



ÉCOLE **POLYTECHNIQUE**

Recent developments in the Study of Rapid Human Movements with the Kinematic Theory

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SCRIBENS LABORATORY

École Polytechnique

Theory

Modelling of Trajectory Perception
and Human Movement Generation

Applications

Automatic Processing of Handwriting

PROJECTS

BIOMETRY

Automatic
Signature
Verification

RECOGNITION

On-line
Handwriting
Processing

EDUCATION

Handwriting
Learning
Tools

BIOMEDICAL

Neuromuscular
Condition
Evaluation

DOCUMENTS

Model-based
Preprocessing

Collaborators

- Dr Moussa Djoua
- Dr Chunhua Feng
- Dr Anna Woch
- Mr. Christian O'Reilly
- Mr. Mohamed-Kefil Landou
- Prof. Pierre A. Mathieu
- Prof. Brigitte Stemmer

What is a Stroke?

Marque allongée, exécutée dans une direction déterminée (ligne droite ou courbe ouverte) , surtout quand on la forme sans lever l'instrument (crayon, pinceau, plume, ...)

Petit Robert 2006

A mark made by the movement in one direction of a pen or a pencil.

Canadian Oxford 2004

Basic Characteristics of a Single Stroke

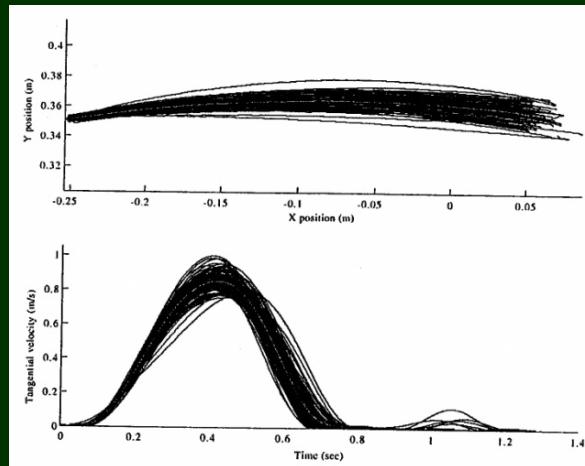
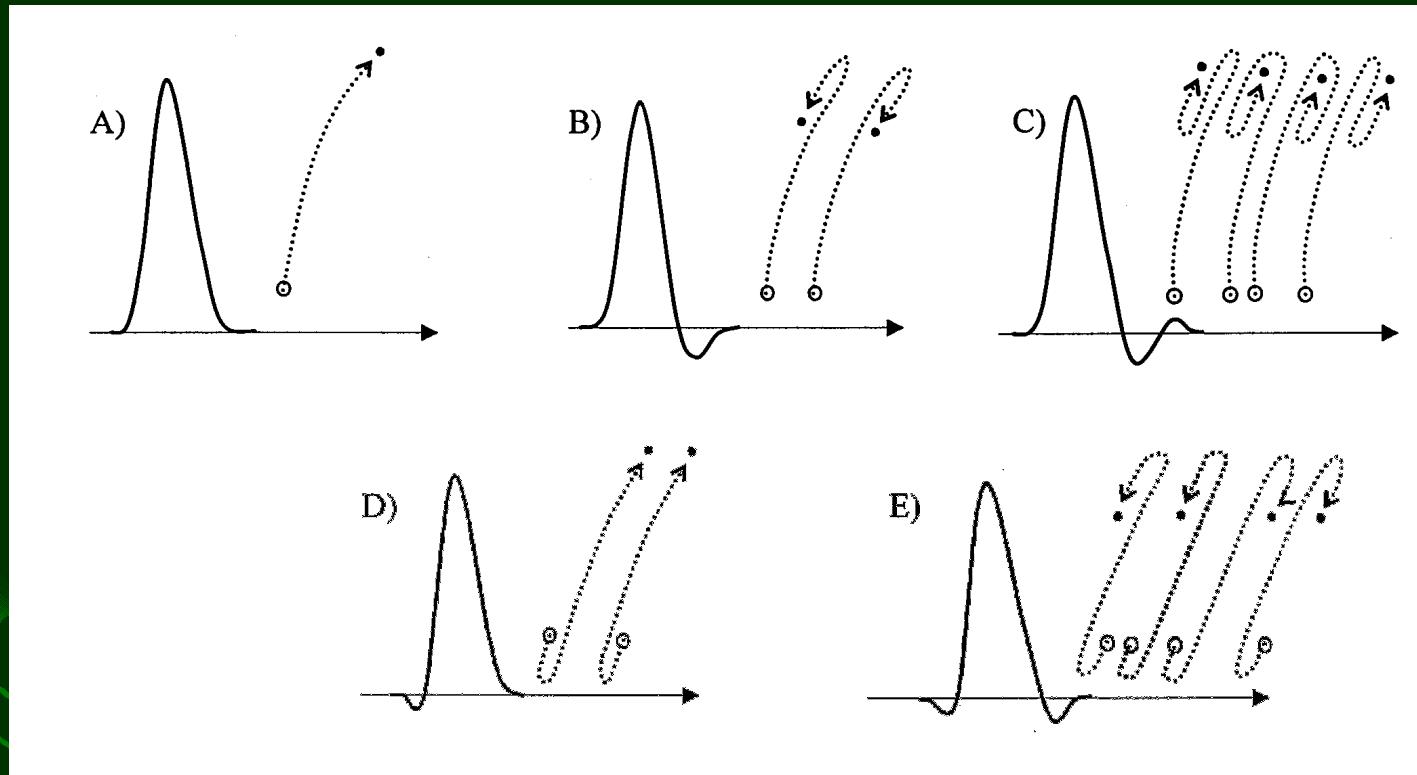


Figure : Typical trajectories and velocity profiles

- **No visual feedback**
- **Almost rectilinear trajectory of the end effector**
- **Asymmetric bell-shaped velocity profile**
- **Up to two secondary velocity peaks**
- **Possible direction inversion at the beginning and/or at the end**
- **Speed accuracy trade-offs**

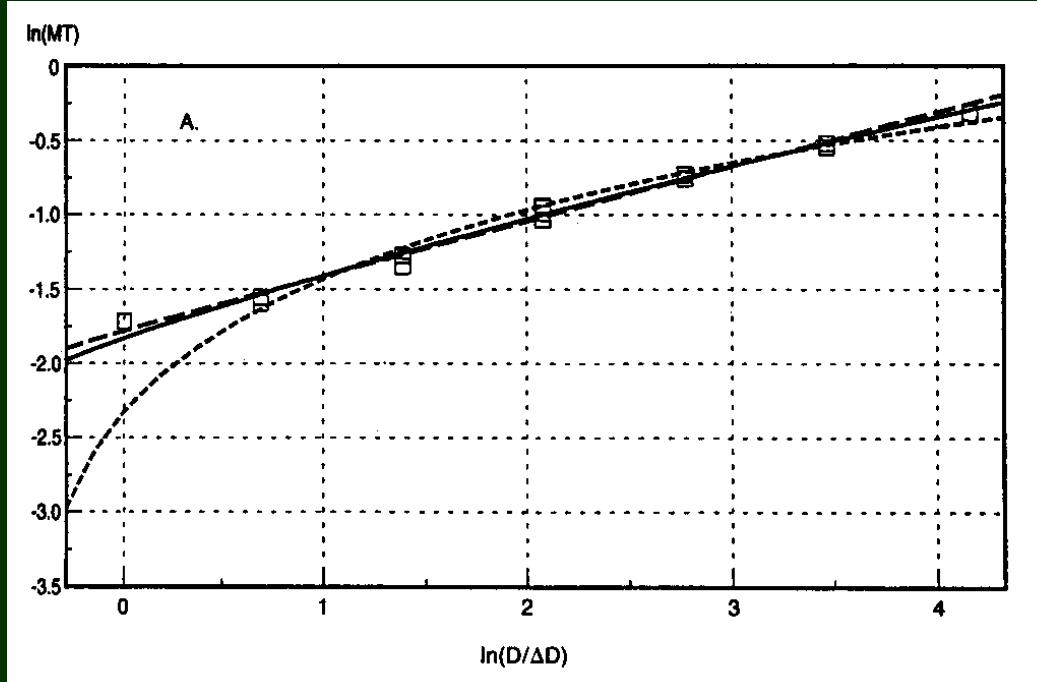
Miyamoto H., Wolpert D.M., Kawato M., (2002) in: Biologically Inspired Robot Behavior Engineering, Springer-Verlag.

Typical Velocity Profiles and Trajectories



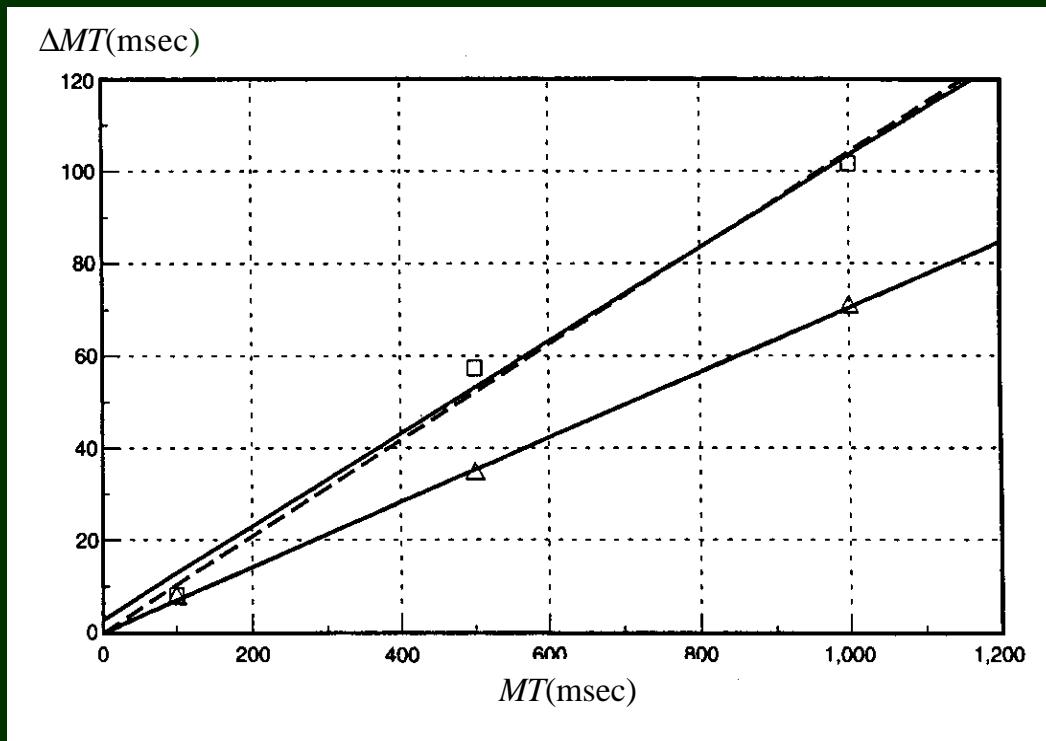
WOCH, A., PLAMONDON, R., "Using the Framework of the Kinematic Theory for the Definition of a Movement Primitive", Motor Control, vol 8, pp.547-557, 2004.

Speed accuracy trade-offs: spatial accuracy



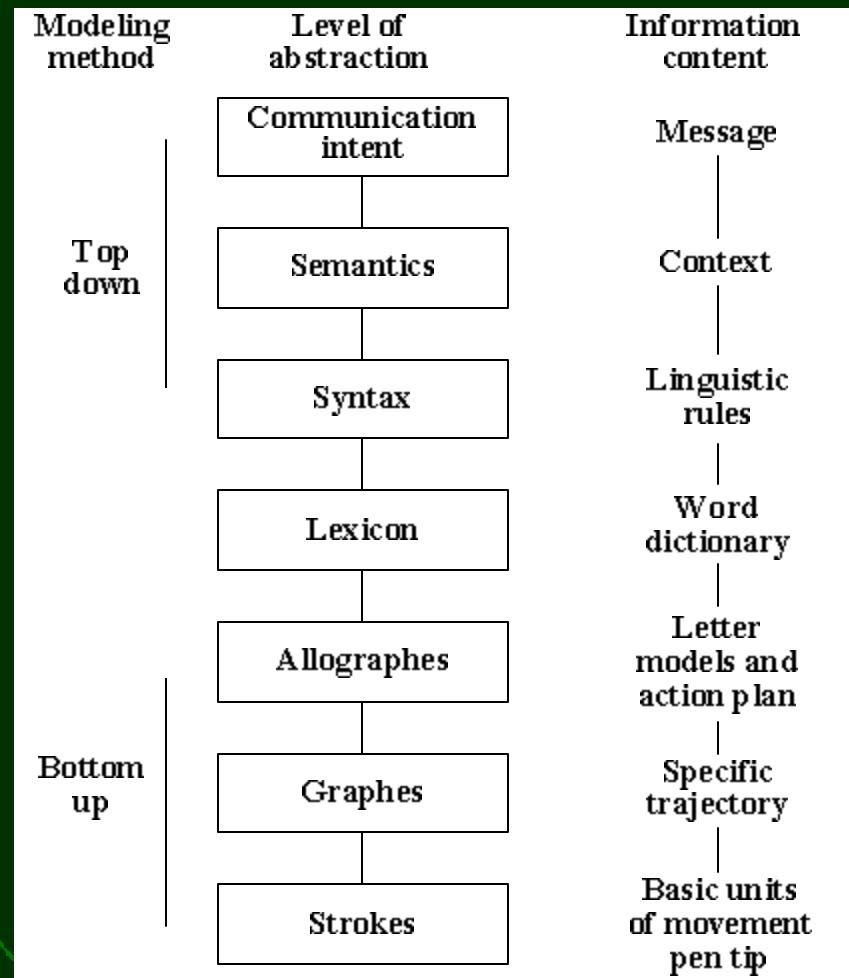
PLAMONDON, R., ALIMI, A., "Speed/Accuracy Tradeoffs in Target Directed Movements", Behavioral and Brain Sciences, vol. 20, no 2, 1997, p. 279-349.

Speed accuracy trade-offs: temporal accuracy



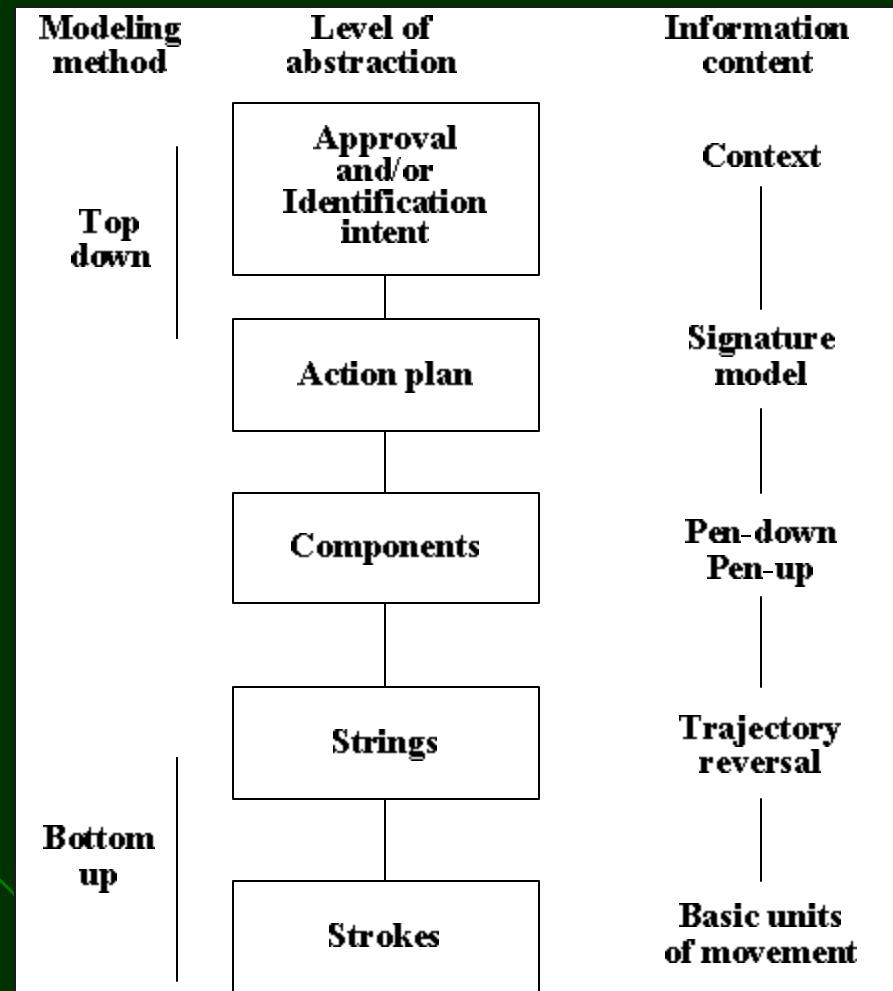
PLAMONDON, R., ALIMI, A., "Speed/Accuracy Tradeoffs in Target Directed Movements", Behavioral and Brain Sciences, vol. 20, no 2, 1997, p. 279-349.

HANDWRITING GENERATION



PLAMONDON, R., LOPRESTI, D., SCHOMAKER, L.R.B., SRIHARI, R., "On-Line Handwriting Recognition", Encyclopedia of Electrical and Electronics Engineering, J.G. Webster (Ed.), John Wiley & Sons, N.Y., vol. 15, 1999, p. 123-146.

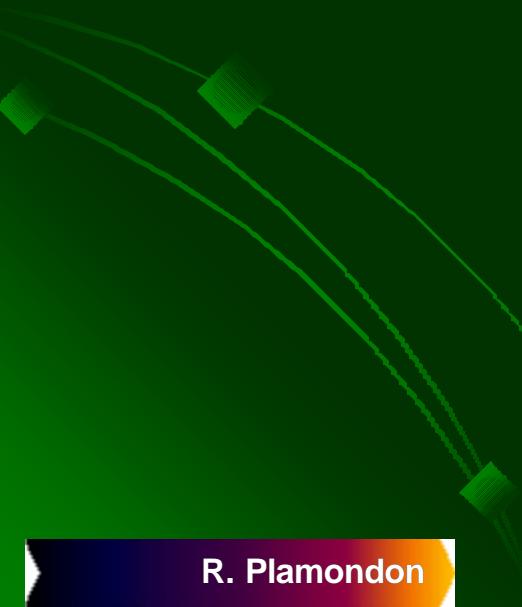
SIGNATURE GENERATION



Model Classification

- Criterion: Motor Control Basic Hypothesis
 - ❖ Equilibrium Point (Feldman ,Bizzi, Hollerbach...)
 - ❖ Neural Networks (Bullock, Schomaker, Gangadhar...)
 - ❖ Optimization Principles (Flash, Hogan, Kawato...)
 - ❖ Behavioral Action Plans (Schmidt, van Galen...)
 - ❖ Non-linear Dynamics (Kelso, Athenes, Zazone...)
 - ❖ Proportionality and Convergence (Plamondon)

Introduction to the Kinematic Theory



Basic Hypothesis

The invariant properties of some characteristics of rapid human movements reflect the asymptotic behavior of complex systems, made up of a large number of coupled neuromuscular networks.

Agonist – Antagonist Synergy

Agonist system working in the direction of the movement

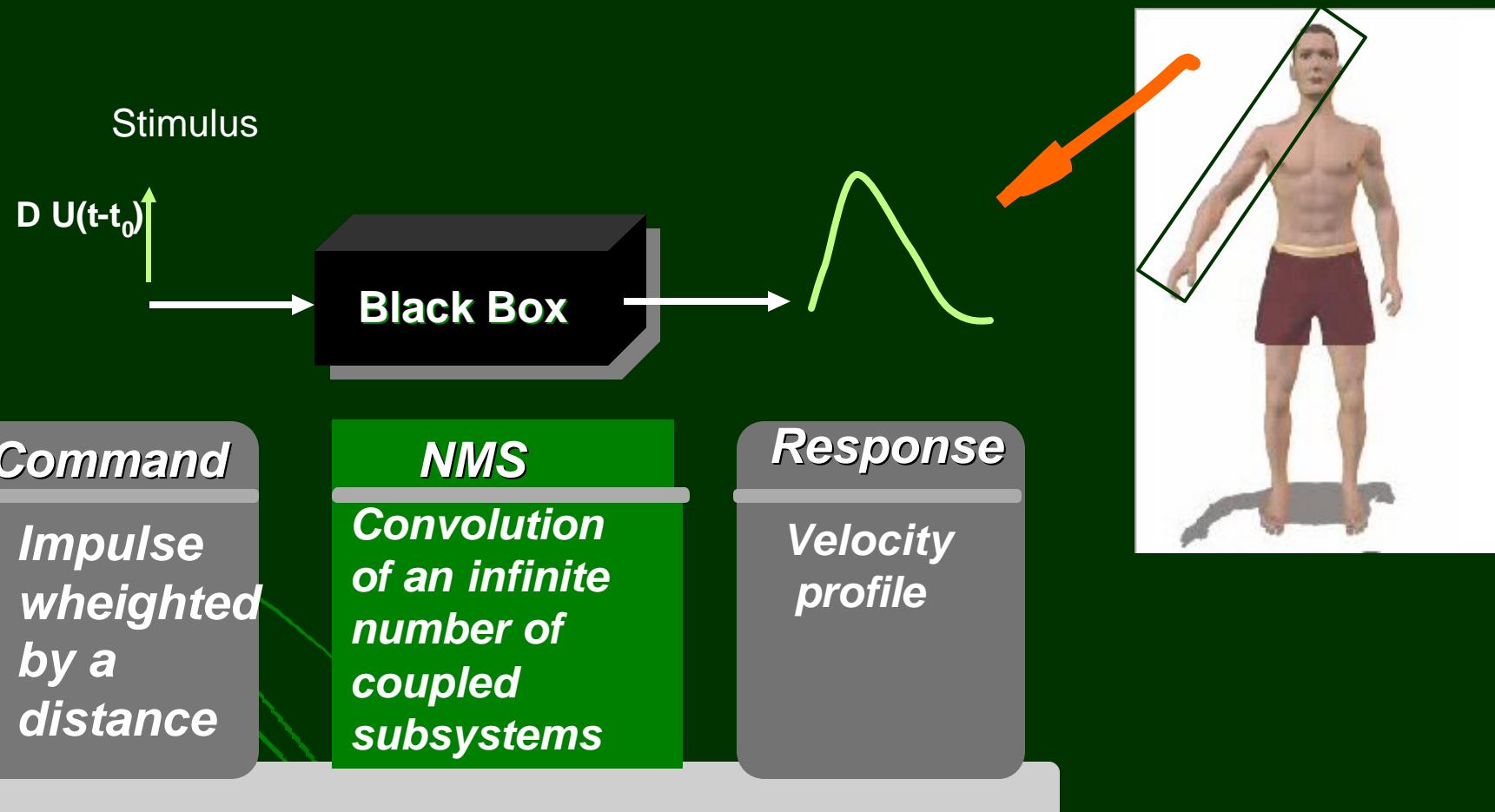
Origin

Movement

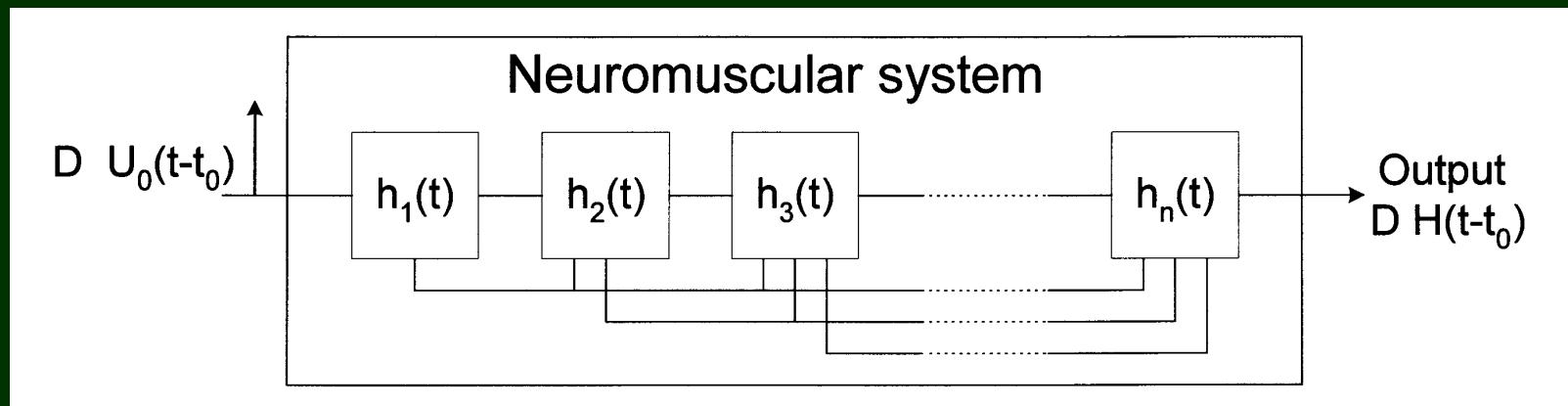
Target

Antagonist system working in the opposite direction

Modeling a neuromuscular system



- Mathematical proof:
- Convergence of the NMS impulse response towards a lognormal profile



