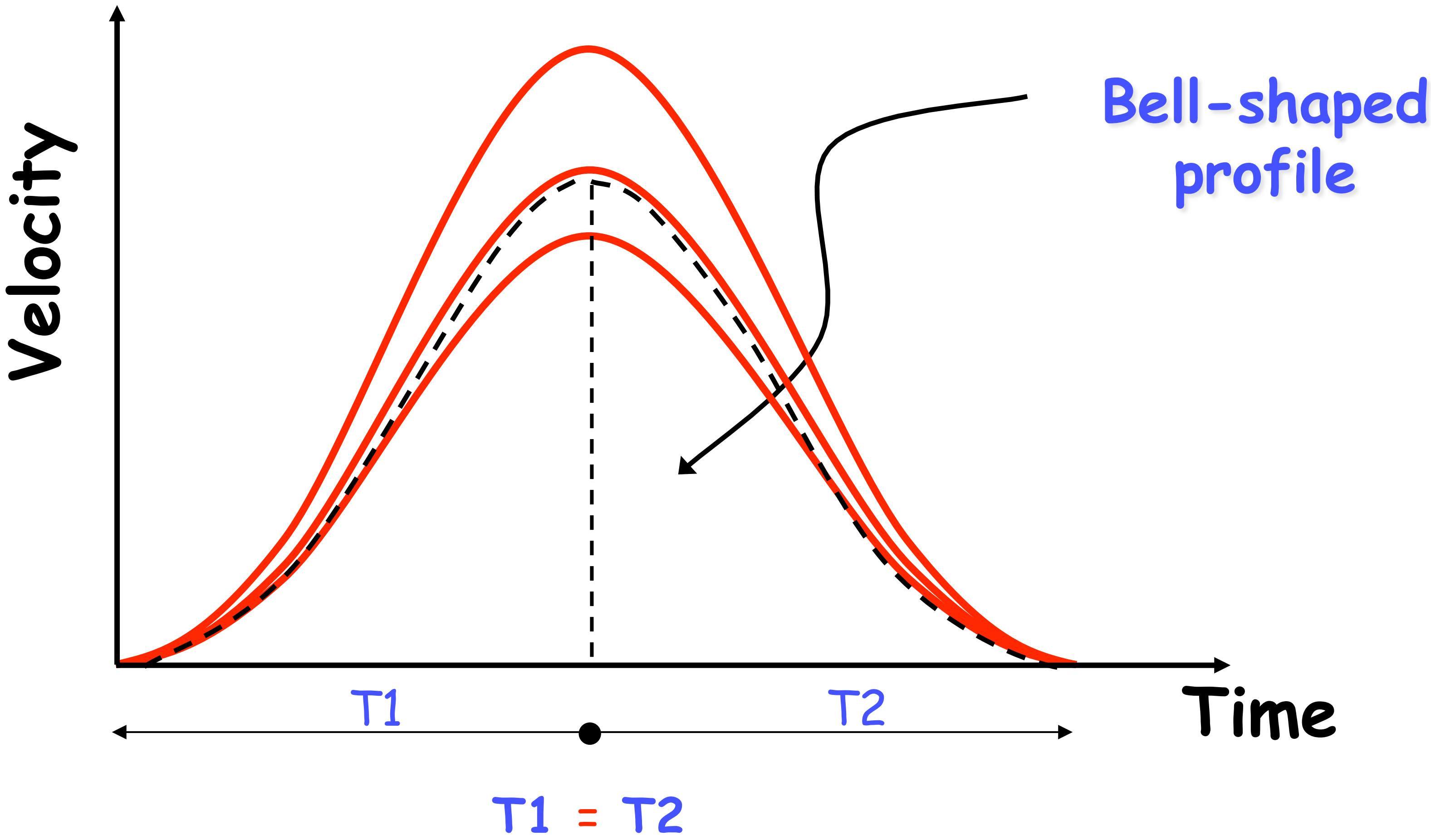
- The majority of human activities show a trade-off between movement speed and accuracy

Unconstrained fast and Ballistic movements are characterized by invariant kinematic features

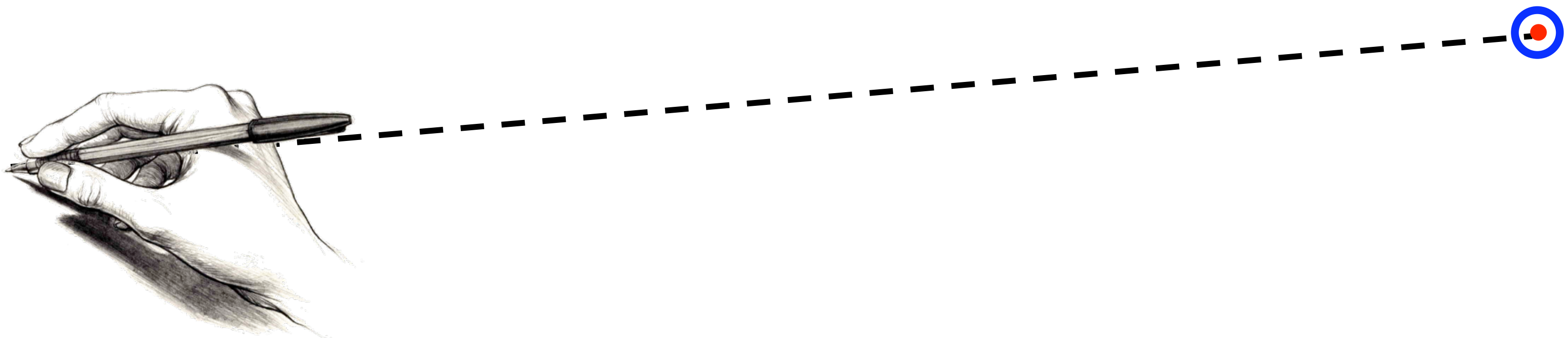


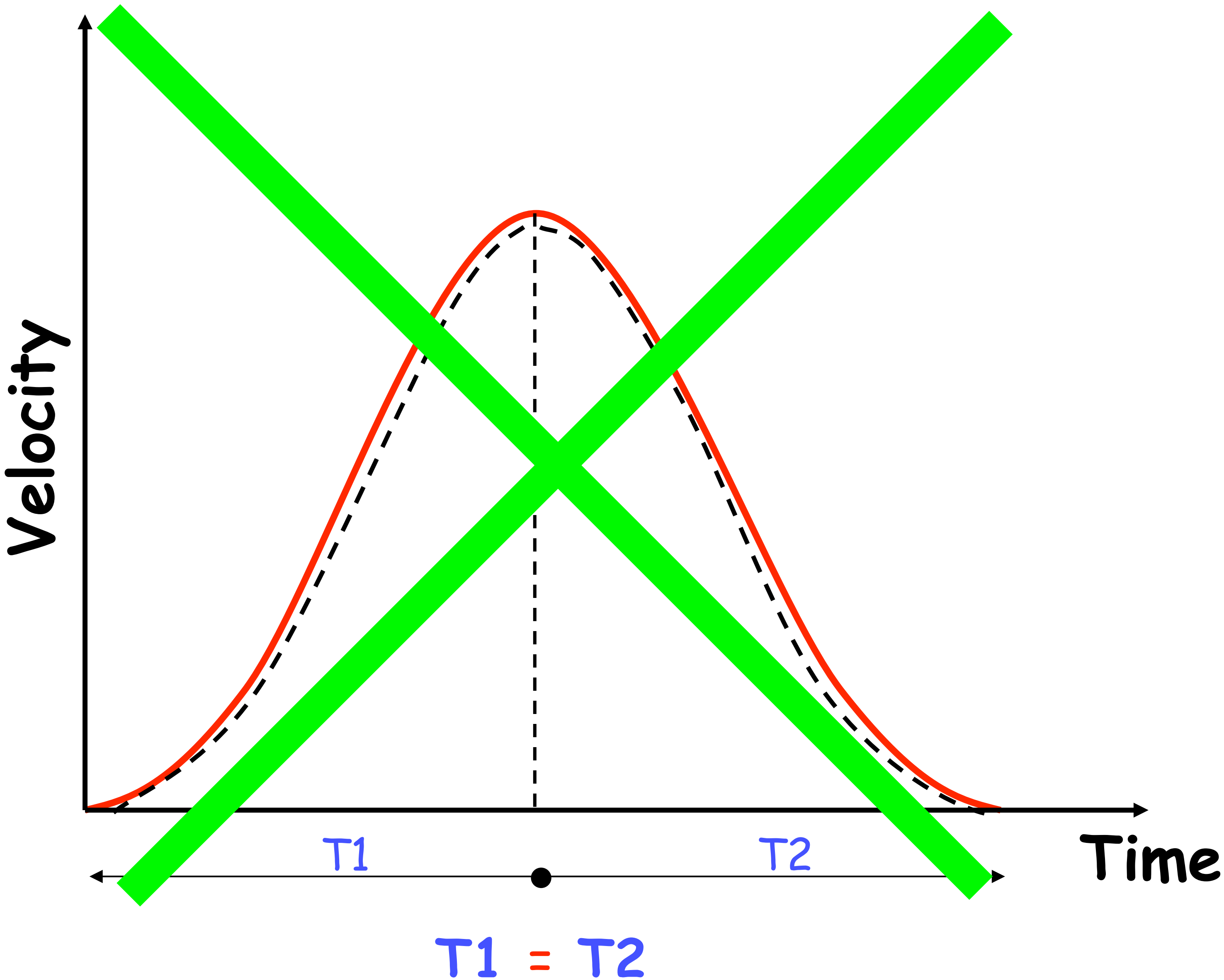
(Morasso, 1981; Abend et al. 1982; Atkenson & Hollerbach, 1985; Flash & Hogan, 1985; Uno et al, 1989)

But accuracy demand affects movement kinematics

Movements

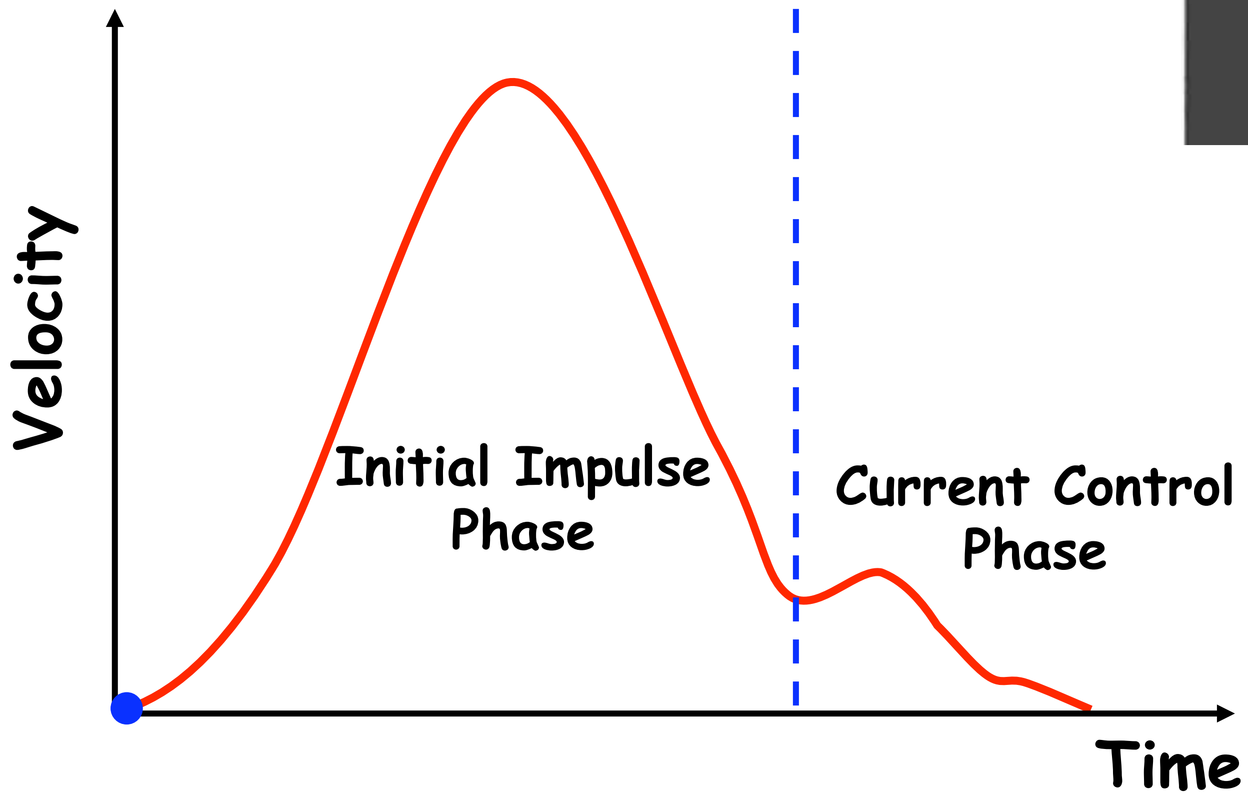
Fast **Accurate**




Velocity
Time
T1
T2
T1 = T2

Robert S. Woodworth, 1899

- As velocity increases accuracy decreases
- As accuracy request increases velocity decreases



TRADE-OFF

Is there a relationship between movement velocity and accuracy?

