# Motor Equivalence and Handwriting

# Motor Equivalence

- Classic Definitions:
  - Observations of variable means to invariant ends (Lashley, 1933)
  - Principle of "equal simplicity". The capacity of an organism to adapt to variable environmental or internal conditions (Bernstein, 1935)

# Motor Equivalence and Handwriting

Karl Lashley
1890-1958

Kikolai Bernstein
1896-1966

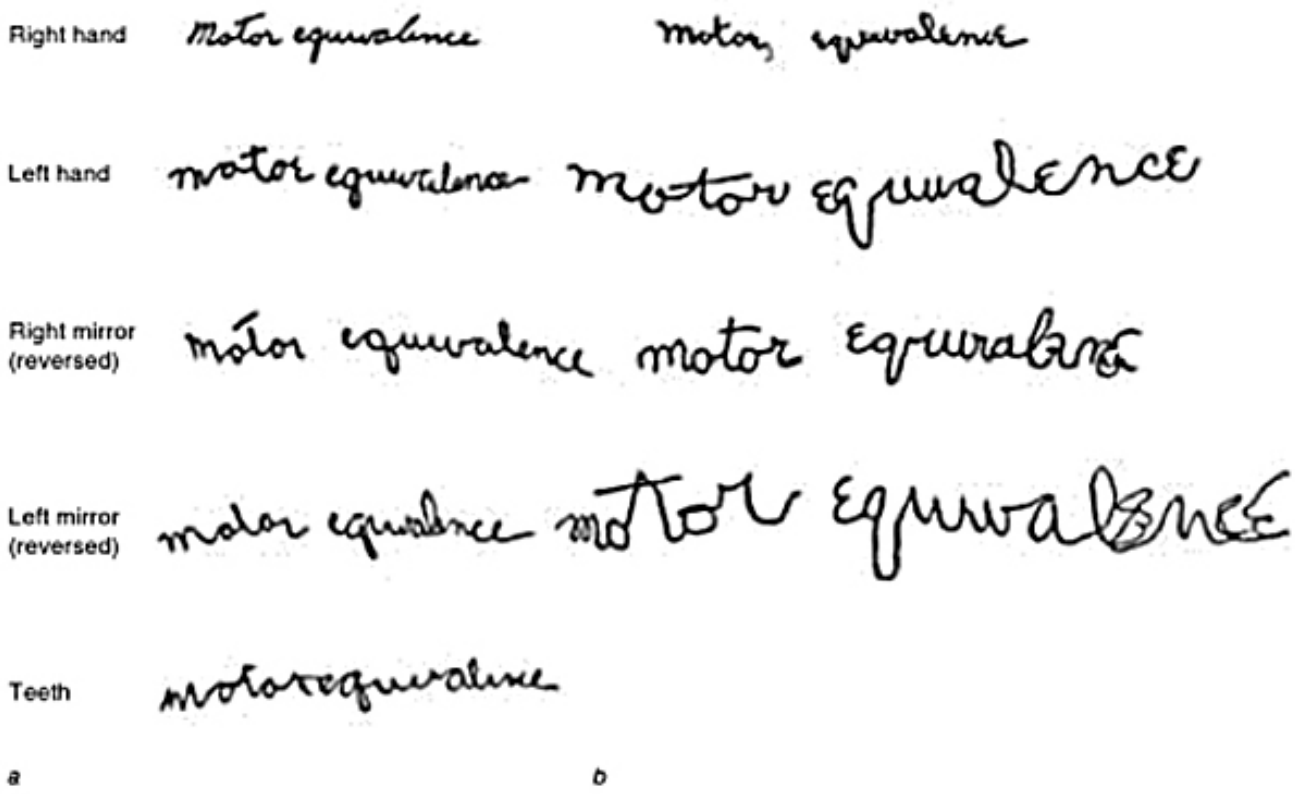
# Motor Equivalence and the Concept of a Motor Program

- The existence of motor equivalence supports the notion of a motor program as a theoretical memory structure capable of transforming an abstract code into an action sequence.
- It presumes that the memory structure contains a fixed set of commands timed in such a way that movement parameters such as torque, trajectory, speed, and distance may be reliably repeated.
- It also presumes that movement parameters are not stored as discrete instructions to specific muscles, but rather as a general spatial code representing the final motor output attainable under a variety of physical or environmental constraints.

