



# Academy of Distinction

Building an Ethic of Excellence in Education



## Apprendimento “de novo” e adattamento motorio *differenze e similitudini*

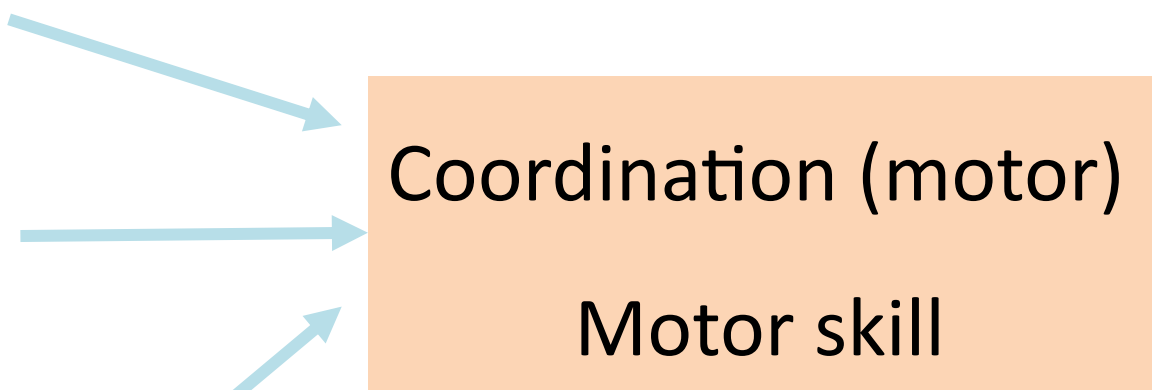


**Matteo Bertucco**

Università di Verona  
Dipartimento di Neuroscienze,  
Biomedicina e Movimento

# Preface - Introduction

- Motor control
- Motor learning
- Motor development



Coordination (motor)  
Motor skill



Capacità che permette di eseguire un qualsiasi movimento corporeo.

La coordinazione motoria è la capacità che permette di eseguire, in modo appropriato, azioni motorie **efficaci**, così da trarne i migliori risultati.

Muovere **differenti parti del corpo** con efficacia e controllo. Ma dietro a ciò c'è una combinazione di skills motorie, cognitive e percettive che permettono di raggiungere una performance.

La capacità di eseguire un movimento in maniera **efficace ed efficiente**, raggiungendo, quindi, l'obiettivo prefissato con il minor dispendio energetico possibile.

Capacità che permette di eseguire dei movimenti nel miglior modo possibile con **efficacia ed economicità**.

Capacità di **organizzare e controllare il movimento** per raggiungere un obiettivo

Complesso armonico di movimenti

Dipende dalla dimensione intellettuale. Influenza l'apprendimento.

Capacità di controllare/adattare ogni **segmento corporeo** in modo armonioso e col minimo dispendio di energia

Movimenti in relazione allo spazio e all'ambiente esterno.

L'insieme di più **capacità (coordinative e condizionali)** che permettono ad un individuo di eseguire movimenti proficui e utili

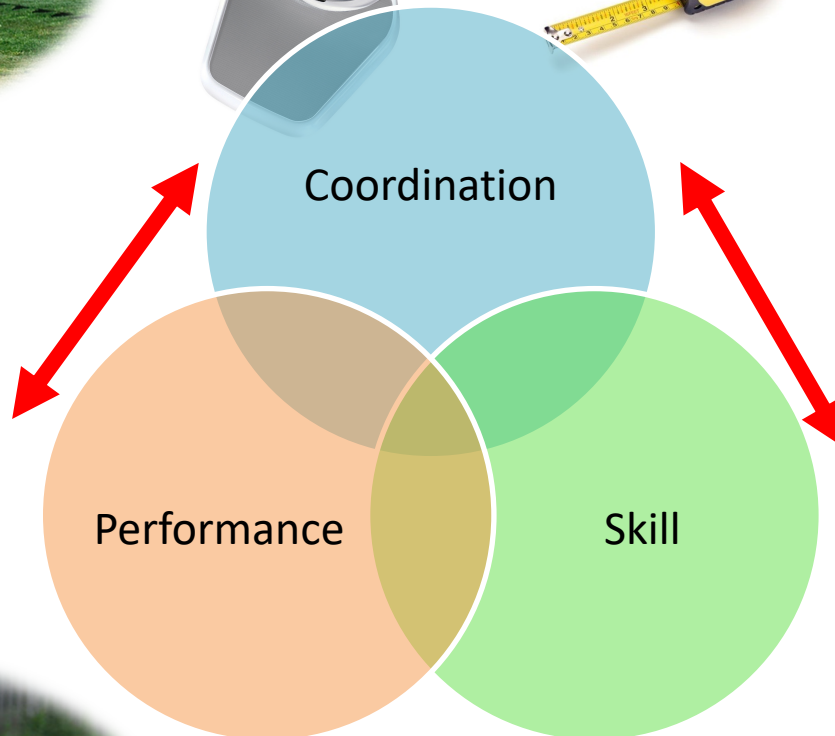
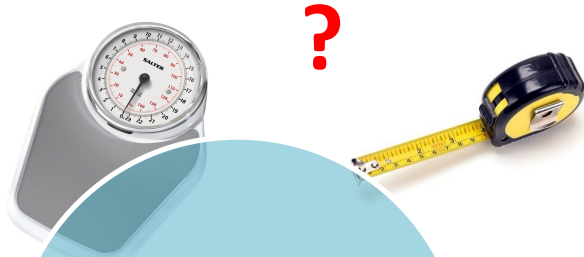
Capacità motoria correlata intimamente al funzionamento del sistema nervoso, che caratterizza in maniera visibile le attività svolte dalle persone, sia di tipo motorio sportivo che nella vita quotidiana.

La capacità di **sincronizzare i movimenti** del nostro corpo. Maggiore è la coordinazione e maggiore la possibilità di fare movimenti combinati e complessi.

Insieme di **capacità motorie** che stanno alla base della pianificazione e regolazione del movimento di diverse parti del corpo in maniera **fluida ed economica**

La coordinazione motoria è la capacità di controllare, regolare e **organizzare il movimento delle varie parti del corpo nello spazio e nel tempo** per raggiungere un determinato obiettivo





# Motor skill

Per **"abilità motorie"** si **definiscono tutte quelle azioni** che, attraverso la ripetizione del gesto, **sono state apprese e consolidate** e che ricorrono in modo automatizzato, cioè si realizzano senza l'intervento consapevole dell'attenzione. **Le abilità motorie rappresentano dunque il risultato finale di un processo di apprendimento.**

[https://archivio.pubblica.istruzione.it/essere\\_benessere/moto.shtml](https://archivio.pubblica.istruzione.it/essere_benessere/moto.shtml)



# Motor skill

Mechling (1987) definisce l'abilità come un elemento **dell'attività umana cosciente, eseguito in gran parte in modo automatico, che si sviluppa ampiamente attraverso l'esercizio.**

Meinel sostiene che le abilità sono azioni che vengono consolidate prevalentemente con **l'esercizio ripetuto**, che si svolgono, **almeno in parte, automaticamente**, cioè senza che l'attenzione venga intenzionalmente concentrata su di essa.

[https://liguria.coni.it/images/liguria/Abilità\\_motorie\\_e\\_capacità\\_coordinative.pdf](https://liguria.coni.it/images/liguria/Abilità_motorie_e_capacità_coordinative.pdf)



# Motor skill

“A learned, goal-directed activity accomplished primarily through muscular contributions to action.” (Edwards, 2010)

“Activities or tasks that require voluntary control over movements of the joints and body segments to achieve a goal.” (Magill and Anderson, 2017)

“Movement that are dependent on practice and experience for their execution.” (Schmidt et al., 2005)



# Motor coordination

“La coordinazione motoria è la capacità che permette di eseguire un qualsiasi movimento corporeo in modo efficace.”

[https://it.wikipedia.org/wiki/Coordinazione\\_motoria](https://it.wikipedia.org/wiki/Coordinazione_motoria)

“Motor coordination is the orchestrated movement of multiple body parts as required to accomplish intended actions.”

[https://en.wikipedia.org/wiki/Motor\\_coordination](https://en.wikipedia.org/wiki/Motor_coordination)



# Motor coordination (*Physical education*)

## FOUNDATIONS OF PHYSICAL EDUCATION, EXERCISE SCIENCE, AND SPORT

**Jennifer L. Walton-Fisette**  
*Kent State University*

**Deborah A. Wuest**  
*Ithaca College*

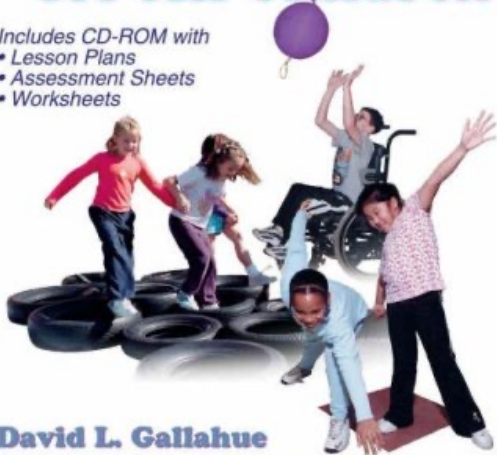
“Ability to execute movements smoothly and efficiently”



# Motor coordination (*Physical education*)

## Developmental Physical Education for All Children

Includes CD-ROM with  
 • Lesson Plans  
 • Assessment Sheets  
 • Worksheets



David L. Gallahue  
 Frances Cleland Donnelly

“The ability to integrate separate motor systems with varying sensory modalities into efficient movement, as in kicking or dribbling a ball.”

Motor fitness components	Common tests	Specific aspect measured	Synthesis of findings
Coordination	Cable jump	Gross body coordination	Year-by-year improvement with age in gross body coordination. Boys superior from age 6 on in eye-hand and eye-foot coordination.
	Hopping for accuracy	Gross body coordination	
	Skiping	Gross body coordination	
	Ball dribble	Eye-hand coordination	
	Foot dribble	Eye-hand coordination	



# Motor coordination (*Physical education*)

*Scand J Med Sci Sports* 2011; 21: 663–669  
doi: 10.1111/j.1600-0838.2009.01027.x

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SCANDINAVIAN JOURNAL OF  
MEDICINE & SCIENCE  
IN SPORTS

## Motor coordination as predictor of physical activity in childhood

V. P. Lopes<sup>1,2</sup>, L. P. Rodrigues<sup>3</sup>, J. A. R. Maia<sup>4</sup>, R. M. Malina<sup>5,6</sup>

MC was evaluated with the Kiphard–Schilling body coordination test, Körperkoordination Test für Kinder (KTK), developed on children in Germany (Schilling, 1974). The KTK battery has four items:

- [1] Balance – the child walks backward on a balance beam 3 m in length but of decreasing widths: 6, 4.5, 3 cm; the number of successful steps is recorded.
- [2] Jumping laterally – the child makes consecutive jumps from side to side over a small beam (60 cm × 4 cm × 2 cm) as fast as possible for 15 s. The child is instructed to keep his/her feet together; the number of correct jumps is recorded.
- [3] Hopping on one leg over an obstacle – the child is instructed to hop on one foot at a time over a stack of foam squares. After a successful hop with each foot (the child clears the square without touching it and continues to hop on the same foot at least two times), the height is increased by adding a square (50 cm × 20 cm × 5 cm). The child has three attempts at each height and foot; the height of the final successful jump is recorded.
- [4] Shifting platforms – the child begins by standing with both feet on one platform (25 cm × 25 cm × 2 cm supported on four legs 3.7 cm high) and holding a second identical platform in his/her hands; the child is instructed to place the second platform alongside the first and to step on to it; the first box is then lifted and placed alongside the second and the child steps on to it; the sequence continues for 20 s. Each successful transfer from one platform to the other is given two points (one for shifting the platform, the other for transfer the body); the number of points in 20 s is recorded. If the child falls off in the process, he/she simply gets back on to the platform and continues the test.



# Motor coordination (*Physical education*)

## Motor Coordination Correlates with Academic Achievement and Cognitive Function in Children

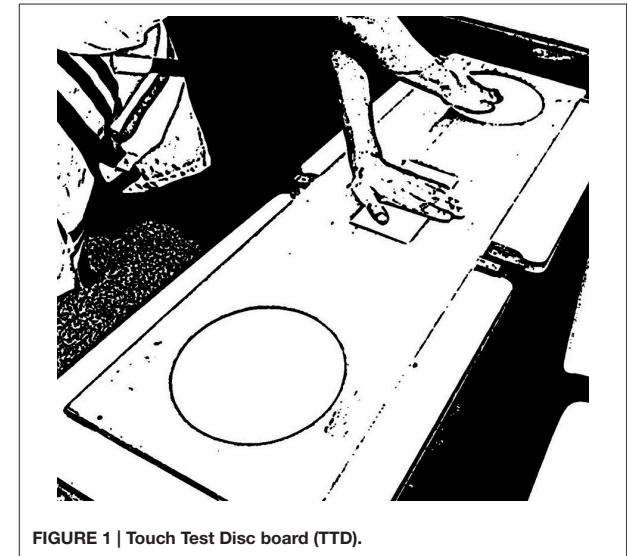
Valter R. Fernandes<sup>1\*</sup>, Michelle L. Scipião Ribeiro<sup>2</sup>, Thais Melo<sup>1</sup>, Paulo de Tarso Maciel-Pinheiro<sup>3</sup>, Thiago T. Guimarães<sup>4</sup>, Narahyana B. Araújo<sup>2</sup>, Sidarta Ribeiro<sup>5</sup> and Andréa C. Deslandes<sup>6</sup>

### Touch Test Discs (TTD)

Evaluates Motor coordination, especially hand-eye coordination. The test is performed on a rectangular wooden plank with 120 cm wide by 60 cm wide. In the center of the board, it contains a rectangle of 10 cm high by 20 wide and a circle of 20 cm in diameter on each side with a distance of 5 cm between the figures (**Figure 1**). The individual has to keep the non-dominant hand in the central rectangle, and touch with the dominant hand in the circle on the opposite side, crossing his arm over the other, and come back to complete one cycle. Each attempt comprises 25 correct cycles, and the smallest time for completion out of three attempts is considered (Gobbi et al., 2005).

### Shuttle Run Speed—“Running Back and Forth” Test

Evaluates agility that consists in the ability to change the position of the body or movement direction with velocity. For its realization, a space of 5 m is marked with tape on the ground. The subject must perform five cycles, running back, and forth, to complete the test. The result is written down with a precision of tenths of seconds (Gobbi et al., 2005).

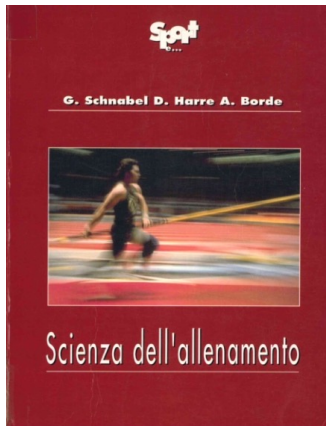
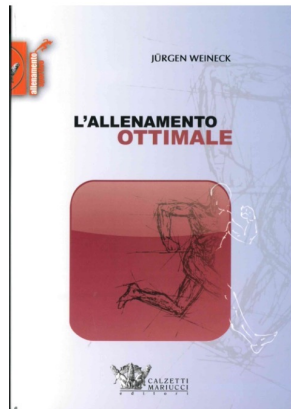


# Motor coordination (*Sport science and training*)

Blume, D. D. (1981). Le capacità coordinative: definizione e possibilità di svilupparle. Trad. it. in *Didattica del Movimento*, 42/43, 60-82, 1986.

## LE CAPACITÀ COORDINATIVE: DEFINIZIONE E POSSIBILITÀ DI SVILUPPARLE

1986



## Capacità coordinative

Capacità dell'uomo, primariamente determinate da processi di controllo e regolazione dei movimenti (Hirtz, 1981)

Determinate dai processi di controllo e di regolazione del movimento, cioè da processi formativi (Blume 1981)

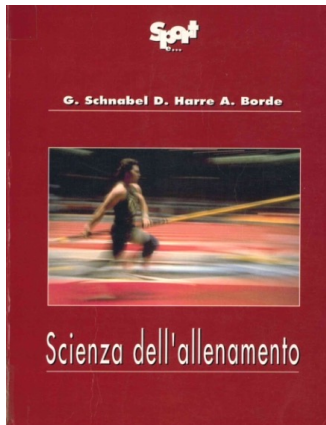
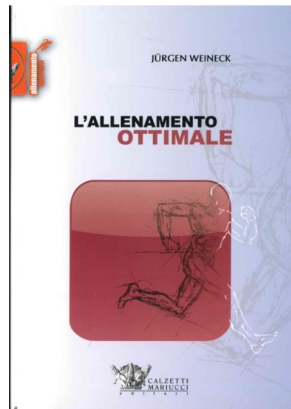


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## LE CAPACITÀ COORDINATIVE: DEFINIZIONE E POSSIBILITÀ DI SVILUPPARLE

1986



## Capacità coordinative

- Capacità di abbinamento - coordinazione segmentaria
- Capacità di differenziazione
- Capacità di orientamento
- Capacità di equilibrio
- Capacità di reazione
- Capacità di trasformazione
- Capacità di ritmo

[https://it.wikipedia.org/wiki/Coordinazione\\_motoria](https://it.wikipedia.org/wiki/Coordinazione_motoria)

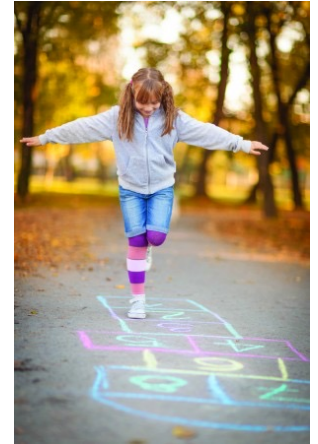
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[https://liguria.coni.it/images/liguria/Abilità\\_motorie\\_e\\_capacità\\_coordinative.pdf](https://liguria.coni.it/images/liguria/Abilità_motorie_e_capacità_coordinative.pdf)

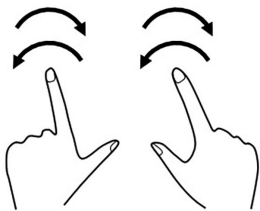


# Motor coordination (*Ecological perspective*)

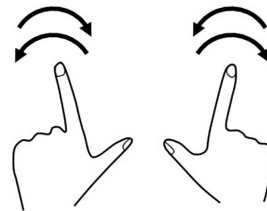
- The coordination between is a temporary functional grouping of elements that emerges without input from a controller *via* self-organizing processes.
- Coordination is called self-organized coordination.
- Self-organization is a process in which the order emerges solely from the interactions between elements and their surrounding environment, situation, and context.



Anti-phase



In-phase



The frequency of the metronome was increased

(Haken et al., 1985)



# Motor coordination

## *(Biomechanics - motor control & learning)*

“Although a common **colloquial** use of the term coordination relates it to a characteristic of skilled performance, it should not be limited to this use.”

### MOTOR LEARNING AND CONTROL

Concepts and Applications



Richard Magill  
David Anderson  
Eleventh Edition



# Motor coordination

## *(Biomechanics - motor control & learning)*

“Coordination refers to the organizational relationship of movement characteristics of the head, body, and limb involved in the performance, regardless of the skill level of the performer.”

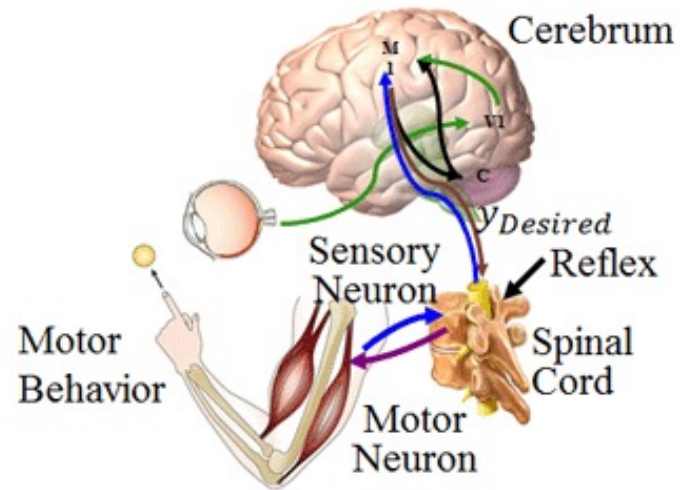
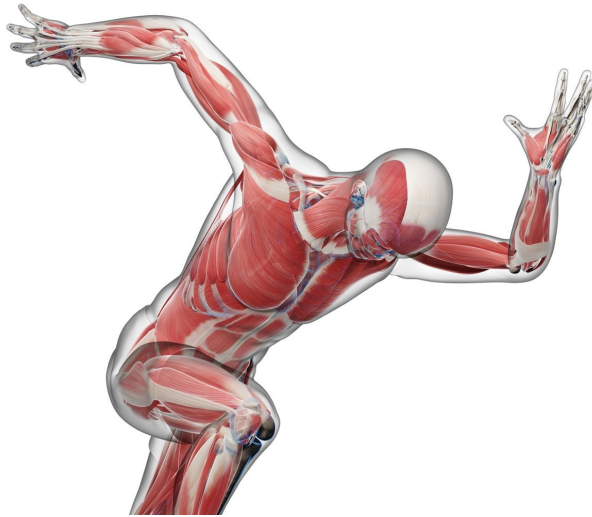
“When we consider the assessment of movement characteristics of the performance of a skill, it is necessary to consider coordination as referring to the relationship among the head, body, and/or limbs at a specific point in time during the skill performance.”

