Effort | Neck-Effort | | 0.292 |
| | L5/S1 Fix/Ext | L5S1-Fix | Nm | -42.99 |
| | Lateral | L5S1-Lat | Nm | 6.90 |
| | Axial | L5S1-Ax | Nm | 3.69 |
| | Peak Compression | Ph-Comp | N | 1,086 |
| | Peak Compression-Sust | Ph-Comp-S | N | 0 |
| | Overall Peak Compression | Overall-Ph-Comp | N | 1,086 |
| | Cumulative Comp | CC-S | | 0.000 |
| Capacities | Cumulative Comp-Sust | Overall-CC | | 0.000 |
| | Peak Shear | Peak-Shear | N | 183 |
| | Peak Shear-Sust | Peak-Shear-S | N | 0 |
| | Overall Peak Shear | Overall-Ph-Shear | N | 183 |
| | TBD | | | |
| | Mid Hip Flex | Mid-Hip-Flex | Nm | -39.57 |
| | Lateral | Mid-Hip-Lat | Nm | -7.57 |
| | Axial | Mid-Hip-Twist | Nm | 9.19 |
| | LM-MMH Force | LM-MMH-Load | N | N/A |
| | LM-MMH Sustained Force | LM-MMH-S | N | N/A |
| Manual Materials Handling Corp | TBD | | | |
| | -Back/+Forward Min | CoFF-BF-Min | m | 0.27 |
| | -Back/+Forward Max | CoFF-BF-Max | m | -0.02 |
| | -Left/+Right Min | CoFF-LR-Min | m | 0.00 |
| | -Left/+Right Max | CoFF-LR-Max | m | 0.08 |
| | MAE | MAE | | 0.626 |
| | Neck MAE (Push/Pull) | Neck-MAE | | 0.626 |
| | MAE-Sust | MAE-S | | N/A |
| | Arm Strength | Arm-MVC-L | N | 84.8 |
| | Arm MAF | Arm-MAF-L | N | 53.0 |
| Left Upper Extremity | Arm MAF-Sust | Arm-MAF-S-L | N | 9999.6 |
| | Hand Strength | Hand-MVC-L | N | 161.5 |
| | Hand MAF | Hand-MAF-L | N | 101.1 |
| | Hand MAF-Sust | Hand-MAF-L-S | N | 9999.8 |
| | Arm Strength | Arm-MVC-R | N | 77.8 |
| | Arm MAF | Arm-MAF-R | N | 49.7 |
| | Arm MAF-Sust | Arm-MAF-S-R | N | 9999.7 |
| | Hand Strength | Hand-MVC-R | N | 161.5 |
| | Hand MAF | Hand-MAF-R | N | 101.1 |
| | Hand MAF-Sust | Hand-MAF-R-S | N | 9999.9 |
| Neck (C7/T1 Joint) | Neck Strength | Neck-MVC | Nm | 25.9 |
| | Neck MAT | Neck-MAT | Nm | 16.2 |
| | Comp Ultimate Strength | Comp-US | N | 4,646 |
| | Peak Comp TLV | Ph-Comp-TLV | N | 3,856 |
| | Cumulative Comp TLV | CC-TLV | | 1,000 |
| | TBD | | | |
| | LM-MMH MAF | LM-MAL | N | N/A |
| | LM-MMH Sust MAF | LM-MAL-S | N | N/A |
| | TBD | | | |
| | MAF | MAF-Tot | N | 125.6 |
| Demand / Capacity Ratios | MAF-Sust | MAF-Tot | N | 9999.0 |
| | Percent -DCR = 1 | DCR-Rtg | % | 0.84 |
| | DCR Overall | DCR-Overall | | 0.70 |
| | Arm DCR | Arm-DCR-L | | 0.66 |
| | Arm DCR-Sust | Arm-DCR-S-L | | N/A |
| | Hand DCR | Hand-DCR-L | | 0.35 |
| | Hand DCR-Sust | Hand-DCR-S-L | | N/A |
| | Arm DCR | Arm-DCR-R | | 0.59 |
| | Arm DCR-Sust | Arm-DCR-S-R | | N/A |
| | Hand DCR | Hand-DCR-R | | 0.30 |
| Right Upper Extremity | Hand DCR-Sust | Hand-DCR-S-R | | N/A |
| | Neck DCR | Neck-DCR | | 0.47 |
| | Peak Comp DCR | Comp-DCR | | 0.28 |
| | Cumulative Comp DCR | CC-DCR | | 0.000 |
| | Cumulative Comp DCR-Sust | Overall-CC-Sust | | 0.000 |
| | Overall Cumul. Comp DCR | Overall-CC-DCR | | 0.000 |
| | TBD | | | |
| | LM-MMH DCR | LM-DCR | | N/A |
| | LM-MMH DCR-Sust | LM-DCR-S | | N/A |
| | TBD | | | |
| Manual Materials Handling | # of CPUs | CPUs | | N/A |
| | Processing Time | Process-Time | min | 1.40 |
| | Total Postures | Postures-Total | | 84319 |
| | Sampled Postures | Postures-Samp | | N/A |
| | Date of Analysis | Date-Analysis | | 2024-04-05 |
| | Time of Analysis | Time-Analysis | | 11:52:06 |

Cumulative Fatigue Analysis for Each Tasks

To the right of the Summary data is a table that can be used to compile cumulative fatigue-related data from multiple tasks that comprise a full job. This table calculates the duty cycle, MAE, and peak hand/wrist/forearm, arm, and neck efforts, and peak compression forces, as well as the cumulative muscle fatigue and compression DCRs.

