Muscle Mechanics and Muscle Injury

Dawn Mackey

Related Reading
Chapter 3 (pp70-90), Hamill and Knutzen

Outline
• Factors influencing muscle force production
• Muscle injury
• EMG
• Reducing risk of MSI (examples)

Muscle Mechanics

• Muscle mechanics is a key area of knowledge for the ergonomist.
  – Physical stress reduction
  – Strength requirements
  – Optimum performance
  – Fatigue prevention
  – Prevention and pain prevention

Factors Influencing the Production of Muscular Force

• Muscle Size (cross-sectional area)
• Muscle Fibre Type
• Angle of Pennation
• Force-Length Relationship
• Force-Velocity Relationship
• Prestretch (elastic energy storage and recoil)
• Prior contraction history (fatigue)
• Muscle Temperature
• Activation: recruitment of motor units, firing frequency, synchronization of firing

You can review all of these properties in your Kin 201 notes

Force-Length Curve of Muscle

Muscle fibres cannot generate high amounts of active tension in extremely shortened or lengthened states
Total Length-Tension Curve

- The contractile component is not the only contributor to tension in a muscle at different lengths.
- As tension in the active contractile component decreases due to elongation (slipping of cross bridges), total tension increases due to the contribution of passive resistance from tendon (series elastic component) and muscle fascia (epi-, peri- and endomysium, parallel elastic component).

Torque vs. Forearm Flexion Angle

Torque is the product of force and moment arm (Torque ≠ Force)

- Force is equal
- ...but
- ...moment arms are very different

Factors Affecting Muscle Torque (Force x Moment Arm)

- Force
  - Muscle Size (cross-sectional area)
  - Muscle Fibre Type
  - Angle of Penetration
  - Force-Length Relationship
  - Force-Velocity Relationship
  - Prestretch (elastic energy storage and recoil)
  - Prior Contraction History (fatigue)
  - Muscle Temperature
  - Activation: recruitment of motor units, firing frequency, synchronization of firing

- Moment Arm
  - Insertion point
  - Line of action of muscle and joint angle

Force- Velocity Curve

- During shortening contractions, max force can be generated at zero velocity, and max velocity can be achieved with the lightest load.
- As the velocity of shortening increases, rate of cross bridge cycling increases, leaving fewer cross bridges attached at one time.
- More force can be generated during lengthening than shortening contractions.

- You want to design tasks that do not require highly dynamic movements.
More torque can be produced during eccentric than concentric contractions

Power

\[ \text{Power} = \text{Force} \times \text{Velocity} \]

Maximum power occurs at about 30-33% of maximal velocity of shortening and about the same percentage of maximum concentric force.

Power Output (energy expenditure)

Athletes must find as high a level of power output as possible that can be sustained for the duration of their event. Workers need to have a job that does not excessively fatigue muscles causing potential overload. Example of hill climbing, straight-up or zigzag

Optimal Power in Industry?

- Workers must be able to sustain their energy expenditure (and power bursts) for extended periods of time (8-12 hours) over a number of days.
- For example, NIOSH lifting equation factors in energy expenditure.
- Psycho-physical measurements are obviously effected by physical fatigue

Muscle Activation

- While length and velocity have a major effect on muscle force (for any given muscle) activation is also a key factor.
- Recruitment of motor units follows the size principle: small units (low force production) are recruited first. Increasingly large units are recruited over time to produce more force.
- Rate Coding means that the motor unit firing rate starts slowly and becomes faster when more force is needed.

Muscle Stiffness

- Many tasks require the muscles to stabilize a joint rather than exert force to move a limb.
- When hammering for example, forearm extensors provide the force to move the forearm and hammer and muscles crossing the wrist provide stiffness to prevent the wrist from breaking on impact.
- All structures crossing the wrist provide some stiffness but muscles have the largest effect.
Muscle Injury

- Muscles are not as commonly injured as tendons in occupational settings but they obviously play a role in the process.
- With repeated or prolonged activity there will be differential fatigue of the muscles.
- More fatigued muscle can cause variations in force and jerky motions (coordination problems) that can result in tendon injuries.

Muscle Force, Modelling and EMG

- Muscle force is not easily measured.
- We will develop mechanical analogues (models of the human) to help estimate muscle force.
- As it is practically impossible to measure muscle force directly, EMG is often used.
- EMG as an indicator of muscular force and/or activity level will be covered later in the lecture.

Loading, Muscular Activity, and Injury

- Injury vs. Loading
  - Whether a given loading configuration and pattern will result in injury is a complex problem, and depends on genetic and morphological characteristics, loading level, direction, speed, skeletal maturity, and conditioning.
- Muscular Activity vs. Loading
  - Muscular activity influences loading (generating acceleration, stiffening joints, reducing tensile loading). If muscles are weak or fatigue their ability to do this is compromised.

