Aging and Skeletal Muscle Work Efficiency

Russell S. Richardson, Ph.D.

The University of Utah
Division of Geriatrics
Department of Exercise and Sports Science

Salt Lake City Geriatric Research, Education, and Clinical Center
United States Department of Veterans Affairs
OUTLINE:

- Work efficiency
- Work efficiency and “typical” aging (70 yrs)
- Work efficiency and the “oldest-old” (>85 yrs)
- Maximal Strength Training (MST) as a countermeasure for changes with normal aging
Work Efficiency

PULMONARY

\[ r = 0.999 \]

\[ Y = 0.68 + 0.0099X \]

TWO LEG

\[ r = 0.989 \]

\[ Y = 0.29 + 0.0092X \]
Work Efficiency

Gross Efficiency

Net Efficiency

Delta Efficiency

VO₂

Work Rate (Watts)

Work Rate (Watts)

Work Rate (Watts)
Work efficiency and typical aging
Typical elderly and walking efficiency

Cost of Transport (J kg\(^{-1}\) m\(^{-1}\))

Speed (m s\(^{-1}\))

Elderly

Young

Ortega et al. J. Appl. Physiol., 2007
Cycling efficiency and the typically old

Young: 39 yrs (n=9)
Old: 69 yrs (n=40)
Two components of work efficiency

Mitochondrial Efficiency

Contractile Efficiency

Work Efficiency

P/O x 2

Work/ATP

Work/O₂

Conley K E et al. Exp. Physiol. 2013
Contractile efficiency and the typically old

Plantar flexion - dynamic
120% of max power
$^{31}$P MRS
Young 22 yrs (n=18)
Old 74 yrs (n=18)
Contractile efficiency (non contractile processes) and the typically old

Continuous contraction (cross-bridge cycling)

Intermittent contractions (ion pumping)

Knee-extensor - isometric

Gwenael Layec

Typical aging and skeletal muscle fiber type

Skeletal Muscle Fiber Type:
Type II -> Type I

Skeletal Muscle Fiber Type and Work Efficiency

Coyle et al. J. Appl. Physiol., 1992
Work efficiency and exceptional aging....the oldest-old
Limitations to exercise in female centenarians: evidence that muscular efficiency tempers the impact of failing lungs

Massimo Venturelli · Federico Schena · Renato Scarsini · Ettore Muti · Russell S. Richardson

Table 2  Maximal work rate, oxygen consumption, and heart rate in centenarians and young controls at the end of a graded exercise test to maximum effort

<table>
<thead>
<tr>
<th></th>
<th>Centenarians (N=8)</th>
<th>Young (N=8)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean±SD</td>
<td>Range</td>
<td>Mean±SD</td>
</tr>
<tr>
<td>Maximal work rate (watts)</td>
<td>33±4</td>
<td>(25–35)</td>
<td>179±24</td>
</tr>
<tr>
<td>VO$_{2peak}$ (ml min$^{-1}$ kg$^{-1}$)</td>
<td>7.5±1.1</td>
<td>(6.1–9.3)</td>
<td>39.6±3.5</td>
</tr>
<tr>
<td>HR$_{peak}$ (beats min$^{-1}$)</td>
<td>102±4</td>
<td>(97–109)</td>
<td>178±10</td>
</tr>
</tbody>
</table>
Exercise in Centenarians
evidence of failing lungs, but......
Skeletal muscle: oldest-old and inactivity
Subject Selection

Oldest-old (>85 yr)

OM  OI

1 month  6 months  3 years  6 years  12 years  18 years  25 years
36 years  45 years  55 years  60 years  70 years  80 years
dead  RIP

Massimo Venturelli

Skeletal muscle, the oldest-old, and inactivity

Massimo Venturelli
Fiber type, the oldest-old, and inactivity
Fiber type, the oldest-old, and inactivity
Work efficiency, the oldest-old, and inactivity

Exercise: dynamic flexion and extension

ΔVO₂ (ml/min) ∆ Efficiency (%)

Y  OM  OI

Y  OM  OI

Arm

Leg

Massimo Venturelli
Maximal Strength Training (MST) as a countermeasure for typical aging

HIGH RATE OF FORCE DEVELOPMENT STRENGTH TRAINING

YIELDS 5-20% IMPROVEMENTS IN WORK EFFICIENCY
Maximal strength training and increased work efficiency: contribution from the trained muscle bed

Knee-extensor exercise

Pre and Post MST

4x4 85-90% of 1RM
3 x week

Fig. 3. Changes in pulmonary and 2-legged $\dot{V}O_2$ after 8 wk of MST. Values are means $\pm$ SE; $n = 5$. 
Old: 70 yrs
Young: 23 yrs
n = 22

Eivind Wang
Walking
5 mins
4.5 km/hr
3° inclination

A

$\text{VO}_2 (\text{L} \cdot \text{min}^{-1})$

16%↑

Pre | Post | Young
---|---|---
Old

B

Work efficiency (%)