Summary of Data for a Cumulative Task Analysis

| Output File Name | Task Type | Units | Effective Duration (s) | Frequency per day | Duty Cycle | Max Accept Effort |
|------------------|-----------|--------|------------------------|-------------------|------------|-------------------|
| Sample Lift | Lift Load | Metric | 0.922 | 900 | 0.0329 | 0.559 |

| Muscle Effort DCRs | | | | | | | | | | Compression Force DCRs | |
|--------------------|------------|-------------|------------|-------------|------------|-------------|------------|-------------|------------|------------------------|------------|
| Left | | | | Right | | | | Neck | | Peak DCR | Cumul. DCR |
| Arm | | Hands | | Arm | | Hands | | Peak Effort | Cumul. DCR | | |
| Peak DCR | Cumul. DCR | Peak Effort | Cumul. DCR | Peak Effort | Cumul. DCR | Peak Effort | Cumul. DCR | | | | |
| 0.452 | 0.500 | 0.392 | 0.262 | 0.452 | 0.403 | 0.392 | 0.262 | 0.381 | 0.242 | 0.786 | 0.527 |

Note: The row(s) above (highlighted in yellow) can be pasted into the "Cumulative Risk" sheet of the file called "Work(s) Cumulative Task Analysis Template.xlsx" (available on request by emailing info@worksergo.com) to calculate the cumulative demands and risk from multiple tasks making up a whole job.

Cumulative Fatigue Analysis Across Subtasks

The data from each subtask can be further compiled for a full job using the "Work(s) Cumulative Risk Template.xlsx" file that is available on request. Some sample results are added in addition to the Sample Lift above, including the Initial and Sustained phases of a Push (where the HandPak analyses were not applicable) and a Lower task. The Overall DCRs are calculated by summing the peak and cumulative DCRs in each column, and values >1.00 are considered unacceptable. As all Overall DCR values are <1.00, this full task is considered to be acceptable.

Work(s)™ Cumulative Risk Analysis

| Output File Name | Task Type | Units | Effective Duration | Frequency per day | Duty Cycle | MAE |
|------------------|----------------------|--------|--------------------|-------------------|------------|-------|
| Lift | Lift Load | Metric | 0.922 | 900.0 | 0.033 | 0.559 |
| Push - Initial | Push and Walk (Init) | Metric | 1.000 | 180.0 | 0.007 | 0.695 |
| Push - Sustained | Push and Walk (Sust) | Metric | 5.833 | 180.0 | 0.042 | 0.534 |
| Lower | Lower Load | Metric | 0.608 | 900.0 | 0.022 | 0.601 |

| Muscle Effort DCRs | | | | | | | | | | Compression Force DCRs | |
|--------------------|------------|-------------|------------|-------------|------------|-------------|------------|-------------|------------|------------------------|------------|
| Left | | | | Right | | | | Neck | | Peak DCR | Cumul. DCR |
| Arm | | Hands | | Arm | | Hands | | Peak Effort | Cumul. DCR | | |
| Peak DCR | Cumul. DCR | Peak Effort | Cumul. DCR | Peak Effort | Cumul. DCR | Peak Effort | Cumul. DCR | | | | |
| 0.452 | 0.500 | 0.392 | 0.262 | 0.452 | 0.403 | 0.392 | 0.262 | 0.381 | 0.242 | 0.786 | 0.527 |
| 0.436 | 0.078 | | | 0.436 | 0.078 | | | 0.404 | 0.062 | 0.550 | 0.003 |
| 0.308 | 0.193 | | | 0.307 | 0.192 | | | 0.404 | 0.359 | 0.549 | 0.018 |
| 0.431 | 0.228 | 0.385 | 0.165 | 0.431 | 0.228 | 0.385 | 0.165 | 0.380 | 0.159 | 0.759 | 0.278 |

| | | | | | | | | | | | | |
|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Overall DCRs | 0.452 | 0.999 | 0.392 | 0.426 | 0.452 | 0.901 | 0.392 | 0.426 | 0.404 | 0.822 | 0.786 | 0.826 |
|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|

MAE: Maximum Acceptable Effort
 DCR: Demand/ Capacity Ratio
 Cumul.: Cumulative

All Acceptable

Version 1.10 (2024-04-05)