Paul M. Fitts, 1954

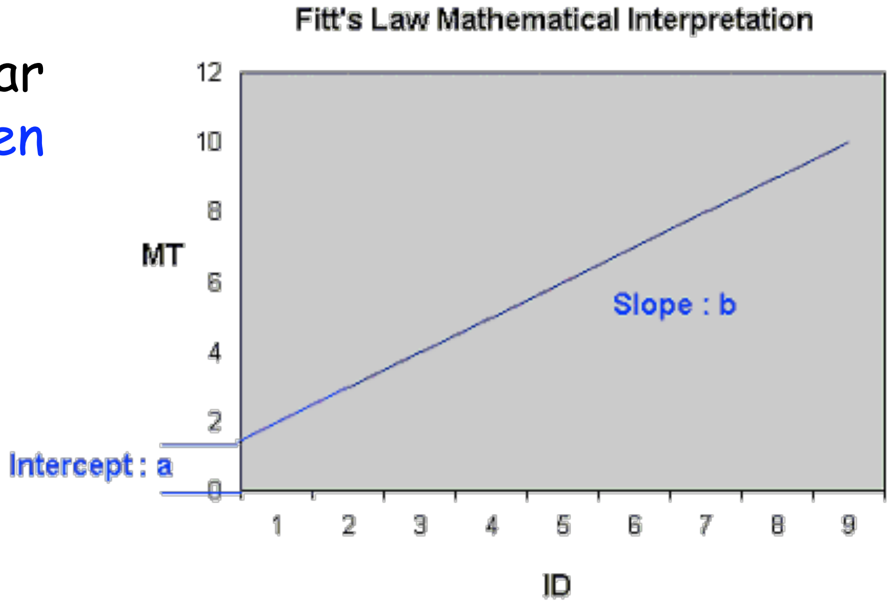
$$MT = a + b \log_2(2A/W)$$

The movement time (MT) is a linear function of the ratio between movement amplitude and target width

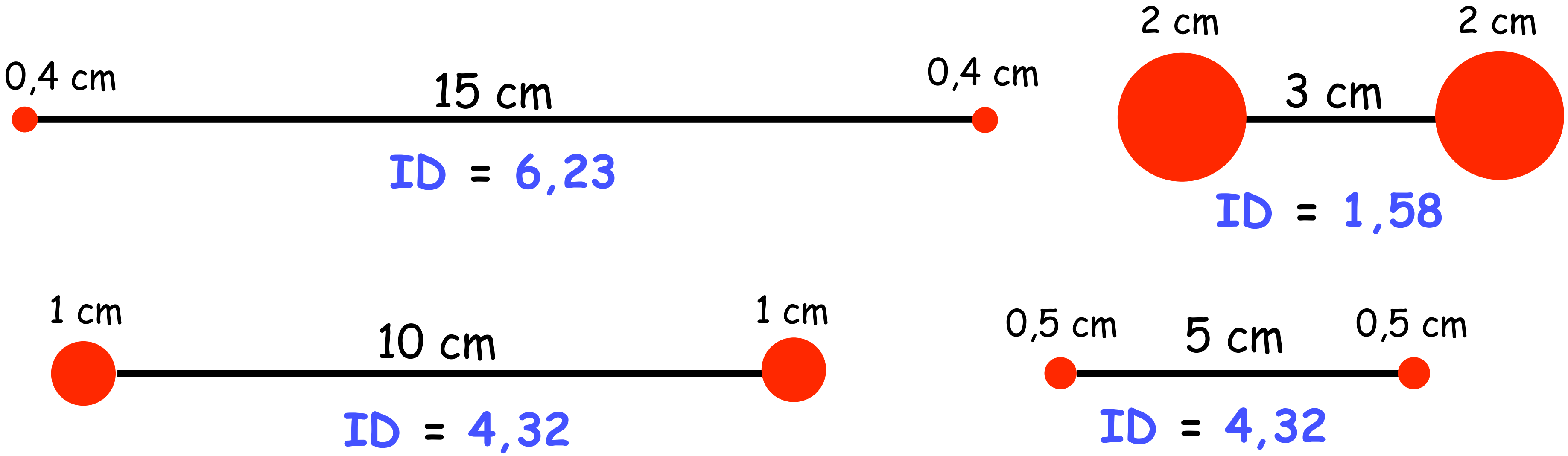
$\text{Log}_2(2A/W)$

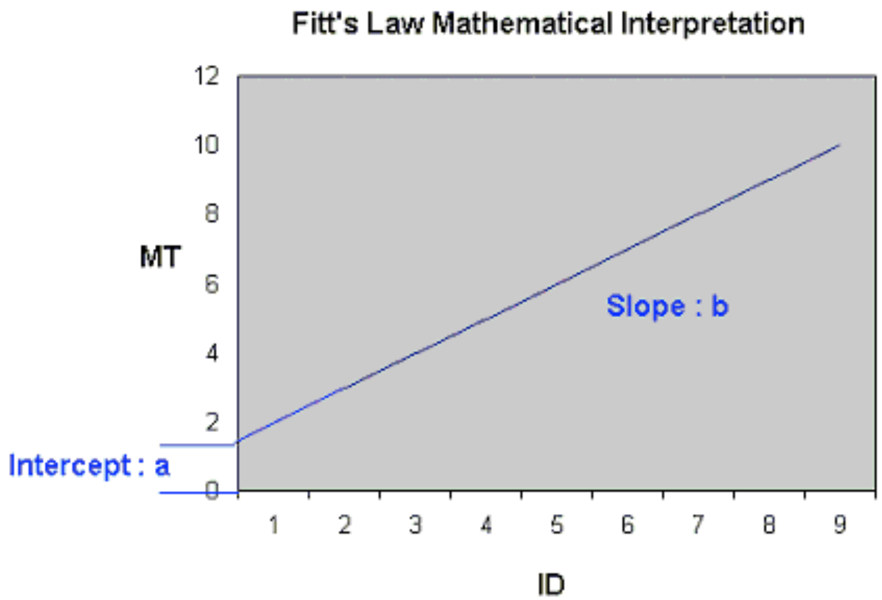
↓

Index of Difficulty (ID)



$$MT = a + b \log_2(2A/W)$$





Category	Study	Authors
Movements	a) Serial or continuous	a) Fitts (1954); Kvalseth (1975)
	b) Discrete	b) Carlton (1979; 1980); Fitts & Peterson (1964).
	c) Tapping	c) Fitts (1954); Fitts & Peterson (1964); Kantowitz & Elvers (1988); Megaw (1975);
	d) Object transferral	d) Fitts (1954); Raouf & Tsui (1978)
	e) Dart throwing	e) Kerr & Langolf (1977)
	f) Three-dimensional	f) MacKenzie et al. (1987)
	g) Rotary	g) Knight & Dagnall (1967)
	h) Pointing and dragging	h) Gillan et al. (1990)
Limbs and muscle groups	a) Wrist flexion and rotation	a) Crossman & Goodeve (1963/1983); Meyer et al. (1988); Wright & Meyer (1983)
	b) Foot movements	b) Drury (1975); Hoffmann (1991b)
	c) Head movements	c) Andres & Hartung (1989a; 1989b); Jagacinski & Monk (1985)
	d) Finger manipulation	d) Hoffmann & Sheikh (1991); Langolf et al. (1976)
	e) Arm extension	e) Kerr & Langolf (1977)
	f) Rapid elbow flexion	f) Corcos et al. (1988)
	g) Speech	g) Jafari & Kondraske (1988)
	h) Hand movements	h) Beggs & Howarth (1972); Howarth et al. (1971)
	i) It has been suggest that the law would hold for the mouth or any other organ for which a suitable motor task could be devised	i) Glencross & Barrett (1989); MacKenzie (1992)

Plamondon & Alimi (1997)

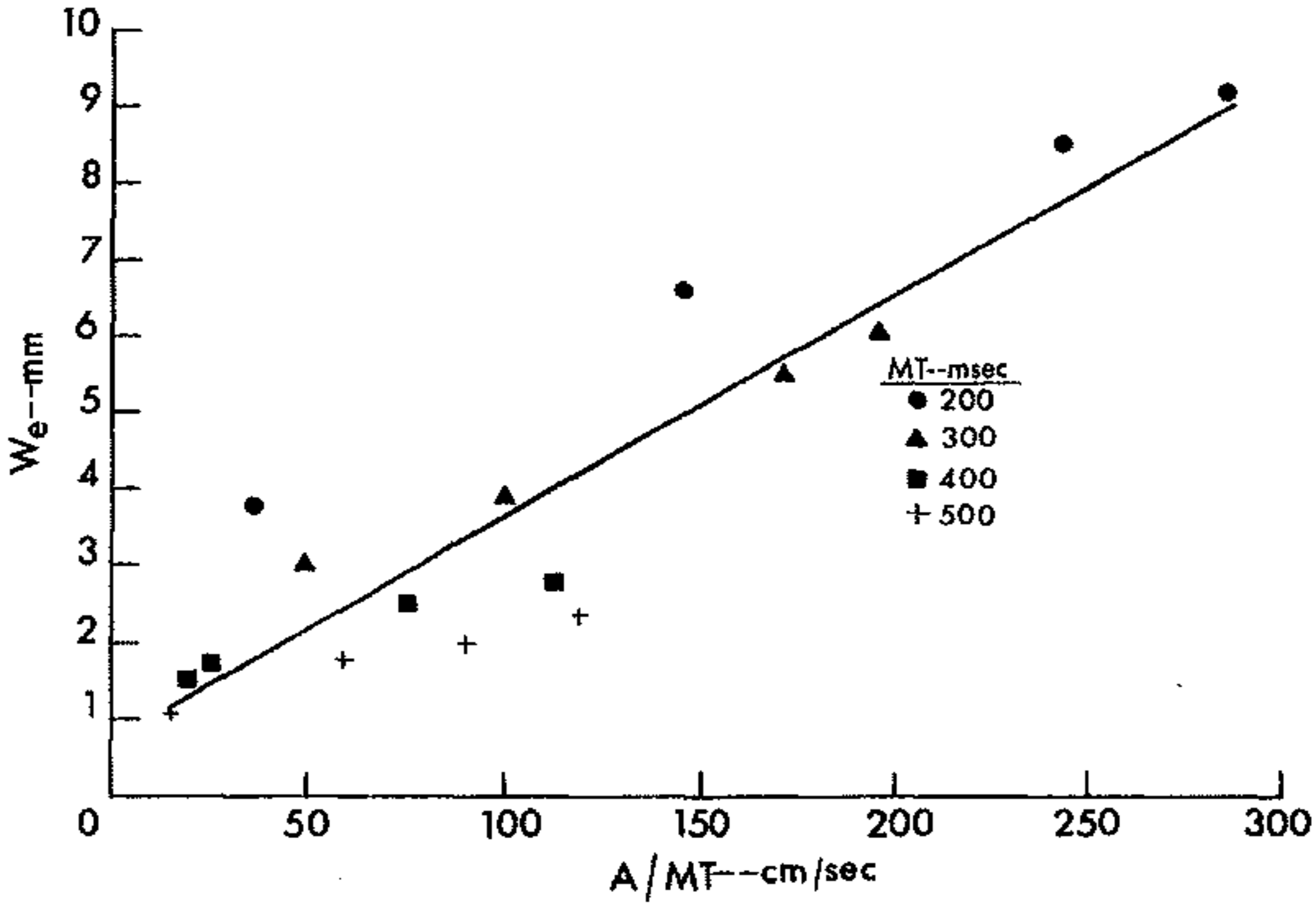
Fitts' Law → Requires elevated movement velocity

Richard A. Schmidt et al. (1979)

↓

Impulse Variability Model
(Schmidt's law)

Richard A. Schmidt et al., 1979



The variability at the target (We) is linearly related with the speed (A/MT) of the movement

