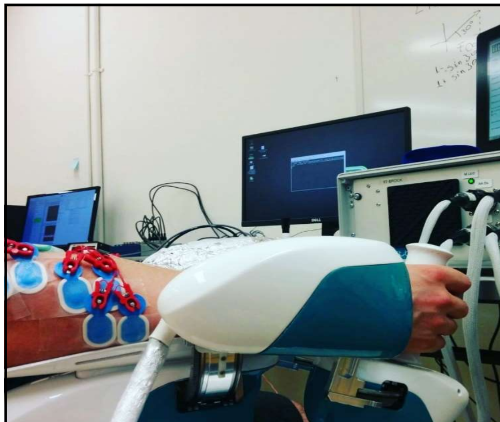
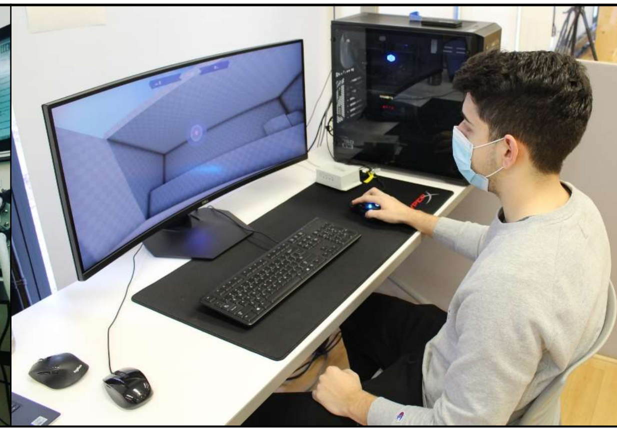
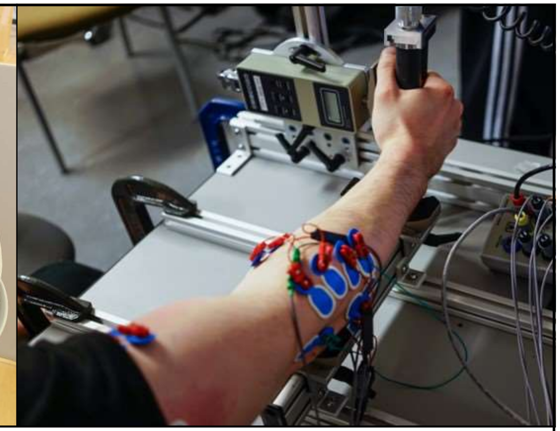

Understanding Fatigue in Occupational Hand Tasks

Repetitive Strain Injury Day 2026

Mike Holmes
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1

Our Vision
Neuromechanical Control of the Hand

- How we interact with tools and objects is one of the most fundamental aspects of human movement
- The events that take place at the **spinal cord and brain** to develop **control strategies** to compensate for **unstable dynamics** (preventing one from spilling hot coffee or manipulating a tool) are not entirely understood

Hypothesis

Our ability to interact with our environment is remarkable given the complex biomechanical and neural circuitry underlying human movement. ***Limited understanding of this interaction is a key reason why it is difficult to identify injury mechanisms.***

2

OUTLINE

1. Hand and Wrist RSIs
   - Stats and mechanisms
2. Fatigue – Injury & Performance
3. Evaluation of forearm muscle function
   - Highlight studies from our group
4. Reframing [Repetition]
   - Inadequate Recovery and Fatigue

3

1

Hand and Wrist RSIs

4

The Challenge
Hand & Wrist RSIs

- ~ **1 in 10 Canadians** report RSIs serious enough to limit normal activities
- Largely work-related: **55%** of RSIs are caused by work activities, and many involve the neck/shoulder (**25%**) or wrist/hand (**23%**)
- In Ontario, MSDs (which include most RSIs) represent over **40%** of all lost-time WSIB claims
  - Direct and indirect costs estimated at **$19 billion** (1996–2006)
- **High human cost**: Those reporting RSIs are about twice as likely to report chronic pain and elevated psychological distress, and these problems persist after the injury

Tjepkema (2003); Workplace Safety North; Workplace Safety and Insurance Board (WSIB)

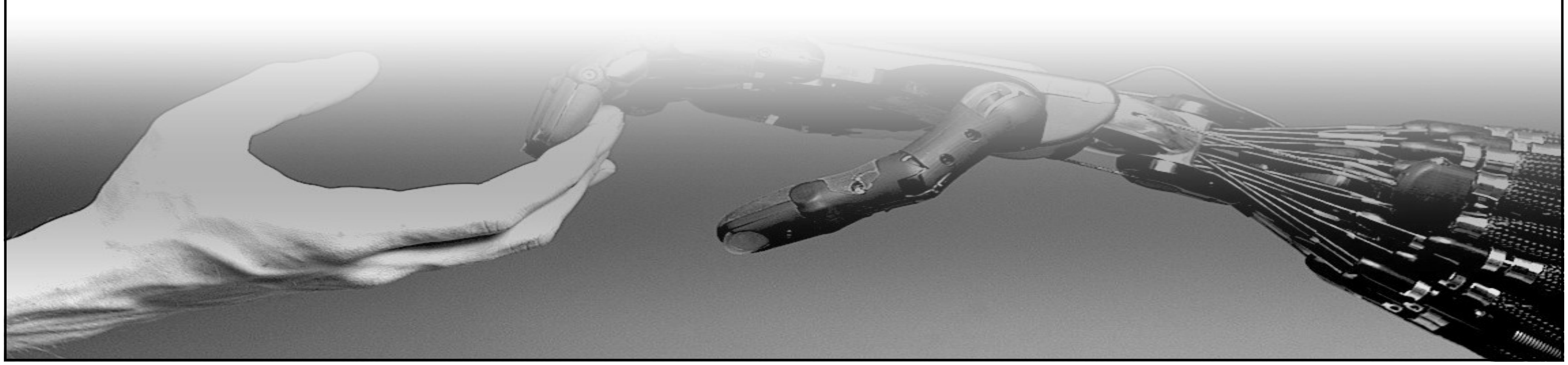
A Global Burden

- **Upper-limb pain is widespread among workers**
  - EU-wide survey - **41%** of workers report neck/shoulder/upper-limb pain (over 12-month period)
  - **5–10%** of the general population report non-specific upper-limb strain that interferes with daily activities
  - High-risk jobs - **22–40%** report complaints
- **Severity and cost**
  - Hand/wrist WMSDs have the longest sickness absences and are among the most expensive occupational injuries
  - CTS: **€12,780** per case in France; U.S. medical costs >US**$2 billion/year**

