Ergonomics Software | User's Manual

v 4.1

BAKPAK

An Integrated Software Package
for the Ergonomic Assessment
of Lifting and Lowering Tasks

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The BakPak Approach to Analysing Lifting and Lowering Tasks

We are all aware of the prevalence of low back injuries that result from occupational lifting. A great deal of effort has been dedicated to the scientific development of methods for assessing the physical demands associated with manual materials handling tasks. These methods have relied on various scientific approaches and have focussed on different factors that limit the loads that can be lifted.

The three main scientific approaches are summarized in the following table:

Scientific Approach	Definition	Factors that limit safe loads
Biomechanics	the study of forces acting on, or produced by, the body	- compression and/or shear forces on the low back - joint strength demands
Work Physiology, Metabolic	the study of cardiovascular and muscular energetics and fatigue	- heart rate - oxygen consumption - muscle fatigue
Psychophysics	the study of relationships between physical loading and a person's perception of physical loading	- an integration of the perception of tissue forces and physiological fatigue

A number of tools are currently being used by ergonomists to analyse lifting and lowering tasks. The integration of the information from these methods can become very difficult for a number of reasons.

1) the methods often predict different things, usually:
   a) the biomechanical or physiological implications of given lifting conditions
   or
   b) loads that would be safe to lift under given lifting conditions
2) even when two methods predict the same variable (eg. safe load) the values they provide are often not consistent with each other
3) the input parameters are different for each method

Often, the users of these methods are not experts in ergonomics and they cannot resolve the inconsistencies in a valid or reliable way. This can lead to errors that either reduce the productivity of a job or increase the risk of injury. As such it would be useful to have the following:

1) only one set of measurements that need to be made
2) information from each of the available ergonomic methods using this one set of measurements
3) an intelligent software package that would interpret the results (especially inconsistencies) for the user and provide recommendations with a rationale for the decision that was made.

There are a number of methods that are currently available for this purpose. They generally have different scientific approaches, input parameters and output parameters. There is a potential for confusion when attempts are made to combine the information that each method provides. The BakPak software package incorporates each of these methods while being very easy to use.

The following is a description of some of methods currently used for assessing lifting and lowering tasks.

NIOSH Lifting Equations

Description:	This equation was developed in 1981 by the National Institute of Occupational Safety and Health (in the U.S.) to estimate loads that can be lifted safely under particular lifting conditions. It is widely used in industry in both the U.S. and Canada. A new equation was proposed by Waters et al (1993).
Scientific Approach:	The equations were developed by a group of experts in epidemiology, biomechanics, physiology and psychophysics.
Input Parameters:	The equation requires the following inputs: H = horizontal distance from the ankle to the hand held load V = vertical location of the load at the start of the lift D = vertical distance of the lift F = frequency of lifting (lifts/minute) A = asymmetry angle C = coupling factor
Output Parameters:	The equation claims to predict load that can be lifted safely by 75% of females and 99% of males (termed the Action Limit or AL).

Psychophysical Tables

Description:	These look-up tables were commissioned by Liberty Mutual Insurance and developed by Stover Snook over the past 20 years. They provide estimates of safe loads or forces for a variety of lifting, lowering, pushing and pulling tasks with a variety of characteristics. Similar tables have also been published by Ayoub and his colleagues.
Scientific Approach:	Psychophysics was used to develop these tables as the experimenter altered particular characteristics of lifting tasks and individual selected loads they felt they could lift safely over an 8-hour day.
Input Parameters:	W = width of the box being lifted D = vertical distance of the lift Lifting Region = location of the load at the start of the lift Time = duration between lifts (seconds or minutes/lift)
Output Parameters:	These tables are used to determine the Maximal Acceptable Weight of Lift (MAWL). This is similar in nature to the NIOSH Action Limit.

Biomechanical Modelling

Description: Software packages have been developed to estimate the mechanical demands on body joints during lifting. These models provide detailed information on low back forces and joint moments.

Scientific Approach: Biomechanical modelling is used to determine joint moments and internal muscle forces

Input Parameters:

- 2 dimensional (x, y) coordinates for 10 joints or segment endpoints
- OR angles of the lower arm, upper arm, torso, thigh and lower leg
  - taken from the individual performing the lift
- coordinates for a calibration objects for scaling joint coordinates
- hand held load magnitude
- subject sex and body mass

Output Parameters:

- joint moments for the elbow, shoulder, low back, hips and knees
  - these can be compared to strength data
- compression and shear forces on the lumbar intervertebral discs
  - these can be compared to recommended safety limits
- lumbar erector spinae muscle forces

Metabolic Energy Expenditure Equations

Description: Equations were developed by Garg, Chaffin and Herrin (1978) to estimate the metabolic cost of various lifting conditions. They can be used to determine if a particular lifting condition will result in undue fatigue to the lifter.

Scientific Approach: Work Physiology is based on measurements of heart rate and/or oxygen consumption

Input Parameters:

- type of lift (bent knees or straight legs)
- subject body weight
- starting height of the lift (h_1)
- finishing height of the lift (h_2)
- hand held load magnitude
- lifting frequency (lifts/minute)
- subject sex

Output Parameters:

- energy expenditure associated with a particular lifting condition
- this can be compared to recommended limits

Epidemiology

Mital et al (1993) have stated that the Job Stress Index (JSI, from Ayoub and Mital, 1989) should not exceed 1.5 as the occurrence of injuries increases substantially when the JSI exceeds this value. Based on remaining at JSI values below 1.5, they determined that the maximum acceptable loads were 27 kg for males and 20 kg for females.