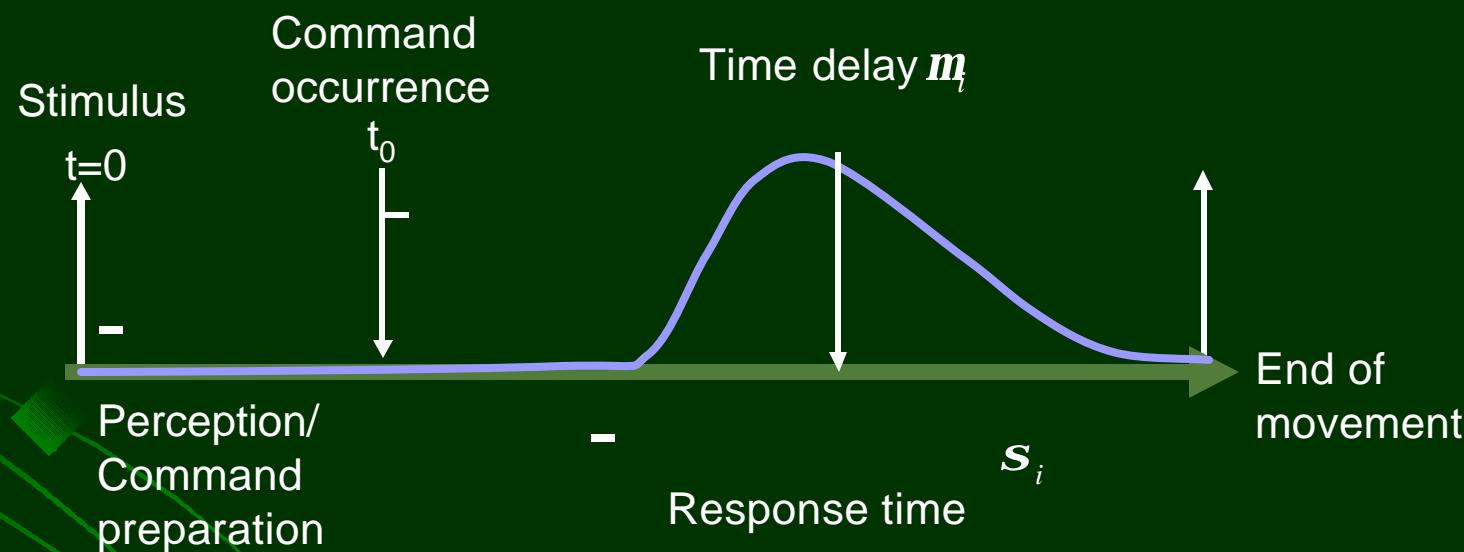
- Hypothesis

$$T_n = (1 + e_n) T_{n-1}$$

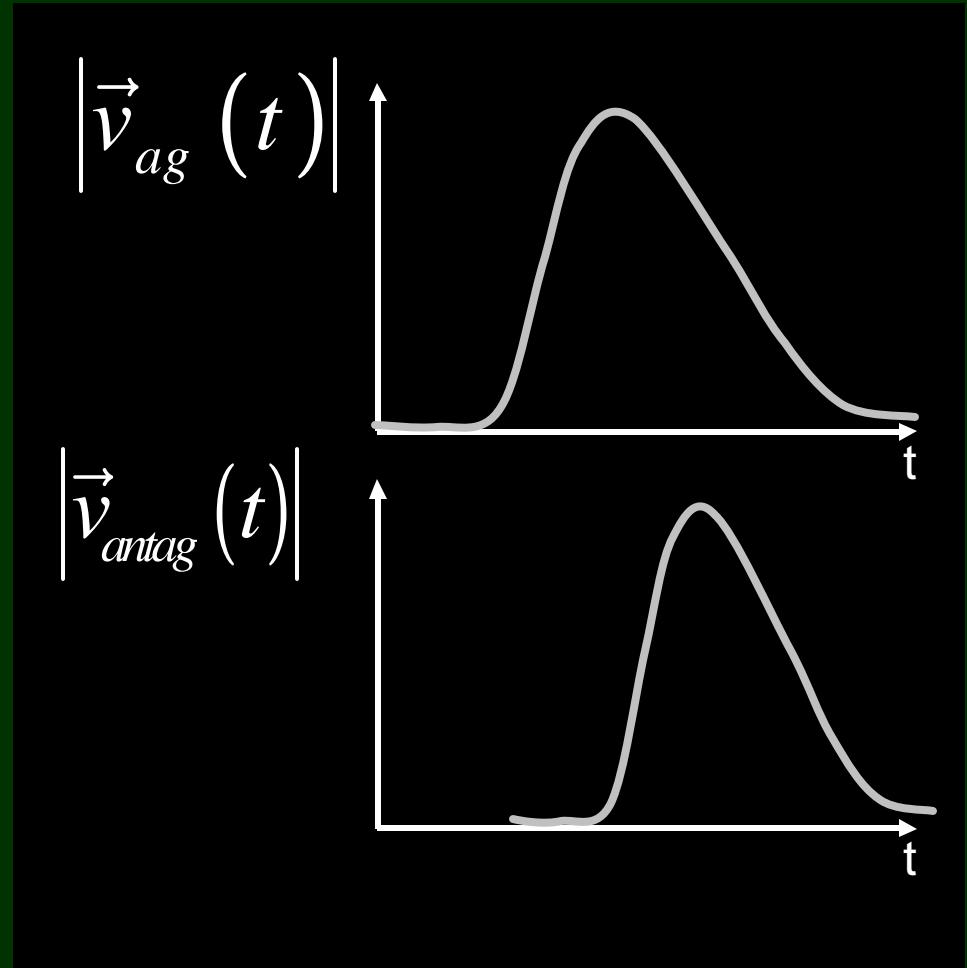
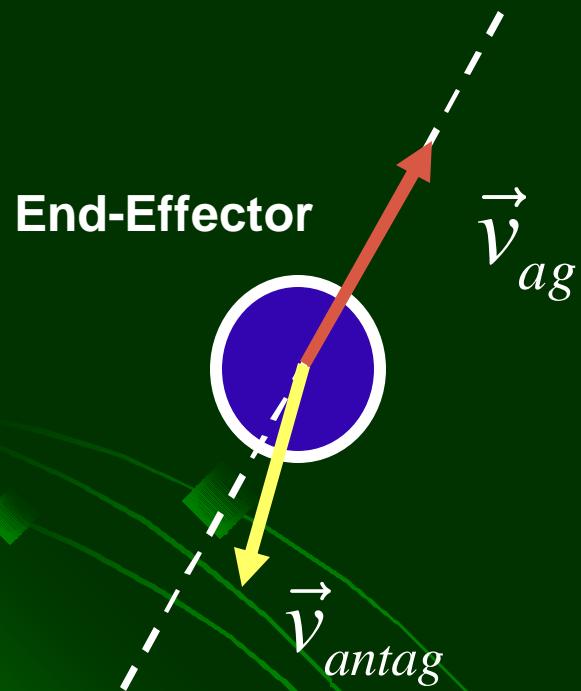
$$n \rightarrow \infty$$

$$H(t - t_0) \Rightarrow \Lambda(t; t_0, m, s^2)$$

- **Temporal analysis of a system output**



Vectorial summation



Velocity profile of a single stroke

$$\vec{v}(t) = \vec{v}_{ag}(t) + \vec{v}_{antag}(t)$$

Special case: perfect opposition of the agonist and the antagonist components

$$v(t) = v_{ag}(t) - v_{antag}(t)$$



Delta-Lognormal Model

Delta-Lognormal equation

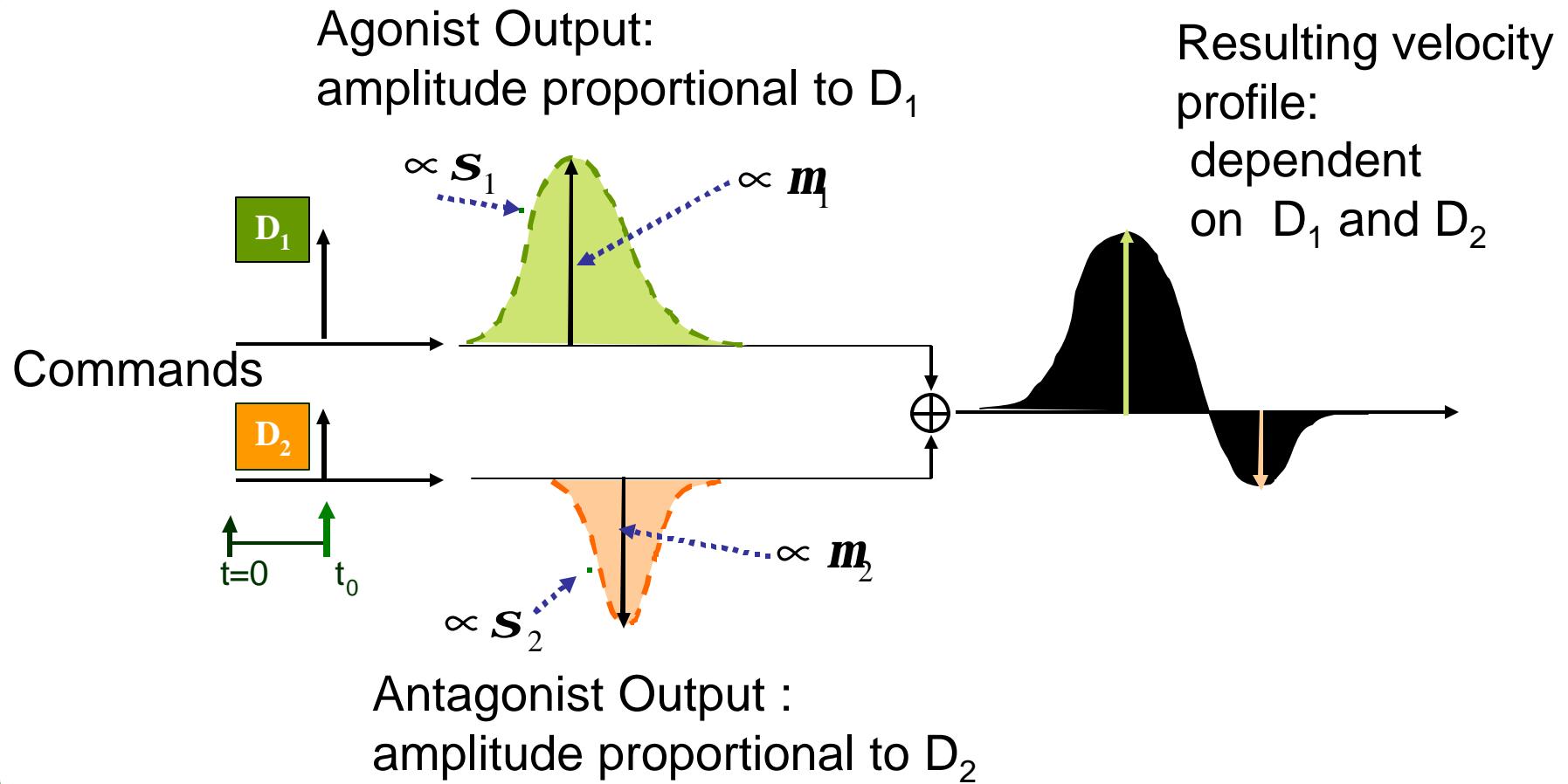
$$|\vec{V}(t)| = D_1 \Lambda(t; t_0, \mathbf{m}_1, \mathbf{s}_1^2) - D_2 \Lambda(t; t_0, \mathbf{m}_2, \mathbf{s}_2^2)$$

where

$$\Lambda(t; t_0, \mathbf{m}_i, \mathbf{s}_i^2) = \frac{1}{\mathbf{s}_i \sqrt{2\pi} (t - t_0)} \exp\left(\frac{-[\ln(t - t_0) - \mathbf{m}_i]^2}{2\mathbf{s}_i^2}\right)$$

PLAMONDON, R., "A Kinematic Theory of Rapid Human Movements: Part I: Movement Representation and Generation", Biological Cybernetics, vol. 72, no 4, 1995, p. 295-307.

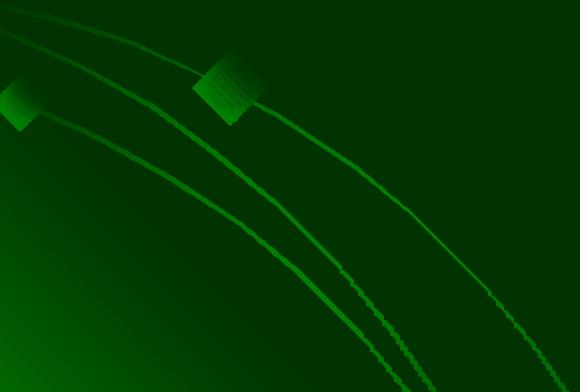
Schematic Summary



Some predictions for a single stroke

$$MA = \int_{t_0}^{t_1} v(t) dt \cong D_1 - D_2$$

$$a_1 (\ln MT)^2 + a_2 \ln MT + a_3 = \ln \frac{D_1}{D_2}$$



$$a_1 = \frac{\mathbf{s}_2^2 - \mathbf{s}_1^2}{2\mathbf{s}_1^2 \mathbf{s}_2^2}, \quad a_2 = \frac{\mathbf{m}_2 \mathbf{s}_1^2 - \mathbf{m}_1 \mathbf{s}_2^2}{\mathbf{s}_1^2 \mathbf{s}_2^2}, \quad \bar{V} = \text{mean velocity}$$

$$a_3 = -\frac{\mathbf{m}_1^2 \mathbf{s}_2^2 - \mathbf{m}_2^2 \mathbf{s}_1^2 + 2\mathbf{s}_1^2 \mathbf{s}_2^2 \ln \frac{\mathbf{s}_1}{\mathbf{s}_2}}{2\mathbf{s}_1^2 \mathbf{s}_2^2}, \quad a_4 = a_3 + \ln \left(\frac{\mathbf{g}_2}{\mathbf{g}_1} \right)$$

PLAMONDON, R., ALIMI, A., "Speed/Accuracy Tradeoffs in Target Directed Movements", Behavioral and Brain Sciences, vol. 20, no 2, 1997, p. 279-349.

Speed accuracy trade-offs for a single stroke

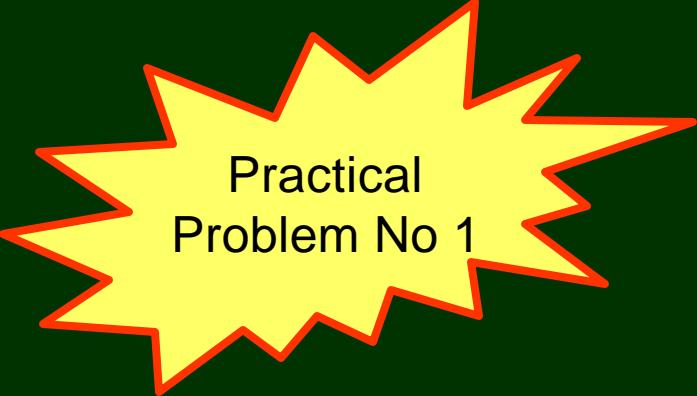
$$a_1(\ln MT_{\min})^2 + a_2 \ln MT_{\min} + a_4 = \ln\left(\frac{D}{\Delta D}\right)$$

$$\Delta MT = \left(\frac{MT}{2a_1 \ln MT + a_2} \right) \Delta D = \frac{\Delta D}{(2a_1 \ln MT + a_2) \bar{V}}$$

PLAMONDON, R., ALIMI, A., "Speed/Accuracy Tradeoffs in Target Directed Movements", Behavioral and Brain Sciences, vol. 20, no 2, 1997, p. 279-349.

Conference Overview

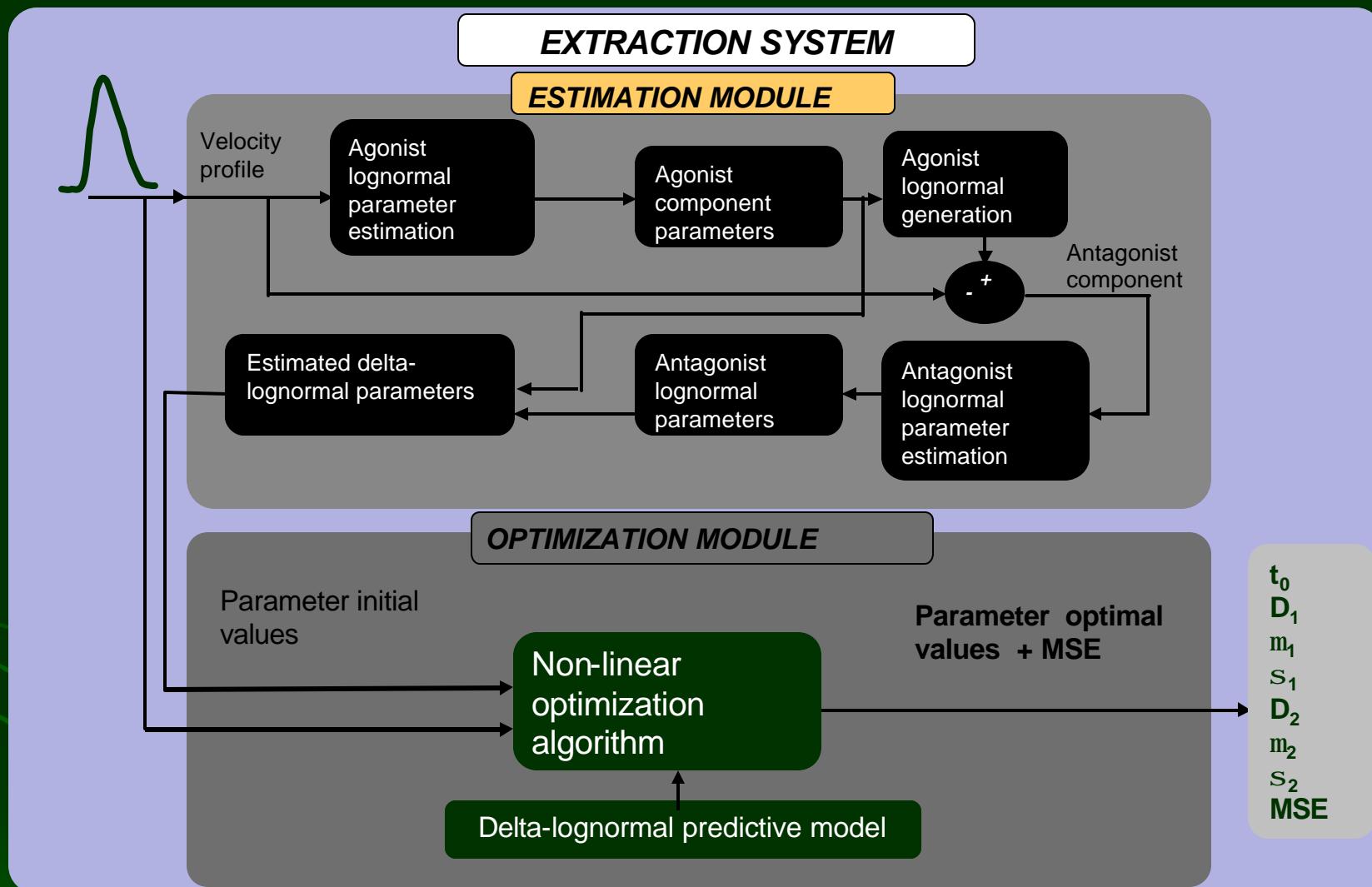
- From theory to practice, to theory, to practice...
 - ❖ Practical problem # 1 to theoretical application # 1
 - ❖ Theoretical problem # 2 to practical applications # 2
 - ❖ Theoretical problem # 3 to practical application # 3
 - ❖ Theoretical problem # 4 to practical problem # 4
 - ❖ Practical application # 5 to practical problem # 5
 - ❖ Potential applications # n



Practical
Problem No 1

Design of a Delta-Lognormal Parameter extraction system

Kinematic Theory : Extraction system : Architecture

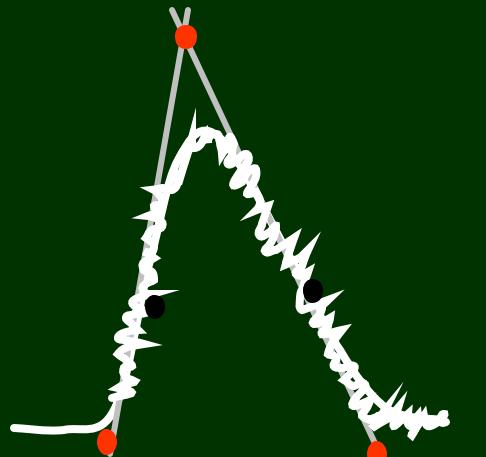


Analysis of our two previous estimation algorithms

INFLEX Algorithm

(Guerfali&Plamondon,1995)

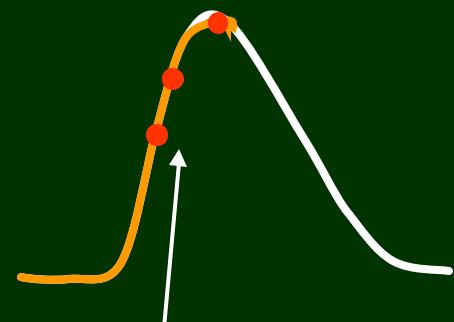
Graphical method
based on three points defined
by the intersection
of the inflection point tangents
and a table of values
computed by Wise (1963)



MINIT Algorithm

(Plamondon et al.2007)

Use of three points :
the maximum and
two arbitrary points
taken on the rising phase
of the velocity signal



Limitations

- negative t_0
- very sensitive to noise
- sensitive to the antagonist vs agonist component location

Advantages

Less sensitive to noise

Limitations

Sensitive to the profile asymmetry

sensitive to the antagonist vs. agonist component location

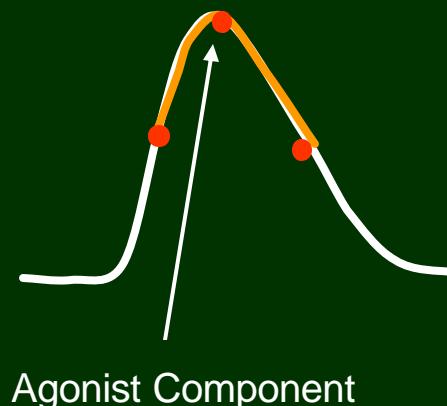
A new algorithm

XZERO Algorithm

(Djioua and Plamondon, PAMI 2008)

Use of three points :
the maximum and
the two inflection points

Exploit the analytical relationships
between these points
and the four parameters
of a single lognormal



Advantages

- Less sensitive to noise
- Independent of the antagonist vs. agonist position

Limitations

Sensitive to the number of velocity samples between the two inflection points



Optimization Module

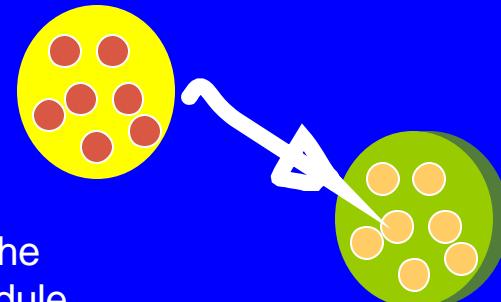
$$(t_{0e}, D_{1e}, \mathbf{m}_{1e}, \mathbf{s}_{1e}, D_{2e}, \mathbf{m}_{2e}, \mathbf{s}_{2e})$$

Principle

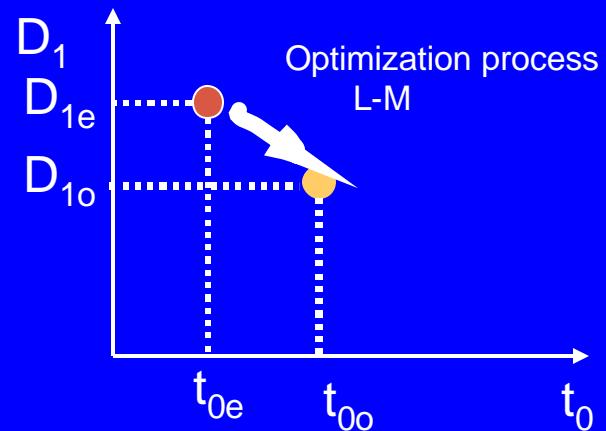
Converge from an initially estimated solution towards an optimal one using a non-linear optimization minimizing the MSE

Levenberg-Marquardt (L-M).

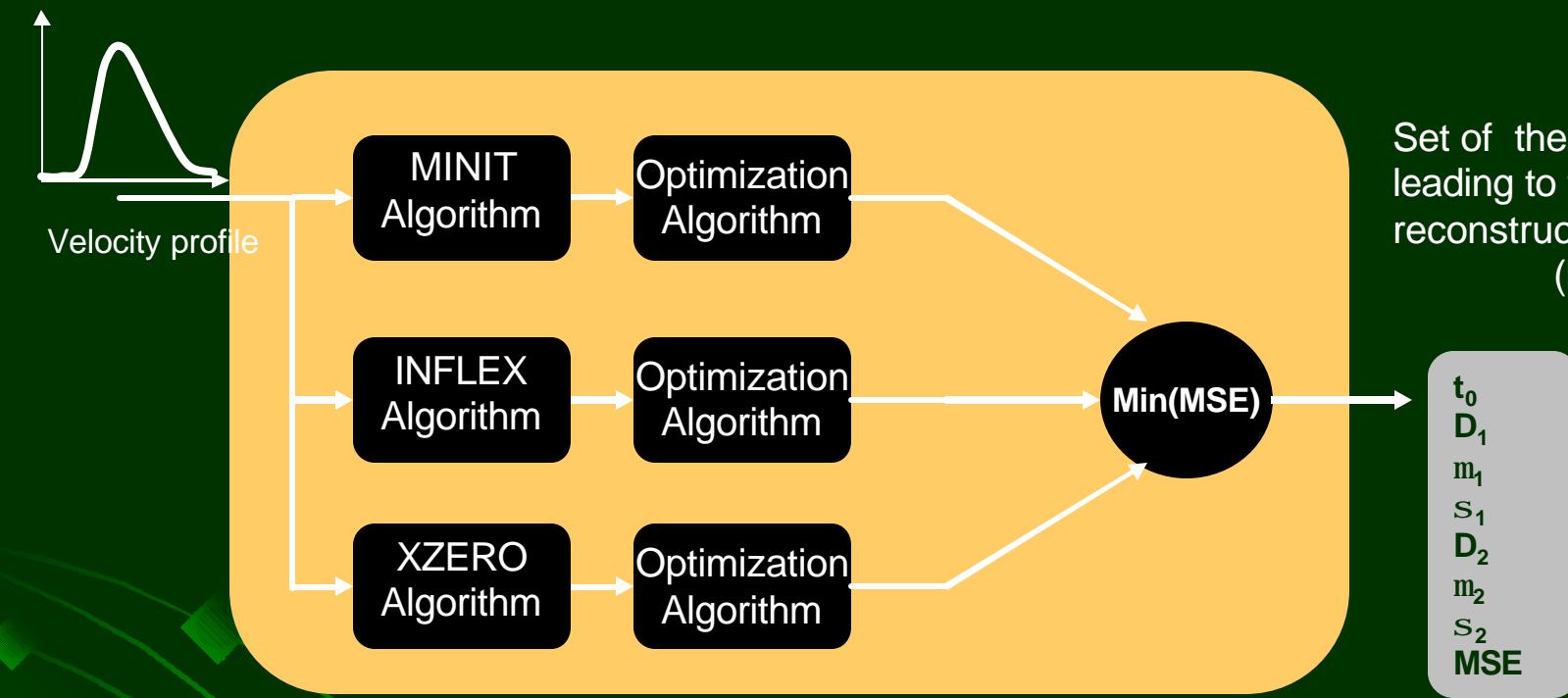
Initial solution :
7 parameters
computed by the
estimation module



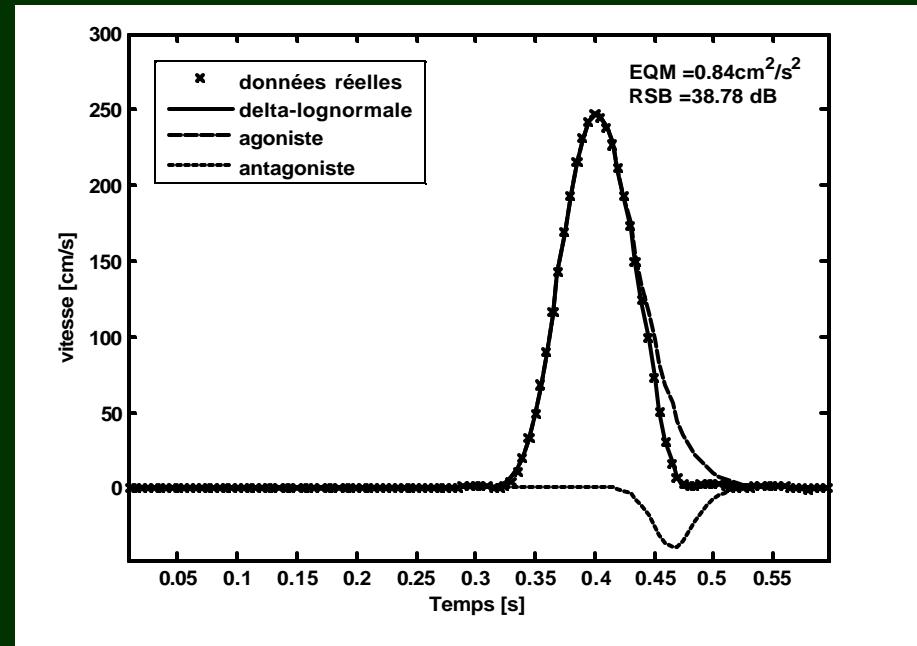
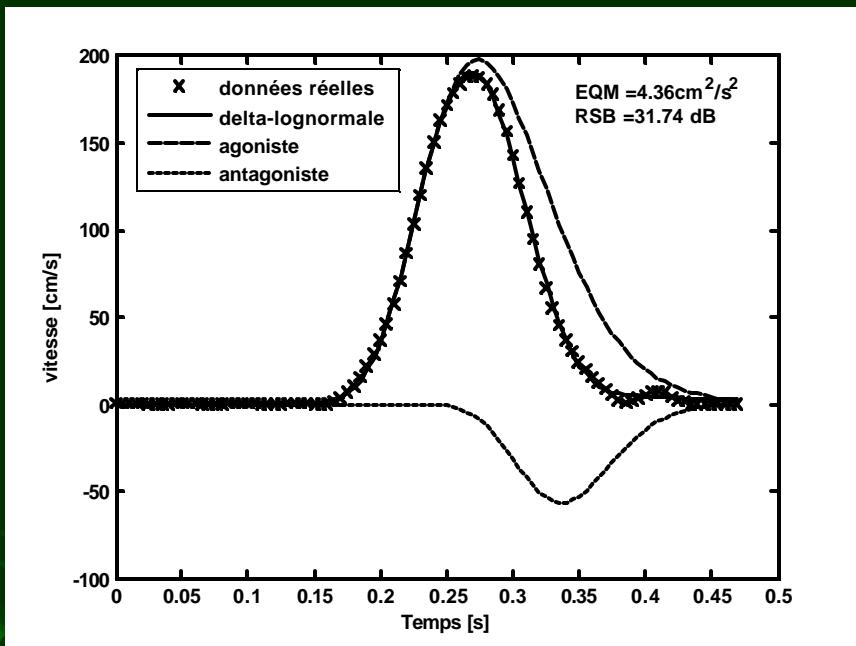
Optimal solution
(MSE Minimum)



Extraction system architecture



Typical examples with real data



Extraction system characterization

Goals:

1. Comparative evaluation of the three estimation algorithms
2. Computation of the confidence intervals on the delta-lognormal parameters