Dale et al. 2013; EU-OSHA

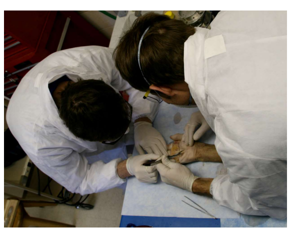
ENGINEERING MARVEL

- Most activities of daily living and work tasks involve manipulating objects/tools with our hands
- Even trivial human-object interactions require a complex series of coordinated events from the brain to control limb dynamics



Complexity of the Distal Upper Extremity

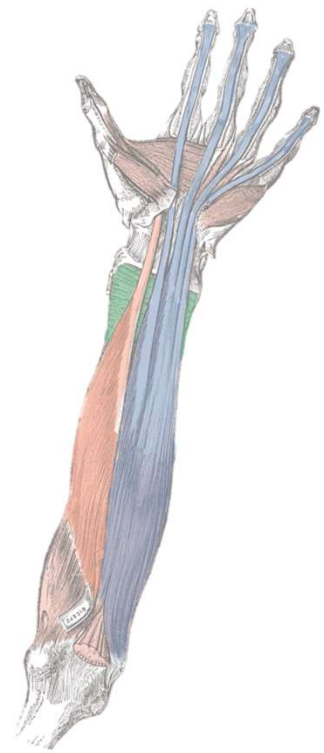
- I dissected my first cadaver hand and realized it was NOT like the textbook!
- Anatomical variation → Movement variability and injury predisposition?
  - The wrist has many anatomical variants
    - Vascular structures, nerves, tendons and muscles
    - 12%–23% of the population have a third artery (median artery)
    - FDS, FDP muscles (not just tendons) can travel inside the carpal tunnel….but not in everyone!
    - Thenar muscles can travel into the carpal tunnel….but not in everyone!



CRE-MSD
Centre of Research Expertise for the Prevention of Musculoskeletal Disorders

DISTAL UPPER EXTREMITY

- Anatomical & Biomechanical considerations….
  - Redundant (or abundant?) system → Multiple muscles, offers task variability
  - Carpal tunnel as a pully → Mechanical advantage
  - Force control → Range of needs from power grip to great precision
  - Dual demands → Grip & wrist actions, many muscles contribute to both grip and wrist actions, vastly different demands



Latash, 2000; Armstrong, 1979; Hägg et al. 1997; Forman et al. 2019

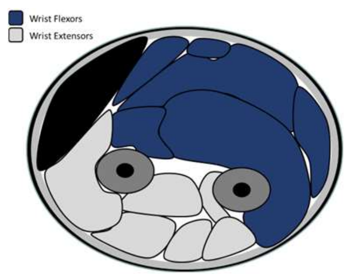
Why is the Hand Vulnerable?
Biomechanical Considerations

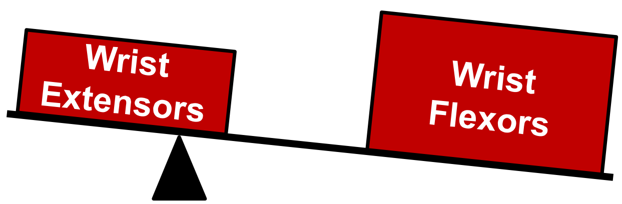
"Grasping and pinching always cause a flexing moment at the wrist joint. To avoid flexion of the joint, there must be equilibrium of moments

Snijders et al. 1987

WHY IS THE HAND VULNERABLE?

Biomechanical Considerations





Large Disparities

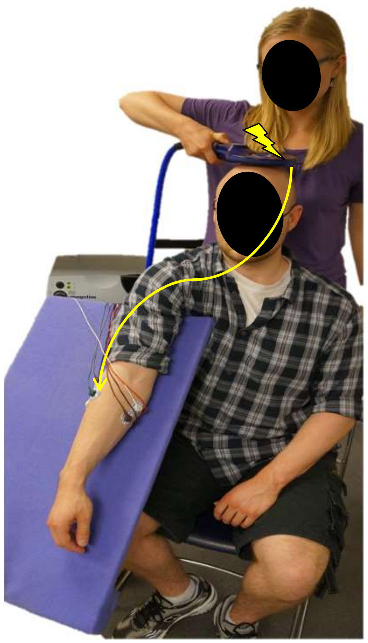
PCSA
2 : 1
Flexor : Extensor

Moment Arms
Flexors > Extensors
(8-23%)

Lines of Action
Flexors -> More Direct

Lieber et al. 1990; 1992; Jacobson et al. 1992; Loren et al. 1996; Gonzalez et al. 1997; Bawa et al. 2000

Why is the Hand Vulnerable?
Neurophysiology Considerations



- Forearm muscle demands can remain **constant** (from a biomechanical perspective), but corticospinal excitability to the forearm changes across arm orientations
- Implications for workplace design considerations, particularly in situations where proximal limb positioning is constrained while distal muscles perform a task

Adjusting limb position impacts *central drive* to muscles & can influence/guide workplace design

