The XXIXth Annual Occupational Ergonomics and Safety Conference
Seattle, Washington, USA
June 1-2, 2017

Calculating the Maximum Acceptable Effort for an Isolated Subtask While Still Accounting for the Demands of all Other Subtasks

Murray Gibson[1] and Jim R. Potvin[2]

[1]Saturn Ergonomics, Auburn, Alabama, USA

[2]Potvin Biomechanics, Tecumseh, Ontario, Canada

Corresponding author's Email: murray@saturnergonomics.com

Author Note: Murray Gibson is the founder and consulting leader of Saturn Ergonomics Consulting, Auburn, Alabama, USA. He has over 20 years of combined experience in industry and consulting, developing practical ergonomics solutions to real-world problems. Prior to starting Saturn Ergonomics Consulting in 2015, Murray worked as a Consulting Engineer in ergonomics for Auburn Engineers (3 yrs, 1996-98) and then as Senior Consultant in ergonomics for Aon Global Risk Consulting (16 yrs, 1999-2014). Over his career Murray has completed a wide variety of ergonomics consulting projects, ranging from plant-level projects to larger projects such as design and implementation of company-wide ergonomics programs. Murray has completed consulting projects for over 150 companies including ITT, Exelis, Gannett, Hershey, LabCorp, Ross Stores, Tesla Motors, Credit-Suisse, Tyco International, Joy Global, Bally Technologies, Henkel, Yamaha-Motors, Sun Chemical, Harley-Davidson, and Lincoln Electric.
Dr Jim Potvin received a B.H.K. in Kinesiology from the University of Windsor (1986) and a M.Sc. (1988) and Ph.D. (1992) in biomechanics from the University of Waterloo. He was a professor for 23 years at the University of Guelph, University of Windsor and McMaster University, where is he now a Professor Emeritus. He is also the owner of Potvin Biomechanics Inc. Jim researches in the areas of biomechanics and physical ergonomics. His basic research focuses on the study of joint mechanics and muscle fatigue and his applied research focuses on developing valid ergonomic methods to quantify injury risk in the workplace; including the assessment of manual materials handling tasks and the evaluation of risk of upper limb disorders. Jim has supervised 70 graduate students, employed 57 graduates and consulted for companies in the manufacturing, health care, technology and legal sectors.

Abstract: This paper presents a practical approach for determining the maximum acceptable effort (% MVC) for an isolated subtask within the context of the other subtasks comprising the complete job. Often, an ergonomist needs to evaluate a single subtask of interest, such as "insert plug by pressing with right thumb". It can be difficult to determine the acceptable exertion effort for this isolated subtask because of the influence of similar, but different subtasks comprising the remainder of the job. The other subtasks could consist of, for example, "press electrical connector with right thumb" and "press with right thumb to seat assembly" (both being thumb-press exertions). These other two subtasks would very likely have a different magnitude, duration, and frequency than the isolated subtask of interest (i.e. "insert plug by pressing with right thumb"). This situation places the ergonomist in a quandary when the engineer or supervisor asks the seemingly straightforward question, "How much effort is acceptable for [isolated subtask]?"

This question is difficult to answer because the forces, frequencies and effort durations associated with the other subtasks (let's call them *Contextual Subtasks*) tend to "cloud" the situation by adding to the overall risk, making it difficult to evaluate the initial *Isolated Subtask* (IS) of interest. The approach presented in this paper enables the ergonomists to determine the acceptable exertion for an IS while simultaneously accounting for the demands of Contextual Subtasks.

Keywords: complex work tasks, ergonomics, force evaluation, force analysis, muscle fatigue

1. Introduction

Ergonomics force evaluation models have generally been designed to evaluate isolated subtasks (IS). Only recently have methods been introduced to quantitatively evaluate more complex jobs comprised of multiple subtasks. One approach for passive tissues is the fatigue-failure process of tissue damage (Gallager & Schall, 2016), and another approach for active muscle is the Recommended Cumulative Rest Allowance (RCRA) (Gibson & Potvin, 2016), which indirectly evaluates force exertions by the comparing model recommended cummulative rest allowance to the actual rest allowance in the work cycle.

Background: The RCRA was developed by rearranging an existing single subtask evaluation model, the MAE equation of Potvin (2012). The MAE equation is used to estimate the maximum acceptable effort (MAE) of an isolated subtask, based on Duty Cycle (DC = holding time as a percentage of cycle time) as a percentage of maximum strength. Although a highly useful model, the MAE equation only assesses isolated subtasks, without regard for the contribution of other subtasks to the overall risk associated with a complete job. Physical work often involves multiple subtasks, placing complex demands on muscle groups and potentially resulting in the accumulation of fatigue. To address this issue, the MAE equation was rearranged to solve for the rest allowance required during each cycle based on the effort magnitude, duration and frequency of each individual subtask. The rest allowances of the indivudal subtasks are then accumulated across the entire work cycle to calculate the RCRA. If the sum of the effort durations and the RCRA are less than the total cycle time, then the task is assumed to be acceptable. The ratio of the RCRA divided by the rest provided gives an indication of the risk of muscle fatigue accumulation.

