Ergonomics Applications for Muscle Fatigue Modelling

2017 System Ergonomics Collaboration and Knowledge Exchange Day

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Ergonomist

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Muscle Fatigue
Muscle Fatigue
Preventing Fatigue

The Ergonomists’ Bat Belt
Preventing Fatigue

ERGO

Yung & Wells, 2012
Preventing Fatigue

Time (seconds)

% Maximum Voluntary Contraction
CURRENT METHODS FOR EVALUATING FATIGUE
Evaluation of Fatiguing Tasks

• Rhomert (1973) Rest Allowance Equation

\[ RA = 18 \times (\text{Holding Time}) \times \left( \frac{\text{Holding Time}}{\text{Endurance Time}} \right)^{1.4} \times \sqrt{\frac{\text{Joint Moment}}{\text{Joint Strength}}} - 0.15 \]

• Limitation: For tasks below 15% MVC, holding time is infinite.
  – Refuted by many studies, EX) fatigue 2.6% MVC (Hagberg, 1981); 7.9% MVC (Bjorksten & Jonsson, 1977).
Evaluation of Fatiguing Tasks

- Potvin (2012) compared maximum acceptable efforts from psychophysical research against DC to generate an equation to predict MAE.
Evaluation of Fatiguing Tasks

\[
\text{Duty Cycle} = \frac{\text{Work}}{\text{Work} + \text{Rest}}
\]
Evaluation of Fatiguing Tasks

• MAE Equation developed using psychophysical data, however; limited data for DC > 0.5

• Psychophysics – Important method in ergonomics
  – Allows for simulation of industrial tasks, integration of internal mechanisms
    • (Fischer et al., 2012)
A psychophysical study to determine maximum acceptable efforts for a thumb abduction task with high duty cycles

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(Received 9 April 2014; accepted 14 August 2014)

Potvin (2012, ‘Predicting Maximum Acceptable Efforts for Repetitive Tasks: An Equation Based on Duty Cycle’, Human Factors: The Journal of the Human Factors and Ergonomics Society, 54 (2), 175–188) developed an equation using psychophysical data to estimate maximum acceptable efforts (MAEs) as a function of duty cycle (DC). However, only ~6% of the data featured DCs ≥ 0.50. The purpose of this study was to evaluate the MAE equation in the high DC range. We tested a repetitive thumb abduction task with DCs of 0.50, 0.70 and 0.90, at frequencies of both 2 and 6 per minute (n = 6 conditions). Participants were trained for 2 hours and tested for 1 hour on each condition. The MAE decreased with increasing DC, and MAEs at 2/min were higher than those at 6/min. When these current six means were added to the original psychophysical studies, the root-mean squared difference of the MAE equation decreased from 7.23% to 7.05% maximum voluntary contraction. The values from our study are also consistent with those demonstrating physiological evidence of fatigue during both continuous isotonic and high DC tasks.

DCs of 0.5, 0.7, and 0.9
Frequencies of 2/min, 6/min
A psychophysical... high duty cycles

- MAE \( \Rightarrow \) with \( \uparrow \) DC
- RMSD between experimental and MAE equation decreased
- Still no account for multiple tasks
Repetitive Work Assessment
Multiple Task Assessment vs. Fatigue Levels

• How much fatigue is too much fatigue?
• Is there a fatigue threshold?
• How do you interpret fatigue?
MODELLING FATIGUE IN ERGONOMICS: A REVIEW
Fatigue Models

A three-compartment muscle fatigue model accurately predicts joint-specific maximum endurance times for sustained isometric tasks

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The University of Iowa, 1-252 Medical Education Building, Iowa City, IA 52242-1190, United States
Fatigue Models

• The problem remained…
UNDERSTANDING FATIGUE ACCUMULATION IN COMPLEX FORCE PROFILES
Fatigue in Complex Force Patterns

- 10 female graduate students
  - Right hand dominant
  - 23.3 ± 3.7 years
  - 1.65 ± 0.1 m
  - 63.4 ± 7.3 kg

