Relationships between Physical and Mental Fatigue and Task Performance

Ranjana Mehta, Ph.D.

Michigan Technological University

Fatigue

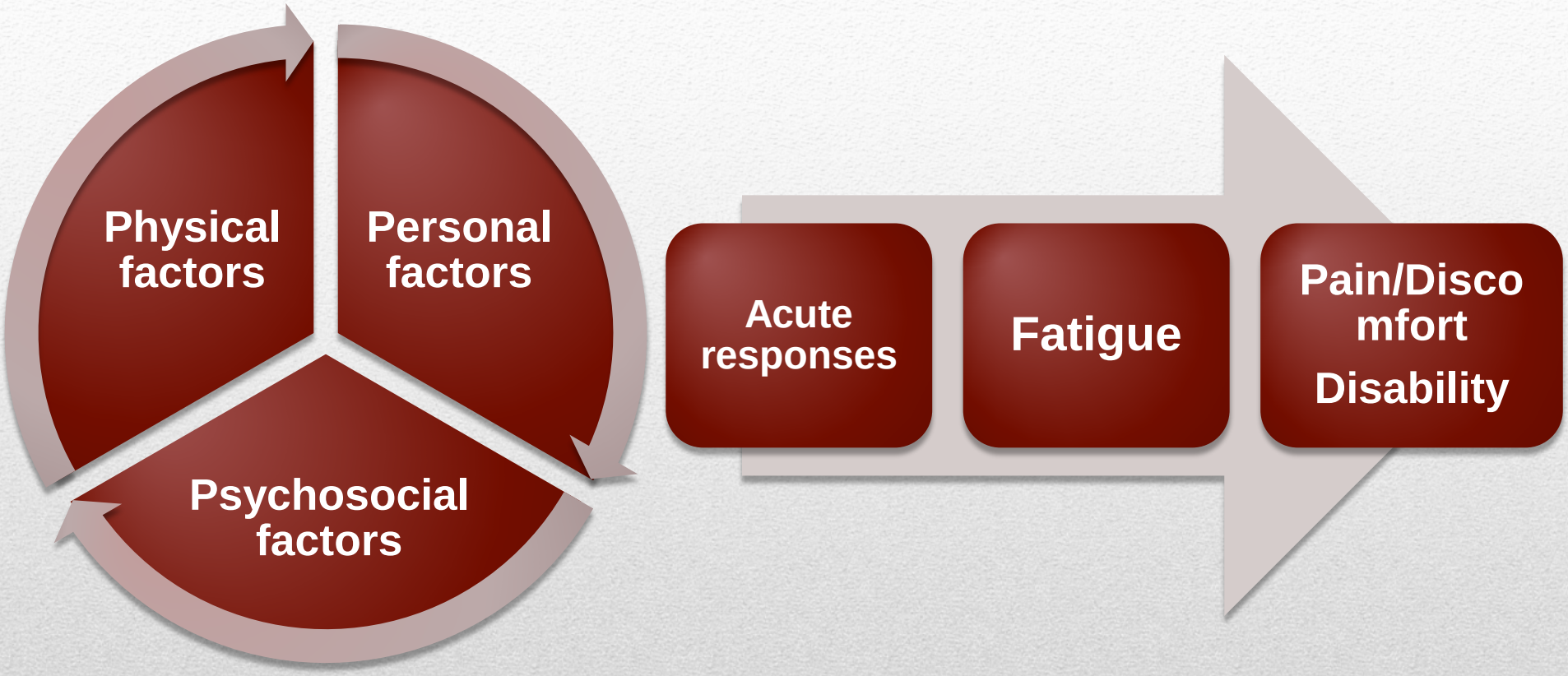
- … *is the decline in a person's ability to exert desired force*
- ... *is a complex state characterized by a lack of alertness and reduced mental and physical performance*
- … **is multidimensional**

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”

Work Risk Factors

Physical	Psychosocial	Personal
• Heavy physical work • Lifting/ forceful movement • Static work posture • Awkward postures • Prolonged duration • Insufficient rest, recovery	• Intensified workload • Time pressure • Monotonous work • Low Job control • Limited Social support • Job dissatisfaction	• Age • Gender • Personality • BMI • Fitness level • Experience



Injury Development

Physical and Mental Fatigue

Potential Mechanisms

- 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)

What We (don't) Know

- 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

Force- and Muscle-dependent changes during concurrent physical and mental work

Phase I

Research Questions

- 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?