Combining movement kinematic with perception

David E. Meyer

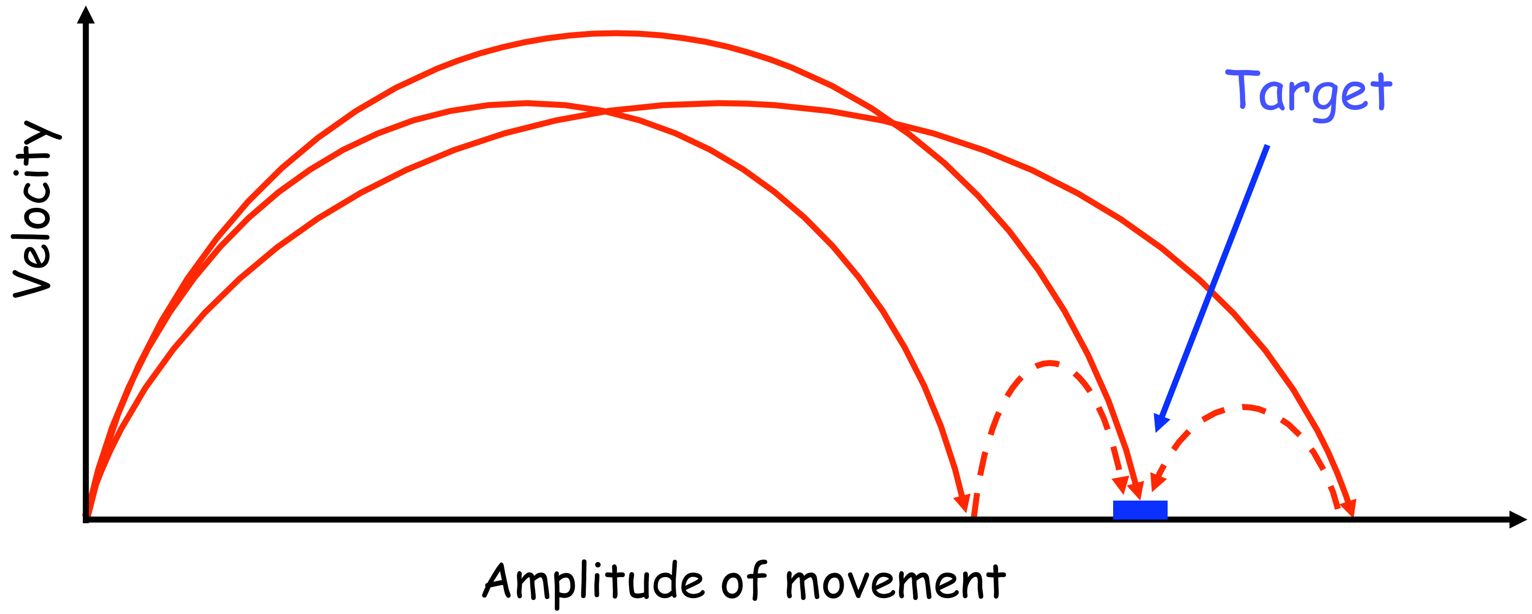
(1988,1990)

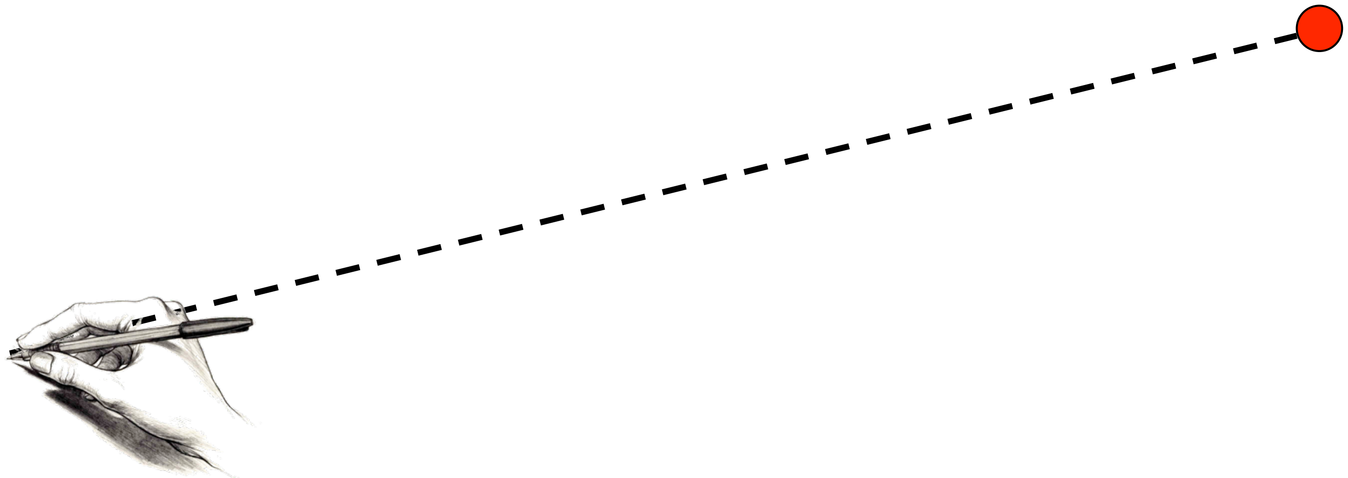
Visual feedback control
(Woodworth, 1899)

Impulse variability Model
(Schmidt, 1979)

Fitts' Law (1954) = ...

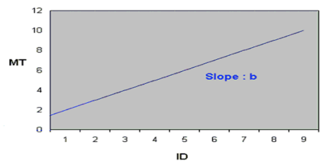
The Optimized Submovement Model





The Optimized Submovement Model

Fitts' Law



Movement time represents an outcome that merges from the relationship between the optimization of the initial impulse duration and the sub-movements under the control of vision that works as a feedback

Is the initial impulse modulated in a feedforward manner?

… but, violations of Fitts' law were observed :

- Whole body movements

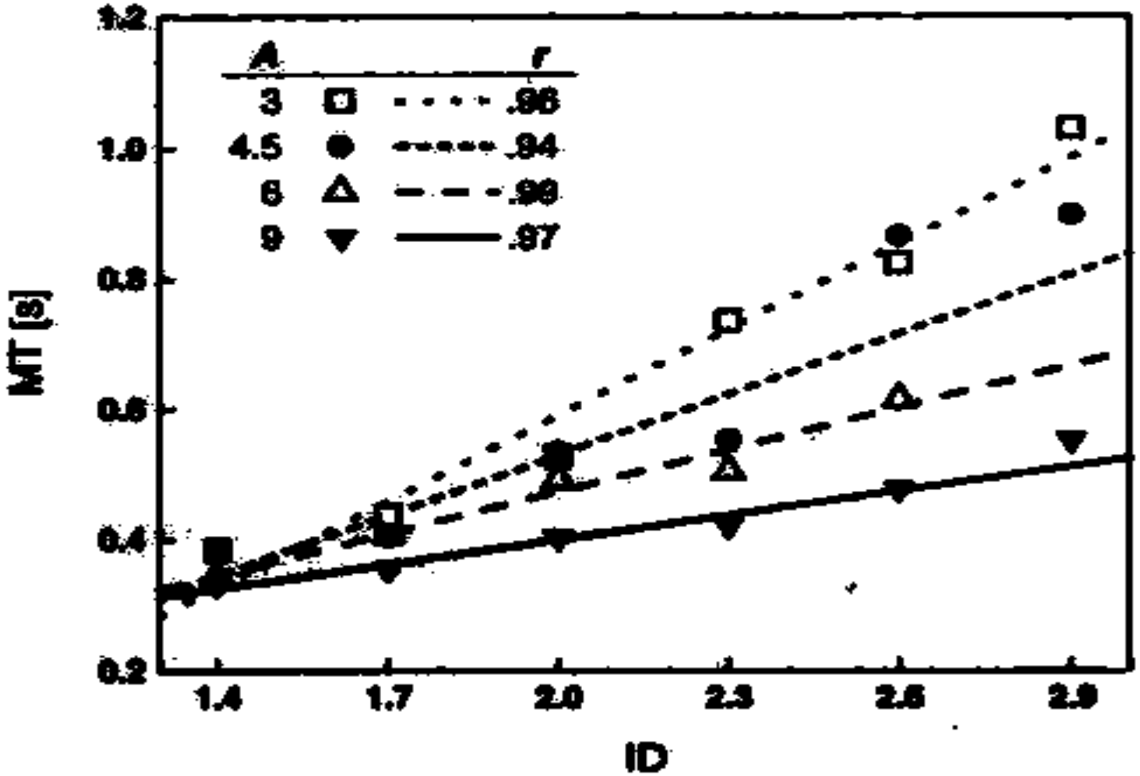
  Danion et al., 1999; Duarte & Latash, 2007

- Object transportation

  Cesari & Newell, 1999

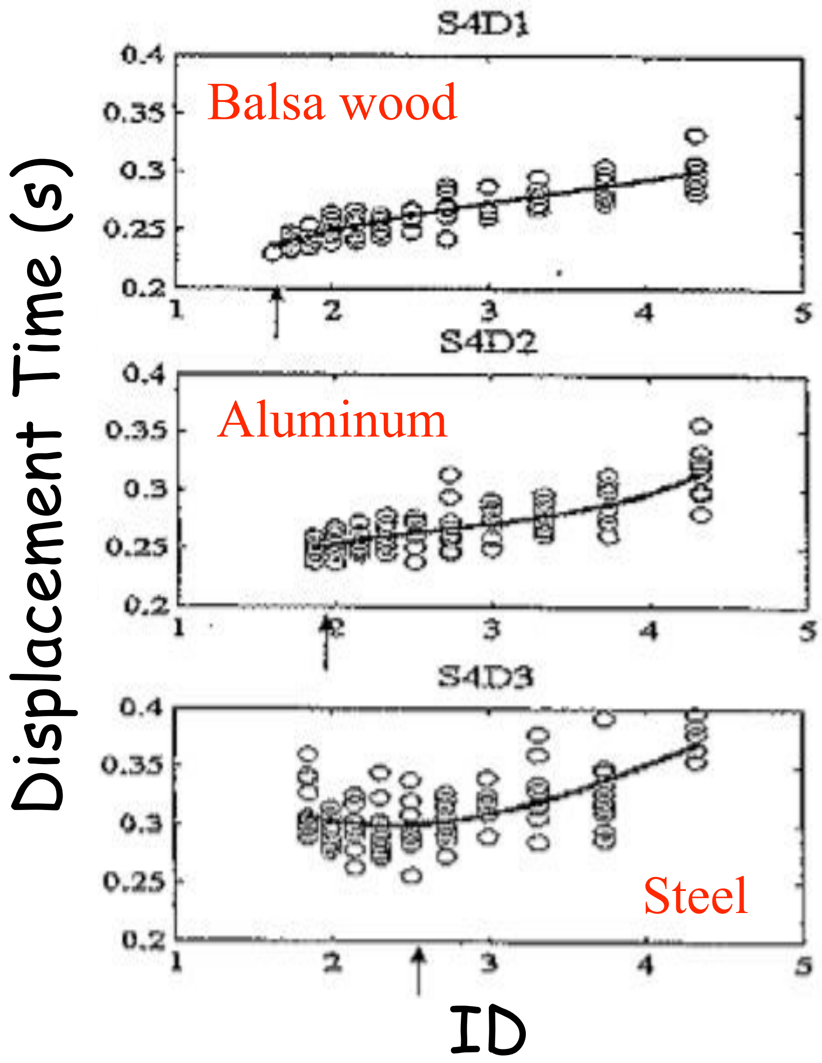
Danion et al. (1999): Body balance

COP oscillation under visual feedback in a Fitts' law paradigm.



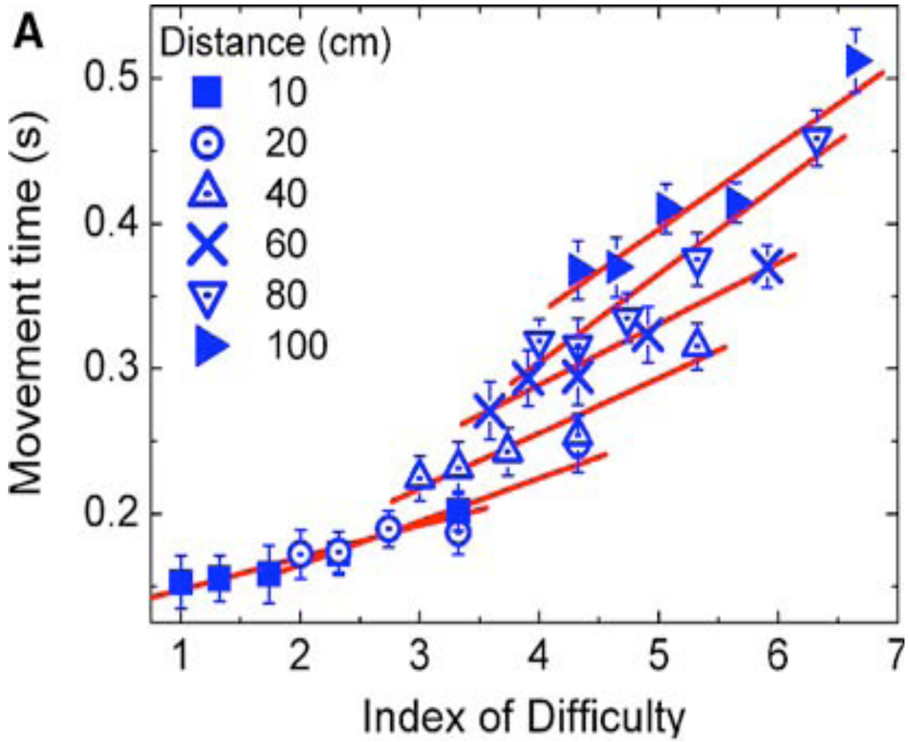
Cesari & Newell (2002): Object displacement

Displacement of spheres with different sizes and densities



Duarte & Latash (2007): Body displacement

Discrete pointing task with the foot at different target distances and widths



If Fitts' law (at a behavioral level) does not account for the influence of relevant biomechanical constraints

↓

What happen at the level of movement planning?