Integration of Tools

As noted earlier, the integration of information provided by each of the ergonomic methods is complicated by the fact that each has different input parameters and different output parameters. However, the general principles guiding the recommended safe lifting loads are the same for each method. BakPak is presented as one computer package that provides the same information as each of the discussed methods while requiring only a few simple measurements from the beginning and end of the lift or lower. These parameters are similar to those from the NIOSH equation:

H = horizontal distance from the ankle to the hand held load
V = vertical location of the load
A = asymmetry angle
L = lateral displacement of the load
F = frequency of lifting (lifts/minute)
D = duration the task is performed

We have conducted a study to determine what the "H" value would be in the Snook tables for the various box widths "W" that it provides values for (Potvin and Bent, 1997). Subsequently a regression equation was developed to determine if the values in the Snook tables for males and females could be estimated accurately with the estimated "H", "V", "D" and "F" factors used in the NIOSH equation. The predicted value was very highly related to the Snook table values and the average error was less than 1 kg. Now, it appears that the same four measurements (H, V, D, and F) can be used to determine the NIOSH and Snook recommendations for safe loads instead of the need to teach ergonomists how to use both the equation and the look-up tables with different input parameters.

The biomechanical programs are difficult to use because they required a great deal of information to be input before they can tell the user what the forces are on the low back. However, it is possible to greatly simplify the required inputs while obtaining accurate estimates of lumbar compression forces. To demonstrate this, we have collected data from 22 male and female subjects and have processed over 9,000 load/posture combinations. Regression equations were developed to predict almost the same values as the biomechanical models while requiring only the following easily measured variables (H, V, hand load and body mass). These equations have been incorporated into BakPak.

The metabolic energy expenditure equations of Garg et al (1978) have also been rearranged to estimate the loads that would not result in undue fatigue.

Summary

In summary, a computer software package has been developed that uses essentially the NIOSH equation inputs to estimate the following:

1) NIOSH estimates of acceptable loads (1981 and 1993 equations)
2) Snook Table estimates of acceptable loads
3) the maximum loads that would result in safe compression and shear forces on the low back
4) the maximum loads that will not result in undue metabolic cost

Unfortunately, it is not likely the acceptable loads determined based on the NIOSH equations, Snook Tables, lumbar compression forces and metabolic constraints will all be the same. In this event, the software package has been designed to select the most appropriate value(s). These decisions are generally made based on the most conservative estimate for the lifting or lowering condition being tested. This kind of information was integrated into the package to allow for correct decisions to be made regarding the load limits that should be set. In this way, the software serves as an expert system so that aids the user in making informed and valid decisions.

In the preceding pages we have attempted to outline the variability in the ergonomic measurement tools currently available for assessing lifting conditions for their risk of injuries. The BakPak software package has bee developed to:

1) eliminate the variability in input parameters
2) make it very easy for the ergonomist to use and interpret
3) maintain the accuracy that previously required the use of 5 different methods with numerous input parameters.

Advantages of the BAKPAK Software Package

1) It has the potential to replace a number of the packages currently only providing a portion of the information available in the BakPak package. Most currently available software requires substantial education and experience for their proper use while the BAKPAK software requires only the NIOSH inputs that most ergonomists are already familiar with.

2) The package integrates the most current literature regarding the validity of each of the methods used. This information is used so that the software can recommend the most appropriate safe load. This will eliminate decisions being made by the user where the limitations of each method are not fully accounted for.

3) The computer model has been developed to provide suggestions for the components of each task where modifications would be of most benefit to the workers with regard to reducing injuries. In this way the model can be used to guide "what if" scenarios in the redesign process.

Using BakPak

The BakPak software package has been developed to allow for a comprehensive analysis of lifting and lowering tasks based on the biomechanical, physiological (metabolic) and psychophysical criteria available in the literature. The program requires a few simple measurements and provides estimates of acceptable loads based on each criteria.

Input Parameters

Units of Measurement:

these can be either centimetres or inches.

Posture Data

Horizontal distance:

This variable is the same as the NIOSH AH@ value measured as the horizontal distance from the midpoint between the ankles to the midpoint between the hands. This can be different for the start and end of the lift if the AH@ changes substantially. Just use the same H value for start and end if you want to do a more standard analysis

Vertical distance:

You must enter the vertical height of the load (hands) at both the start and end of the lift. The difference between the start and end height are the same as the NIOSH AD@ (or displacement) values

Asymmetry angle:

This is used for the new NIOSH equation and for Mital corrections. The angle should be measured in degrees and it represents the twist of the trunk. This can be best approximated by estimating the angle between the line draw between the ankles and the line drawn between the hands (or shoulders) when viewed from above.

Lateral Displacement of the Load:

This is the distance that the midpoint of the hands is shifted laterally from the midpoint of the ankles. This is used for Mital corrections.

Fatigue Data

Lifting Frequency:

This value should represent the average number of times the lift or lower is performed each minute.

Coupling:

Used for the new NIOSH equation and the Mital corrections. You must define the coupling as good, fair or poor. Good involves handles allowing for a power grip while poor requires substantial pinching or awkward static postures of the hand and/or wrist.

