

AN EQUATION TO CALCULATE THE RECOMMENDED CUMULATIVE REST ALLOWANCE ACROSS MULTIPLE SUBTASKS

Murray Gibson¹ and Jim R. Potvin²

1. Saturn Ergonomics, Auburn, Alabama, USA, 2. Potvin Biomechanics, Tecumseh, Ontario, Canada

While many ergonomic tools exist to determine the acceptability of isolated subtasks, few methods are available to assess more complex tasks with multiple subtasks. This paper describes how the existing MAE equation can be rearranged to calculate the required rest allowance if effort level, duration and frequency are known for individual subtasks, and determine the recommended cumulative rest allowance (RCRA) across multiple subtasks. The method is easy to use, and a natural extension of current ergonomic analysis methods.

Key words: complex work tasks, muscle fatigue, acceptable loads, ergonomics

1. INTRODUCTION

Based on data from psychophysical studies of the upper extremities, Potvin (2012) developed an equation to estimate the maximum acceptable effort (**MAE**), as a percentage of maximum strength, based on the duty cycle of an isolated subtask. That equation was subsequently shown to match the lifting and lowering data of Snook and Ciriello (1991) and the data used to develop the equation became the basis for the recent ACGIH TLV for Localized Muscle Fatigue (ACGIH, 2016).

One limitation of the MAE equation is that, in its current form, it can only be applied to isolated subtasks. While this is valuable, most work involves multiple subtasks that can place complex demands on muscle groups that may subsequently accumulate unacceptable muscle fatigue, even if each subtask was deemed to be acceptable in isolation. Rohmert (1973) developed a method to determine the rest allowance necessary for repetitive isotasks, but that method was limited by its assumption that efforts below 15% of maximum could be held indefinitely. Enoka and Stuart (1992) state that "*most evidence indicates that activation of the neuromuscular system at any intensity will eventually elicit fatigue*". Thus, the purpose of this paper was to develop a new method by rearranging the MAE equation to determine the rest allowance required for individual subtasks, so that a recommended cumulative rest allowance (**RCRA**) could be estimated across subtasks.

2. METHODS

The MAE equation is: $MAE = 1 - [DC - DC_{MIN}]^{0.24}$ where: DC is the duty cycle and $DC_{MIN} = 0.000035$, representing the assumption that a 100% effort could be held for 1 s each 8 hours (28,800 s). Duty cycle represents the holding time as a percentage of the cycle time (t_C), and is calculated as $(t_E)(f) / t_C$ where; t_E is the effort duration, f is the frequency, and t_C is the effort duration (t_E) plus the recovery time per cycle ($t_{R/C}$). Substituting $[(t_E)(f)] / [(t_E)(f) + t_{R/C}]$ for DC in the MAE equation, and solving for $t_{R/C}$ yields:

$$t_{R/C} = \frac{(t_E)(f)}{[1 - E]^{4.167} + DC_{MIN}} - (t_E)(f)$$

where: E is the known effort, as a percentage of maximum strength. With this equation, the recovery allowance can be calculated for each subtask, and the RCRA can be calculated as the sum of all subtask rest allowances. If the cycle time minus the total of all effort durations is less than the RCRA, then the task would be assumed to be unacceptable. It should also be noted, that each subtask must be found to be acceptable before the user can proceed to the RCRA analysis. If the rest is not sufficient for one subtask in isolation, it surely will not when combined with other subtasks.

Table 1: Summary of original inputs and modified job inputs (highlighted) and results.

3. RESULTS AND DISCUSSION

The RCRA method can best be illustrated with examples. Table 1 shows three subtasks, requiring efforts of 10%, 55% and 20% MVC and their associated efforts/cycle and durations per effort. The cycle duration is 60 s. Since the 55% effort was found to be unacceptable, that task should be addressed before proceeding to a determination of whether the whole job has an acceptable rest allowance. If the second subtask's force demand is decreased from 55% to 50%, all subtasks are now acceptable in isolation. However, the total rest provided for the whole job (49.00 s) is less than the total cumulative rest allowance required (61.16 s). An RCRA Ratio > 1 should be redesigned. This spreadsheet is available from the authors on request.

Original Job						Subtask Acceptable in Isolation?		Rest Required (s / cycle)
Effort (% MVC)	Frequency (per cycle)	Duration of each Effort (s)	Total Duration (s/cycle)	Actual Duty Cycle (DC)	Maximum Acceptable DC	MAE	Decision	
10%	2.0	1.0	2.0	0.0333	0.645	55.8%	Yes	1.10
55%	2.0	1.5	3.0	0.0500	0.036	51.3%	No	80.52
20%	3.0	2.0	6.0	0.1000	0.395	42.5%	Yes	9.20

Total Cycle Duration (s)	60.00
Total Effort Duration (s/cycle)	11.00
Duty Cycle	0.1833

Modified Job						Subtask Acceptable in Isolation?		Rest Required (s / cycle)
Effort (% MVC)	Frequency (per cycle)	Duration of each Effort (s)	Total Duration (s/cycle)	Actual Duty Cycle (DC)	Maximum Acceptable DC	MAE	Decision	
10%	2.0	1.0	2.0	0.0333	0.645	55.8%	Yes	1.10
50%	2.0	1.5	3.0	0.0500	0.056	51.3%	Yes	50.86
20%	3.0	2.0	6.0	0.1000	0.395	42.5%	Yes	9.20
Total Rest Required								61.16
Total Rest Provided								49.00
RCRA Ratio								1.25

4. DISCUSSION

The RCRA method now provides practicing ergonomists with a quantitative method to combine the demands of different subtasks so that a decision can be made on the acceptability of the whole job in its entirety. A separate analysis could be made for each joint or system (eg. hand) if ergonomics software is used. Some judgement is needed regarding which tasks to combine. For example, the right and left hands would be treated separately and, for example, pulling tasks would challenge different shoulder muscles than pushing tasks, so should be separated. The method has already been used successfully to evaluate work allocation, and justify workplace modifications.

5. REFERENCES

- ACGIH (2016) *Threshold Limit Values for Chemical Substances and Physical Agents*, Cincinnati, OH.
- Enoka R.M. & Stuart D.G. (1992) Neurobiology of muscle fatigue. *J. Appl. Physiol.* 72(5):1631-1648
- Potvin J.R. (2012) Predicting maximum acceptable efforts for repetitive tasks - an equation based on duty cycle, *Human Factors*, 54(2):175-188.
- Rohmert W. (1973) Problems in determining rest allowances - Part 1: Use of modern methods to evaluate stress and strain in static muscular work. *Applied Ergonomics*, 4(2):91-95.
- 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.