# Generalized Motor Programs

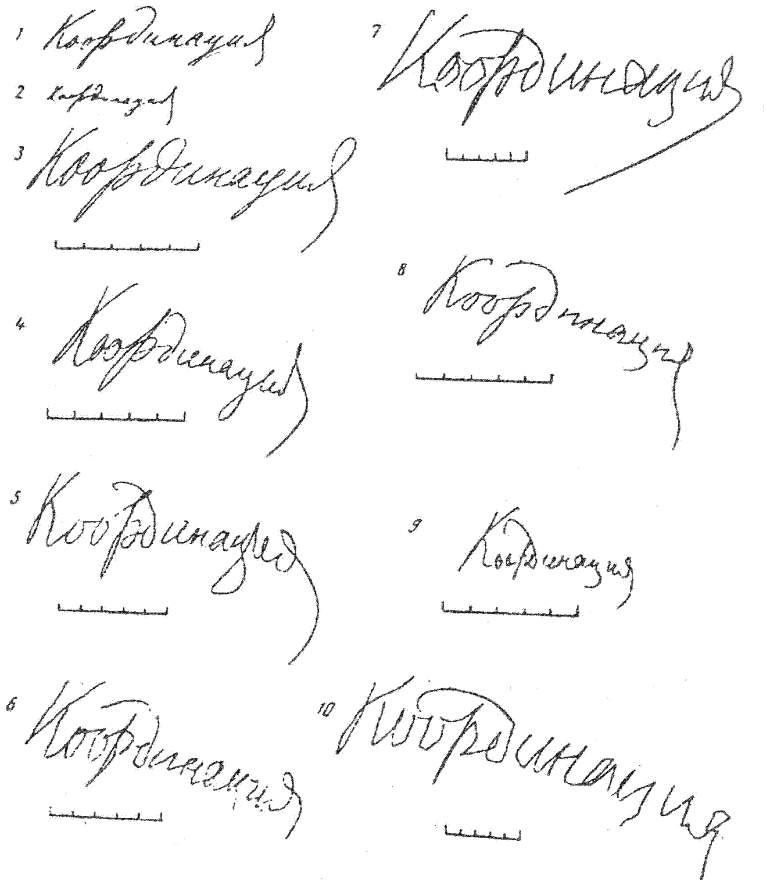
- Consist of a set of invariant features that may be shared by movements having a common goal.
- Manage novelty and environmental constraints by mapping invariant features onto the movement as required.
- Allow for variation in movement extent (size) and compensation for unexpected perturbations.
- Viviani and Terzuolo (1980) argued that centralized timing helps maintain temporal relationships between writing strokes while allowing variation is stroke size and shape. This is the principle of **isochrony**.