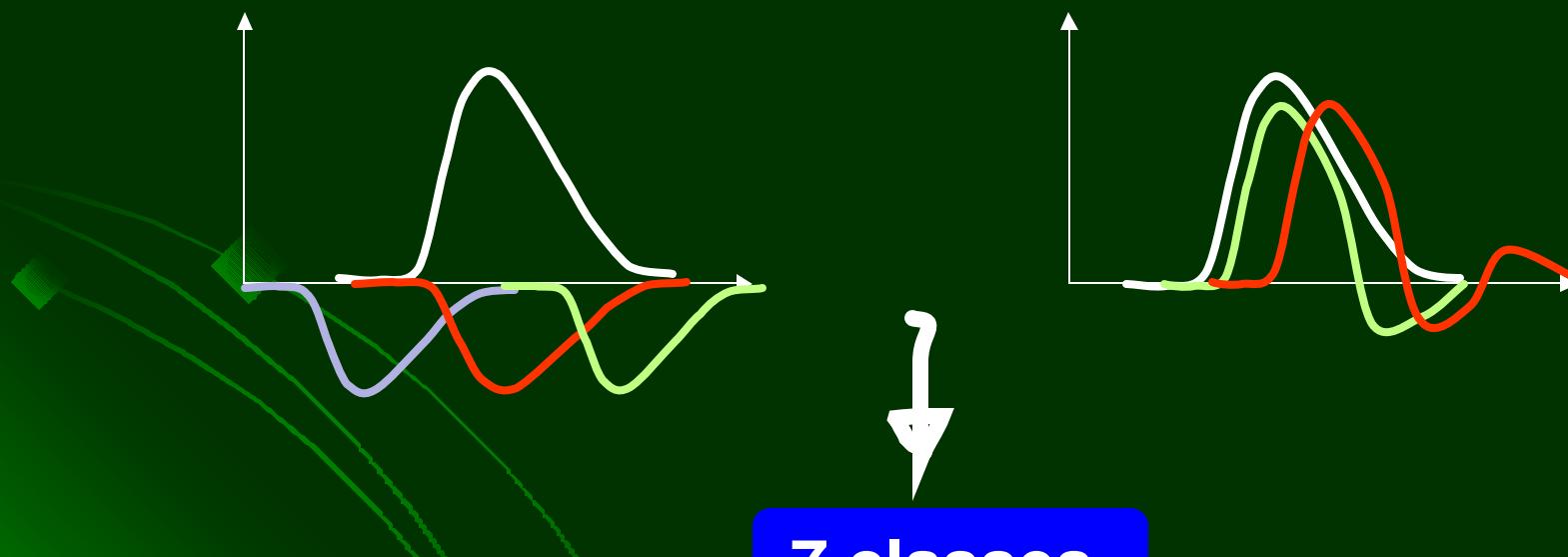
Methodology

- Generate a database of ideal profiles
- Compare the performances of each algorithm
- Add Gaussian noise to the ideal profiles
- Evaluate the precision on each parameter value

Database generation: Classification of the Delta-Lognormal profiles

Two criteria:

1. Relative position of the antagonist vs. agonist component
2. Number of zero crossings

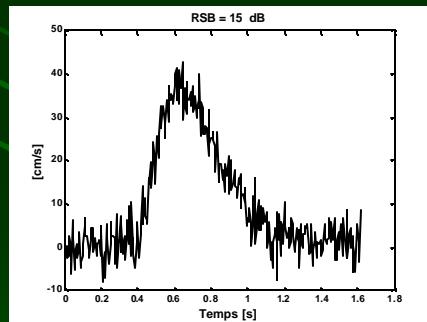
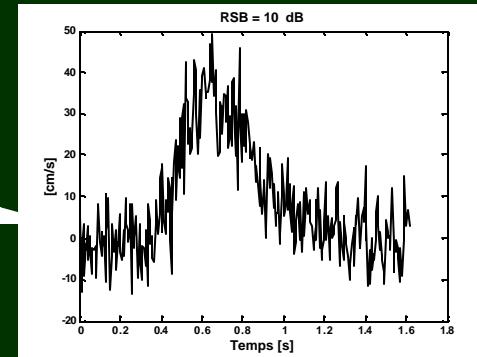
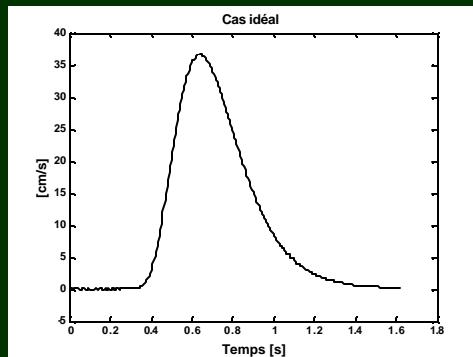


Performance : ideal case

Algorithms	Performance: % of successful extraction for each class							
	C_{f0}	C_{di}	C_{fi}	C_{d1}	C_{f1}	C_{s2}	C_{f2}	Total (%)
INFLEX	77.1	0	75.1	6.9	89.4	87.9	90	60.9
MINIT	74.6	0.4	95.9	39.4	89.2	57.5	100	65.2
XZERO	95.2	98.1	100	97.9	96.6	92.0	100	97.1
Extraction System	99.7	98.1	100	98.5	99.5	99.6	100	99.3

Performance: noisy conditions

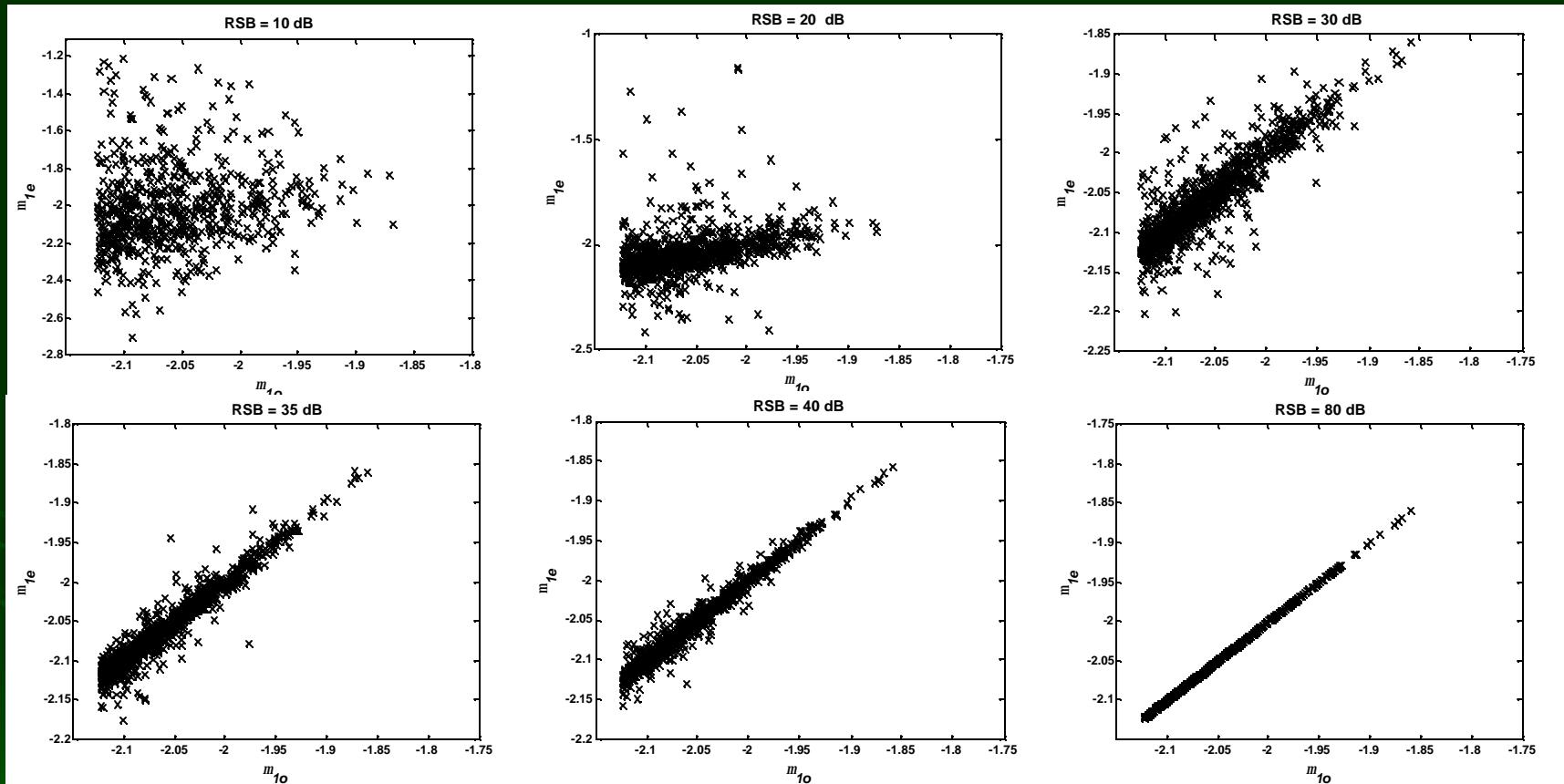
8 noise levels: 10,15,20,25,30,35,40,80 dB



Extraction System

$t_0 \pm \Delta t_0$
 $D_1 \pm \Delta D_1$
 $m_1 \pm \Delta m_1$
 $s_1 \pm \Delta s_1$
 $D_2 \pm \Delta D_2$
 $m_2 \pm \Delta m_2$
 $s_2 \pm \Delta s_2$
MSE
SNR

TYPICAL RESULTS



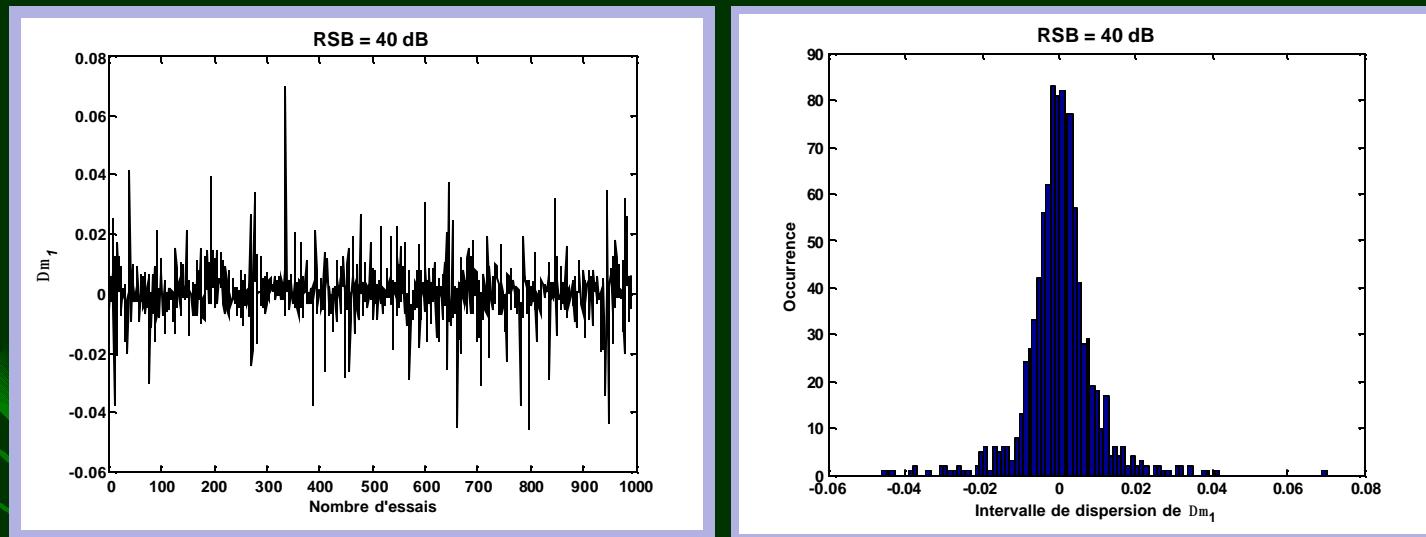
Variation of the parameter m_1 as a function of the SNR

Important observations

- First result

Distribution of the parameter errors :

$$\Delta \mathbf{m}_1 = \mathbf{m}_{1o} - \mathbf{m}_{1m}$$



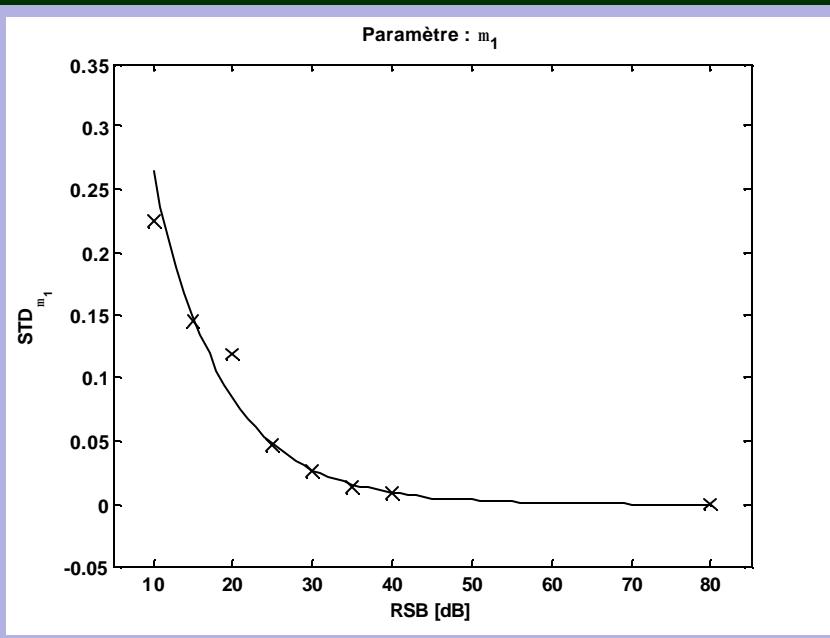
The parameter measurement error is a Gaussian noise

Important observations

- Second result :**

Relationship between the SNR and the parameter confidence interval (PIC)

$$PIC_m = [m_e - 1.96 * STD_m, m_e + 1.96 * STD_m]$$



$$STD_{t_0} \simeq 0.1304 e^{-0.116 * SNR}$$

$$STD_{D_1} \simeq 13.4248 e^{-0.1089 * SNR}$$

$$STD_{m_1} \simeq 0.827 e^{-0.1139 * SNR}$$

$$STD_{s_1} \simeq 0.2818 e^{-0.1121 * SNR}$$

$$STD_{D_2} \simeq 11.953 e^{-0.1075 * SNR}$$

$$STD_{m_2} \simeq 2.1089 e^{-0.1276 * SNR}$$

$$STD_{s_2} \simeq 0.4823 e^{-0.1084 * SNR}$$

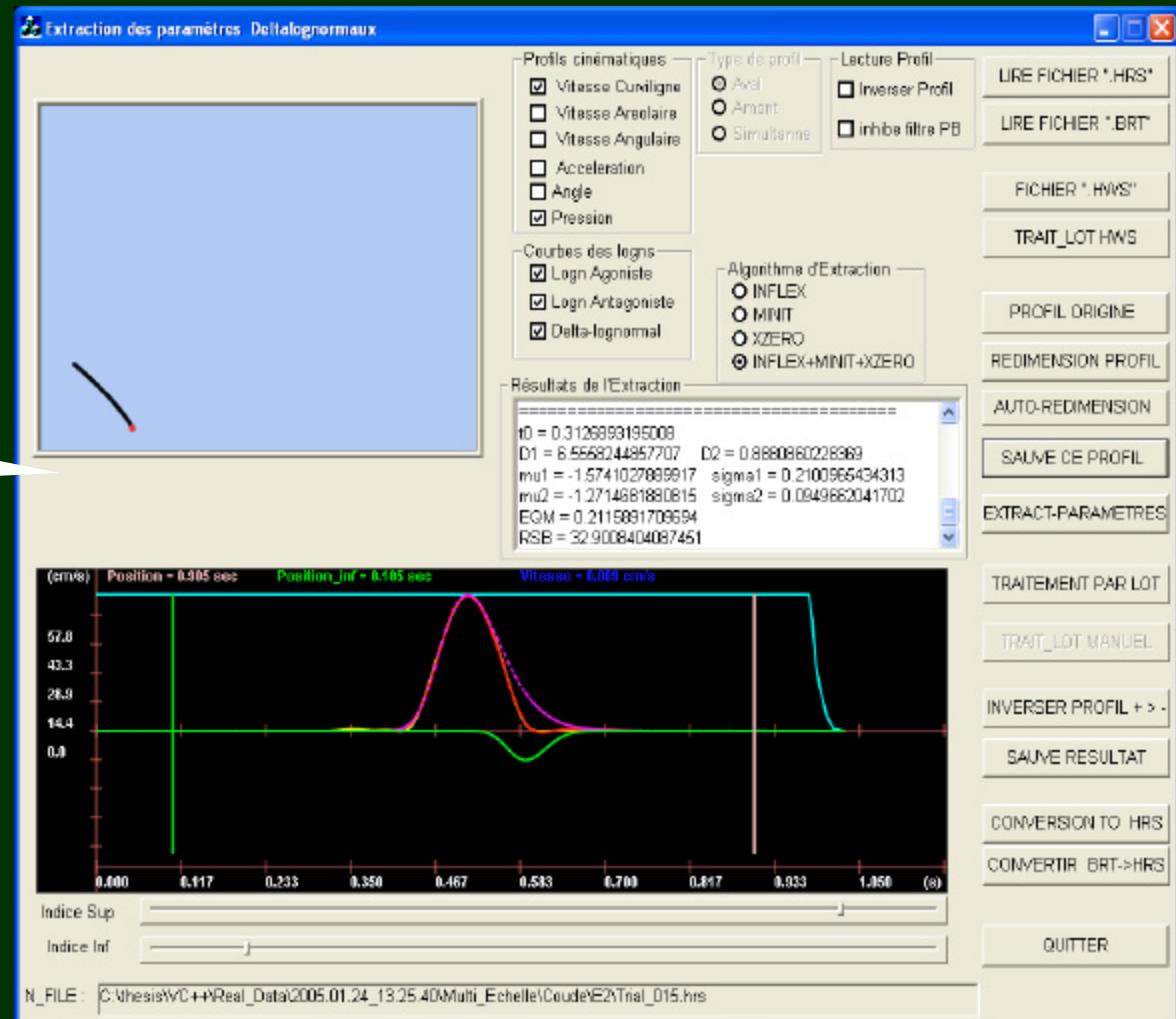
Extraction System: final version

Implementation
of the three
extraction algorithms



Extraction system
characterization

Djioua, M., Plamondon,R.
IEEE PAMI 2008 online

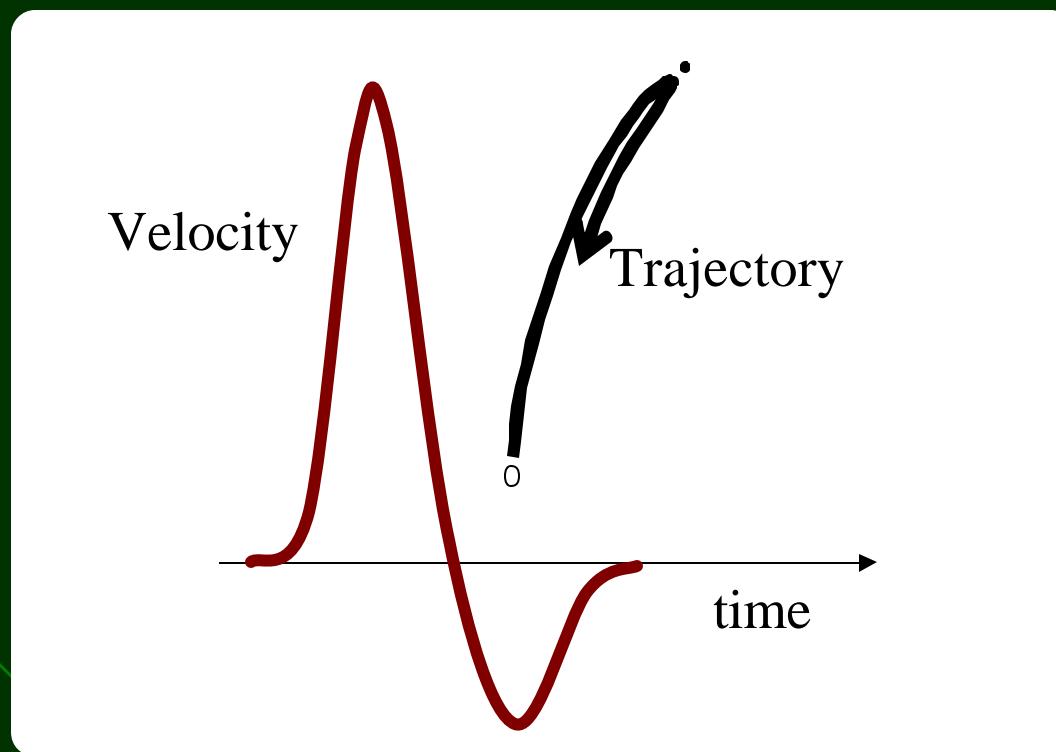


Theoretical
Application No 1

Studying the effect of age on the production of movement primitives

Woch A. and Plamondon R. (2007) Analysis of movement primitives with the Delta-lognormal model : insights on the age effect. *Proceedings of the 13th Conference of the International Graphonomics Society (IGS2007)*, 13, pp:56-60

A specific Delta-Lognormal prediction: a stroke with a direction reversal



Goals of the experiment

- Check for the existence of bidirectional primitives
- Compare the performances of young and aged subjects

Experiment Description

- 7 aged subjects between 63 and 70
- 7 young subjects between 26 and 29
- Task: production of a rapid stroke with a direction reversal (without pause at the breaking point)
- 100 trials per subject

Experimental Protocol and Equipment

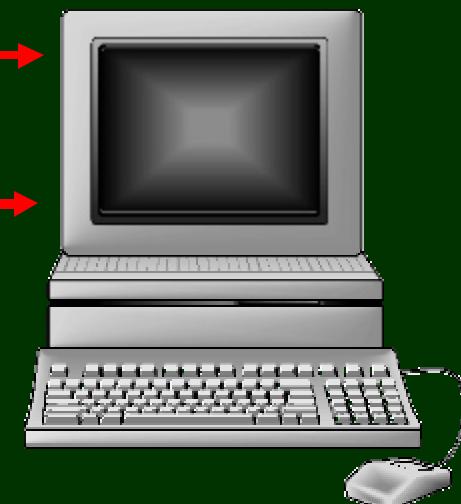
Stimulus
generator



Acquisition System



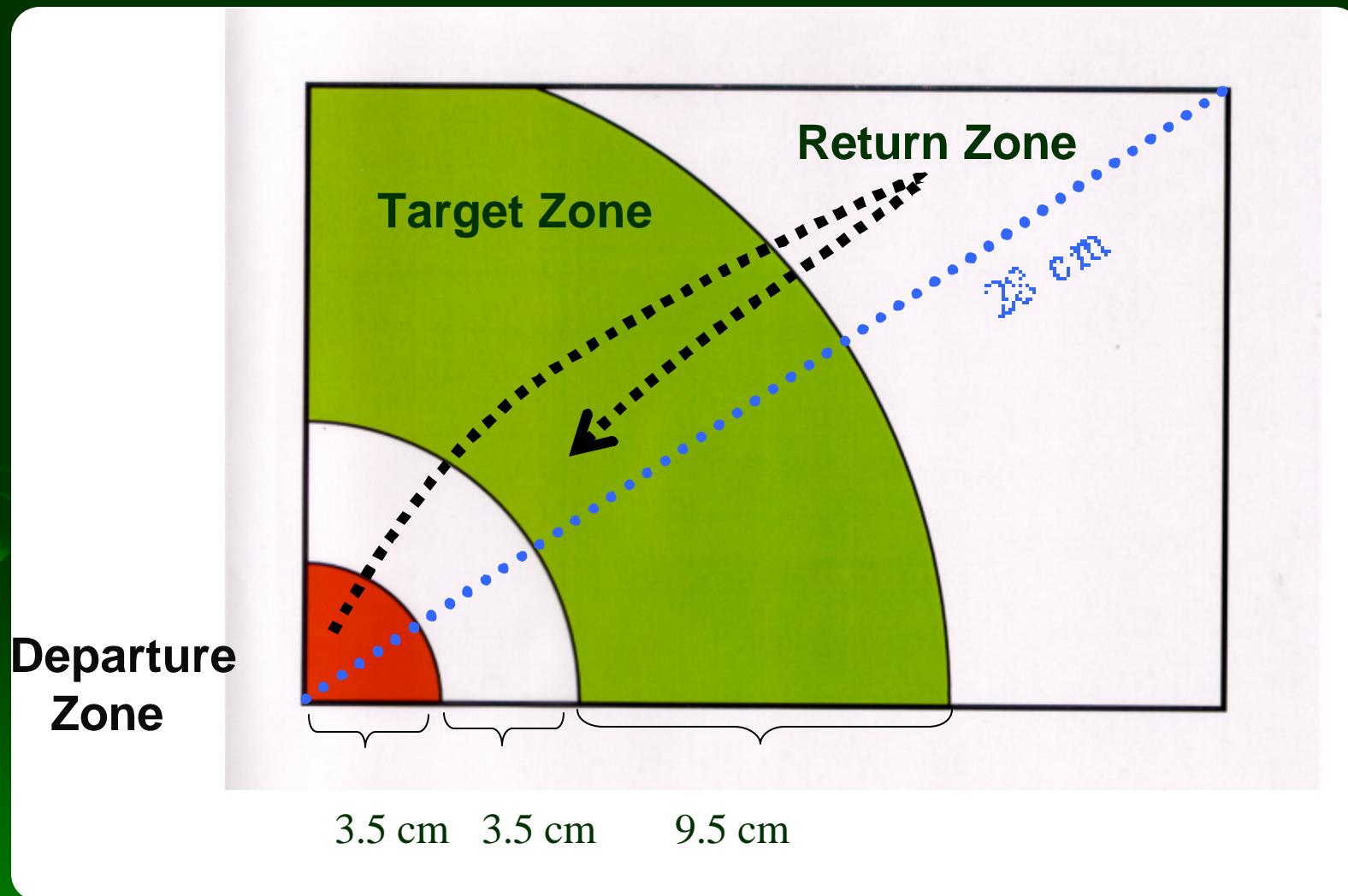
Digitizer (Wacom SD-510C)



Stylus

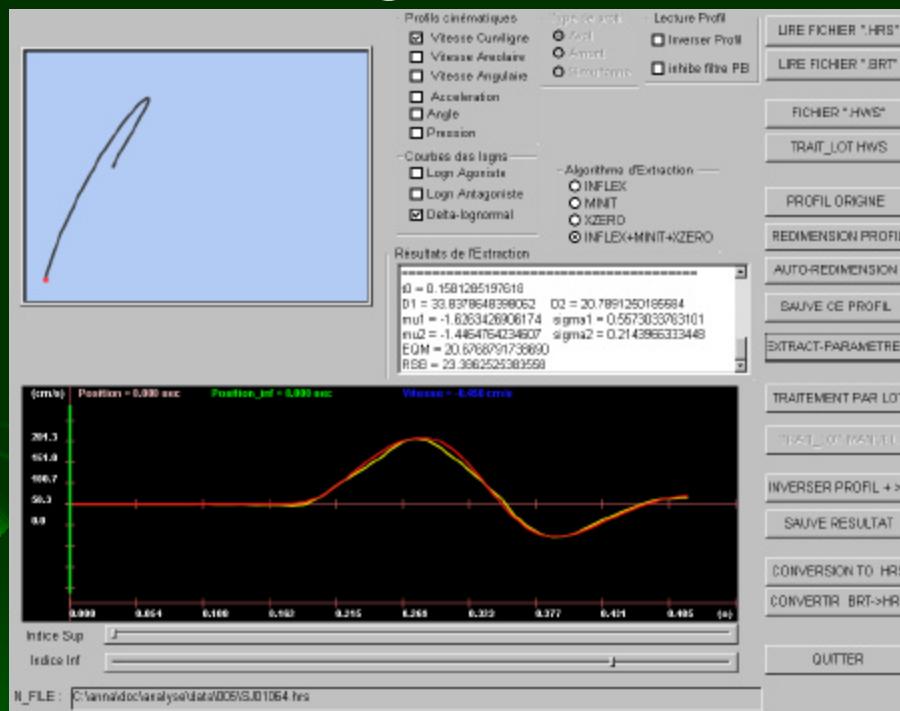


Experimental Protocol and Equipment

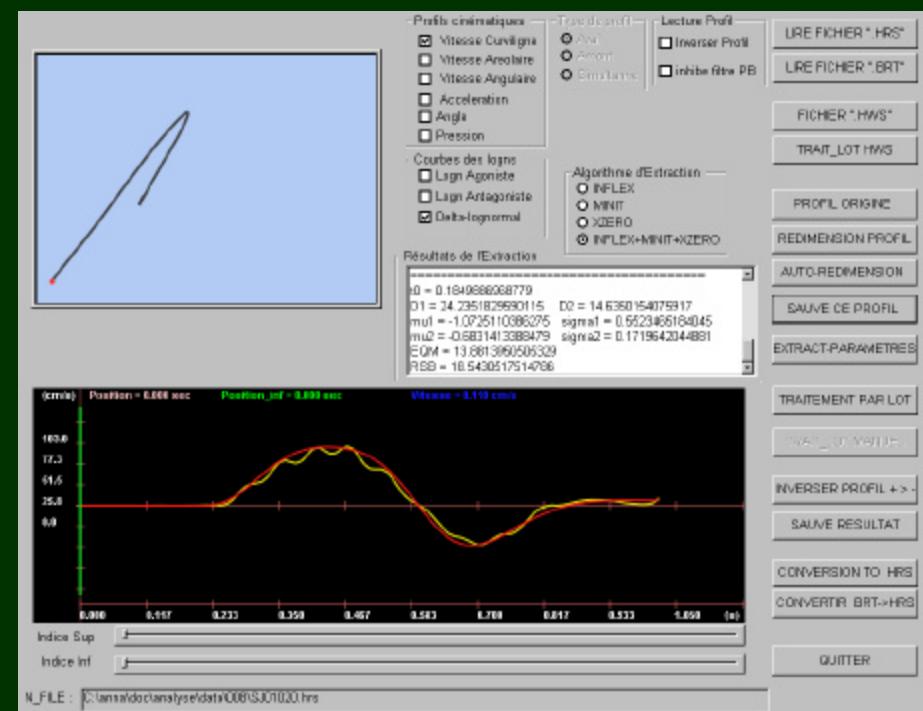


Typical Results

Young subject



Aged subject



Confirmation of the bidirectional primitive prediction

→Number of primitives observed

Young subjects:
27 to 106 per person

Aged subjects:
3 subjects only produced 3 to 8 primitives
the others: 28 to 73 per person

