USING THE DUTY CYCLE CALCULATION: IT'S OUR DUTY!

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ABSTRACT

In 2012, Jim Potvin published a duty cycle equation that allows us to evaluate force demands based on frequency and duration of exposure. This paper reviews the use of Potvin's duty cycle equation, in conjunction with a biomechanical model (University of Michigan), in order to calculate a "risk index" for upper limb (shoulder, elbow, and wrist) and back musculoskeletal hazards. The "risk index" reflects the ratio of the (observed) job demands to the (calculated) target maximum, such that a value greater than 1 indicates a high risk of injury. The paper reviews our method of applying the duty cycle equation, and provides case studies to demonstrate how it can be used to evaluate job demands, to evaluate job rotation, and to evaluate potential interventions. The paper also discusses current limitations and challenges associated with this approach.

KEYWORDS: Ergonomics, duty cycle, maximum acceptable exertion

L'UTILISATION DU CALCUL DU CYCLE DE TRAVAIL : C'EST NOTRE RESPONSABILITÉ!

RÉSUMÉ

En 2012, Jim Potvin publiait une équation du cycle de travail qui nous permet d'évaluer les exigences de force en fonction de la fréquence et de la durée d'exposition. Cet article jette un regard sur l'utilisation de l'équation du cycle de travail de M. Potvin en association avec un modèle biomécanique (Université du Michigan), afin de calculer un « indice de risque » pour les membres supérieurs (épaules, coudes et poignets) et les risques de lésions musculo-squelettiques au dos. L'indice de risque représente le rapport entre les exigences du travail (observées) et la valeur cible maximale (calculée). Un rapport dont la valeur est supérieure à un (1) indique un risque de blessure élevé. L'article examine notre méthode d'application de l'équation du cycle de travail et propose des études de cas afin de démontrer comment elle peut être utilisée pour évaluer les exigences du travail, l'alternance des tâches et les interventions possibles. L'article traite aussi des limites actuelles et des défis liés à cette approche.

MOTS CLÉS : ergonomie, cycle de travail, effort maximal acceptable

DESCRIPTION OF THE PROBLEM

The primary hazards for musculoskeletal injury (MSD) are widely accepted to include awkward posture, high force, and repetitive or prolonged exposure. A wide variety of ergonomics assessment tools yields an equally wide variety of outputs. Some tools are designed to evaluate one hazard without considering the combined effect of multiple hazards. For example, the University of Michigan's 3D Static Strength Prediction program can be used to evaluate isolated force demands for workers of various anthropometries. Similarly, some thresholds have been identified to guide companies to ensure that jobs are not "too repetitive" (Kilbom, 1994) or "too prolonged" (Rodgers, 1998). Some tools, such as the Liberty Mutual tables (Snook and Ciriello, 1991) and the Strain Index (Moore and Garg, 1995) do attempt to evaluate the combined effect of force, posture, and repetition for an isolated task, but cannot account for the accumulated exposure of multiple tasks.

In 2012, Jim Potvin published his duty cycle equation, which integrates data about force/strength (in a given posture) with the frequency and duration of exposure. In theory, this equation could be used to predict maximum acceptable loads for any muscle group, during a mono-task job. We have been using this equation in various work environments, and this paper summarises some of our experiences.

1. METHODS

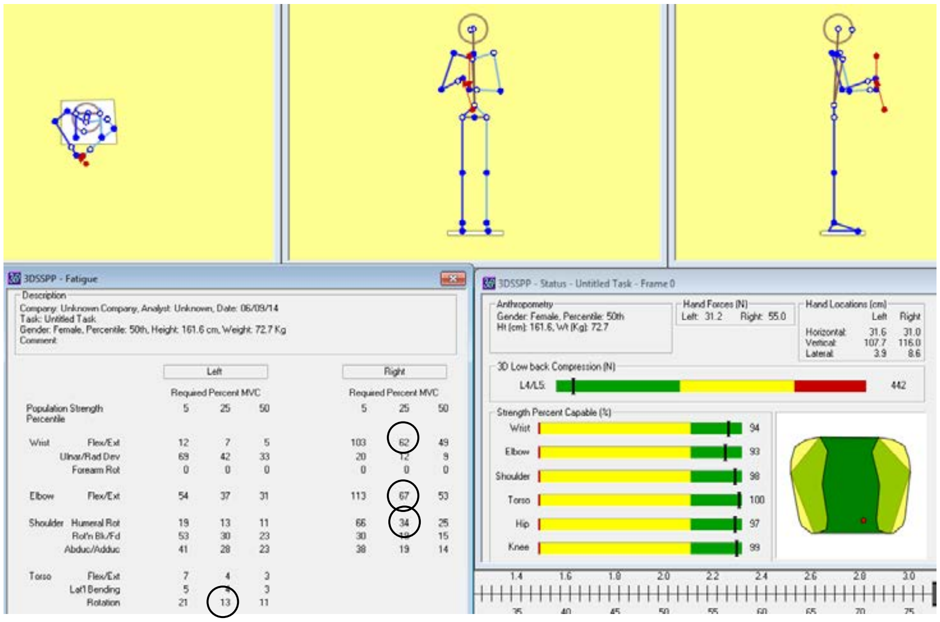
In order to use the duty cycle calculation, the ergonomist needs to measure or estimate the external force requirements, frequency of exertion, duration of exertion, and cycle time. S/he then needs to estimate strength in the working posture, typically using a biomechanical model.