Is there an initial impulse that is modulated in a feedforward manner?

↓

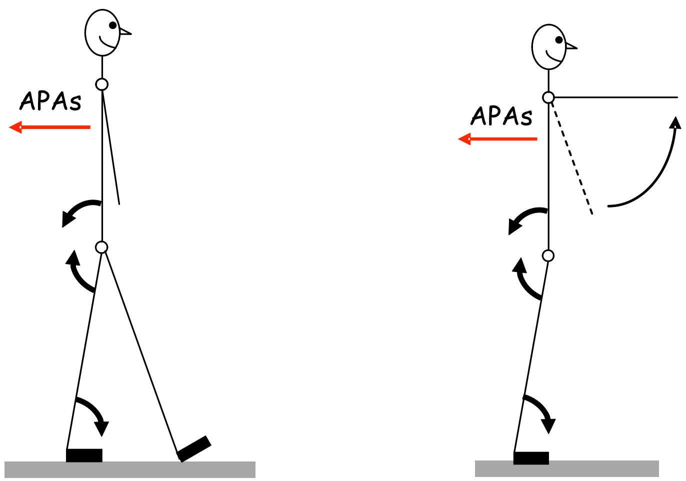
We may study the activity of the postural muscles before movement initiation: APA

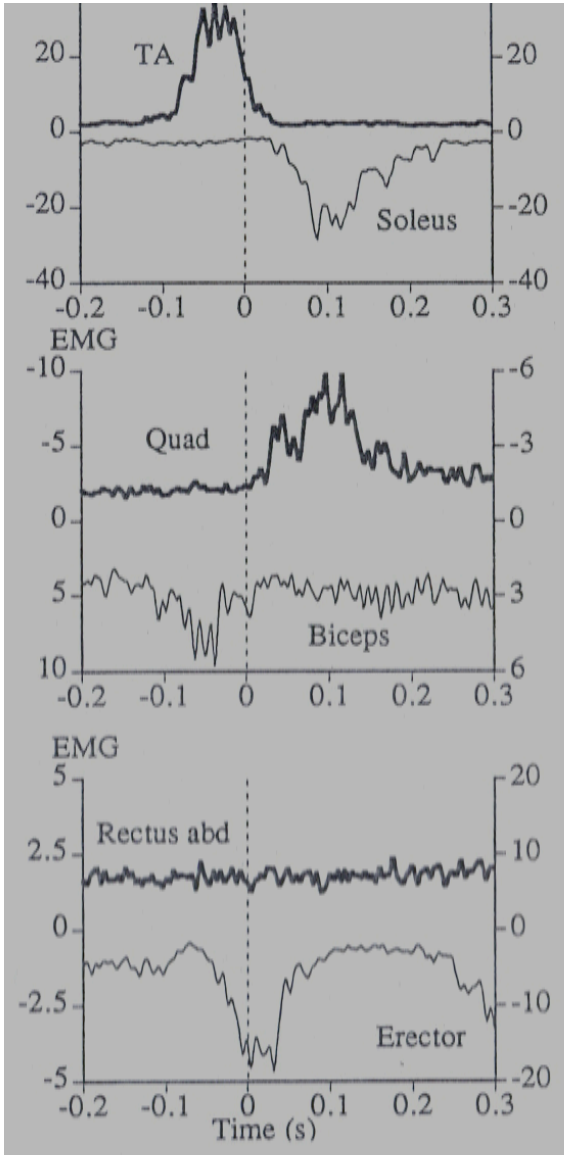
Anticipatory Postural Adjustments

❖ The APAs are postural muscles contractions that occur 150-200 ms before the actual movement initiation to counterbalance the expected perturbations generated by the actions.

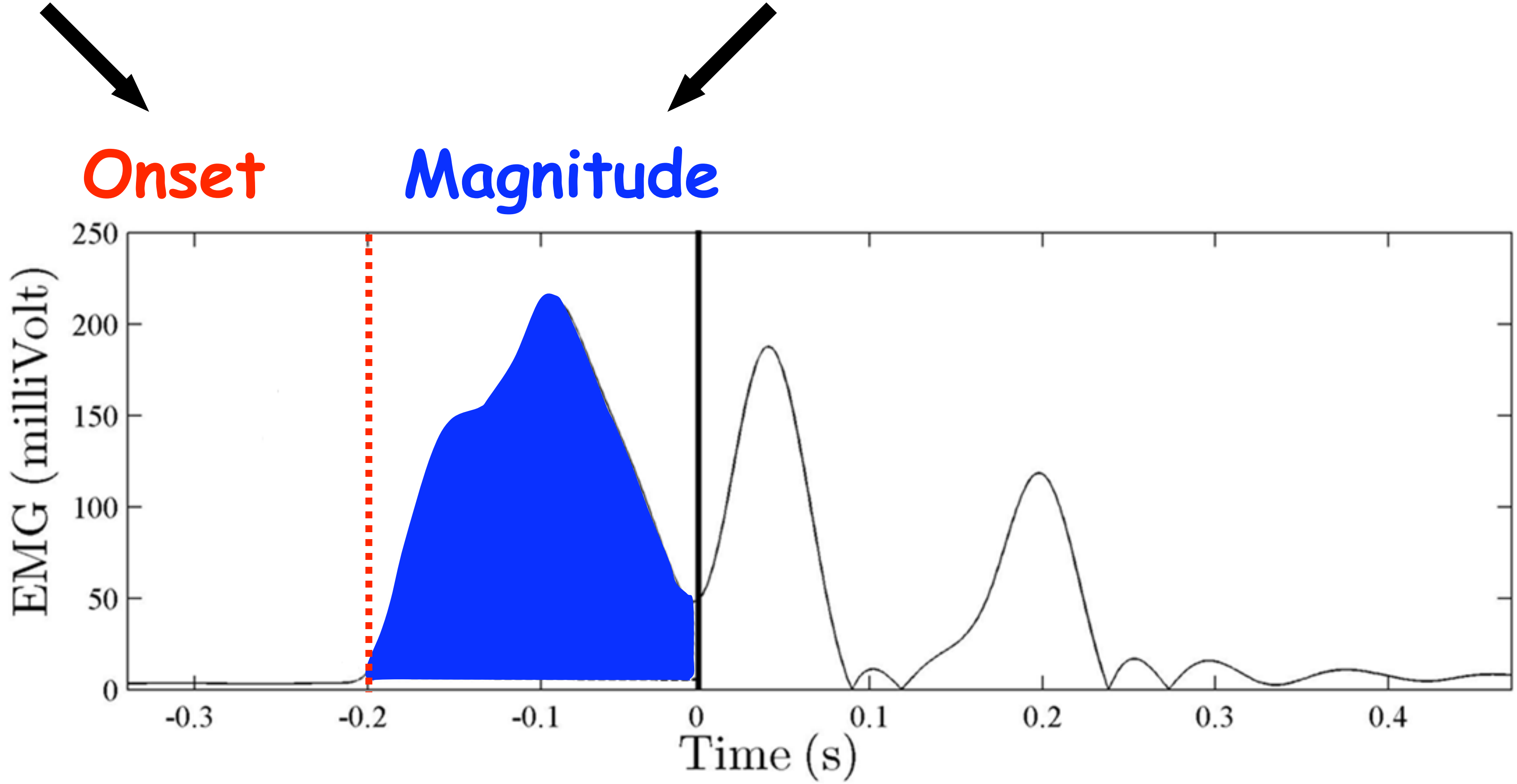
❖ They represent a typical feed-forward control.

(Belenkiy V.Y., et al, 1967; Bouisset S.M. & Zattara M., 1987; Massion J., 1992,1994; Latash M.L. 1998)





APAs parameters



Magnitude: Linearly related with the amount of action (Aruin & Latash, 1996) and with movement velocity (Horak et al., 1984; Ito et al., 2003)

Onset: Sensitive to the initial posture (Bouisset et al., 2000) and to the movement velocity (Brunt et al., 1999; Ito et al. 2003)

Main ideas

The beauty of testing APAs in a Fitts' task resides in taking advantage of the model's prediction about task parameters over performance as indicated by the ID

We might reveal how the CNS tunes the timing and the magnitude of APA with respect to task parameters for successfully accomplishing an action

Method: procedures

Subjects: 12 expert dancers

age = 26 ± 8 years

height = 1.64 ± 0.06 m

body mass = 52.4 ± 5.3 kg

Task: A discrete pointing movement to a target, as fast as precise as possible, with the preferred foot from a standing position.

→ Similar to a classical ballet exercise "*battement tendu*"