Cumulative analysis methodologies enable the ergonomist to evalaute multiple subtask forces in the same analysis, but they have limitations from an application standpoint. Often, the ergonomist needs to calculate an acceptable force for an isolated subtask, while also taking into account other related forces exertions occuring in surrounding subtasks. To accomplish this, the MAE_{IS} equation was developed, and is a natural extension of the MAE equation and RCRA method, to calculate the MAE of an isolated subtask when it is a part of a larger job with other contextual subtasks. The maximum acceptable effort for the IS is easily calculated using the "surplus" recovery time remaining after the recovery demands of the contextual tasks have been met. The MAE_{IS} equation will be described below, and demonstrated with examples.

2. RCRA Methodology & Example

The RCRA evaluation model is summarized below.

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

where:
$t_{R/C}$ is the recovery time per cycle (in seconds) expressed in the formula below as:
t_E is the duration of each effort (s)
f is the effort frequency
E is the known effort expressed a percentage of maximum strength
DC_{MIN} = 0.000035 representing the assuption that a 100% effort could be held for 1 s each 8 hours (28,800 s)

With this equation, the recovery allowance can be calculated for each subtask, and the RCRA 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 assumemd to be unacceptable. It should 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. A basic example of applying the RCRA follows.

Table 1: The RCRA for all three subtasks, requring efforts of 10%, 30%, and 20% MVC and the associated frequency (efforts/cycle) and effort duration for each subtask. The total cycle duration (cycle time of job) is 45 s.

Subtask	Effort (% MVC)	Frequency (per cycle)	Duration of each Effort (s)	Total Duration (s/cycle)	Actual Duty Cycle (DC)	Maximum Acceptable DC	Acceptable in Isolation?	Rest Required (s / cycle)
(1) insert plug pressing w/R thumb	10%	2.0	1.0	2.00	0.044	0.645	Yes	1.10
(2) press electrical connector w/ R thumb	30%	2.0	1.5	3.00	0.067	0.226	Yes	10.26
(3) press w/ R thumb to seat assembly	20%	3.0	2.0	6.00	0.133	0.395	Yes	9.20

Total Cycle Duration (s)	45.00
Total Effort Duration (s/cycle)	11.00
Total Duty Cycle	0.244

Total Rest Required	**20.57**
Total Rest Provided	**34.00**
RCRA Ratio	**0.60**

Interpreting the above RCRA analysis for the 3 subtasks, we see that the Total Rest Provided in the whole job (34.0 s) is greater than the Total Rest Required (20.57 s). Therefore the RCRA Ratio of 0.60 is < 1, and the cumulative requirements of the subtasks is considered to be acceptable.

ISBN: 97819384965-5-4

Note that if the RCRA Ratio had been > 1, there would be insufficient recovery time available, and the cumulative effects of the three subtasks would be considered to be unacceptable, requring redesign to either increase the Total Rest Provided or reduce the Total Rest Required. This redesign could be accomplished using a variety of approaches. One approach is to modify individual subtasks by reducing the effort magnitude, duration and/or frequency associated with one or more subtasks (% MVC). The RCRA evaluation methodology is very robust evaluation model and has a high degree of specificity, providing the ergonomist multiple choices for how to achieve demonstrable improvements. Note that the total time required for the three subtasks is the total effort durations (11.00 s) plus the total rest required (20.57 s) for a total of 31.57 s. Since the full cycle is 45 s, there is 13.43 s remaining.

3. MAE_{IS} Equation and Example

Working from the above example, assume a Manufacturing Engineer is evaluating part design options that may impact this job. To help decide upon acceptable options, the engineer asks the ergonomist the question, "What is the acceptable force for Subtask 1 (insert plug pressing w/ R thumb)?". The MAE_{IS} equation enables the ergonomist to determine an acceptable maximum force design limit for Subtask 1. The MAE_{IS} equation uses a three-step method.

Step 1: Determine Isolated Subtask & calculate the Total Rest Required for the remaining Contextual Forces

If we consider subtask #1 to be the IS and subtasks #2 and #3 to be the "contextual tasks" (or "CTs"), then the CTs have a total effort time of 3 + 6 = 9 s and rest requirement of 10.26 + 9.20 = 19.46 s (see Table 2).

Step 2: Calculate the Time Remaining for the Isolated Subtask

Since the total cycle is 45 s, the time remaning for the IS is 45 - 28.46 = 16.54 s. Thus, given a frequency and effort duration, and total effort time, for the IS (subtask #1), the maximum effort magnitude is such that the effort time and rest required for the IS must not exceed 16.54 s.