Duration:

This represents the number of hours the task is performed each day (0.05 to 12 hours).

Percentile

This represents the percentage of the male and female population for which you would like to design

Output Parameters

To the right of the inputs, the estimates for acceptable load are provided based on each of the criteria. The diagrams in the bottom right corner illustrate the predicted postures for the duration of the lift. It is assumed that the load moves in a straight line from the start position to the end position. Each posture represents the a worst-case scenario, for compression force, based on the range of likely postures for that combination of horizontal reach and vertical distance of the load from the floor.

Acceptable Loads

note: all values are displayed but it is recommended that decisions about the acceptability of the lifting conditions be made based only on the values highlighted in blue. These values are the most conservative for the given materials handling condition.

Lumbar Compression

For each of ten load positions from the trajectory of the lift, the model determines the worst posture that is likely to occur. In that posture it determines the load that will result in the threshold compression force for males and females. The compression limits are based on the data of Jager and Luttman (1991). The suggested limit is the lowest (most conservative) value of the ten postures analysed. The biomechanical criterion is most valid at low frequencies. and, thus, the values are only highlighted when either the compression is below 2 lifts/minute or the compression based load is lower than recommended loads from methods that are presumed to be more conservative in that frequency range

The lumbar compression limits have been corrected for spine twisting and lateral load asymmetry based on Mital et al (1993).

Psychophysical Lifting Tables

These outputs are based on an equation that takes the start and end AH@ and AV@ and the frequency as inputs and estimates the value in the Snook lifting or lowering tables. The psychophysical criterion is most valid for frequencies less than 7/min for females and between 2 and 7/min for males. Thus, numbers are only highlighted if they fall in this range or if the psychophysical load is lower than recommended loads from methods that are presumed to be more conservative in that frequency range.

The Snook Table estimates have been corrected for twisting asymmetry, coupling and duration of the task based on Mital et al (1993).

Metabolic Equations

The outputs are based on loads that would not result in fatigue at metabolic limits based on Mital et al (1993) and Mital (1984). These metabolic cost estimates are based on the equations of Garg et al (1978). The physiologic criterion is most valid for lifting and lowering frequencies greater than 5/min and, thus, numbers are only highlighted if they fall in this range or if the metabolic based load is lower than recommended loads from methods that are presumed to be more conservative in that frequency range. The metabolic estimates are corrected for task duration based on Mital et al (1993).

Epidemiology

These values are based on recommendations made in Mital et al (1993) and are always 20 kg for females and 27 kg for males. These values are only highlighted when all other limits exceed them.

NIOSH Equations

Values are provided from both NIOSH equations using the inputs at the start and end of the lift. It is recommended that the other criterion provide a more direct and valid estimation of acceptable loads.

Criteria

These values represent the acceptable levels for the percentile selected. For lumbar compression force, the values are based on Jager and Luttman (1991). For the psychophysical estimates the values are based on Snook and Ciriello (1991). For the metabolic criterion the values are based on Mital et al (1993) and Mital (1984).

File Menus

File: From this menu you can print or exit the program. When printing the program will ask you to enter any notes you want attached to the printout.

Edit: This menu can be used to return values to default, transfer data to a Clipboard, copy or paste.

Tools: Used to transfer to other modules, including the Strain Index and RULA sheets, where applicable.

Option: Used to return values to original defaults or to set the current values as default.

RULA Module

The Rapid Upper Limb Assessment (RULA) module is based on the work of McAtemmy and Corlett (1993). This tool bases decisions mainly on posture, but it also accounts for exertion level and repetition. The body is broken down into the neck, trunk, legs, shoulder, elbow and wrist. For each of these components, figures are provided and the user chooses which best represents the posture of the worker. As the posture becomes less optimal, the number associated with each figure increases from one, in increments of one. Look-up tables are used to determine a posture score based on the number associated with each component. Finally, this posture score is combined with a force/repetition score, from another look-up table, to determine the Action Level or severity score. This final score increases from 1 (most optimal conditions) to 7 (conditions with the highest need for redesign). The main advantage of RULA is that it is easy to use and it can provide an indication of the relative ranking of each task in a work environment, with regards to their risk for injury.

Strain Index Module

The Strain Index is based on the work of Moore and Garg (1995) and can be used to assess tasks placing demands on the hands and wrists. This tool is much like the NIOSH Lifting Equation in that it is multiplicative in nature. It is intended mainly as a quantification method for hand and wrist injury risk. The user evaluates the: 1) exertion level, relative to maximum, 2) the posture of the wrist, 3) frequency of exertions per minute, 4) number of hours the task is performed in a day, 5) percentage of a work cycle for which the hand is engaged in this activity and 6) the speed of work. For each of these six categories, there are five levels of severity and each is associated with a score. The Strain Index is calculated by multiplying out each of these six scores. Limits are provided such that Strain Index values above a level 7 are considered to have a higher risk of injury than those below 3.

Tool Summary Sheets

The following sheets provide a summary and some examples of the inputs and outputs associated with each tool.