Correlation between the agonist and the antagonist components

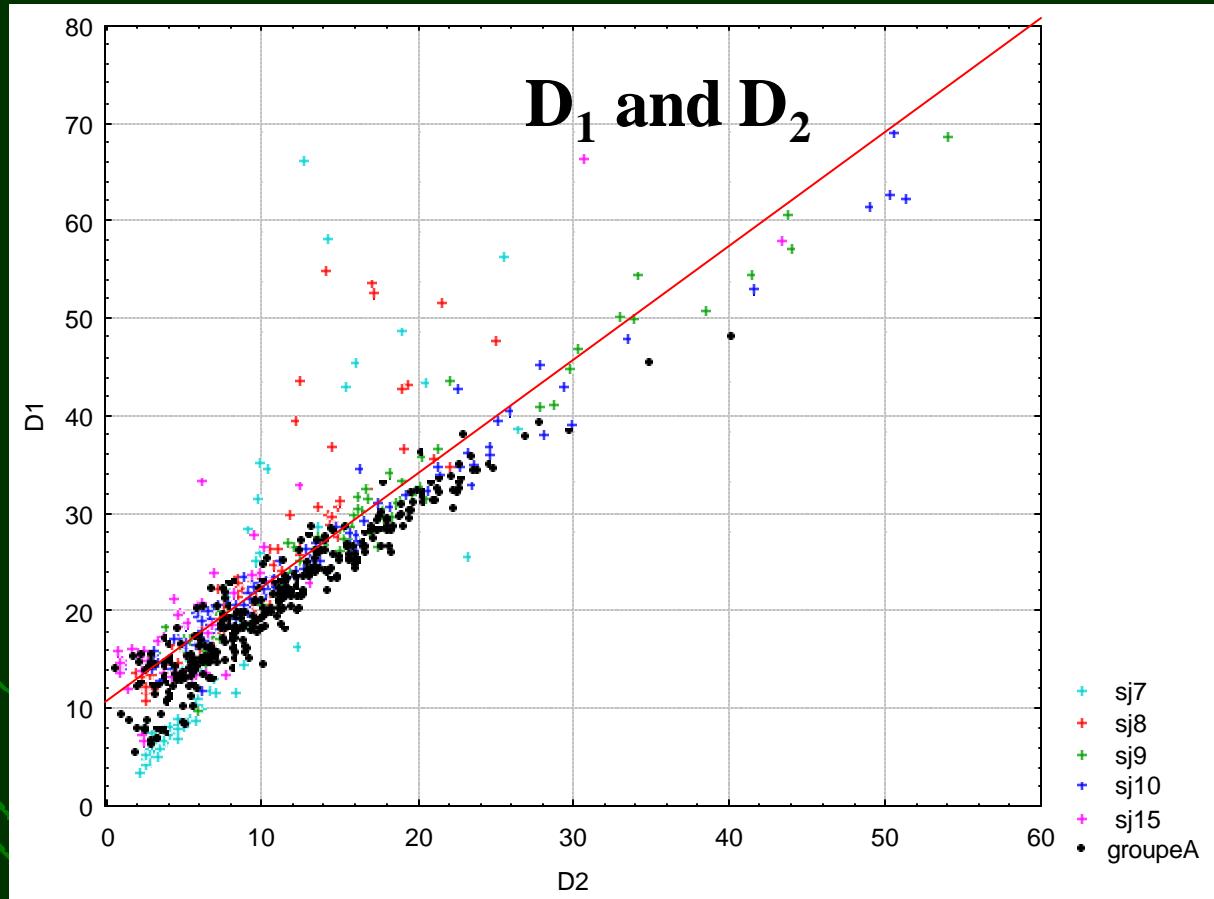
D_1 and D_2

m_1 and m_2

s_1 and s_2

Variable	Corrélations (sujet5) femme jeune Corrélations significatives marquées à $p < .01000$ $N=64$											
	TM	Vmax	distance	TR	t0	D1	mu1	s1	D2	mu2	s2	
MT	1.00	-0.86	0.20	0.21	0.27	0.21	0.40	0.38	0.14	0.34	0.04	
Vmax	-0.86	1.00	0.05	-0.15	-0.26	-0.24	-0.32	-0.48	-0.21	-0.25	-0.20	
distance	0.20	0.05	1.00	0.25	0.30	0.16	-0.01	0.29	0.04	-0.14	0.19	
TR	0.21	-0.15	0.25	1.00	0.85	0.03	0.10	0.19	-0.02	0.10	0.03	
t0	0.27	-0.26	0.30	0.85	1.00	0.13	-0.32	0.57	0.05	-0.35	0.37	
D1	0.21	-0.24	0.16	0.03	0.13	1.00	0.22	0.48	0.99	-0.12	0.68	
mu1	0.40	-0.32	-0.01	0.10	-0.32	0.22	1.00	-0.34	0.24	0.90	-0.34	
s1	0.38	-0.48	0.29	0.19	0.57	0.48	-0.34	1.00	0.39	-0.53	0.75	
D2	0.14	-0.21	0.04	-0.02	0.05	0.99	0.24	0.39	1.00	-0.09	0.65	
mu2	0.34	-0.25	-0.14	0.10	-0.35	-0.12	0.90	-0.53	-0.09	1.00	-0.61	
s2	0.04	-0.20	0.19	0.03	0.37	0.68	-0.34	0.75	0.65	-0.61	1.00	

Correlation between the agonist and the antagonist components



IS-THIS AN ARTEFACT?

Variable	Corrélations Corrélations significatives marquées à $p < .01$ $N=100$							
	t0	D1	u1	s1	D2	u2	s2	
t0	1.00	-0.12	-0.16	0.12	-0.13	-0.13	0.09	
D1	-0.12	1.00	0.02	0.00	0.98	-0.05	0.01	
u1	-0.16	0.02	1.00	-0.05	0.01	0.42	-0.21	
s1	0.12	0.00	-0.05	1.00	-0.01	0.00	0.61	
D2	-0.13	0.98	0.01	-0.01	1.00	-0.04	-0.01	
u2	-0.13	-0.05	0.42	0.00	-0.04	1.00	-0.17	
s2	0.09	0.01	-0.21	0.61	-0.01	-0.17	1.00	

Simulation A: corrélations observées en production de traits simples

Variable	Corrélations Corrélations significatives marquées à $p < .01$ $N=100$							
	t0	D1	u1	s1	D2	u2	s2	
t0	1.00	-0.07	-0.06	-0.07	-0.05	0.08	-0.10	
D1	-0.07	1.00	0.22	0.07	0.23	0.16	-0.07	
u1	-0.06	0.22	1.00	0.42	0.06	0.82	0.25	
s1	-0.07	0.07	0.42	1.00	-0.00	0.43	0.59	
D2	-0.05	0.23	0.06	-0.00	1.00	-0.01	0.24	
u2	0.08	0.16	0.82	0.43	-0.01	1.00	0.14	
s2	-0.10	-0.07	0.25	0.59	0.24	0.14	1.00	

Simulation B: corrélations en production de traits aller-retour avec un seul passage de la vitesse par zéro

Variable	Corrélations Corrélations significatives marquées à $p < .01$ $N=100$							
	t0	D1	u1	s1	d2	u2	s2	
t0	1.00	0.10	-0.07	0.21	0.12	0.02	0.26	
D1	0.10	1.00	-0.02	0.06	0.98	-0.05	0.13	
u1	-0.07	-0.02	1.00	0.06	-0.02	0.60	0.19	
s1	0.21	0.06	0.06	1.00	0.05	0.19	0.47	
d2	0.12	0.98	-0.02	0.05	1.00	-0.06	0.14	
u2	0.02	-0.05	0.60	0.19	-0.06	1.00	0.07	
s2	0.26	0.13	0.19	0.47	0.14	0.07	1.00	

Simulation C: corrélations en production de traits aller-retour avec deux passages de la vitesse par zéro

Variable	Corrélations Corrélations significatives marquées à $p < .01$ $N=100$							
	t0	D1	u1	s1	D2	u2	s2	
t0	1.00	-0.06	-0.03	0.09	-0.06	0.04	0.18	
D1	-0.06	1.00	0.00	0.20	0.99	-0.07	0.21	
u1	-0.03	0.00	1.00	-0.05	0.01	0.74	0.18	
s1	0.09	0.20	-0.05	1.00	0.19	0.20	0.41	
D2	-0.06	0.99	0.01	0.19	1.00	-0.07	0.21	
u2	0.04	-0.07	0.74	0.20	-0.07	1.00	0.04	
s2	0.18	0.21	0.18	0.41	0.21	0.04	1.00	

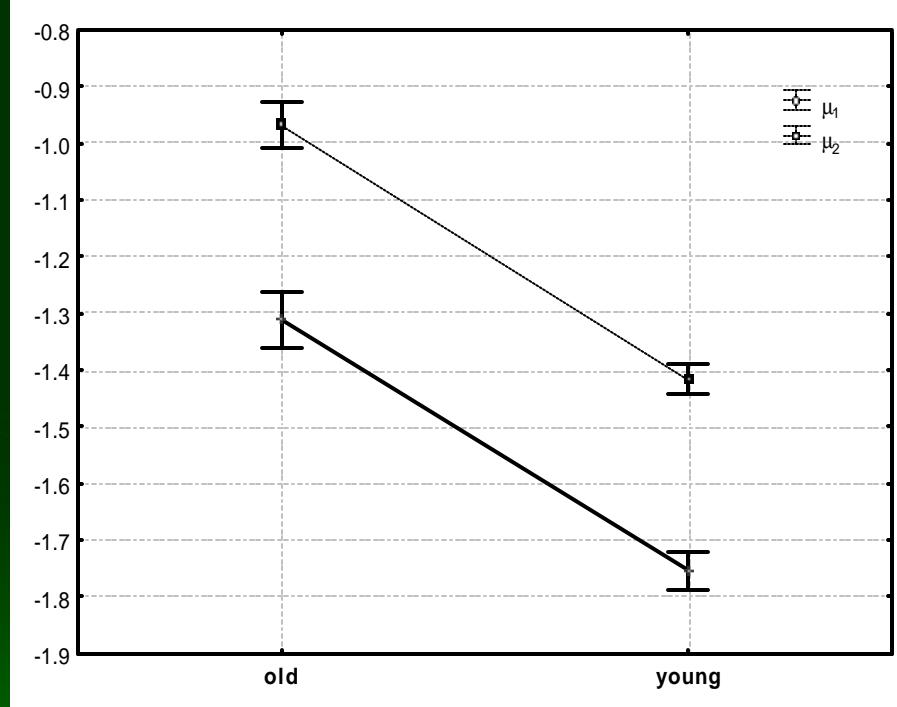
Tableau 6.25 Simulation D: corrélations en production de traits aller-retour avec deux passages de la vitesse par zéro et des contraintes supplémentaires sur l'action agoniste – antagoniste

ANOVA ANALYSIS

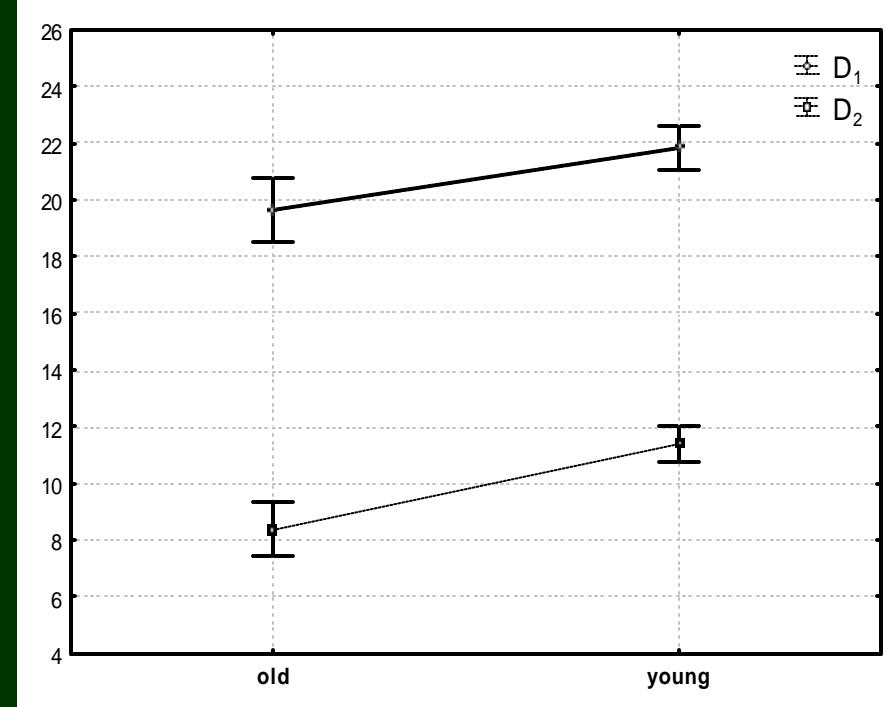
- The Delta-Lognormal parameters m_i , D_i and t_0 differences statistically significant ($p < .01$, 0,95 confidence interval):
- Significant age effects on the parameters
 - m_i increases with age
 - D_i decreases with age
 - t_0 increases with age
- Similar changes observed both on the agonist and the antagonist components

ANOVA ANALYSIS

Effect on m_i

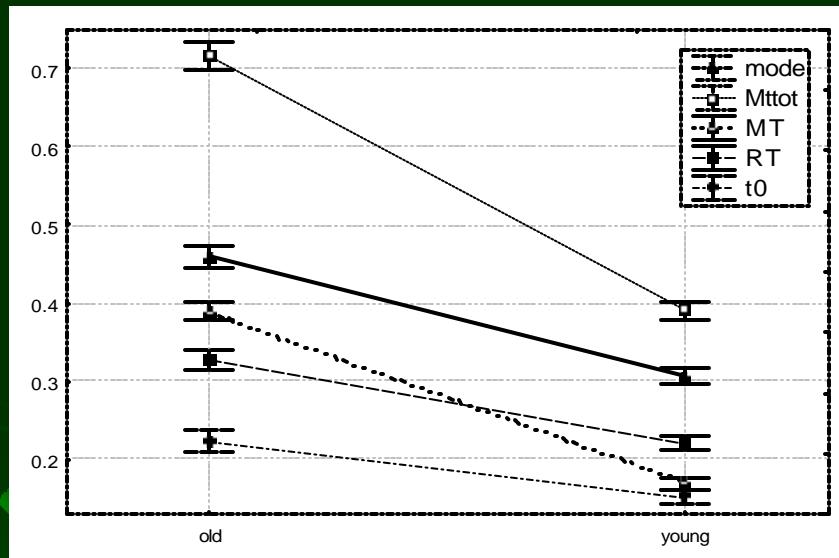


Effect on D_i

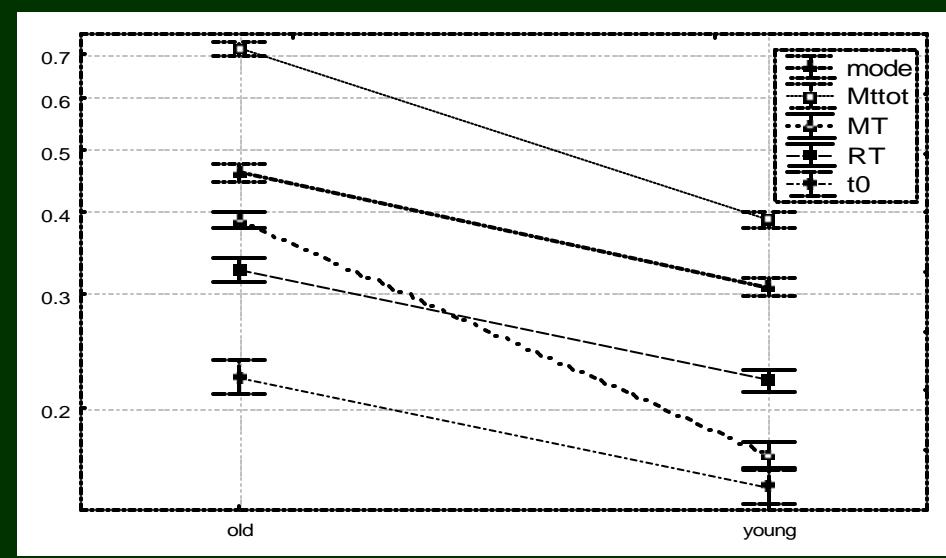


ANOVA ANALYSIS

Effects on the temporal parameters



Linear time scale



Logarithmic time scale

Theoretical
Problem No 2

Experimental Observation of the Proportional Effect Hypothesis

Apparatus

Data Acquisition System



Amplifier

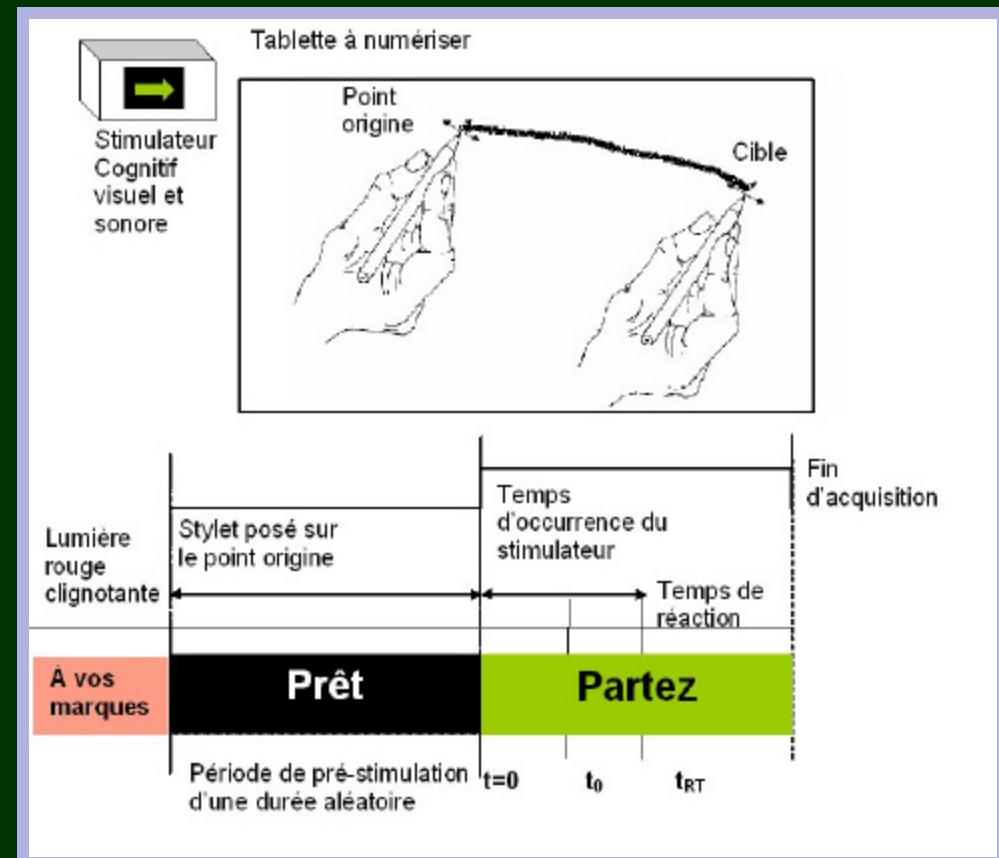


EMG Signal
Acquisition System
(GRASS)



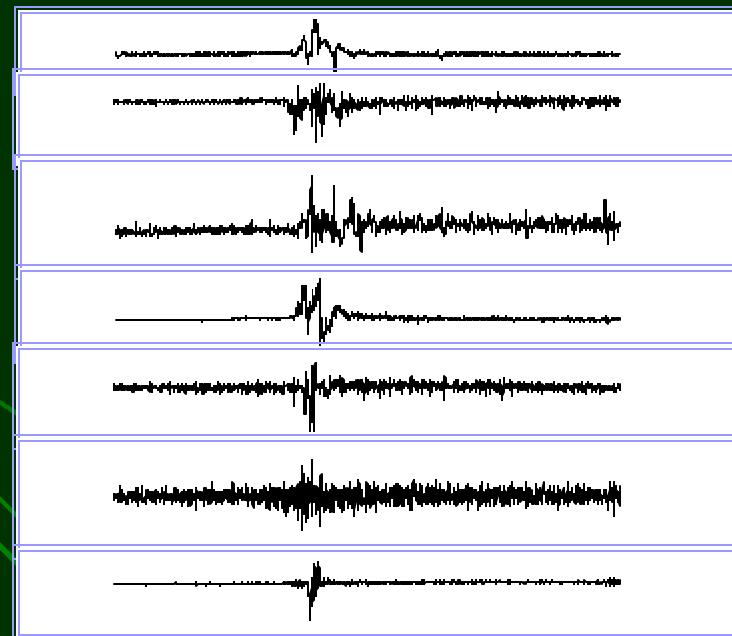
Experimental Protocol

- 10 subjects
- right handed, good health,
- between 22 and 38
- Produce large strokes between a departure point and a target zone, following a reaction time protocol
 - Auditory stimulus
 - 20 valid trials

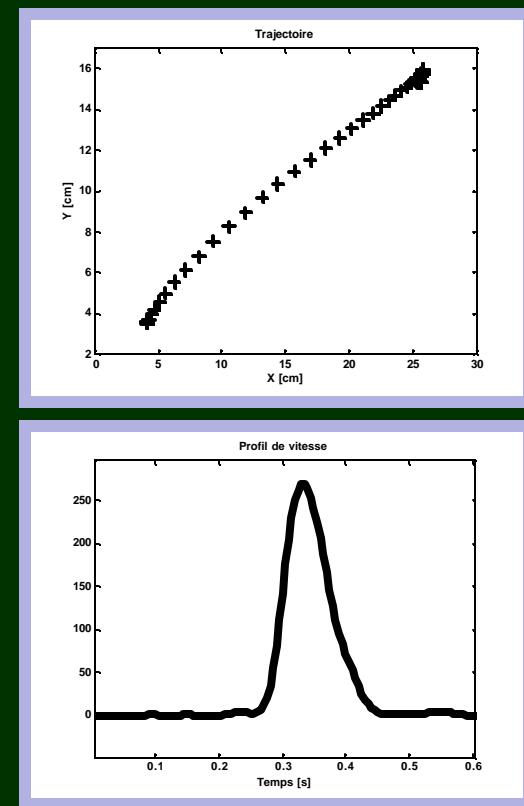


Typical raw data of biosignals

Raw EMG signals



Kinematic data



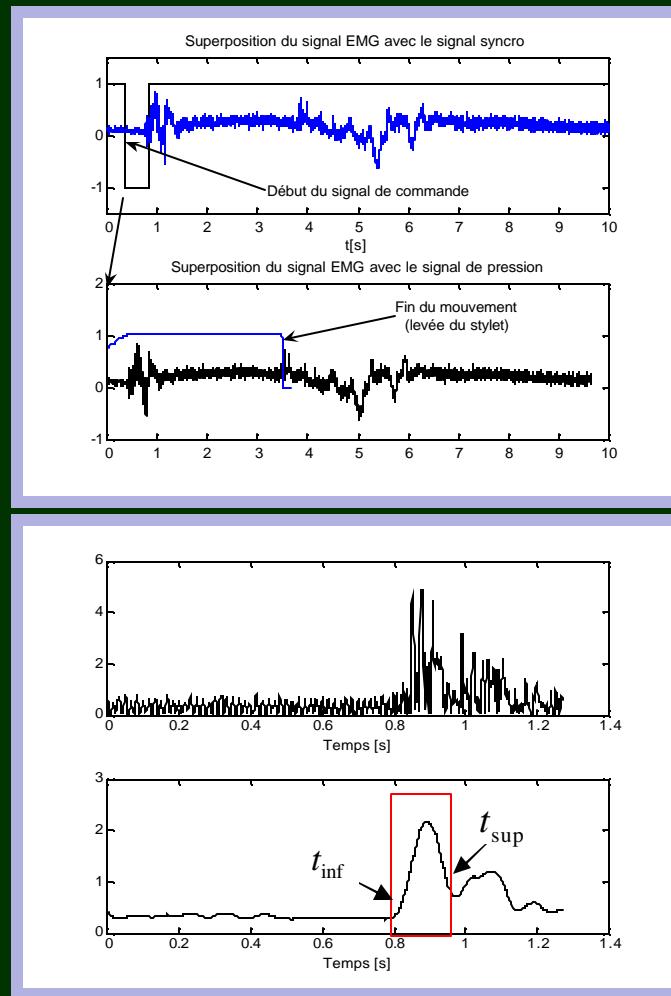
Preprocessing

1. Time Origin Definition

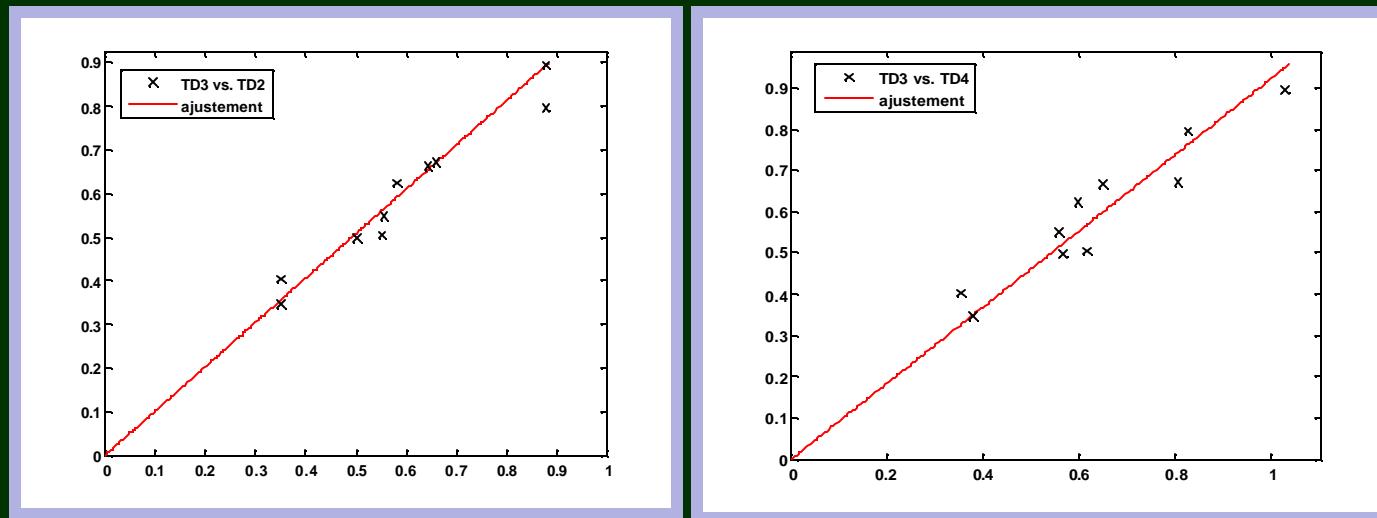
2. Computation of EMG envelopes and cumulative time delays

Savitzky-Golay Filter

$$T = \frac{\int_{t_{\inf}}^{t_{\sup}} t \cdot \text{Enveloppe}_{EMG}(t) dt}{\int_{t_{\inf}}^{t_{\sup}} \text{Enveloppe}_{EMG}(t) dt}$$



Typical proportional regressions



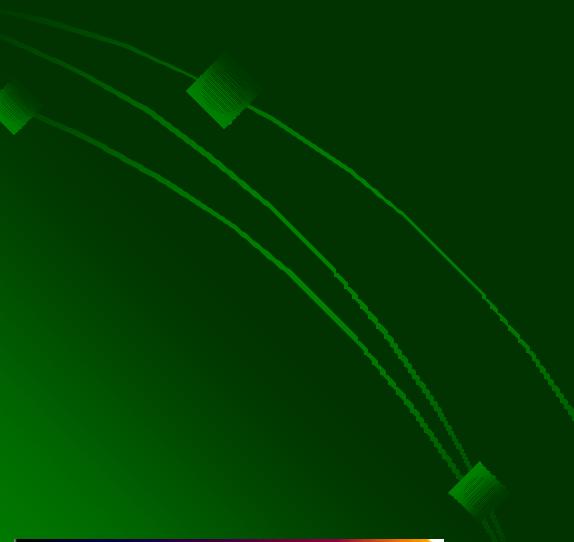
Correlation Coefficient r^2

X Y(X)	TD1	TD2	TD3	TD4	TD5	TD6
TD1	1.0	0.92	0.95	0.89	0.92	0.89
TD2	0.93	1.0	0.94	0.90	0.84	0.86
TD3	0.96	0.95	1.0	0.95	0.94	0.90
TD4	0.89	0.89	0.88	1.0	0.93	0.88
TD5	0.93	0.85	0.93	0.94	1.0	0.92
TD6	0.87	0.82	0.85	0.86	0.89	1.0

$r^2 > 0.82$

Practical
Applications No 2

Improving EMG signal processing



Movement Generation

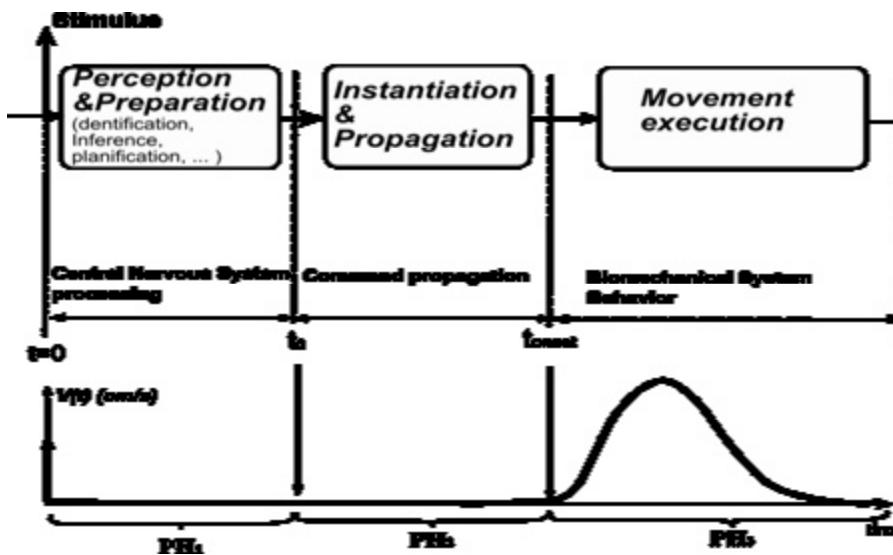


Figure 1a: Temporal analysis of a rapid movement generation.