References

- Brinckmann, P., Johannleweling, N., Hilweg, D., Biggemann, M., 1988. Fatigue fracture of human lumbar vertebrae. *Clinical Biomechanics*, S1, 94–96.
- Chaffin, D.B., Andres, R.O., Garg, A., 1983. Volitional postures during maximal push/pull exertions in the sagittal plane, *Human Factors*, 25(5): 541-550.
- Chaffin, D.B., Andersson, G.B.J., Martin, B.J., 2006. *Occupational Biomechanics* (4th edition), 4th ed. John Wiley & Sons, Inc., Hoboken, NJ.
- Dempsey, P., 1998. A critical review of biomechanical, epidemiological, physiological and psychophysical criteria for designing manual materials handling tasks. *Ergonomics*, 41, 73–88.
- Dempsey, P.G., Ciriello, V.M., Maikala, R.V., O'Brien, N.V., 2008. Oxygen consumption prediction models for individual and combination materials handling tasks. *Ergonomics*, 51, 1776–1789.
- Durkin, J.L., Dowling, J.J., 2003. Analysis of body segment parameter differences between four human populations and the estimation errors of four popular mathematical models. *Journal of Biomechanical Engineering*, 125, 515–522.
- Dvoretzky, A., Kiefer, J., Wolfowitz, J., 1956. Asymptotic minimax character of the sample distribution function and of the classical multinomial estimator. *Ann Math Statistics*, 27, 642–669.
- Fromuth, R.C., Parkinson, M.B., 2008. Predicting 5th and 95th percentile anthropometric segment lengths from population stature, in: *ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, SAE.
- Fryar, C., Carroll, M., Gu, Q., Afful, J., Ogden, C., 2021. Anthropometric Reference Data for Children and Adults - United States, 2015–2018. *Vital and Health Statistics*, 3, 1–44.
- Gallagher, S., Marras, W.S., 2012. Tolerance of the lumbar spine to shear: A review and recommended exposure limits. *Clinical Biomechanics*, 27, 973–978.
- Gelb, D.E., Lenke, L.G., Bridwell, K.H., Blanke, K., McEnery, K.W., 1995. An analysis of sagittal spinal alignment in 100 asymptomatic middle and older aged volunteers. *Spine* 20, 1351–1358.
- Gibson, M., Potvin, J.R., 2016. An equation to calculate the recommended cumulative rest allowance across multiple subtasks, in: *Association of Canadian Ergonomists Conference*, Association of Canadian Ergonomists Conference. Niagara Falls, ON, pp. 1–2.
- Grenier, T.M., 1991. Hand Anthropometry for US Army Personnel, Technical Report Natick/TR-92/011. United States Army Natick Research, Development and Engineering Center, Natick, MA.
- Harms-Ringdahl, K., Schüldt, K., 1988. Maximum neck extension strength and relative neck muscular load in different cervical spine positions. *Clinical Biomechanics*, 4, 17–24.
- Jäger, M., 2023. *The Dortmund Lumbar Load Atlas, A Contribution to Objectifying Lumbar Load and Load-Bearing Capacity for an Ergonomic Work Design of Manual Materials Handling*. Springer Nature.

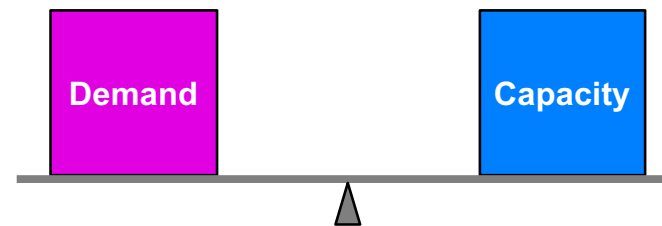
- Jordan, A., Mehlsen, J., Bülow, P.M., Østergaard, K., Danneskiold-Samsøe, B., 1999. Maximal isometric strength of the cervical musculature in 100 healthy volunteers. *Spine*, 24, 1343.
- La Delfa, N.J., Potvin, J.R., 2017. The 'Arm Force Field' method to predict manual arm strength based on only hand location and force direction. *Applied Ergonomics*, 59, 410–421.
- Lavender, S.A., Andersson, G.B.J., Schipplein, O.D., Fuentes, H.J., 2003. The effects of initial lifting height, load magnitude, and lifting speed on the peak dynamic L5/S1 moments. *International Journal of Industrial Ergonomics*. 31, 51–59.
- Lee, K.S., Chaffin, D.B., Herrin, G.D., Waikar, A.M., 1991. Effect of handle height on lower-back loading in cart pushing and pulling. *Applied Ergonomics*. 22, 117–123.
- Leva, P. de, 1996. Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of Biomechanics* 29, 1223–1230.
- Lin, C.J., Bernard, T.M., Ayoub, M.M., 1999. A biomechanical evaluation of lifting speed using work- and moment-related measures. *Ergonomics* 42, 1051–1059.
- NIOSH, 1981. *Work Practices Guide for Manual Lifting*. DHHS (NIOSH), Cincinnati, OH.
- Potvin, J.R., 2012. Predicting maximum acceptable efforts for repetitive tasks - An equation based on duty cycle. *Human Factors*, 54, 175–188.
- Potvin, J.R., Ciriello, V.M., Snook, S.H., Maynard, W.S., Brogmus, G.E., 2021. The Liberty Mutual manual materials handling (LM-MMH) equations. *Ergonomics*, 1–17.
- Queisser, F., Blüthner, R., Seidel, H., 1994. Control of positioning the cervical spine and its application to measuring extensor strength. *Clinical Biomechanics*, 9, 157–161.
- Rempel, D., Potvin, J., 2022. A design tool to estimate maximum acceptable manual arm forces for above-shoulder work. *Ergonomics*, 1–27.
- Schimpl, M., Moore, C., Lederer, C., Neuhaus, A., Sambrook, J., Danesh, J., Ouwehand, W., Daumer, M., 2011. Association between Walking Speed and Age in Healthy, Free-Living Individuals Using Mobile Accelerometry—A Cross-Sectional Study. *PLoS ONE* 6, e23299.
- Seng, K.-Y., Peter, V.-S.L., Lam, P.-M., 2002. Neck muscle strength across the sagittal and coronal planes: an isometric study. *Clinical Biomechanics*, 17, 545–547.
- Snook, S.H., 1978. The design of manual handling tasks. *Ergonomics*, 21, 963–985.
- Snook, S.H., Ciriello, V.M., 1991. The design of manual handling tasks: revised tables of maximum acceptable weights and forces. *Ergonomics*, 34, 1197–1213.
- Tilley, A.R., 1993. *The Measure of Man and Woman – Human Factors in Design*. Henry Dreyfuss Associates.
- Vasavada, A.N., Li, S., Delp, S.L., 2001. Three-dimensional isometric strength of neck muscles in humans. *Spine*, 26, 1904–1909.
- Waters, T.R., Putz-Anderson, V., Garg, A., Fine, L.J., 1993. Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics*, 36, 749–776.