BakPak Lift & Lower Module

Inputs ⟵ | ⟶ **Outputs**

Menu Bar
File (print and exit), Edit (copy, paste return to defaults), Tools (move to RULA or Strain Index where applicable), Options (setting defaults)

Percentile
Defines the percentage of the population for which you want the task to be acceptable

Horizontal Displacement
NIOSH "H" at the start and end of the lift or lower

Input Units
Define metric or empirical units

Vertical Height
NIOSH "V" at the start and end of the lift or lower

Asymmetry Angle
Angle of rotation of hands relative to feet at the start and end of lift or lower

Lateral Displacement
Displacement of the load sideways in the frontal plane

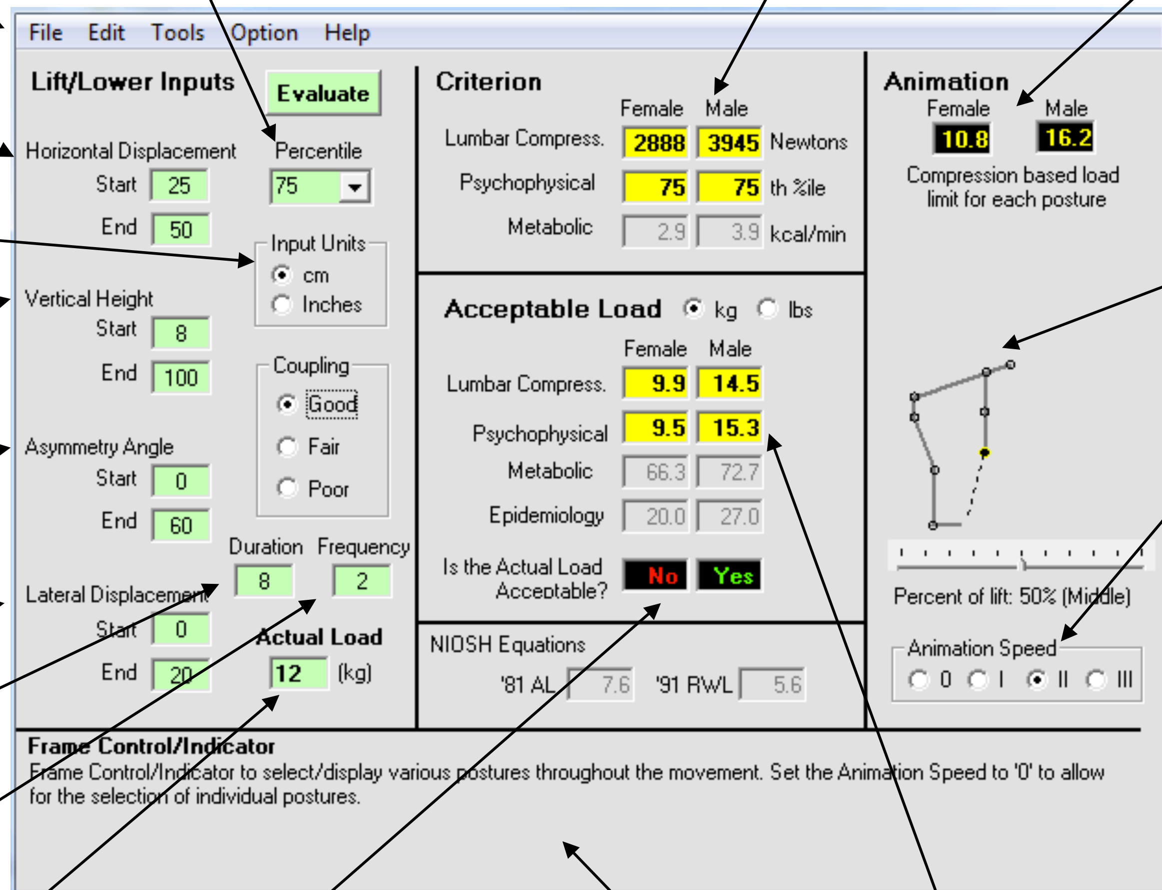
Duration
Time that the task is performed each day (hours)

Frequency
Lifts/lowers per minute

Actual Load Is it Acceptable?
Enter the actual load so that BakPak can determine if it is acceptable for parameters that have been entered

Criterion
Recommended limits for the percentile that was selected (eg. acceptable to 75% of the male and female population)

Compression Based Load Limit: unique value for each posture with lowest highlighted