12%↓

Pre | Post | Young
---|---|---
Old

Eivind Wang
Effect of MST

**A**

<table>
<thead>
<tr>
<th>Type</th>
<th>Old Pre</th>
<th>Old Post</th>
<th>Young</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber Percentage (%)</td>
<td><img src="#" alt="Graph showing 30%↑ and 20%↓" /></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**B**

<table>
<thead>
<tr>
<th>Type</th>
<th>Old Pre</th>
<th>Old Post</th>
<th>Young</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber Area (μm²)</td>
<td><img src="#" alt="Graph showing 40%↑" /></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Eivind Wang
Walking
5 mins
4.5 km/hr
3° inclination

Eivind Wang
Key Points:

• Normal aging (~ 60-75 yrs) attenuates work efficiency

• With exceptional aging (>85 yrs) work efficiency is improved

• Inactivity has a major impact on skeletal muscle aging

• MST appears to be a good countermeasure for both decreased work efficiency and Type II fibers
Systems energy conservation and efficiency

- Law of Conservation of Energy:
  - Total energy in an isolated system remains constant over time.

- First Law of Thermodynamics:
  - Energy output cannot exceed energy input.

- Efficiency:
  - Ratio of output energy to input energy.
OLD

\[ r = -0.52, P < 0.05 \]

YOUNG

\[ r = -0.36, P > 0.05 \]
<table>
<thead>
<tr>
<th>Muscle volume (cm$^3$)</th>
<th>Y = 8</th>
<th>OM = 8</th>
<th>OI = 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm (EF)</td>
<td>350±21</td>
<td>325±22</td>
<td>322±47</td>
</tr>
<tr>
<td>Leg (Q)</td>
<td>1844±230</td>
<td>1133±122 *</td>
<td>778±217 *†</td>
</tr>
</tbody>
</table>

* and † denote statistical significance.
∆ Blood flow (ml/min) ∆ CO (l/min)

![Bar charts showing changes in blood flow, CO, and HR for different conditions.

- **Arm**:
  - Δ HR (BPM): Y, OM, OI
  - Δ CO (l/min): Y, OM, OI
  - Δ Blood flow (ml/min): Y, OM, OI

- **Leg**:
  - Δ HR (BPM): Y, OM, OI
  - Δ CO (l/min): Y, OM, OI
  - Δ Blood flow (ml/min): Y, OM, OI

Legend:
- §: Significant difference
- †: Significantly different from baseline
- *: Significant interaction
Distinct fiber type differences in muscle of patients with COPD (more type II) may explain reduced mechanical efficiency
HIGH RATE OF FORCE DEVELOPMENT STRENGTH TRAINING AND SUBMAXIMAL MECHANICAL EFFICIENCY

NORMAL CYCLING
MECHANICAL EFFICIENCY = 22 - 28%

COPD PATIENTS CYCLING
MECHANICAL EFFICIENCY = 15%

THIS TYPE OF TRAINING HAS YIELDED 5 - 20% IMPROVEMENTS IN ALREADY TRAINED HEALTHY SUBJECTS
<table>
<thead>
<tr>
<th></th>
<th>Strength Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre VO$_2$ (mL·kg$^{-1}$·min$^{-1}$)</td>
<td>14.0±1.7</td>
<td>11.0±0.9*$</td>
</tr>
<tr>
<td>Post VO$_2$ (mL·kg$^{-1}$·min$^{-1}$)</td>
<td>11.8±1.43</td>
<td>11.3±1.1</td>
</tr>
<tr>
<td>Pre VO$_2$ (L·min$^{-1}$)</td>
<td>0.98±0.06</td>
<td>0.81±0.05*#</td>
</tr>
<tr>
<td>Post VO$_2$ (L·min$^{-1}$)</td>
<td>0.91±0.02</td>
<td>0.88±0.06</td>
</tr>
<tr>
<td>HR (beats·min$^{-1}$)</td>
<td>125±4.5</td>
<td>115±7.5</td>
</tr>
<tr>
<td>VE (L·min$^{-1}$)</td>
<td>30.9±2.2</td>
<td>28.0±1.8</td>
</tr>
<tr>
<td>[La$-$] (mmol·L$^{-1}$)</td>
<td>2.35±0.34</td>
<td>2.42±0.32</td>
</tr>
<tr>
<td>RER</td>
<td>0.89±0.01</td>
<td>0.90±0.01</td>
</tr>
<tr>
<td>SaO$_2$ (%)</td>
<td>93±1.2</td>
<td>92±0.4</td>
</tr>
<tr>
<td>Perceived Exertion (0-20)</td>
<td>13.7±1.1</td>
<td>11.8±0.53*</td>
</tr>
</tbody>
</table>

EFFECT OF HIGH RATE OF FORCE DEVELOPMENT STRENGTH TRAINING ON SUBMAXIMAL CYCLING
Remarkable results in terms of restoring mechanical efficiency and, somewhat surprisingly, several indices of lung function with high rate of force development strength training in patients with COPD.