Relationships between Physical and Mental Fatigue and Task Performance

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• ... is the decline in a person’s ability to exert desired force

• ... is a complex state characterized by a lack of alertness and reduced mental and physical performance

• ... is multidimensional

Fatigue
- **Physical fatigue**
  - A transient decrease in muscular performance usually seen as a failure to maintain or develop a certain expected force or power

- **Mental fatigue**
  - A psychobiological state caused by prolonged periods of demanding cognitive activity and characterized by subjective feelings of “tiredness” and “lack of energy”

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**Fatigue**
## Work Risk Factors

### Physical
- Heavy physical work
- Lifting/ forceful movement
- Static work posture
- Awkward postures
- Prolonged duration
- Insufficient rest, recovery

### Psychosocial
- Intensified workload
- Time pressure
- Monotonous work
- Low Job control
- Limited Social support
- Job dissatisfaction

### Personal
- Age
- Gender
- Personality
- BMI
- Fitness level
- Experience

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**Work Risk Factors**
Injury Development

Physical factors

Psychosocial factors

Personal factors

Acute responses

Fatigue

Pain/Discomfort Disability

Psychosocial factors

Physical factors

Personal factors
Mental fatigue may produce increased muscle tension and exacerbate task-related biomechanical strain (Bonger et al., 1993)

Mental fatigue may affect awareness and reporting of musculoskeletal symptoms (Sauter & Swansson, 1996)

Mental fatigue impairs recovery after work (Melin & Lundberg, 1997)

Similar brain regions activated during physical and mental fatigue manifestation (Dettmers et al., 1996)
Effects of physical work and fatigue on cognitive performance is studied extensively (Tompowroski, 2003)

- Limited evidence of mental fatigue on muscle function and performance (Marcora et al., 2009, Yoon et. al 2009)

Existing ergonomic tools do not consider interaction of physical and mental fatigue

- RULA/REBA
- Rest allowances
- Rohmert’s endurance curve
- NIOSH Lifting Equation (?)

A need to investigate this relationship in the context of different task parameters

What We (don’t) Know
Force- and Muscle-dependent changes during concurrent physical and mental work

Phase I
- How is performance affected by concurrent physical and mental work (not fatigue)?
- Do certain force levels and muscle groups have greater susceptibility to psychological demands?
- Which measures are more sensitive to multidimensional demands?
Experimental Design

- Independent Variables
  - Physical workload (PWL): Low (5% MVC), Moderate (35% MVC), High (65% MVC)
  - Mental workload (MWL): Control, Mental Arithmetic
  - Muscle group: Shoulder, Torso, Wrist

- Participants
  - 24 healthy young volunteers
  - Mean (SD) age, height, weight: 22.4 (1.9) yrs, 1.68 (0.11) m, 65.2 (10.1) kg
  - No pain, disorders in the last one year

Experiment Design
- 3 experimental sessions
  - Each focusing on one muscle group
- Intermittent static work at 3 force levels
  - Control vs Mental arithmetic
- Sessions and conditions counterbalanced

![Diagram of work and rest intervals](image)

**Protocol**
- **Muscle activity** (Electromyography)
  - Average EMG RMS
  - Co-contraction

- **Muscle oxygenation** (Near Infrared Spectroscopy)
  - Percent Oxygen Saturation

- **Cardiovascular response** (HR monitor)
  - Average heart rate
  - Heart rate variability (SDNN)

**Physiological Measures**
Task Performance

- Motor performance
  - Force fluctuations (SD/Mean) per cycle

- Mental performance
  - Accuracy (# errors) on mental arithmetic
• Ratings of Perceived Exertion: Borg CR10 Scale
  (0: “Nothing” – 10: “Extremely Strong”)

• NASA Task Load Index: 6 subscales
  (0: “Low” – 20: “High”)
  ▪ Overall workload (OWL) = \( f \) [Mental demand, Physical demand, Temporal demand, Effort, Frustration, Performance]
Results
Muscle Activity

- **Increase** in all EMG measures with increasing force levels
- **MWL decreased** mean (5.4-9%) and agonist EMG (4.3-7%) for all muscle groups
  - At higher force levels
Muscle Oxygenation

- Oxygen saturation decreased at higher force levels
- Not influenced by MWL
Heart Rate Measures

- HR increased linearly with force levels
- MWL increased HR (by 2-4%)
- HRV increased at low force levels but decreased at high force levels with MWL in the wrist
U-shaped curve in response to force levels

MWL increased force fluctuations in the shoulder (by 9.6%) and torso (by 24.6%)
- U-shaped curve in response to force levels
- Females made 59% more errors than males during wrist extension
Human Performance Curve

- Low arousal – Boredom, Drowsiness
- Moderate arousal – Optimum performance
- High arousal – Stress, Anxiety

(Yerkes & Dodson 1908)
Perceptual Responses

- **Borg CR-10 Scale**
  - Higher ratings with increasing force levels
  - Not sensitive to mental demands

- **NASA-TLX scores**
  - Higher scores with increasing force levels on all sub-scales and OWL for all muscle groups
  - Main effects of MWL on all sub-scales (except physical demand) and OWL for all muscle groups