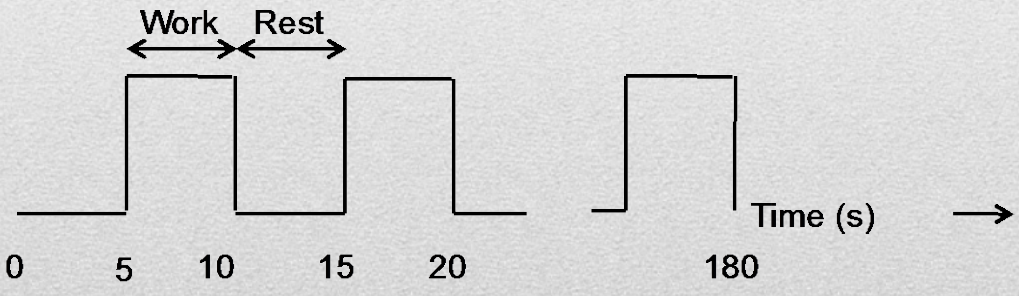
Experimental Design

- 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

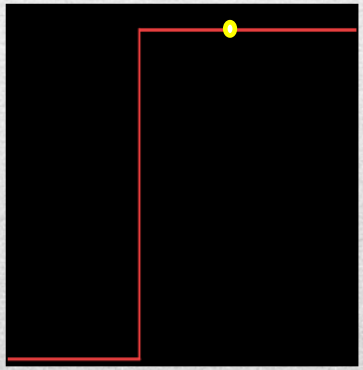
Protocol

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



Wrist extension

Torso extension

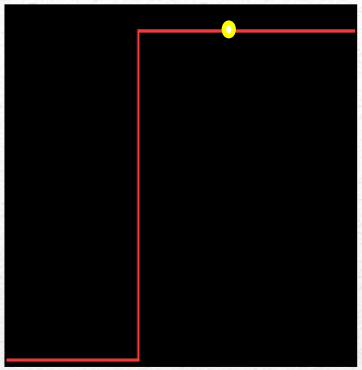


Shoulder abduction

Physiological Measures

- **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)

Task Performance



- **Motor performance**
  - Force fluctuations (SD/Mean) per cycle
- **Mental performance**
  - Accuracy (# errors) on mental arithmetic

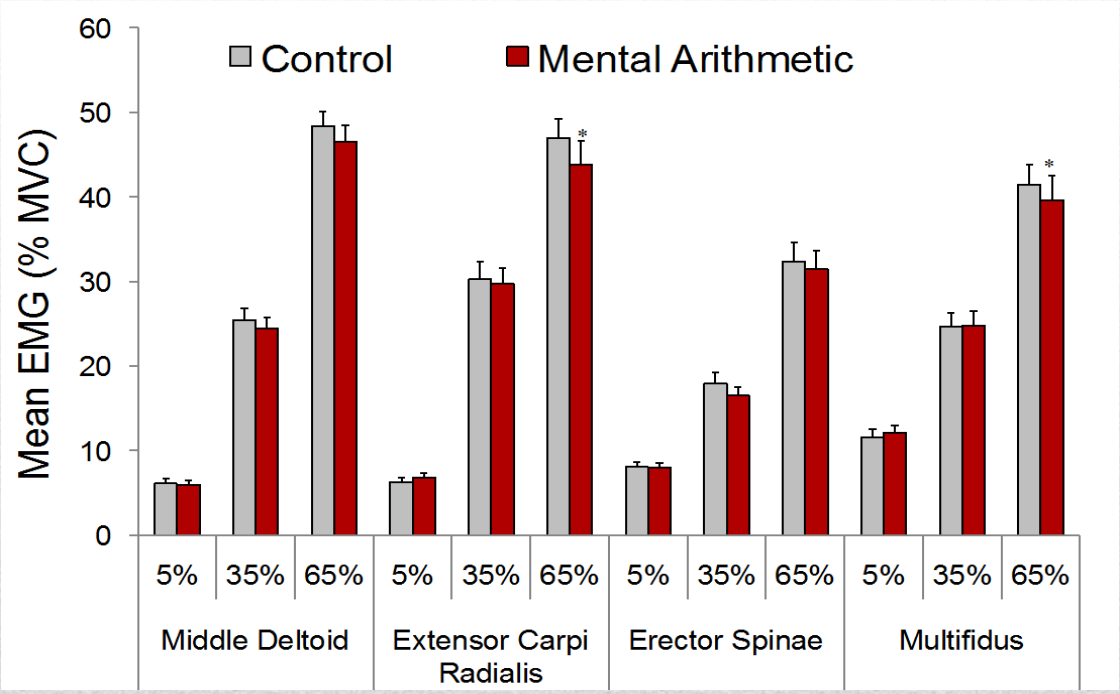
Perceptual Measures

- **Ratings of Perceived Exertion**: Borg CR10 Scale
  (0: "*Nothing*" – 10: "*Extremely Strong*")