- Performed an isometric hand grip task
  - Hand hanging loose by the side, following a pattern on screen
Methods

![Graph showing the plateau intensity (%MVC) over time (seconds). The graph includes multiple time points: 0, 21, 42, 63, 84, and 105 seconds. The y-axis represents Plateau Intensity (%MVC) ranging from 0 to 100, and the x-axis represents Time (seconds) from 0 to 105. The graph displays multiple peaks and plateaus at different intensity levels.]
Protocol

• Practice profile – non dominant hand
  – Practice from submaximal level to maximum
• Three MVCs with dominant hand
  – Profile normalized to average of three MVCs
• End condition – 65% of max not met, 2 plateaus not completed
Results

- 5 participants completed 2 cycles, 5 participants completed 3 cycles of pyramid
- Analysis was performed on the first cycle and last cycle completed
Results - Force

Graph showing the relationship between Force Plateau (%MVC) and Post Plateau MVC (%). The graph includes data points for Force Plateau Level, First Cycle MVC, and Last Cycle MVC. Significant differences are indicated by asterisks.
Discussion

- Force history – less fatigue accumulation on back side of pyramid
  - No significant change in force (trend to have increase in MVC)
Discussion

• Force history effect?
  – What influence does the order of forces have on fatigue?

• Central vs. Peripheral
  – Motivation, pain tolerance
  – Does 30% after 45% feel like a break?
Understanding Fatigue Accumulation

S-Type Load Cell

Thermoplastic Brace
Understanding Fatigue Accumulation

- 0 - 15 - 30 - 45%
- Reference Plateau

- 15 - 45 - 0 - 30%
- Reference Plateau

- 30 - 0 - 45 - 15%
- Reference Plateau

- 45 - 30 - 15 - 0%
- Reference Plateau
Understanding Fatigue Accumulation

![Graph showing force level over time](image-url)
Understanding Fatigue Accumulation
Understanding Fatigue Accumulation

- Overall fatigue level was the same, despite the order of forces
- PAP ↑ twitch force during first cycle
- How can this be assessed in the workplace?
Understanding Fatigue Accumulation

![Graph showing force decline and plateau intensity](image)

- **Force Decline (%MVC)**
- **Plateau Intensity (%MVC)**

Legend:
- **Blue Squares**: Front Load
- **Red Triangles**: Even Load

*Occupational Health Clinics for Ontario Workers Inc.*
Understanding Fatigue Accumulation
Ratings of Perceived Fatigue

Rating of Perceived Fatigue Scale

Michael W.L. Sonne, Rachel Whittaker, Jim R. Potvin

Script to be read to participant

Please give a rating of perceived fatigue when prompted on the screen.

We would like you to give us a rating on the provided 1-10 scale that describes the level of fatigue you feel at each point throughout the efforts.

This rating should reflect your current perception of your force generating ability. This means we would like you to tell us how tired you feel in comparison to how you felt before we began the trial (i.e., complete rest).

For example, imagine you had just run a sprint race, and had to run another race 30 seconds later. You felt you could only run at 90% of your previous speed—therefore, you’d indicate that your fatigue level was 10%.

This rating should reflect your perception and is independent of the effort intensity. For example, when you are at rest your perceived effort would rate as 0, however your perceived rating of fatigue, depending on how fatigued you currently felt, would not have to be zero, for example you could rate a score of 2 indicating that you currently feel slightly fatigued.

It is important to focus on how you feel at each point in time when you are asked to give the rating. This means that your rating does not have to reflect the intensity of the effort but instead should provide an indication of how fatigued you are currently feeling.