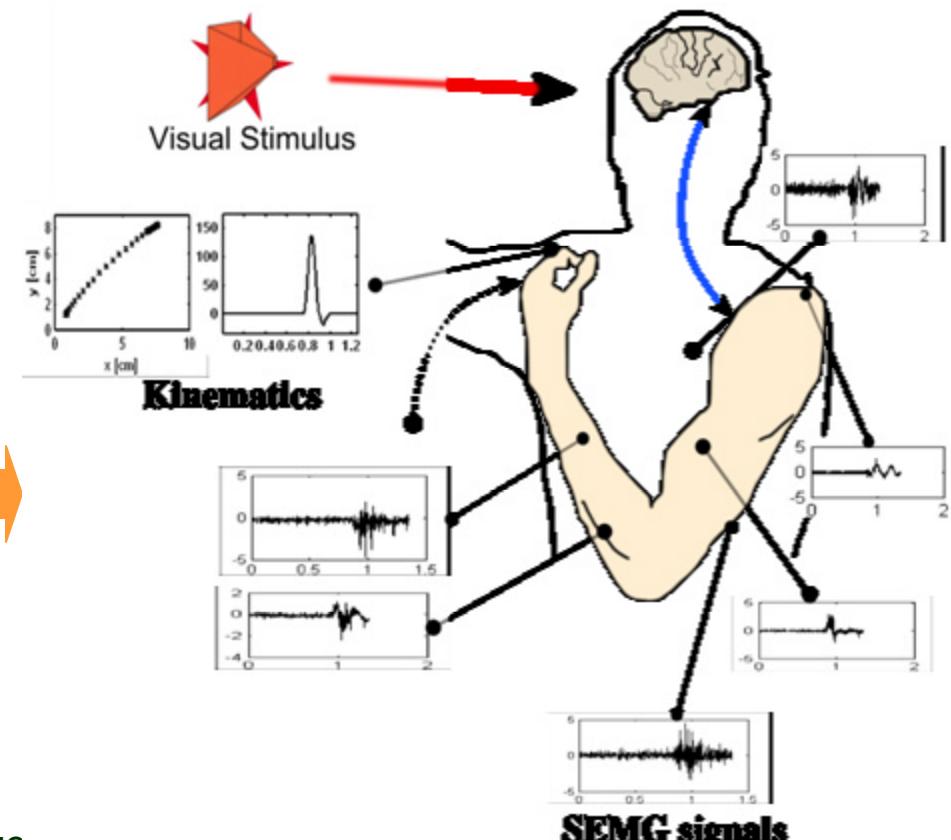
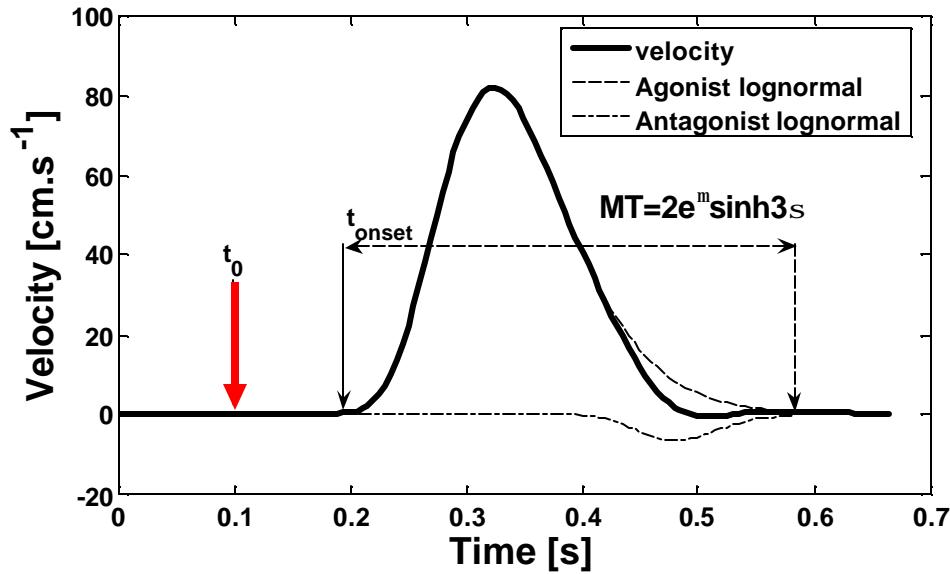


Figure 1b: Collecting bio-signals
(Kinematics and SEMG)

Djioua, M. & Plamondon, R. (2008). A New methodology to improve myoelectric signal processing using Handwriting. *International Conference on Frontiers in Handwriting Recognition, ICFHR'08*, 112-118.

Theoretical recalls



$$v(t) = D_1 \Lambda(t; t_0, \mathbf{m}_1, \mathbf{s}_1^2) - D_2 \Lambda(t; t_0, \mathbf{m}_2, \mathbf{s}_2^2)$$

$$\Lambda(t; t_0, \mathbf{m}, \mathbf{s}^2) = \begin{cases} \frac{1}{s\sqrt{2}\pi} \frac{1}{(t-t_0)} \exp\left\{-\frac{1}{2s^2} [\ln(t-t_0) - \mathbf{m}]^2\right\} & \text{si } t_0 < t \\ 0 & \text{sinon} \end{cases}$$

Movement kinematics completely described

With seven parameters

Motor control level :

(t_0, D_1, D_2)

Neuromuscular level :

$(\mathbf{m}_1, \mathbf{s}_1, \mathbf{m}_2, \mathbf{s}_2)$

Movement onset analytical expression

- $t_{onset} = t_0 + \min\{e^{\mathbf{m}_1 - 3s_1}, e^{\mathbf{m}_2 - 3s_2}\}$

Movement duration analytical expression

- $MT = \max\{e^{\mathbf{m}_1 + 3s_1}, e^{\mathbf{m}_2 + 3s_2}\} - \min\{e^{\mathbf{m}_1 - 3s_1}, e^{\mathbf{m}_2 - 3s_2}\}$

Application 2a: Temporal Index Estimation

Psychophysical Experiment

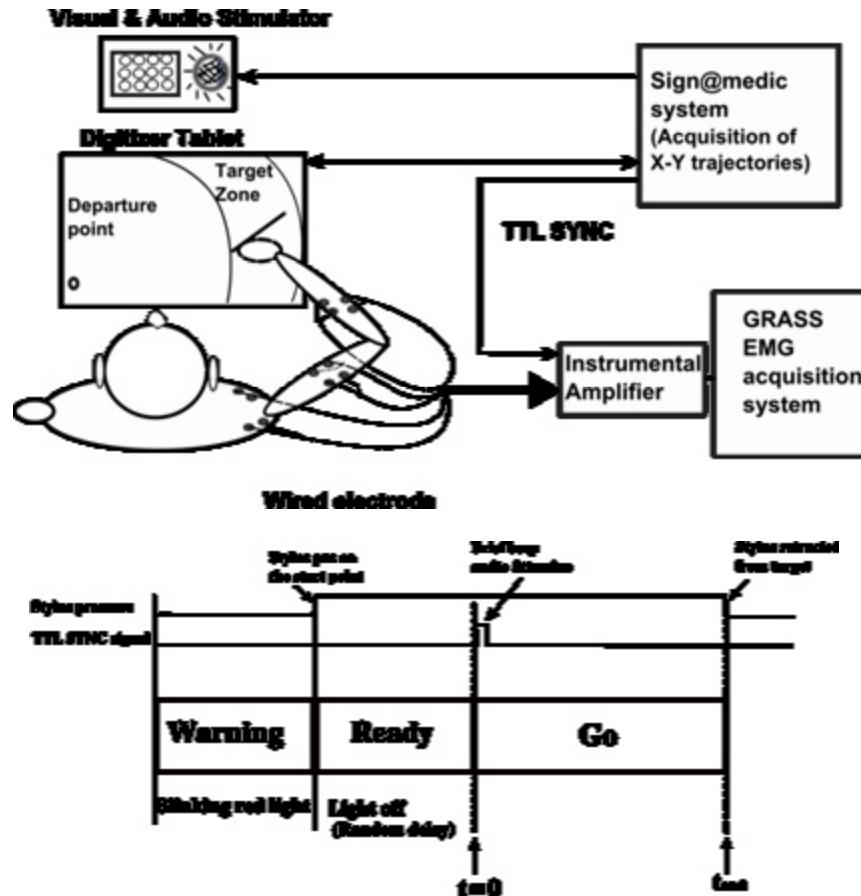


Figure 3b: Experimental protocol

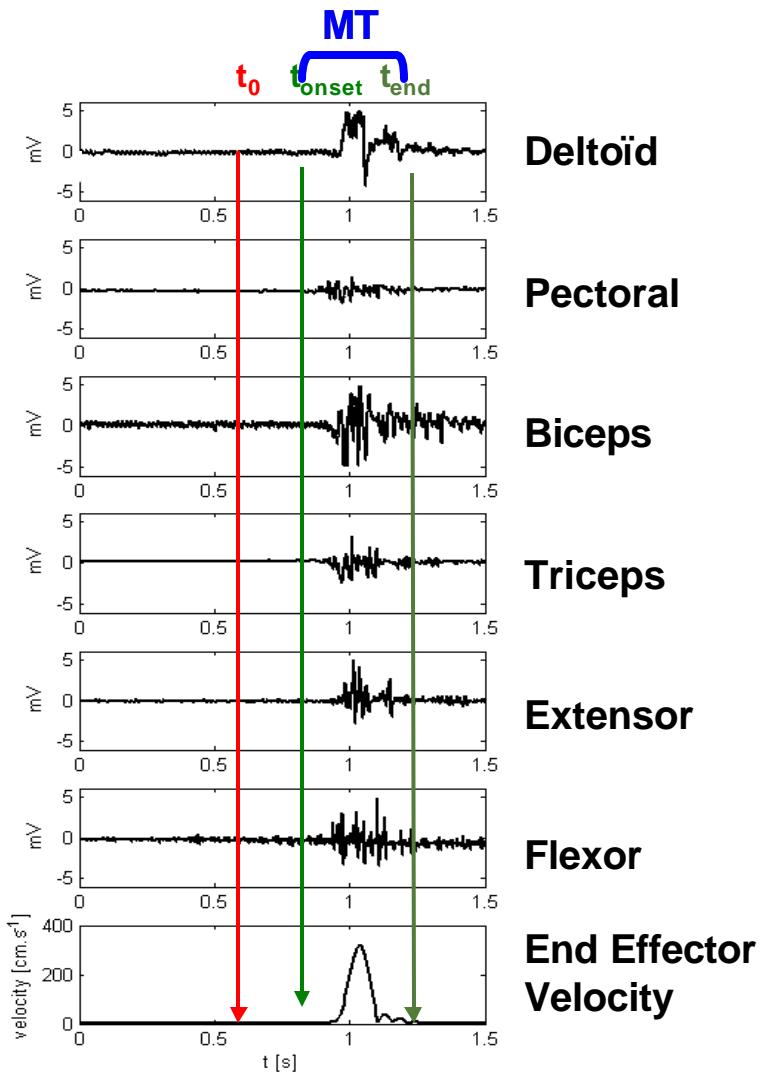
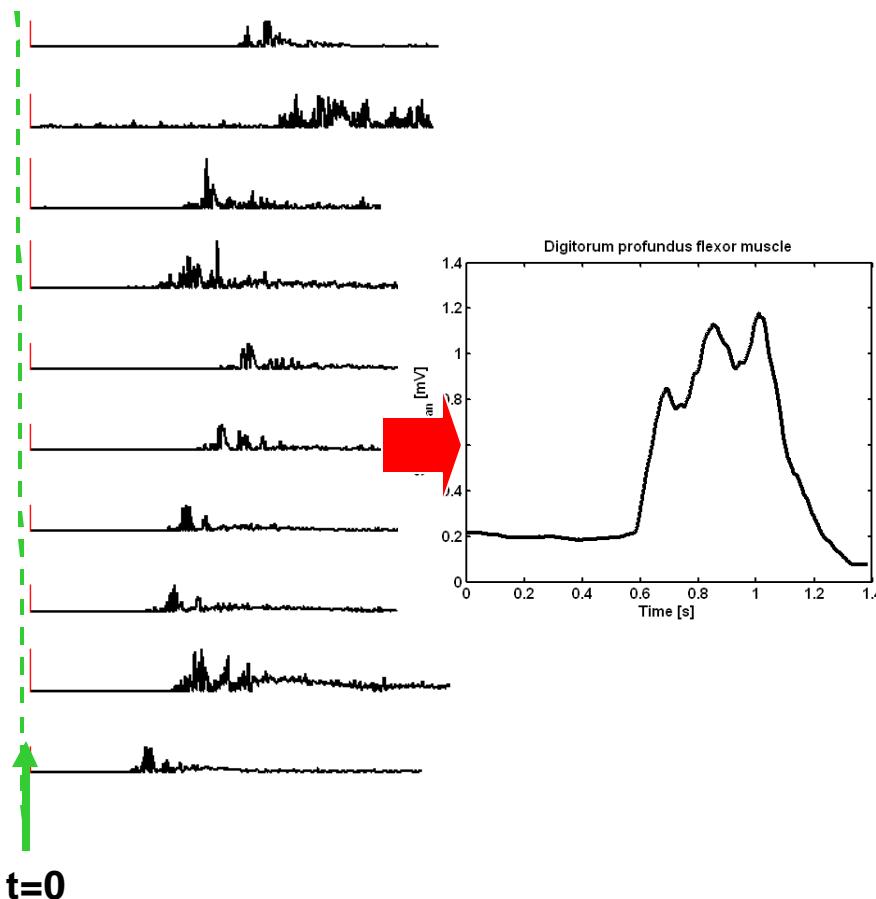


Figure 3c: Selecting EMG signals corresponding to a movement

Application 2b: SEMG Signal Synchronization

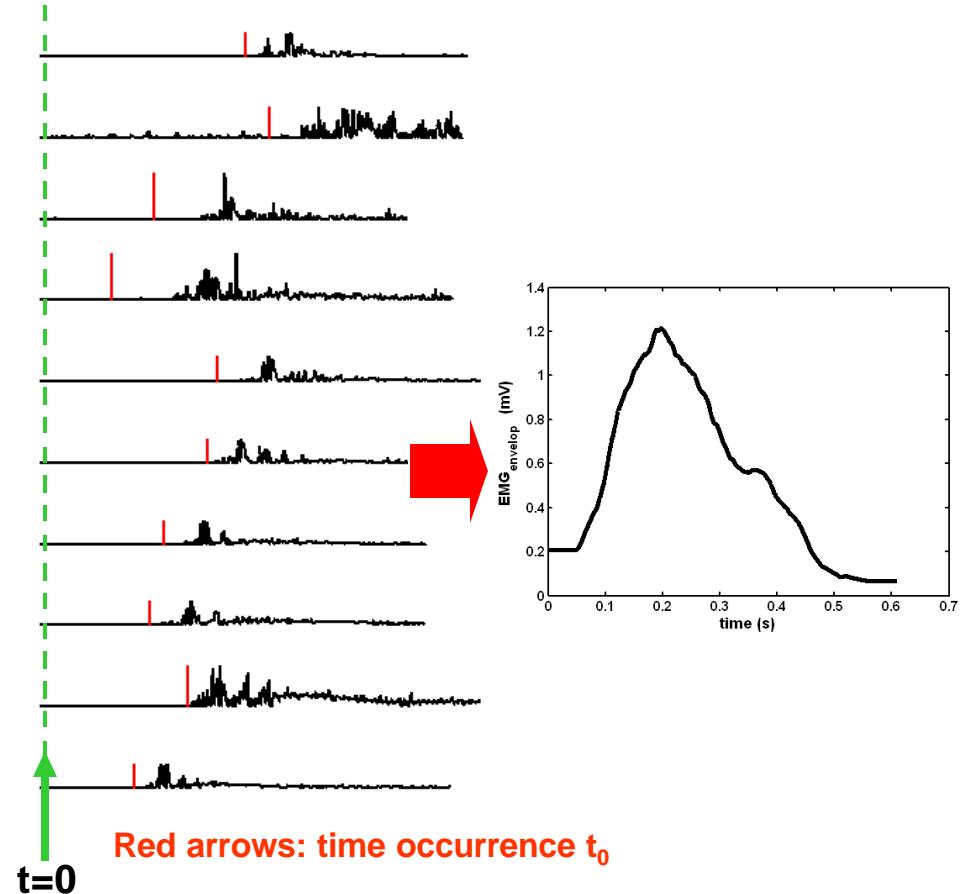
Reference time : Stimulus onset ($t=0$)



Red arrows: Stimulus onset

Figure 4a: Typical SEMG signals recorded on a flexor muscle and its envelope as computed from the Stimulus onset ($t=0$)

Reference time: Time occurrence t_0 (Djioua & Plamondon, 2008)



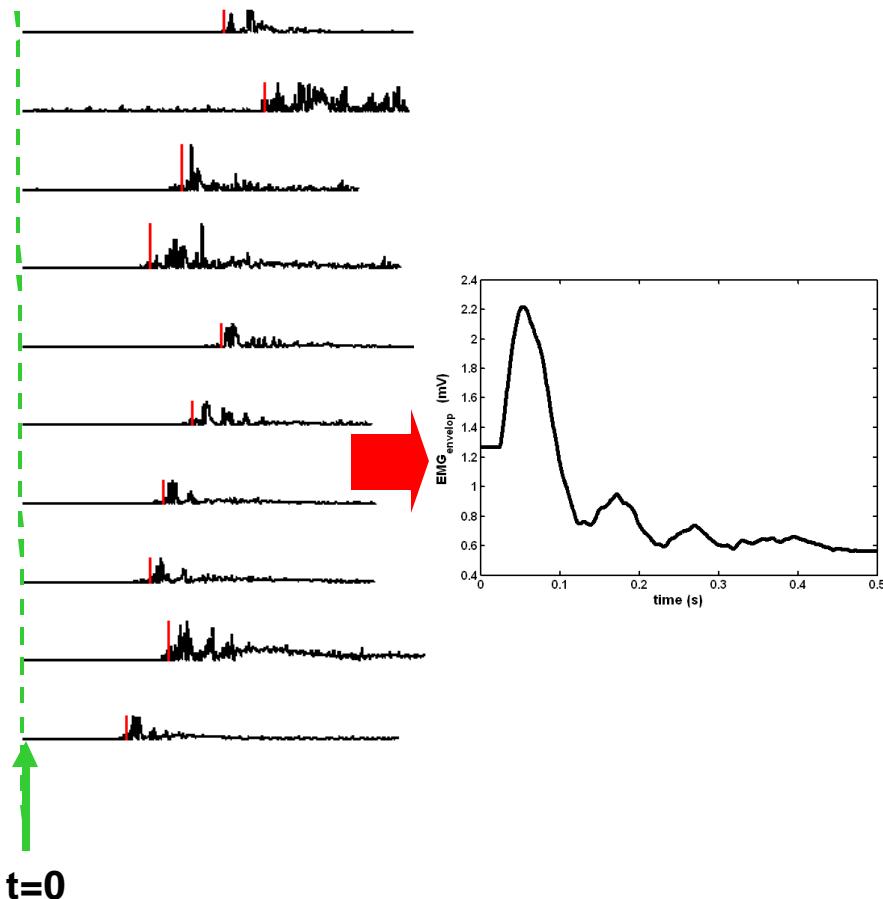
Red arrows: time occurrence t_0

Figure 4b: Same SEMG signals recorded on a flexor muscle and its envelope as computed from t_0

4a

Application 2b: SEMG Signal Synchronization

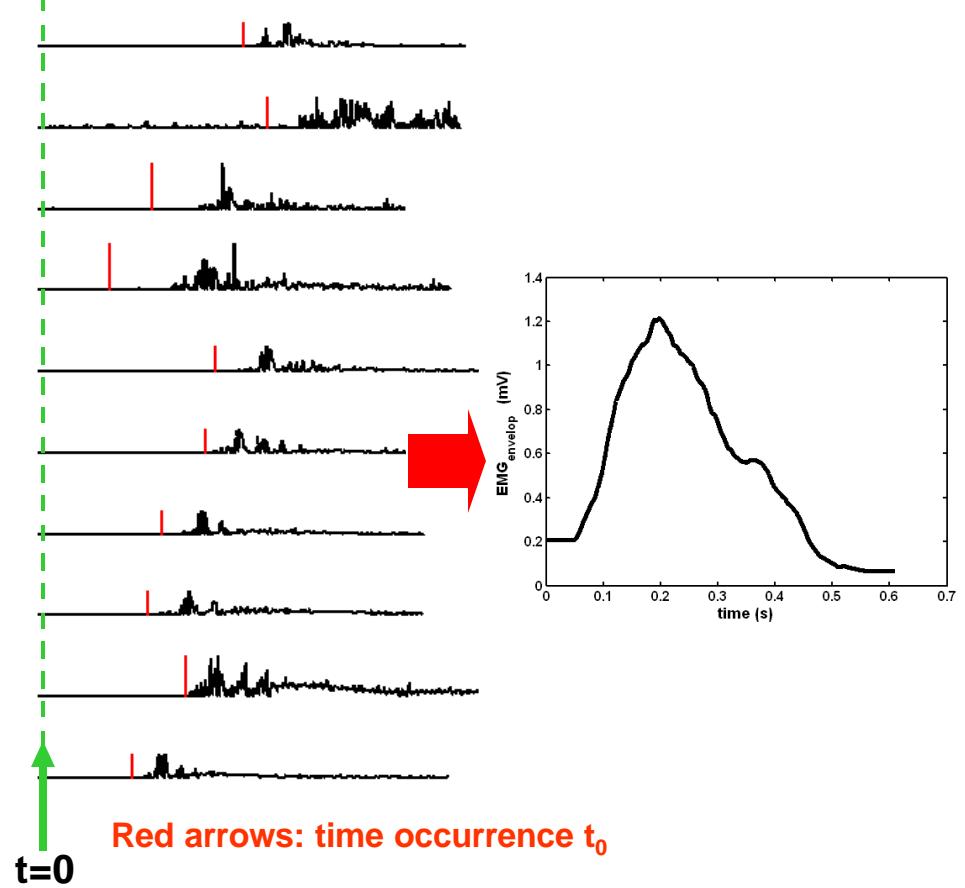
Reference time : Movement onset (Hodges and Bui, 1996)



Red arrows: Movement onset (Hodges and Bui, 1996)

Figure 4c: Typical SEMG signals recorded on a flexor muscle and its envelope as computed from the movement onset (tonset)

Reference time: Time occurrence t_0 (Djioua & Plamondon, 2008)



Red arrows: time occurrence t_0

Figure 4b: Same SEMG signals recorded on a flexor muscle and its envelope as computed from t_0

Application 2c: Recovering the Action Plan of the Muscular Activity without Kinematic Information

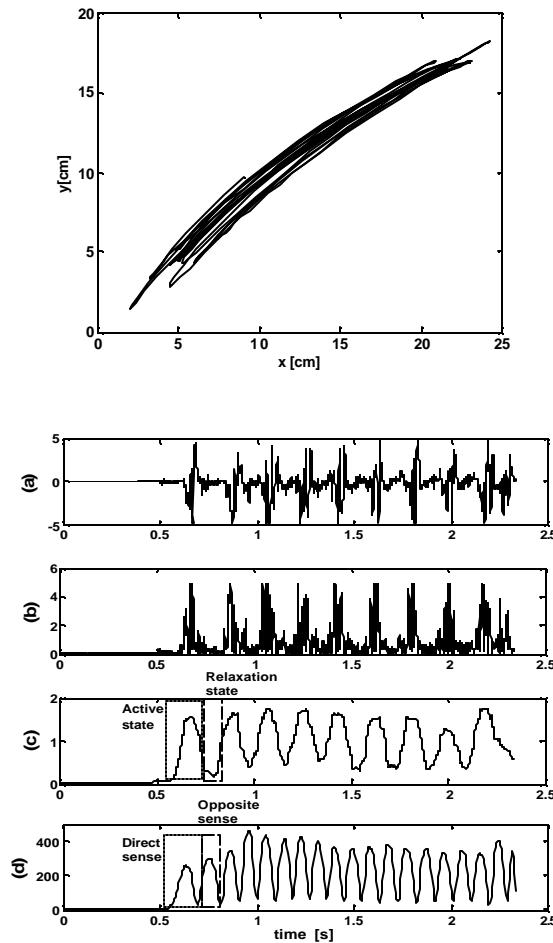


Figure 5a: Typical SEMG signals recorded during an oscillatory movement

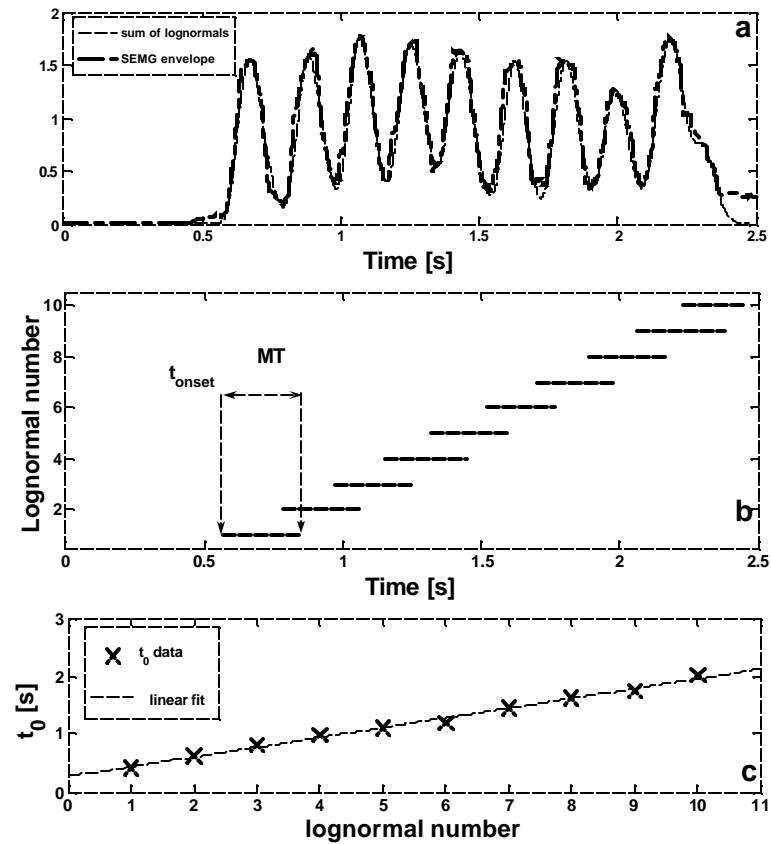
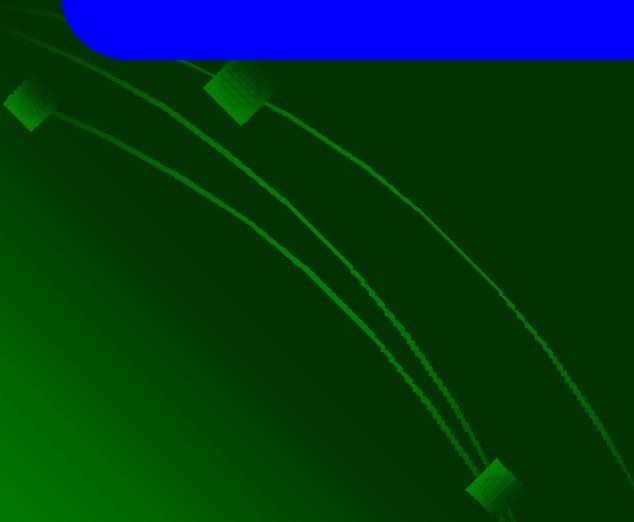


Figure 5b: (a) Fitting of the SEMG envelop with 10 lognormals,
(b) Identification of the activity period of the flexor muscle.
(c) Evolution of the time occurrence of the $\{t_0\}$ neuromotor command.