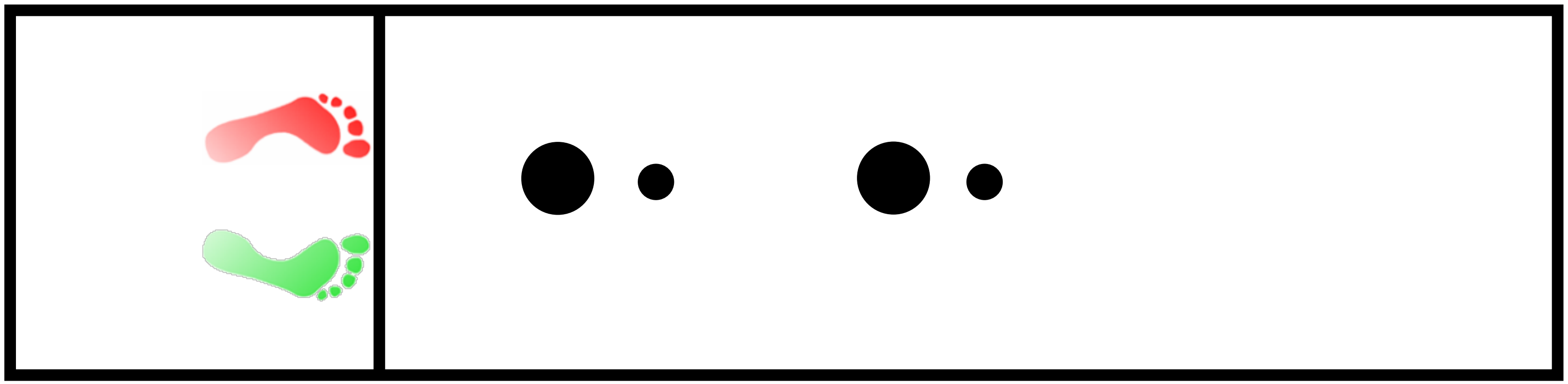
Method: procedures

Movement distances: 10 - 20 - 40 - 60 - 80 - 100 cm

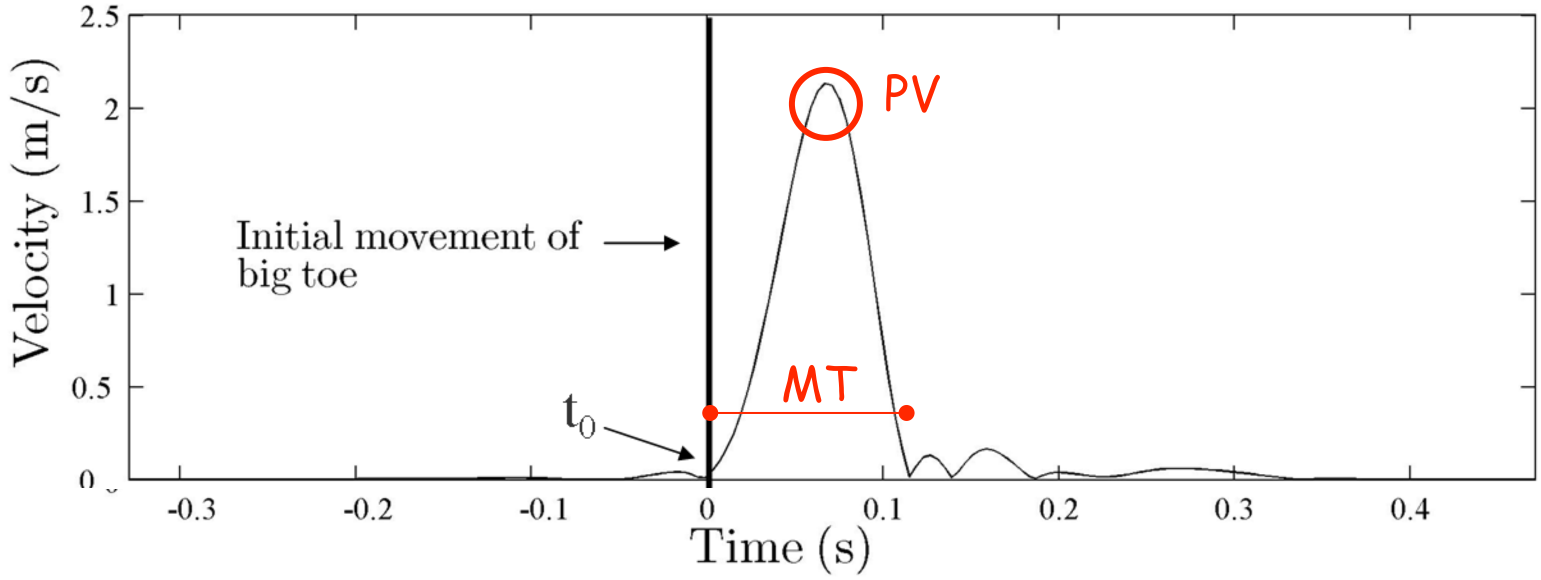
Target widths: 2 - 4 - 6 - 8 - 10 cm

ID [$\log_2$= (2A / W)] = from 1.00 to 6.64

30 conditions, 20 trials X condition



Method: kinematics variables



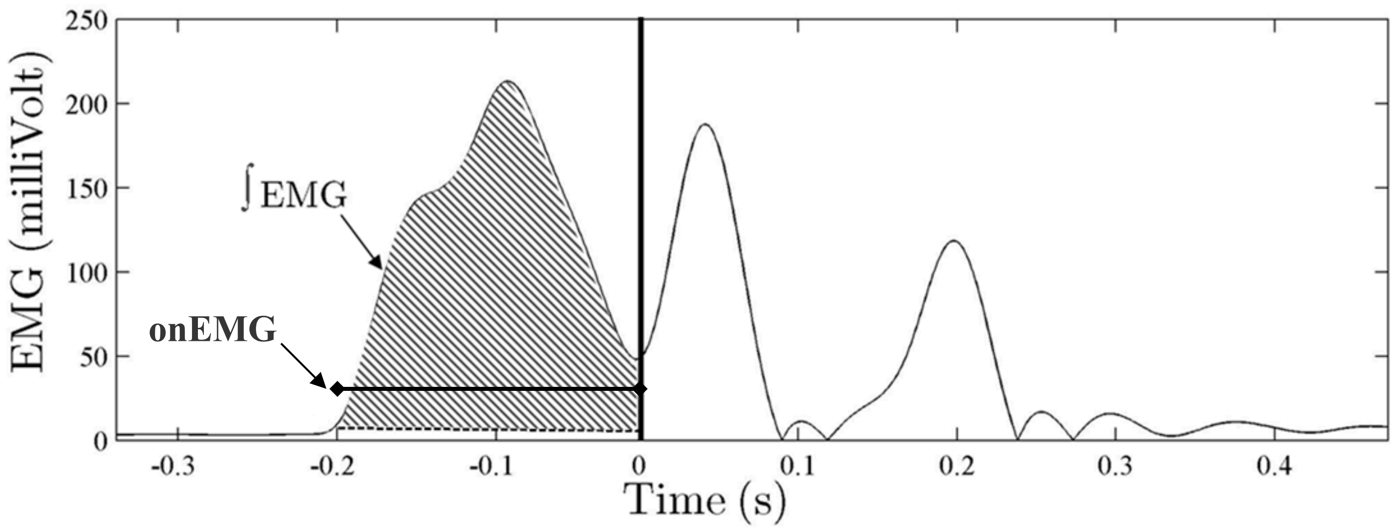
- Movement Time (MT)
- Peak of Velocity (PV)
- End-point Variability (We – Effective target width)

*defined as 4 * SD*

Method: EMG variables

APAs for both Tibialis Anterior

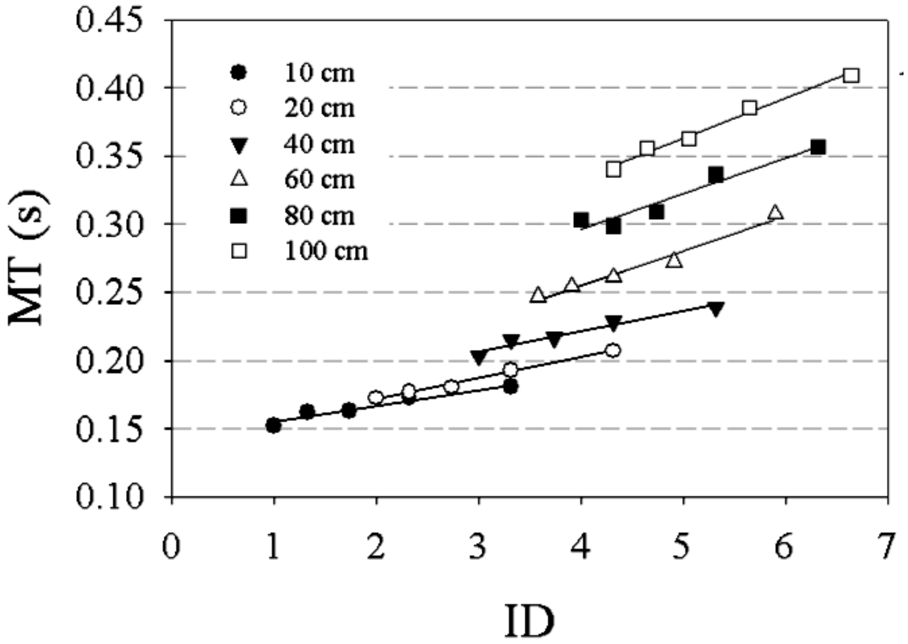
(TA Stance & TA Swing)

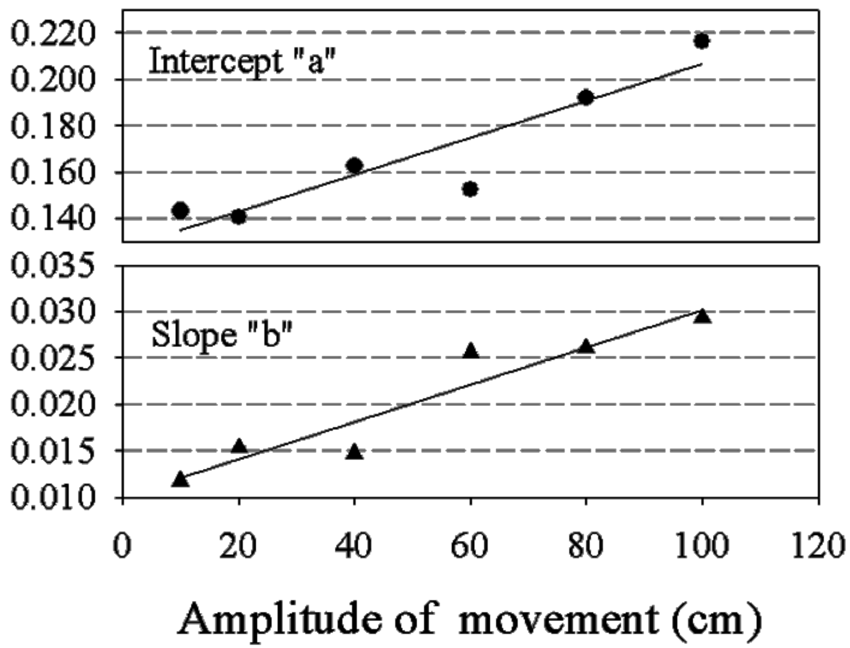


- Magnitude of the APA ($\int_{EMG}$)
- Onset of the APA (onEMG)

Eble et al., 1994; Brunt et al., 1991, 1999, 2000; Ito et al., 2003

Results-1

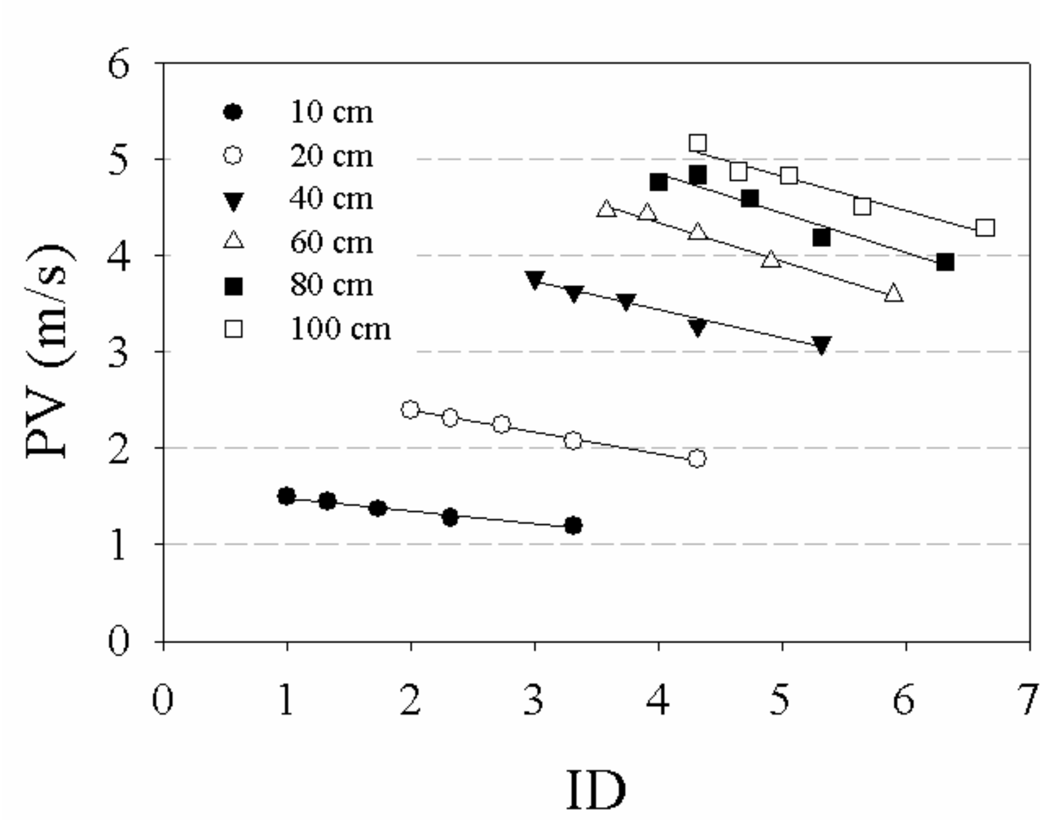




- As in Duarte & Latash linearity between MT and ID was not found
- MT scaled with ID within each amplitude separately

- The different slopes "b" and intercepts "a" are scaled with movement amplitudes

Results-2

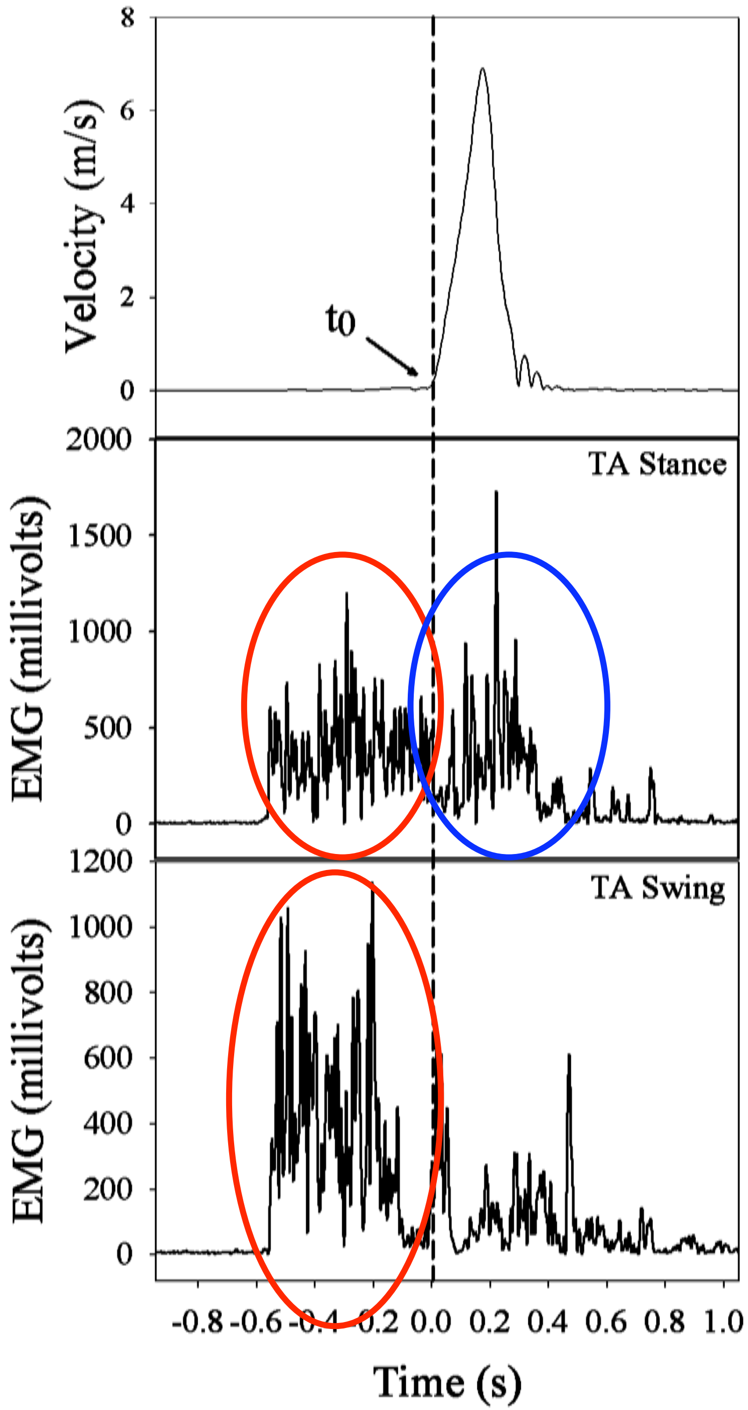


The peak of velocity (PV) was inversely related with ID for each movement distance separately

