Variational Approach of Motor Control

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Abbreviated abstract: The dynamics that govern the temporal evolution of the trajectory of the upper limbs has been derived from the minimum jerk principle and has been experimentally confirmed. This work proposes another organizational principle for the control and execution of movement and compares which model better fits the experimental data. The motor control theory proposed in this work is based on parameter optimization methods, through variational calculus and optimal control theory. The cost function to be minimized is the integral of time of the square of acceleration.

Related publications:

– MIRANDA, J.G.V. et al., *Scientific Reports 8 (1),* 12918 (2018)
– FLASH, T.; HOGAN, *The Journal of Neuroscience* 5 (7), 16688-1703 (1985)

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Previous Works

Minimum Jerk Model
- (Hogan, 1984)

Reach

$$A = \int_{t_0}^{t_f} \left(\left(\frac{d^3x}{dt^3} \right)^2 + \left(\frac{d^3y}{dt^3} \right)^2 \right) dt.$$

- (Flash; Hogan, 1985)

Reach

$$q(t) = q(t_f)\left(6\left(\frac{t}{t_f} \right)^5 - 15\left(\frac{t}{t_f} \right)^4 + 10\left(\frac{t}{t_f} \right)^3 \right).$$

Minimum Jerk Model Plus Time Cost
- (Hoff, 1994)

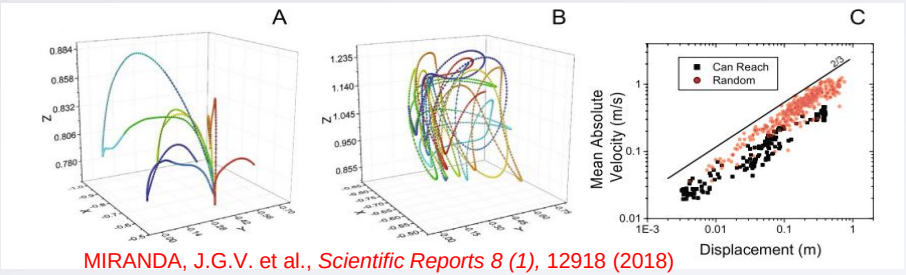
Reach

$$t_f = (60D)^{1/3} R^{1/6}.$$

Movement Element Decomposition
- (MIRANDA, J.G.V. et al., 2018)

Random

$$v_m = \frac{D^{2/3}}{60^{1/6} K^{1/6}},$$



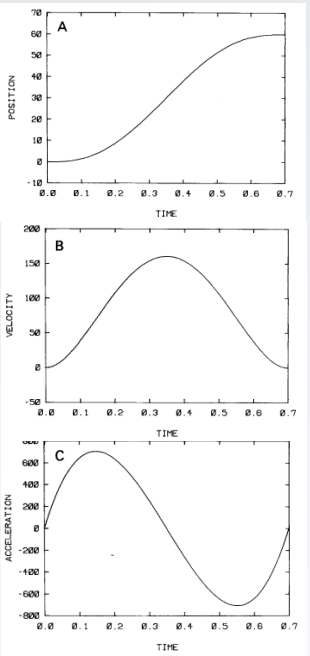
MIRANDA, J.G.V. et al., *Scientific Reports 8 (1)*, 12918 (2018)

Our Proposal

Minimum Aceleration Model

$$A = \int_{t_0}^{t_f} \left(\left(\frac{d^2x}{dt^2} \right)^2 + \left(\frac{d^2y}{dt^2} \right)^2 \right) dt.$$

$$q(t) = q(t_f)\left(-2\left(\frac{t}{t_f} \right)^3 + 3\left(\frac{t}{t_f} \right)^2 \right).$$



HOGAN., *Jornal of Neuroscience 4 (11), 2745-2574 (1984)*

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Methods

Participants:

- Ten healthy subjects
- Seven males, Nine right-handed

Experimental Procedures:

- Ten camera
- Tree-dimensional random
- One-dimensional goal-directed movements

Data Processing:

- Low-Pass Filter (10 Hz)
- Derived Velocity Profile
- Movement Element Decomposition (MED)