Step 3: Calculate MAE for the Isolated Subtask (ie. MAE_{IS})

An equation was derived to calculate the MAE for the IS, given a total effort and rest time remaining:

$$MAE_{IS} = 1 - \left[\frac{(t_{E:IS})(f_{IS})}{\text{time remaining for IS}} - DC_{MIN}\right]^{0.24}$$

where:
MAE_{IS}: maximum acceptable effort of the isolated subtask
$t_{E:IS}$: effort duration of the isolated subtask
f_{IS}: frequency of the isolated subtask

For our example, the IS task has $T_{E:IS}$ = 1.0 s and f_{IS} = 2.0/cycle for a total time per cycle of 2.0 s. The MAE for the IS is calculated as follows:

$$MAE_{IS} = 1 - \left[\frac{(2.0)(1.0)}{(16.54)} - 0.000035\right]^{0.24} = 0.398$$

and can be seen in Table 2:

Table 2: Summary of analysis to calculate the MAE of the IS task, if it was subtask #1.

Contextual Task	Effort (% MVC)	Frequency (per cycle)	Duration of each Effort (s)	Total Duration (s/cycle)	Actual Duty Cycle (DC)	Maximum Acceptable DC	Acceptable in Isolation?	Rest Required (s / cycle)	Total: Effort + Recovery Time (s)
(2) press electrical connector w/ R thumb	30%	2.0	1.5	3.00	0.067	0.226	Yes	10.26	13.26
(3) press w/ R thumb to seat assembly	20%	3.0	2.0	6.00	0.133	0.395	Yes	9.20	15.20
Total				9.00				19.46	28.46
	MAE_{IS}								Time for IS
IT: (1) insert plug pressing w/R thumb	39.8%	2.0	1.0	2.00	0.044	0.121	Yes	14.54	16.54

Total Cycle Duration (s)	45.00
Total Effort Duration (s/cycle)	11.00
Total Duty Cycle	0.24

Total Rest Required	34.00
Total Rest Provided	34.00
RCRA Ratio	1.00

In this example, an effort of 0.398 (or 39.8% MVC) would result in a rest requirement of 14.54 s for the IS, such that its total time would be 2.0 + 14.54 = 16.54 s, which is exactly equal to the time remaining after accounting for the two CTs (subtasks #2 and #3). Another example is provided below in Table 3.

Table 3: An example of calculating the MAE for an isolated subtask, if you know the effort, frequency and duration of 5 contextual tasks and the frequency and duration of the IS (i.e., in example below, IS frequency & duration is 1/cycle & 1 s respectively).

Contextual Task	Effort (% MVC)	Frequency (per cycle)	Duration of each Effort (s)	Total Duration (s/cycle)	Actual Duty Cycle (DC)	Maximum Acceptable DC	Acceptable in Isolation?	Rest Required (s / cycle)	Total of Effort + Recovery Time (s)
1	10%	5.0	1.0	5.00	0.111	0.645	Yes	2.76	7.76
2	15%	1.0	1.5	1.50	0.033	0.508	Yes	1.45	2.95
3	20%	3.0	1.1	3.30	0.073	0.395	Yes	5.06	8.36
4	33%	1.0	0.7	0.70	0.016	0.189	Yes	3.01	3.71
5	57%	1.0	0.5	0.50	0.011	0.030	Yes	16.32	16.82
Total				11.00				28.60	39.60
	MAE_{IS}								Time for IS
Isolated Task	33.3%	1.00000	1.00	1.00000	0.022222	0.185234	Yes	4.40	5.40

Total Cycle Duration (s)	45.00
Total Effort Duration (s/cycle)	12.00
Duty Cycle	0.267

Total Rest Required	33.00
Total Rest Provided	33.00
RCRA Ratio	1.00

4. Summary

A method is presented to determine the acceptable effort for an isolated subtask, in the context of other subtasks making up a whole job. This method is an extension of the MAE equation (Potvin, 2012) and the RCRA method (Gibson & Potvin, 2016) and accounts for the complexity of most jobs.

5. References

Gallagher, S & Schall, M.C. (2016): Musculoskeletal disorders as a fatigue failure process: evidence, implications and research needs, Ergonomics, DOI: 10.1080/00140139.2016.1208848

Gibson, M., Potvin, J.R. An equation to calculate the recommended cumulative rest allowance across multiple subtasks, Assoc. of Canadian Ergonomists (ACE) Conference, Niagara Falls, ON, Oct 2016.

Potvin J.R. (2012) Predicting maximum acceptable efforts for repetitive tasks - an equation based on duty cycle, *Human Factors*, 54(2):175-188.