2

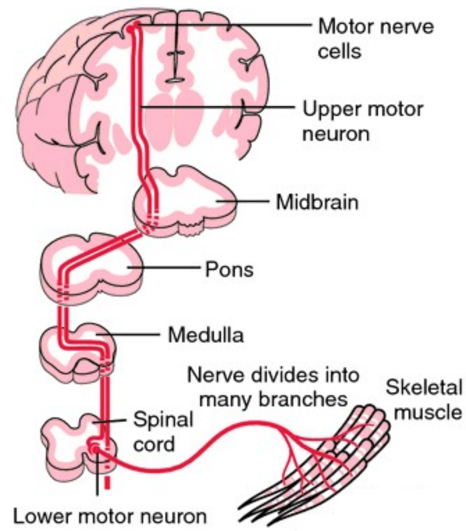
Fatigue – Injury & Performance

13

NEUROMUSCULAR FATIGUE

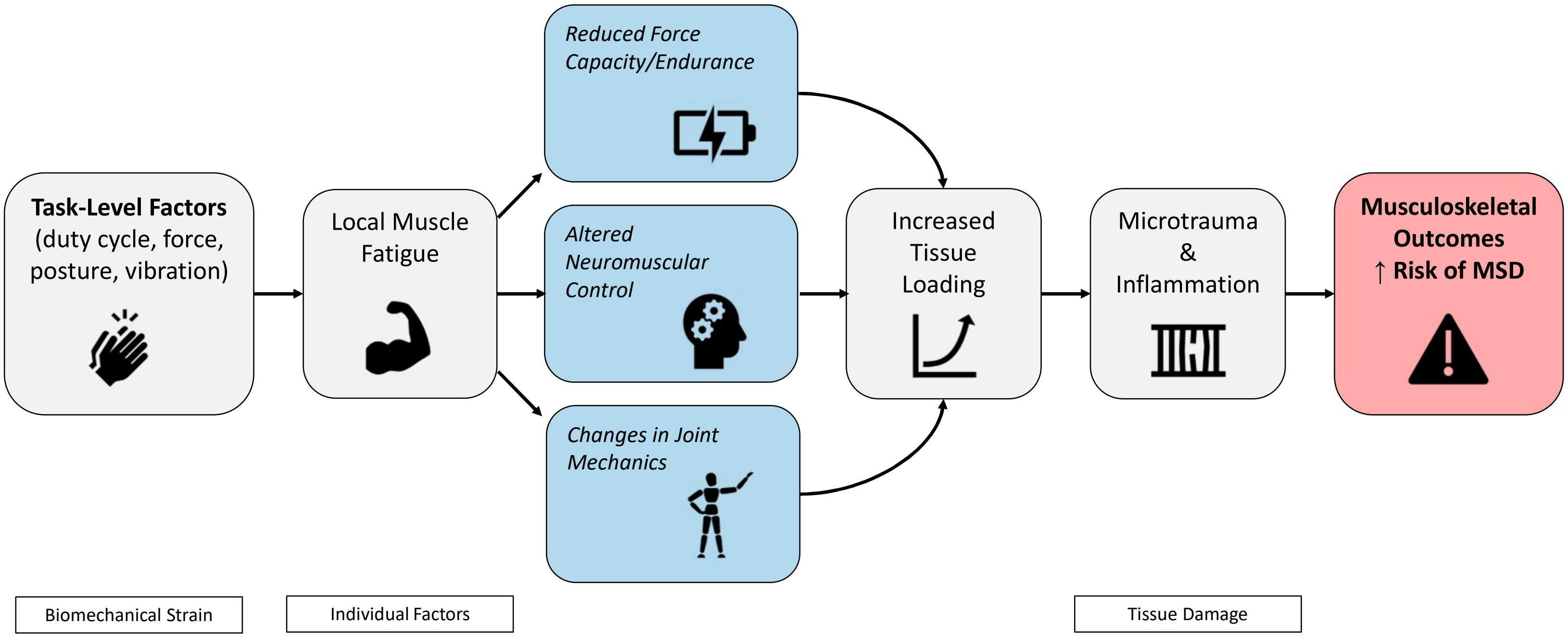
- A reduction in the ability of muscle to produce force (*performance fatigability*), plus the subjective sense of tiredness (*perceived fatigability*)

- Mechanistically, it reflects alterations to the neuromuscular system:
  - **Peripheral** changes in the muscle (metabolite accumulation, reduced conduction velocity, impaired cross-bridge function)
  - **Central** changes in motor drive



Gandevia, 2001; Enoka & Duchateau, 2016

Fatigue & Injury
How are they connected?

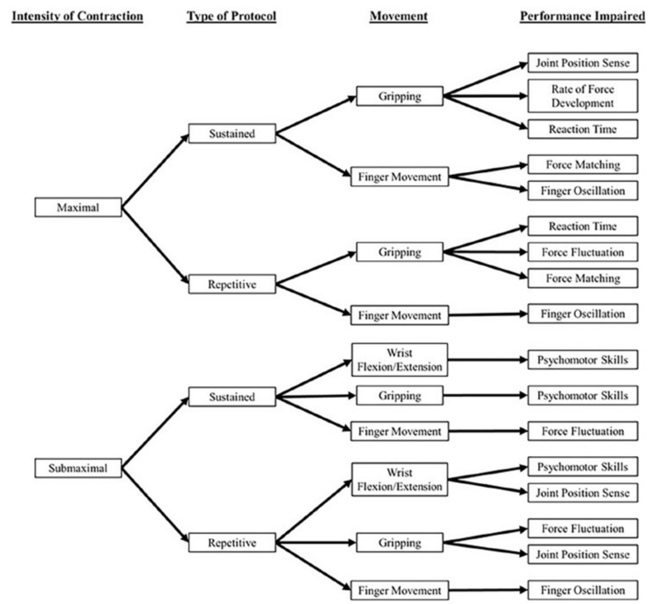


Fatigue & Performance
Impaired hand function

Human Movement Science 81 (2022) 102912
Contents lists available at ScienceDirect
Human Movement Science
journal homepage: www.elsevier.com/locate/humov

Influence of muscle fatigue on motor task performance of the hand and wrist: A systematic review

Garrick N. Forman[a], Michael W. Sonne[b], Aaron M. Kociolek[c], David A. Gabriel[a], Michael W.R. Holmes[a,*]



Performance changes could translate into more damaging load histories on tissues

3

Evaluation of forearm muscle function

Evaluating Forearm Muscle Function

Three Themes

A

Define muscle roles during dual tasks with wrist and grip force requirements

B

Given known biomechanical disparities, how does neuromuscular fatigue uniquely influence task performance?