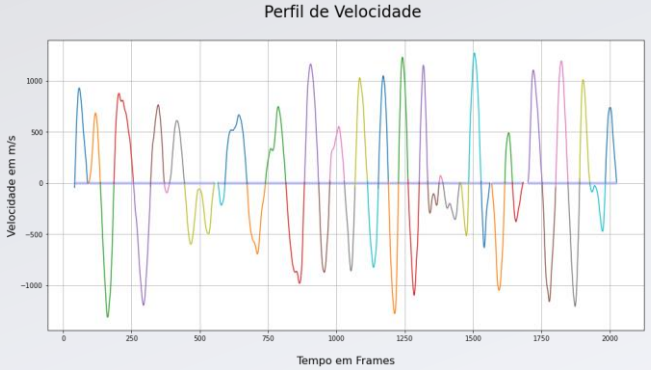
Statistical:

- Descriptive Statistics
- Pearson Correlation
- Estimator W
- Wilcoxon Teste

$$W = \frac{1}{N}\sum_{i=1}^{N}\frac{\sigma\left(w_{i,m}(t) - v_{i,m}(t)\right)}{\overline{w_{i,m}}},$$

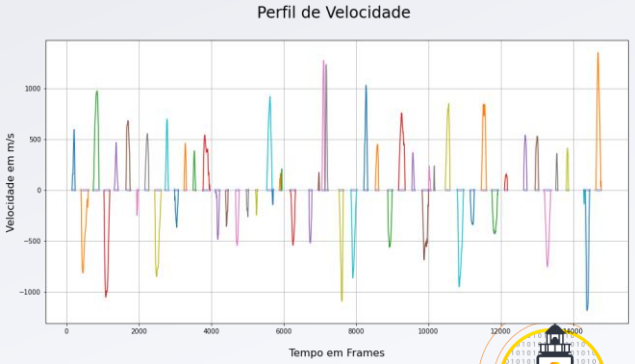
Random:

LimT = 100 ms
LimD = 3mm
LimV = 10 mm/s



Reach:

LimT = 200 ms
LimD = 20 mm
LimV = 10 mm/s



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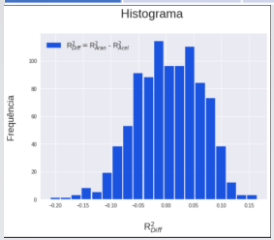
Results and Conclusions

Reach

Estatística Descritiva

	Modelo	N	Média	Mediana	Desvio Padrão
R^2	Arranque	936	0.809	0.862	0.178
	Aceleração	936	0.805	0.858	0.161



Shapiro-Wilk: p-value < 0.001
Kolmogorov-Smirnov: p-value = 0.036

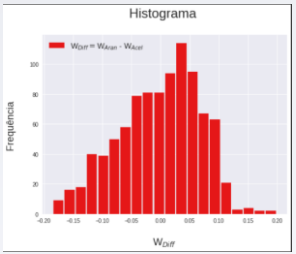
Wilcoxon: p-value = 0.002

Estatística Descritiva

	Modelo	N	Média	Mediana	Desvio Padrão
W	Arranque	936	0.287	0.239	0.184
	Aceleração	936	0.298	0.251	0.164

Shapiro-Wilk: p-value < 0.001
Kolmogorov-Smirnov: p-value = 0.03

Wilcoxon: p-value = 0.86



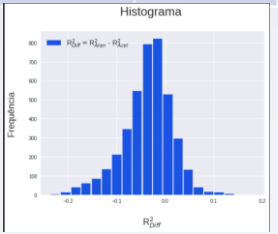
Random

Estatística Descritiva

	Modelo	N	Média	Mediana	Desvio Padrão
R^2	Arranque	4084	0.752	0.872	0.276
	Aceleração	4084	0.787	0.904	0.262

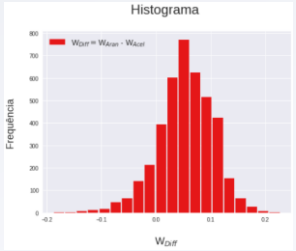
Shapiro-Wilk: p-value < 0.001
Kolmogorov-Smirnov: p-value < 0.001

Wilcoxon: p-value = 0.002



Estatística Descritiva

	Modelo	N	Média	Mediana	Desvio Padrão
W	Arranque	4084	0.307	0.217	0.249
	Aceleração	4084	0.253	0.175	0.226



Shapiro-Wilk: p-value < 0.001
Kolmogorov-Smirnov: p-value < 0.001

Wilcoxon: p-value = 0.002

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