1.1 Force and strength measurement

To measure force requirements for push or pull, a force gauge is used. Weights can be measured with a scale. Some grip or pinch forces can be directly measured with a force gauge, but an accepted force-matching procedure can be used when this is not possible (See Bao and Silverstein, 2005, and Molenaar et al., 2011).

In order to estimate strength requirements, the ergonomist first selects the "limiting user" (Pheasant and Haslegrave, 2006). For gripping and reaching demands, this is typically the small female worker. However, for back bending with low external loads, a large male may be exposed to higher relative loads than the smaller female. In accordance to the "NIOSH" approach (Waters et al., 1995), selecting 25^{th} percentile female strength usually protects 75% of females and most males. The actual load must be compared to the 25^{th} percentile female strength for that task to estimate the load as a percentage of the maximum voluntary contraction (or %MVC). This can be accomplished using ergonomics software such as 3D Static Strength Prediction Program (University of Michigan, 2012), or HandPak (Work in Progress, 2007).

The example below shows a task called "ink-stamping parts" for a "typical height" (50^{th} percentile height) female worker. In order to protect a majority of the population, the ergonomist evaluated the 25^{th} percentile female strength using the Fatigue Report from 3DSSPP. These values peaked at 59% strength (MVC) for right wrist, 66% for right elbow, 33% for right shoulder, and 13% for torso. (Lower strength demands are usually discarded for the purpose of this analysis.)



1.2 Time parameters

The duty cycle calculations also require the ergonomist to measure exertion duration, frequency, and cycle duration. Some of this data may be obtained through production data; for example, if a task is required twice per part, and 300 parts are produced per shift, then the exertion would be completed 600 times per shift. The cycle may be one full shift (28800 seconds, or 8 hours), as in this case. A smaller, repeating cycle may also be used; if a part is produced every minute, a logical cycle might be 60 seconds. Similarly, if operators rotate every hour, a 3600 second cycle (60 minutes x 60 seconds) might be appropriate.

Exertion time needs to be measured using a stopwatch, or estimated using industrial engineering data such as MTM or MOST studies. To measure exertion time for short exertions, a video tape might be used. Whether performed "live", or through video analysis, ergonomists are prudent to measure the time required for several different operators, and on different days if production conditions may vary from day to day. It is important that exertion time corresponds only to the time of the actual effort.

1.3 Calculating Maximum Acceptable Effort (MAE)

The duty cycle calculation is expressed as follows:

$MAE = 1 - (DC - [1 / 28,800])^{0.24}$

Where DC represents the portion of the cycle that the muscles are active (total effort duration divided by cycle duration) and 28,800 is the number of seconds in 8 hours.

To calculate a risk index for each body part, we calculate the actual load as a percentage of the MAE. If the risk index is less than 1, the job demands fall within guidelines; if the risk index is greater than 1, the job warrants improvement. The chart below shows an excel spreadsheet that calculates the risk indices, for the case study described above.