(Magill and Anderson, 2017)



# Motor coordination

## *(Biomechanics - motor control & learning)*



## Clarifying the Biomechanical Concept of Coordination Through Comparison With Coordination in Motor Control

Arata Kimura\*, Toshiharu Yokozawa and Hiroki Ozaki



# Motor coordination

(*Biomechanics - motor control & learning*)

1

**Functional** relationships between elements for the **achievement of a motor task**

Muscle coordination as the distribution of muscle activation or force among individual muscles **to produce a given motor task**

(Zatsiorsky & Prilutsky, 2012)

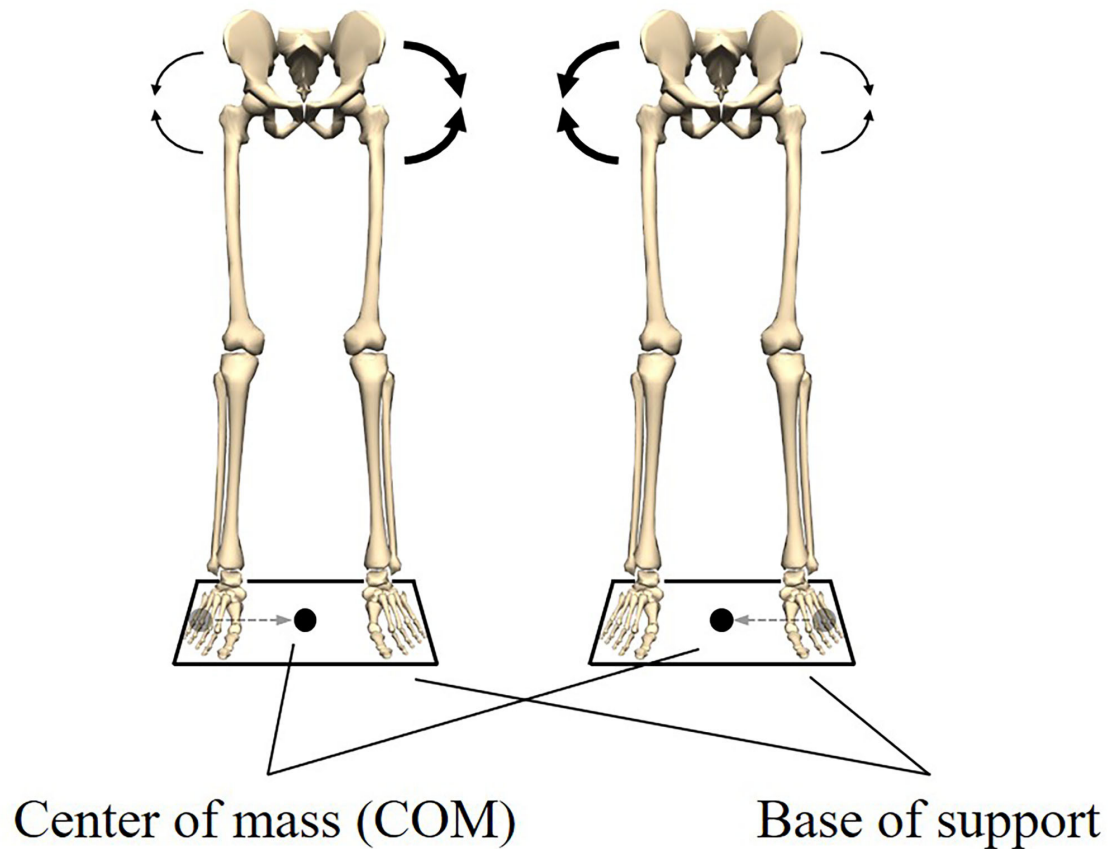
Coordination = Synergy

(Zajac, 2022; Winter, 2009)



# Motor coordination

(*Biomechanics* - motor control & learning)



# Motor coordination

## (*Biomechanics - motor control & learning*)

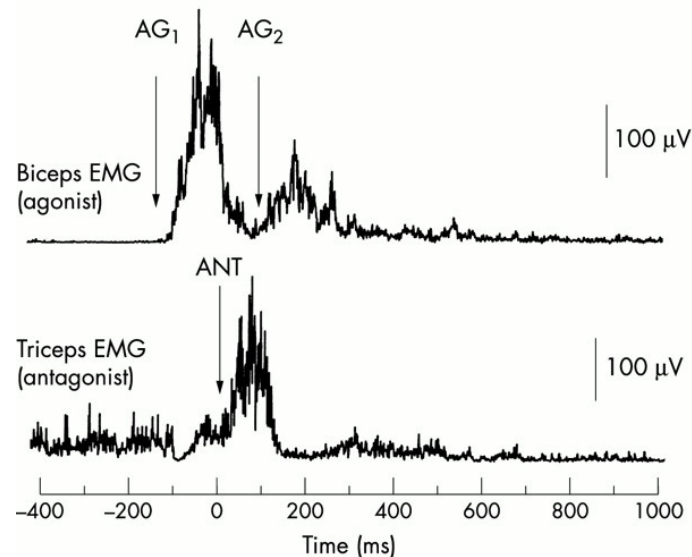
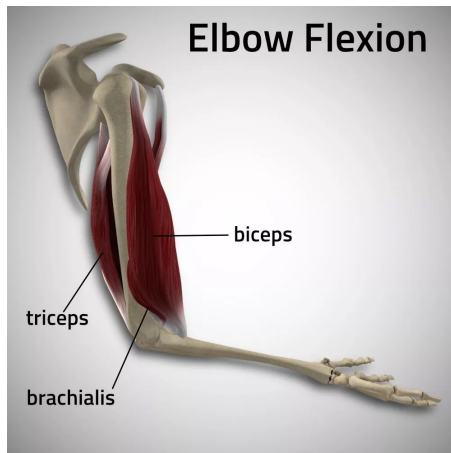
### 2

Coordination as the coupling of muscle activation pattern.

(Larivière & Arsenault, 2008; Donath et al., 2015)

Does not explicitly include acting toward a specific goal

Inter- and extra-  
muscular coordination



# Motor coordination

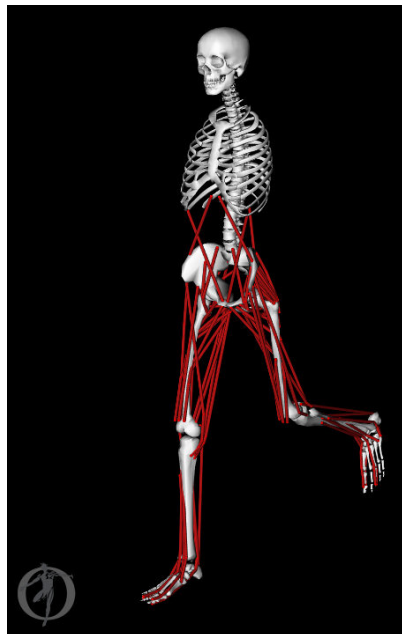
(*Biomechanics - motor control & learning*)

2

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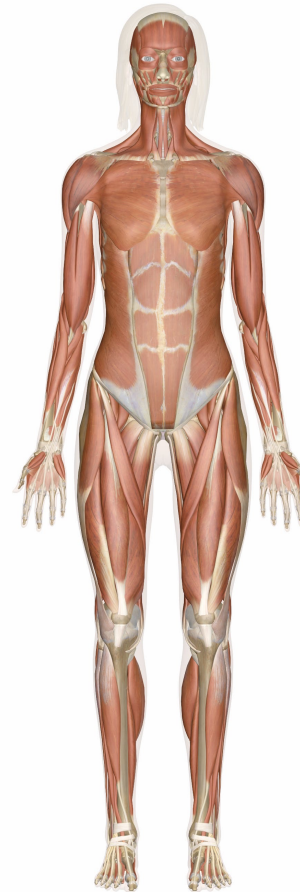


# Motor coordination

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206-213 bones



~ 650 muscles



# Motor coordination

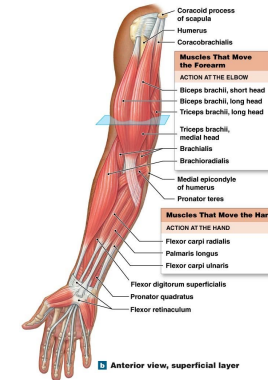
## (*Biomechanics - motor control & learning*)



~ 30 bones

8 joints  
(> 20 w/ hand)

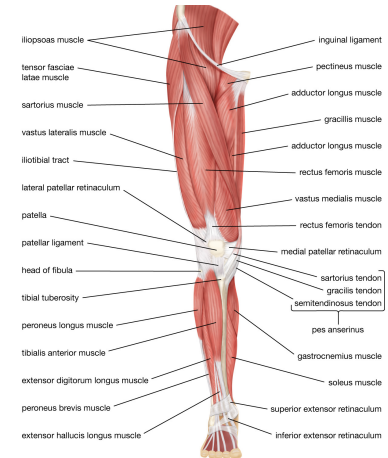
27 muscles  
(> 50 w/ hand + scapulae)



~ 30 bones

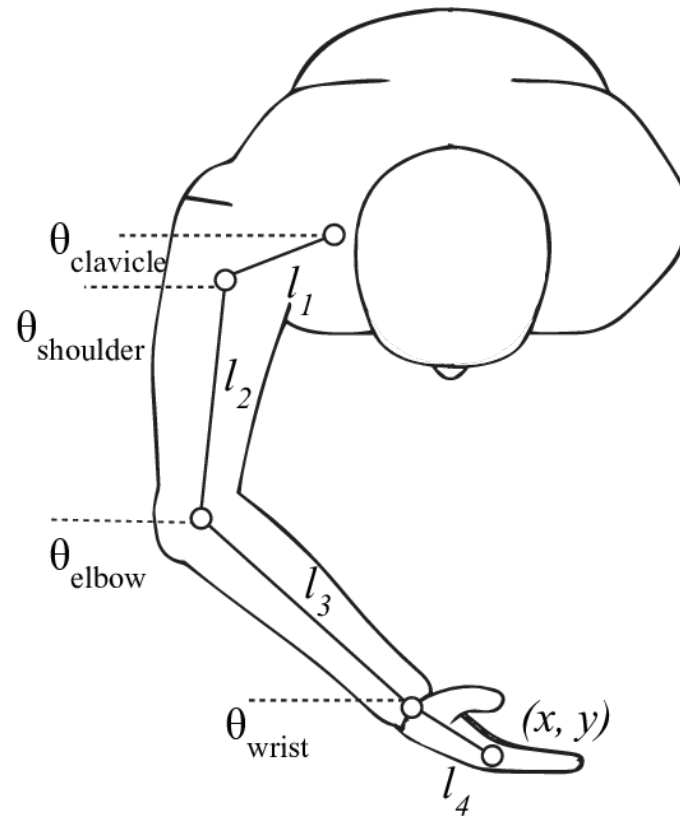
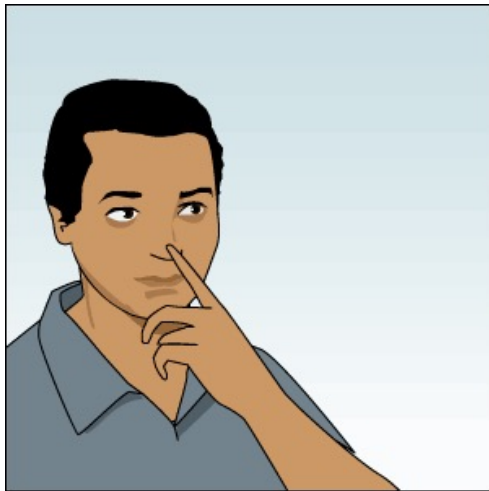
6 joints  
(> 20 w/ foot)

28 muscles  
(> 50 w/ foot + hip)



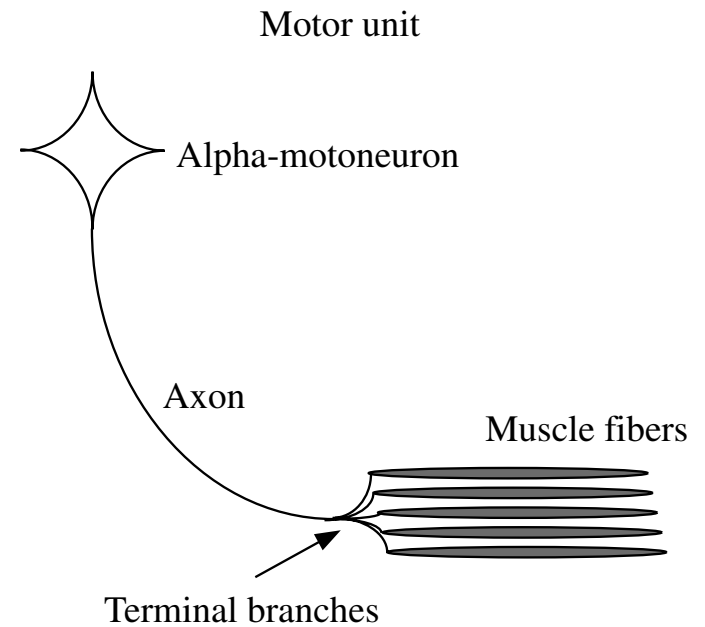
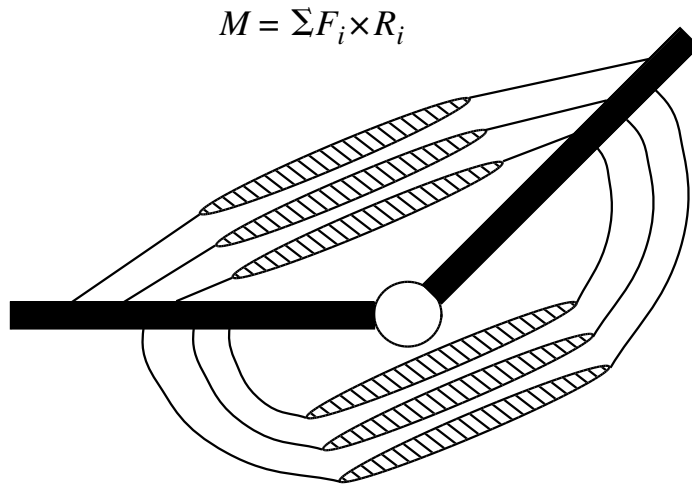
# Motor coordination

(*Biomechanics - motor control & learning*)



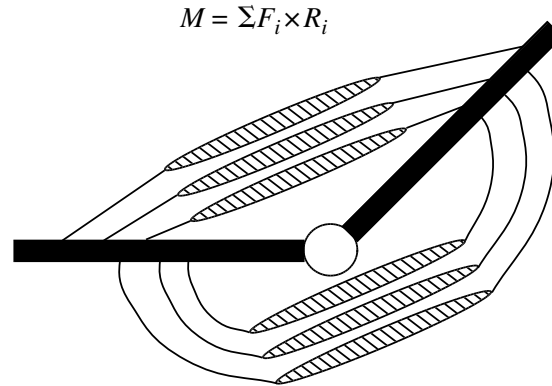
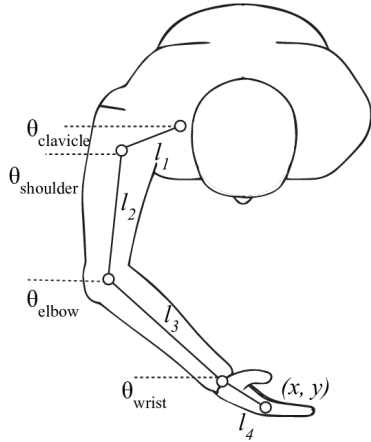
# Motor coordination

(*Biomechanics - motor control & learning*)



# Motor coordination

(*Biomechanics - motor control & learning*)



Nikolai A. Bernstein (1947)

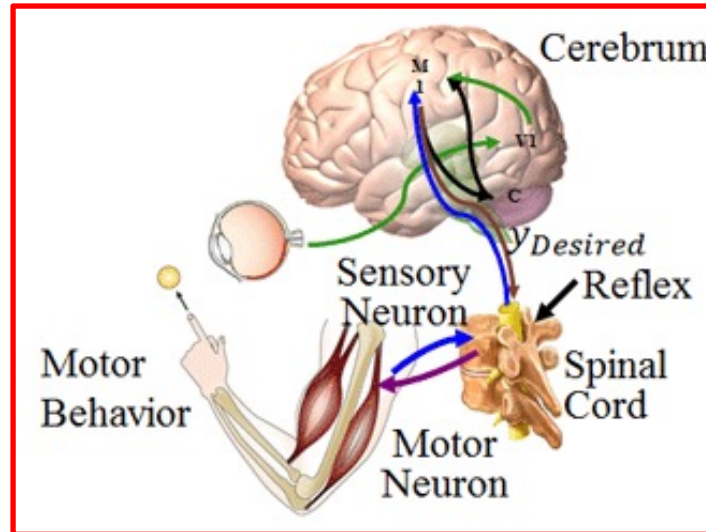
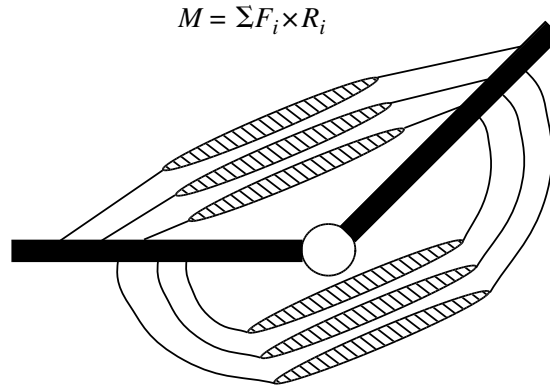
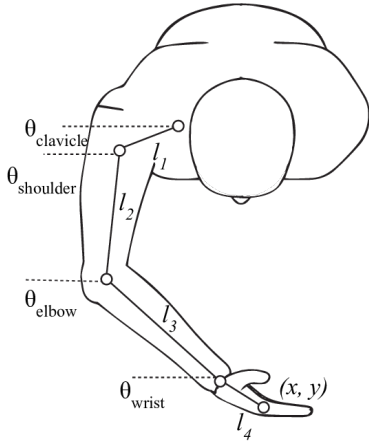
## Problem of the redundancy of the degrees of freedoms

The human body has a greater number of degrees of freedom than necessary to successfully perform motor tasks



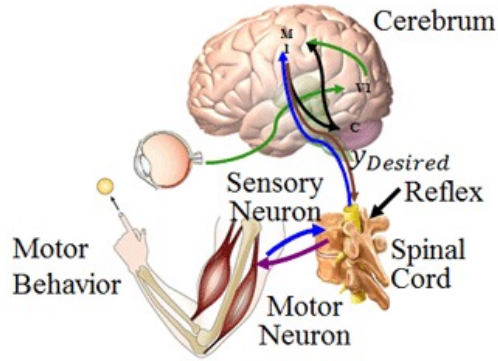
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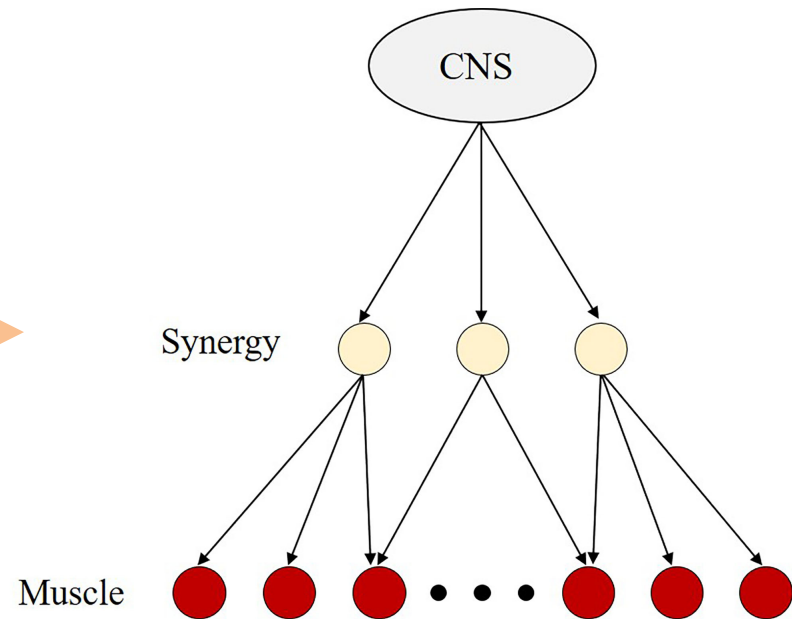
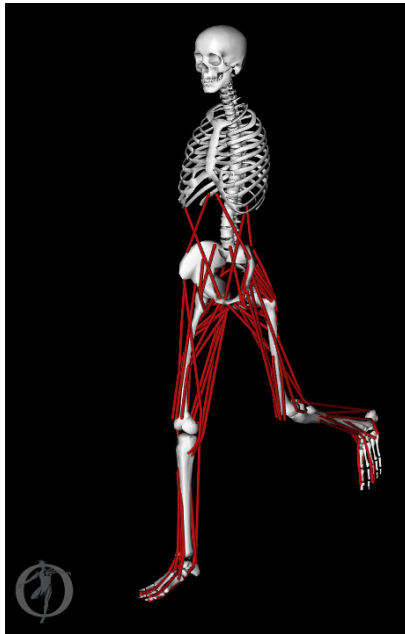
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# Motor coordination

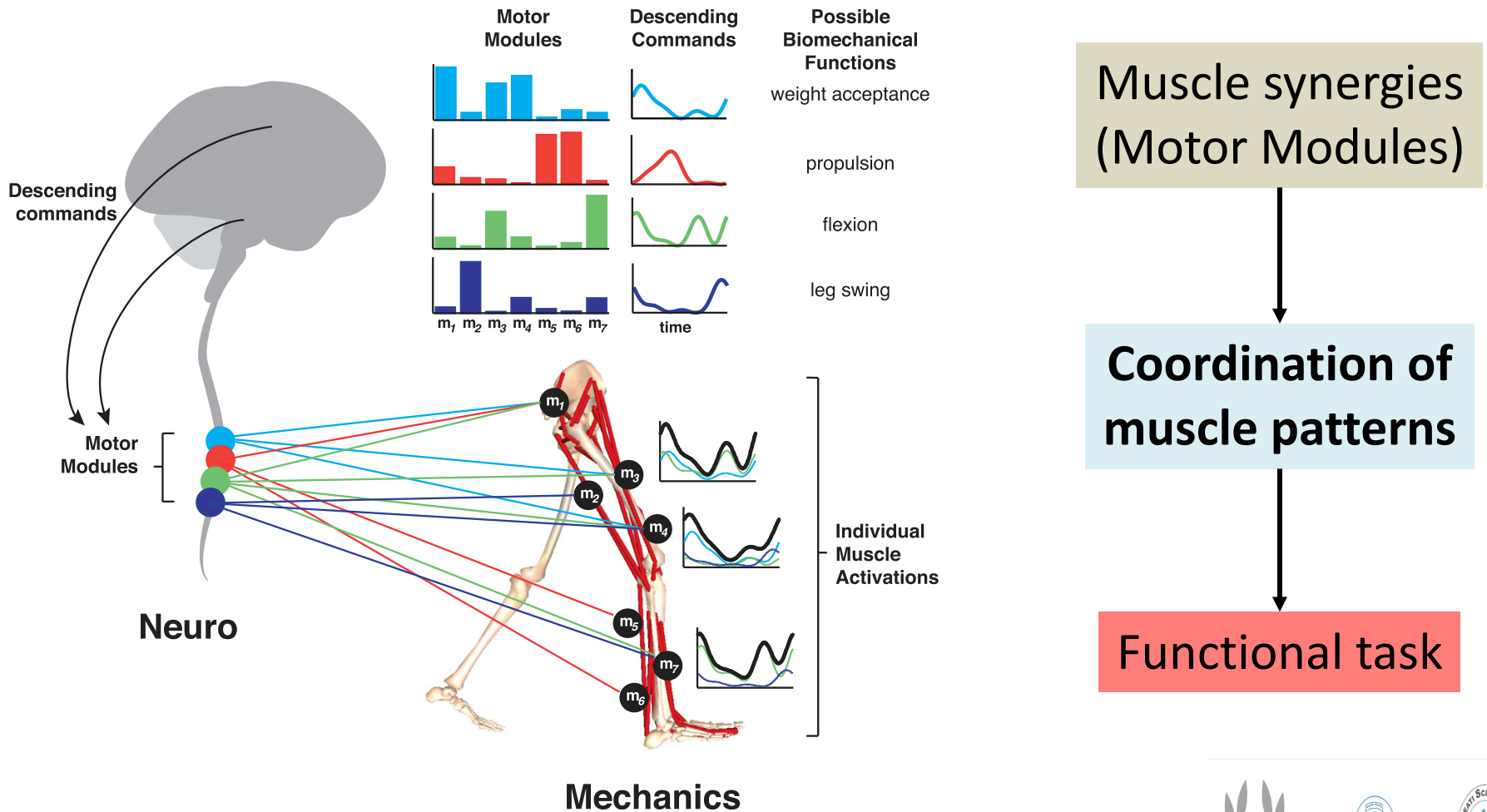
(*Biomechanics - motor control & learning*)



(Tresch et al., 1999, 2006; d'Avella et al., 2003, 2006; Hart and Giszter, 2004; Ivanenko et al., 2004; Ting and Macpherson, 2005; Tresch and Jarc, 2009; Cheung et al., 2012)

# Motor coordination

(*Biomechanics - motor control & learning*)