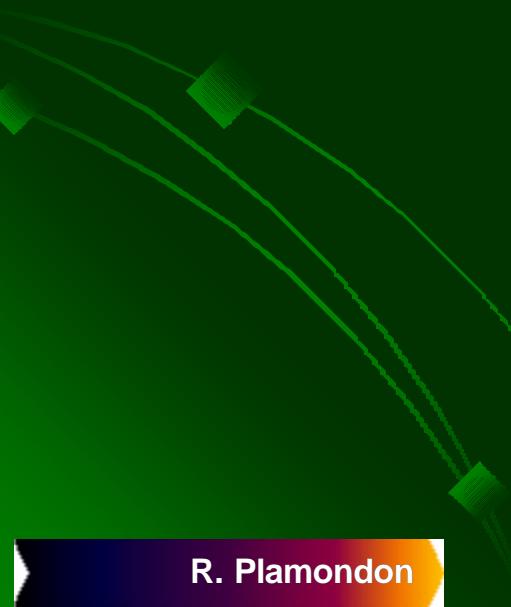
Theoretical
Problem No 3

Experimental investigation of t_0



Goal

**Look for Correlations Between EEG Signals
(through evoked response potentials)
and the Parameter t_0
of the Delta-Lognormal Model**

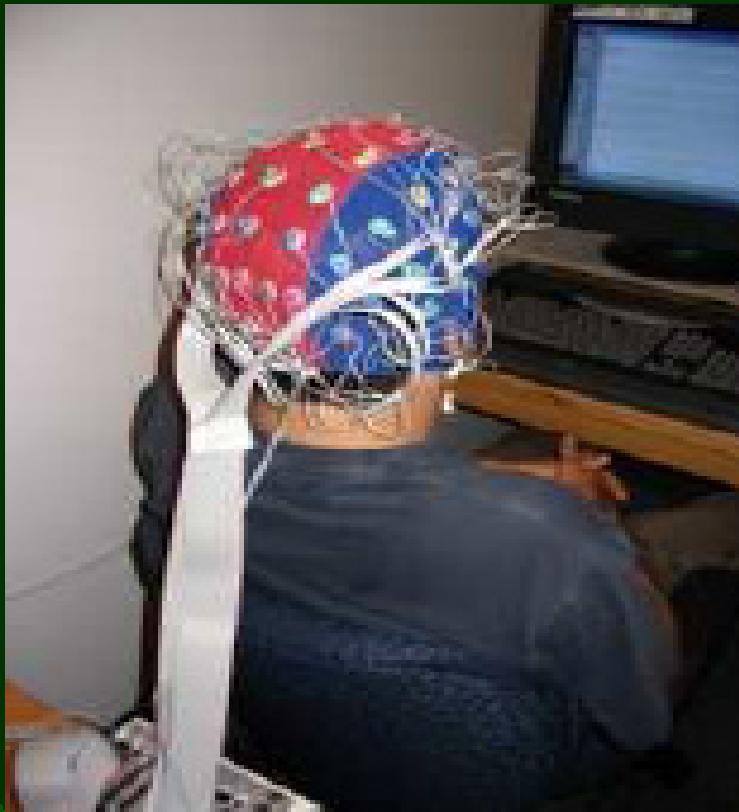


Experimental Protocol

- Reaction time experiment.
- Audio or visual stimuli
- Task: to produce a handwriting stroke as fast as possible
- Twelve subjects
- Experiments performed at the laboratoire de neuropragmatique du Centre de Recherche de l'Institut Universitaire de Gériatrie de Montréal

Experimental Protocol

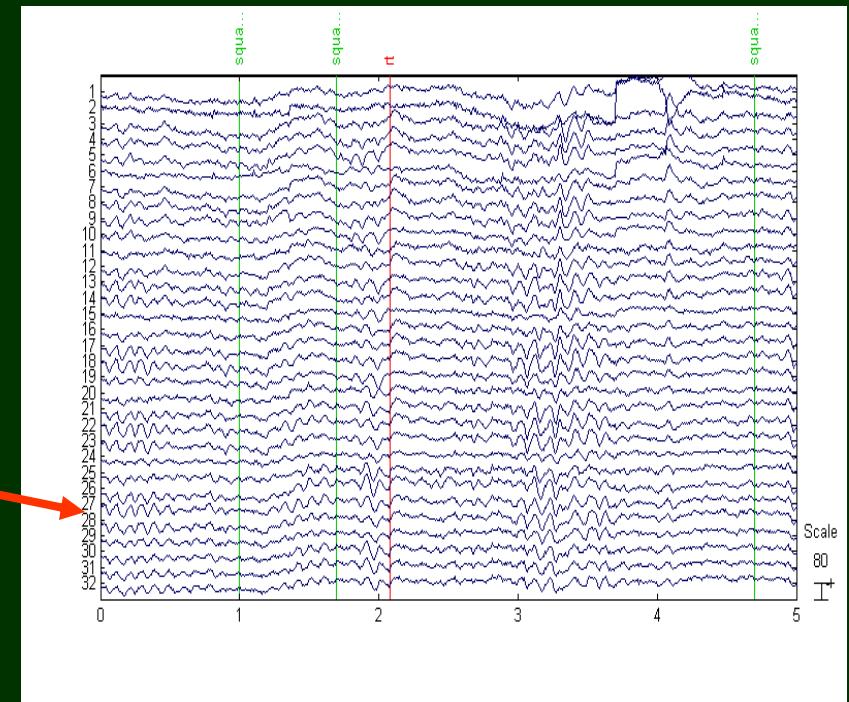
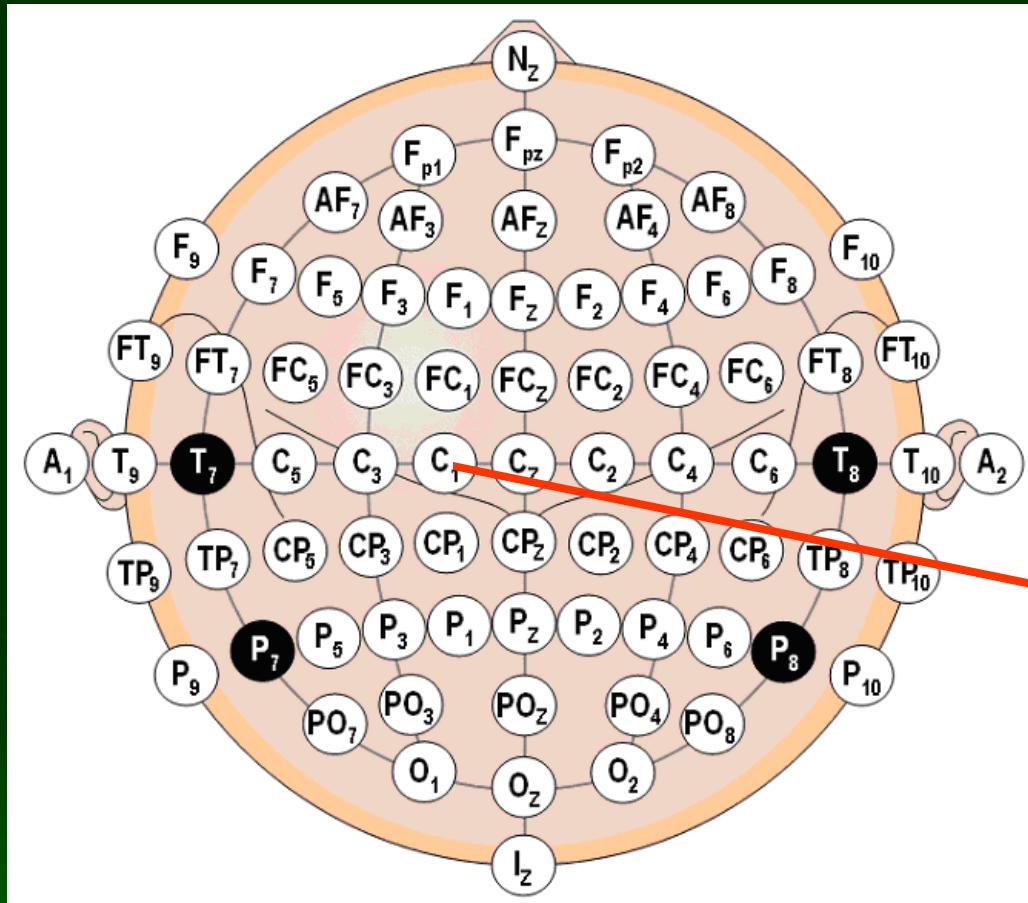
- Recording evoked potentials with 64 electrodes



Typical trial

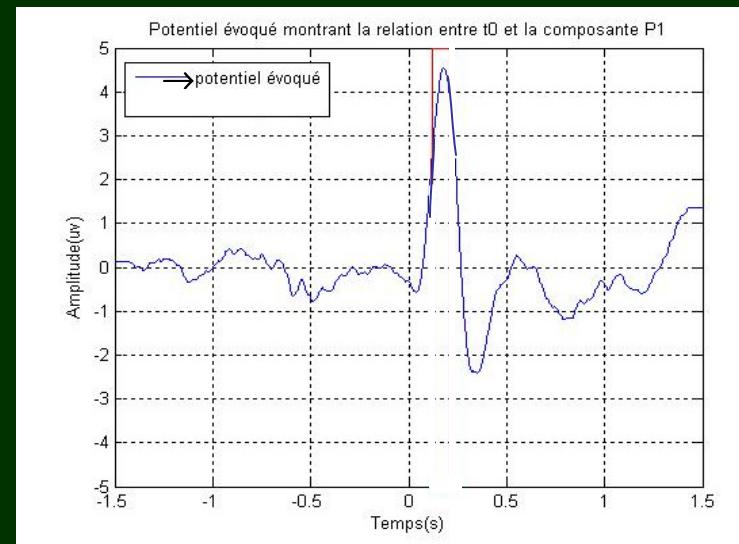
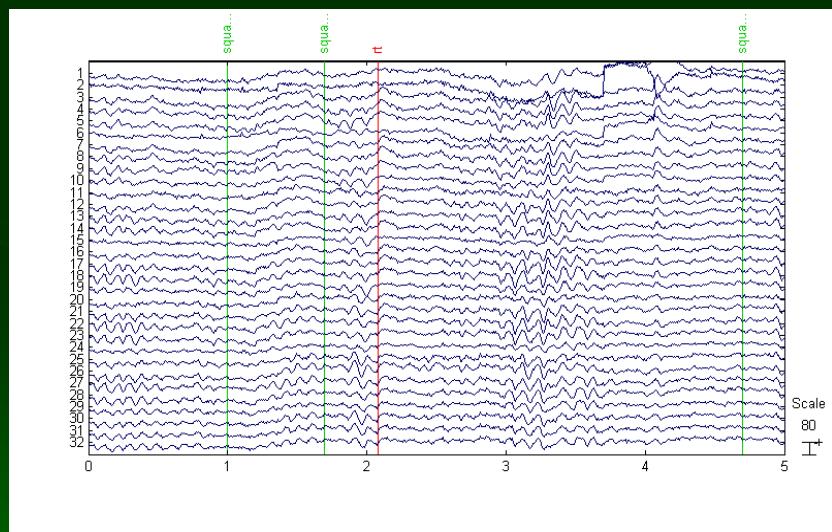
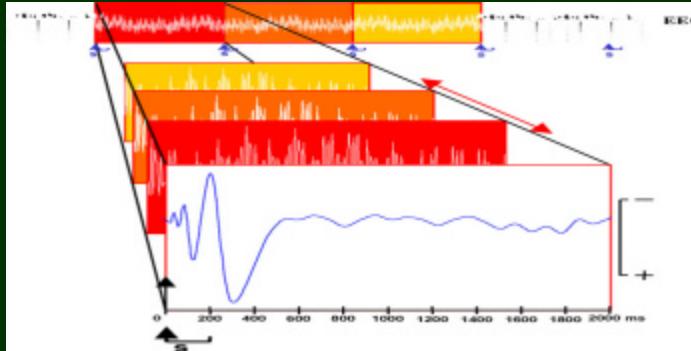


EEG recording



- Position of the Electrodes
- 32 Typical Recordings of the C1 Channel

Computation of the Evoked Response Potentials

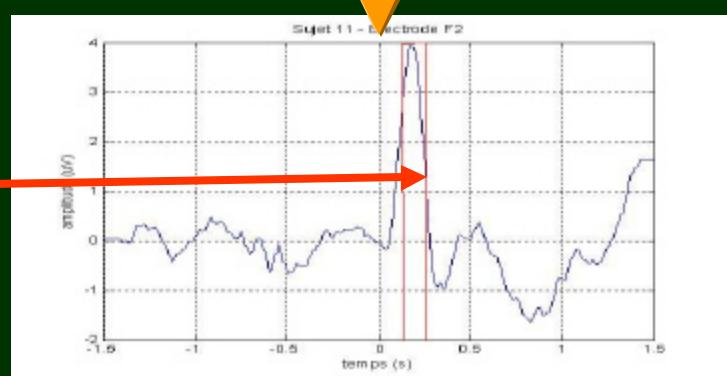
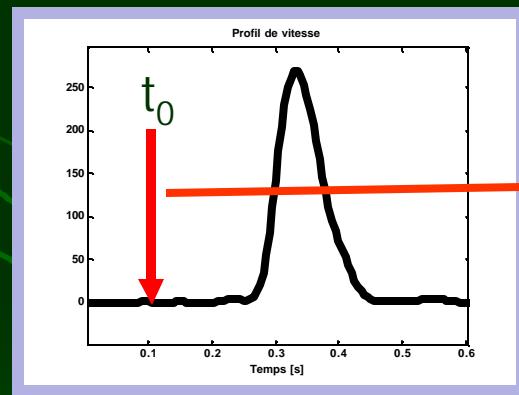
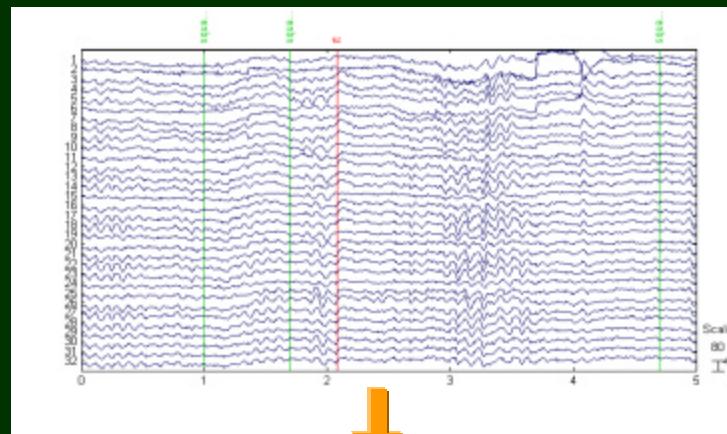
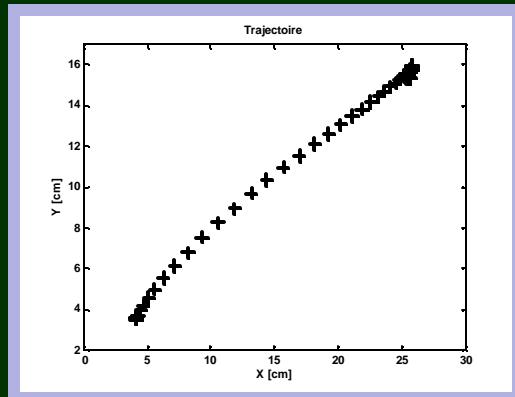


ERP can emerge through mean trace computation among trials for each electrode

Typical Correlation

EEG signals

Kinematic data



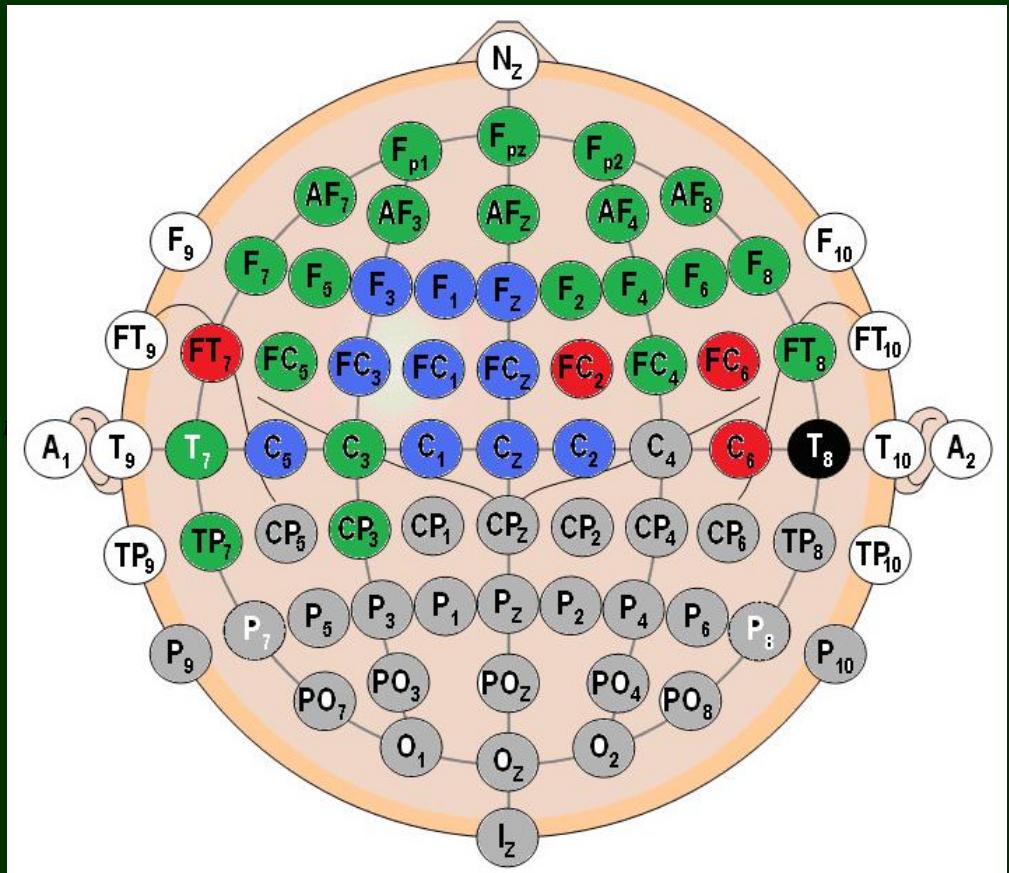
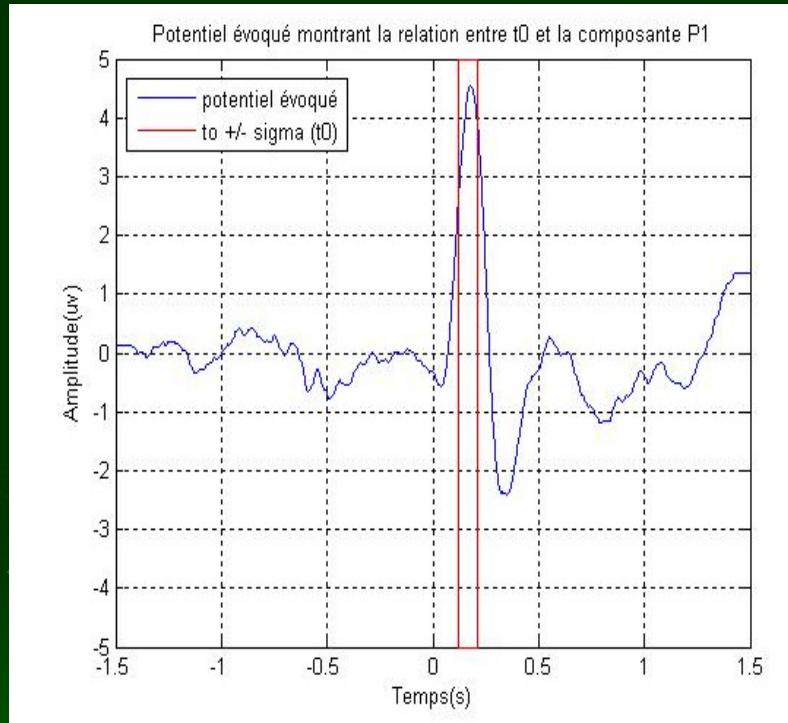
- A visually evoked response potential emerges at t_0

Summary of the results on the visual data

- Visually evoked response potentials are observed in such an experiment !
- For any subject, there are always many electrodes for which the ERP positive peak matches the time occurrence (t_0) of the command
- Some of these electrodes are the same for a majority of subjects

Summary of the Results

GOOD MATCH



Blue: $t = t_0$
Red: $t > t_0$
Green: $t < t_0$

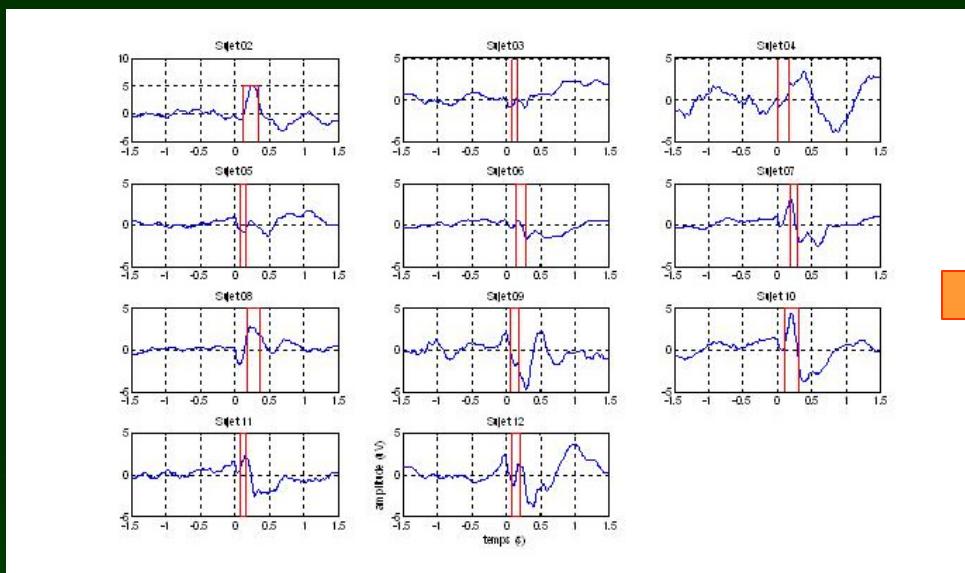
Practical
Application No 3

Improving EEG signal processing

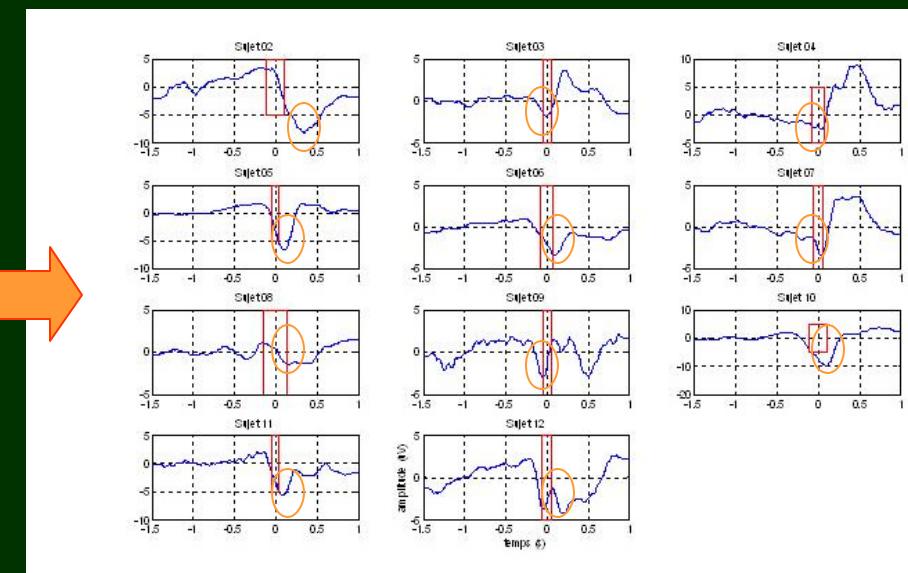


Emergence of Audio ERP

Reference time : Stimulus onset



Reference time : t_0



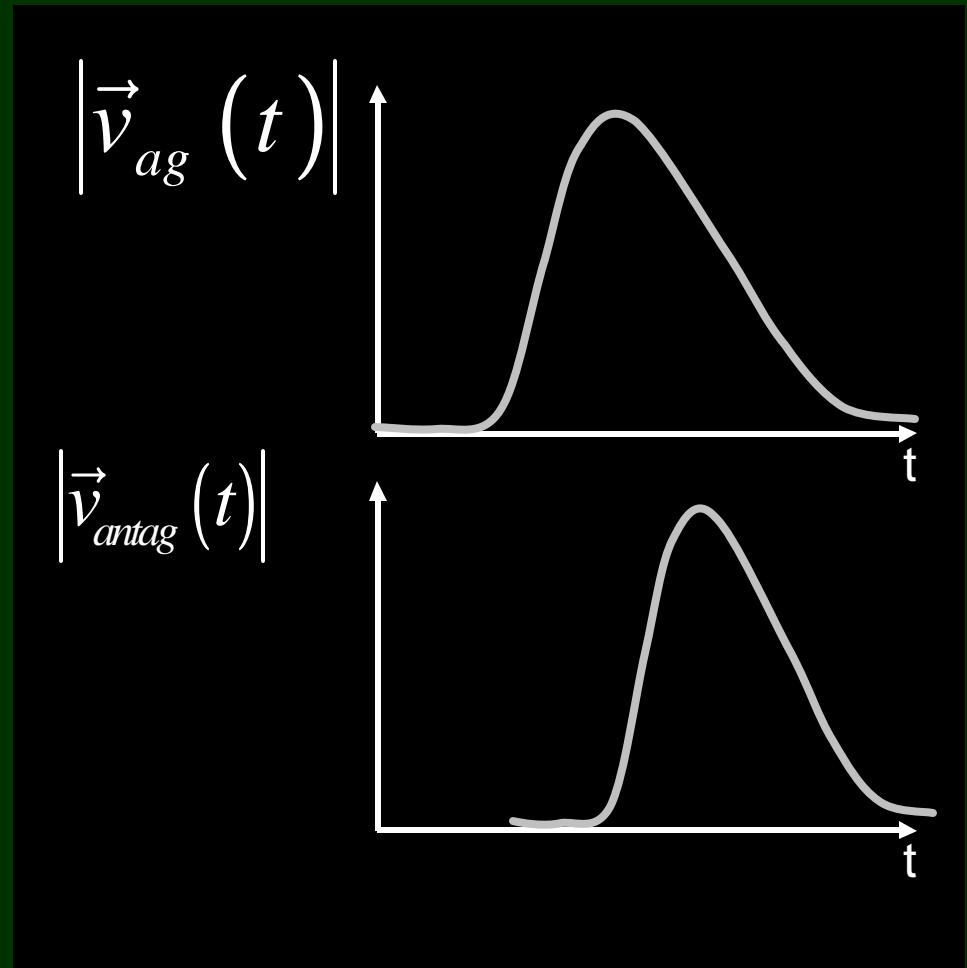
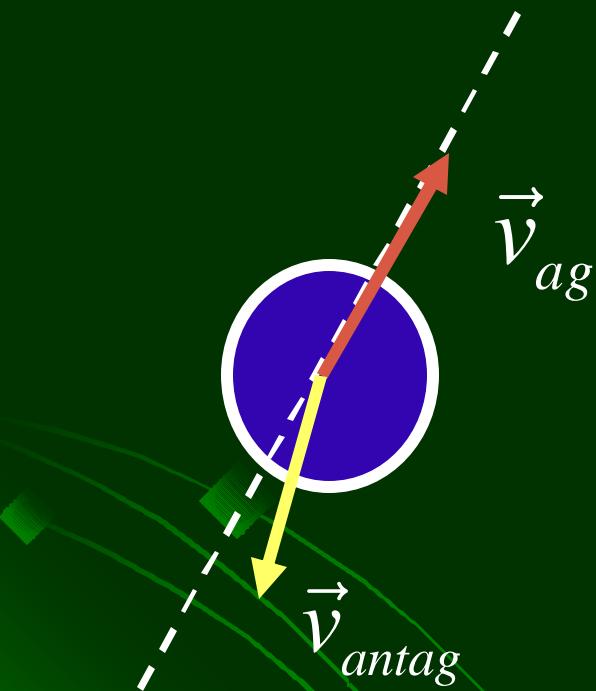
- A negative wave emerges in the C1 channel, for all the 11 subjects,
- after synchronization of each trial on the command time occurrence (t_0) instead of the stimulus onset ($t=0$).