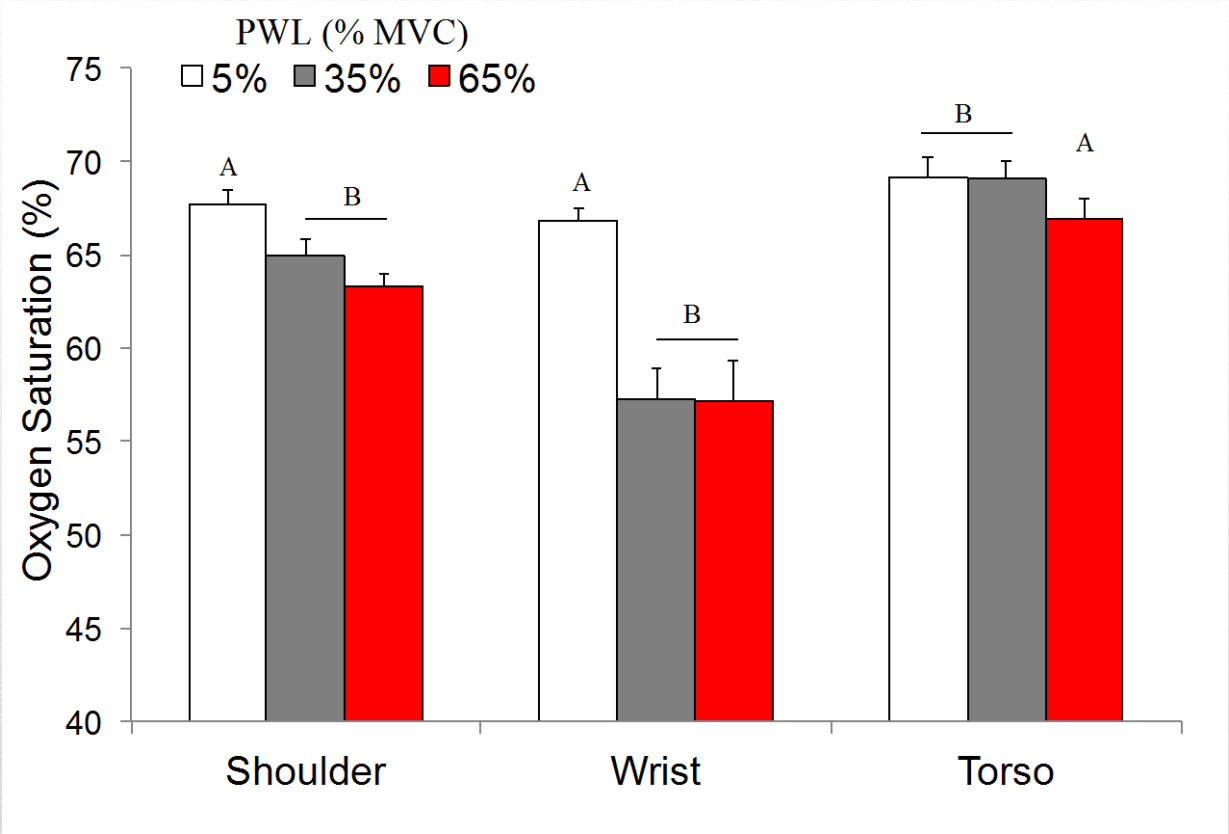
- **NASA Task Load Index**: 6 subscales
  (0: "*Low*" – 20: "*High*")
  - Overall workload (OWL) = *f* [Mental demand, Physical demand, Temporal demand, Effort, Frustration, Performance]