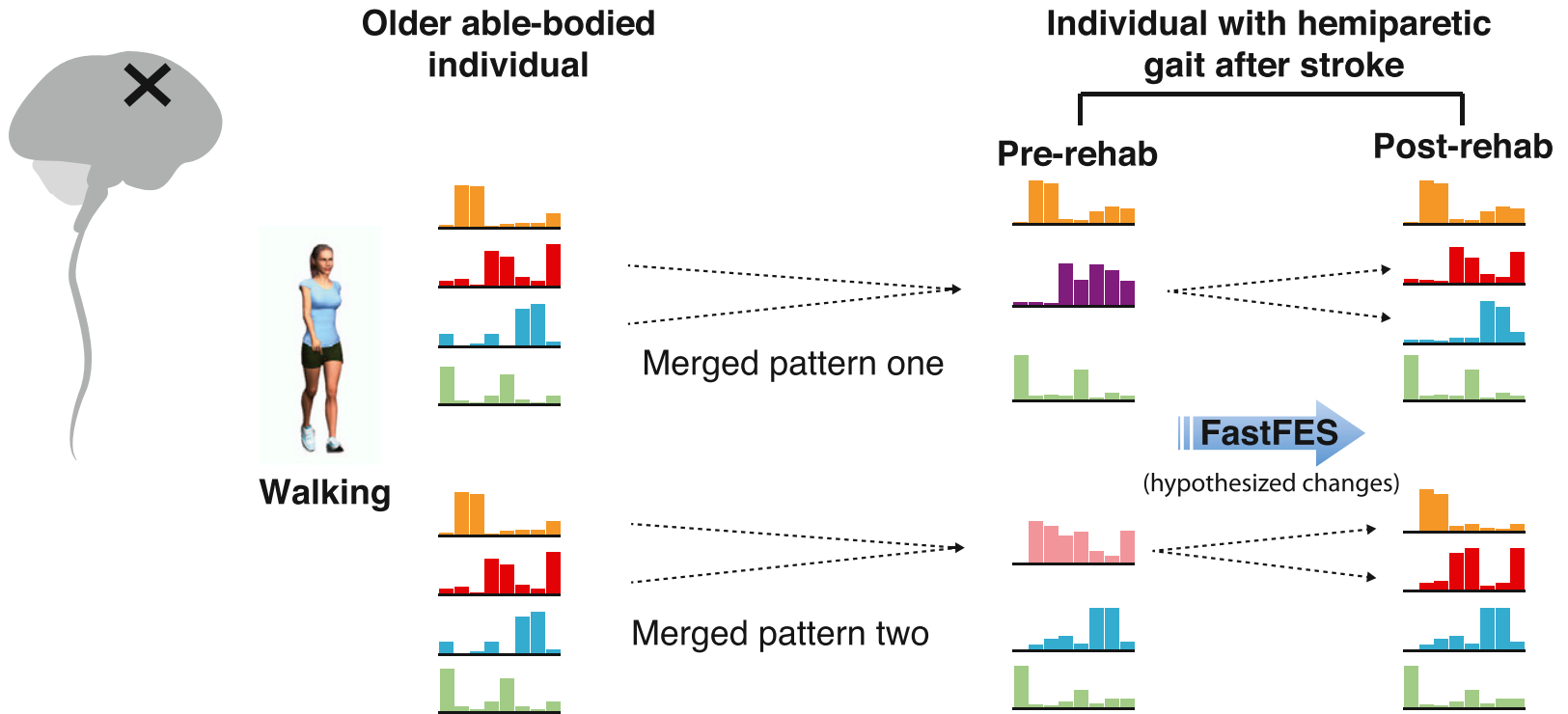


(Ting et al., 2015)

# Motor coordination

(*Biomechanics - motor control & learning*)

## B Cortical stroke



(Clack et al., 2010; Ting et al., 2015)

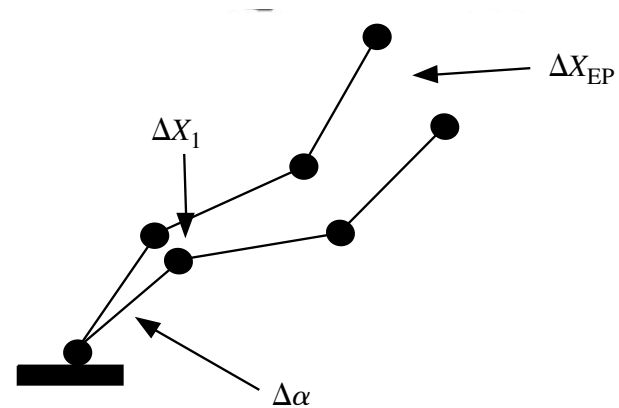
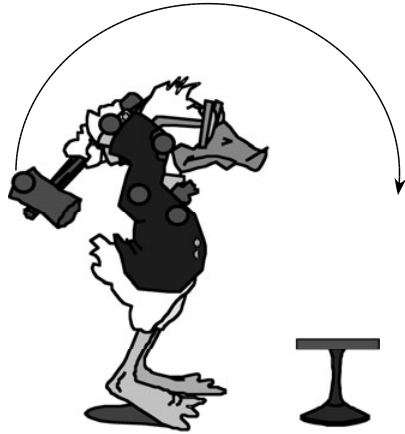


# Motor coordination (*Biomechanics - motor control & learning*)



# Motor coordination

(*Biomechanics - motor control & learning*)



## Motor Synergy (Coordination)

“Neural organization that ensures co-variation among elemental variables (along time or across repetitive attempts at a task) that stabilizes the value or time profile of the performance variable.”

(Latash, 2010)



# Motor coordination

(*Biomechanics - motor control & learning*)

Index left

Index right

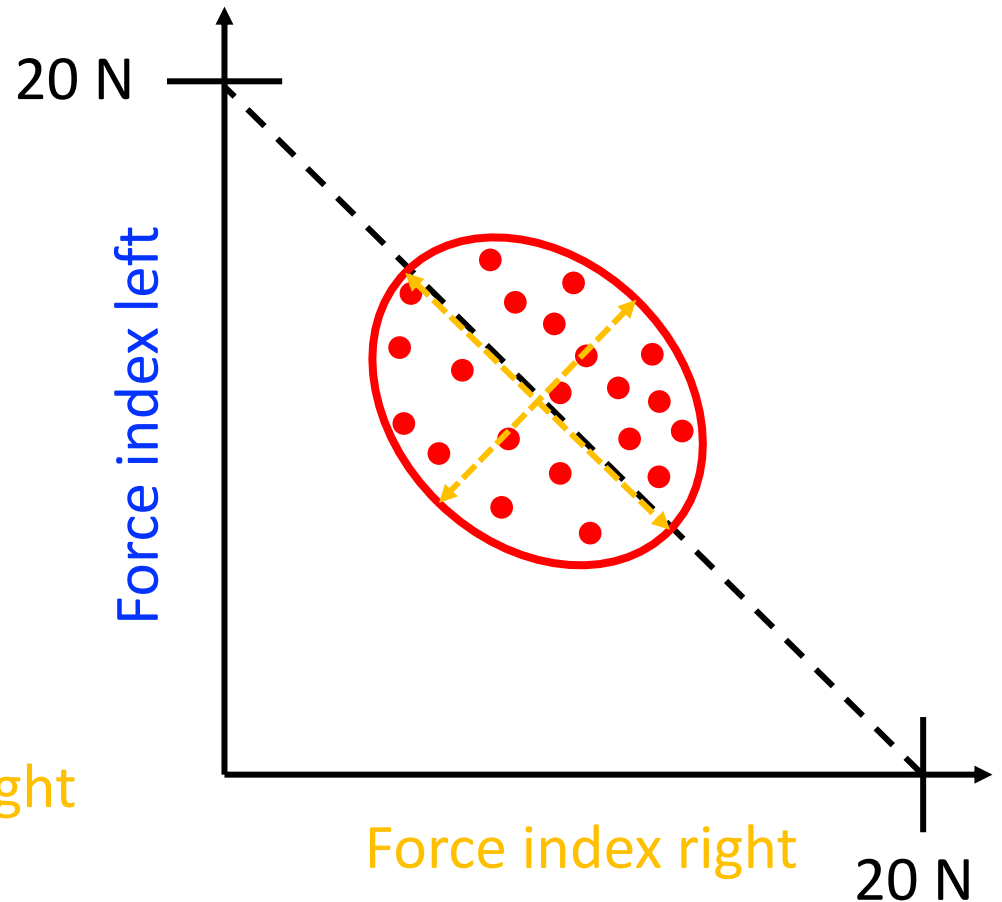


**Task**

Force index left + Force index right

=

20 N



(Scholz & Schoner 1999; Latash et al., 2007)

# Motor coordination

(*Biomechanics - motor control & learning*)

Index left

Index right

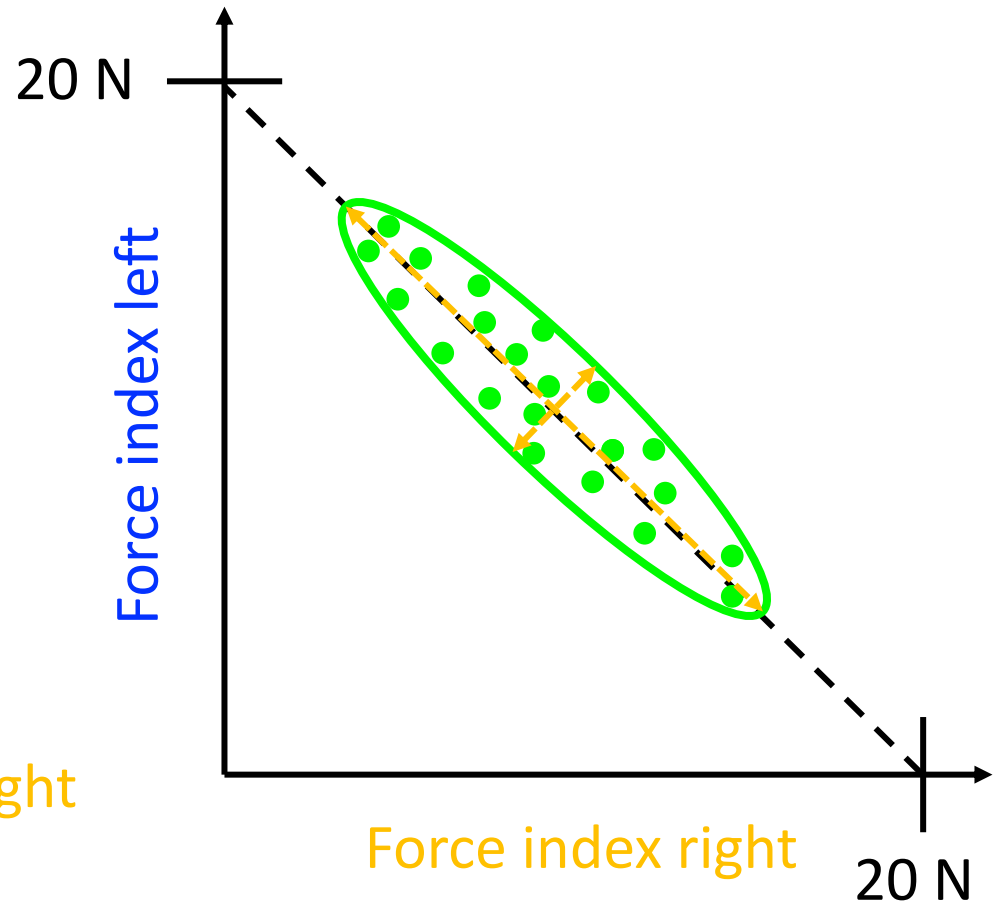


**Task**

Force index left + Force index right

=

20 N



(Scholz & Schoner 1999; Latash et al., 2007)



# Motor coordination

(*Biomechanics - motor control & learning*)

Index left

Index right

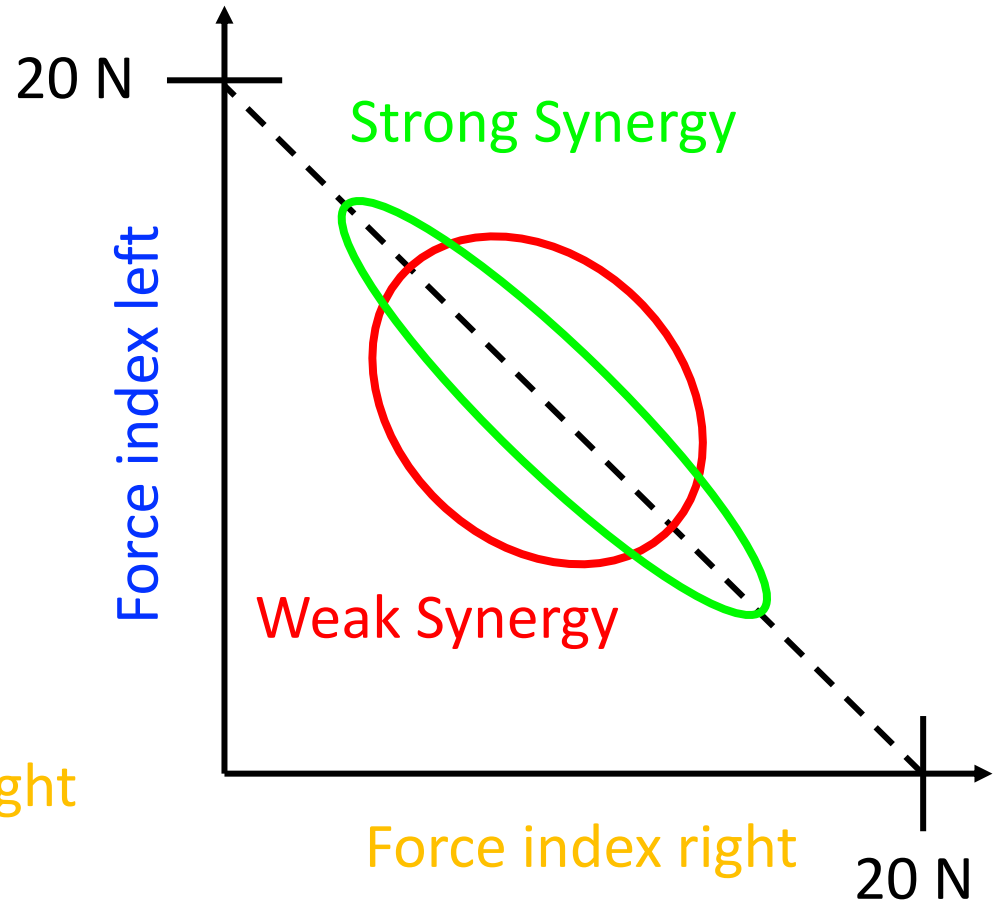


**Task**

Force index left + Force index right

=

20 N



(Scholz & Schoner 1999; Latash et al., 2007)

# Motor coordination (*Biomechanics - motor control & learning*)

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“Neural organization that ensures co-variation among elemental variables (along time or across repetitive attempts at a task) that stabilizes the value or time profile of the performance variable.”

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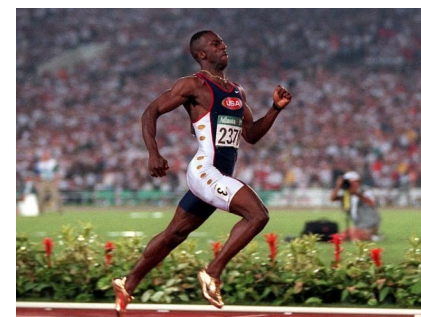
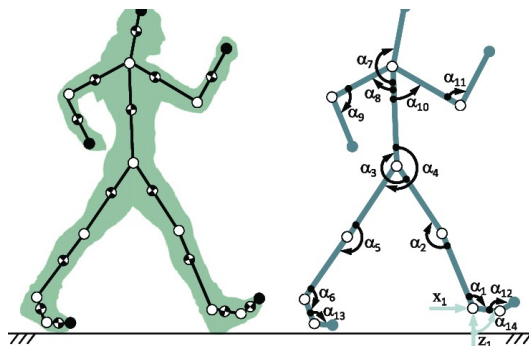
## Motor Synergy (Coordination)

“Neural organization that ensures co-variation among elemental variables (along time or across repetitive attempts at a task) that stabilizes the value or time profile of the performance variable.”

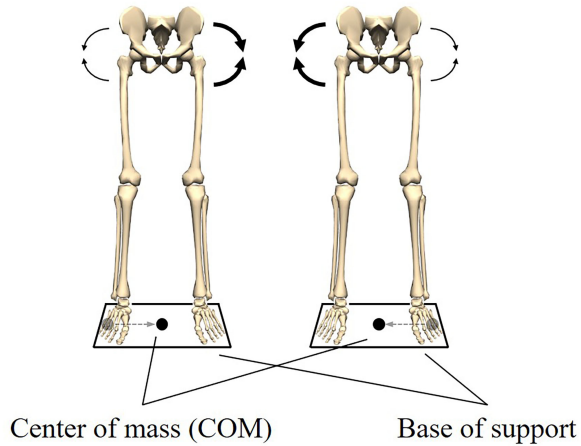
(Latash, 2010)

Optimal biomechanical model ?

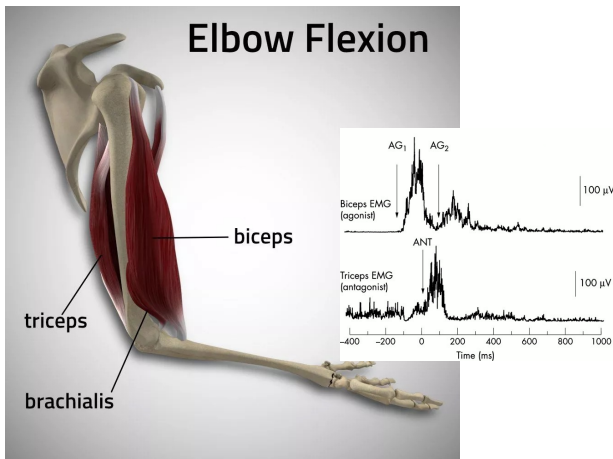
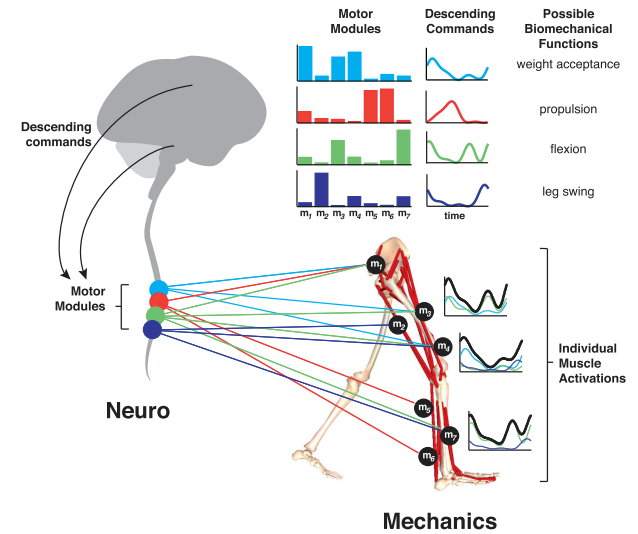
Optimal biomechanical models



# Motor coordination



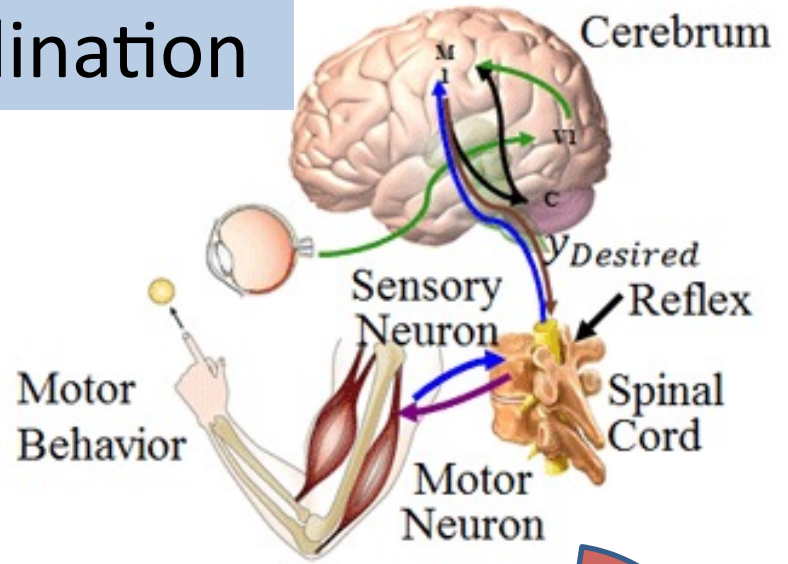
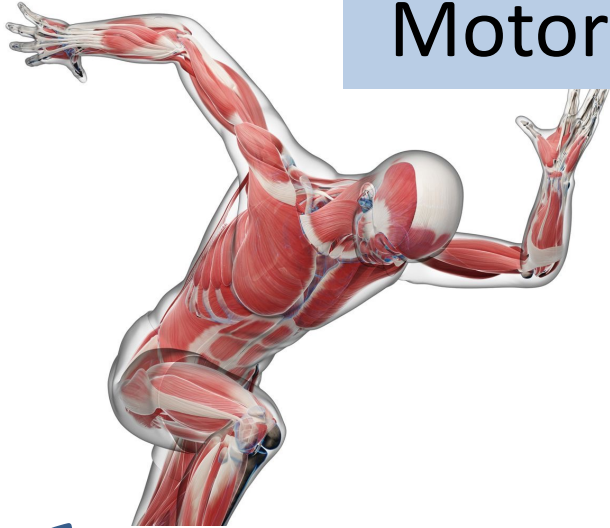
$$y = f(x)$$



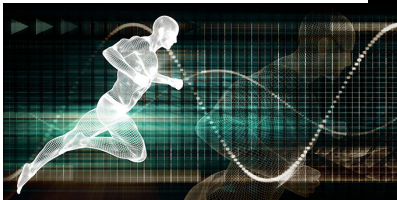
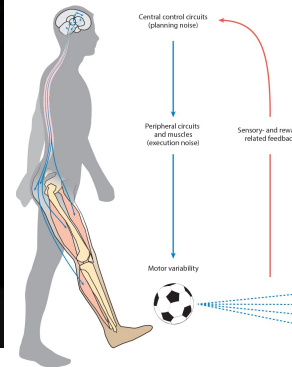
# Motor coordination



# Motor coordination



# Motor learning



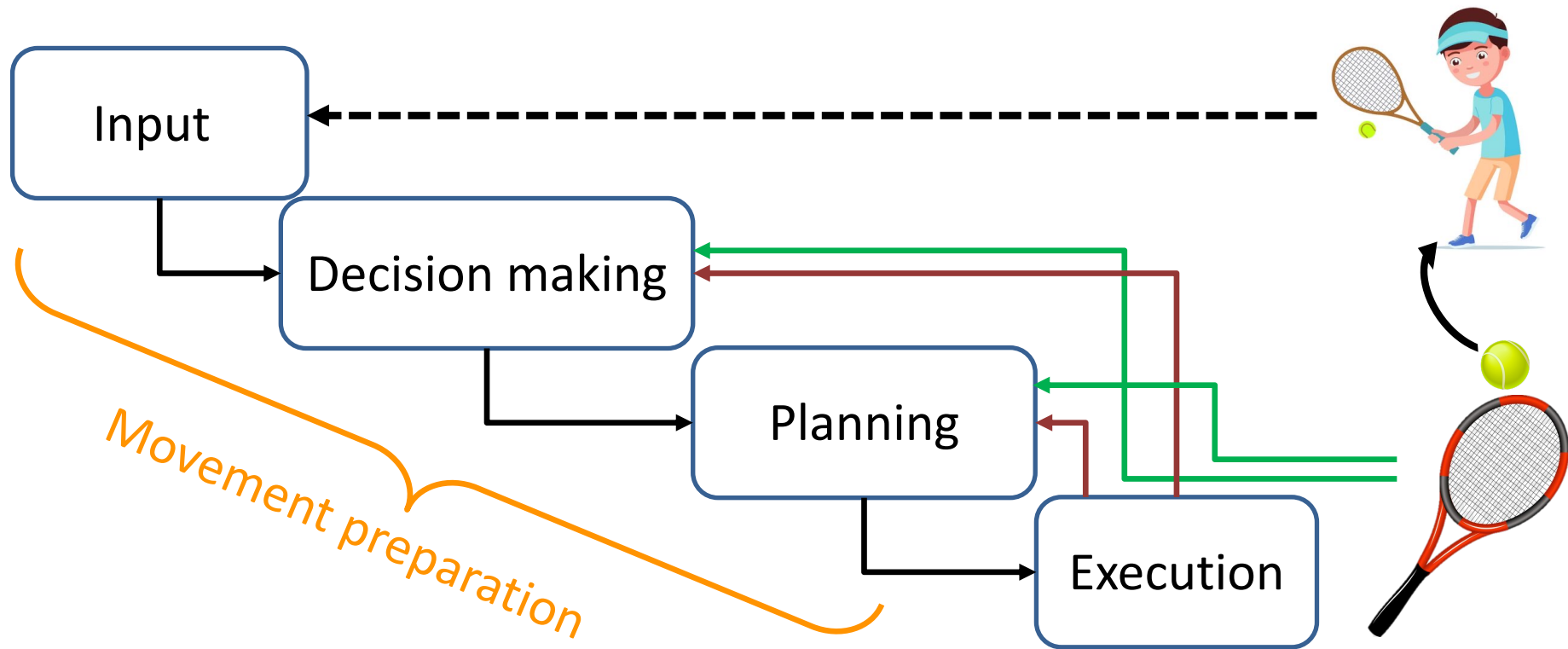
# Motor learning: Definition



It is a set of processes associated with practice or experience leading to relatively permanent changes in the capability of movement.