# Samples from two blindfolded writers

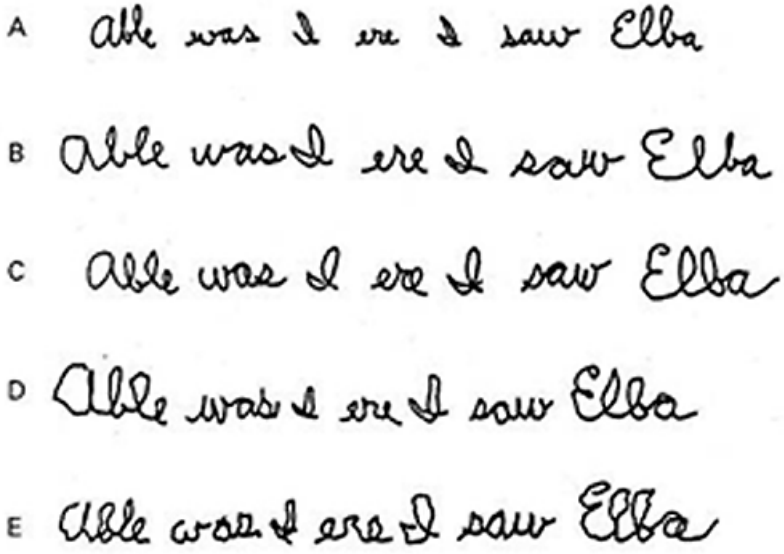



Lashley, 1942

# Others followed.....



Bernstein 1947




Raibert, 1977

# Degrees of Freedom Problem

- Russian neurophysiologist Nikolai Bernstein: "It is clear that the basic difficulties for co-ordination consist precisely in the extreme abundance of degrees of freedom…" (1967)
  - There are multiple DoF that a set of joints can move within leading to a near infinite number of ways by which many movements can be performed
  - Yet, movements are quite stereotyped across individuals

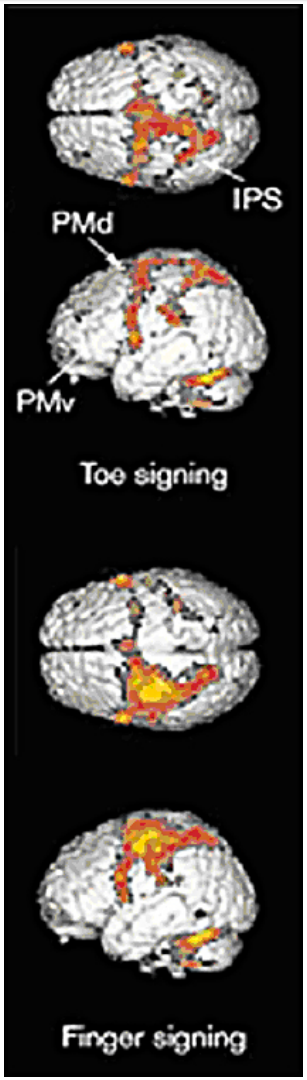
# Degrees of Freedom Problem

- Question:
  - How many degrees of freedom does the hand have?

# Degrees of Freedom Problem

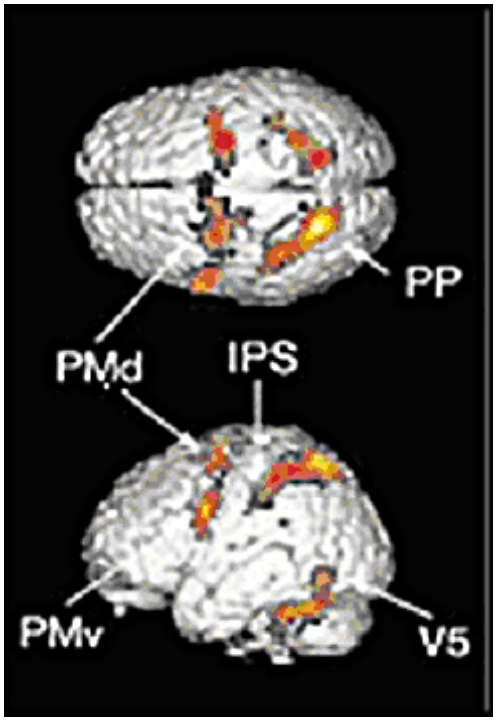
- Answer:

# Neuroanatomy of Motor Equivalence (Rijntjes et al., 1999)




**Cortical areas active during signing vs rest**

1. SMA
2. Primary Motor Cortex
3. Dorsal Premotor Area
4. Intraparietal Sulcus




**Some cortical areas active during both finger and toe signing**

1. Dorsal Premotor Area
2. Intraparietal Sulcus

# Neuroanatomy of Motor Equivalence (Rijntjes et al., 1999)

- Toe signing involved activation of all finger areas involved in finger signing, including:
  - Dorsal Premotor Area
  - Ventral Premotor Area
  - SMA
  - Intraparietal Areas
  - Thalamus
  - Cerebellum
  - But not the Primary Motor Cortex

# Handwriting and the DoF Problem

- Much of our understanding of motor programming stems largely from research on handwriting
- While handwriting is useful in developing general models of motor control, redundant degrees of freedom and motor equivalence can be problematic in signature and handwriting authentication.