C

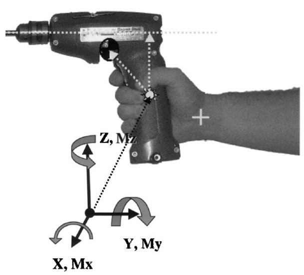
Sensorimotor assessments to evaluate changes in mechanical properties, providing insights for function and injury risk

Continuous feedback, interconnected

A

Define muscle roles during dual tasks with wrist and grip force requirements

Dual Tasks
Grip Force + Wrist Torque

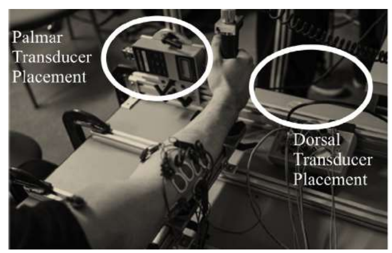


Wells and Greig (2001)

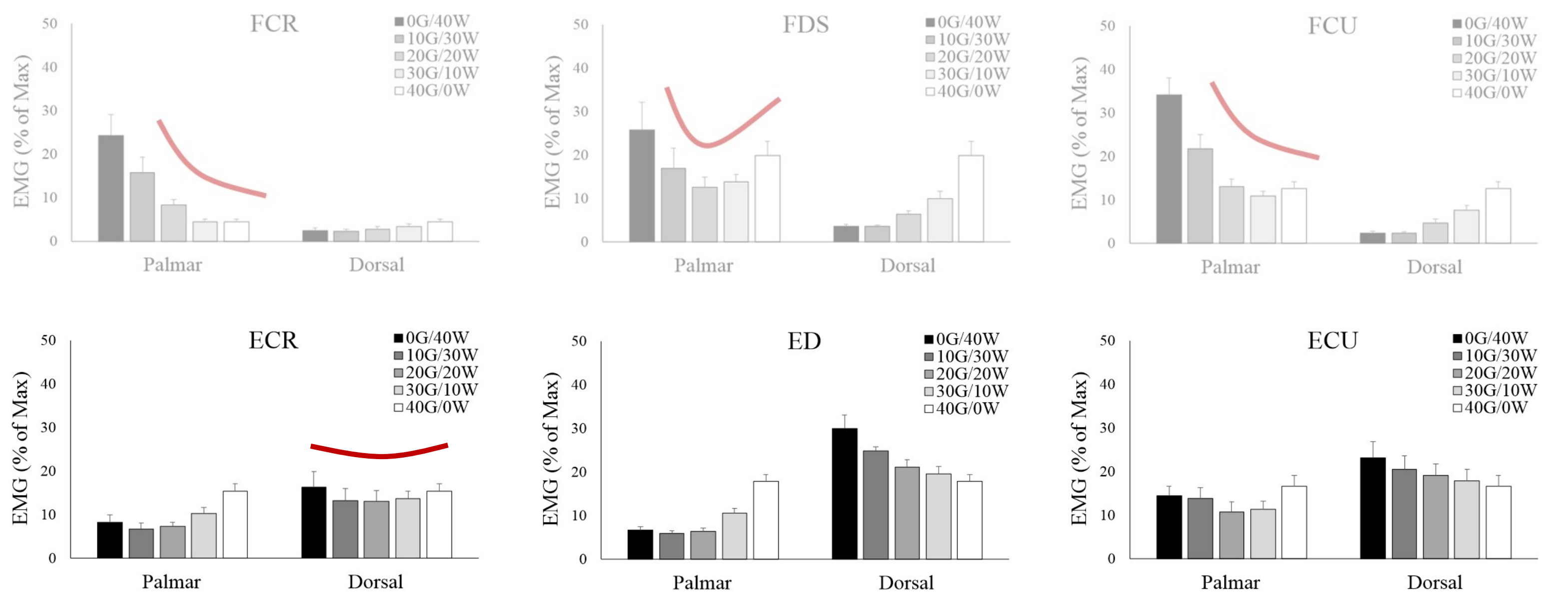
Contents lists available at ScienceDirect
Journal of Electromyography and Kinesiology
journal homepage: www.elsevier.com/locate/jelekin

The influence of simultaneous handgrip and wrist force on forearm muscle activity

Davis A. Forman[a], Garrick N. Forman[b], Jason Robathan[c], Michael W.R. Holmes[b,*]



40% Combined Effort		
Condition Number	Handgrip Force	Palmar or Distal Wrist Force
1	0	40
2	10	30
3	20	20
4	30	10
5	40	0



Holmes – Repetitive Strain Injury Day 2026

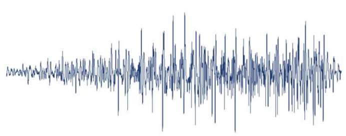
CONCLUSIONS
Muscle Activity, Dual Tasks

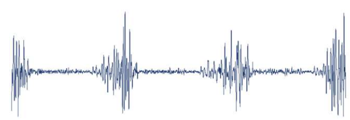
Forearm Muscle Function

<u>Wrist Extensors</u>
Wrist joint stabilizers
Exhibit static, low level muscle activity

<u>Wrist Flexors</u>
Prime Movers
Exhibit task-dependent activity
Co-contraction Palmar > Dorsal

Snijders et al. 1987; Duque et al. 1995; Hägg et al. 1997; Mogk and Keir, 2003; Holmes et al. 2015; Forman et al. 2019





CONCLUSIONS
Muscle Activity, Dual Tasks

Isometric Dual Tasks
40 and 60% MVC
Wrist + Grip

Dynamic Wrist Actions
Flexion/Extension
Radial/Ulnar

- **Wrist flexors: Task-dependent**
- **Wrist extensors: Constant activity**
- **Co-contraction driven by wrist extensors**

Next Steps?

Flexor vs Extensor Fatigue?
Largest influence on performance?

B

How does neuromuscular fatigue uniquely influence task performance?

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> *“It is remarkable that the fatigue signs generally are more pronounced on the extensor side in spite of the fact that FDS is the prime mover*
>
> Hägg and Milerad, 1997

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PURPOSE

To examine the influence of forearm muscle fatigue on strength and performance during a hand-tracking task

Research Questions

1) How do various forearm muscle fatigue protocols impair task performance (hand tracking)?
2) Is their greater impairment with flexor or extensor fatigue?