(Schmidt & Lee, 2005)

# Motor learning: Definition



(Wolpert et al., 2011; Krakauer et al., 2019)

# Motor learning: Definition

## Skill acquisition

- The processes by which an individual acquires the ability to rapidly identify an appropriate movement goal given a particular task context ...
- Select the correct action given a sensory stimulus and/or the current state of the body and the world ...
- And execute that action with accuracy and precision

## Skill maintenance

The ability to maintain performance levels of existing skills under changing conditions.

(Krakauer et al., 2019)



# Motor learning: Characteristics

**Improvement:** performance of a skill shows improvement over a period of time.

**Consistency:** performance becomes increasingly more consistent.

**Persistence:** the improved performance capability is marked by an increasing amount of persistence.



# Motor learning: Characteristics

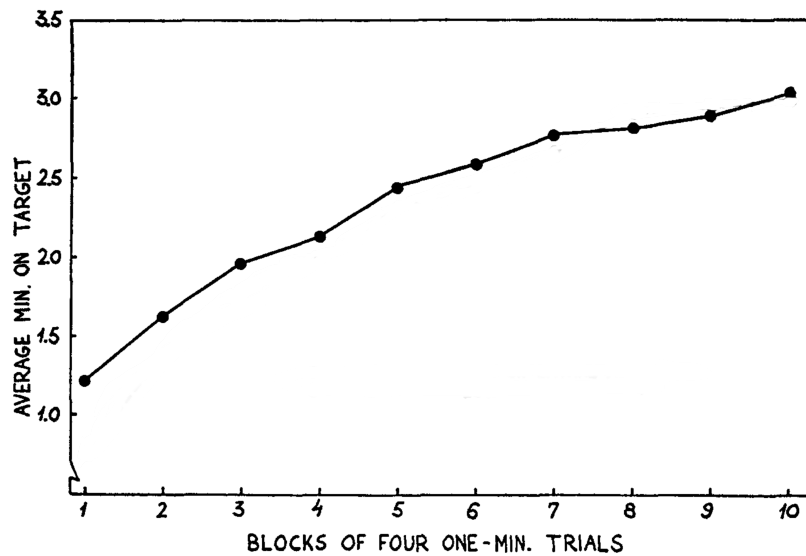
**Stability:** a person increases the capability to perform the skill despite the perturbations that exist.

**Adaptability:** the improved performance is adaptable to a variety of performance context characteristics.

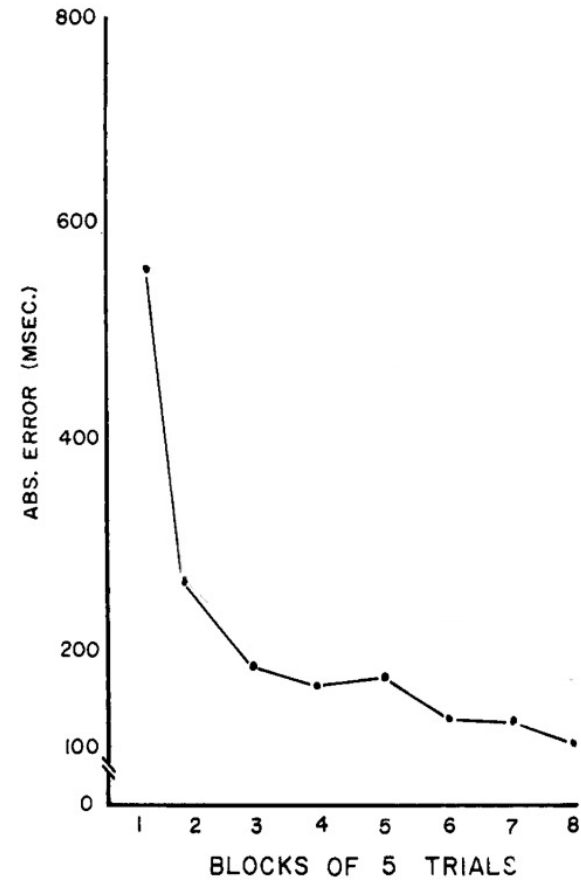
**Reduction of attention demand:** as a person learns a skill there is a reduction in the amount of attention demanded to perform the skill



# Learning curve

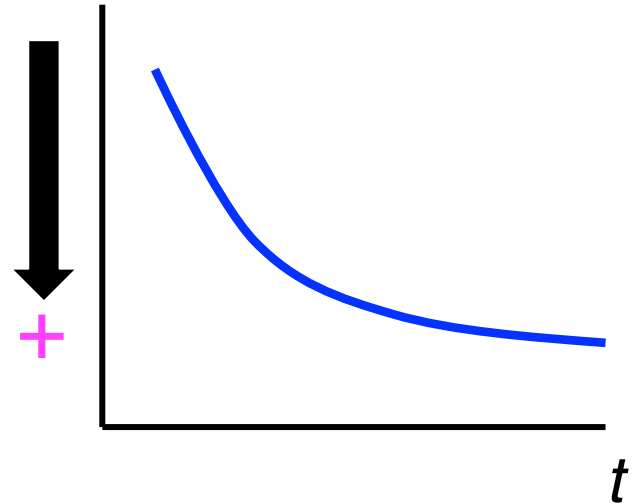
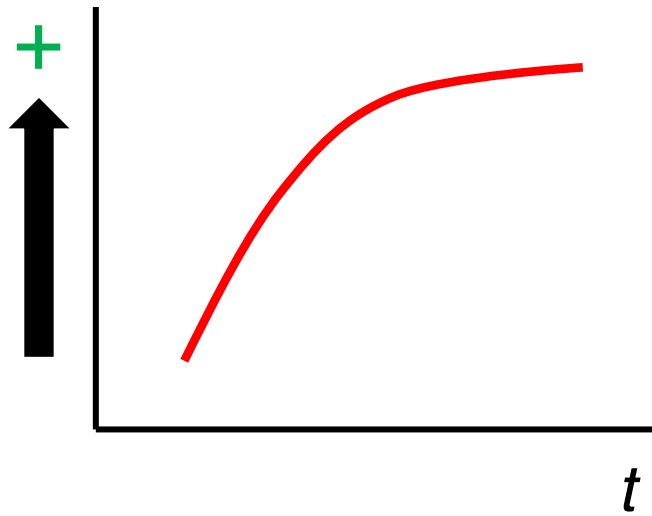


(Fleishman & Rich, 1963)



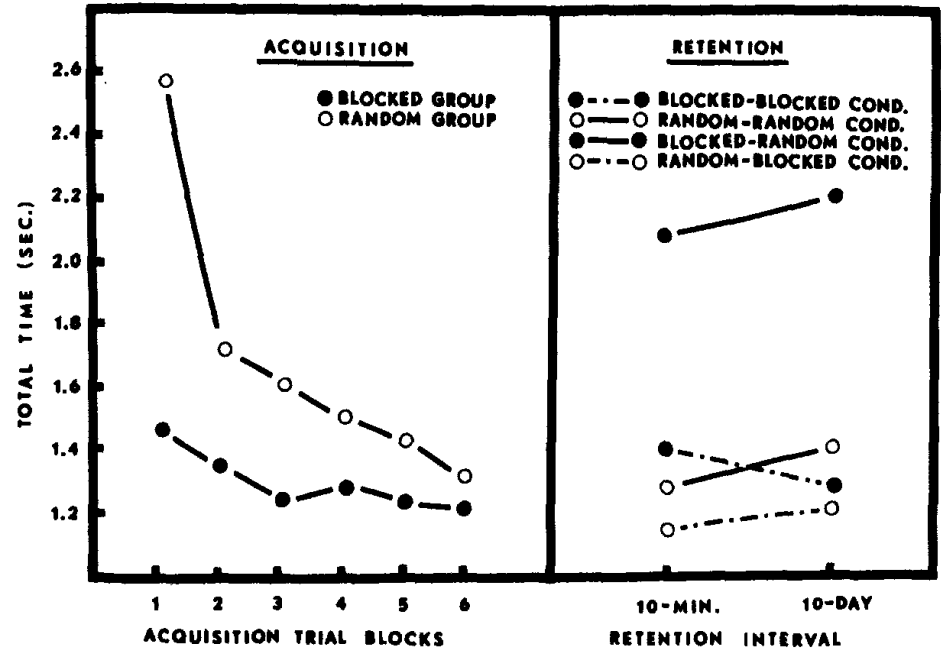
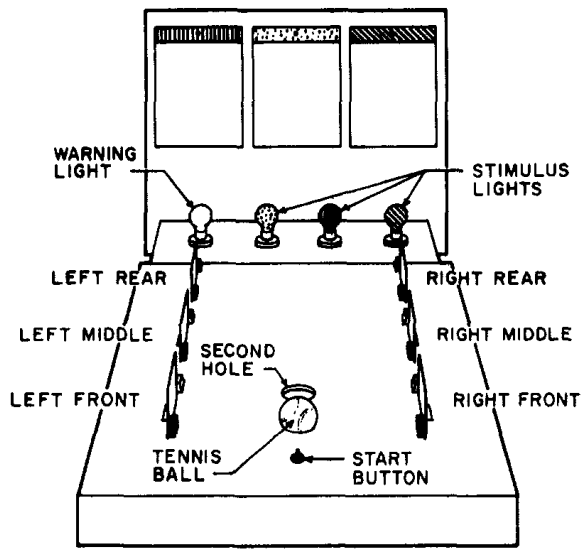
(Quesada & Schmidt, 1970)

# Learning curve



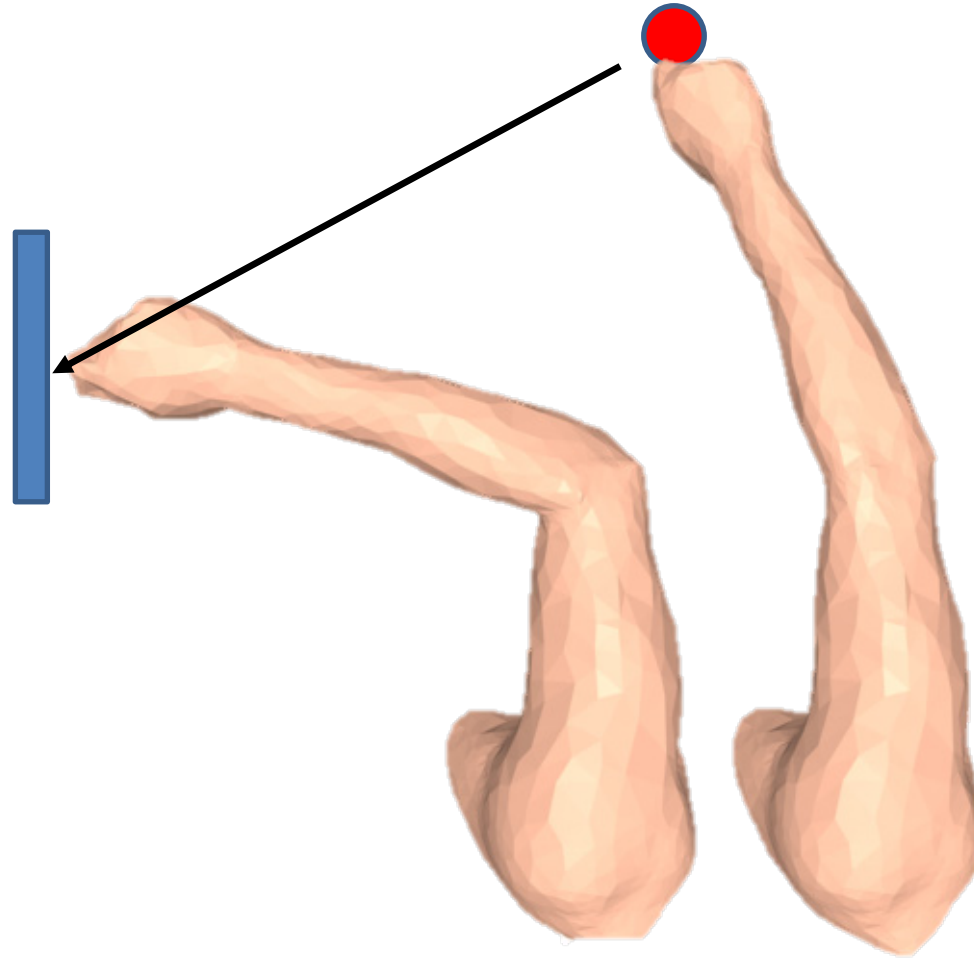
# Motor learning: Classic paradigms

(a) right rear, left middle, and right front; (b) right front, left middle, and right rear; (c) left front, right middle, and left rear. Each of the



(Shea & Morgan, 1979)

# Motor learning: Classic paradigms



(McCracken & Stelmach, 1977)



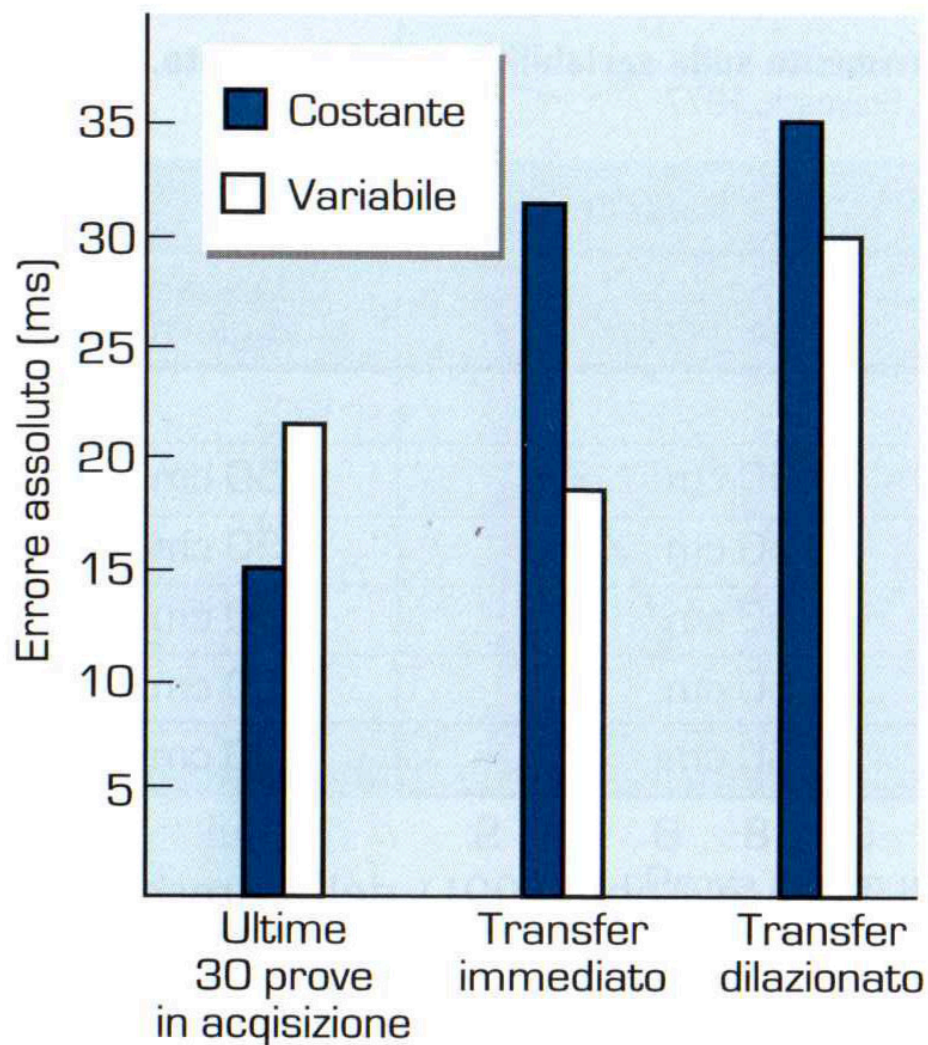
# Motor learning: Classic paradigms

	Allenamento originale	Fase del test di transfer	
	300 prove Primo giorno	Immediato Primo giorno	Dilazionato 2 giorni
Costante			
Sottogruppo a	solo 15 cm	50 cm	50 cm
Sottogruppo b	solo 35 cm	50 cm	50 cm
Sottogruppo c	solo 60 cm	50 cm	50 cm
Sottogruppo d	solo 65 cm	50 cm	50 cm
Variabile	15, 35, 60, 65 cm	50 cm	50 cm

(McCracken & Stelmach, 1977)



# Motor learning: Classic paradigms



(McCracken & Stelmach, 1977)



# Motor learning: Classic paradigms

## Results of Baddeley and Longman Study of Postal Workers

Practice Schedule	Hours to Learn Keyboard	Hours to Type 80 Keystrokes/Min.
1 hr. session, 1 session/day, 12 weeks	34.9	55
1 hr. session, 2 sessions/day, 6 weeks	43	75
2 hr. session, 1 session/day, 6 weeks	43	67
2 hr. session, 2 sessions/day, 3 weeks	49.7	80+*

\* Achieved only 70 keystrokes/min. after 80 hours.

(Baddeley & Longman, 1978)

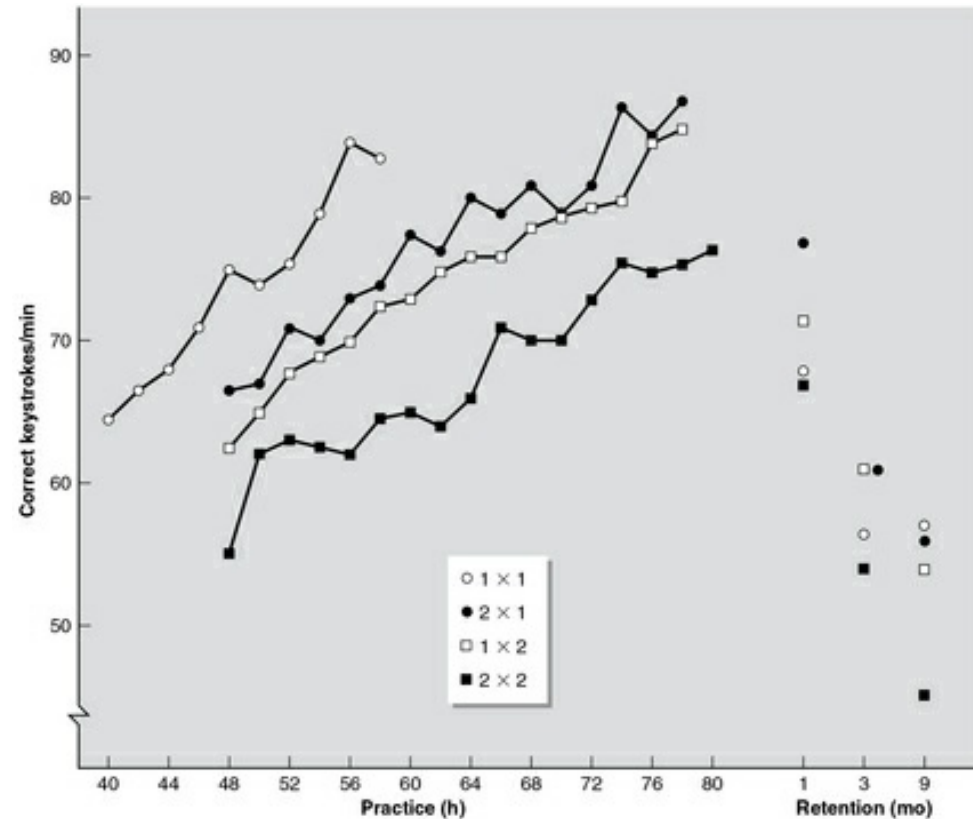


# Motor learning: Classic paradigms

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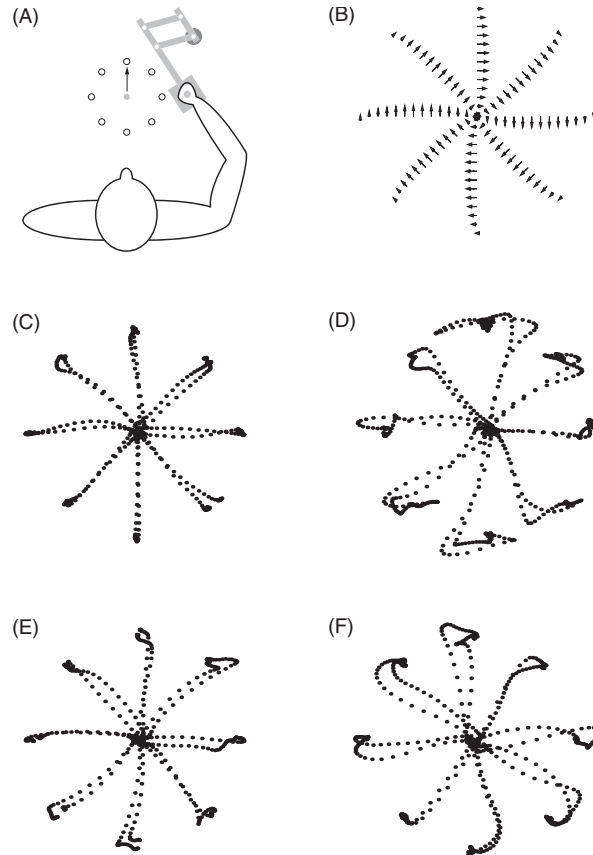
# Motor learning: Perturbation paradigms

The Journal of Neuroscience, May 1994, 14(5): 3208-3224

## Adaptive Representation of Dynamics during Learning of a Motor Task

Reza Shadmehr and Ferdinando A. Mussa-Ivaldi

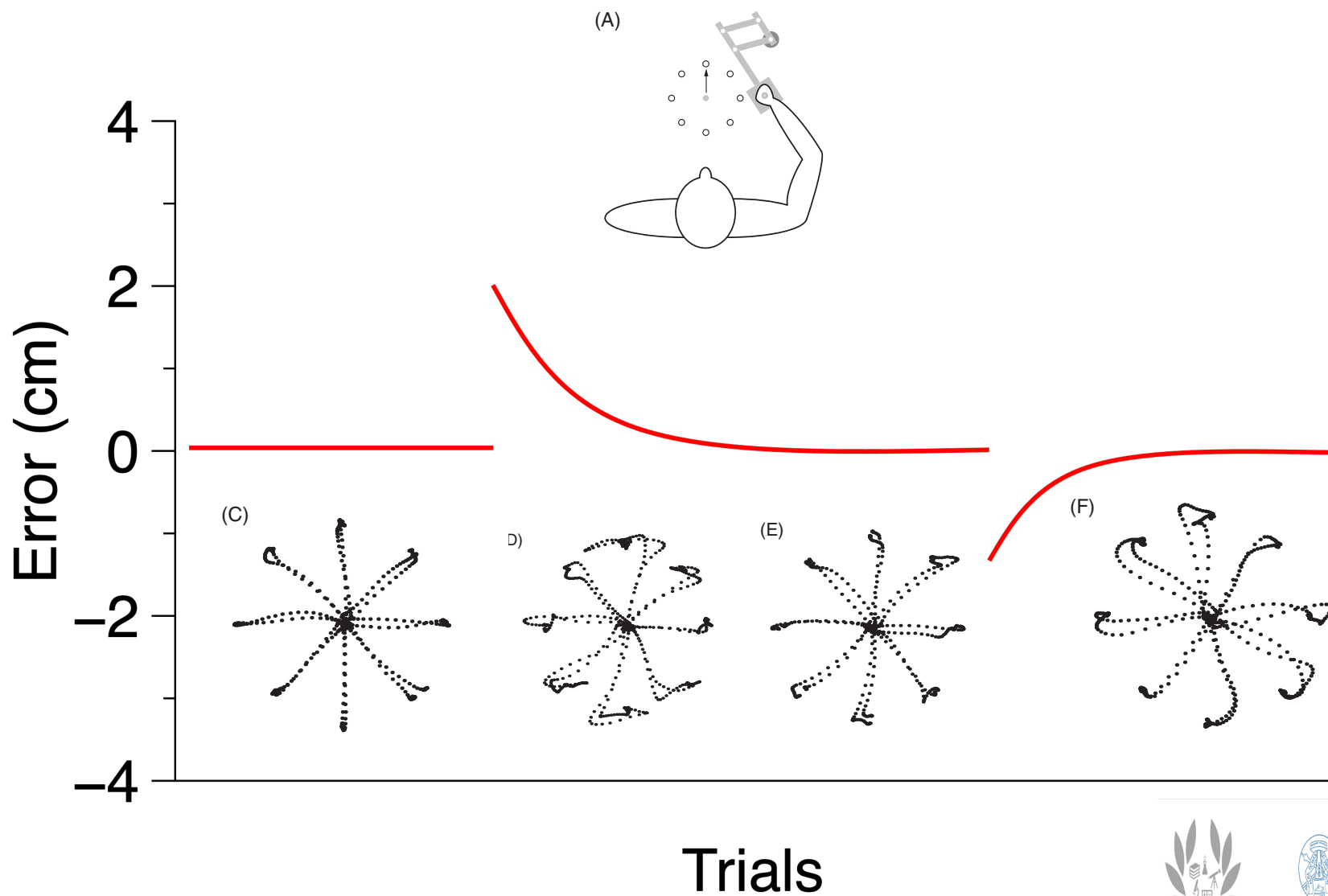
Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139