Results

Muscle Activity

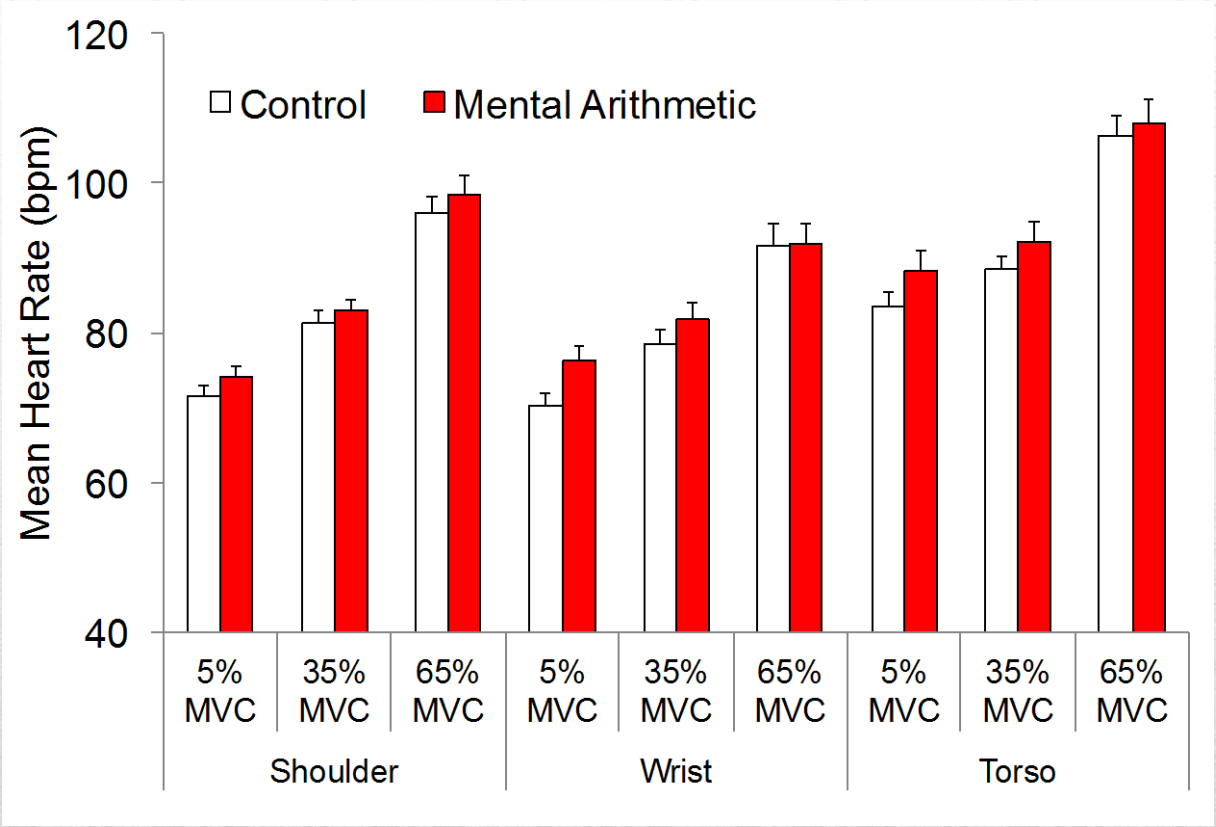


- **Increase** in all EMG measures with increasing force levels
- MWL **decreased** mean (5.4-9%) and agonist EMG (4.3-7%) for all muscle groups
  - At higher force levels



