Force Sense & Reactive Stiffening in Patients with Unstable Ankles & Potential Copers

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Ankle Sprains

• Most prevalent injury in physically active
  – Hootman 2007, Waterman 2010

• 850,000 annually in emergency rooms
  – Waterman 2010

• Common long-term sequelae include functional instability and ankle osteoarthritis
  – Valderabanno 2006
Functional Ankle Instability

• Sensations of “rolling” or “giving-way” during normal activity
  – Freeman 1965

• Presents following 30-50% of initial ankle sprains
  – Konradsen 2002, Anandacoomarasamy 2005

• Diagnosed using questionnaires
  – No gold standard

http://4.bp.blogspot.com/_E1tEsdn7gHE/TEygsLEExI/AAAAAAAENI/RZwtUEh-GoU/s1600/scott_dunlap_trail_running_xterra_2010.jpg
Functional Ankle Instability

• Original thought to be secondary to damage to static restraints

• Paradigms altered to include damage to mechanoreceptors and loss of neuromuscular control
  – Hertel 2002, Hiller 2010
Problems

• Mechanisms not established
  – Inconsistent relationship between measures of **stiffness**, **proprioception**, and **instability**
  – Central versus peripheral?

Courtesy of Erik Wikstrom
Ankle “Copers”

• 50-70 percent of ankle sprain patients DO NOT develop FAI

• What is important for prevention of subsequent sprains?
Purpose

• To understand the neuromechanical causes behind ankle instability

• To investigate the relationship between laxity, stiffness, and proprioception (kinesthetic awareness, force sense) in healthy, previously injured, and unstable ankles.
METHODS
Participants

• 78 participants
  – 22.3±3.1 yrs; 171.2±9.7 cm; 71.8±17.4 kg
  – Control (CON, n=20)
  – Copers (COP, n=19)
  – Functionally Unstable (UNS, n=19)
  – Sprainers (Mild Functional Instability) (SPR, n=20)

• *Determined using Cumberland Ankle Instability Tool with History of Ankle Injury*
Instrumentation

- Stiffness and Proprioception Assessment Device (SPAD)
  - Servomotor and torque sensor affixed to a foot plate
  - Force sense, Kinesthetic Awareness, Stiffness

- Instrumented Ankle Arthrometer (Blue Bay Research, Milton, FL)
  - Mechanical laxity
Methods – Laxity

- Arthrometer affixed to foot and shin
- 3 Anterior-Posterior (AP) translations to 125 N
- 3 Inversion-Eversion (IE) rotations to 4 Nm
- Peak anterior displacement, inversion rotation, and inversion-eversion range extracted
Methods - Stiffness

- Subjects seated on SPAD with hip flexed 120° and knee flexed 90°
- 20° ankle supination perturbation
  - 240°/sec, 3000°/sec²
- Stiffness calculated as $\Delta$ Torque/$\Delta$ Rotation at short range, mid-range, peak and total’
## Methods - Stiffness

<table>
<thead>
<tr>
<th>Condition</th>
<th>Instructions</th>
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<tbody>
<tr>
<td>Passive Stiffness (PS)</td>
<td>“Remain completely relaxed throughout the entire perturbation”</td>
</tr>
<tr>
<td>Active Stiffness (AS)</td>
<td>“Push out to [30% MVIC] prior to the move. When you feel the perturbation, hold that amount of contraction without pushing more or less.”</td>
</tr>
<tr>
<td>Reactive Stiffness (RS)</td>
<td>“Push out to [30% MVIC] prior to the move. When you feel the perturbation, resist it as hard and as fast as possible as if you are stopping your ankle from rolling in”</td>
</tr>
<tr>
<td>Deactivating Stiffness (DS)</td>
<td>“Push out to [30% MVIC] prior to the move. When you feel the perturbation, turn off all your muscles and relax as quickly as possible.”</td>
</tr>
</tbody>
</table>
Methods – Kinesthesia

• Subjects seated on SPAD as previously described

• Blindfolded with noise cancelling headphones

• Ankle supinated at 0.5°/sec
  – controlled accelerations (0.1, 1, 1000°/sec²)

• Identify motion (detection) OR recognize direction of motion (recognition)
Methods – Force Sense

• Subjects seated on SPAD as previously described

• Practice replicating 30% and 50% of MVC

• Replicate force level 3 times w/out feedback

• Relative Error, Variable Error, Coefficient of Variation over 500ms match window of match
Data Analysis

• ANOVAs used to compare between groups and across conditions

• Pearson’s product-moment correlation coefficients used to compare variables

• Alpha set a priori less than 0.05
RESULTS
Results - Laxity

• UNS displayed ↑ laxity compared to CON & COP 
  \[ p = 0.024 \text{ & } p = 0.007 \]

• No differences between groups in inversion rotation (F=0.105, 
  \[ p = 0.95 \])
Results - Stiffness

- Significant 3-way interaction of Group, Condition, and Range
  - F=1.73, p=0.012
Passive Stiffness

- Short-range stiffness is affected in SPR
- Total stiffness $\uparrow$ in COP
Active Stiffness

- Short-range stiffness ↓ in SPR
- Mid-range & Total stiffness ↓ in UNS
Reactive Stiffness

- CON & COP has ↑ short-range and mid-range stiffness than UNS
  - SPR again has ↓ short-range
Deactive Stiffness

- Short-range stiffness ↓ in SPR
- Mid-range & total stiffness ↓ in UNS
Results - Stiffness

• Short-range stiffness ↓ in SPR ankles across conditions

• Active & reactive stiffness ↓ in UNS ankles
  – Mid-range and total most affected

• Short-range stiffness – parallel and series elastic components of muscle

• Mid-range stiffness – regulation of reverse cross-bridge cycling
Results – Force Sense

• COP and UNS had *better* force sense compared to CON
  – Lower variable error at 30% MVC

• No other variable significantly different between groups
Results – Kinesthesia

• No differences between groups or accelerations

• Significant difference between instructions
Results – Kinesthesia

• Negatively correlated with inversion stiffness
  – Short-range stiffness negatively correlated with detection & recognition of motion (r=-0.23 to -0.40, p<0.03)

  – Total stiffness of passively & reactively correlated with recognition of motion (r=-0.23 to -0.37, p<0.03)

  – Recognition errors positively correlated with short-range stiffness (r=-0.24 to -0.40, p<.03)
Discussion

• Both mechanical and sensory alterations observed in functionally unstable ankles

• Increased laxity observed in UNS
  – Mechanical instability may exist simultaneously or independently of functional instability *Delahunt et al* 2010
  – Laxity not correlated with measures of proprioception
Stiffness Alterations

• Altered stiffness regulation strategies observed in COP, UNS, and SPR

• Patterns suggest mechanical alterations in mild instability (short-range), and copers (total)

• Unstable ankles demonstrate altered stiffness regulation strategies
Force Sense

• Previous studies suggested diminished force sense in unstable ankles \textit{Arnold et al 2010}

• COP & UNS have improved ability to match loads compared to CON

• Potential adaptation of musculotendinous receptors following injury to capsuloligamentous tissue \textit{Needle 2010, Needle 2011}
Kinesthesia

- Increased short-range stiffness appears beneficial for improving kinesthesia

- Stiffness regulation may be optimized based on mechanical properties

- Recognition & Detection of passive motion may test different components of the nervous system
Future Directions

• How are muscle activation strategies affecting stiffness regulation?

• Where in the nervous system are these changes occurring?
Thank You

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