Design of Static Effort

The design of static effort (isometric muscle contractions) is based on the relative effort expressed as the percent of strength (maximum voluntary contraction) for the design person, the effort time (contraction time) and no-load recovery time. Once any two of these factors are set, the other becomes the limiting aspect of the design.

The formulation of relative effort, endurance time, effort time, and recovery time are provided in the following sections.

For reference, the design person is one who has the 25th percentile strength for the given posture.

Maximum Voluntary Contraction [MVC] and Relative Effort as Percent Maximum Voluntary Contraction [%MVC]

The Maximum Voluntary Contraction (MVC) is a measure of strength. The measure can be a maximal exertion of force reported as force (e.g., lb, kg, Newtons) or as a moment around a joint (e.g., Newton-meters, foot-pounds, kilogram-meters). Data are available from open sources for muscle strength for various postures and how the strength is distributed in the general population.

The Percent Maximum Voluntary Contraction (%MVC) is the percentage ratio of the applied force (as either a force or a resulting moment on a joint) to the MVC for the same muscle group in the same posture and expressed in the same units.

$$\%MVC = 100\% \times \{\text{Force or Moment}\} / MVC_{\{\text{Force or Moment}\}}$$

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Endurance Time [min] versus Percent Maximum Voluntary Contraction [%MVC]

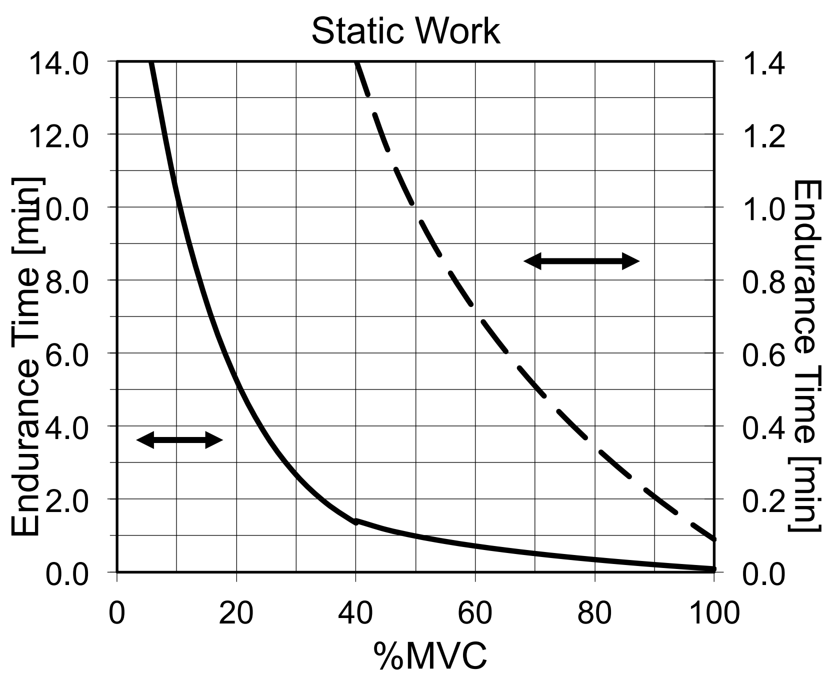
For a given %MVC, either for a design strength or for an individual, the maximum contraction time (t_{end}) is computed from the following curves. The curve from 40 to 100% MVC is attributed to Rohmert as cited by Muller in the following equation, and further reduced by 10% to account for some variation and the likelihood that Rohmert's endurance time was to physical exhaustion (and not an acceptable maximum effort in the workplace). The 10% decrease is arbitrary.

t_{end} [min]$_{40\text{-}100\%}$ = 0.9 [-1.5 + 2.1/(%MVC/100) - 0.6/(%MVC/100)^2 + 0.1/(%MVC/100)^3]

Data from 5 to 25% are unpublished data from Wan and Bernard, which was extended to include Rohmert data reduced by 10% from 25 to 40%. The curve to describe to combined data is

t_{end} [min]$_{5\text{-}40\%}$ = 20.5 e$^{-0.068\ \%MVC}$

Finding the endurance time from a %MVC begins with the x-axis and is read from the left curve to left axis for %MVC between 5 and 40% or from the right curve and axis for %MVC from 40% to 100%. For %MVC < 5, the sustained effort time should be limited to about 15 minutes.