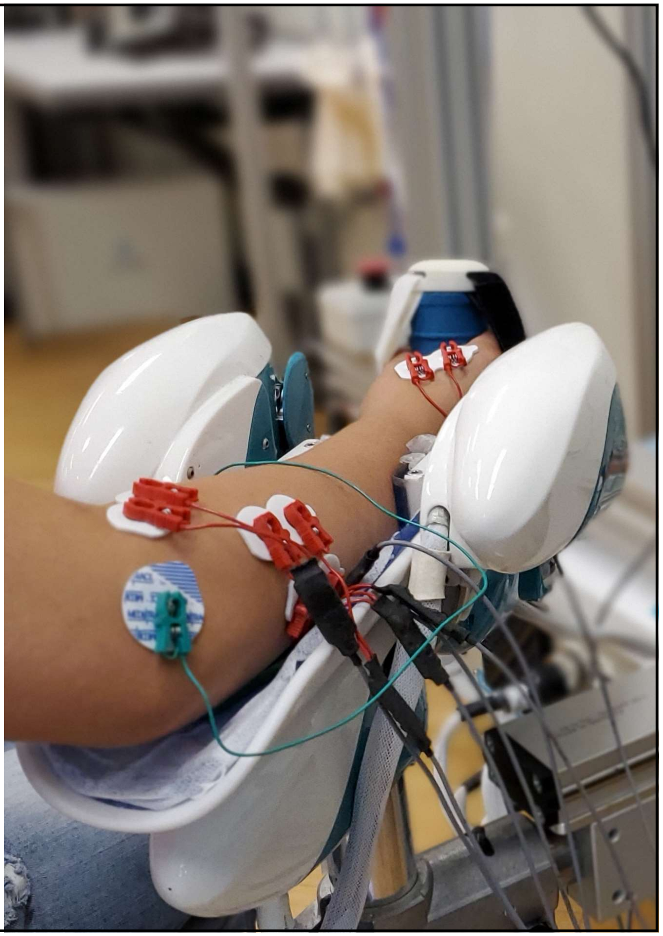
FATIGUE

Robotic Assessments of Performance

- Wrist extensors thought to be more vulnerable to fatigue and overuse than flexors Shiri et al. 2006
- Lack of fatigue and performance research conducted on the hand/wrist/forearm

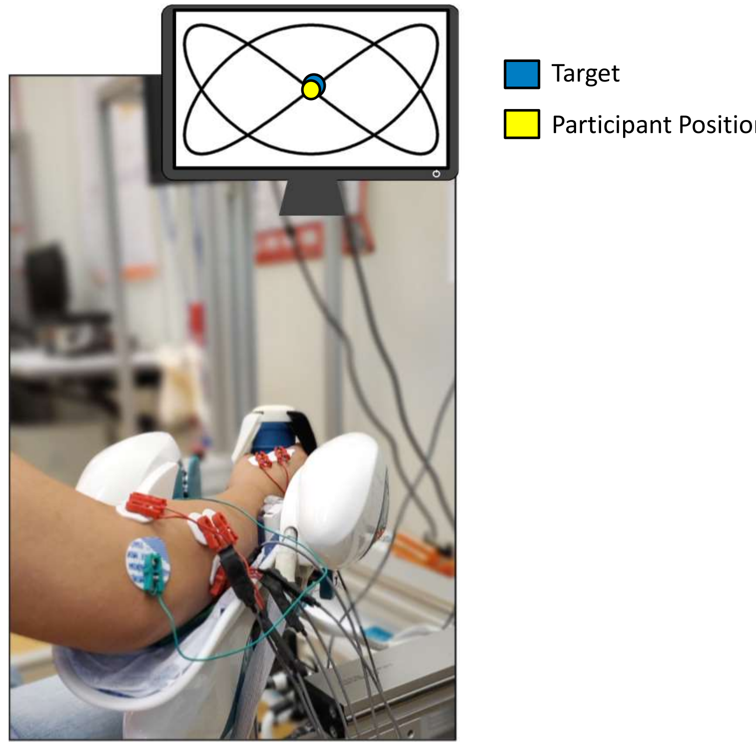
Fatigue Protocols:
Isometric
Dynamic
Maximal
Submaximal