- Oxygen saturation **decreased** at higher force levels
- Not influenced by MWL

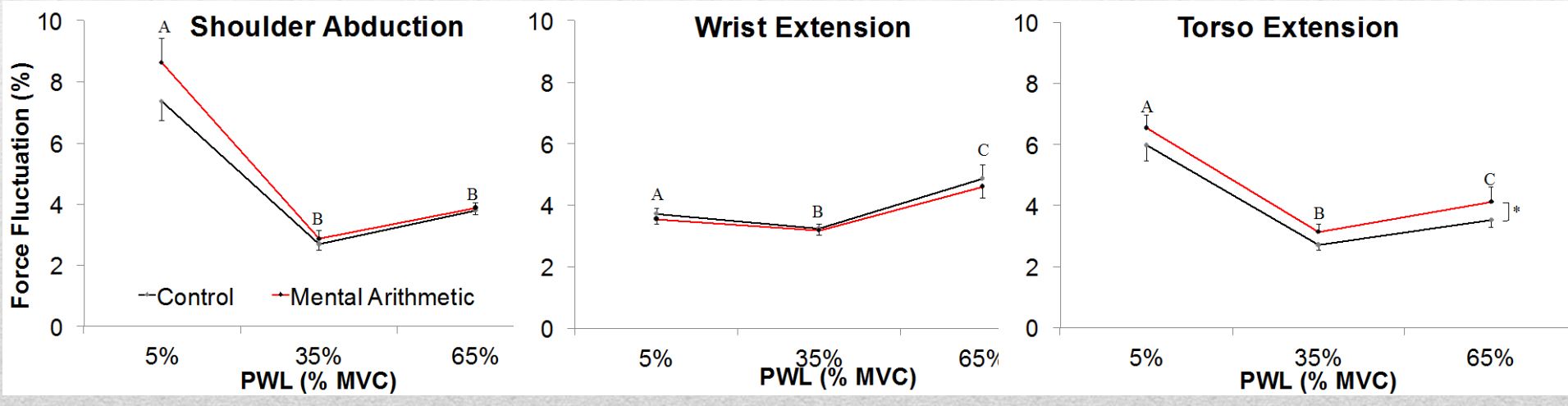
Muscle Oxygenation



- 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

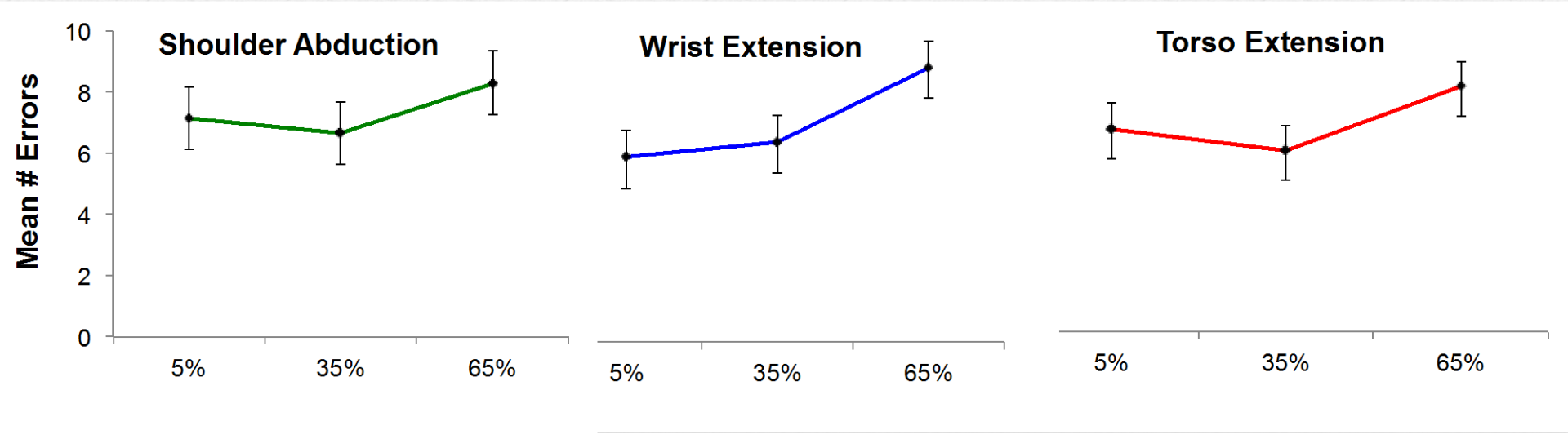
Heart Rate Measures

- U-shaped curve in response to force levels
- MWL **increased** force fluctuations in the shoulder (by 9.6%) and torso (by 24.6%)

