Biomechanics

Theories of Movement Control

Patient studies
Importance of Whole-Body Equilibrium in reaching movements

**Task:** Grasp and transport and object initially on the ground

**Problem:** Define hand trajectory and keep Centre of Gravity within base of support

**Therefore:** both equilibrium and spatial components to movement execution

Motor Programs

- **Keele (1968):** “a set of muscle commands that are structured before a movement sequence begins, and that allows the sequence to be uninfluenced by peripheral feedback”

- **Engineering Control Theory:** formulation of relationships between inputs (sensory) and outputs (motor command)

**Internal Models:**

- **Inverse Models:** Transforming desired trajectories of the hand into appropriate muscle activations
- **Forward Models:** Predicting consequences of action
Control Strategy 1

Ballistic

Inverse model alone
- inaccuracy
- changes in plant

Effects of loss of feedback
- peripheral neuropathy
Deafferentation

- Large fibre sensory neuropathy
  - cutaneous
  - proprioceptive
Control Strategy 2

Ballistic with Feed-forward

Inverse Model incorporating prediction of the errors in movement execution to adjust controller parameters
Force Field Learning Experiments

- Reaching movements with imposed forces from a mechanical forces
- Manipulandum altered the dynamics of the task
- Initial movements were distorted

Shadmehr, R & Mussa-Ivaldi (1994)
With practice movements, hand trajectories in the force field became similar to those observed without a force field.
How does the CNS learn to control movements with different dynamics?

- **After-effects** after sudden removal of the field were *mirror images* of those observed when subjects were initially exposed to the field.

- This suggests the motor controller was *composing a model of the force field*, that was predicting and compensating for the imposed force field.
Control Strategy

Internal feedback
Location of Internal Models of Motor System

- **Cerebellum**: storing of internal models
- **Pre-motor** and **Parietal** linking stored internal models to context cues
Cerebellar Disorders

Behavioral signs:

- Delay in movement initiation (clumsiness, but movement execution is not prevented)
- Incomplete and inaccurate movement forms (errors of force, velocity, and timing)
- Muscle strength is diminished (gait changes include wide base stance, tremor, irregularly placed steps, excessive leg lift)
Symptoms and Signs of Cerebellar Diseases

The most sensitive indicators of cerebellar disease in humans are disturbances of upright stance and gait.

Disorders of the cerebellum can be grouped into 3 categories:

1. **Hypotonia**: a lack of muscle tone that results in less resistance to passive limb displacements. An example is the continued oscillation of the leg after a tap to the patellar tendon to evoke the knee jerk reflex.

2. **Ataxia**: an impaired ability to execute voluntary movements, lack of coordination. Delay in initiating responses, errors in the range of movement, impairment in ability to match a prescribed rate of movement, difficulty in producing the appropriate timing of components of a multijoint movement.

3. **Tremor**: an intention tremor that occurs when a limb approaches a target. The tremor represents erroneous connections to the range of motion due to poor adaptive control by the cerebellum.
Control vs Cerebellar: Irregular trajectories during reaching
Control vs Cerebellar:
Long delay and slow movement initiation
Sensory Prediction Error to Adjust Movement

- Adaptation of motor commands essential as our body and environment can change

- **Cerebellum** thought crucial for this adaptation process

- Compare healthy normals with a group of patients congenital cerebellar deficits

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FIG. 1. Illustration of 2 different types of error. A: sensory prediction error ($S_e$). Based on an initial motor command ($u$), the forward model makes prediction about the sensory outcome of the movement ($\hat{S}$). Difference between the actual hand position ($S$) and the predicted hand position ($\hat{S}$) based on visual feedback represents sensory prediction error ($S_e$). B: sensory prediction error can be monitored and transformed into motor commands ($m$) that produce motor corrections to compensate for this error. In all plots, the square represents target position.
Sensory and Motor Corrections

- **Sensory prediction errors**: Difference between the actual sensory feedback and the expected sensory feedback (visuomotor errors eg prism glasses)

- **Motor correction of the error** (by a reflex) could train adaptation. Motor corrections act as a teaching signal from the brain

J Neurophysiology 98 pp54-62
• Visuomotor adaptation task (healthy controls vs cerebellar)

• Cerebellar subject’s have deficits in adaptation of movement compared with healthy normal controls
Control vs Hereditary Cerebellar Ataxia

Comparison between tasks where there can be no on-line corrections and reliance on sensory prediction errors for adaptation (shooting) and a task where online correction is possible (pointing)

Sensory prediction errors sufficient for adaptation
Stroke

- In a cerebrovascular accident (CVA), the clinical picture is strongly dependent on the area of stroke.
- After a cortical stroke, the limbs on the two sides of the body often show **large differences in impairment** (cross-over of pyramidal tract)
- Stroke is followed by **plastic changes of projections within** the brain and **between** the brain and the spinal cords
- Role of **non-pyramidal tract** descending tracts may increase, shifting balance of limb control from the injured contralateral to the spared ipsilateral hemisphere
Movement Trajectories after stroke

- After a stroke, reaching movements are characterized by irregular, curved trajectories.
- Reaching by the ipsilateral arm may show normal trajectories.
Stroke: Compensatory Trunk Involvement in Reaching

- After stroke, patients use **trunk motion** during reaching as an adaptive strategy.
- The more severe the impairment, the more trunk motion.
- **Adaptive** as trunk motion compensates for loss of control of arm muscles.
References


Control Theory approaches to Movement Execution