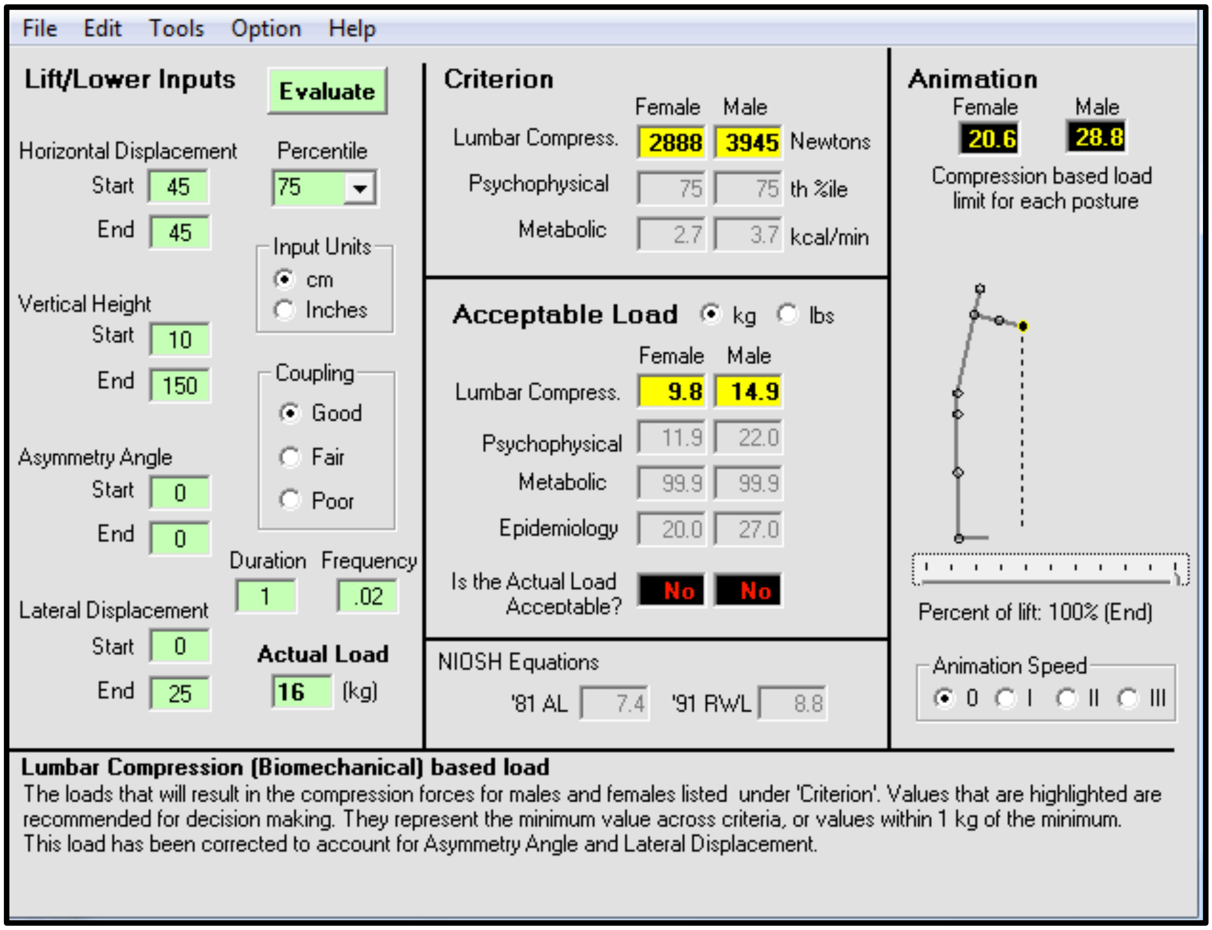
Animation
This stick figure will go through the full range of movement in increments of 10% from the start to the end. In each position the worst case of likely trunk flexion angles is indicated.
The speed can be altered or stopped (0).
The values on the top indicate the acceptable load based on compression force for that posture.

Description Area
This area will provide a detailed description for any area under the cursor.

Acceptable Loads
Based on each criterion. Highlighted values are those that are recommended as the most valid for the given conditions

Example 1

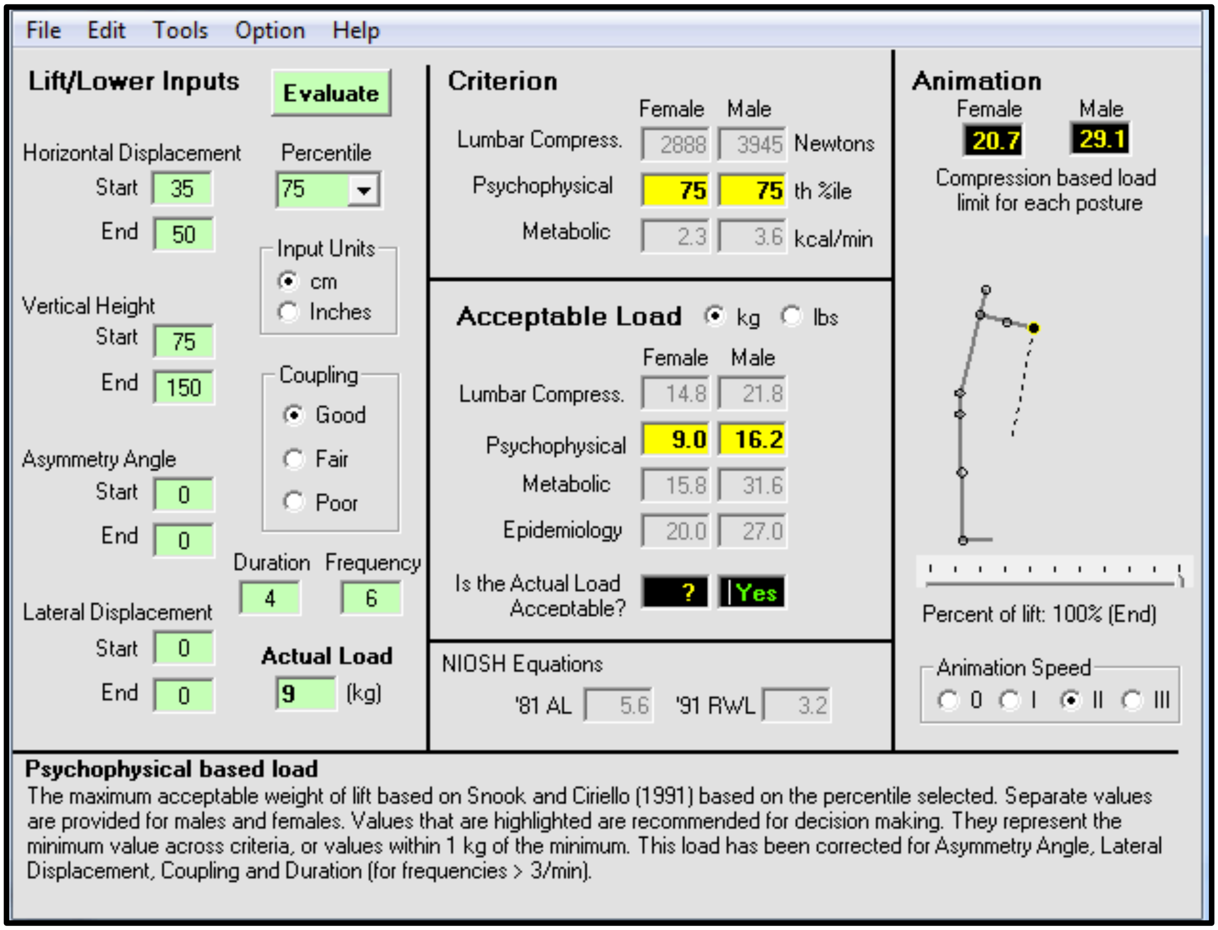
Floor to Shoulder Height Lifting
at a low frequency (0.2 lifts per minute)