Yoganandan, N., Ray, G., Pintar, F.A., Myklebust, J.B., Sances, A., 1989. Stiffness and strain energy criteria to evaluate the threshold of injury to an intervertebral joint. *J. Biomech.* 22, 135–142. Buchholz, B., Armstrong, T.J., Goldstein, S.A., 1992. Anthropometric data for describing the kinematics of the human hand. *Ergonomics*, 35, 261–273.

Appendix A: Demand/Capacity Ratios

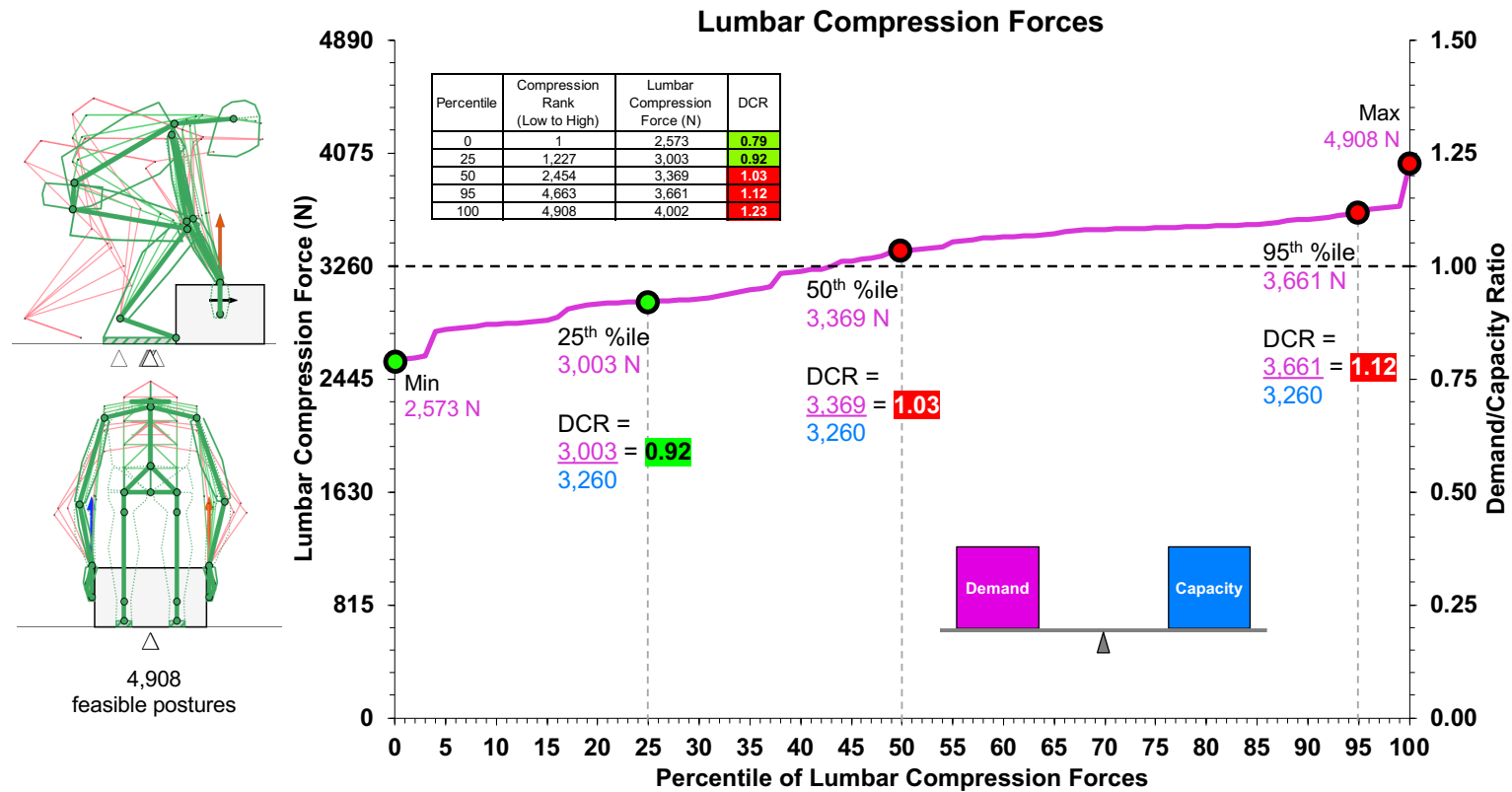
The Demand/Capacity Ratio (ie. “D/C Ratio” or “DCR”) is simply the demand of the task divided by the assumed capacity to meet that demand, and it provides a unitless measure of WMDS risk from each of the ergonomics assessment tools in Work(s). The capacity may be based on a single effort strength or could be corrected to account for the fatigue associated with the frequency and effort duration. Unlike most ergonomics software, Work(s) doesn’t just assess one task posture, so it will have multiple demands from multiple postures (usually thousands) for any analysis. The DCR Percentile represents the percentile of the DCR values used to determine if the demand for a particular variable is acceptable (≤ 1.000) or unacceptable (>1.000). We recommend that the 25th percentile DCR be used to represent the risk for each demand variable across the many feasible postures for a given task.

