Sensory-Motor Control of the Upper Limb: Effects of Chronic Pain

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Objectives

- Review of neural innervation of the upper limb (UL) – Brachial Plexus.

- Sensory-motor connections between the central nervous system and upper limb.

- Internal Models of motor control: Forward Models. Basis for Motor Coordination.

- Functional compromise of the UL due to chronic neck pain.
  - Recent studies on Upper Limb coordination during a functional task.
Review of neural innervation of the upper limb (UL) – Brachial Plexus.
Neural Innervation

- The brachial plexus is formed from 5 ventral rami (C5 - T1)
- 6 divisions
  - 3 anterior divisions
  - 3 posterior divisions
- 3 Trunks
- 3 Cords
- 5 Peripheral Nerves
  - Branches
• **Important neural structures for shoulder girdle and joint:**
  - Dorsal Scapular N.
    - Levator S; Rhomboids
  - Suprascapular
    - Supraspinatus, Infraspinatus
  - Long Thoracic N.
    - Serratus Anterior
  - U and L Subscapular N.
    - Subscapularis, Teres Major
  - Thoracodorsal N.
    - Lat. Dorsi
  - Lat and Med Pectoral
    - Pec. Major (LP), Pec Minor (LP, MP)

• **Important Neural structures for the arm:**
  - Axillary N.
    - Deltoid; Teres Minor
  - Musculocutaneous N.
    - Coracobrachialis; Biceps, Brachialis
  - Radial (P. Cord)
    - Triceps, brachioradialis, supinoator, all extrinsic extensors
  - Median (Med & Lat Cord)
    - Pronator Teres, Most Extrinsic Flexors, Thenar muscles and 1st 2 lumbricals
  - Ulnar (Med. Cord)
    - Flexor Carpi Ulnaris, FDP III & IV, all other intrinsic hand muscles.
Sensory-motor connections between the central nervous system and upper limb
Motor Systems
From "Raise MR Peripheral nerve injuries in the dog, Part II Compendium on Continuing Education for the Small Animal Practitioner 1 269 276, 1979)
Corticospinal Tract
(AKA Pyramidal Tract)

- Two groups of fibers
  - Corticospinal tract
  - Corticobulbar tract

- Fibres originate in both the frontal and parietal lobes

- Lateral CSPt decussates at the medullary pyramids
Sensory Systems
Structural Reminder

From "Raise MR Peripheral nerve injuries in the dog, Part II Compendium on Continuing Education for the Small Animal Practitioner 1 269 276, 1979)
Afferent Events Important to the Control of Movement

- Exteroception
- Proprioception
Exteroception
Cutaneous Mechanoreceptors
Segmental signaling of sensory Receptors

• Afferent information is carried via myelinated fibers to the dorsal horn

• Axons have varying properties
Proprioception
Proprioception

- Proprioception, is mediated via proprioceptors.

- Proprioceptive feedback provides information from stimuli generated by the system itself. Examples are the mechanical variables associated with activation of muscle (length, velocity, tension).

- Proprioceptors are involved in the moment-to-moment control of movement and include, muscle spindles, tendon organs and joint receptors (e.g. deep joint receptors in cervical vertebral joints).
The Stretch Reflex

- The stretch reflex is a reflection of the "phasic" components of muscle spindles.

- Tonic components convey important static information about muscle length.
The Dorsal Columns

Major Pathway for Touch and Proprioception
The CNS knows what a muscle is actually doing from decoded information from four input sources:

- The peripheral sensing of the joint angles and skin deformation.
- The peripheral sensing of muscle lengths and their changes by muscle spindles.
- The peripheral sensing of muscle forces generated by Golgi tendon organs.
- The reference (corollary) copies of the instructions sent by the CNS middle level to alpha and gamma motor neurons.
Cortical Structures Involved in Motor Coordination
Areas of Brain involved in Motor Control

• Lots of “traffic” involved in the planning, execution and shaping of movement

• Areas of the frontal lobe are involved in the planning and execution of movement. Areas of the parietal lobe are involved in the ongoing performance and shaping of movement.

• Many sources of communication between cortical areas and sub-cortical areas such as the cerebellum.
Internal Models of Motor Control.
Forward Models: Basis for Motor Coordination
The acquisition of complex motor skills is facilitated by the formation of internal models which are neural representations of the input-output characteristics of the motor systems.

The cerebellum contains inverse or forward models of the motor system.
Mathematically, the term internal model refers to two transformations:

- **Forward model** – the set of operations that change a motor command into motor behaviour.

  - **Forward Internal Models** can predict sensory consequences from efference copies of issued motor commands

- **Inverse Model** – The set of operations needed to retrieve a motor command from motor behaviour.

  - **Inverse Internal Models** – Can calculate necessary feedforward motor commands from desired trajectory information
Coordination of Grip-Force Load-Force Coupling

- When holding an object with the tips of the fingers there is a frictional force exerted to keep the object from slipping.

- This is precisely controlled so that it is just slightly greater than the minimum force needed to prevent slip.

- This coupling is explained by a framework that contains both inverse and forward models of the arm.
fMRI studies have revealed cerebellar activity specific to grip-force – load-force coupling, suggesting the existence of forward models in the cerebellum.
Cervical Muscle Coordination
Whiplash Associated Disorder
The presence of pain:

- Alters the activity of muscles during functional movement.
-Specifically – inhibition or delayed activation of muscles.
-There are suggestions that this occurs in the deep muscles involved in joint stability.
- The action of the superficial muscles is reflective of a compensation for loss of joint stability.