16 kg is not acceptable for females or males
based on lumbar compression forces exceeding 2888 and 3945 respectively

Example 2

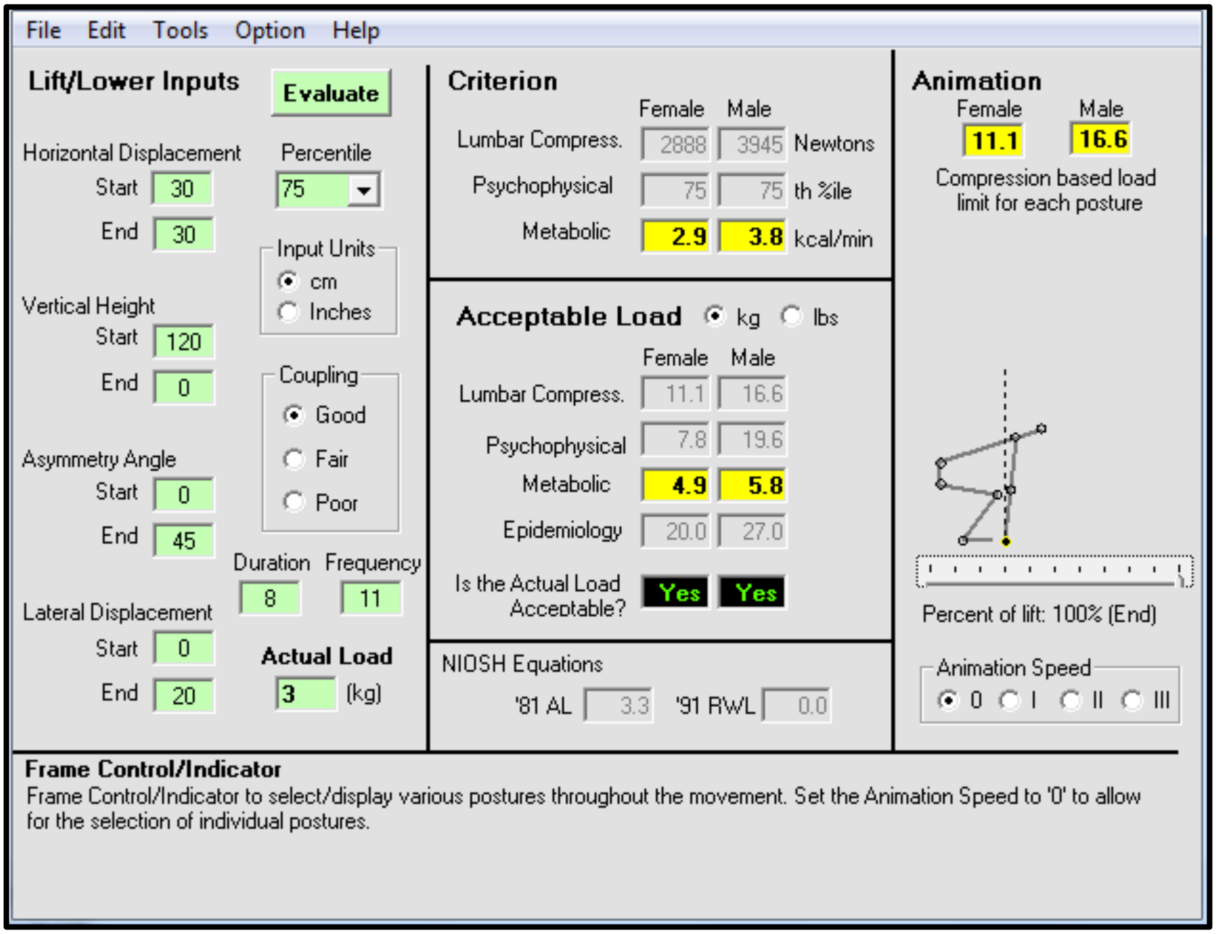
Symmetrical, Knuckle to Shoulder Height Lifting at moderate frequencies (6 lifts per minute)