# Motor Equivalence and its Implications for FDE

- A flexibly organized motor system is capable of producing large variability in the metrics of movements to attain a goal.
- Hand and finger movements are highly flexible with multiple degrees of freedom and can attain single trajectories using multiple solutions.
- Variation in handwriting features is generally greater within than between individuals (Wing, 2000)

# Motor Equivalence and its Implications for FDE

- Thus, reliance upon parameter variation to attribute different authorships can be dangerous, unless:
  - The FDE can identify parameters (a priori) that do not vary within an individual
  - The FDE can identify parameters (a priori) that vary systematically with changes in state

# Motor Equivalence and Handwriting

## Preliminary Findings on Motor Equivalence and Signature Writing:

## Quantitative Analyses of Handwriting Kinematics

# Experimental Questions

- Is there evidence of motor equivalence in signature writing when altering the:
  - writing angle
  - DoF for wrist/finger movements
  - or writing space?
- Are timing features invariant across manipulations as predicted by Viviani and Terzuolo?
- Which execution variables exhibit invariance; i.e. motor equivalence?

# Writers and Procedures

- 3 healthy writers were asked to write their signature 5 times for 9 experimental manipulations
- The main effects of each manipulation were examined using graphic analyses; histograms, and measures of central tendency.
- Formal statistical tests were not conducted.

# Signature Writing Template

1 

1 cm V 8 cm H

2 

2 cm V 8 cm H
Other Signatures

3 

2 cm H

4 

4 cm H

# Instrumentation

Reducing Degrees of Freedom: Wrist Brace

# Experimental Variables

## Input Variables

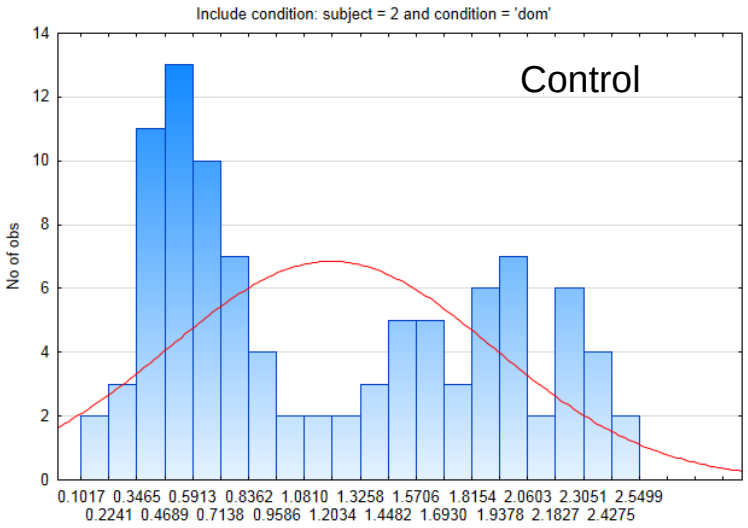
- Horizontal Space
  - 2 cm Horizontal Boundary
  - 4 cm Horizontal Boundary
  - 8 cm Horizontal Boundary
- Vertical Space
  - 1 cm Vertical Boundary
  - 2 cm Vertical Boundary
- Writing Surface
  - Flat
  - 45 degree elevation
  - 90 degree elevation
- Degrees of Freedom
  - Unrestrained
  - Wrist Brace
  - Fist Clenched
- Effector
  - Dominant Hand
  - Non-Dominant Hand