<table>
<thead>
<tr>
<th>RPF Scale</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completely Rested</td>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
<td>Very light fatigue</td>
</tr>
<tr>
<td>1</td>
<td>Light fatigue</td>
</tr>
<tr>
<td>2</td>
<td>Fairly fatigued</td>
</tr>
<tr>
<td>3</td>
<td>Moderately fatigued</td>
</tr>
<tr>
<td>4</td>
<td>Fatigued</td>
</tr>
<tr>
<td>50% Rested</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Nearly exhausted</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Completely Fatigued</td>
<td>10</td>
</tr>
</tbody>
</table>
Ratings of Perceived Fatigue

Ratings of Perceived Fatigue (RPF) vary with force level (expressed as a percentage of Maximum Voluntary Contraction, MVC). The graph compares the effects of front load versus even load on perceived fatigue. The x-axis represents force levels ranging from 0 to 45% MVC, while the y-axis represents the scale of perceived fatigue ranging from 0 to 5. The blue line indicates front load, and the red line represents even load. The data points show a notable increase in perceived fatigue at certain force levels, with a peak at around 30% MVC for both conditions. The error bars suggest variability in the measurements.
Three Compartment Model with Graded Motor Units

Participant Data
- Experimental
- 3CM XFL
- 3CM GMU
- 3CM OPT

Fatigue level (% of pre-trial MVC force lost)

Plateau intensity level (% MVC)

Time (s)
Three Compartment Model

<table>
<thead>
<tr>
<th>RMSD</th>
<th>Final Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.2%</td>
<td>-1.3% MVC</td>
</tr>
</tbody>
</table>

![Graph showing the relationship between time (s), fatigue (% of pre-trial MVC force lost), and plateau (% MVC).](image)

- **RMSD**: 4.2%
- **Final Error**: -1.3% MVC

**Time (s)**: 18 72 126 180 234 288 342 396 450 504 558 612 666 720

**Plateau Intensity (% MVC)**: 0% 5% 10% 15% 20% 25% 30% 35% 40% 45% 50% 60% 70% 80% 90%

**Fatigue (% of pre-trial MVC force lost)**: 0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

**Plateau (% MVC)**: 3CM XFL, 3CM GMU, Experimental, and 3CM OPT with standard deviation (SD).
Application
Application

Fatigue Level (Residual Capacity Lost)

Demand (% MVC)

Time (Minutes)

Post-Wrist - Demands
Pre-Wrist - Demands
Pre-Wrist - Fatigue
Post-Wrist - Fatigue

A  B
C  D
E
CO₂ Gun - Demands

- 2.3 kg (including force of spraying) CO₂ gun is held at waist to above shoulder height, and CO₂ is sprayed on core to remove sand and debris.
- Height ranges between 78cm and 140cm.
- Posture is held for approximately 3 minutes.
CO\textsubscript{2} Gun - Demands

- This job is unacceptable, given that it is only acceptable to 65% of the population when using the gun at the top of the core.
- This may lead to increased injury claim risk for the shoulder.
CO$_2$ Gun - Demands

- Peak shoulder fatigue during 3 minutes of this task reached a 7% loss of shoulder flexion force.
CO$_2$ Gun - Recommendations

• Height adjustable platform will allow the core to be lowered when using the CO2 gun on the top of it.

• Movable stairs are also an option – however, these pose a trip hazard, and moving the stairs are an additional physical demand.
CO$_2$ Gun - Recommendations

- Lowering the platform on an adjustable surface resulted in Fatigue levels reduced to 4.94% for the shoulder, a nearly 40% decrease in fatigue.
OTHER APPLICATIONS AND THE FUTURE
MLB has experimented with ways to speed up games
- Rule 8.04 – 12 seconds between pitches
- Arizona Fall League (AFL) – 20 second pitch clock
Major League Baseball pace-of-play rules and their influence on predicted muscle fatigue during simulated baseball games

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Pace-of-play condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Maximum Fatigue (% of MVC force lost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-Selected</td>
<td>4.00%</td>
</tr>
<tr>
<td>Rule 8.04 (12 seconds)</td>
<td>8.00%</td>
</tr>
<tr>
<td>AFL - 20 Seconds</td>
<td>6.00%</td>
</tr>
</tbody>
</table>
Baseball Fatigue