Independently Fatigue:
Flexors/Extensors

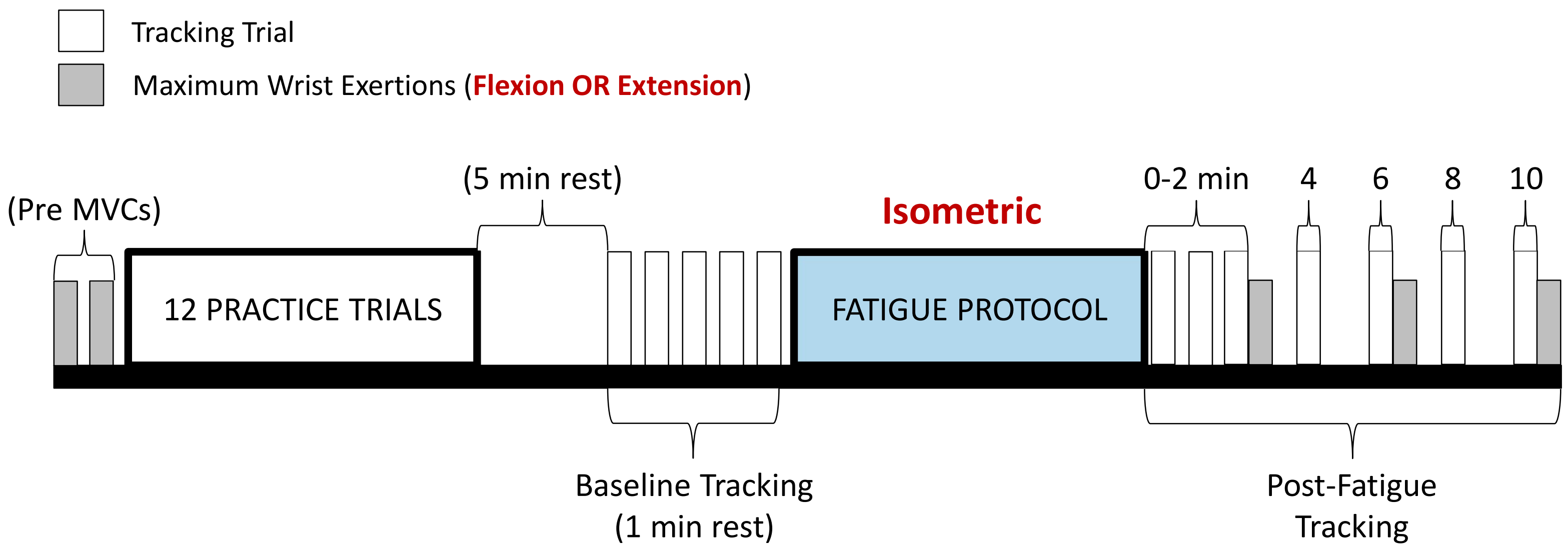


TRACKING TASK

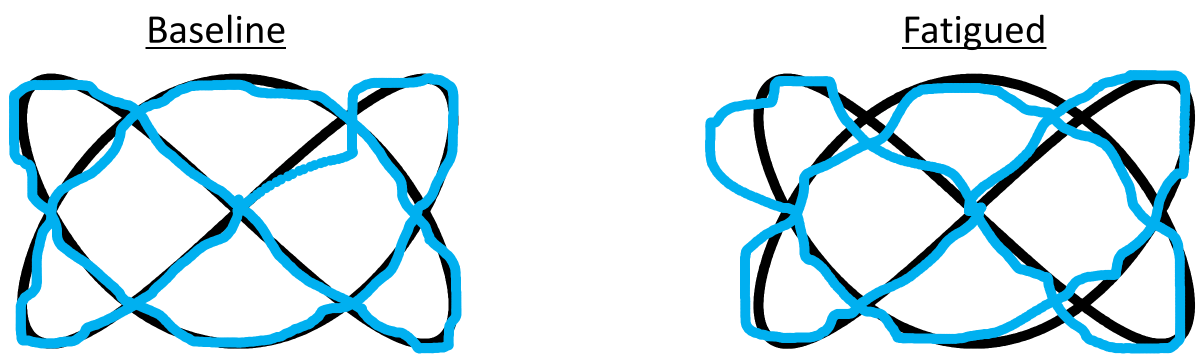
3:2 Lissajous Curve
- ± 45° Flexion/Extension
- ± 25° Radial/Ulnar
- 20 seconds (9°/sec)



Fatigue Protocols and Performance



Performance Metrics



Tracking Error: Overall performance measure of error in all directions
Figural Error: How well the participant reproduced the shape of the trajectory, insensitive to speed
Jerk Ratio: A measure of movement smoothness

Maximal Isometric Fatigue Protocol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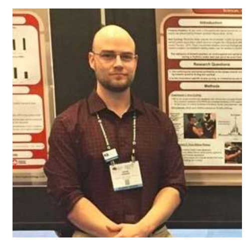
ORIGINAL RESEARCH article

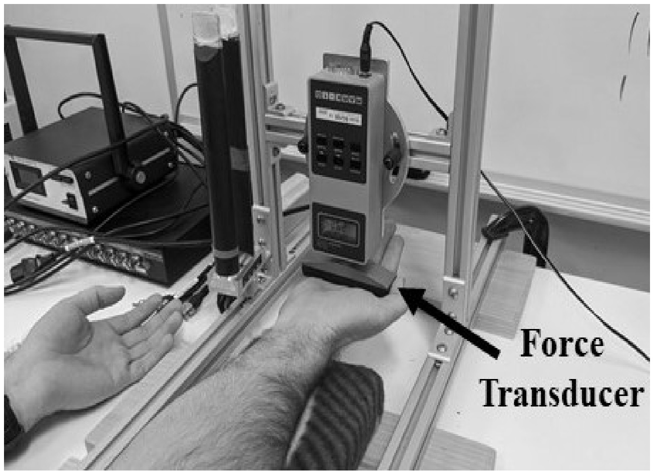
Front. Sports Act. Living, 08 May 2020 | https://doi.org/10.3389/fspor.2020.00053

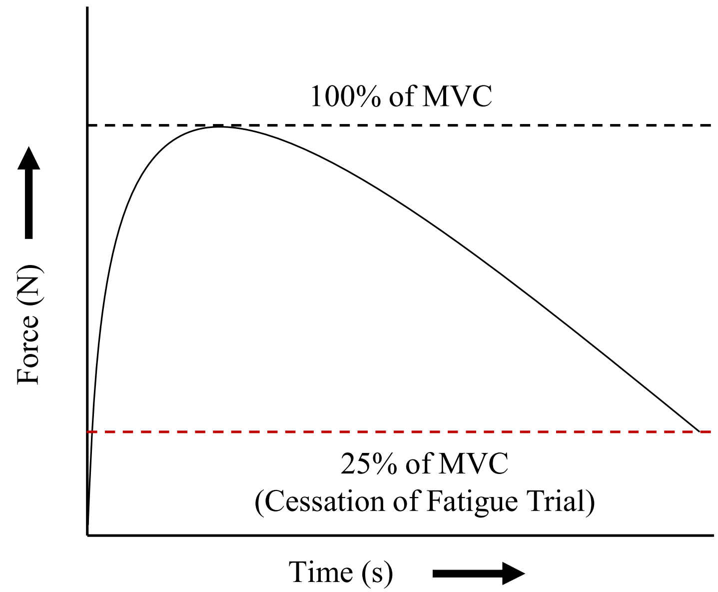
Sustained Isometric Wrist Flexion and Extension Maximal Voluntary Contractions Similarly Impair Hand-Tracking Accuracy in Young Adults Using a Wrist Robot

Davis A. Forman[1], Garrick N. Forman[2], Maddalena Mugnosso[3], Jacopo Zenzeri[3], Bernadette Murphy[4] and Michael W. R. Holmes[2*]