Note: There is a 4% (0.06 min, 4 s) discontinuity at 40 %MVC between the two equations.

Duty Cycle and Maximum Acceptable Effort [%MAE]

Recovery time recommendations assume that the endurance time of any one sustained exertion is not exceeded. Potvin surveyed the existing literature for static work design and framed the results as a relationship between duty cycle (DC) and relative exertion (expressed as maximum acceptable effort or %MAE) that can be supported for a workday (JR Potvin, Predicting Maximum Acceptable Efforts for Repetitive Tasks: An Equation Based on Duty Cycle, *Human Factors*, 54(2):175-188, 2012).

DC [%] = 100% (t_{eff} / t_{cycle}) = 100% $\{t_{eff} / (t_{eff} + t_{rec})\}$

%MAE = 100% Effort Force / MVC

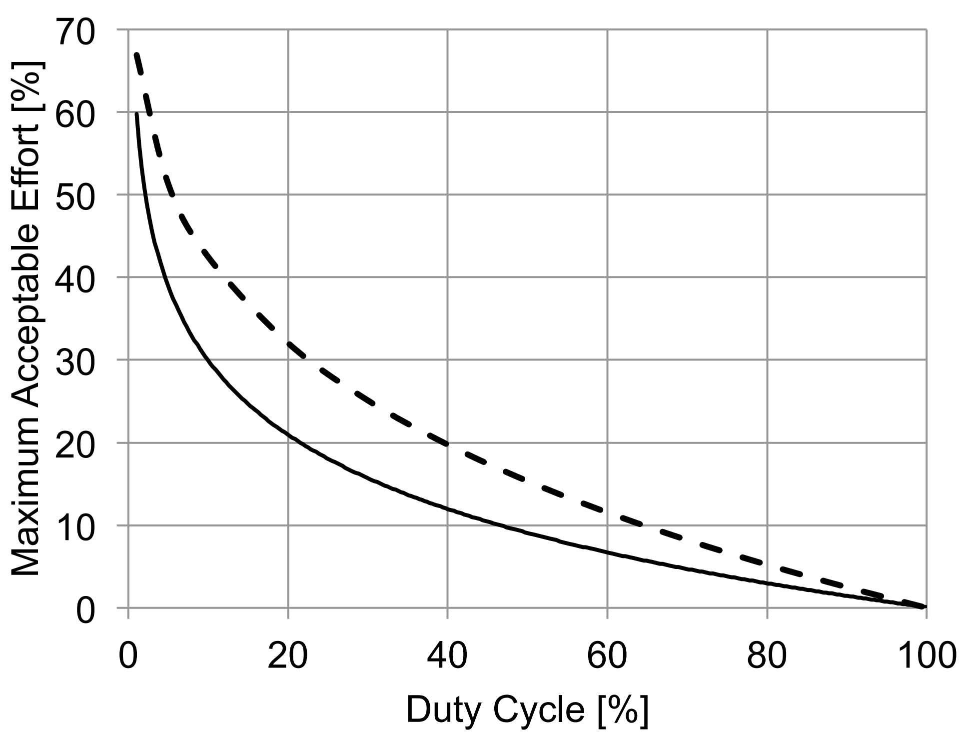
Potvin proposed the following relationship,

%MAE = 100% $\{1 - (DC[\%]/100\%)^{0.24}\}$ – OR – DC[%] = 100% $(1 - \%MAE/100\%)^{4.17}$

From Potvin's data, a more restrictive (adapted) line follows.

%MAE = 60 – 13 ln (DC[%]) – OR – DC[%] = $e^{(60 - \%MAE)/13}$

Both limits are illustrated in the following figure. Potvin's equation is the dashed line and the adapted equation is the solid line.