Theoretical
Problem No 4

Generalizing the Kinematic Theory: The Sigma-lognormal model

PLAMONDON, R. DJIOUA, M., «A Multi-Level Representation Paradigm for Handwriting Stroke Generation», **Human Movement Science**, vol. 25, pp. 586-607, 2006

Vectorial summation



Velocity profile of a single Delta-Lognormal stroke

$$v(t) = v_{ag}(t) - v_{antag}(t)$$

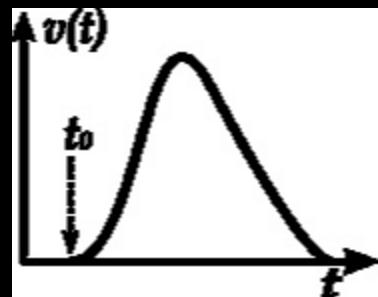
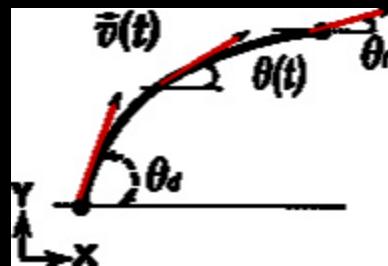
General case: non perfect opposition of the agonist and the antagonist components

$$\vec{v}(t) = \vec{v}_{ag}(t) + \vec{v}_{antag}(t)$$



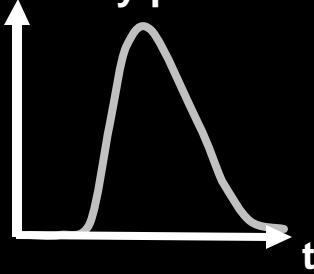
Sigma-Lognormal Model

Sigma-Lognormal vectorial model

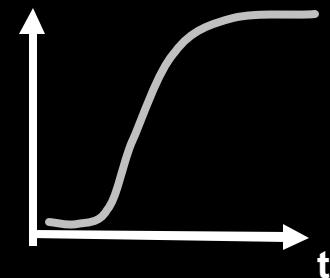


Movement primitive

Lognormal Velocity profile



Erf angular direction profile



$$\vec{v}(t) = \sum_{i=1}^L \vec{v}_i(t) = \sum_{i=1}^L \vec{D}_i \Lambda(t; t_0, m_i, s_i^2); \quad L \geq 2$$

$$q_i(t) = q_{di} + \frac{(q_{fi} - q_{di})}{2} \left[1 + erf \left(\frac{\ln(t - t_{0i}) - m_i}{s_i \sqrt{2}} \right) \right]$$

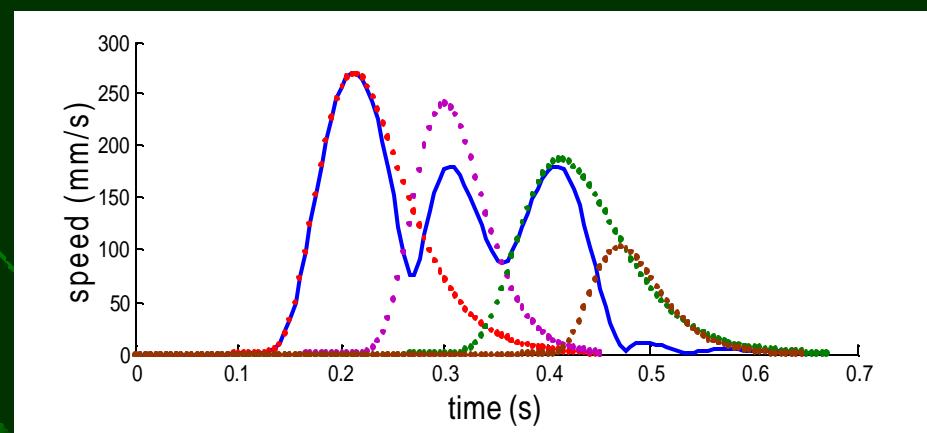
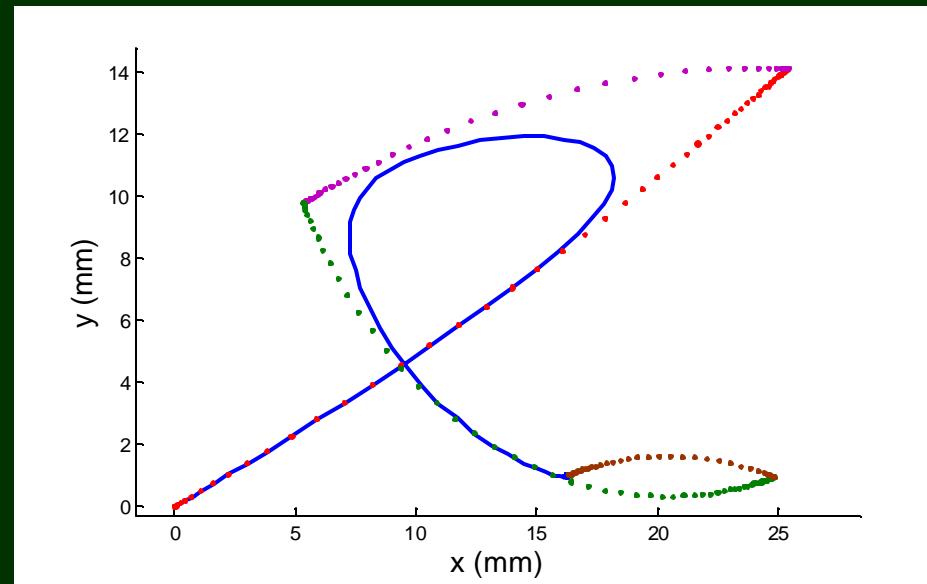
$$x(t) = x_0 + \sum_{i=1}^L \int_{t_0}^t v_i(t) \cos [q_i(t)] dt$$

$$y(t) = y_0 + \sum_{i=1}^L \int_{t_0}^t v_i(t) \sin [q_i(t)] dt$$

Sigma-Lognormal model

- Discontinuous action plan
- Virtual targets
- Vectorial summation of strokes
- Time overlap
- Individual strokes hidden in the signal
 - Velocity profiles : Lognormal functions
 - Direction angle profiles: Error functions (Erf)

Complex movement generation



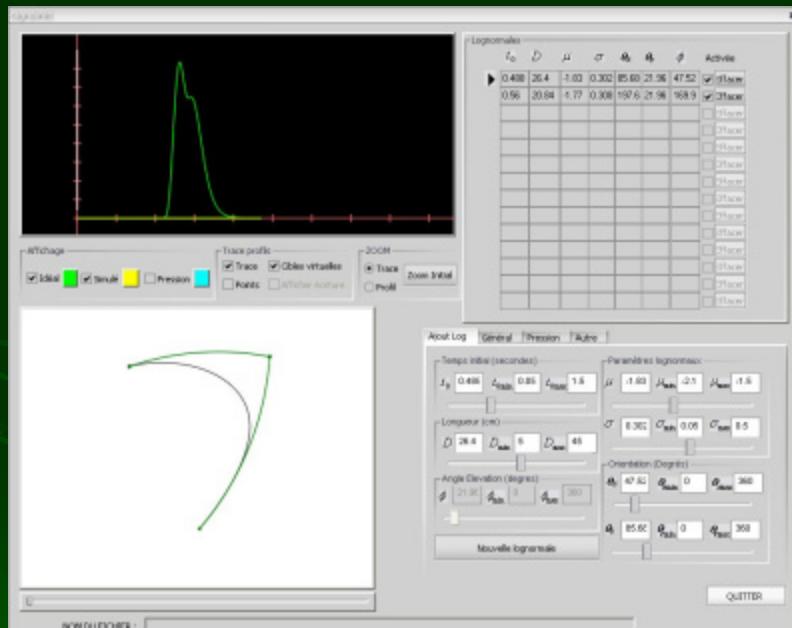
Practical
Problem No 4

Sigma-Lognormal parameter extraction (Complex trajectories)

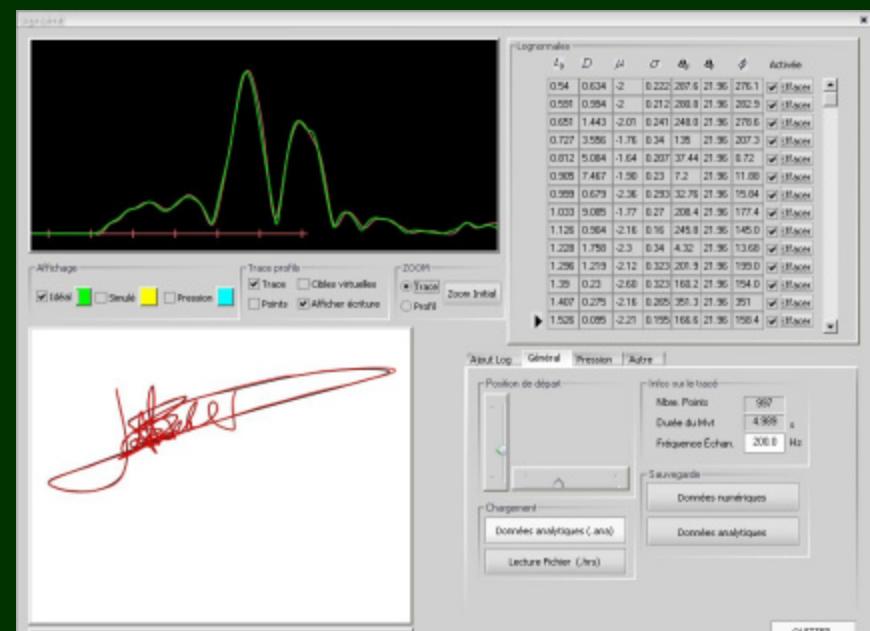
Phase 1: interactive approach

Partly automated interactive tool: Complex movement synthesis

Superposing two strokes

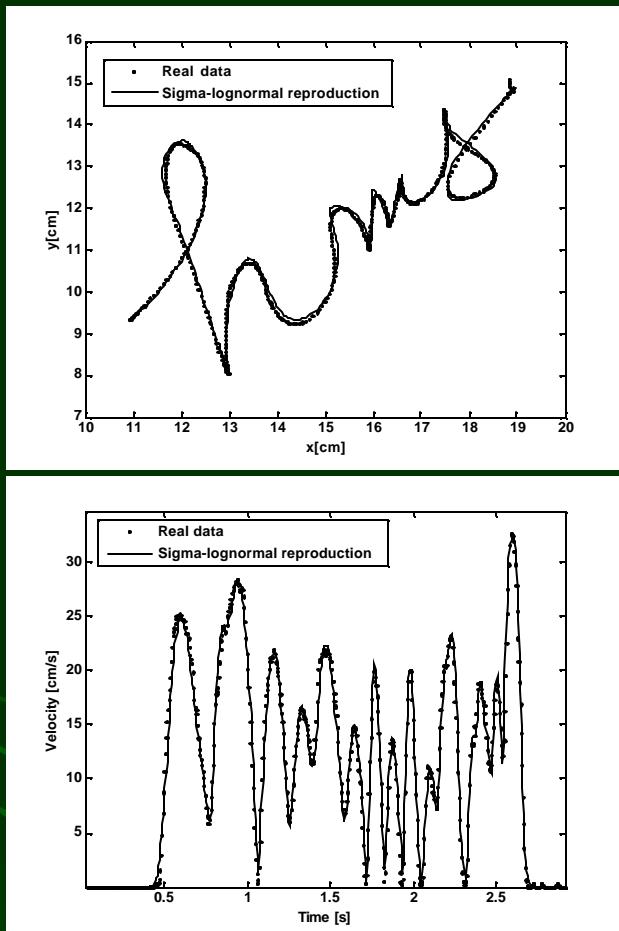


Signature analysis-by-synthesis



Ref : M. Djoua, C. O'Reilly, and R. Plamondon, " An interactive trajectory synthesizer to study outlier patterns in handwriting recognition and signature verification," *Proceedings of the 18th International Conference on Pattern Recognition (ICPR'06)*, vol. 1, pp. 1124-1127, 2006.

Handwriting

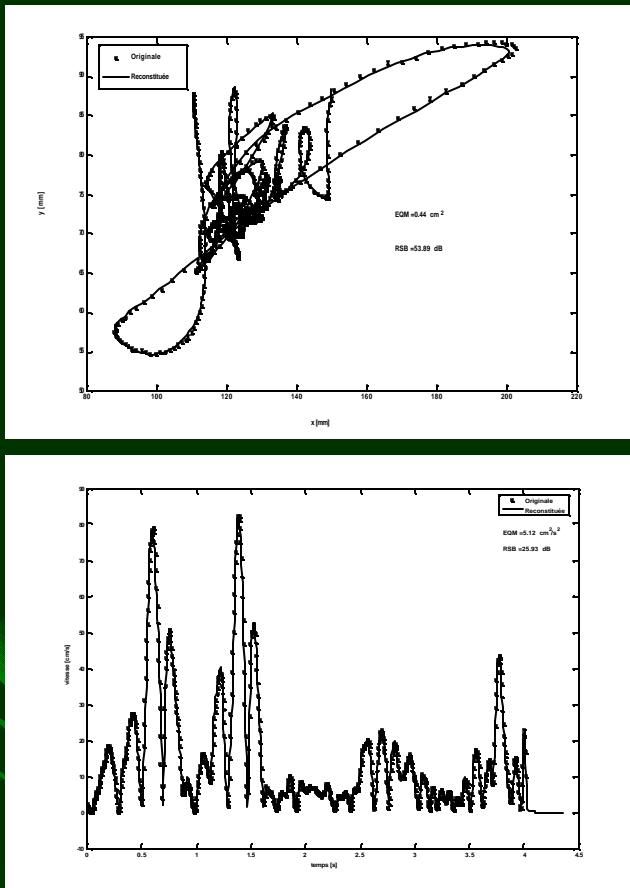


Sigma-Lognormal parameters of 20 strokes

#Log normal	t_0	D	μ	σ	θ_s	θ_e
1	0.321	5.399	-1.183	0.294	98.64	43.92
2	0.495	0.679	-1.457	0.215	212.76	174.24
3	0.595	1.946	-1.4	0.149	309.6	224.28
4	0.6	5.087	-1.015	0.203	287.64	282.96
5	0.804	4.797	-0.979	0.22	61.56	104.04
6	0.826	3.686	-0.677	0.138	280.8	273.96
7	1.014	4.265	-0.762	0.146	118.44	42.84
8	1.421	1.849	-1.485	0.195	265.68	351
9	1.523	1.559	-1.388	0.116	92.16	83.88
10	1.616	1.076	-1.329	0.118	283.32	297.72
11	1.723	1.366	-1.329	0.102	77.04	81.36
12	1.937	0.931	-1.738	0.198	294.12	264.96
13	1.959	1.704	-1.412	0.138	94.32	27
14	1.999	0.931	-1.365	0.097	105.48	83.88
15	2.105	0.713	-1.365	0.086	313.92	280.8
16	2.158	0.931	-1.365	0.086	313.92	323.64
17	2.202	0.545	-1.365	0.086	313.92	278.64
18	2.243	1.398	-1.314	0.105	197.64	208.44
19	2.337	1.318	-1.232	0.081	46.08	65.52
20	2.391	1.994	-1.664	0.142	39.24	92.52

Ref : R. Plamondon and M. Djouia, "A multi-level representation paradigm for handwriting stroke generation " *Human Movement Science*, vol. 25, pp. 586-607, 2006.

Signature



Sigma-Lognormal parameters

c	D	H	a	sd	sf
0.540	0.634	-2.000	0.222	287.640	21.960 276.120
0.551	0.594	-2.000	0.212	280.800	21.960 282.960
0.651	1.442	-2.016	0.241	248.040	21.960 278.640
0.727	0.556	-1.760	0.240	195.000	21.960 207.260
0.812	5.084	-1.641	0.207	37.440	21.960 0.720
0.905	7.467	-1.904	0.230	7.200	21.960 11.880
0.999	0.679	-2.365	0.293	32.760	21.960 15.840
1.032	9.095	-1.774	0.270	209.440	21.960 177.480
1.126	0.594	-2.160	0.160	245.880	21.960 148.080
1.190	1.758	-2.050	0.170	4.520	21.960 1.610
1.286	1.219	-2.124	0.223	201.960	21.960 190.080
1.380	0.230	-2.606	0.323	160.200	21.960 154.080
1.407	0.275	-2.167	0.265	351.860	21.960 351.000
1.526	0.095	-2.214	0.155	166.680	21.960 158.400
1.594	0.410	-2.423	0.259	333.720	21.960 163.080
1.636	0.230	-2.343	0.207	30.600	21.960 6.840
1.662	0.230	-2.300	0.247	72.360	21.960 83.880
1.679	0.095	-2.343	0.247	204.120	21.960 242.280
1.712	0.140	-2.278	0.247	345.520	21.960 110.880
1.721	0.140	-2.186	0.247	345.210	21.960 346.320
1.757	0.110	-2.277	0.263	166.680	21.960 0.000
1.857	0.485	-2.080	0.268	360.000	21.960 87.680
1.925	0.859	-2.167	0.177	105.480	21.960 92.880
1.967	1.219	-2.257	0.185	100.800	21.960 68.040
2.035	1.892	-2.167	0.212	315.360	21.960 242.280
2.078	0.455	-2.102	0.160	147.240	21.960 276.640
2.129	0.265	-2.214	0.212	74.520	21.960 187.920
2.171	0.265	-2.214	0.185	18.320	21.960 54.360
2.222	0.544	-2.124	0.160	252.360	21.960 298.880
2.232	0.455	-2.214	0.172	94.320	21.960 49.680
2.455	0.185	-2.214	0.172	269.800	21.960 240.120
2.476	0.200	-2.164	0.170	119.320	21.960 41.920
2.500	0.230	-2.211	0.172	295.120	21.960 478.680
2.545	0.220	-2.214	0.172	0.000	21.960 9.000
2.587	0.230	-2.214	0.172	92.160	21.960 59.040
2.630	0.589	-2.214	0.172	142.560	21.960 97.200
2.659	1.938	-2.080	0.241	239.400	21.960 190.080
2.783	0.544	-2.192	0.330	360.000	21.960 312.480
2.800	0.589	-2.037	0.207	85.680	21.960 47.520
2.855	0.820	-2.145	0.207	100.800	21.960 72.360
2.978	0.230	-2.148	0.207	89.520	21.960 97.200
3.032	0.445	-2.148	0.207	67.880	21.960 91.880
3.242	1.533	-2.112	0.241	300.880	21.960 276.640
3.335	2.342	-2.102	0.224	140.440	21.960 242.280
3.411	2.477	-2.167	0.183	17.680	21.960 24.840
3.488	1.989	-2.145	0.189	200.520	21.960 224.280
3.564	2.882	-2.102	0.230	197.280	21.960 226.240
3.649	1.399	-2.145	0.224	30.600	21.960 27.000
3.692	1.174	-2.278	0.235	0.000	21.960 33.480
3.751	0.820	-2.257	0.185	162.360	21.960 240.120
3.802	0.366	-2.235	0.143	226.050	21.960 176.920
3.927	0.455	-2.214	0.181	9.640	21.960 0.000
3.980	0.510	-2.167	0.183	158.720	21.960 281.120
4.049	0.320	-2.257	0.119	87.840	21.960 80.720
4.134	0.095	-2.476	0.085	0.000	21.960 54.360
4.159	0.265	-2.145	0.177	245.880	21.960 251.280
4.227	0.095	-2.167	0.181	335.880	21.960 267.120
4.285	0.634	-2.167	0.181	61.560	21.960 40.680
4.329	0.634	-2.145	0.181	74.520	21.960 65.520
4.388	1.129	-2.080	0.172	265.480	21.960 221.760
4.473	0.410	-2.182	0.186	107.640	21.960 45.360
4.532	0.949	-2.166	0.177	360.000	21.960 200.000
4.582	0.949	-2.365	0.177	87.240	21.960 33.680
4.635	0.500	-2.322	0.177	177.840	21.960 72.360
4.660	1.309	-2.080	0.203	360.000	21.960 246.960
4.711	0.275	-2.322	0.181	360.000	21.960 342.000
4.762	1.219	-2.214	0.183	85.680	21.960 105.840
4.805	0.275	-2.554	0.160	0.000	21.960 124.560

Ref :M. Djouia , Ph.D. dissertation, École Polytechnique de Montréal, 2007



Practical
Application No 5

Analysis and Synthesis of handwriting variability and automatic data base generation

Potential sources of variability

Command Level: Action Plan

Time occurrence of the command : t_{0i} parameters

Trajectory Amplitude & Direction : D_i, q_{di}, q_{fi} parameters

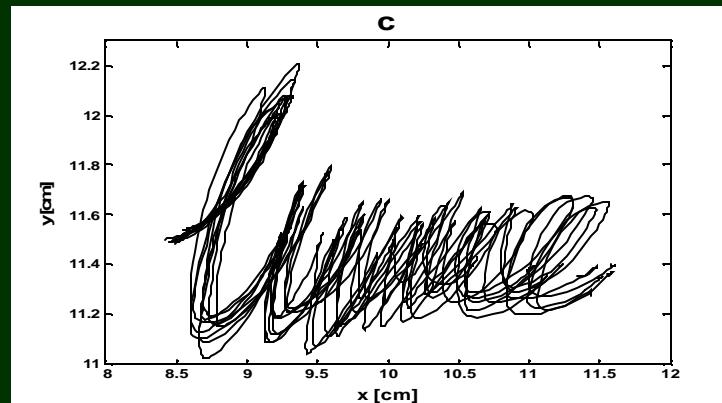
Response level : Peripheral System

Neuromuscular System Status : m_i, S_i parameters :

Ref : Djoua, M. & Plamondon, R. (2007). Analysis and synthesis of handwriting variability using the sigma-lognormal model. *Proceeding of the 13th Conference of the International Graphonomics Society (IGS2007)*. 13, 19-22.

Method and protocol

1. Three subjects wrote three times the word «lune» within a rectangle on a digitizer.

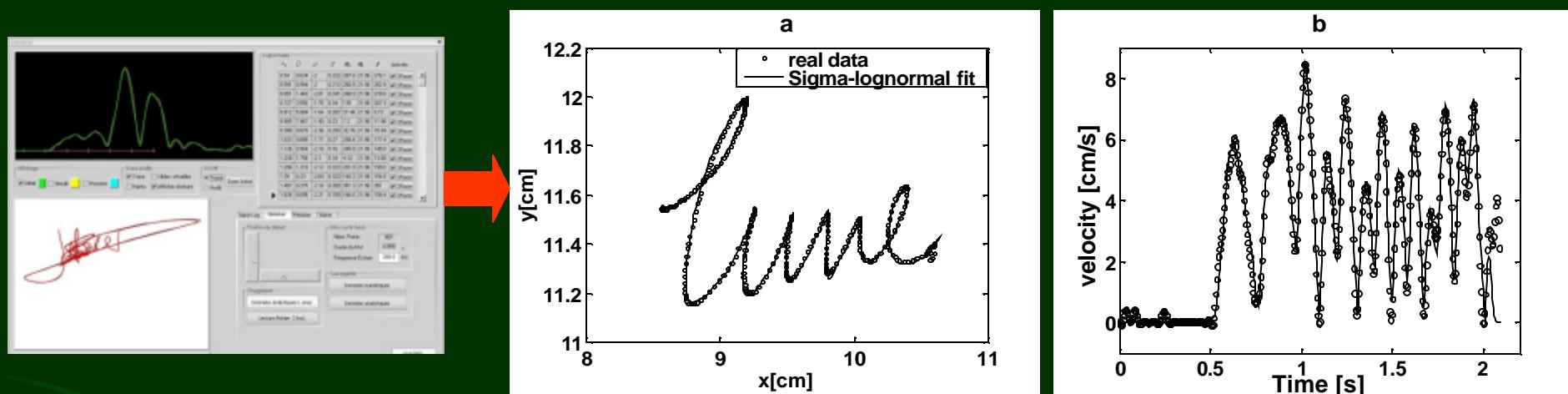


2. Using our software tool, we created a Sigma-Lognormal model of the word «lune» using 14 superimposed strokes.



Method and protocol

3. Interactive extraction of the sigma-lognormal parameters on the real specimens



4. Delimitation of the handwriting variability by computing the variability intervals of the Sigma-Lognormal parameters.

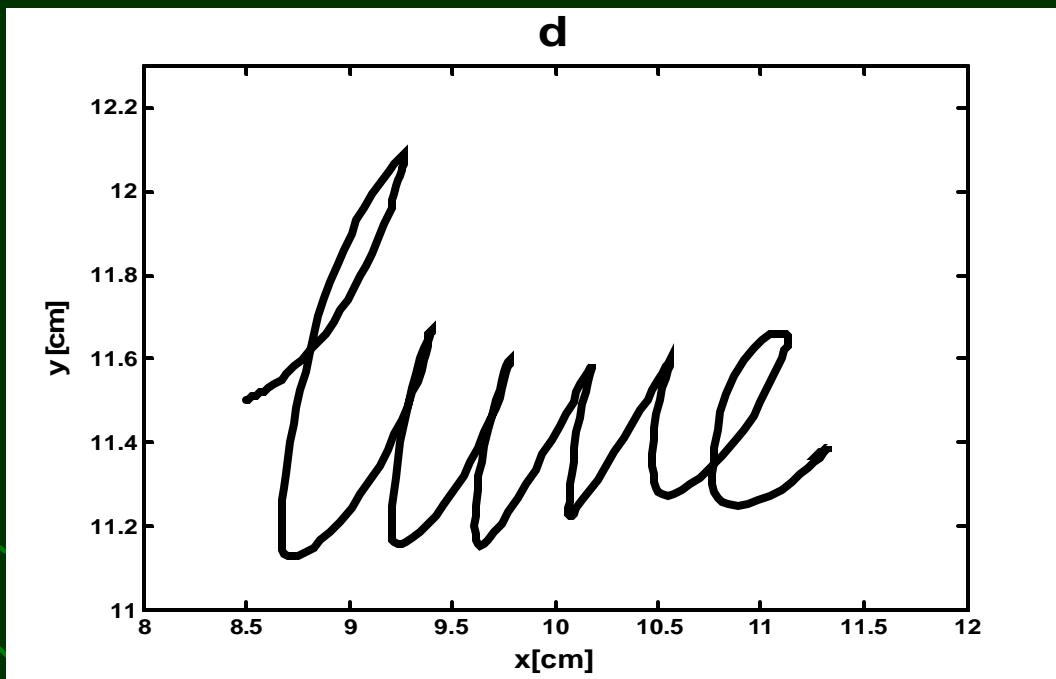
$$p_i \rightarrow p_{i_{mean}}, p_{i_{std}} \rightarrow [p_{i_{mean}} - kp_{i_{std}}, p_{i_{mean}} + kp_{i_{std}}]$$

$$p_i \in [t_{0i}, D_i, \mathbf{q}_{d_i}, \mathbf{q}_{f_i}, \mathbf{m}_i, \mathbf{s}_i];$$