How can work tasks be designed to reduce the risk of MSI from forceful exertions?

- Some tasks (e.g., transferring heavy patients) can be very strenuous
- Often, lifting devices are the only safe solution
- Design tasks to use optimum joint angles
- Design tasks to have low and possibly negative velocities of movement (e.g., lowering rather than lifting)
- Utilize large stronger muscles
- Technique training and motivation can be helpful
- Keep objects close
- Exercise programs can also increase worker strength

Increasing a worker’s force producing capabilities has its drawbacks

- Increasing muscle force will obviously increase stresses on the body.
- Therefore, reducing the force required by the task is a more common ergonomic strategy (e.g., lifting devices).

Ceiling Lifts

- Ceiling lifts can help reduce the risk of MSI from forceful exertions.
- They are especially useful in settings where heavy lifting is required.
Electromyography (EMG)

Can EMG be related to muscle force?

- A suitably calibrated linear envelop EMG can be a coarse predictor of muscle tension for muscles that are not changing length rapidly (Winter, 1979).
- EMG signal amplitude during negative and positive work is similar despite more work being possible during negative work.
- Still an indicator of muscle activity.
- Suitable for most ergonomic (and rehab) work when properly calibrated with the subject’s maximum voluntary contraction (MVC).

### TABLE 5.1

<table>
<thead>
<tr>
<th>Measurement Factors</th>
<th>General Effect of Ratio (EMG/Load)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large electrode</td>
<td>Increase</td>
</tr>
<tr>
<td>Close electrode proximity to muscle</td>
<td>Increase</td>
</tr>
<tr>
<td>High electrode impedance</td>
<td>Decrease</td>
</tr>
<tr>
<td>Surface electrode (vs. indwelling)</td>
<td>Varied</td>
</tr>
<tr>
<td>Bipolar electrode (vs. monopolar)</td>
<td>Varied</td>
</tr>
<tr>
<td>Bipolar electrode spacing increase</td>
<td>Varied</td>
</tr>
</tbody>
</table>

**Physiological Factors**

- Prolonged contraction (fatigue)              Increase
- High muscle temperature                      Decrease
- Specific muscle tested                       Varied
- Highly strength-trained muscle               Decrease
- Muscle length                                Varied
- High speed of shortening                     Increase

**Static**

**Isometric Contraction**

**Ballistic**

![Graphs showing EMG in different muscle contractions](image1)

![Graph showing EMG and Force relationship](image2)
Biceps Brachii EMG activity depends on the type of contraction

The magnitude of EMG activity changes as a function of contraction time (fatigue)

Static Postures: The longer a posture is held, the less force should be exerted.

- The Rohmert Curve (1968) opposite was not tested over prolonged time periods.
- Jonsson’s criteria is more readily accepted today.

Limit Values for Muscular Load

- Based on studies of muscular endurance during constrained static and dynamic work, Jonsson (1978) suggested the following limit values for work of one hour or longer duration.
  - Static Load ideally ≤2% MVC & must not >5%
  - Median Load ideally ≤10% MVC & not >14%
  - Peak Load ideally ≤50% MVC & not >70%

Maximum Voluntary Contraction (MVC) for Trapezius

EMG as % of MVC

A = table at correct height
Blood supply is hindered by high muscle forces
- Sustained posture (or very short rest periods) keeps the blood supply away from the working tissue reducing the rate of repair.
- When the effort reaches 50-60% of the maximum, the flow is almost zero.
- At 10% MVC there is little mechanical hindrance to blood flow.
- However, studies have shown significant perceived fatigue at 5% of MVC.

Ergonomic Assessments
- Due to the difficulty of relating EMG to force the majority of ergonomic/biomechanical research has looked at expressing muscle activity as a percentage of maximal voluntary contraction (MVC).
- Recently EMG has been related to spinal compression but not by predicting erector spinae force.
The protocol calls for collection of EMG data for three trials. The average EMG is taken for a section of curve that has plateaued. The average of the three trials is taken. This EMG level is then related to the spinal compression calculated with the 4D WATBAK lifting program.

Problems with Field Research

The subject must keep the back straight to involve the erector spinae. If you round your back you support the same load on your ligaments and yet the erector spinae EMG would be low.

Like most ergonomic research we are making assumptions, specifically that:

- most lifts involve low accelerations and velocities.
  - EMG for subject while in upright position is negligible.
  - EMG has a linear relationship to spinal compression. (U of W Ontario Back Pain study group).
  - cumulative moment and compression are linearly related to low back pain reporting
- Protocol required subjects to be free of back pain for 6 months prior to participation in study.