For example, if the lumbar L5/S1 joint compression force demand is estimated to be 3,500 N, and the L5/S1 force capacity is assumed to be 3,260 N (based on data adapted from Jäger (2018) for a 45-year-old female), then the DCR is calculated to be $3,500 / 3,260 = 1.07$. Since the demand is greater than the capacity, the DCR is greater than 1.000 and the L5/S1 compression force is considered to be unacceptable. For a lifting task, if the load mass of a lifted box is 10 kg and the LM-MMH Equations (Potvin et al, 2022) estimate the maximum acceptable load (MAL) for a lift to be 13 kg, then the DCR is $10 / 13 = 0.77$ and, since the demand is less than the capacity, the DCR is less than 1.000 and the load is considered to be acceptable. Other examples are provided in the table on the right, with acceptable and unacceptable DCRs highlighted in green and red, respectively.



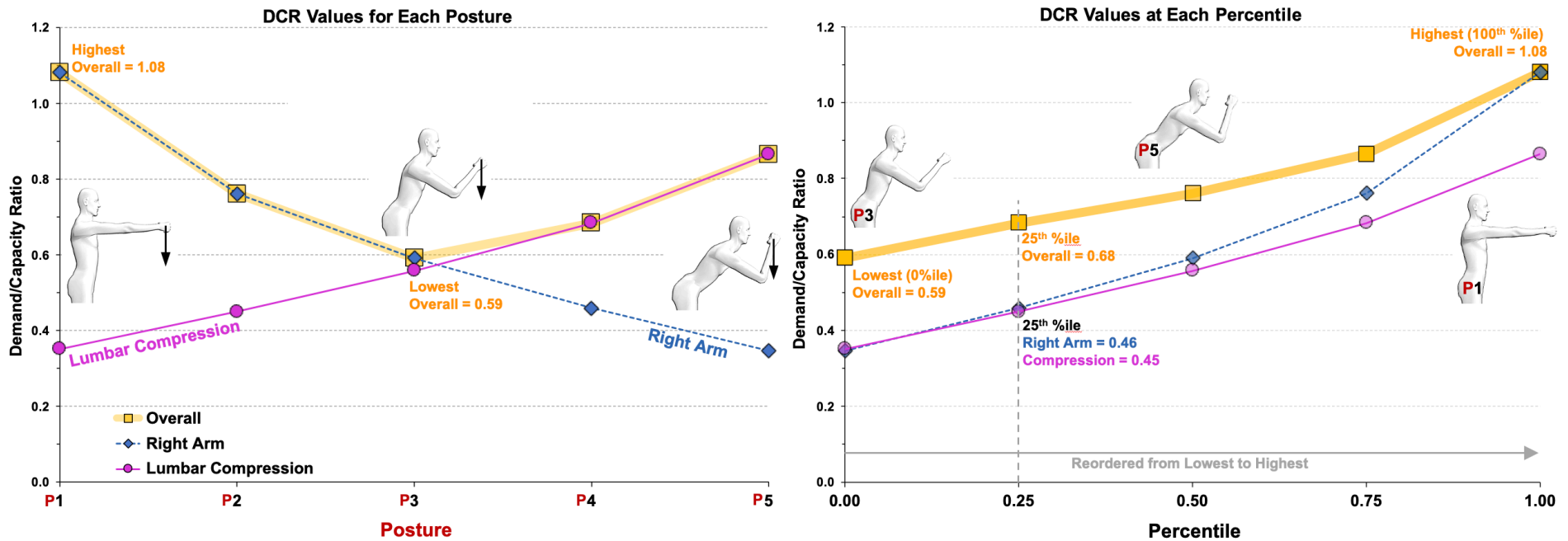
| Criterion | Assessment | Units | Demand | Capacity | DCR |
|----------------------|------------------------|----------|--------|----------|------|
| Compression | 3DSSPP | N | 3,500 | 3,260 | 1.07 |
| Neck | 3DSSPP | Nm | 10 | 22 | 0.45 |
| Manual Arm Strengths | Arm Force Field | N | 75.0 | 90.0 | 0.83 |
| - Above-Shoulder | Rempel & Potvin (2022) | N | 75.0 | 65.0 | 1.15 |
| Hand/Wrist/Forearms | HandPak™ | N | 75.0 | 55.0 | 1.36 |
| Psychophysical | LM-MMH Equations | kg | 10 | 13 | 0.77 |
| Metabolic Cost | Dempsey Equations | kcal/min | 2 | 3.1 | 0.65 |
| Cumulative Demands | RCRA | s | 18,000 | 15,000 | 1.20 |