9 kg is marginal for females but acceptable for males based on the 75th percentile psychophysical criterion

Example 3

Asymmetrical, Shoulder to Floor Height Lowering at high frequencies (11 lifts per minute)



3 kg is acceptable for females and males
based on the metabolic costs exceeding 2.9 and 3.8 kcal/min respectively

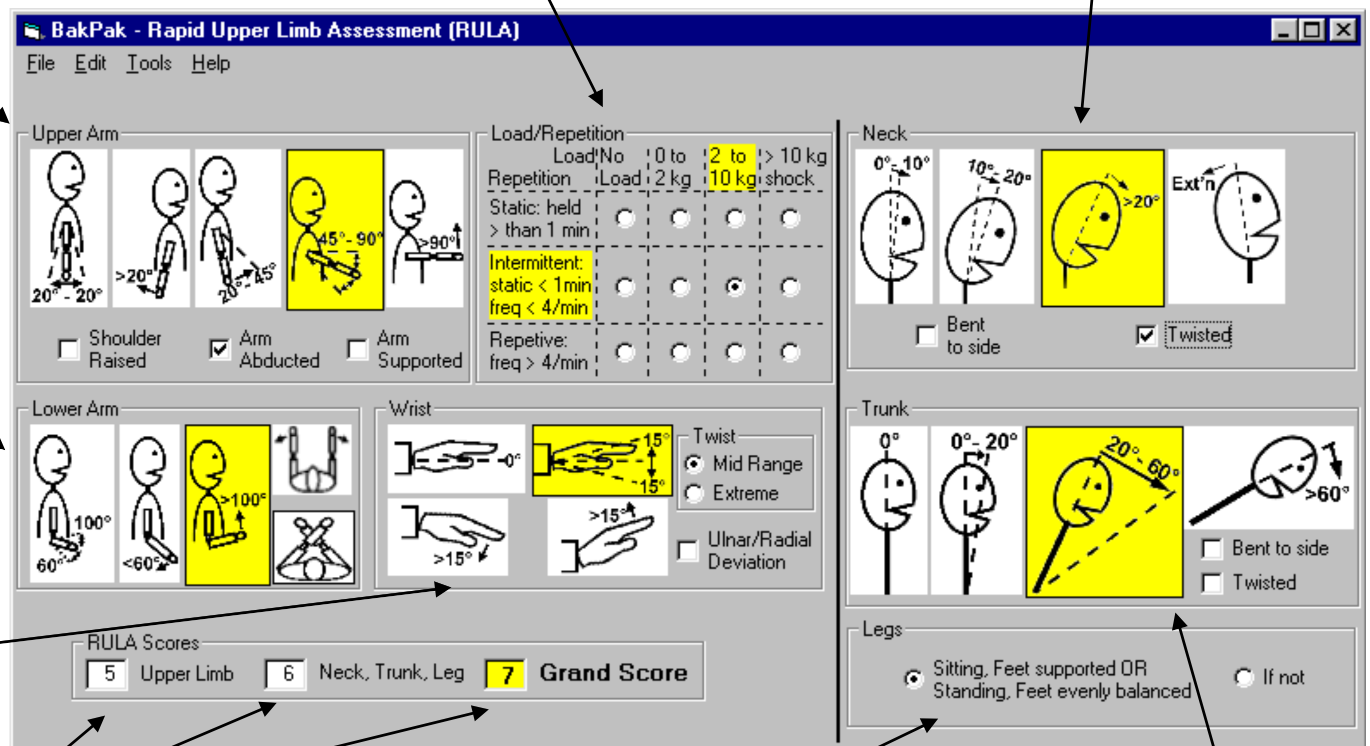
RULA Module

Adapted from McAtamny and Corlett (1993)

Upper Arm
Pick the shoulder rotation that best describes the posture and click on it (it will turn yellow)
Is the shoulder raised? Is the arm abducted? Is the arm supported? Click the box for each case that is true

Load and Repetition
Pick the column that best describes the load being lifted or held statically. Pick the last column if there is an impact (shock).
If it is a static hold, chose between the first and second row (>1 min or <1 min at a time). If it is repetitive chose between the second and third row (<4 per min or > 4 per min)

Neck
Pick the neck rotation that best describes the posture. Is the neck also bent to the side? Is the neck twisted? Click the box for each case that is true



Lower Arm
Pick one of the three elbow rotations to best describe the posture. Also, click on the top right box if the arms are rotated out as shown or click on the bottom right box if the arms cross the midline as shown)

Wrist
Pick one of the four wrist angles. Is there also forearm twist? Is there also ulnar or radial deviation?

RULA Output Scores
This gets calculated by the software. The maximum values are13 for Upper Limb and 9 for Neck, Trunk, Leg. The maximum value for the Grand Score is 7. Grand scores of 1 or 2 are "acceptable", 3 or 4 "may require changes", 5 or 6 "require changes soon" and 7 "require changes now".