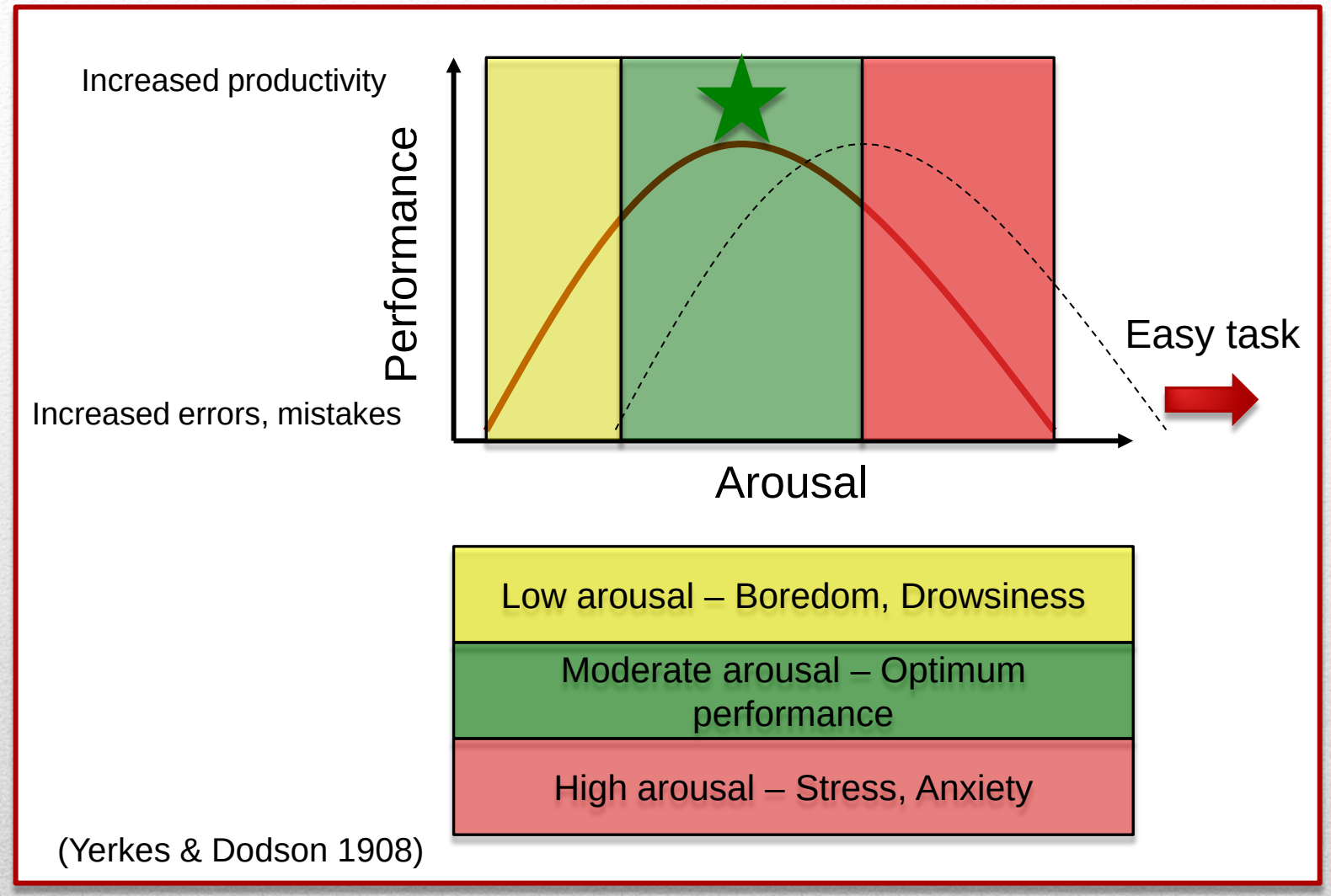


Motor Performance

- U-shaped curve in response to force levels
- Females made 59% more errors than males during wrist extension



Mental Performance



Human Performance Curve

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

Study Conclusions

- 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

  } Generalizable to different task conditions
- Mental demands did not influence:
  - Muscle oxygenation
  - Borg CR10 ratings

  } Need to further investigate sensitivity to mental demands

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?

Experimental Design

FACTORS

PWL
15% MVC
35% MVC
55% MVC

X

MWL
Control
Arithmetic

- 12 young healthy participants (balanced by gender)
- 6 separate sessions
  - counterbalanced