Work(s) is unique in that it doesn’t only assess one posture for a task, so it will have multiple DCRs for any assessment tool used. For example, for a lifting task, the L5/S1 compression force will depend on the posture and Work(s) might determine thousands of feasible compression forces for a particular hand location, ranging from the lowest possible magnitude to the highest possible magnitude, and with a distribution of magnitudes (and DCRs) in between. Under such circumstances, one could choose to represent the risk with the lowest DCR (based on an ideal posture for that metric – though it may be improbable, and even not optimal, for a worker to adopt that posture every repetition), the highest DCR (based on a terrible posture that is not likely to ever be adopted by an experienced worker) or something in between. The graphic on the next page shows the range of compression forces and DCRs for the initiation of a lift from the floor.



This graphic illustrates an example of the DCRs for lumbar compression forces at the initiation of a lift from the floor. Work(s) found 4,908 feasible postures and calculated the compression force for each. They were then sorted from lowest (0 percentile = 2,573 N) to highest (100th percentile = 4,980 N) on the left y-axis and presented as percentiles on the x-axis. Each value can be divided by the lumbar compression capacity (in this case, assumed to be 3,260 N, adapted from Jäger (2018) for a 45-year-old female) to calculate the compression DCR. These are presented on the right y-axis. The 25th, 50th and 95th percentile compression forces (the 1,227th, 2,454th and 4,663rd highest, respectively) were 3,003, 3,369 and 3,661 N, respectively and those convert to DCRs of 0.92 (acceptable), 1.03 (unacceptable) and 1.12 (unacceptable), respectively. Eleven postures are overlaid on the left of the graph, from the side and from behind, for representative postures resulting in the 5th to 95th compression forces, in increments of 5%. We recommend using the 25th percentile DCR to represent the WMSD risk for each variable, and that posture is shown with a full manikin and a bolded stick figure. Postures with a DCR ≤ 1.000 are in green and those with DCRs > 1.000 are in red.

For each posture, a DCR is calculated with each ergonomics assessment tool. Then, within each posture, an Overall DCR is then calculated with the highest DCR across the ergonomics tools (ie. “weakest link”). One might first expect that the Overall DCR curve at each percentile would simply be the highest DCR value at that percentile across the different assessment tools. In other words, the Overall curve would surf across the highest values of the other curves. However, counterintuitively, that is not the case. An example is provided below to illustrate.