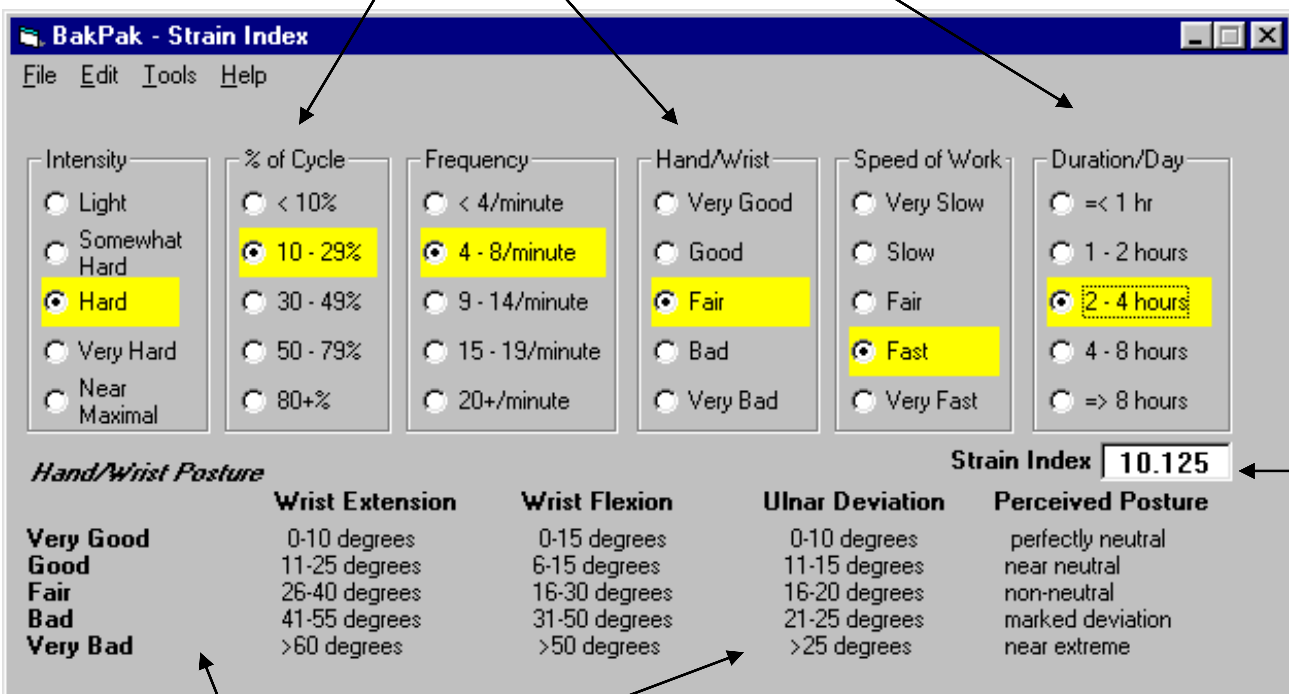
Legs
Indicate whether the person is sitting or standing evenly on both feet OR if they are not (standing predominantly on one foot).

Trunk
Pick one of the 4 trunk angles to best describe the posture. Is the trunk bent to the side? Is the trunk twisted? Click the box for each case that is true.

Strain Index Module

Adapted from Moore and Garg (1995)

Inputs
For each category (Intensity, % of Cycle, Frequency, Hand/Wrist Posture, Speed of Work, Duration during the day) click on the appropriate button.



Strain Index Score
This is calculated by the software. Values under 3 are "probably safe". Values greater than 7 are "probably hazardous".

Description
This area will provide a detailed description for any area under the cursor.

References

Ayoub, M.M., Bethea, N.J., Deivanayagam, et al. (1978) DHHS (NIOSH) Grant No. 5-R01-0H-00545-02.

Ayoub, M.M, Mital, (1989) Manual Materials Handling. London. Taylor & Francis.

Garg, A., Chaffin, D.B., Herrin, G.D. (1978) Prediction of metabolic rates for manual materials handling jobs, American Industrial Hygiene Association Journal, 39(8): 661-674.

Jager, M. and Luttmann, A. (1991) Compressive strength of lumbar spine elements related to age, gender and other influencing factors. In. Electromyographical Kinesiology, Amsterdam:Elsevier Science, pp. 291-294.

McAtammey, L., Corlett, E.N. (1993) RULA: A survey method for the investigation of work-related upper limb disorders. Applied Ergonomics. 24(2):91-99.

Mital, A. (1984) Comprehensive maximum acceptable weight of lift database for regular 8-hour work shifts. Ergonomics 27(11):1127-1138.

Mital, A., Nicholson, A.S., Ayoub, M.M. (1993). A Guide to Manual Materials Handling. Bristol, PA. Taylor & Francis.

Moore, J.S., Garg, A. (1995) The Strain Index: A proposed method to analyze jobs for risk of distal upper extremity disorders. Am. J. Ind. Hyg. Assoc. 56:443-458.

Potvin, J.R. (1997) Use of NIOSH equation inputs to calculate lumbosacral compression forces. Ergonomics. 40(7):691-707.

Potvin, J.R., Bent, L.R. (1997) NIOSH equation horizontal distances associated with the Liberty Mutual (Snook) lifting table box widths. Ergonomics. 40(6):650-655.

Snook, S.H., Ciriello, V.M. (1991) The design of manual handling tasks: Revised tables of maximum acceptable weights and forces. Ergonomics. 34(9): 1197-1213

Waters, T.R., Putz-Anderson, V., Garg, A. and Fine, L.J. (1993) Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 36(7):749-776.