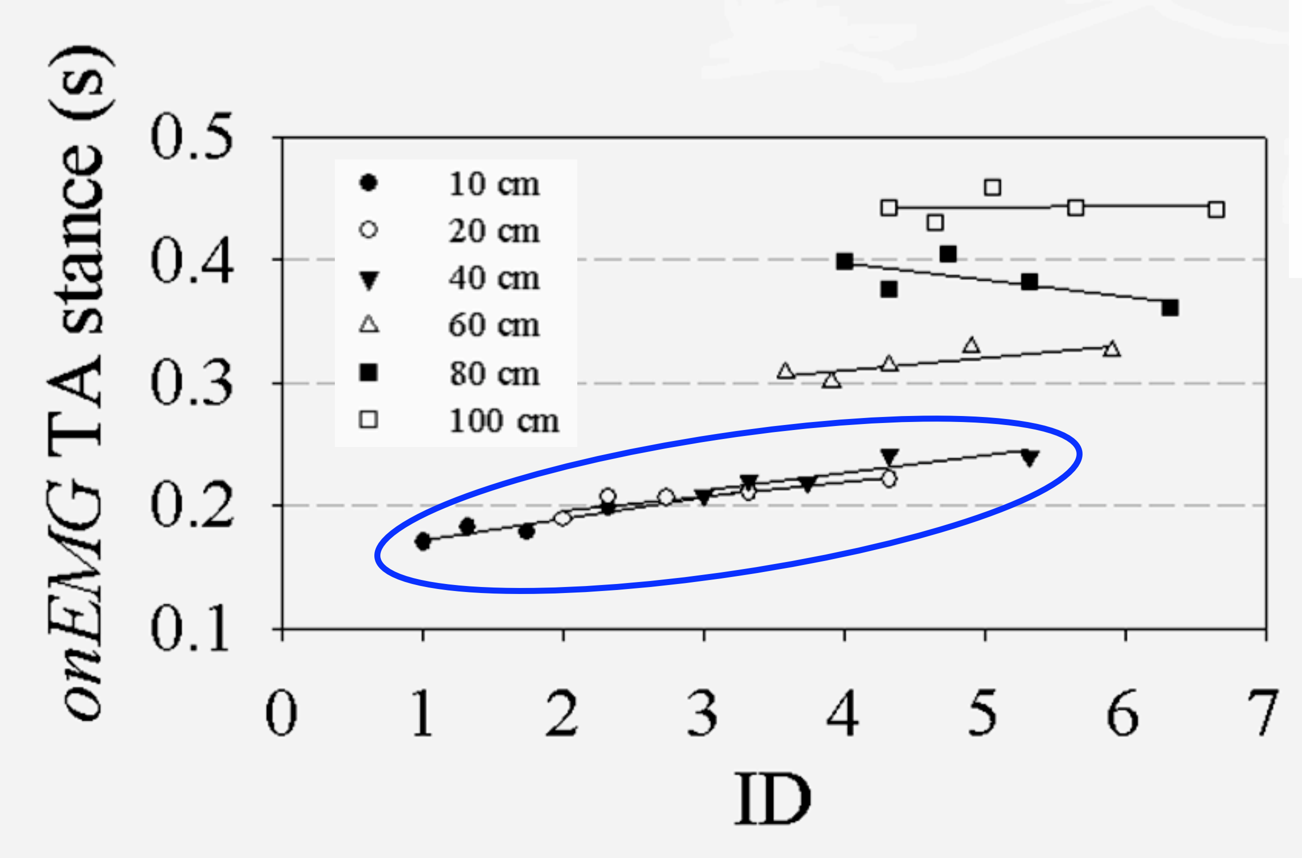
Results-3

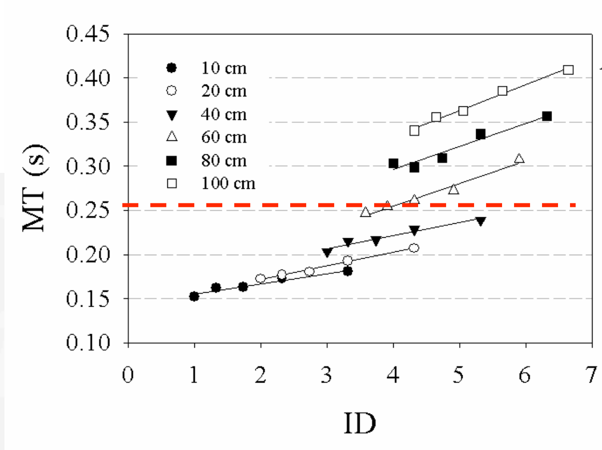
Typical kinematic and EMG profile before and during the pointing movement.

<u>None</u> modulation with the ID for the <u>TA Swing</u> was found



Results-4



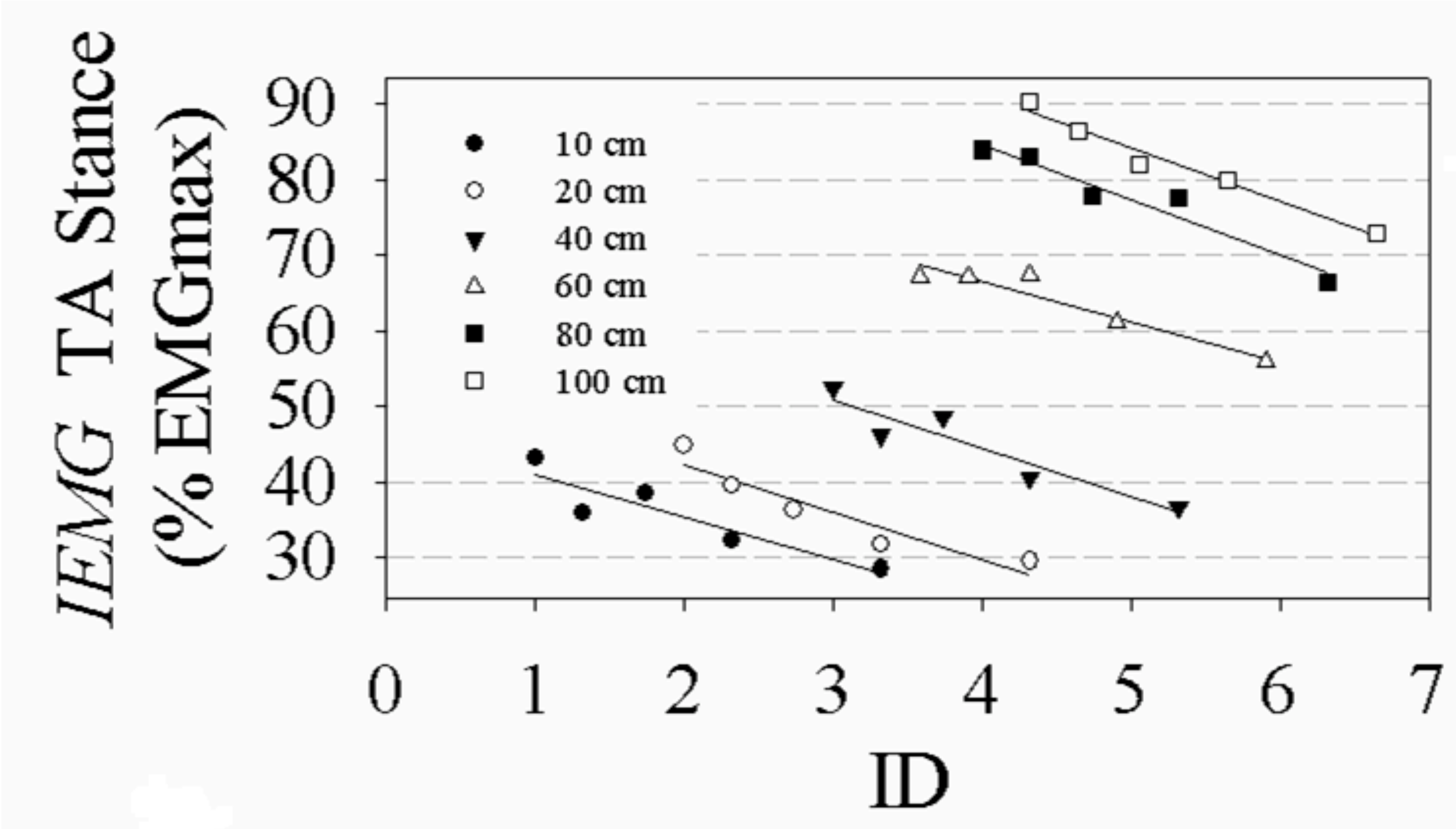


Onset modulation was found just for movements below 250ms with an r^2=0.91.

Critical boundary time below 200-250 ms

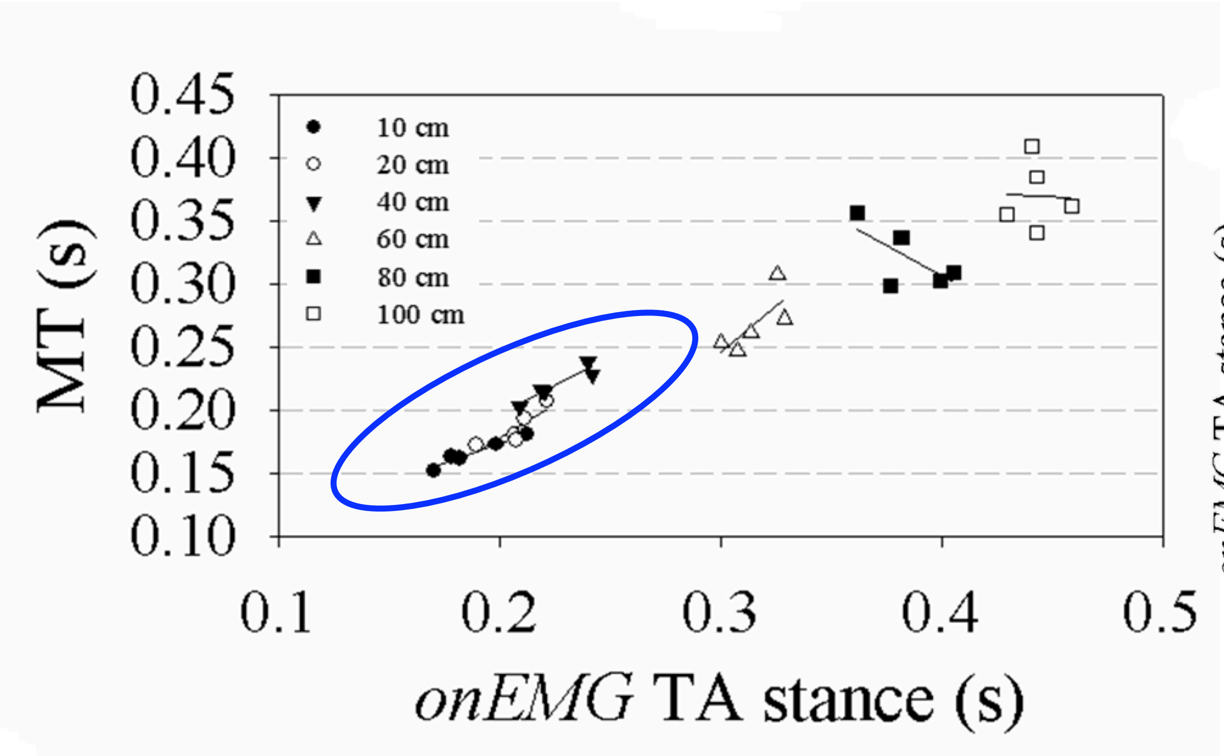
(Keele and Posner, 1968; Paillard, 1996 for a review)