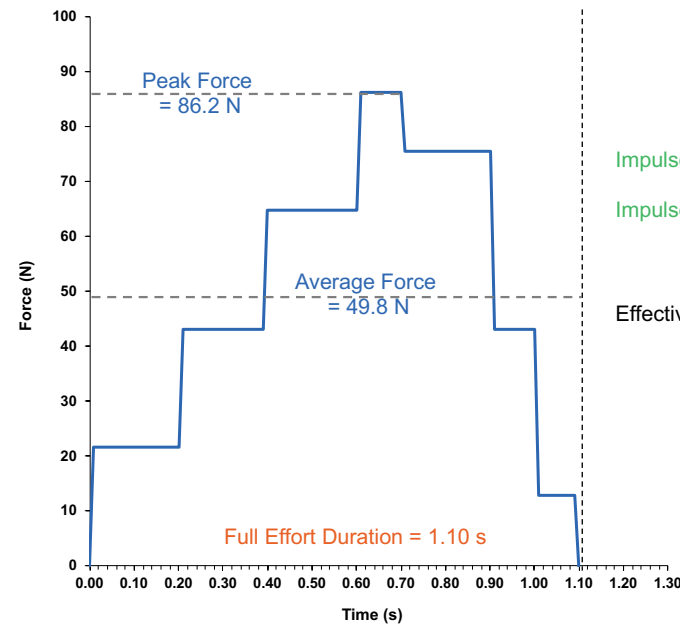
Left: This graph shows DCR data from 5 postures of a fictional task, but with only 2 risk variables (**right arm** & **lumbar compression force**) and the **Overall DCR** from those 2 risk variables. **Posture 1** has a long reach for the **right arm** (ie. relatively high right arm demand and DCR of **1.08**) but an upright trunk (ie. relatively low **lumbar compression force** and DCR of **0.35**). As we progress from **Posture 1** to **Posture 5**, the trunk becomes more flexed (increasing the **lumbar compression forces** and DCRs to a maximum of **0.86**), but the reach decreases (decreasing the moments of force about the shoulder and elbow and decreasing the **right arm** DCRs to minimum of **0.35**).

Right: This graph shows the **right arm**, **lumbar compression force** and **Overall** DCRs reordered from lowest (0 percentile) to highest (100th percentile). If we set our DCR Percentile threshold to 25th, then threshold values for the **right arm**, **lumbar compression force** and **Overall** DCRs are **0.46**, **0.45** and **0.68**, respectively. So, because of the tradeoffs that occur in the DCRs between risk variables, as postures are changed, the 25th Overall DCR will not necessarily be the highest of the 25th percentile values from the various risk variables from the individual ergonomics assessment tools and, in fact, it will often be higher. In other words, the curve with the **Overall** DCR values at each percentile does not necessarily just surf along the top of the risk variable curves. The **Overall** DCR is calculated separately for each posture (as shown in the left graph), then it is sorted from lowest to highest on its own curve and the threshold value is determined from that curve (in this example, **0.68**, as shown in the right graph).

Appendix B: Effective Duration

The Effective Duration represents the best estimate of how long the peak would have to be sustained so that the area under its Effort-Time curve (like an impulse) is the same as that under the actual Effort-Time curve. This does not include the time that the hand may be hovering around the object of exertion (if video is used). It is best to make this estimate from measured force-time curves. It is very important that the effective duration not be overestimated.

The most accurate method to estimate the Effective Duration is to (1) measure the force time-history, (2) estimate the impulse as the average force multiplied by the duration, (3) divide the impulse by the peak force.



Impulse is the area under the force-time curve

$$\text{Impulse} = (\text{Average Force}) (\text{Effort Duration})$$

$$= (49.8 \text{ N}) (1.10 \text{ s})$$

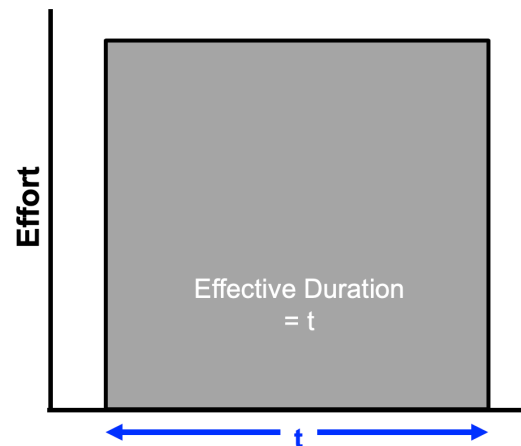
$$= 54.78 \text{ N s}$$

$$\text{Effective Duration} = \frac{\text{Impulse}}{\text{Peak Force}}$$

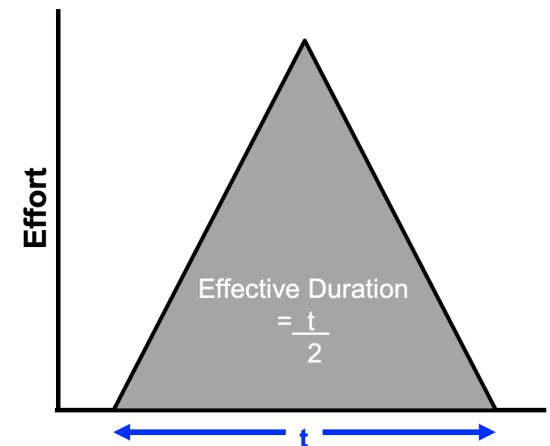
$$= \frac{54.78 \text{ Ns}}{86.2 \text{ N}} = 0.635 \text{ s}$$

If you don't have a force gage that outputs the force time-history, then here are some rules of thumb for estimating Effective Duration.