- **Gender differences**
  - Females perceived more effort, frustration, overall workload, and rated lower performance compared to males during shoulder and wrist exertions
The effect of concurrent physical and mental work:

- **Is force-dependent**
  - Decreases in EMG (i.e., muscle effort) at higher force levels
  - Decreases in motor coordination and mental performance at low and high force levels (extreme ends of force spectrum)

- **Is muscle-dependent**
  - Decreases in motor coordination observed across postural muscles (shoulder and torso)

The effect of mental demands during physical work can be broadly evaluated using:

- Heart rate
- NASA TLX ratings

Mental demands did not influence:

- Muscle oxygenation
- Borg CR10 ratings

Generalizable to different task conditions

Need to further investigate sensitivity to mental demands

**Study Conclusions**
Influence of mental fatigue on muscle capacity

Phase II
Research Questions

- Does mental fatigue impede muscle endurance?
- If so, is this relationship task-dependent?
- How does mental fatigue affect recovery post exhaustion?
12 young healthy participants (balanced by gender)
- 6 separate sessions
  - counterbalanced

**Experimental Design**

### Factors
- **PWL**
  - 15% MVC
  - 35% MVC
  - 55% MVC
- **MWL**
  - Control
  - Arithmetic

### Measures
- **Physiological responses**
  - Muscle activity (EMG RMS, MdPF)
  - Muscle oxygenation (% Saturation)
  - Cardiovascular responses (HR and HRV)
- **Perceptual response**
  - RPE
  - SOFI Scale
  - SWAT Scale
- **Task performance**
  - Motor performance
  - Mental task performance

### Endurance
- **Primary fatigue indicators**
  - Endurance time
  - Rate of MVC decline

### Recovery
- **Strength recovery**
- **Physiological responses**
  - Muscle oxygenation
  - HR and HRV
- **Perceptual responses**
  - RPE
  - SWAT Scale
**Task**: Intermittent static shoulder abduction until exhaustion or a max. of 1 hour (whichever occurs first), followed by 15 min recovery.
Subjective Workload Assessment Technique (SWAT): 3 subscales
- Mental Load
- Time Load
- Stress
### Time Load

| Often have spare time. Interruptions or overlap among activities occur infrequently or not at all | Occasionally have spare time. Interruptions or overlap among activities occur frequently | Almost never have spare time. Interruptions or overlap among activities are very frequently, or occur all the time |

### Mental Effort

| Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention | Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty or unfamiliarity. Considerable attention required | Extensive mental effort or concentration required. Very complex activity requiring total attention |

### Stress

| Little confusion, risk, frustration, or anxiety exists and can be easily accommodated | Moderate stress due to confusion, risk, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance | High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required |
- **Swedish Occupational Fatigue Inventory (SOFI):**
  - 5 fatigue dimensions
  - Lack of Energy
  - Physical Exertion
  - Physical Discomfort
  - Lack of Motivation
  - Sleepiness

(0: “Not at all” – 6: “To a very high degree”)
Results
Shorter endurance times observed during concurrent demand conditions at moderate force levels (25% decrease)

Endurance & Strength Decline

Faster rate of strength decline during concurrent demand conditions compared to control, across all force levels (10-66% increase)
- Decreased heart rate variability in concurrent conditions
  - Indicated increased mental stress
- Fatigue measures
  - EMG, muscle oxygenation, and heart rate were similar across control and concurrent conditions, despite shorter endurance times
- Motor performance trends
Perceptual Responses

- **SOFI**
  - Greater physical fatigue levels (LoE, PE, PD) at 35% compared to 15% and 55% MVC
  - Higher LoM and Sleepiness scores in control conditions

- **RPE & SWAT ratings**
  - RPEs not sensitive to mental fatigue
  - Mental fatigue affected all SWAT scores, especially at higher force levels
- **Strength recovery**
  - Greater recovery at 35% MVC compared to 55% MVC
  - Not influenced by mental fatigue

- **Physiological recovery**
  - Muscle oxygenation recovery was not influenced by physical or mental fatigue
  - Slower heart rate recovery and lower HRV (~10%) during concurrent demand conditions compared to control

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**Recovery**
Mental fatigue:
- **Decreases endurance and strength**
  - Similar changes in EMG (temporal and spectral), oxygenation, and force fluctuations across control and concurrent demand conditions despite shorter endurance times
- **Lowers HRV during concurrent demand conditions** – indicating increased mental stress
- **Increases perception** of time pressure, mental load, and stress and increased mental arousal state at higher force levels
- **Hinders recovery**: cardiovascular (HR and HRV) recovery

**Study Conclusions**
- Fatigue is multidimensional

- Mental fatigue can increase fatigability, enhance perception of pain/discomfort, and impair performance

- Different job parameters can modify this relationship

- Concurrent assessment of physical and psychosocial risk factors is critical for comprehensive evaluation of worker fatigue

- Countermeasures can include job rotation, work-rest scheduling, sufficient recovery, task (re)design to facilitate cognitive processing

**Take Home Message**
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Thank you!

Questions?