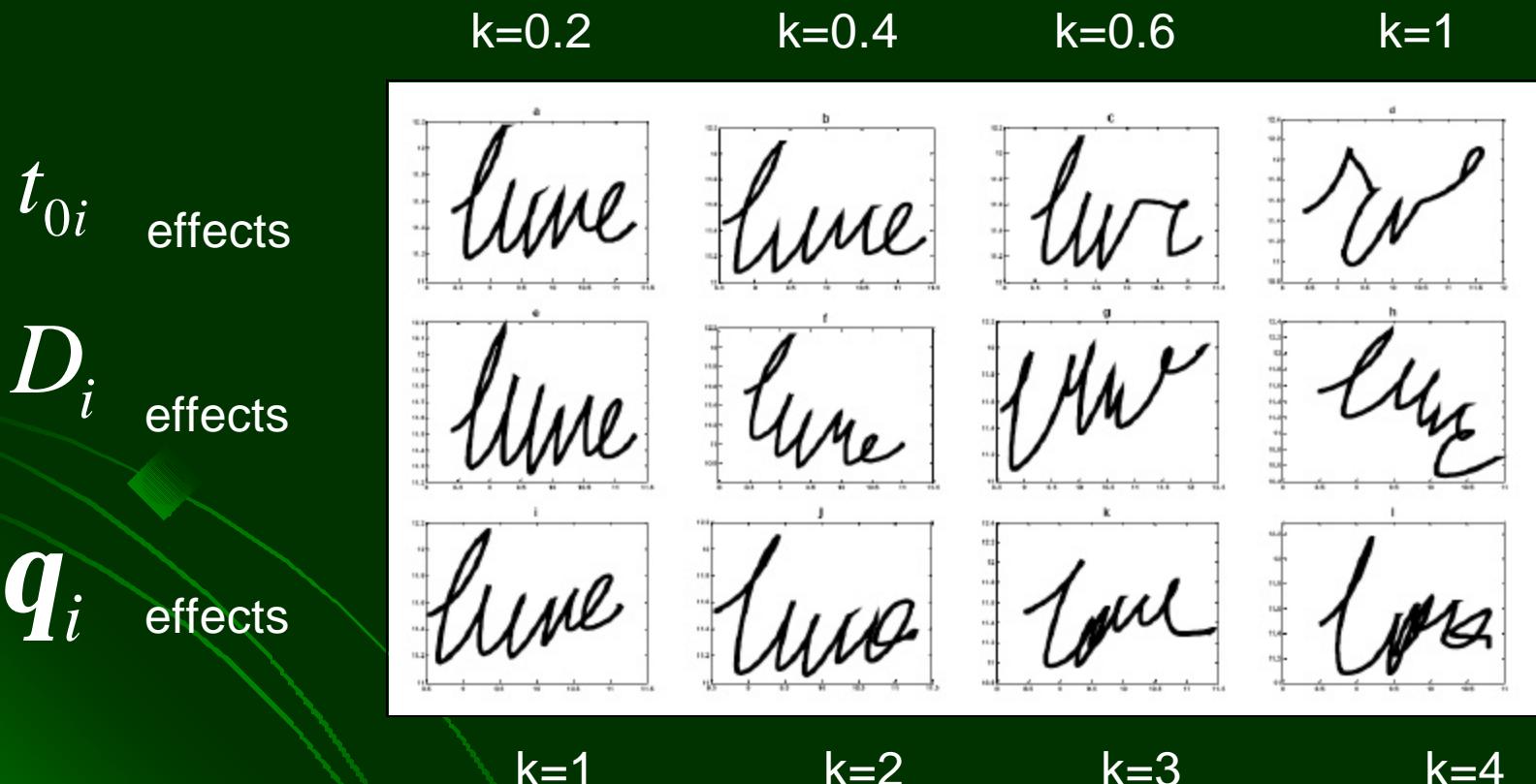
$0 < k \leq 3$ a window width

Method and Protocol

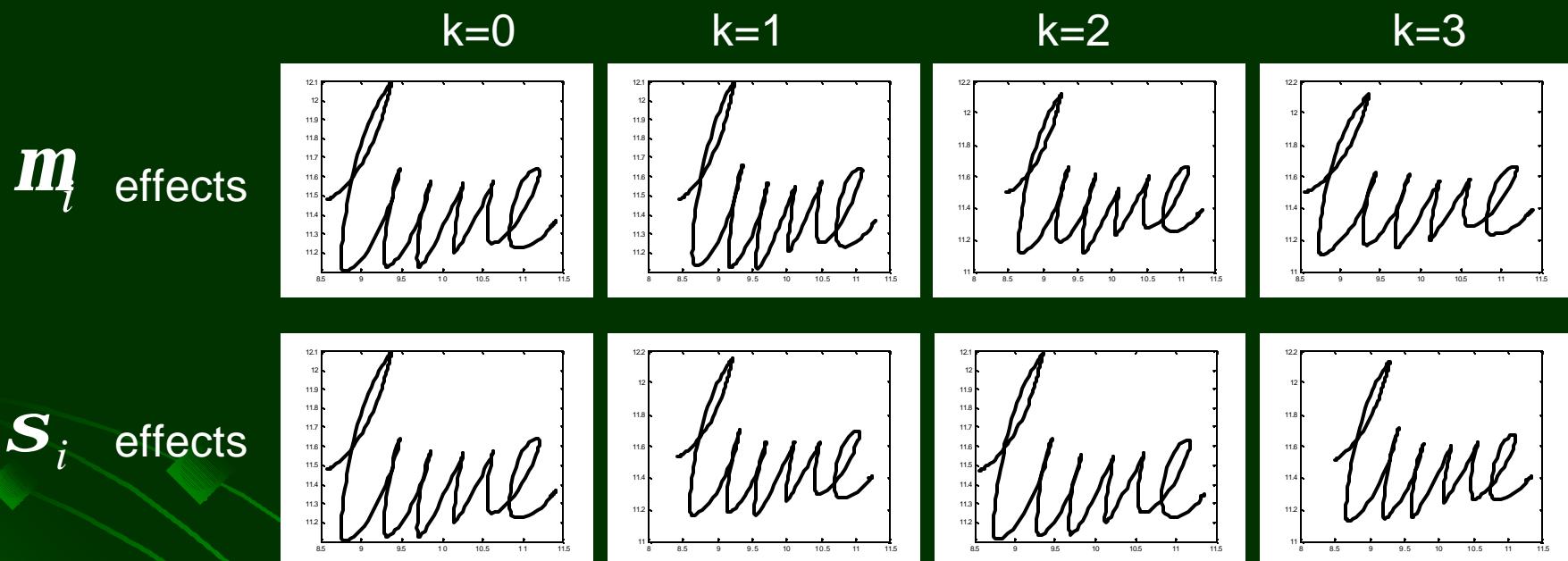
5. Construction of a REFERENCE PATTERN from the mean parameter values



Effects of the command parameters on the variability of the reference profile



Effects of the neuromuscular response parameters on the variability of the reference profile



Summary: sensitivity to parameter fluctuations

Action Plan

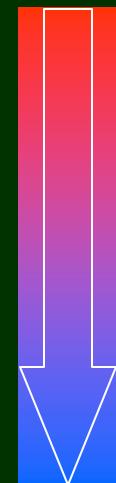
Command time occurrence : t_{0i}

Amplitude and direction commands D_i, q_{di}, q_{fi}

Neuromuscular response

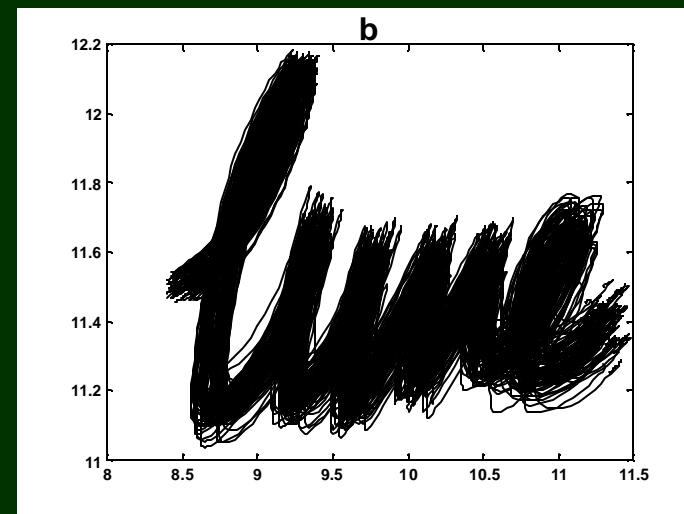
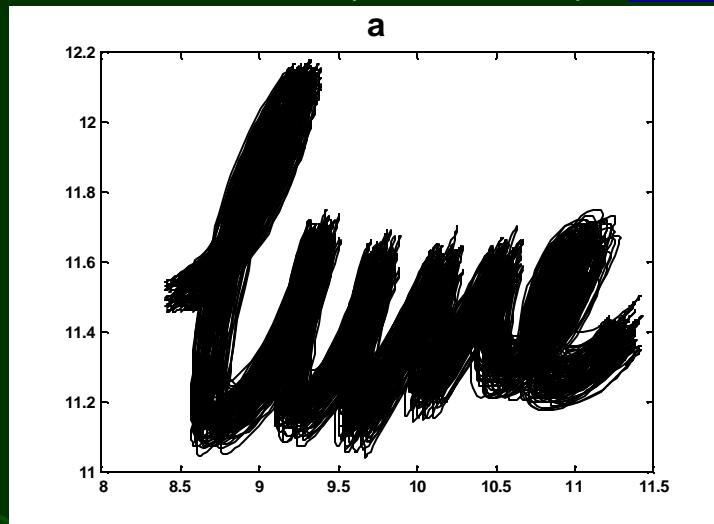
m_i, s_i

Very sensitive



Less sensitive

Effects of \mathbf{M}_i and \mathbf{S}_i $k \leq 2$



EXAMPLE : Effects of the peripheral parameter variability on the fiducial profile

EXAMPLE : Automatic Synthesis of 100 samples of the word «lune» from a random variation of the 6 sigma-lognormal parameters ($k=0.2$, for t_{0i} and $k=1$, for the others)

More to come tomorrow

DJIOUA M., PLAMONDON R., "An Interactive System for
the Automatic Generation of Huge Handwriting Databases
from a few Specimens"

Wednesday. 16.30 ,Session WeCT6.2 , room T6

Practical
Problem No 5

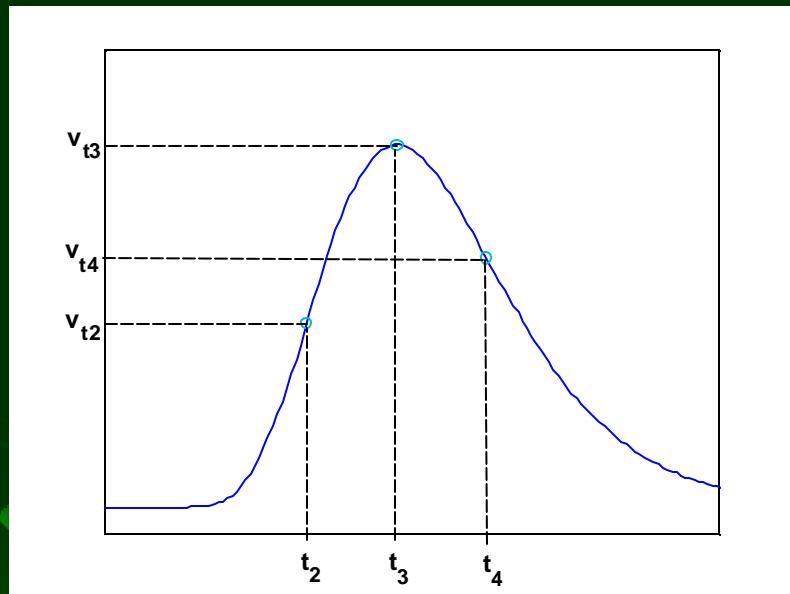
Sigma-lognormal parameter extraction

(Complex trajectories)

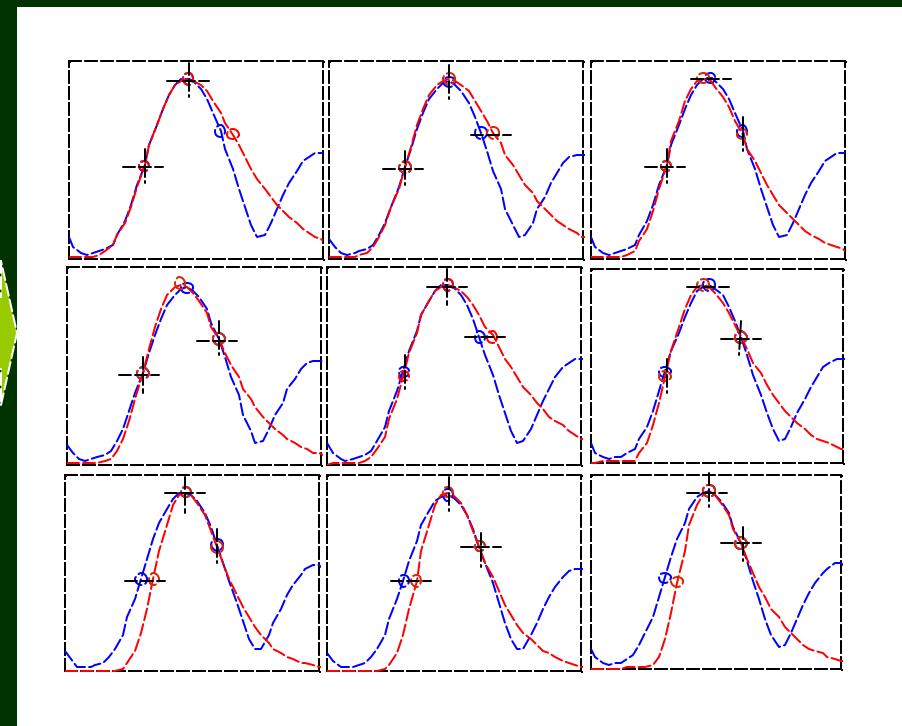
Phase 2: Automatic approach

XZERO Robust Algorithm

Original XZERO

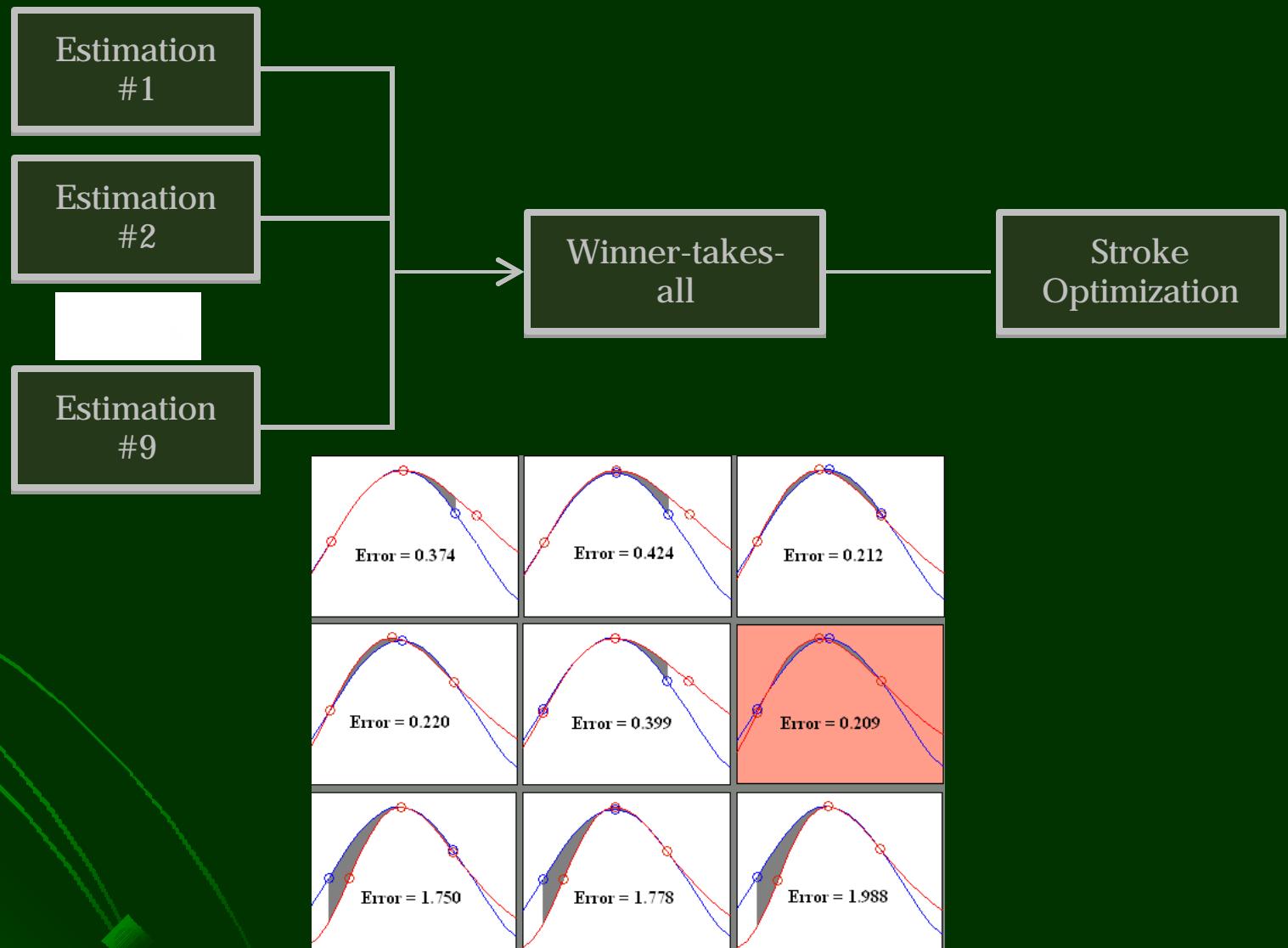


9 Analytic relationships for the initial estimation of the parameters

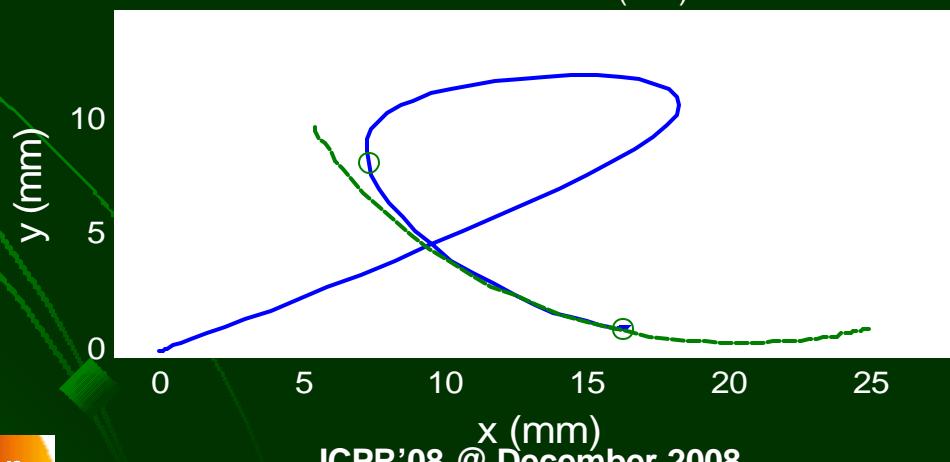
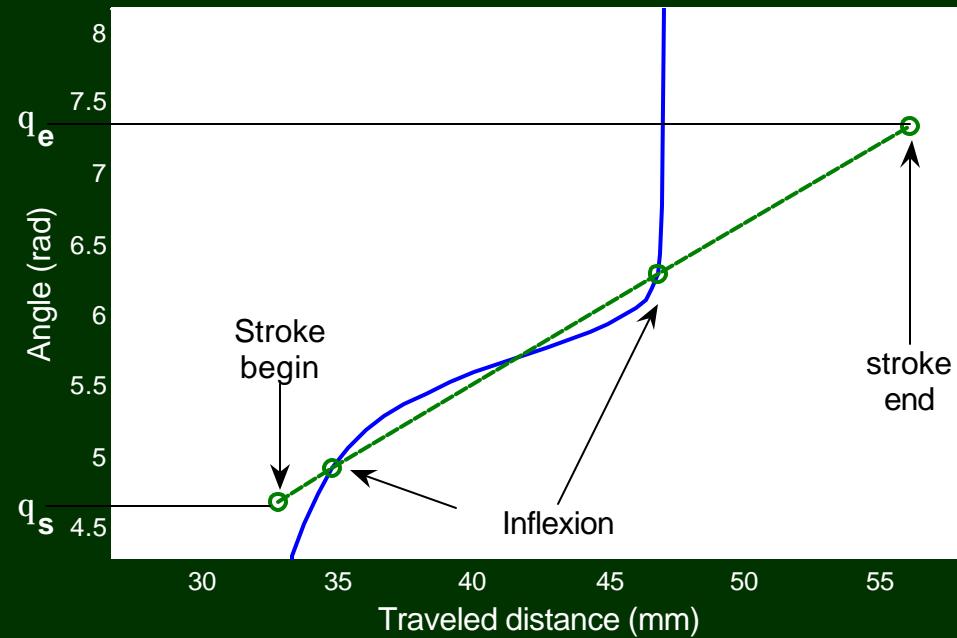


Ref : C. O'Reilly and R. Plamondon "Automatic Extraction of Sigma-Lognormal Parameters on Signatures,"
Proceedings of the 11th Int. Conf. on Frontiers in Handwriting Recognition (ICFHR'08), Montréal, vol. 11, pp. 216-222, 2008.

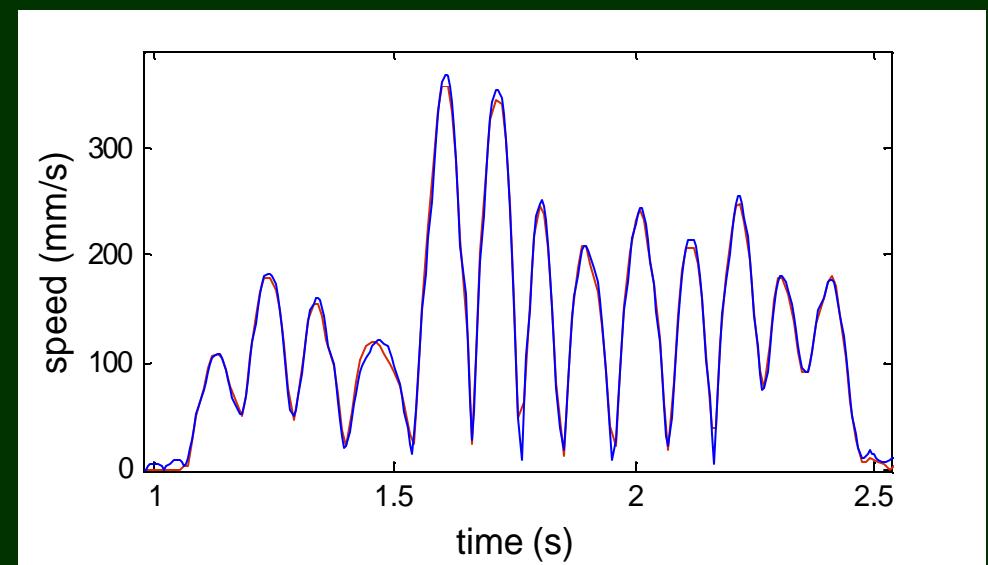
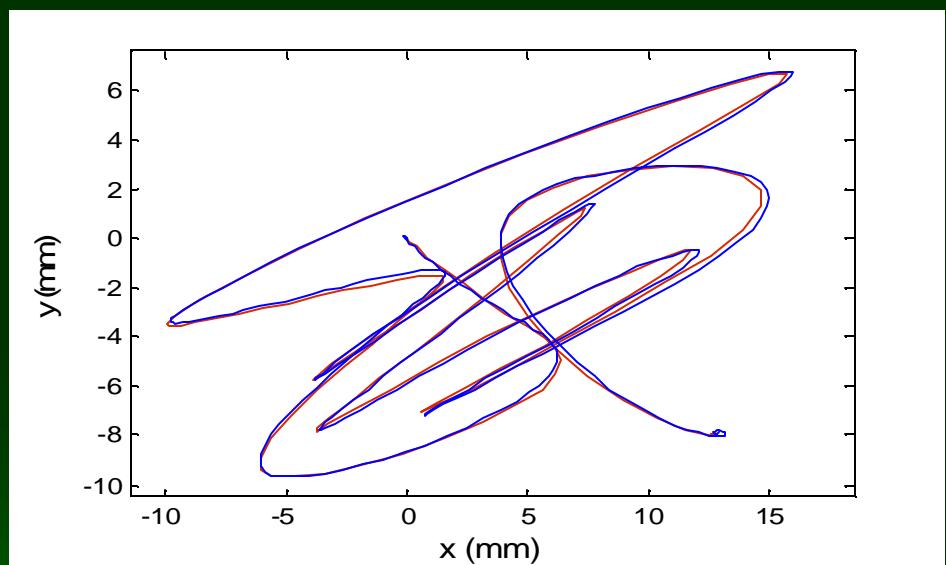
Sigma lognormal Parameter Estimation



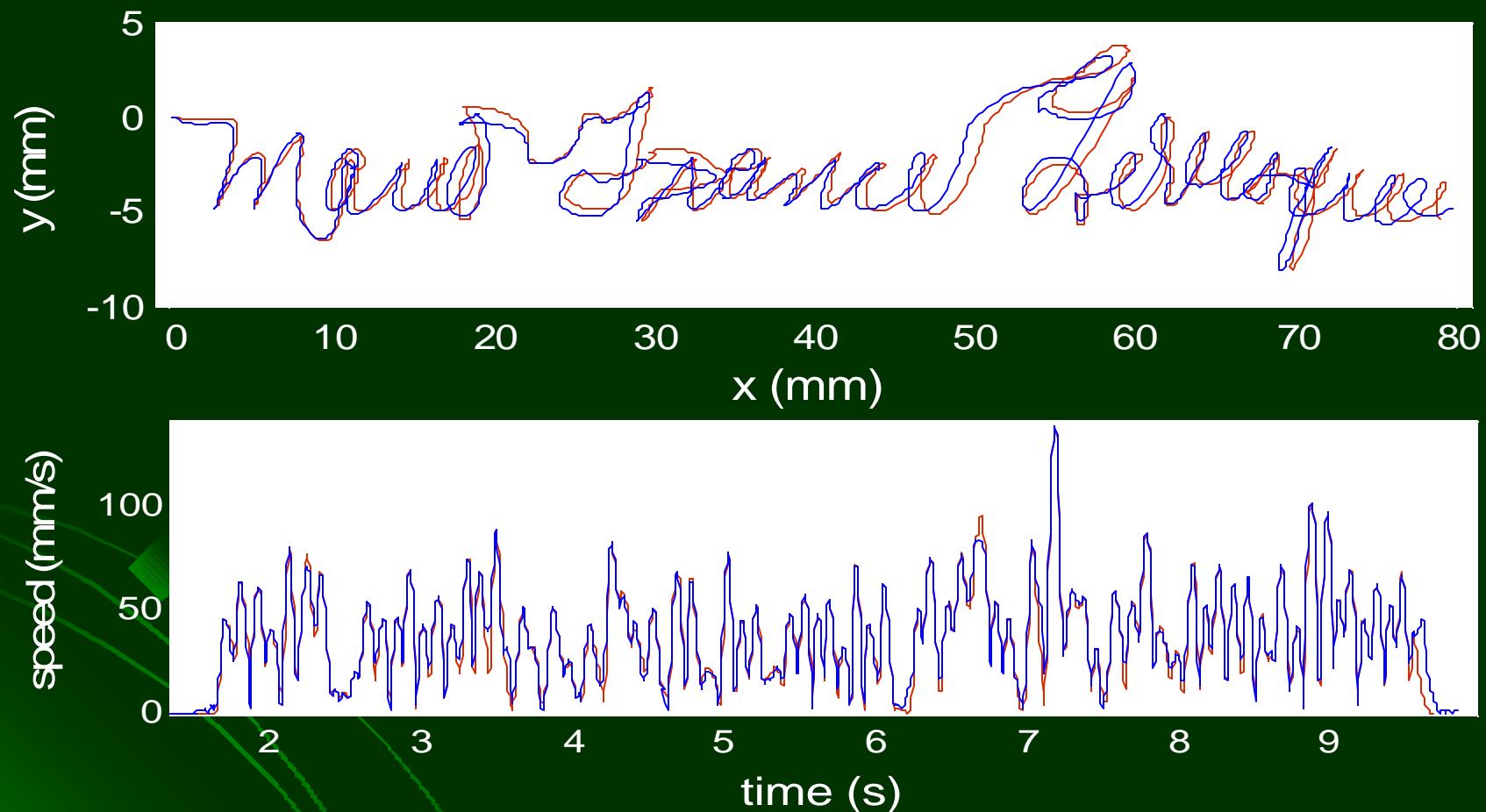
Angle Estimation



Typical results



Typical results



O'Reilly, C., PLAMONDON, R., "Development of a Sigma-Lognormal Representation for On-Line Signatures. In Press, **Pattern Recognition**.

Potential Applications #n

- On-line handwriting recognition / Signature Verification:
 - a new representation space, automatic segmentation...
 - writer style characterization, automatic data base generation
 - new on-line recognizers and verifiers
 - interactive tools to help children to learn handwriting...
- Biomedical signal processing:
 - a new set of parameters to characterize the human motor control system...
 - design of psychomotor evaluation tests
 - detection of fine motor control problems (Parkinson, Alzheimer, CVA)
 - prevention and rehabilitation tests and tools
 - effects of medication, alcohol, drugs, weight loss...
- New open fields:
 - a new set of functions for 2D and 3D smoothest curve modeling
 - anthropomorphic arm design
 - exoskeletons and prosthetics
 - humanoid movements modeling of virtual reality objects.

Anyone interested ?

TWO TYPES OF AGREEMENTS

Share our knowledge and software
with research partners

Share our knowledge and software
with commercial partners

CONCLUSION

Nothing is more
practical than a
good theory!



Recent developments in the Study of Rapid Human Movements with the Kinematic Theory

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École Polytechnique de Montréal
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