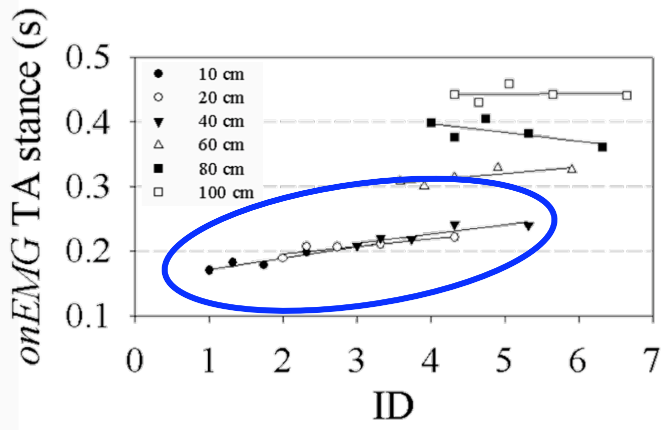
Results-5



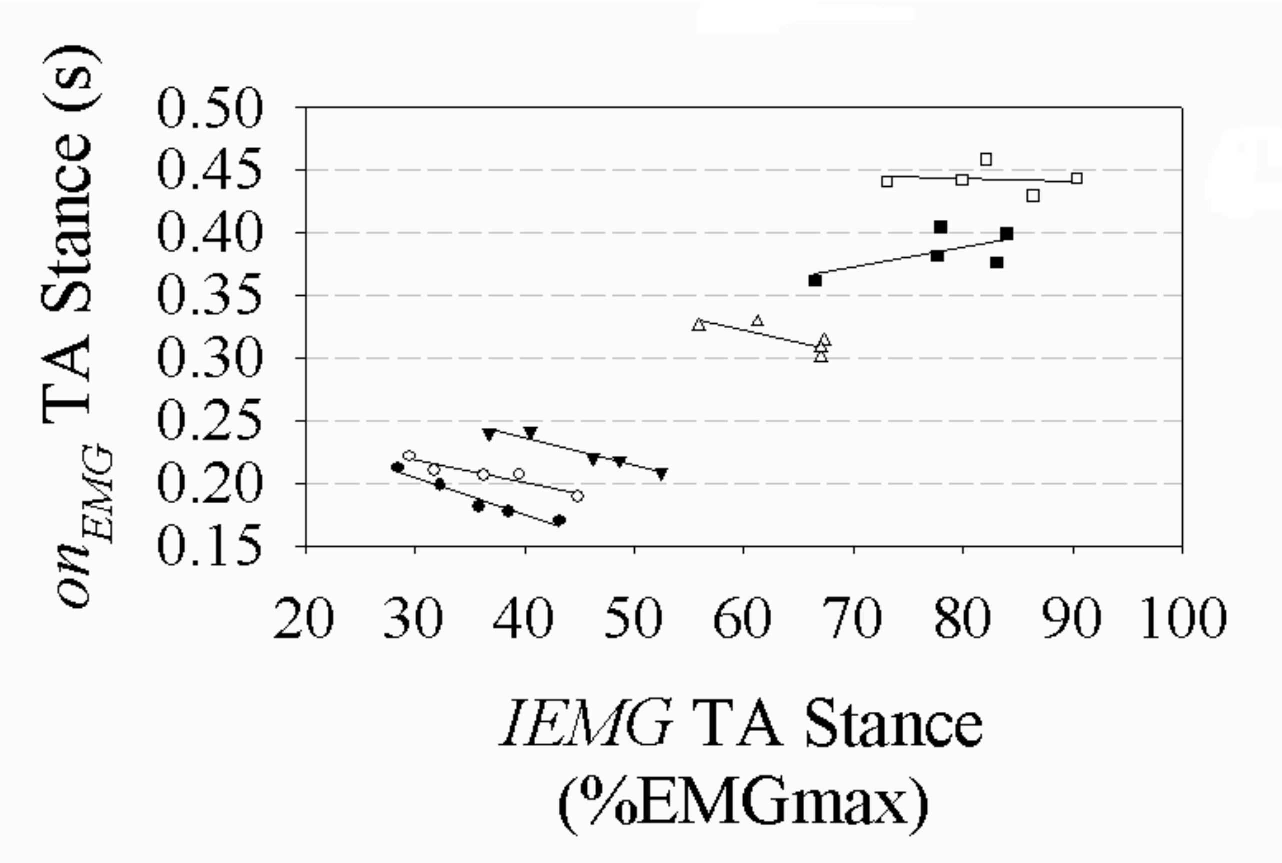
Conversely, the APA magnitude modulated with ID within each movement distance taken separately

Results-6





The same relationship was found just for the short distances considering the onEMG vs MT

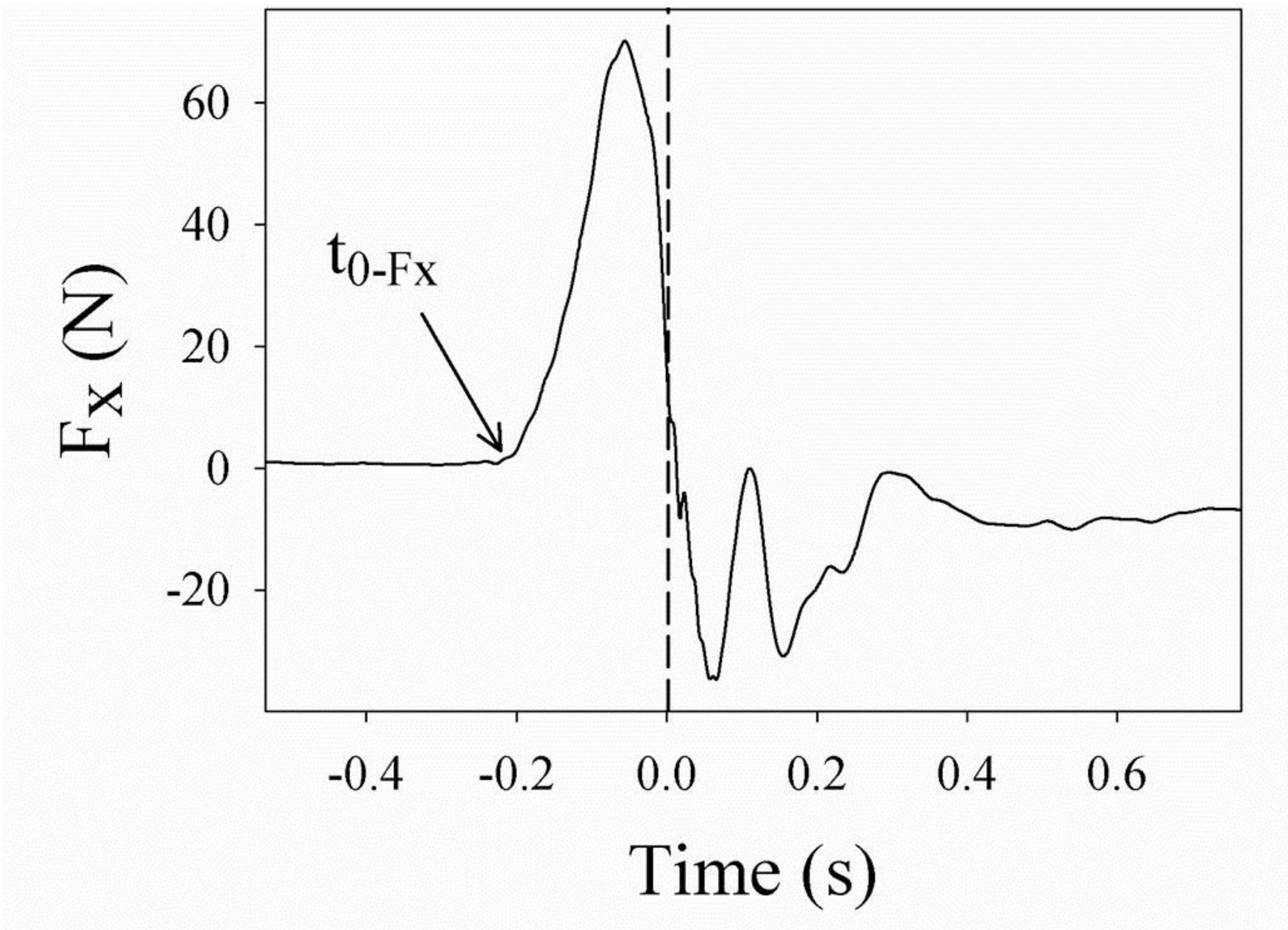


The APA magnitude and onset related exclusively for the **short distances**

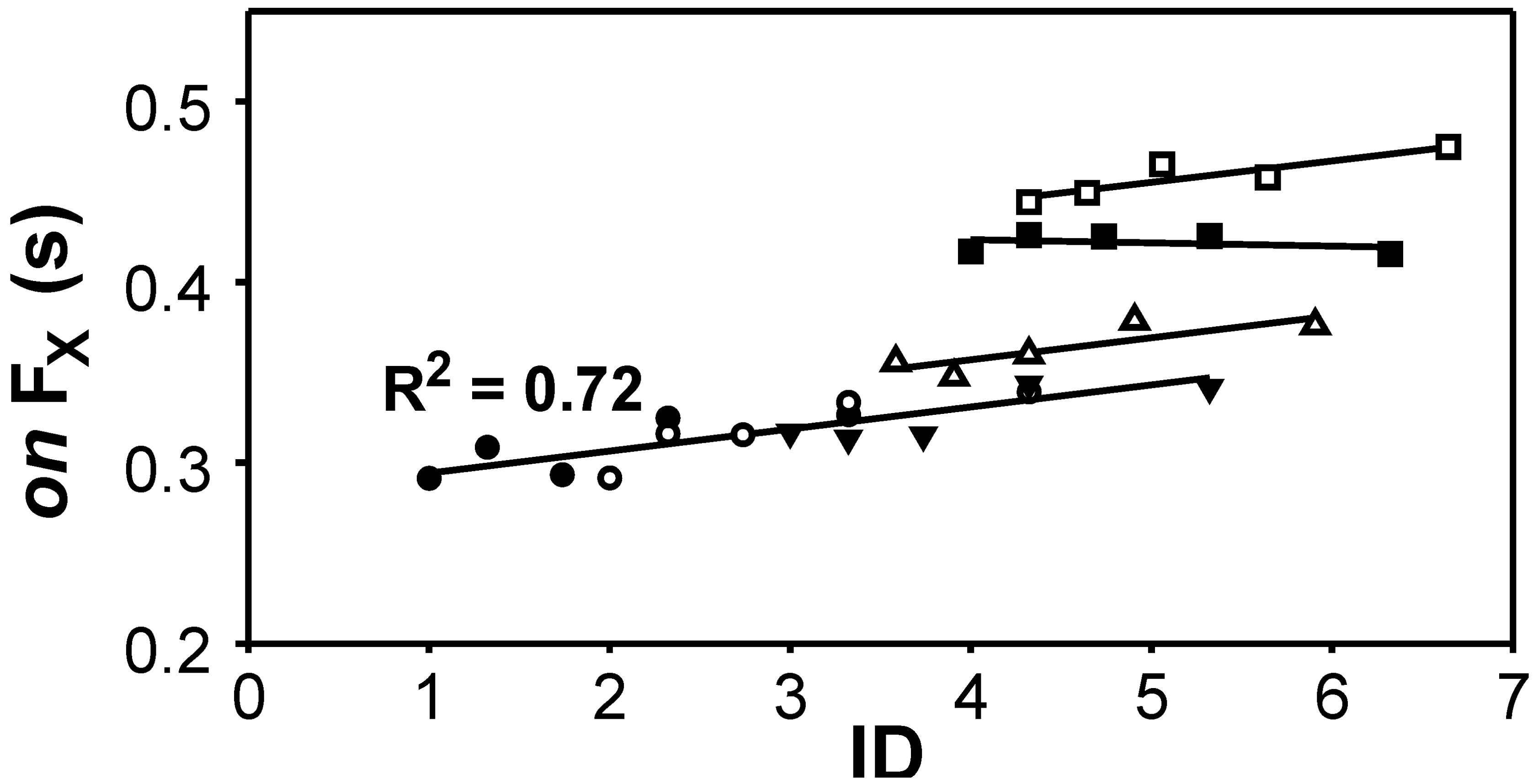
Critical boundary time below 200-250 ms

(Keele and Posner, 1968; Paillard, 1996 for a review)