David Price - August 3, 2015
8 Innings, 11 Ks vs Minnesota Twins

Occupational Health Clinics for Ontario Workers Inc.
The Future of Fatigue modelling
FatigueAssess Beta

• Combining the 3CM Model and RMQ approach
FatigueAssess Beta

• Compare Predicted Fatigue Levels from a Half Day, Full Day, or 5 day work week
Conclusions

- Still left to consider:
  - Stress, Age, Obesity
    - Multipliers for fatigue models

- Understanding what “acceptable” fatigue is
  - Force loss $\rightarrow$ force demands = injury
  - What level of force loss associated with decline in quality/productivity?
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FATIGUE AND THE AGING WORKFORCE

2017 | ESDC Open House
Sandra Patterson, B.Sc., R.Kin., CCPE, CRSP, Ergonomist
What is an Older Worker?

- World Health Organization (WHO)
  - Greater than 45
- WorkSafeBC
  - Greater than 55
- Ontario WSIB
  - No definition
- Functional age may differ from chronological age
Share of Total Labour Force

- In 2001
  - 1 in 10 workers was over 55
- In 2011
  - 1 in 5 workers was over 55
- In 2021
  - 1 in 4 workers will be over 55
Health & Safety Issues

- Older workers generally have a decreased functional capacity
  - Lose about 15%-20% of muscular strength between the ages of 20-60
  - Range of joint movement is reduced
  - Increased incidence of arthritis

- The regulation of posture and balance is slower
  - Greater risk of slips, trips, and falls
Health & Safety Issues contd.

- Reduced
  - Visual acuity
  - Ability to work in dim light
  - Ability to respond to contrast changes
  - Ability to respond to glare, and sudden intensity variations
  - Colour discrimination
  - Depth perception
Priority Items for Older Workers from Literature Search

- Prevention of falls from heights and same level (slips and trips)
  - Increased fatalities, fractures and time to recover
  - Service sector; retail, cleaning, housekeeping and food services

- Prevention of musculoskeletal disorders (MSDs)
  - Increased back injuries
  - Increased time to recover
Strategies to Accommodate an Aging Workforce

1. Review your stats and analyze trends
2. Implement controls
3. Strengthen RTW practices
4. Implement a wellness program
Summary

- The workforce in Canada is getting older
  - Population getting older
  - Workers are staying at work longer
- Older workers are as productive as young workers and do not have more injuries
- Older workers take longer to recover from an injury
- Falls and back injuries are more common in older workers
- These injuries can be reduced with simple workplace adjustments
FATIGUE
Why Measure Fatigue?

- Effect on performance and quality
- Pain and discomfort
- Work-related musculoskeletal disorders
- Diminished motor control
- Reduced strength capability
- Increased force variability
Case Example

Detecting Fatigue in Physically Demanding Work

Residential Plumbing

Problems:

• Plumbers working with plastic pipe (PEX) in residential developments
• Reported hand & forearm pain that interferes with their work.
• Reports of fatigue over a week, with a progressive loss of strength and productivity.
• May be due to repetitive and high forces when cutting and crimping PEX piping.
What should we consider when measuring fatigue at the workplace?
Crimping Study Fatigue Tests

Test Session Measures

Rating of Perceived Discomfort
30% Max Power Grip
Hand and Shoulder Steadiness Tests
Hand Tremor Test
Maximum Power Grip

Day 1: AM (Monday)
Pre-Study Measures: To Determine Forces For All Test Sessions
Before Start of Work
Lunch Break
End of Work Day
Maximum Handgrip Force

Physiological Tremor

RPD (Borg CR-10)

General Observations

- Increasing fatigue of the hand/arm over the day and throughout work week.
- After weekend break, fatigue did not fully return to baseline values from the preceding week (last Monday).
- **Conclusion** - Fatigue is cumulative, and if not fully recovered, can result in decrease productivity, quality, and increase musculoskeletal injuries risk.