The NeuroNet Program

Lecture Topic:
The Vestibular System
The NeuroNet Program: The Vestibular System

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All living things which create their own movement have a vestibular system.

Example: gravitropism

What is the vestibular system?
An OBLIGATORY
Gravito-inertial
Perceptual-motor
Distributed neural network


First to develop in utero
First to myelinate
Fully functional at birth

Primitive reflexes
Postural reflexes
Guide us into the development of a predictive relationship with gravity

Indovina et al., 2005. Representation of Visual Gravitational Motion in the Human Vestibular Cortex. SCIENCE v 308 pp 416-19

What is our PREDICTIVE relationship with gravity?
The ability to predict “time to collision”
Prediction of time to collision for objects accelerated by gravity = temporal processing

Indovina: “Between 5 and 7 months of age, infants begin to implicitly expect a downwardly moving object to accelerate and an upwardly moving object to decelerate.”

Indovina: “Here we propose that an internal model calculating the effects of gravity (1g model) on seen objects is derived from graviceptive information . . .

Indovina: “. . . is stored in the vestibular cortex, and is activated by visual motion that appears to be coherent with natural gravity.”

Indovina: “The basis for this hypothesis is that the vestibular system is able to estimate the gravity vector in head coordinates . . .

Indovina: “. . . by combining signals from the otoliths and semicircular canals, and that multisensory neurons in the vestibular system also respond to visual stimuli.”
In other words:
We have an internalized model of gravity in our head that enables us to predict the consequences (time to collision) of movement.

Indovina: "We surmise that, through experience, the vestibular estimate of the Earth’s gravity is transformed . . .

Indovina: “. . . and stored as an abstract representation of gravity accessible by the visual system.”

Indovina: results showed greater brain activation for movement coherent with gravity.

Indovina: “Here we provided direct evidence that the fundamental physical constraint of Earth’s gravity is internalized in the human brain.


The vestibular system
An OBLIGATORY
Gravito-inertial
Perceptual-motor
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Parts of the vestibular system:
- semi-circular canals
- otoliths

Semi-circular canals:
detect head rotation; not affected by gravity.
Otoliths: detect translational movement; affected by gravity.


http://thalamus.wustl.edu/course/audvest.html
Washington University St. Louis

Translational movement:
along the axis
Rotational movement:
around the axis
The Vestibular system responds to:
- head rotation
- movement against gravity

Maculae of utriculus and sacculus
1. Otolithic membrane: calcium carbonate
2. Linear acceleration
3. Head and body move together

Hair cells and gravity:
- semi-circular canals: NO
- otoliths: YES

Vestibular dysfunction
When Maribeth and I were on vacation last week we took a boat trip that lasted the entire day. I ALWAYS get sea-sick either on the boat or shortly after disembarking.

That night at dinner Maribeth and I were both so dizzy we could hardly eat. A few sets of jumping jacks later… and the dizziness subsided. Thanks to you and Nancy for a night’s rest that I otherwise would not have gotten!
Vestibular dysfunction:
- Seasick
- Carsick
- Space sick

Three kinds of movement:
1. Head rotation, no body movement
2. Body movement, no head rotation
3. Body movement AND head rotation

Functions of the vestibular system
1. Maintaining balance (posture and equilibrium)
2. Stabilizing the eyes relative to the environment


The vestibular neurons that fire most frequently do so during the least amount of body movement.

Balance is the ACTION of not moving.

Vestibulo-ocular and vestibulo-spinal reflexes . . . control most of our balance.
Vestibulo-spinal reflex

DEMO:
Standing balance
Eyes open
Eyes closed

http://ppsbsd.uchicago.edu/faculty/robert_mccrea.html

Context-dependent processing: vestibular pathways . . . are not sensitive to vestibular signals related to active head movement.

Vestibulo-ocular reflex

DEMO:
Knee bends and read

http://thalamus.wustl.edu/course/audvest.html

Adaptation of vestibular reflexes:
Visual/vestibular conflict: 5% change in relative visual movement per diopter of glasses lenses
A new prescription may give better vision but be intolerable due to the perceived change in visual motion.


Sensory channel re-weighting
1. Postural stiffness
2. Damping
3. Feedback time delay

Peterka: resolution of sensory conflict by sensory information re-weighting
- vestibular-lesion patients could not re-weight sensory information

Some vestibular lesion patients may use increased stiffness to help compensate for their vestibular system dysfunction.

Epley: visual dependency
- Otolith dysfunction
- Ignoring vestibular input
- Cognitive dysfunction: CNS processing overload

The vestibular system as a motor system: vestibular stimulation OBLIGATES reflexive movement
The vestibular system as the neural basis of temporal processing:

Vestibular reflexes elicited by rotational and translational movement.

Goal of reflexes is to maintain stable upright posture in the context of purposeful movement.

Purposeful movement in the context of stable upright posture requires an intimate knowledge of gravity!

Perception of motion: fundamental job of the visual system.

Between 5 and 7 months infants begin to anticipate up and down.

Indovina et al, 2005
Gravitational acceleration is factored into visual perception and interception.

Visual system poorly estimates acceleration.
Indovina et al, 2005

Having an internal model of gravity in the brain removes ambiguity from visual information processing.
Indovina et al, 2005

Here we provided direct evidence that the fundamental physical constraint of Earth's gravity is internalized in the human brain.
Indovina et al, 2005

Vestibular neurons that fire most frequently do so during the LEAST amount of body movement.
Llinás: Eye of the Vortex

Balance is the action of not moving!

Vestibular anticipation of time to collision gives rise to motor anticipation of changes needed for accurate balance and movement.
We learn to control temporal processing as we learn to control purposeful movement against gravity.

NeuroNet Model: Learning to calibrate movement against gravity means learning how to calibrate speed of movement.

NeuroNet Model: Learning to predict movement means learning to visualize or anticipate what WILL happen when we move.

NeuroNet Model: Learning to predict movement means learning to visualize or anticipate WHEN (time to collision) results of movement.

NeuroNet Goal: lay the foundation for temporal processing (anticipation of WHAT / WHEN results of purposeful movement).

NeuroNet Goal: lay the foundation for the cognitive process of visualization through the perceptual/motor process of anticipation.
Our PREDICTIVE relationship with gravity forms the basis of our “sense of timing”
Accuracy of prediction
Gives rise to anticipation of accuracy

And, through anticipation, changes a child into an independent learner.

~ end ~