Force platform



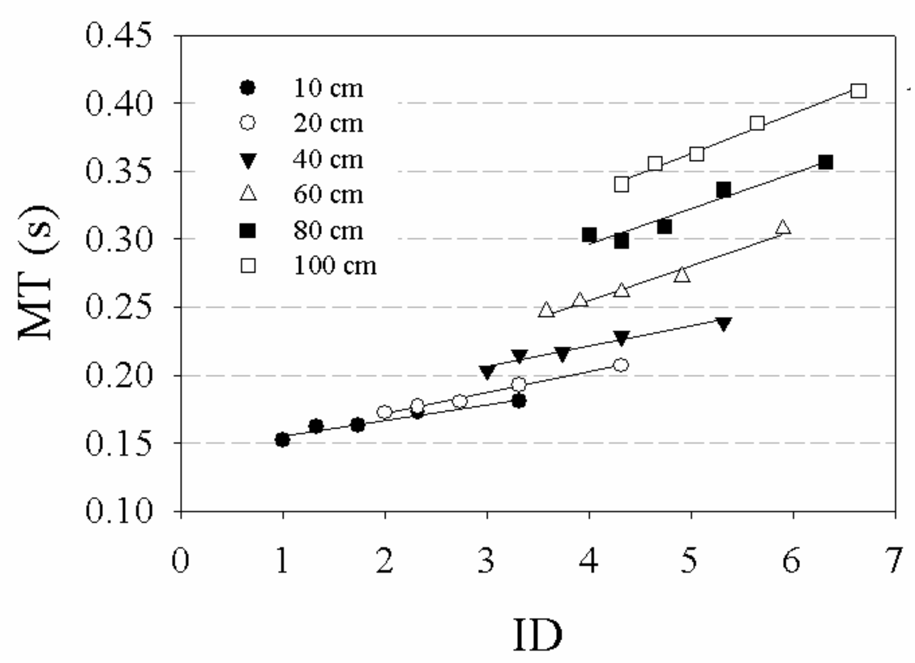
Force Platform latero-lateral direction onset



Conclusions

❖ Postural and mechanical constrains lead to a departure from the classical Fitt' law

❖ … so that the movement time is scaled with the ID within each target distance.



Conclusions

The APA onset is modulated with ID exclusively for the short distances

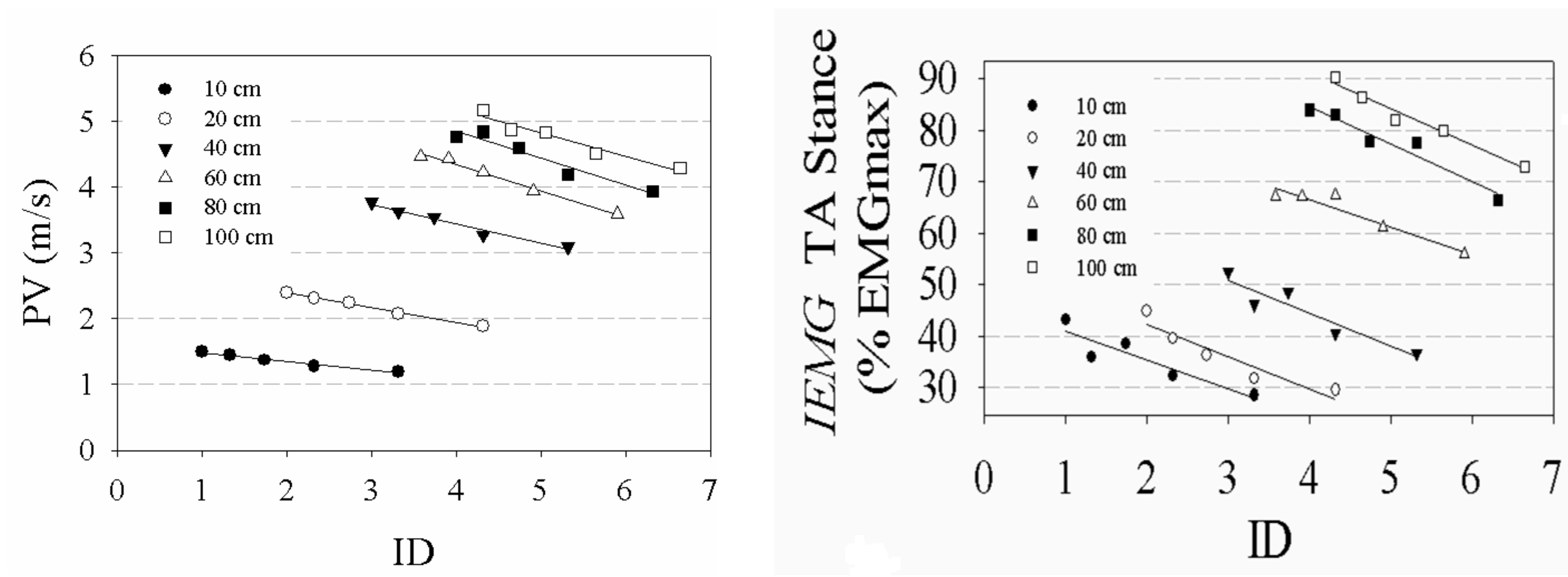
The APA magnitude is modulated with accuracy within each distance separately

APA *onset* and *magnitude* are independently organized by the CNS trough different pre-planning strategies…

In Jacobs et al. (2009) the supplementary motor area control APA timing (the onset) not APA magnitude

Conclusions

The APA magnitude is planned in advance of the forthcoming movement velocity taking into account both the target distance and width.



Conclusions

On the contrary APA onset is a more "*refined*" parameter and when on line feedback is not available the onset modulates with the ID

↳ As the difficulty of the task (ID) increases as the APAs occur earlier to maintain stability and to accomplish the accuracy demand

Conclusions

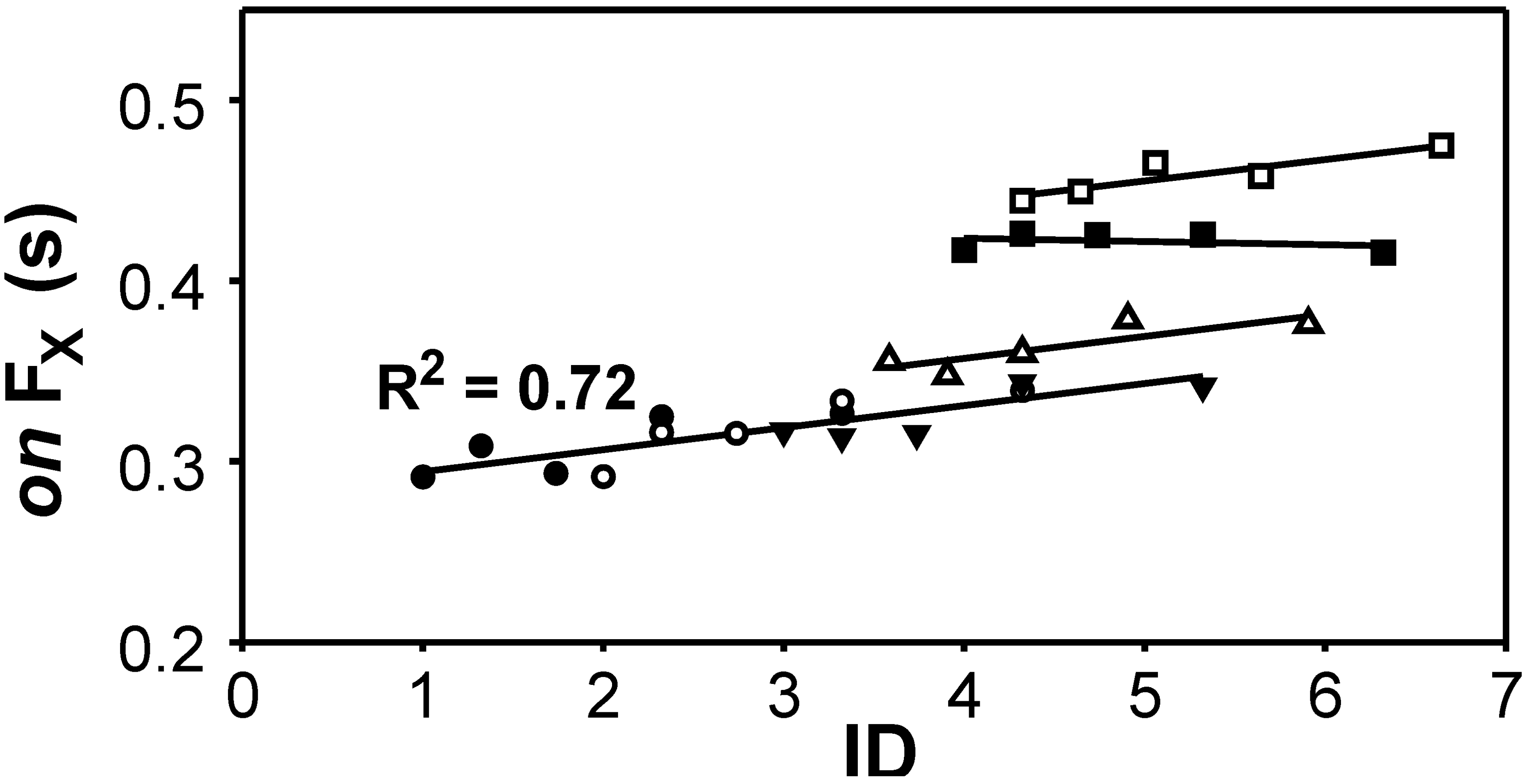
APA onset and magnitude are related when on line feedback is not available

As the difficulty of the task (ID) increases as the APAs occur earlier and magnitude decreases

(APAs may be perturbations for body stability)

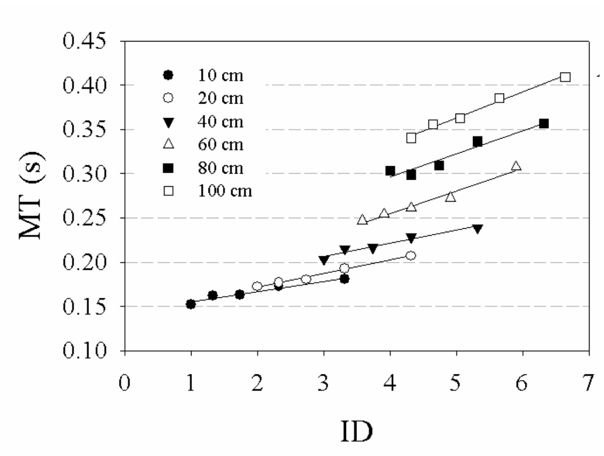
Conclusions

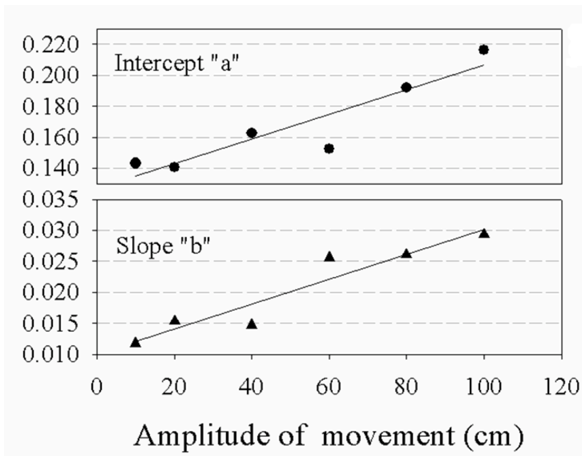
The total body displacement (COP) is related with the ID when on line feedback is not available

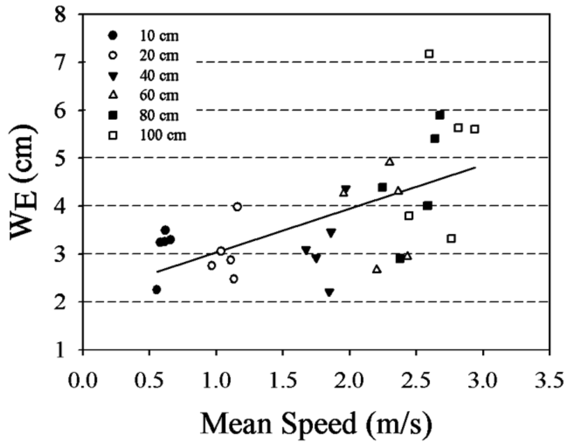


Conclusions

Expertise leads to a more reproducible outcome (the a & b constants) along with less variability at the target







Concluding Remarks

- **For step initiation the postural requirements lead to a departure from linearity (Fitt' law)**
- APAs onset and magnitude scaled according to movement parameters but not in the same way
- APA magnitude scaled with movement velocity while APA duration was sensitive to the ratio amplitude/accuracy by fallowing the ID
- When movement time does not allows for an on-line feedback control, the anticipatory temporal muscle activation acts as an independent central command that triggers a fine-tuning for speed-accuracy trade-off following Fitts' law.