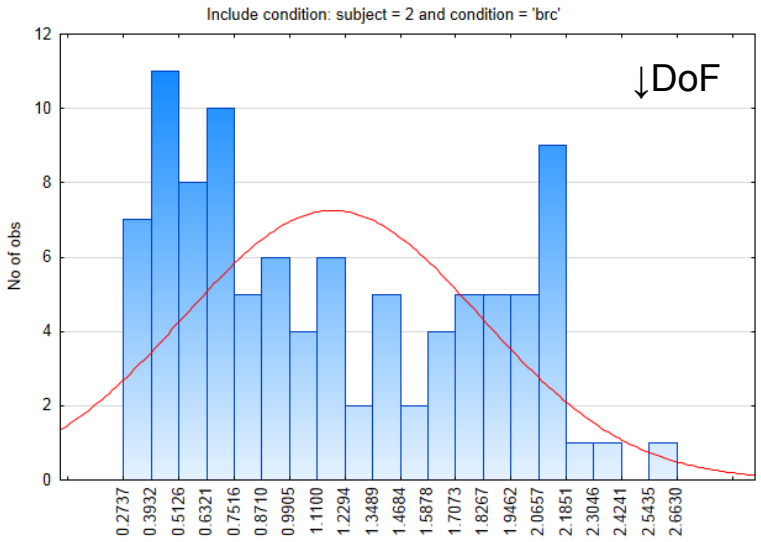
# Experimental Variables

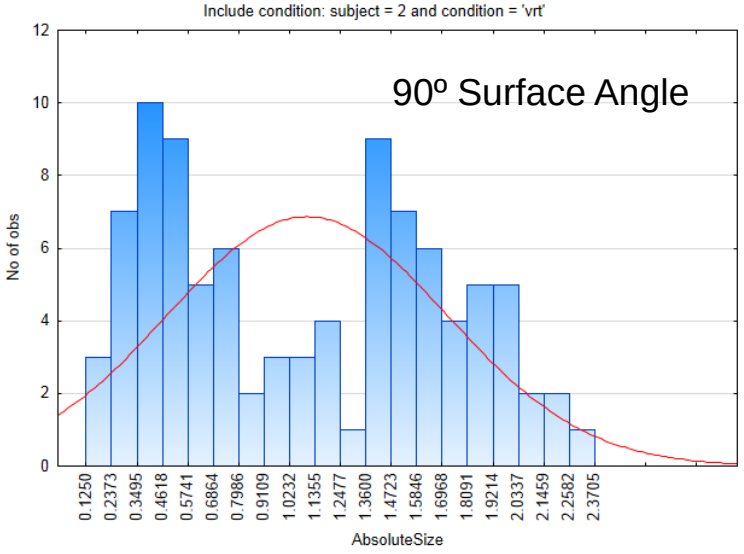
## Output Variables: Handwriting Kinematic Variables

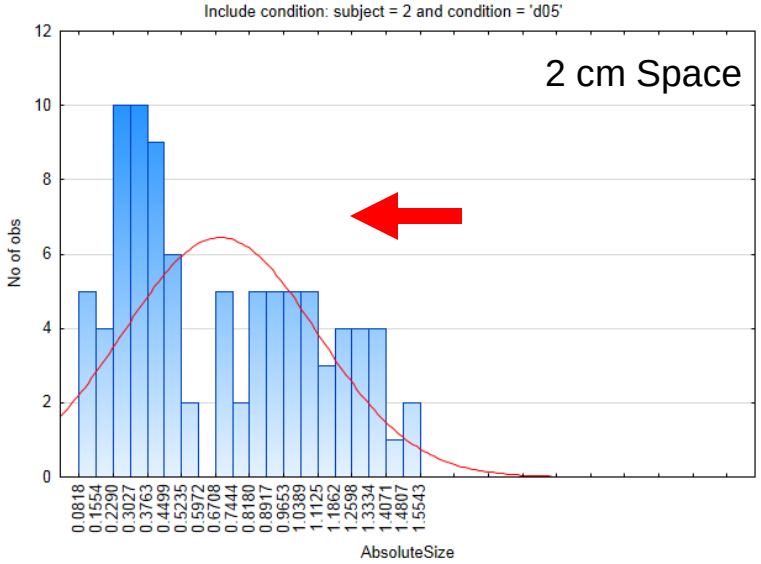
- **Timing/Programming Variables**
  - Stroke Duration
  - Stroke Velocity
  - Isochrony
- **Execution Variables**
  - Vertical Size
  - Smoothness
  - Pen Pressure
  - Relative Slant
  - Loop Surface