(Shadmehr & Mussa-Ivaldi, 1994)



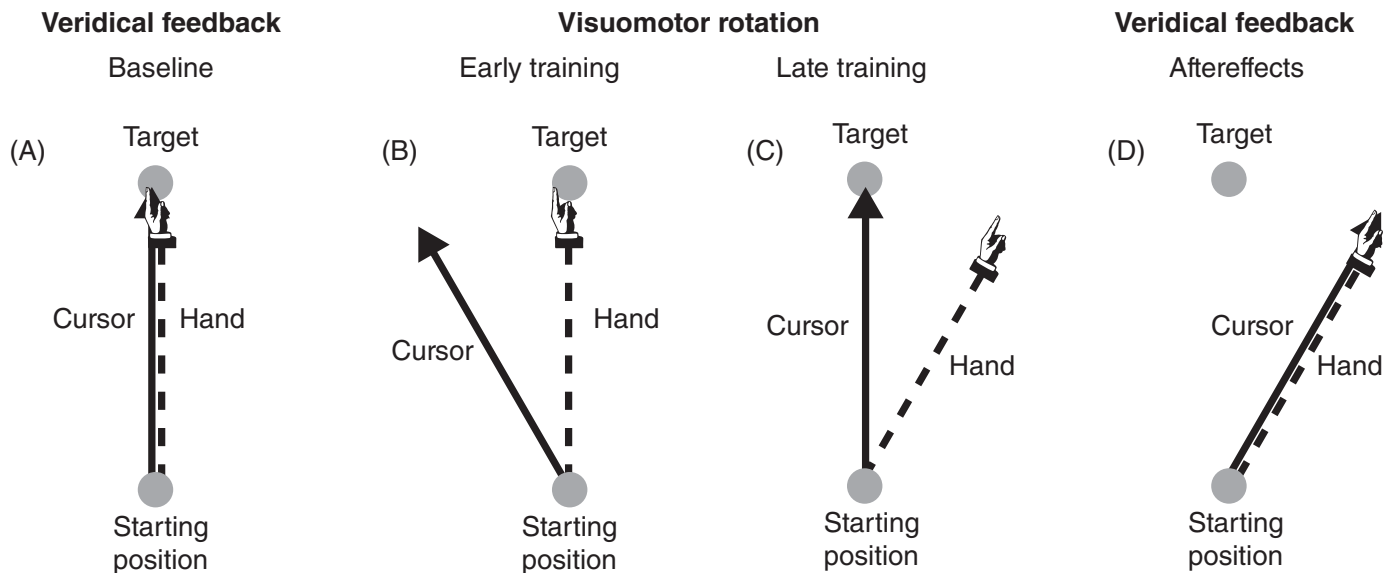
# Motor learning: Perturbation paradigms



(Shadmehr & Mussa-Ivaldi, 1994)



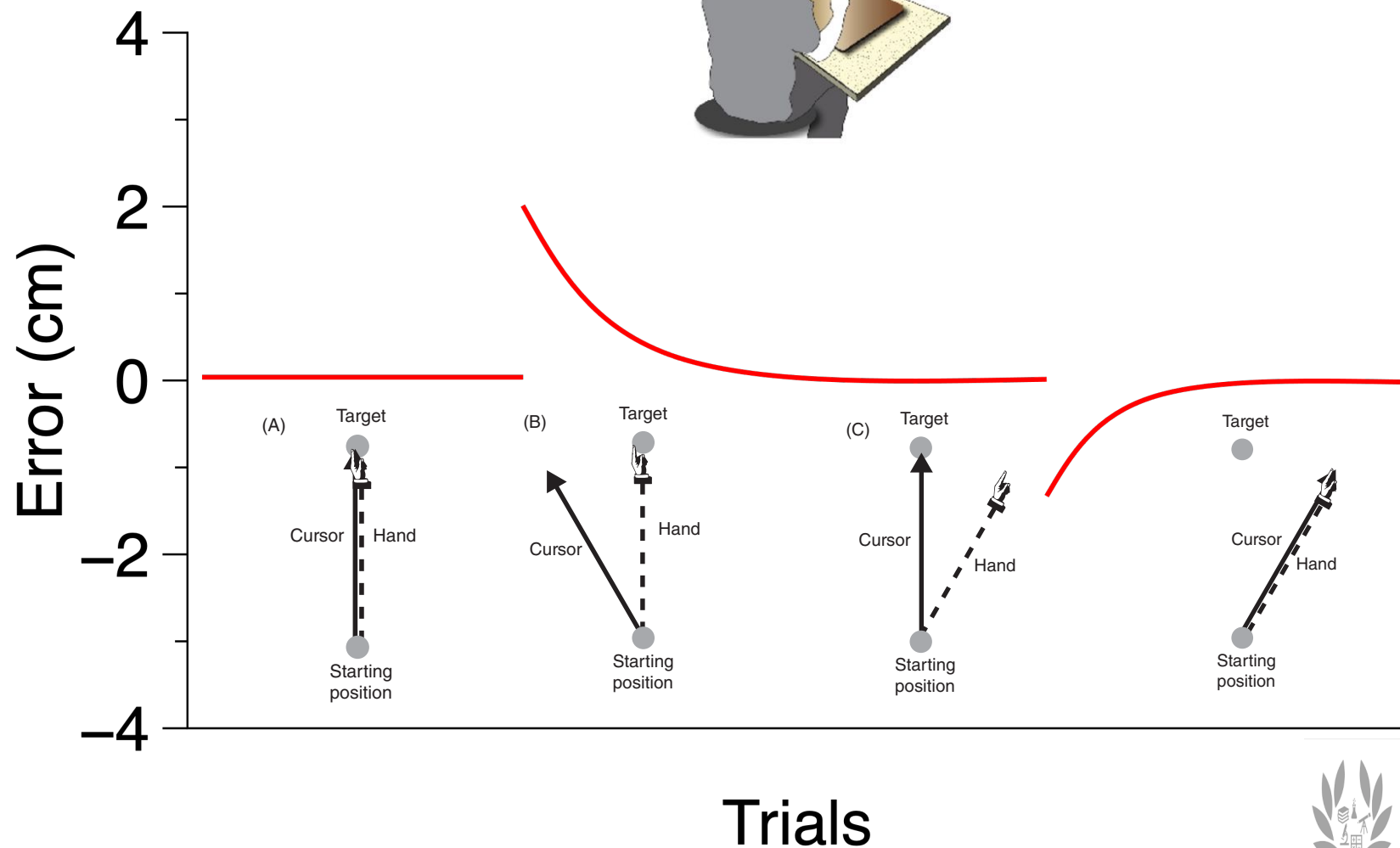
# Motor learning: Perturbation paradigms



(Krakauer et al., 2000)



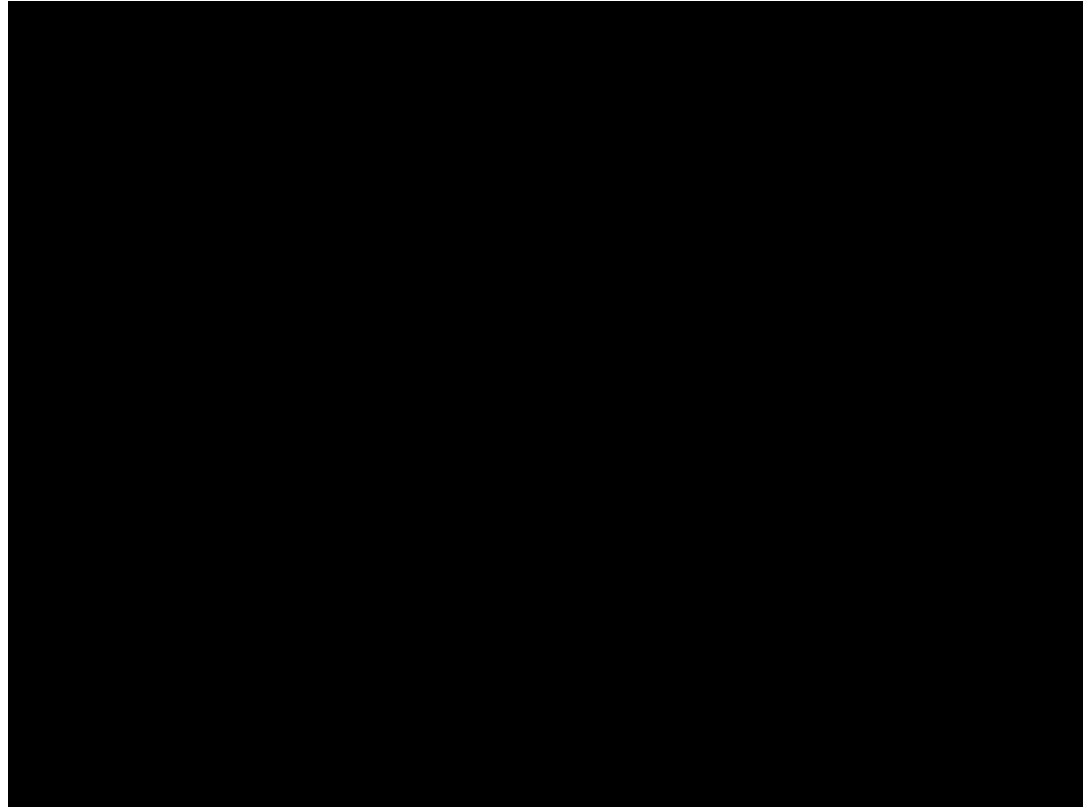
# Motor learning: Perturbation paradigms



(Krakauer et al., 2000)



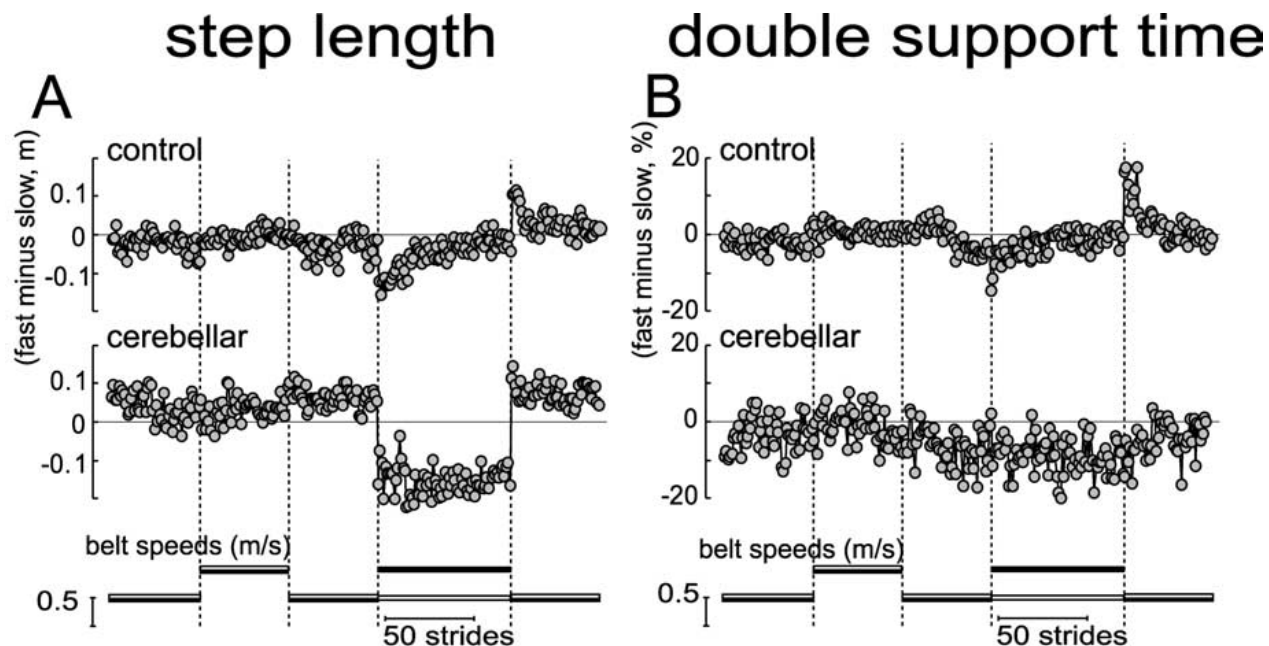
# Motor learning: Perturbation paradigms



(Morton & Bastian, 2006)



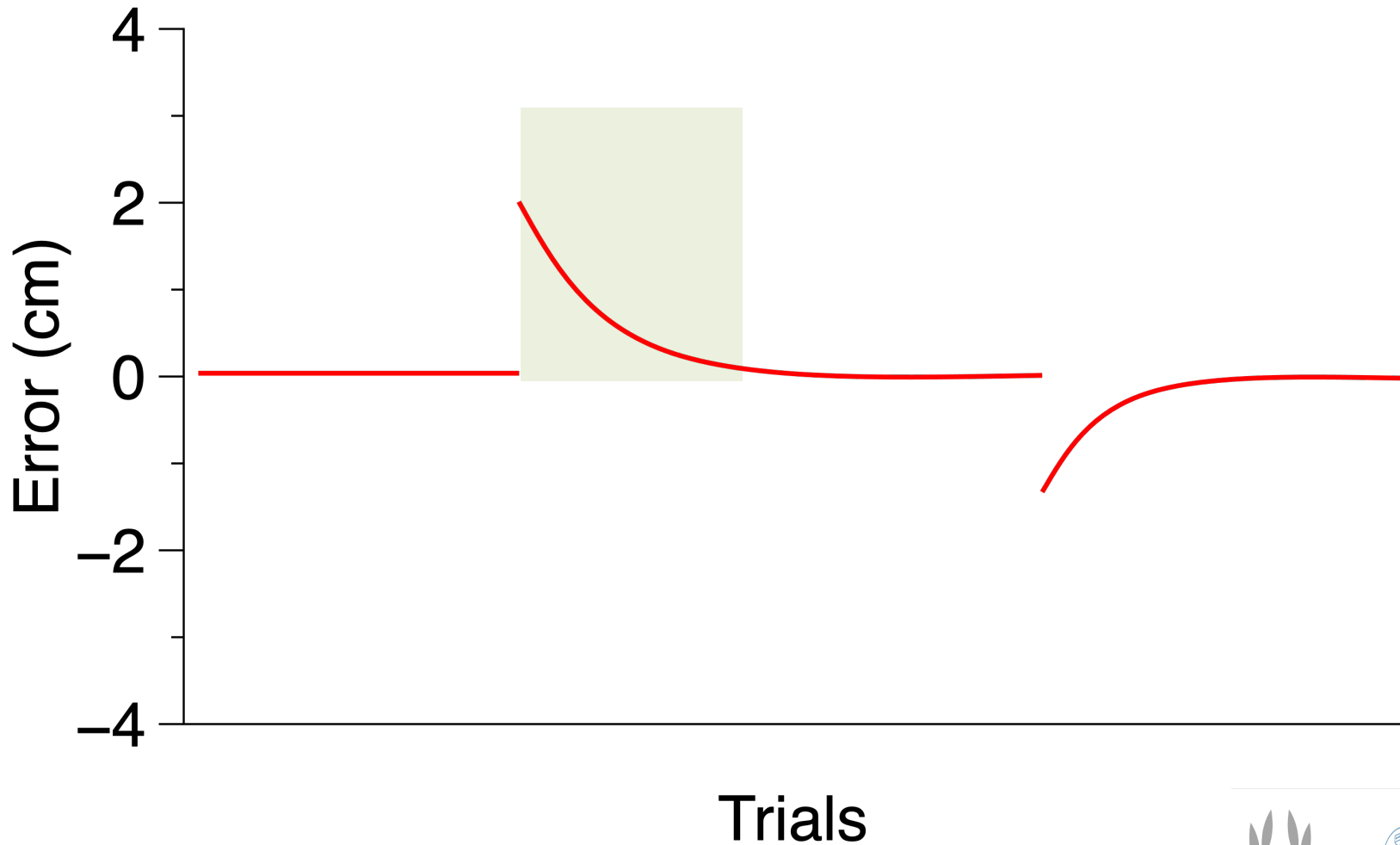
# Motor learning: Perturbation paradigms



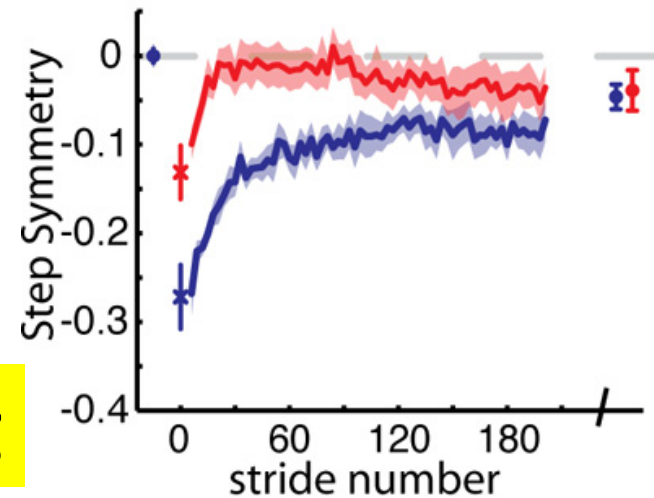
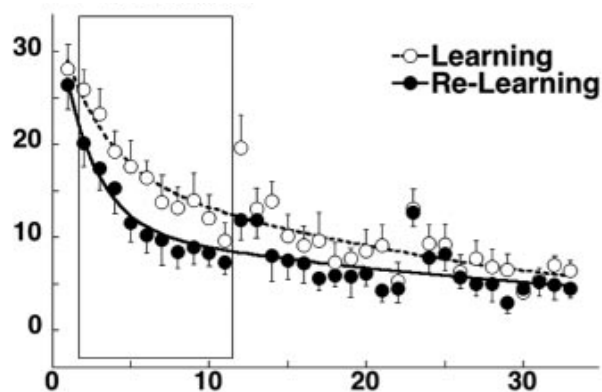
(Morton & Bastian, 2006)



# Motor learning: Perturbation paradigms



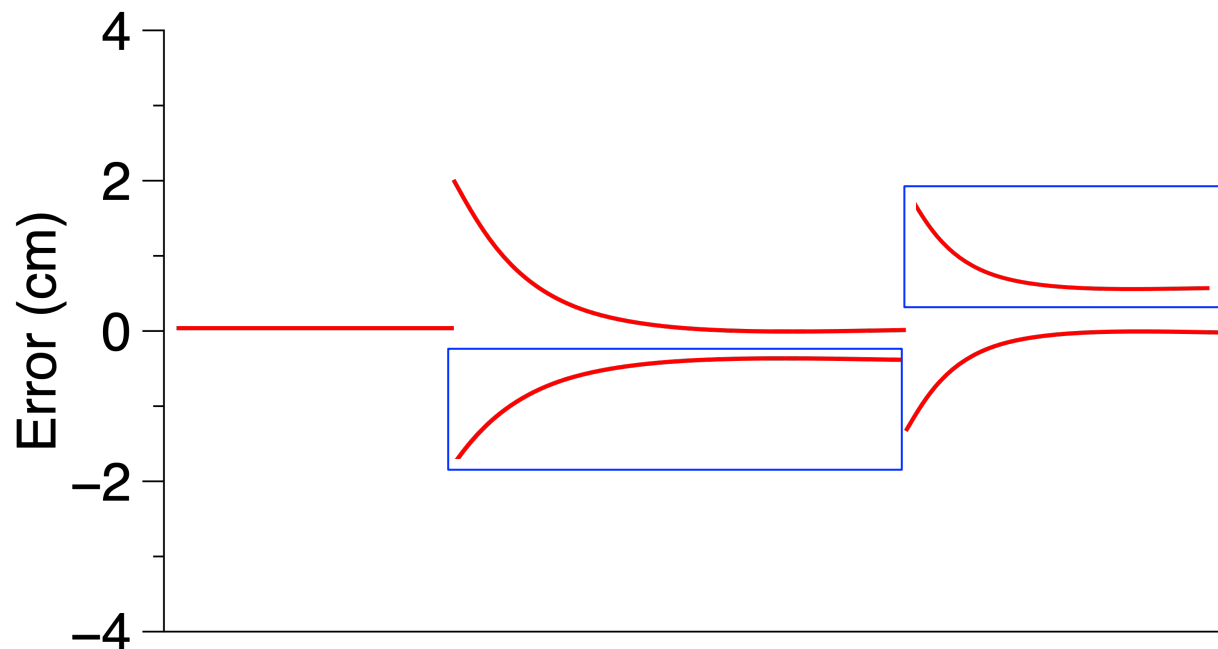
# Motor learning: Perturbation paradigms



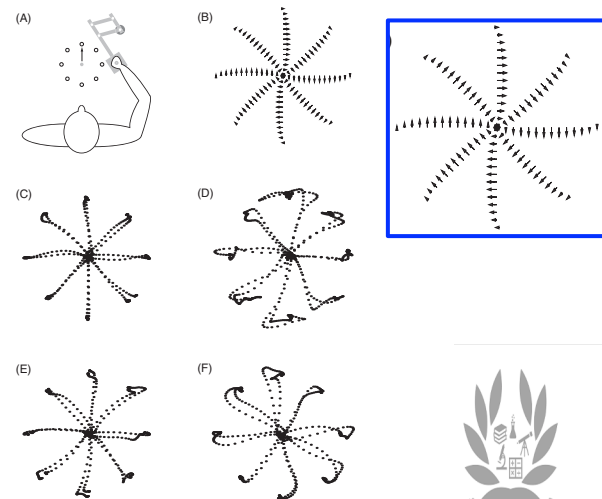
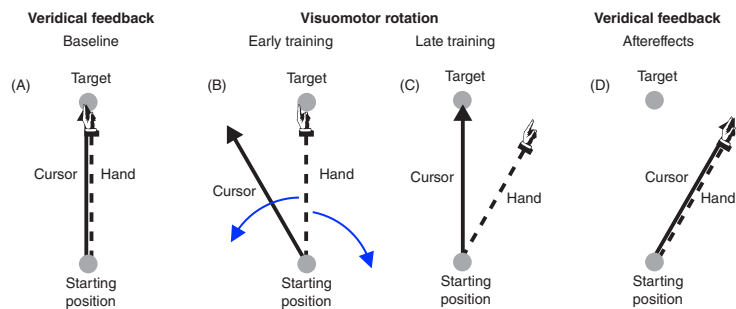
**Saving**

(Krakauer et al., 2005; Malone et al., 2011)