MEASURES

ENDURANCE

Primary fatigue indicators
Endurance time
Rate of MVC decline

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

RECOVERY

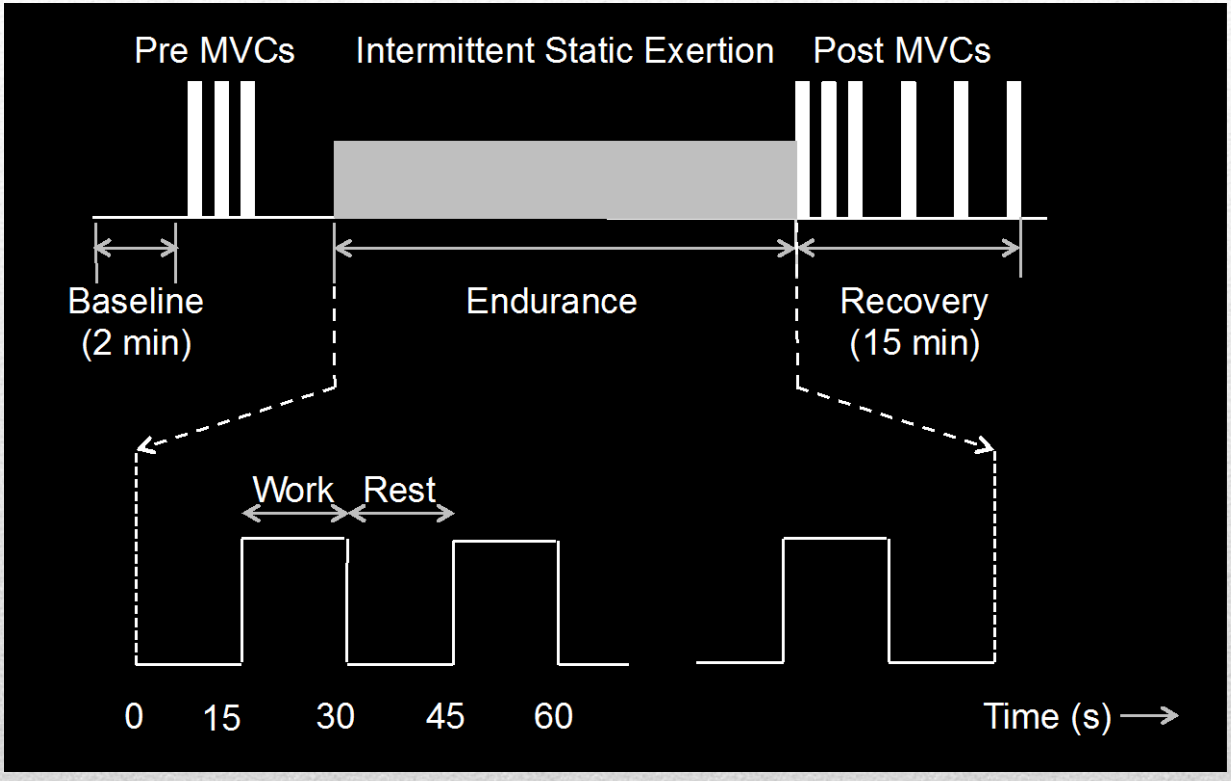
Strength recovery

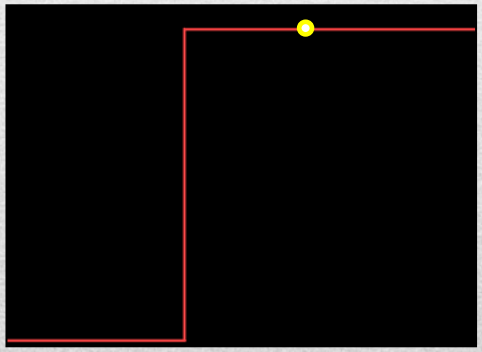
Physiological responses
Muscle oxygenation
HR and HRV

Perceptual responses
RPE
SWAT Scale

Protocol

Task: Intermittent static shoulder abduction until exhaustion or a max. of 1 hour (whichever occurs first), followed by 15 min recovery





Perceptual Measures

- **Subjective Workload Assessment Technique (SWAT):** 3 subscales
  - Mental Load
  - Time Load
  - Stress

SWAT SCALE

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 an 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

Perceptual Measures

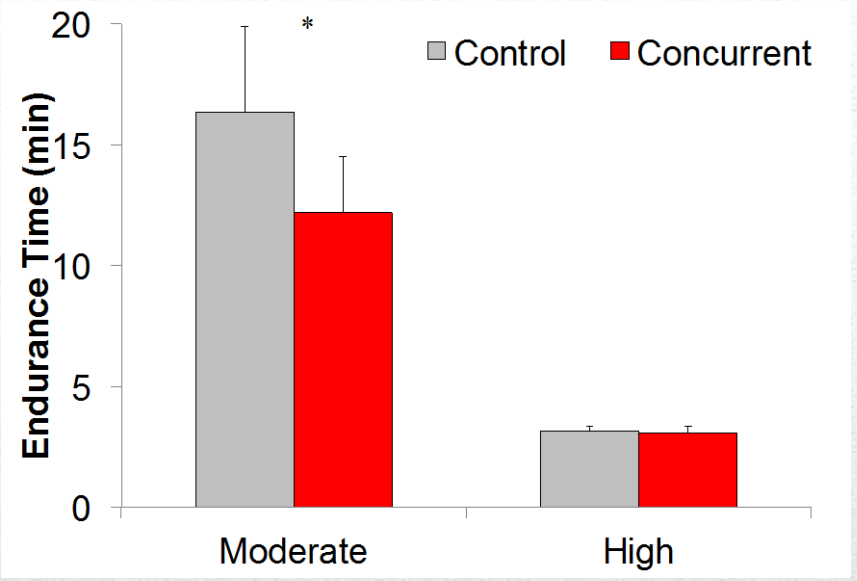
- **Swedish Occupational Fatigue Inventory (SOFI):**
  5 fatigue dimensions
  - Lack of Energy
  - Physical Exertion
  - Physical Discomfort
  - Lack of Motivation
  - Sleepiness