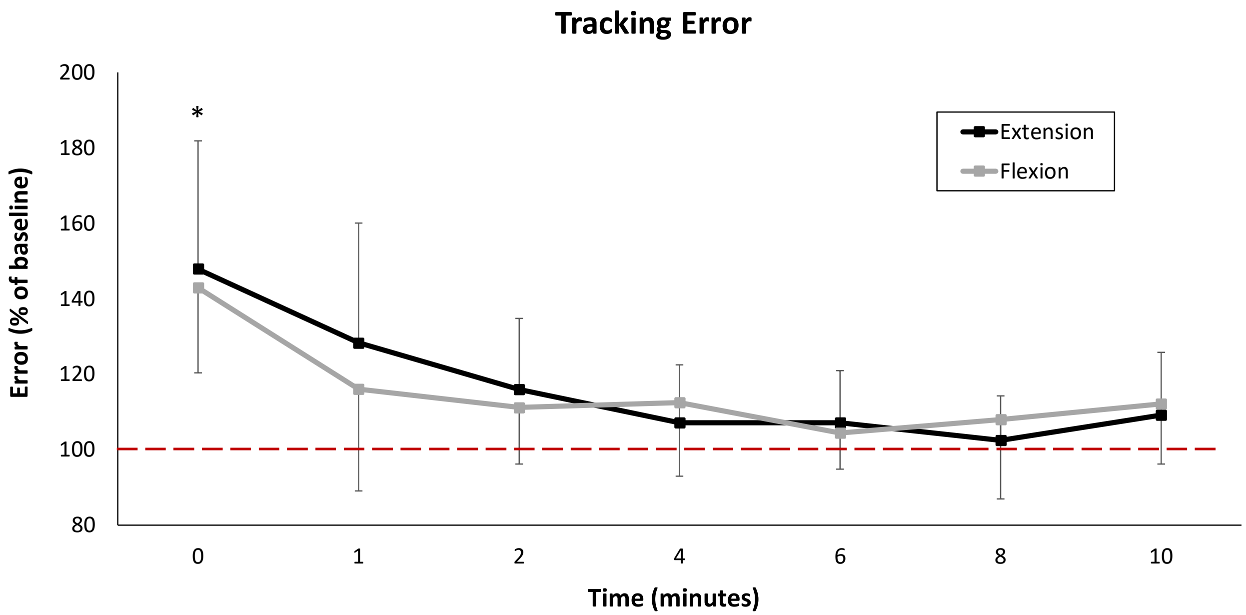


MAXIMAL ISOMETRIC FATIGUE PROTOCOL





Isometric Fatigue and Performance



Summary of Findings

- Max wrist torque remained lower up to 10-minutes post-fatigue
- Error increased immediately post-fatigue
- No differences observed after **1-minute** of recovery
- Wrist flexor and extensor fatigue **equally impaired performance**
- **Equal time to task failure**

Does this go against the traditional thought that the extensors have an earlier onset of fatigue??

Submaximal Dynamic Fatigue Protocol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ORIGINAL RESEARCH article

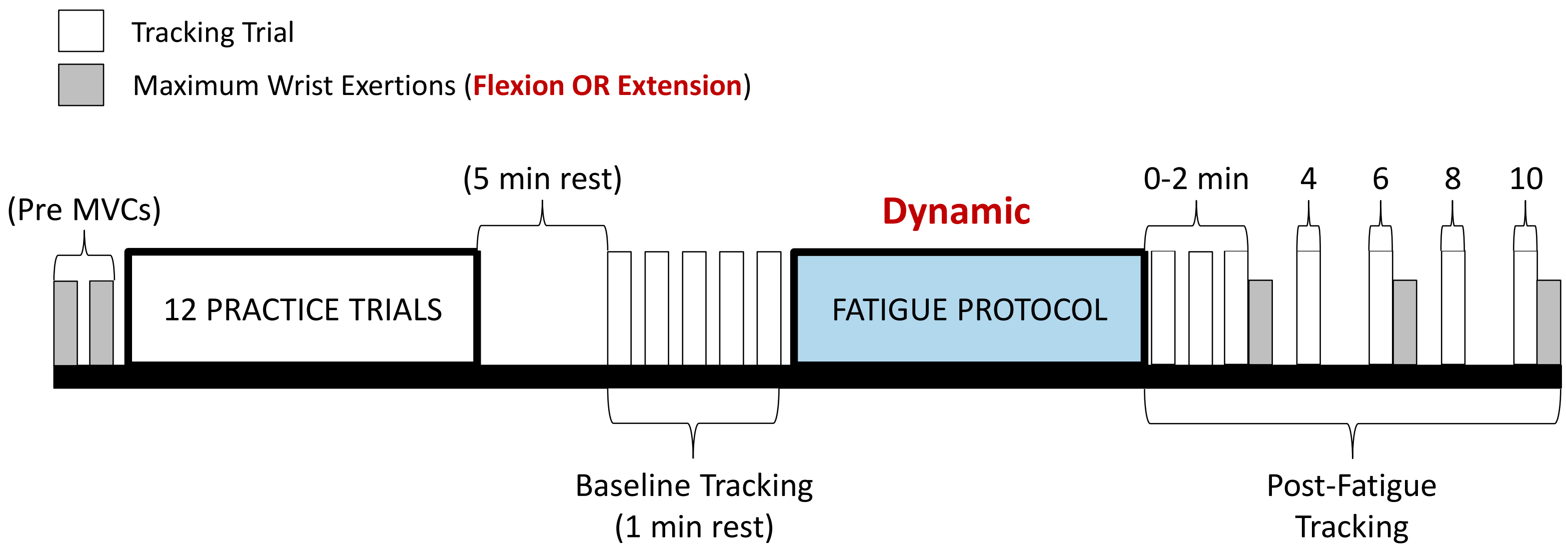
Front. Sports Act. Living, 06 October 2020 | https://doi.org/10.3389/fspor.2020.574650

Check for updates

Dynamic Wrist Flexion and Extension Fatigue Induced via Submaximal Contractions Similarly Impairs Hand Tracking Accuracy in Young Adult Males and Females

Robert I. Kumar[1], Garrick N. Forman[1], Davis A. Forman[2], Maddalena Mugnosso[3], Jacopo Zenzeri[3], Duane C. Button[4] and Michael W. R. Holmes[1*]

FATIGUE PROTOCOLS AND PERFORMANCE



Dynamic Fatigue Protocol

- 5 sets to failure
- Participant specific weight
- 4 sec per repetition

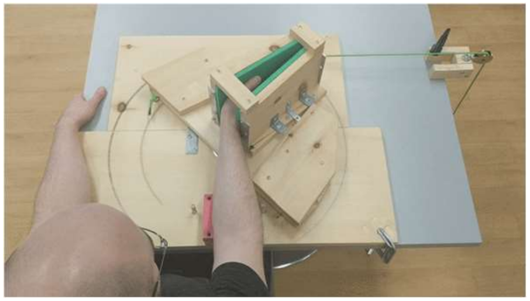


TABLE 1 | Resistance used for males and females during the flexion and extension fatigue task and the number of repetitions achieved for each of the 5 sets.

