MOVEMENT COORDINATION = LEARNING OF COMBINATIONS OF MOTOR ELEMENTS:

There are 206 bones, many joints, and 650 or so muscles in the adult human. Most movements involve many bones, muscles, and joints. Coordination requires that these elements be COMBINED so that they:

1) Start at the correct time,
2) Stop at the correct time, and
3) Contract with the correct amount of force, each element proportionate to all others.

4) This combining is so complex that it apparently must be done “automatically” without having to think about it.

5) It is therefore something that must be learned through repeated trial and error practice.
CEREBELLUM EXCITES ITS DOWNSTREAM TARGETS;
(BASAL GANGLIA INHIBIT THEIR DOWNSTREAM TARGETS)
THE CEREBELLAR CIRCUITRY OF S. RAMON Y CAJAL: PARALLEL FIBERS ARE LONG DISTANCE CONNECTIVES

A CEREBellar FOLIUM
Lám. V. Cajal a los 15 años mientras se dedicaba a escribir una novela tipo Robinson.
CEREBELLAR INACTIVATION IMPAIRS COMPOUND MOVEMENTS MORE THAN SIMPLE MOVEMENTS

**Fastigial:** Falls to side of lesion, wide base

**Interposed:** Antagonist delay, action tremor

**Dentate:** Reach overshoot, X-Y error, and finger incoordination (Kane, Goodkin, & Thach).
RIGHT SCA TERRITORY INFARCT (INVOLVING DENATE)

REACH AND PINCH IMPAIRED, WRIST MOVEMENT NORMAL
MOST SENSITIVE CEREBELLAR TESTS ARE MOVEMENTS THAT INVOLVE ACTIVITY OF MANY MUSCLES OVER MANY JOINTS: STANCE, GAIT, HEEL-KNEE-SHIN, FINGER-NOSE-FINGER, RAM (BABINSKI), FINGER-THUMB (FISHER)

A. 

B. 

C. 

D. 

E. 

F. 

INDEX MP ANGLE

WRIST ANGLE

THUMB ANGLE

COIN-TURNING, EOM, HAND-EYE COORDINATION, SPEECH
PARALLEL FIBERS ARE LONG ENOUGH TO LINK TOGETHER PURKINJE CELLS PROJECTING TO DIFFERENT BODY PARTS WITHIN ONE NUCLEAR BODY MAP, AND MULTIPLE MAPS
5 CHILDREN AGES 6-15 HAD POSTERIOR VERMAL SPLITS TO REMOVE MEDULLOBLASTOMAS IN THE 4TH VENTRICLE.

NORMAL CONTROL

WALKING

VERMAL DAMAGE

TANDEM GAIT

maximum consecutive tandem steps

Hopping

A. Control
B. Vermal damage
C.
D.
ATAXIC REACH: INABILITY TO COMPENSATE FOR INTERACTION TORQUES IN MULTI-JOINT MOVEMENTS

Bastian et al., 1996
PARALLEL FIBERS ARE LONG ENOUGH TO \textit{LINK TOGETHER} PURKINJE CELLS PROJECTING TO DIFFERENT BODY PARTS \textit{WITHIN ONE NUCLEAR BODY MAP, AND MULTIPLE MAPS} 

\textbf{(Mugnaini et al.)}

\ldots\textit{AND ON-BEAM PC'S FIRE IN SYNCHRONY} \textbf{(Heck et al.)} \ldots

\ldots\textit{AND SURGICAL VERMAL SPLIT IMPAIRS TANDEM GAIT BUT NOT ONE LEG HOPPING} \textbf{(Bastian et al.)}
PAIRING CF SHOCK (C) WITH MF SHOCK (A) DEPRESSES

Ito et al, ‘82

PARALLEL FIBER (A) EXCITATION OF PURKINJE CELL (LTD)
THE TWO SPIKE WAVEFORMS OF THE PURKINJE CELL,

"SIMPLE" (MF, PF)  "COMPLEX" (CF)
WHEN ADAPTING TO A NOVEL PERTURBATION

C.F. SPIKES INCREASE, P.F. SPIKES DECREASE (Gilbert & Thach)
CEREBELLAR THEORY OF MOTOR LEARNING

1. Movement can be generated without cerebellar control.

2. Movement may be incorrect, and require correction. Movement may be complex, and require automation.

3. Cerebellum "watches" movement context and movement. Through trial and error repetition, climbing fiber fires and LINKS context-specific mossy fiber-parallel fiber activity to those Purkinje cells which CAN influence the response. After time and practice, CONTEXT causes RESPONSE.

4. Context may combine many external and internal conditions. Response may combine many MPG's, joints, and muscles. Each C-R combination is stored discretely. Many C-R combinations.

5. Response is stereotyped. C-R linkage is arbitrary. Response may be triggered by context early. Anticipates and prevent errors.
DOES THE CEREBELLUM CONTRIBUTE TO MOTOR LEARNING? Martin et al, ’96
"CHEATING" DURING PRISM ADAPTATION (CONSCIOUS CORRECTION OF NEXT MOVE BASED ON SEEN ERROR OF LAST MOVE).

HUMAN: "THROW TO WHERE YOU SEE THE TARGET, NOT TO WHERE YOU THINK IT ACTUALLY IS".

MONKEY: REWARDED FOR HITTING THE TARGET; CHEATING IS HARD TO PREVENT.
COGNITIVE DEFICITS FROM CEREBELLAR LESIONS (W.T.Thach, in Sensory Guidance of Movement, Wiley, 1988)

Cerebellar motor and cognitive deficits result from anatomically distinct lesions:

Anterior-lateral and medial regions, motor control.

Posterior-lateral cerebellar regions are involved in cognitive processes.

Cerebro-cerebellar connectional anatomy (Middleton and Strick, 1998)
Lesions impair Verb Generate (not Adjective Generate) and Tactile Maze Learning (not Visual Maze Recognition)

Are there deficits in Activities of Daily Living?
Right PICA distribution: new onset stuttering, impaired word finding, “harder to think of words”, use of wrong words with unawareness, difficulty following oral instructions.
Left PICA distribution: Errors in route finding and learning (walking, driving), grooming, dressing, household chores…
REPAIR SHOP/RELEARNING FUNCTIONS?


- Bastian, Morton, Reisman, Choi: Split treadbelt training after hemiplegia from motor cortex infarcts and hemispherectomy for seizure control (ongoing studies…)

- Overuse dystonia: Hypothesis of excessive gamma drive with enhanced stretch reflexes responsive to Botox (Granit, Kuffler, Hunt cf Perlmutter & Thach, studies planned…)
DO PARALLEL FIBERS *LINK TOGETHER AND AUTOMATE* COGNITIVE PROGRAM GENERATORS (CPG’s) IN FRONTAL AND PARIETAL CEREBRAL CORTEX, AS IN THEIR PROPOSED ROLE IN LINKING TOGETHER MPG’S AND MUSCLES?
THE CEREBELLUM MAY DO FOR THINKING WHAT IT DOES FOR MOVING

Question still open on the cerebellar roles in Cognition---Schmahman (mood and thought) after cbl stroke, Courchesne (attention) in autism, Andreassen (schizophrenia) Ivry, Llinas (abstract timing) vs. Movement---Decety, Ingvar (mental moves) Haarmier, Thier (mvt not attn) ??? (mental mvt for timing)
Motor cortex Type II neurons (Schieber) appear to control spinal Cord gamma MN’s (Koeze & Phillips, Fromm & Evarts)