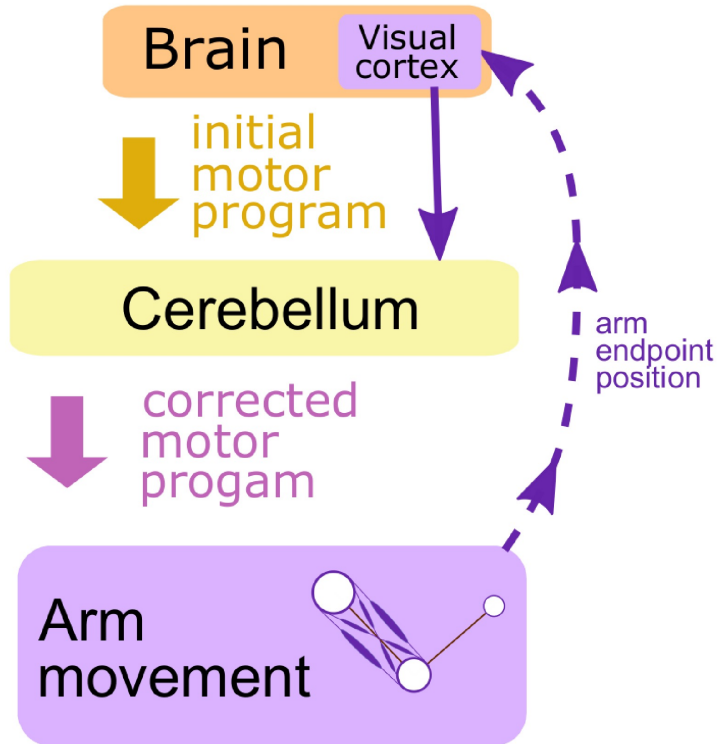
# Motor learning: Perturbation paradigms



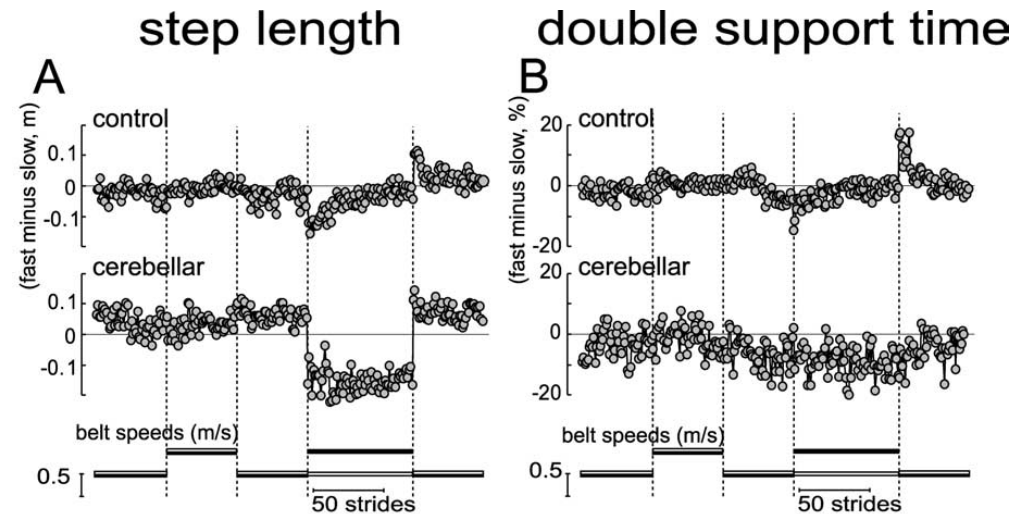
## Trials



# Motor learning: Perturbation paradigms

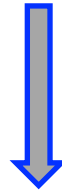


## Error-based learning

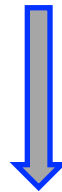


(Morton & Bastian, 2006; Wolpert et al., 2011)

# Perturbation paradigms



What type of motor learning ?



**Motor Adaptation**

# Motor Learning

John W. Krakauer,<sup>1,2,3</sup> Alkis M. Hadjiosif,<sup>1</sup> Jing Xu,<sup>1,3</sup> Aaron L. Wong,<sup>1,4</sup> and Adrian M. Haith\*<sup>1</sup>

## Motor Adaptation

“A particular type of behavioral change that involves **adjusting** how an **already well-practiced action** is **executed to maintain performance** in response to a **change in the environment or the body**, either by selecting an alternative well-practiced action or modifying how the current action is executed.”

“The goal of the action remains the same”



Capacità di adattare, trasformare e correggere il proprio programma motorio in condizioni imprevedibili e che variano repentinamente

Capacità di adeguare lo schema di movimento a una situazione non predeterminata, mutevole e imprevedibile al fine di renderlo adatto alle richieste che si presentano

Capacità di trasformare il proprio obiettivo motorio in base a ciò che accade nell'ambiente e reagendo ai feedback che ricevi. Un aggiustamento del movimento in corso.

Consiste nel variare il movimento appreso in precedenza in base alle nuove condizioni del contesto in cui il soggetto si trova

Specificata capacità coordinativa che rispecchia il sapere adeguare un'azione motoria ai vari cambiamenti situazionali o proseguirla in maniera completamente diversa senza perdere efficienza ed economicità

L'insieme dei processi mentali necessari ad acquisire comportamenti stabili, relativi ad una prestazione motoria

Capacità coordinativa, che ci permette di modificare il nostro progetto motorio a seconda della situazione che si verifica

Trovare la modalità per svolgere un determinato movimento.

Modifica dello schema comportamentale per accogliere eventi nuovi e ignoti

Capacità specifica per adattare gesti abituali a situazioni inaspettate per raggiungere comunque un obiettivo

Capacità coordinativa che ci permette di modificare il nostro progetto motorio a seconda della situazione che si verifica.

L'insieme di più capacità coordinative (equilibrio, ritmo, reazione, orientamento spazio-temporale), che permettono ad un individuo di adattare/modificare un'azione motoria in seguito ad un imprevisto o un avvenimento inatteso

Capacità coordinativa di adattare, a seconda delle cangianti situazioni di contesto, l'azione motoria in corso

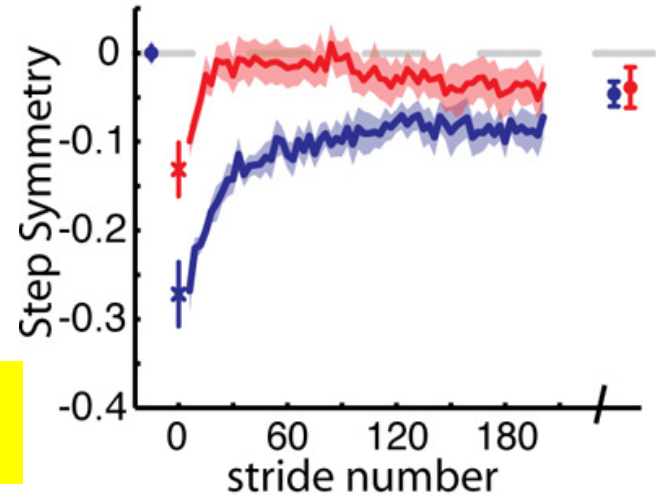
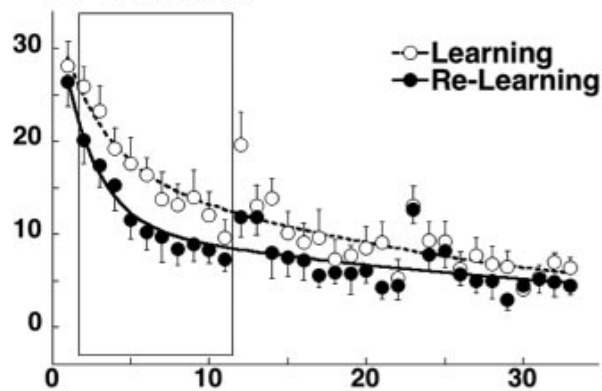
Motorio presuppone che si possa essere in grado di adattare questa abilità ad un contesto, un compito motorio, più o meno simile



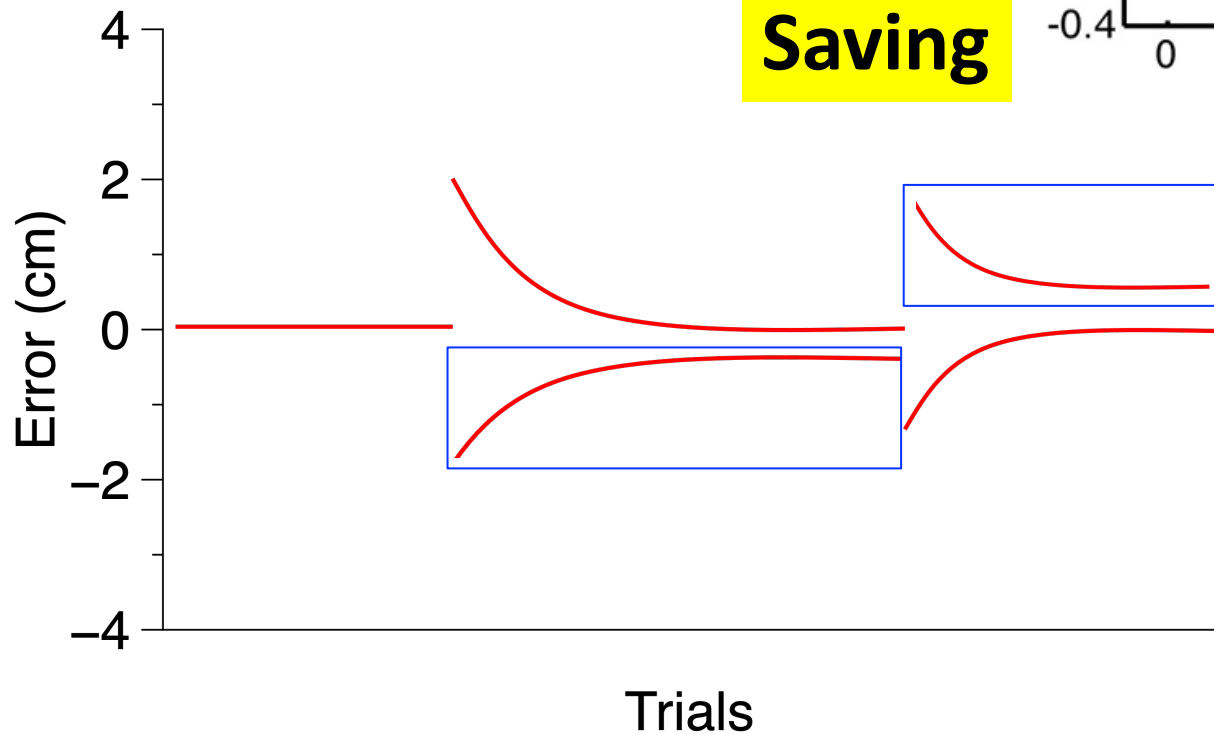
# Motor Adaptation



# Motor Adaptation



**Saving**



# Motor Adaptation

≠

## “De novo” motor learning

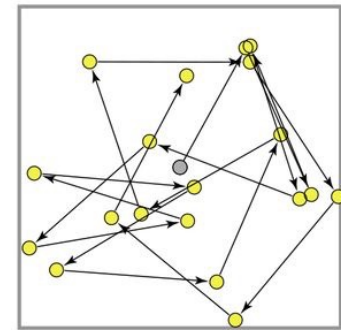
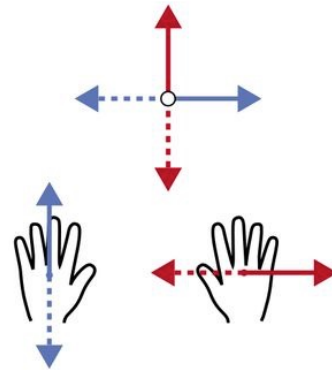
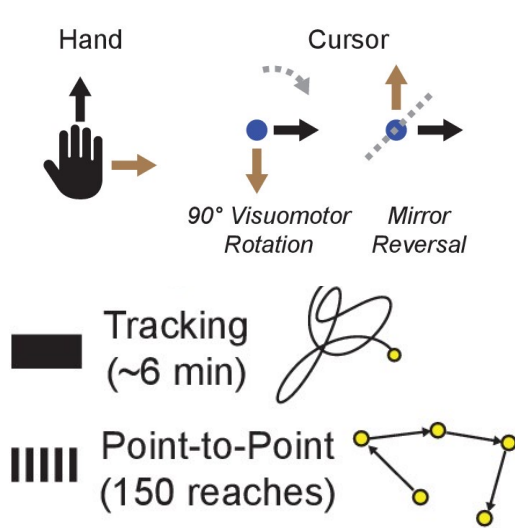
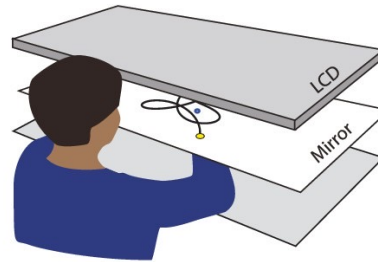
“A **new motor controller** (that is, some network or process that generates motor output given the state of the body and current goals) is **formed from scratch** rather than derived from existing ones”

“Learn new ways to respond to incoming information by selecting the appropriate action response, whether that is information coming from the environment or from sensors within our body”



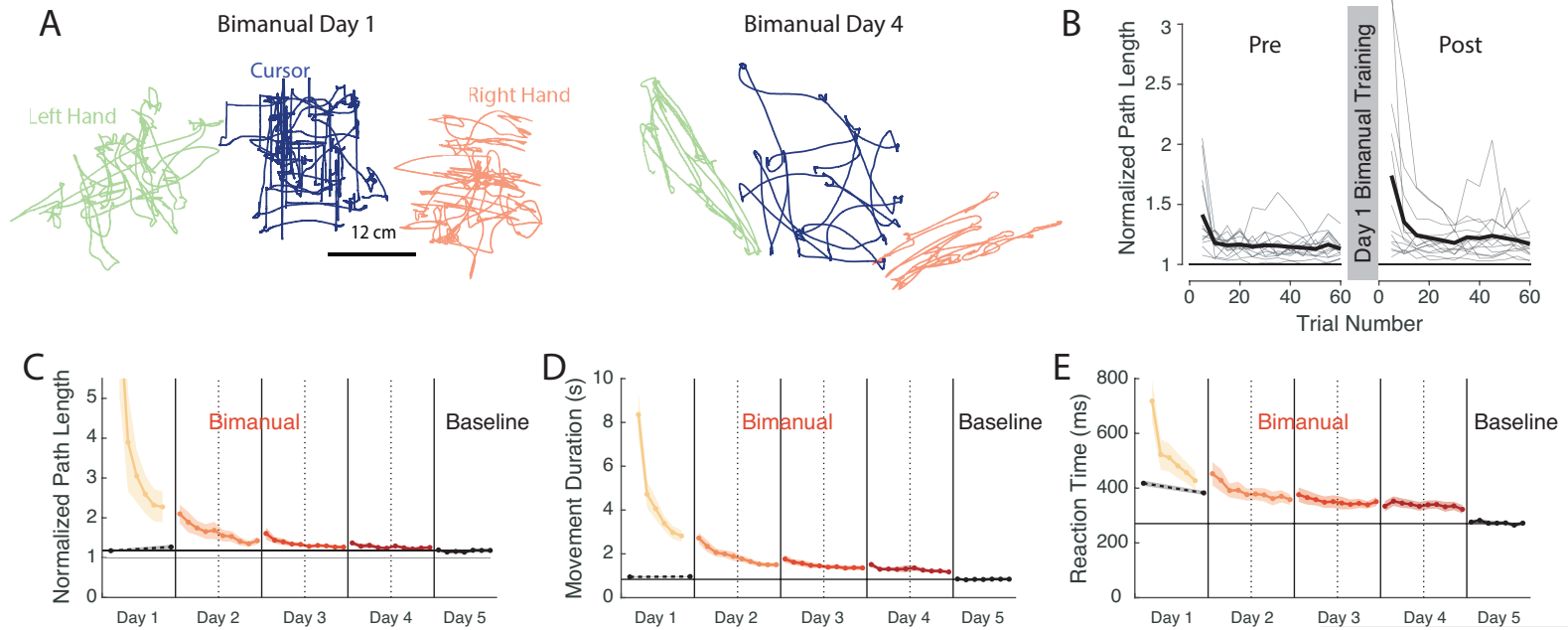
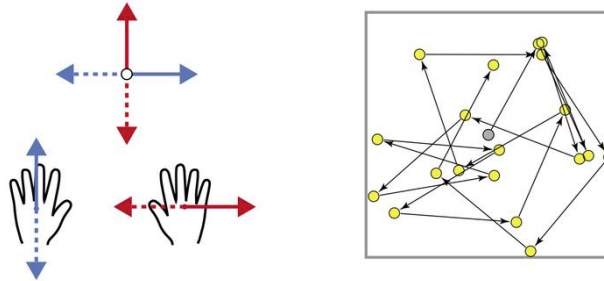
# “De novo” motor learning

## What experimental paradigm?



(Yang et al., 2021; Haith et al., 2021)

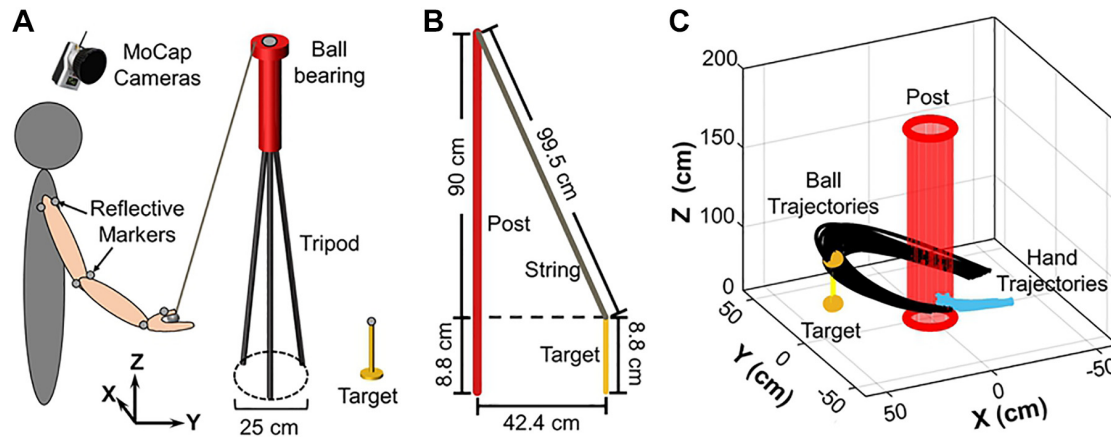
# “De novo” motor learning



(Haith et al., 2021)



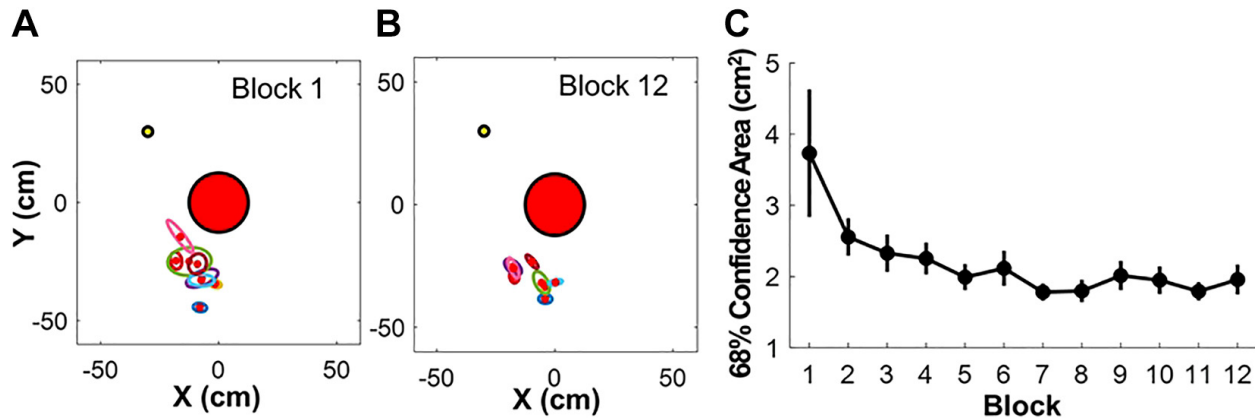
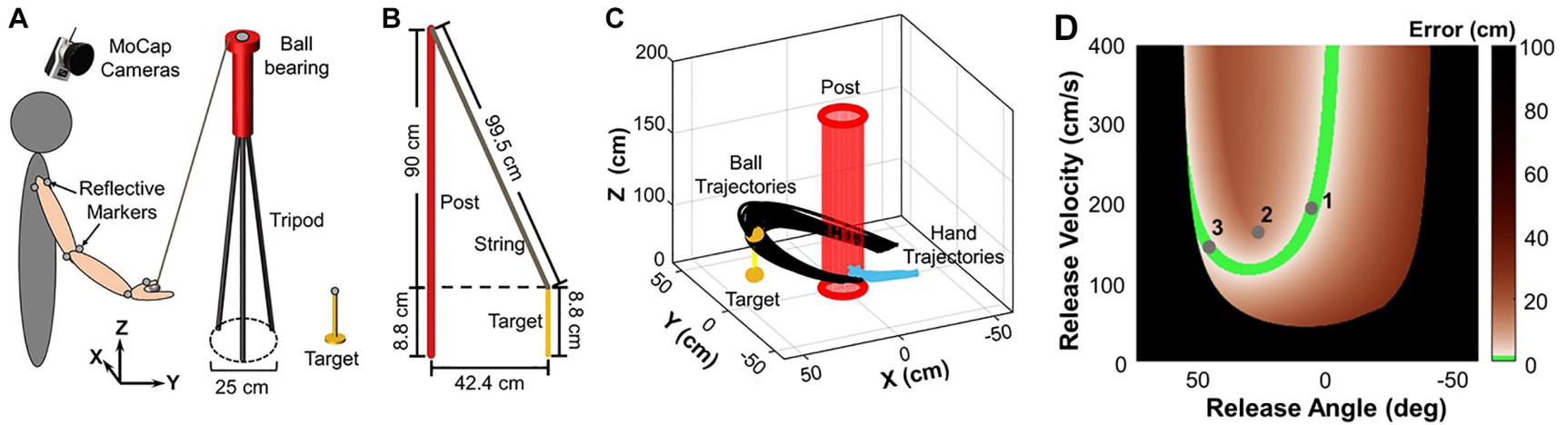
# “De novo” motor learning



(Zhang & Sternad, 2021)



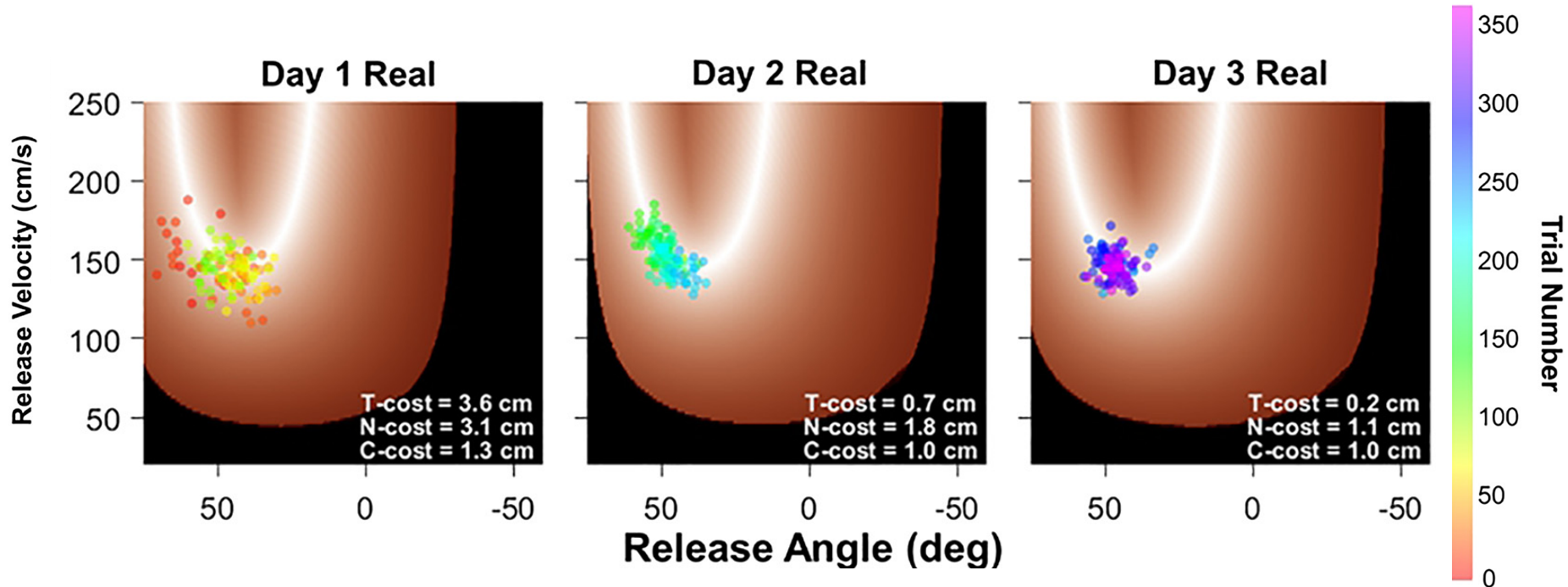
# “De novo” motor learning



(Zhang & Sternad, 2021)