Effort and Recovery Time

The relationships from the previous page can be used to estimate recovery time after an exertion at a specific %MAE as

t_{rec} = (100%/DC[%] – 1) t_{eff}

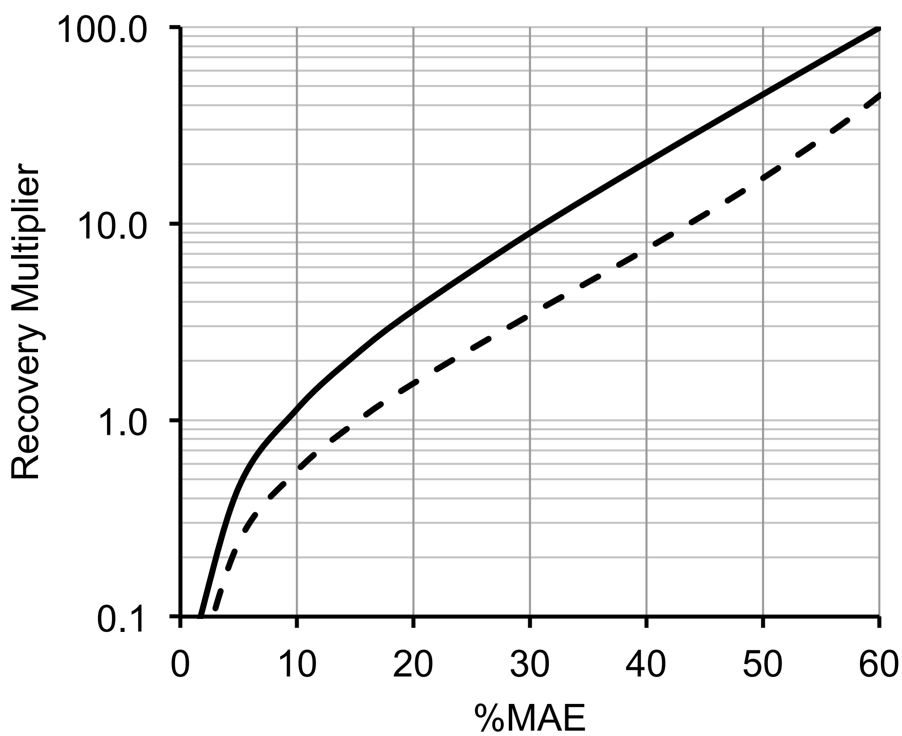
A recovery multiplier (RM) can be defined as RM = t_{rec} / t_{eff}

Then, t_{rec} = RM t_{eff} OR t_{eff} = t_{rec} / RM

For Potvin: RM = $(1 - \%MAE/100\%)^{4.17} / (1 – ((1 - \%MAE/100\%)^{4.17}))$

For the adapted method: RM = $(100\%/e^{(60 - \%MAE)/13} – 1)$

RM as a function of %MAE is illustrated in the figure below (Adapted line is solid and Potvin line is dashed). The valid range is about 1 to 60 %MAE. As the %MAE increases, there is a substantial increase in the required recovery time and/or a requirement to reduce the effort time. There is about a factor of 2 difference between the two lines.



Estimation of Percent Maximum Voluntary Contraction [%MVC]

There may be times when it is difficult to assess %MVC directly. Two methods of estimation follow. Using either of these methods is a poor substitute for direct assessment, but may be useful in the initial consideration of design strategies.

Rating of Perceived Effort Scale

The level of effort can be subjectively assessed using a scale similar to the Borg Scale. Ask people who perform the job (or a mock-up simulation) to provide a score from 0 to 10 with the verbal anchors to aid in the judgment. It is important to rate the effort as it is performed to include the influence of posture. The %MVC is equal to 10 times the scale value. For design purposes, reference a weaker (less strength) worker or use about 70% of a sample mean.

Score	Verbal Anchor	%MVC
0	Nothing at all	0
0.5	Extremely weak (just noticeable)	5
1	Very weak	10
2	Weak (light)	20
3	Moderate	30
4		40
5	Strong (heavy)	50
6		60
7	Very strong	70
8		80
9		90
10	Extremely strong (almost maximal)	100

Observational Scale

Moore and Garg have published a Strain Index to assess the risk of MSDs to the hands and wrists. A component of the assessment process is the level of intensity of the effort in five categories for which an approximate %MVC is associated. While this was not the intention of the investigators, it may provide some insight to the relative effort for the preliminary design of static work.

Observation	%MVC
Barely noticeable or relaxed effort	5
Noticeable or definite effort	20
Obvious effort; Unchanged facial expression	40
Substantial effort; Changes facial expression	65
Uses shoulder, trunk or whole body for force application	90