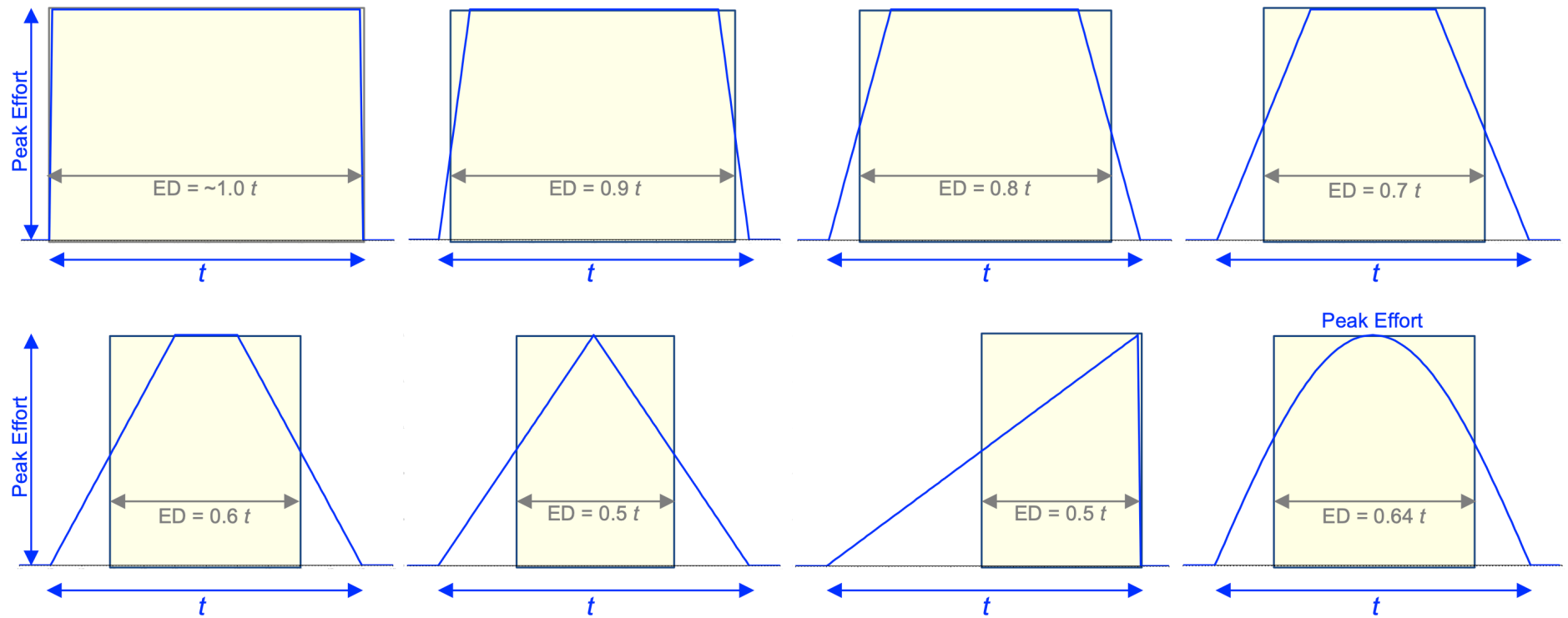
If the Effort-Time curve looks more like this then use "t" as the effective duration



If the Effort-Time curve looks more like this then use "t/2" as the effective duration



Effective Duration (ED) can be estimated based on the shape of the effort time-history. For example, in the bottom left image, there is a slow ramp up, short duration at the peak effort and then slow ramp down. In that case, the impulse (area under the curve) for the full duration of the effort (t) is equal to the peak effort multiplied by $0.6t$, such that the effective duration for calculating duty cycle would be $0.6t$.



The Effective Durations of Manual Materials Handling Tasks

The effective durations are required in Work(s) for the manual materials handling tasks as they are used to estimate the maximum acceptable efforts for the neck and upper extremities. These can be difficult to measure or estimate, so we've made some assumptions based on the scientific literature and estimate these durations based on the vertical displacement during lift and lower tasks and the horizontal displacement for push, pull and carry tasks and.

Lift and Lower Tasks:

Based on our own pilot research, we've developed an algorithm to estimate the durations of lift and lowers based on vertical displacement between the Bottom to Top hand contact heights. Assuming lower average velocities for smaller displacements, given the need to accelerate the load at lift/lower initiation, the predicted durations increase from 0.46 s at 0.25 m to 1.67 s at 2.00 m of displacement. These fall within the ranges cited by Lin et al (1999) and Lavender et al (2003). We are collaborating with researchers at Ontario Tech University to further develop and validate these predictions.

Push and Pull Tasks:

We've assumed a Sustained phase of pushing and pulling would have an average velocity of ~2 miles per hour (0.9 m/s) based on a personal communication with Vince Ciriello, as this was never stated in any of the 19 Liberty Mutual publications used for the LM-MMH Equations (Potvin et al., 2021). Based on data from Lee et al (2014), we've estimated that the Initial phase would occur over the first 0.85 m over a duration of 2.00 s.

Carry Tasks:

The average carrying velocity was assumed to be 1.25 m/s based on the walking data of Schimpl et al (2011).