Table 1. Calculation of risk index using duty cycle equation

Target maximum acceptable exertion (MAE) calculations (Potvin)		
Number of exertions per cycle	30.0	30 parts per 7.2 minute "round" (considered "worst case")
Duration of each exertion	1.0	second
Cycle duration (seconds)	420	seconds, (7.2 minutes)
Duty cycle	0.07	(1=100% of the cycle)
Target maximum acceptable effort (MAE)	0.47	(1=100% of maximum)

Biomechanical assessment		
Hand forces (incl direction)	Left: 3.2 kg lift/resist stamp	Right: 5.6 kg push down

	Left			**Right**		
Peak Demand by Body Part	**Req'd exertion**	**Target MAE**	**Risk index**	**Req'd exertion**	**Target MAE**	**Risk index**
Wrist	42%	47%	0.89	62%	47%	**1.31**
Elbow	37%	47%	0.78	67%	47%	**1.41**
Shoulder	30%	47%	0.63	34%	47%	0.72
Back	13%	47%	0.27			
	Back compress'n	**Target (N)**	**Risk index**			
Low back compressive force	442	3433.5	0.13			

The results indicate that the force demands on the right wrist and elbow exceed guidelines. This corresponded with the complaints reported at this job.

2. APPLICATIONS

In addition to risk assessment of existing jobs, the duty cycle equation may be used in other ways.

2.1 "What if assessments"

In the example above, the ergonomist was asked to specify how many parts the employee should be allowed to stamp per minute. This can be explored by changing the number of exertions per minute (or rearranging the equation to yield a maximum acceptable number of exertions). Similarly, we also investigated whether stamping with less momentum (pressing the stamp to the part rather than "pounding" the stamp into the part) would help. In fact, the part could be ink-stamped with measurably less force, but this technique also required more time, and so the solution was not be effective. A supervisor noticed that the clip that secured the stamp to a retractable cord prevented the stamp from protruding from its housing to contact the part with a light touch. The employee had to press hard enough to push the soft part up into the stamp housing. A change to the clip resulted in a reduction in force demands to only 1.5 kg of downward push, which fell well within the guidelines.

2.2. Job rotation assessments

In the case above, we assumed a "worst case" stamping frequency of 30 parts per round. However, these employees rotate on an hourly basis, and so it would be possible to assess the "daily average" exposure, if we could record the number of parts per cycle in each of the jobs in the rotation. This approach works well when the task that is of concern is the same in all rotations, and no other tasks stress the same muscle groups. Unfortunately, it doesn't work as well when a variety of tasks may stress different muscles, and muscle recovery during "non-exertion" time cannot be assumed.

2.3 Setting strength targets for work conditioning

It would be, at least theoretically, possible to specify minimum strength requirements to complete a specific job. For the job described above, the elbow joint was most limiting, at

67% of maximum strength. By decreasing the hand load in the biomechanical model, the ergonomist can determine the load that limits the relative load to the target MAE (which, in this case, was 47%). In this case, the worker should be able to exert 78 N of stamping force (push down), in order to keep all loads at or below 47% of maximum acceptable effort. Therefore, a conditioning program for this task could set 78 N of downward push force as a strength target. This method has not, to our knowledge, been applied, but it offers an interesting model for work conditioning programs.

3. LEARNING EXPERIENCES AND BENEFITS

In the past, ergonomists could calculate task demands as a percentage of maximum strength, but we had to use guidelines that were not very frequency- or duration-sensitive as thresholds. For example, we used guidelines that were published in a basic ergonomics textbook (Putz-Anderson, 1988) as targets; these guidelines suggested 30% of MVC for "repetitive" loads, and 50% of MVC for "occasional" loads. These load levels were often very restrictive, and meant that most jobs presented unacceptable demands. Anecdotally, we found that a biomechanical assessment done with this method was more likely to produce a "high risk" conclusion than a psychophysical assessment. The guidelines based on duty cycle, for most cases, seem to permit a higher exposure level than the Putz-Anderson guidelines. In the ink-stamping case study, for example, if the task was deemed to be "repetitive" (30 exertions in 7.2 minutes), then the 30% threshold would have "flagged" concerns for the right shoulder, left wrist, and left elbow, in addition to those identified with the duty cycle equation.

The duty cycle calculations are much more sensitive to changes in task frequency and duration and, therefore, allow us to account for small improvements in task demands. If we know the force, we can also work backwards to calculate maximum acceptable frequencies or durations, which was not possible with the previous method. (A task had to be classified as "repetitive" or "occasional".)

Further work is required to allow integration of tasks with different muscle demands, and to account for job rotation. Biomechanical models are not readily available to calculate strength demands for the neck or legs and, therefore, we have been unable to apply the duty cycle to some tasks such as inspection or welding (where neck demands can be repetitive) or driving (where external hip rotation and pedal activation can be repetitive or prolonged). This work would allow us to evaluate many more jobs and work schedules, and to evaluate the effect of line balancing tasks.

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