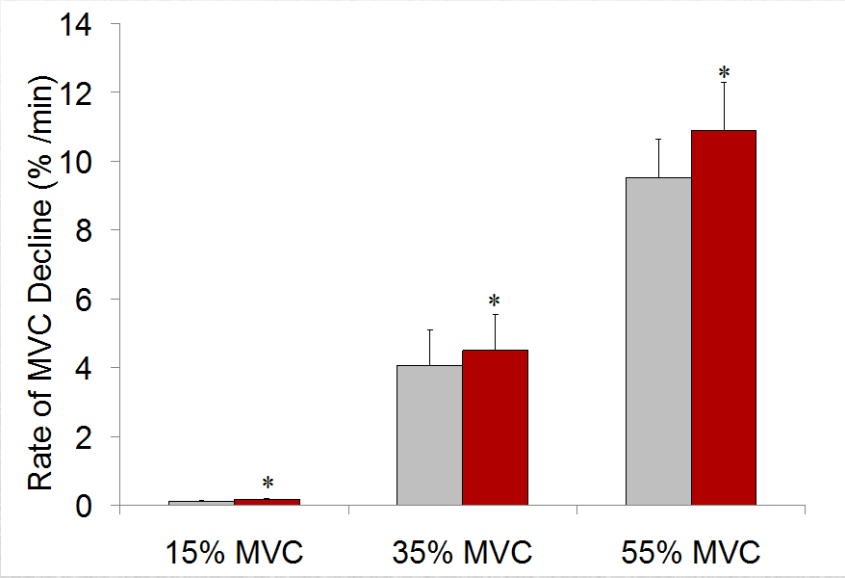
  (0: "*Not at all*" – 6: "*To a very high degree*")

Results

Endurance & Strength Decline

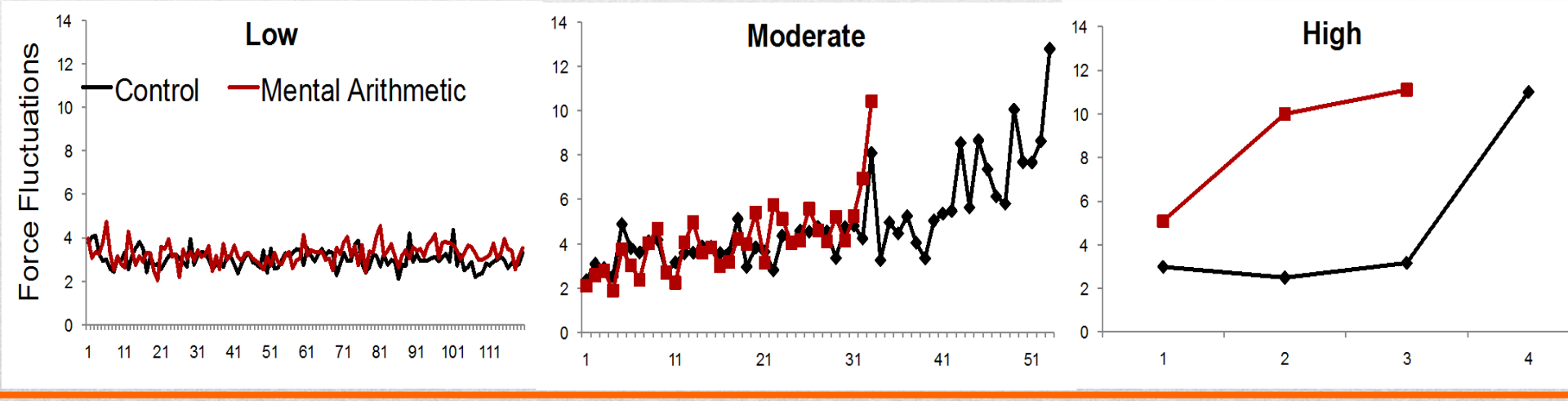
Shorter endurance times observed during concurrent demand conditions at moderate force levels (25% decrease)





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



Physiological & Performance Measures

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

Recovery

- **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

Study Conclusions

- 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

Take Home Message

- 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

Ranjana Mehta, PhD
Department of Cognitive & learning Science
Department of Kinesiology & Integrative Physiology
Michigan Technological University
ranjanam@mtu.edu
+1 (906) 487-1132

Thank you!

Questions?