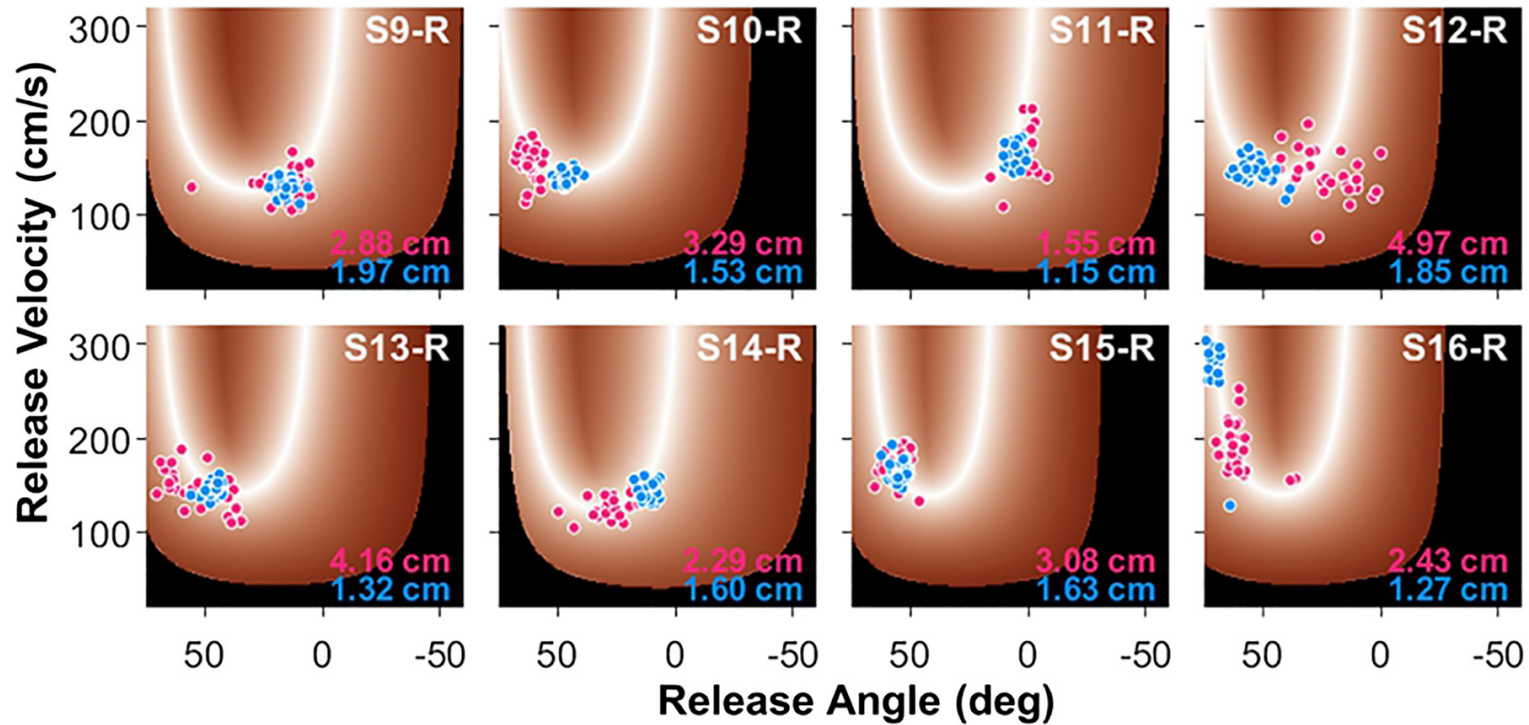
# “De novo” motor learning



(Zhang & Sternad, 2021)



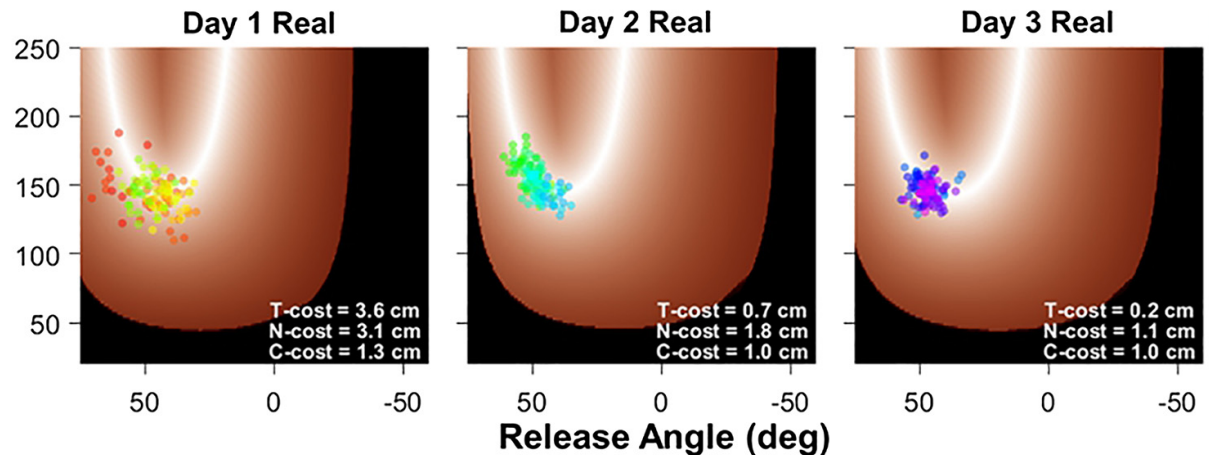
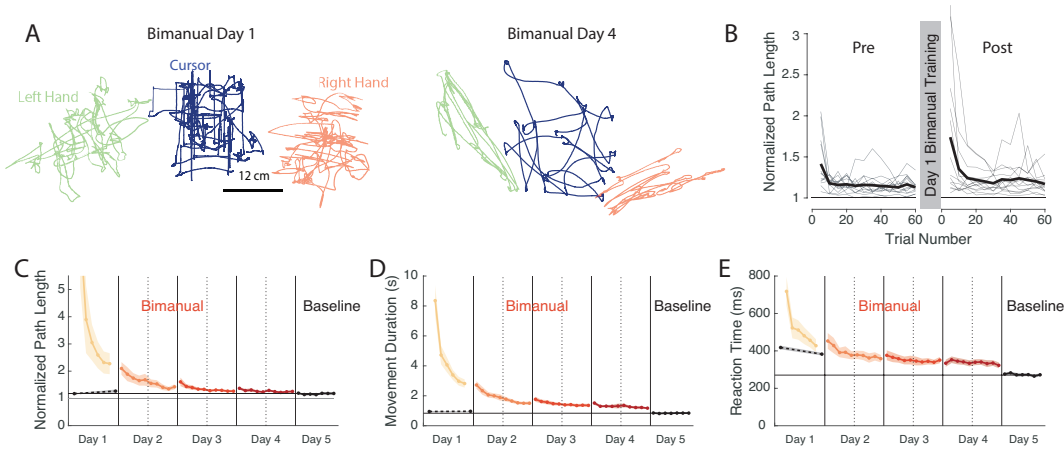
# “De novo” motor learning



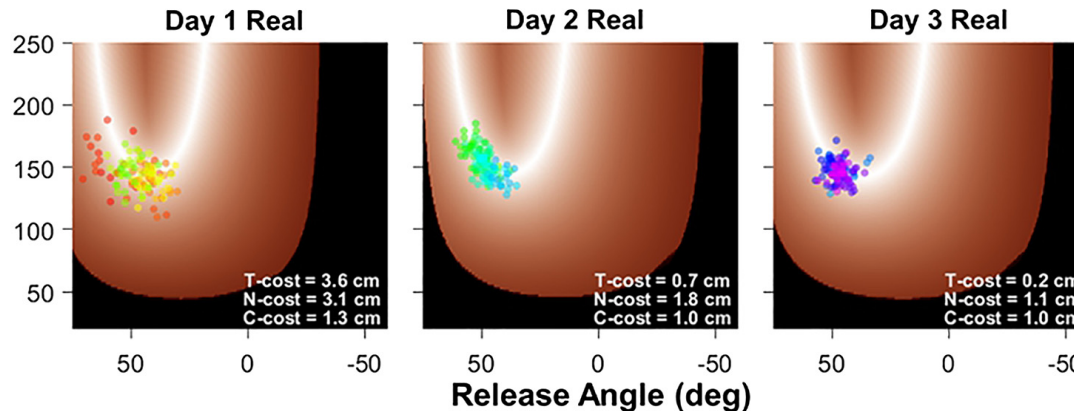
(Zhang & Sternad, 2021)



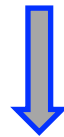
# “De novo” motor learning



# “De novo” motor learning



**Motor exploration as a search strategy  
for novel motor skill acquisition**



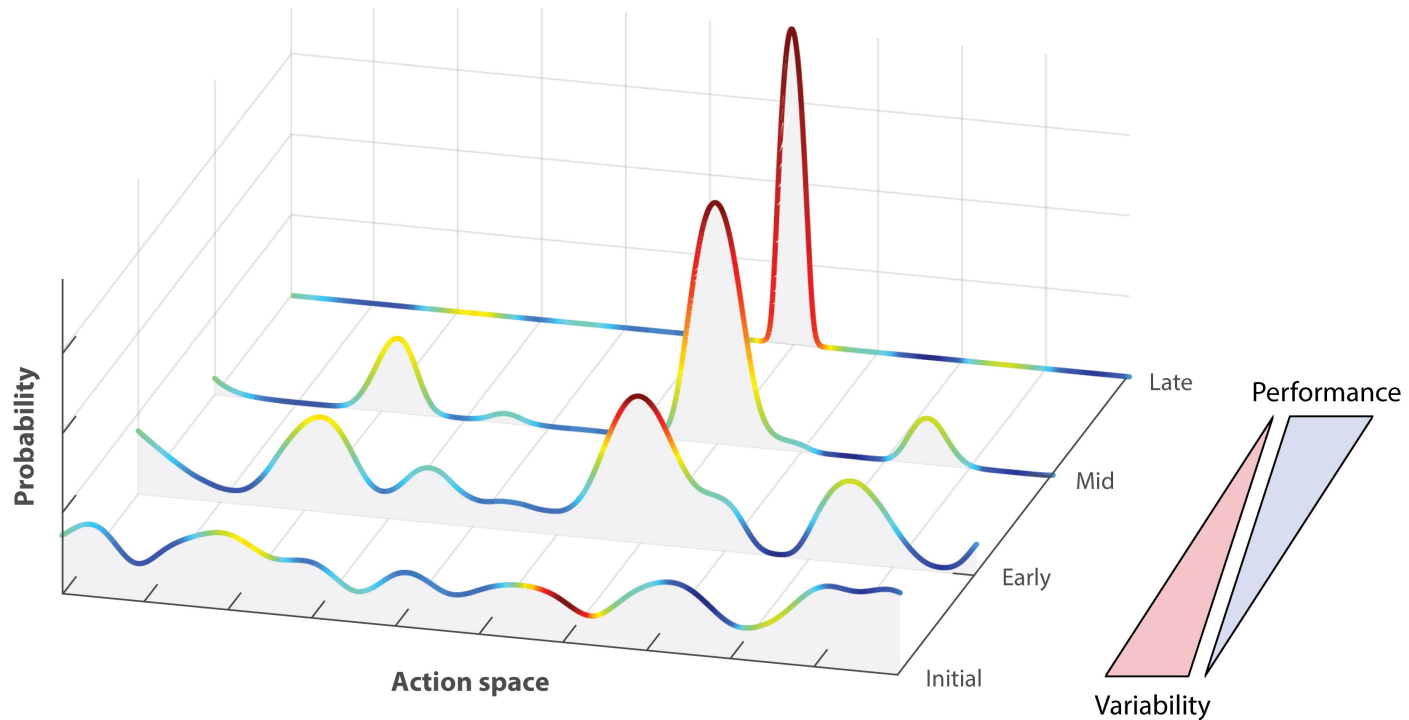
**Reinforcement-based learning**

(Dhawale et al., 2017)



# “De novo” motor learning

## Reinforcement-based learning

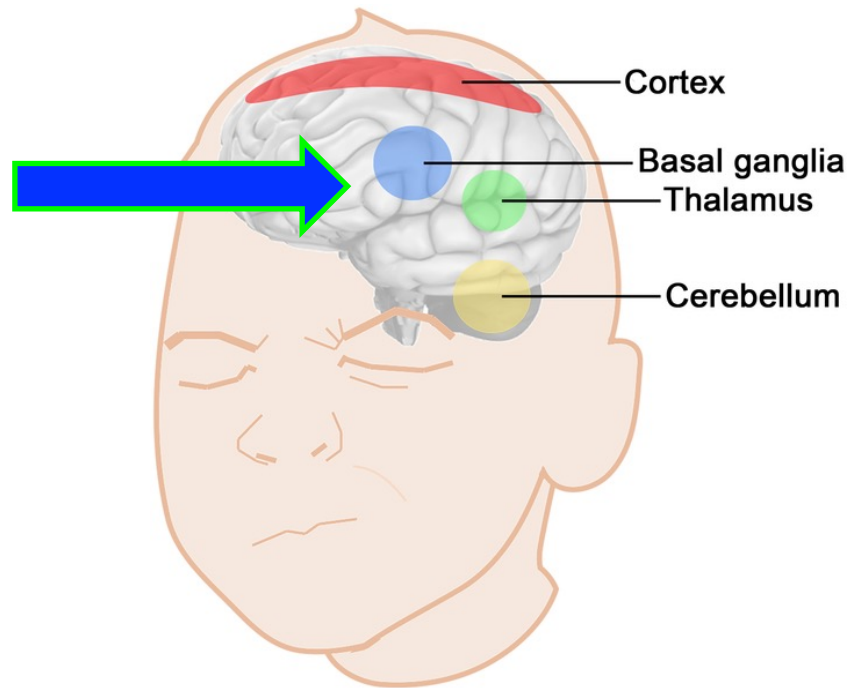


( · Dhawale et al., 2017)



# “De novo” motor learning

## Reinforcement-based learning

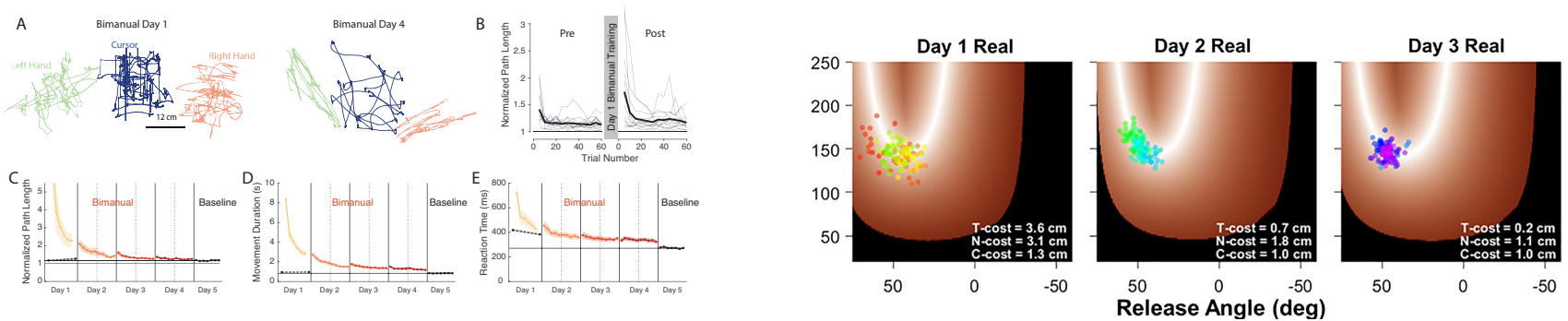


( · Wolpert et al., 2011)

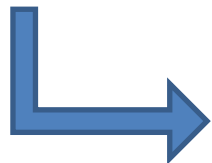


# “De novo” motor learning

“A **new motor controller** (that is, some network or process that generates motor output given the state of the body and current goals) is **formed from scratch**.”



“De novo” motor learning



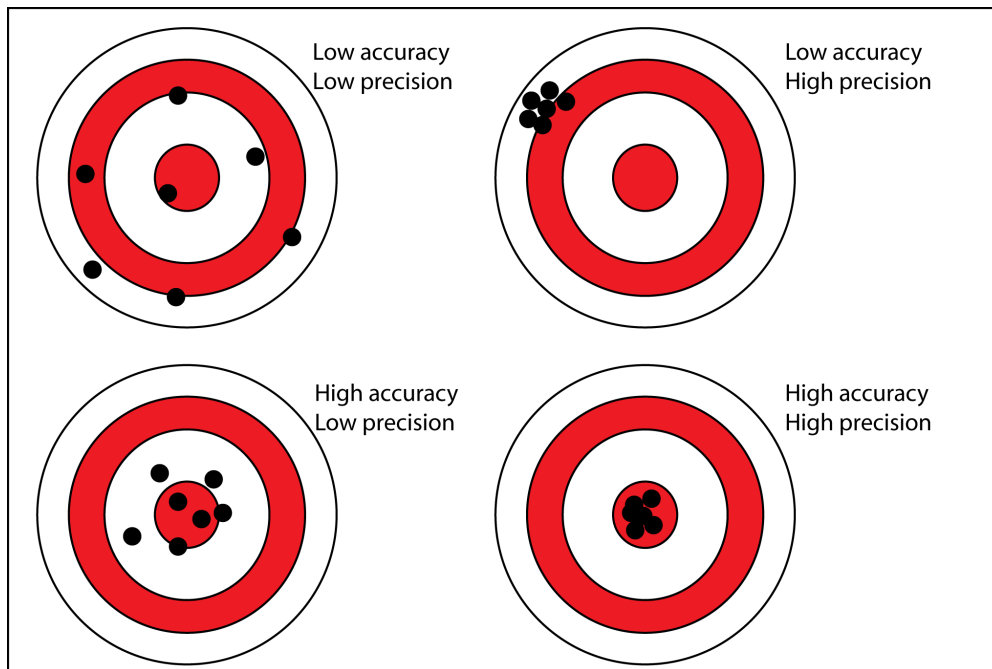
Motor acuity

(Krakauer et al., 2019)



# Motor acuity

Execute motor actions with more accuracy and precision through practice.

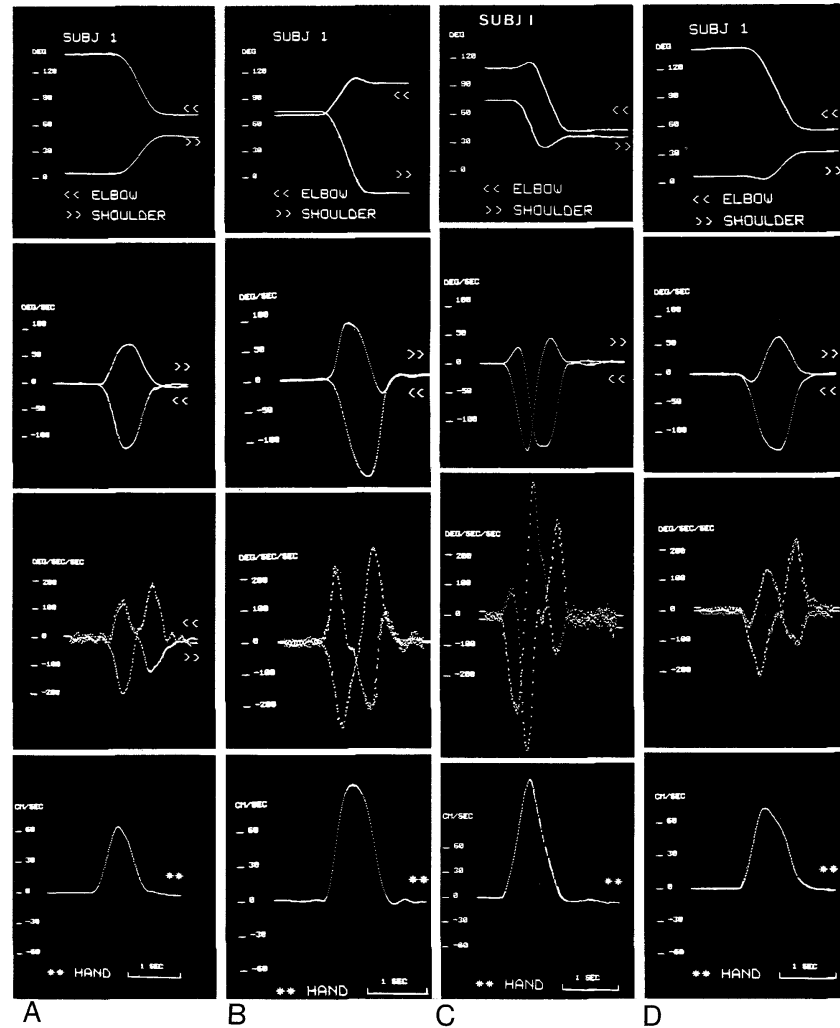
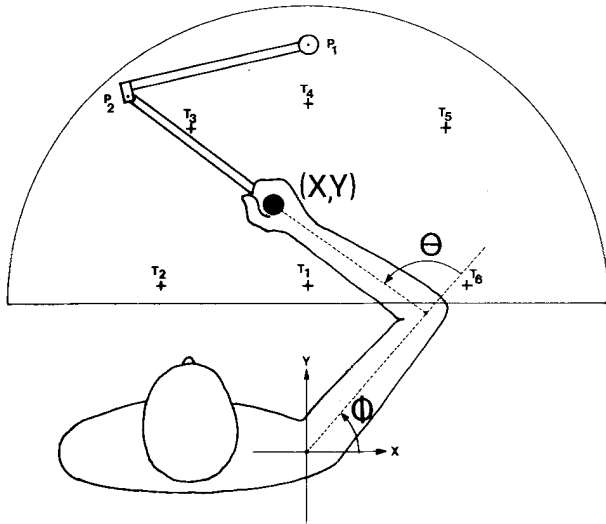


**Improvement:** performance of a skill shows improvement over a period of time.

**Consistency:** performance becomes increasingly more consistent.



# Motor acuity

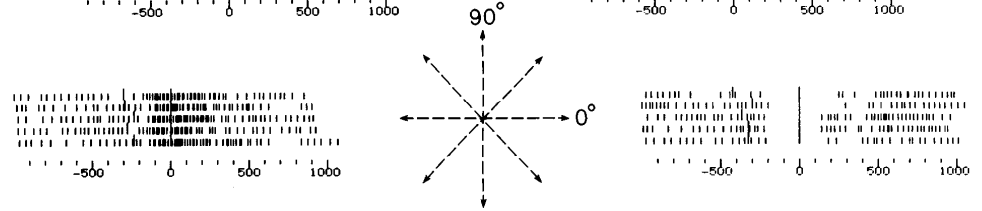
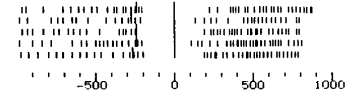
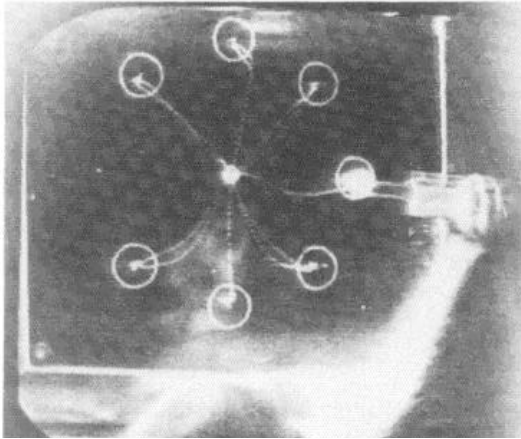


(Morasso, 1981)

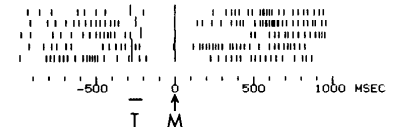
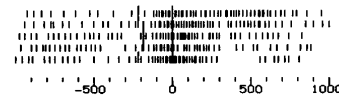
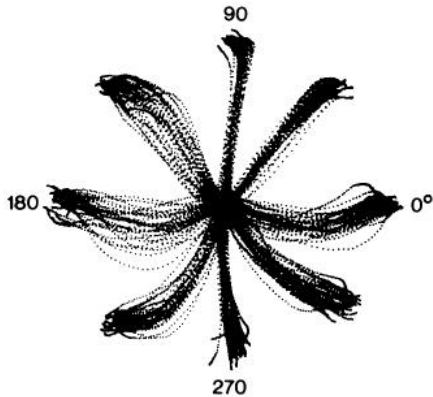


# Motor acuity

B.