	Day	Weight (kg)	Set 1 (repetition #)	Set 2 (repetition #)	Set 3 (repetition #)	Set 4 (repetition #)	Set 5 (repetition #)
Females†	Flexion	2.40 (0.30)#	19.4 (5.9)	9.0 (1.7)*	8.0 (2.1)*	5.9 (1.5)*	6.6 (1.9)*
	Extension	1.57 (0.26)	16.7 (3.8)	8.3 (1.4)*	7.1 (2.0)*	6.7 (2.0)*	7.0 (2.7)*
Males†	Flexion	4.26 (0.83)#	18.9 (4.6)	8.7 (2.3)*	6.6 (1.0)*	5.4 (1.3)*	4.5 (0.7)*
	Extension	2.35 (0.36)	17.4 (3.2)	7.7 (4.2)*	5.9 (2.5)*	5.3 (0.8)*	5.4 (1.3)*

All values are presented as a mean (standard deviation). * *= pooled data are significantly different from Set 1;* † *= data are significantly different between sexes; # = data are significantly different between muscle groups.*

SUMMARY OF FINDINGS

Tracking error rapid recovery (like isometric) after **1-minute** post-fatigue assessment
Jerk ratio failed to return to baseline (**>10 min** post-task termination)
Figural error returned to baseline at approximately **4-minutes** post-task termination

- Males tracked the target with significantly lower JR, less TE, and less FE than females
  - Independent of fatigue, males tracked the target with greater precision and smoother movements
- Based on this work, hand tracking accuracy is **similarly impaired following repetitive submaximal dynamic wrist flexion or extension**
- The effects of performance fatigability are much **longer lasting** than previous maximal isometric fatigue protocol

C

Development of sensorimotor based assessments of wrist function

Fatigue Alters Wrist Mechanics

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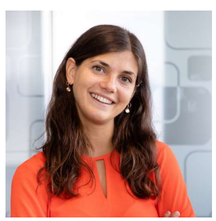
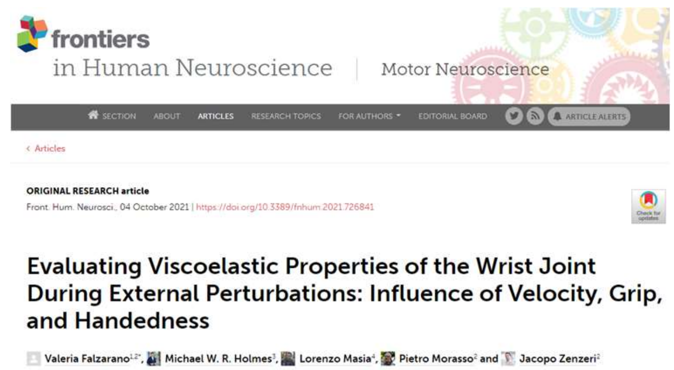
ORIGINAL RESEARCH article

Front. Hum. Neurosci., 30 May 2022 | https://doi.org/10.3389/fnhum.2022.887270

A Dynamic Submaximal Fatigue Protocol Alters Wrist Biomechanical Properties and Proprioception

Giulia A. Albanese[1,2*†], Valeria Falzarano[1,2†], Michael W. R. Holmes[3], Pietro Morasso[1] and Jacopo Zenzeri[1]





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ORIGINAL RESEARCH article

Front. Hum. Neurosci., 04 October 2021 | https://doi.org/10.3389/fnhum.2021.726841

Evaluating Viscoelastic Properties of the Wrist Joint During External Perturbations: Influence of Velocity, Grip, and Handedness

Valeria Falzarano[1,2*], Michael W. R. Holmes[3], Lorenzo Masia[4], Pietro Morasso[2] and Jacopo Zenzeri[2]

Take Home Messages

1

Robot-aided assessments provide accurate and repeatable measures under controlled conditions

- We have developed protocols to model:
  - Wrist mechanics (stiffness, viscoelastic properties)
  - Proprioception, Performance

2

Fatigue impairs hand function and can change wrist biomechanical properties

- Across fatigue protocols, tracking **performance**, **biomechanical** properties and **proprioception** are impaired with **various recovery outcomes**
- Performance uniquely influenced by type of fatigue (central vs peripheral mechanisms)
- Impairment (maximal isometric = rapid recovery; submaximal dynamic = prolonged recovery)

3

Fatigue as a Biomarker for Injury Risk?

- Grip/wrist force variability
- Wrist stiffness – sensitive marker - Does NOT recover within 12 minutes
- Proprioceptive error – Recovery depends on intensity
- Jerk ratio – Indicates ongoing neural compensation

4

Wrap Up
Inadequate Recovery and Fatigue

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REFRAMING [REPETITION]

Repetitive Motion → Inadequate Recovery → Forearm Muscle Fatigue

The Problem
Repetitive hand/wrist work w/ complex force patterns

Key Question
How do complex force-time histories affect fatigue, recovery & safe workload?

- The primary hazard may be insufficient recovery of forearm and hand muscles at a given force demand, not "repetition" per se
  - Local muscle fatigue degrades neuromuscular control, reduces joint stiffness, and shifts load to more vulnerable tissues (tendons, ligaments, cartilage), increasing MSD risk
- Research demonstrates that **force** and **duty cycle** together define the force-time exposure and opportunity for recovery (MAE, RCRA, etc.)

Sonne 2014; Potvin 2012

Reframing [Repetition]

- Sonne et al. (2015) studied repetitive handgrip using a “pyramid” profile:
  - 0 → 15 → 30 → 45 → 30 → 15 → 0 % MVC plateaus
  - 15s each
  - Followed by brief MVC and rest

- Fatigue did not increase uniformly:
  - How effort is sequenced matters
  - Intermittent lower-force segments can allow partial recovery within an overall fatiguing cycle
  - Fatigue accumulation is **history-dependent**. At the same force level, the effect on fatigue depends on what came before

- This supports a force–recovery time model of risk
  - More to this problem than understanding “repetitions per minute”
  - Need to understand sequence and timing of demand and rest

Sonne 2014; Potvin 2012; Yung et al. 2012

Final Thoughts

- **Fatigue ≠ immediate performance failure**
  - Studies show physiological signs of fatigue (MVC decline, EMG frequency) while task accuracy remains stable
  - CNS recruits additional motor units and alters coordination strategies (motor redundancy and compensation)
- **Fatigue can be both protective or harmful**
  - Fatigue can be functional and adaptive in one context (variability, altering coordination to protect tissues)
  - Maladaptive when you ignore warning signs
- **Objective vs subjective fatigue mismatch**
  - Worker perception
  - Underestimated at very high duty cycles
- Great need to monitor fatigue (wearables, sensorimotor tests, etc.) as an early-warning biomarker rather than waiting for pain or performance failure
  - Our work is a good step, but need to evaluate complex force-time histories

THANKS FOR LISTENING!

Contact Info

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