Sterling, Jull & Wright, 2001
Disruption in Muscle Activation with Neck Pain during UL Flexion/Extension.

- Note pattern of activation in controls.
  - This is a feedforward neural strategy pre-planned by CNS structures.

- Note delayed activation in Neck Pain Patients.

- Automatic Neuromuscular control may not be optimal.
  - Falla et al, 2004
Clinical Implications

• Deep Cervical Flexors have to be brought back “on-line” for proper postural adjustments to take place.

• The action of the superficial neck flexors and extensors is not sufficiently “fine” for stability of the cervical spine during upper limb movements.
Clinical Implications

• Proprioceptive acuity is disrupted.

• Further compounding the problem in motor control of the neck and arm

• These tests may be used to train proprioceptive function in patients with Neck/Arm pain and functional disability.
Upper Limb Coordination Studies in Patients with Mechanical Neck Disorder (MND)
MND: Implications to Cervical Function

- With neck pain and headache:
  - Upper and deep cervical flexors lose their endurance. Watson & Trott, 1993; Beeton & Jull, 1994
  - Superficial muscles (such as scalenes and sternocleidomastoid) have to compensate.
  - Atrophy of posterior suboccipital muscles has been noted.
  - Compensation via upper trapezius and levator scapulae.
  - Decreased proprioceptive acuity in cervical spine structures. Revel et al, 1994
Functional Implications

- If the deep muscles are dysfunctional then stabilization of articular segments during movement is compromised.

- Superficial muscles primarily concerned with the performance of the task are being called upon to perform functions that they were not designed for.

- Altered patterns of muscle activation seem to be sustained beyond the acute stage and may contribute to the chronicity of the problem.
Cyclical Reach and Grasp Test (CRGT)

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Questions ???

- Do patients with MND exhibit:
  - Different neural strategies?
  - Altered kinematics?
  - How does this affect the patient’s ability to form internal models? To update the forward model?
Different Neural Strategies
Shoulder Girdle (and Joint) Activation

Patient MND 2

Control MND 0
Group Data

X-Correlation Pairs

<table>
<thead>
<tr>
<th>Muscle pairs</th>
<th>Correlation (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0.84 ± 0.02</td>
</tr>
<tr>
<td>C2</td>
<td>0.88 ± 0.02</td>
</tr>
<tr>
<td>C3</td>
<td>0.86 ± 0.02</td>
</tr>
<tr>
<td>C4</td>
<td>0.84 ± 0.02</td>
</tr>
<tr>
<td>C5</td>
<td>0.90 ± 0.02</td>
</tr>
<tr>
<td>C6</td>
<td>0.86 ± 0.02</td>
</tr>
</tbody>
</table>

Muscle X-Correlations P’s
Muscle X-Correlations C’s
P/C = Patient/Control; A/U = Affected/Unaffected Side; D/T = Standing/Sitting
Conclusions

• The relationship between Upper Trapezius and Serratus Anterior is important to shoulder girdle stabilization.

• We propose that these results are evidence of a disruption of the neuromuscular control of the shoulder girdle. An inability to update the forward model.

• This has implications to upper limb coordination particularly during challenging tasks requiring patients with MND to reach above their heads.
Altered Kinematics?
The Challenge!!

- How do you take a structure with 3 joints each with 6 df attached to a moving trunk controlled by many muscles (many of them multi-joint) and reduce it to a single number!!!
Shoulder During Sitting Trial.

Shoulder Sitting P vs C

Variance

Group

Side

Controls

Patients

UA

A
Elbow During Sitting Trial.

Elbow Sitting P vs C

Variance

Group

Patients

Controls

Side

A

UA
CRGT

- CRGT differentiates
  - Patients from Controls
  - Seated from Standing
  - Shoulder from elbow

- Showing promise as a clinical tool.
Significant Correlation between Upper Trapezius and Serratus Anterior. \( (p \leq 0.10) \).

*Trends* in Upper Trapezius and Lower Trapezius (C1) and Serratus Anterior and Infraspinatus (C6).

There were no significant group effects in the other correlations however significant interactions between posture and side were observed.
Clinical Implications

• Over-activity in large superficial muscles compound the problem for the deep postural muscles.

• The shoulder girdle requires the coordinated action of several muscles in order to function “rhythmically” with the upper limb in complex movements.

• Rehabilitation should include testing using functional tasks and re-training with the integration of sensory-motor systems in mind – i.e. task related therapy.
Conclusions (based on Internal Models).

We propose that there was a disruption of the neuromuscular control of the shoulder girdle leading to possible disruption in upper limb coordination during these tasks.

This may represent a disruption of the dynamic forward model that informs the internal model responsible for postural stability of the shoulder girdle during (high) reach and grasp tasks.
Projects in the Human Movement Laboratory

- **Basic Motor Control**
  - Neural strategies during performance of hypnoticomotor tasks. Effect on cerebellar activity
  - Developmental reach and grasp tasks.

- **Applied studies: Adult**
  - Upper limb coordination in chronic pain patients with mechanical neck disorder
  - Cervical proprioception and postural control after induced perturbations of cervical spine
  - Effects of interferential current on chronic neck pain: InterX device clinical trial.

- **Applied Studies: Paediatric**
  - Upper limb function in children with cerebral palsy
  - Assessment of gait in children with cerebral palsy
  - Effects of Artane on upper limb function in children with dyskinetic cerebral palsy
  - Upper limb motor control in children born with Obstetrical Brachial Plexus Injury
  - Upper limb coordination in children with Developmental Coordination Disorder.
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