C.



PCR110.S01

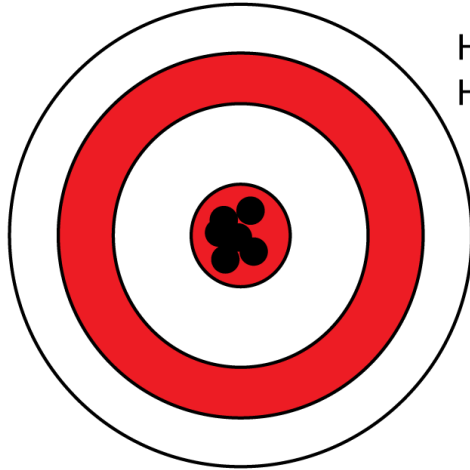


S1A

(Georgopoulos et al., 1982; 2007)



# Motor acuity



High accuracy  
High precision

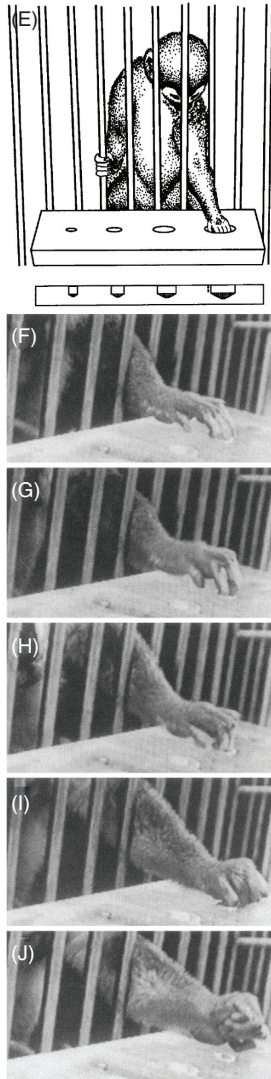
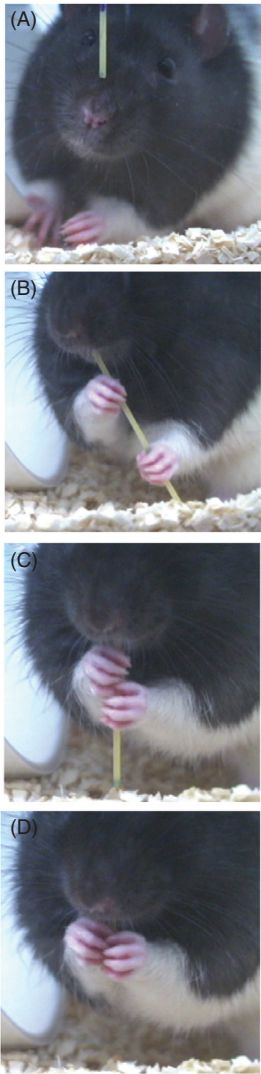


**absolute error (AE)** the unsigned deviation from the target or criterion, representing amount of error. A measure of the magnitude of an error without regard to the direction of the deviation.

**constant error (CE)** the signed (+/-) deviation from the target or criterion; it represents amount and direction of error and serves as a measure of performance bias.

**variable error (VE)** an error score representing the variability (or conversely, the consistency) of performance.

# Motor acuity

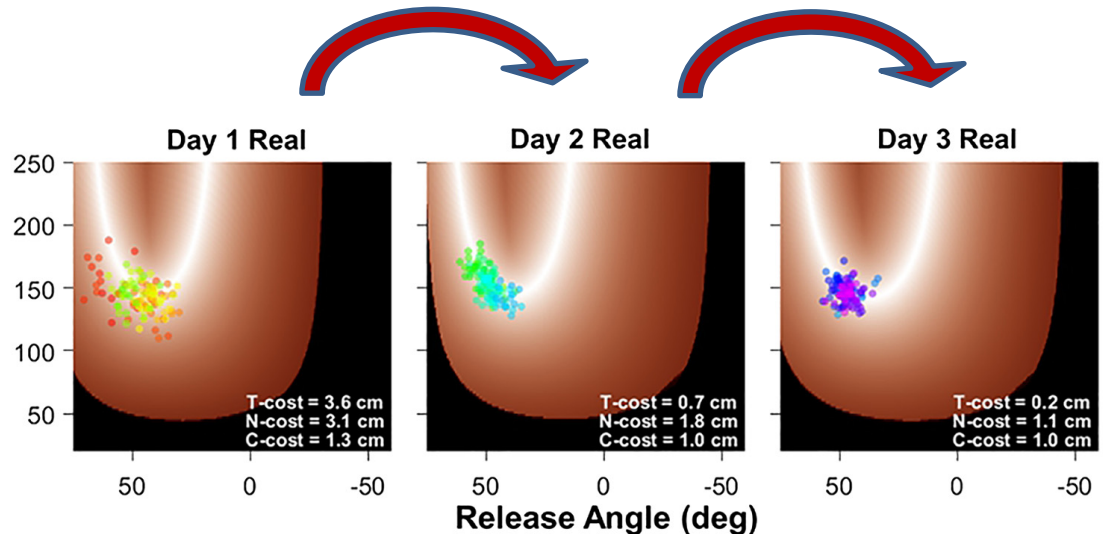
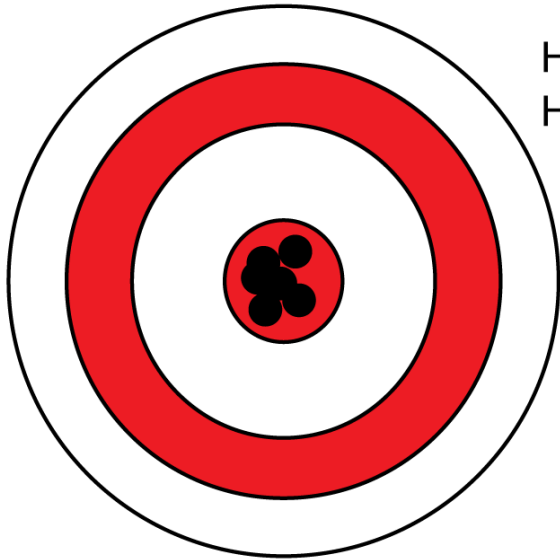


Changes in cortical inhibitory/excitatory balance with skill learning

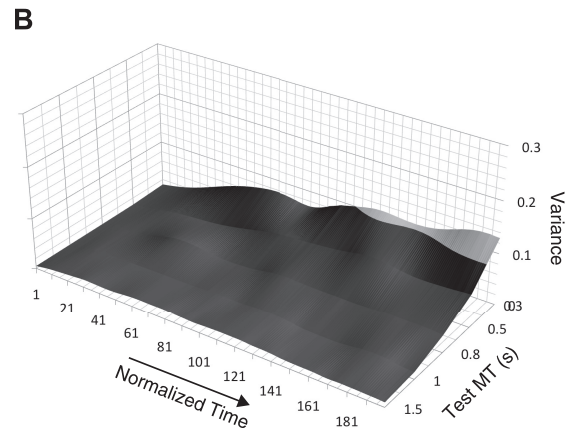
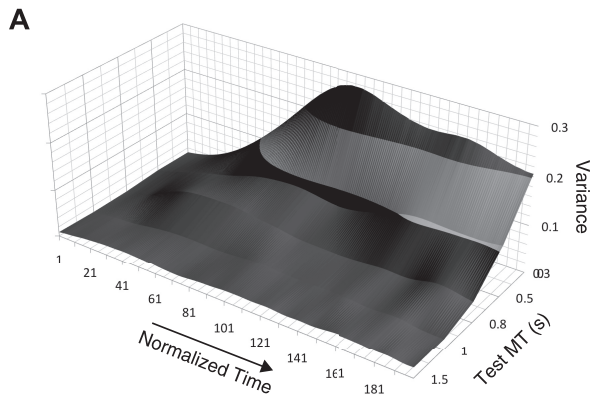
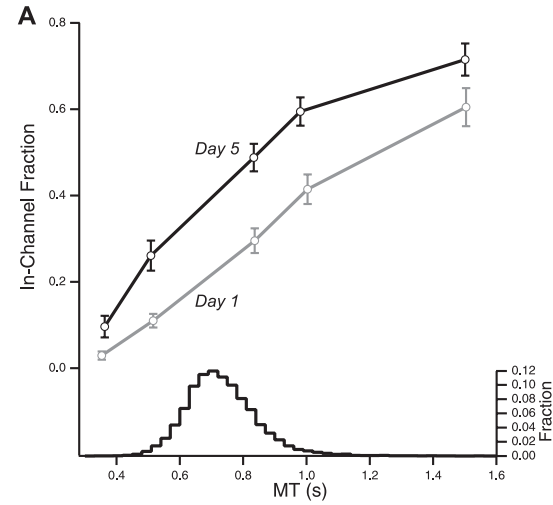
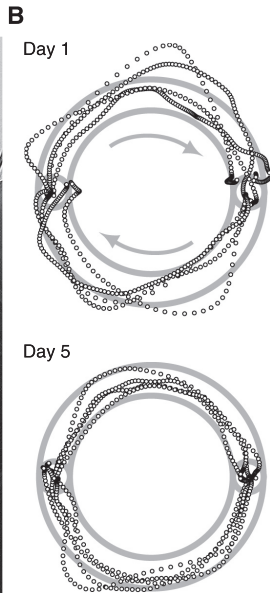
(Nudo et al., 1992;1996; Chen et la., 2015; Peters et al., 2017)



# Motor acuity



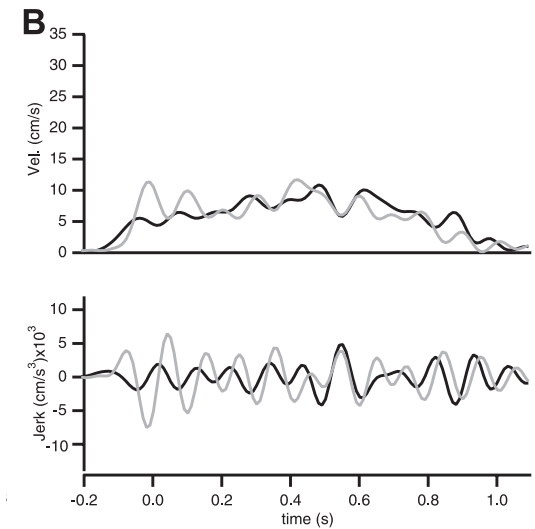
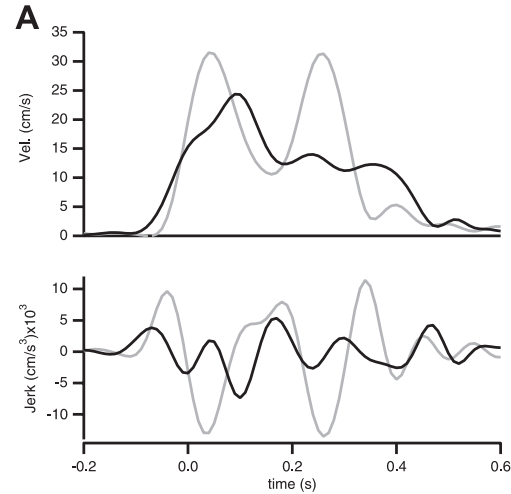
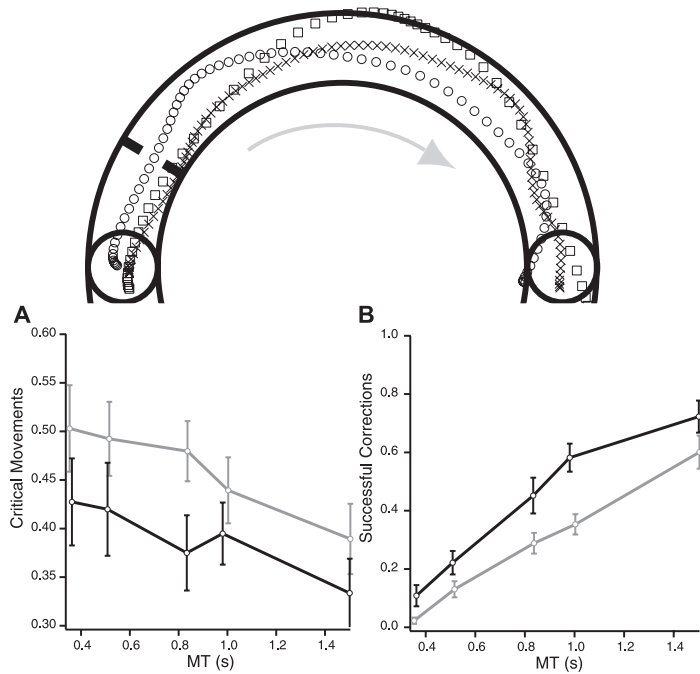
# Motor acuity



(Shmuelof et al., 2012)



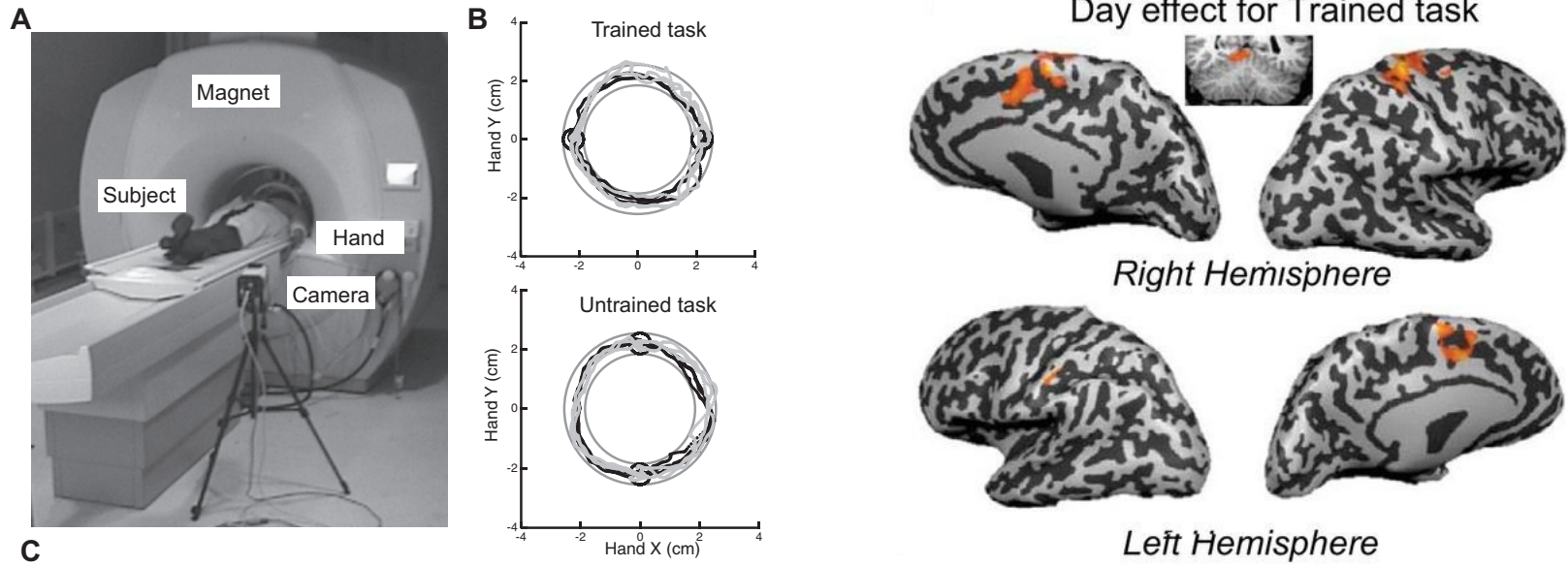
# Motor acuity



(Shmuelof et al., 2012)



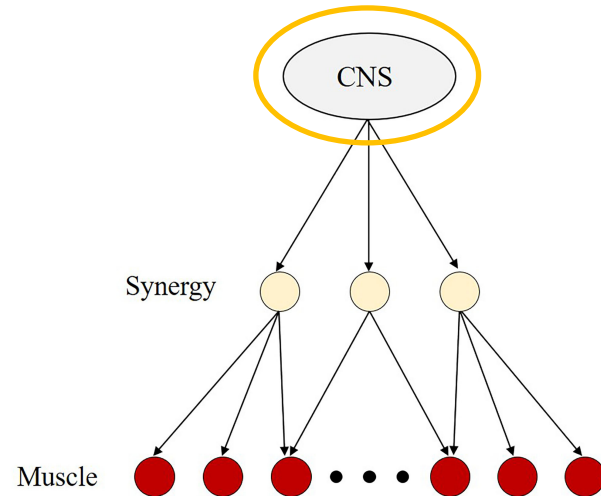
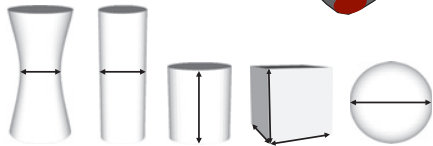
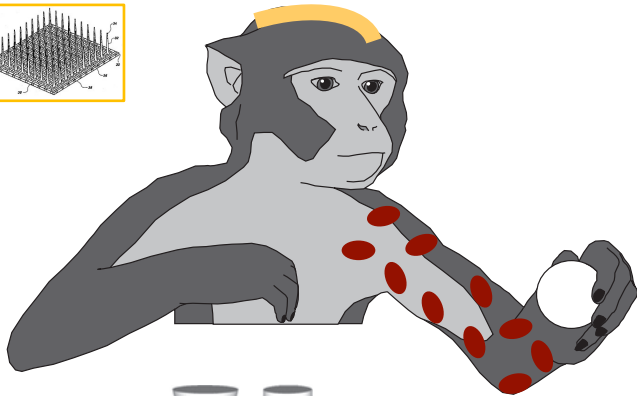
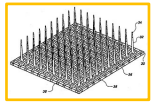
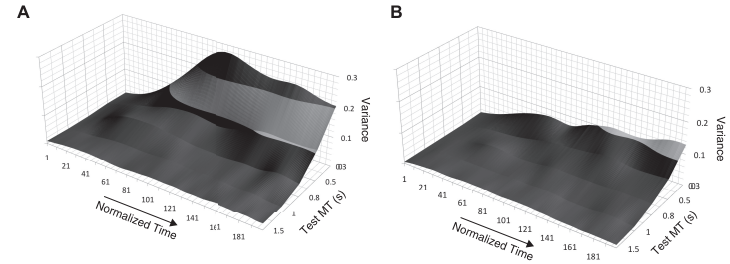
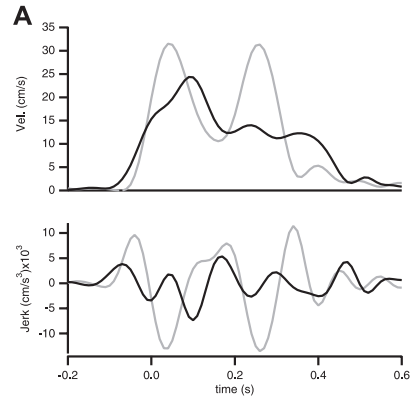
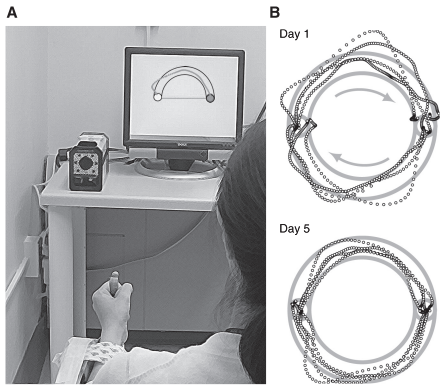
# Motor acuity



(Shmuelof et al., 2014)



# Motor acuity



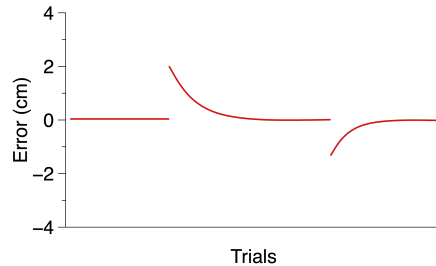
(Overduin et al., 2012;2015)



# Motor Learning

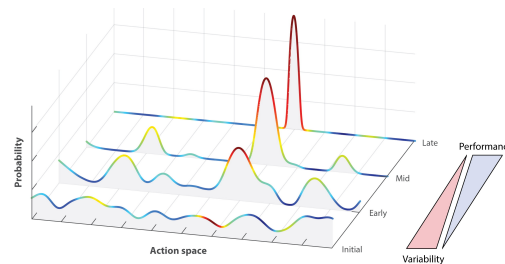
Motor learning is a blanket term that encompasses a huge diversity of phenomena.

❖ Motor Adaptation



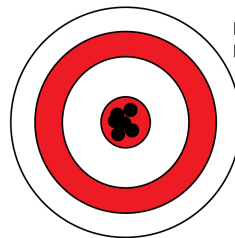
Error-based learning

❖ “De novo” learning



Reinforcement-based learning

❖ Motor acuity



High accuracy  
High precision

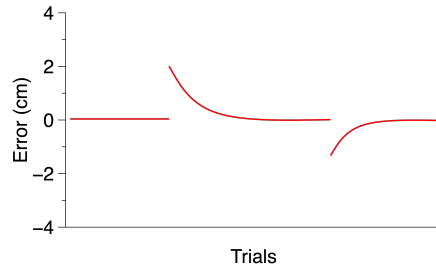
Use-dependent learning



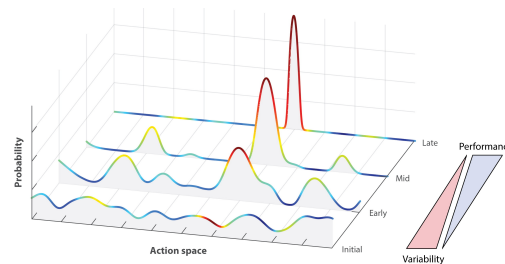
# Motor Learning

Motor learning is a blanket term that encompasses a huge diversity of phenomena.

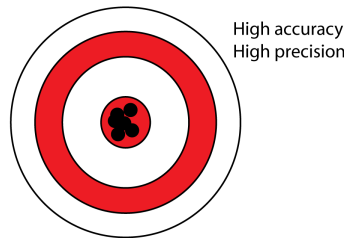
❖ Motor Adaptation



❖ “De novo” learning



❖ Motor acuity



**To be continued ...**

**a. Contextual interference**

**b. Transfer**





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Phone: **045-8425112**