# Results: Vertical Size

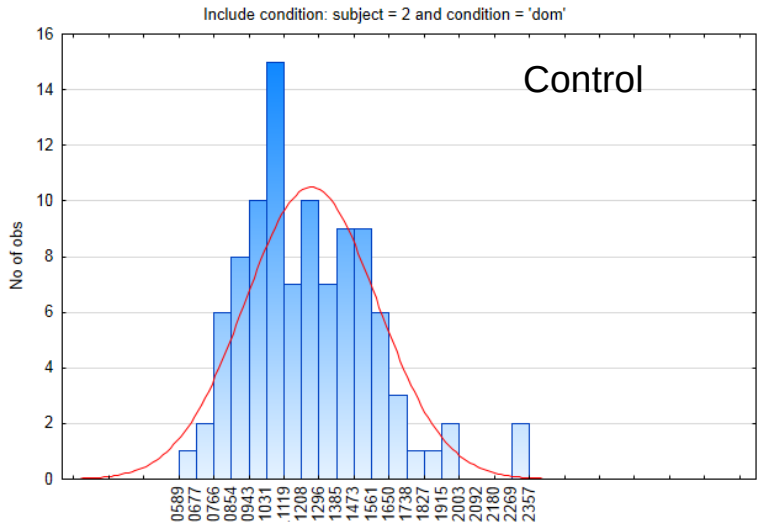


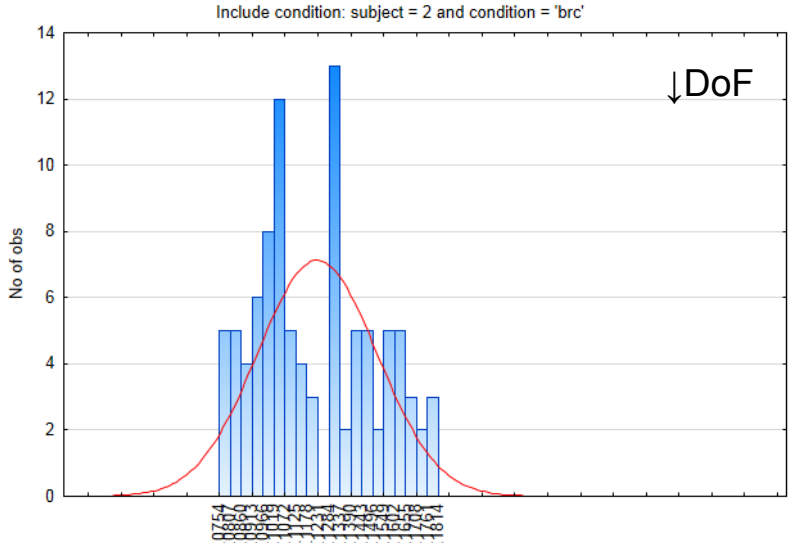



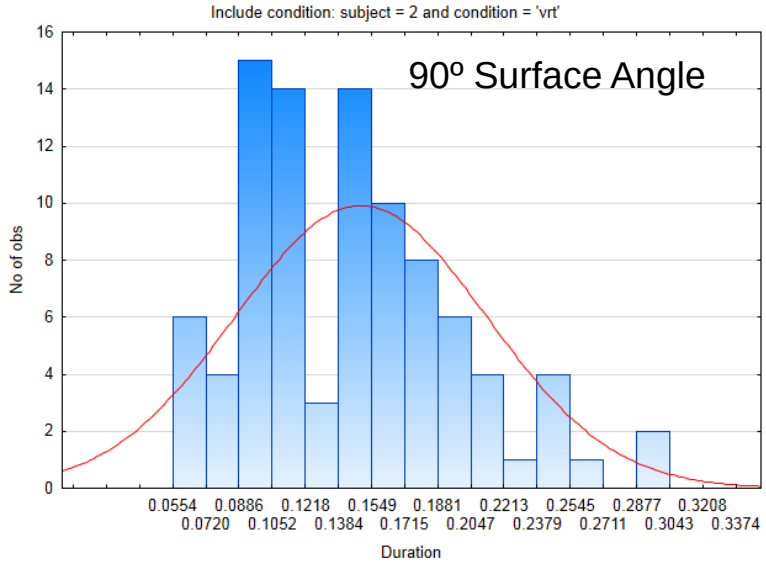



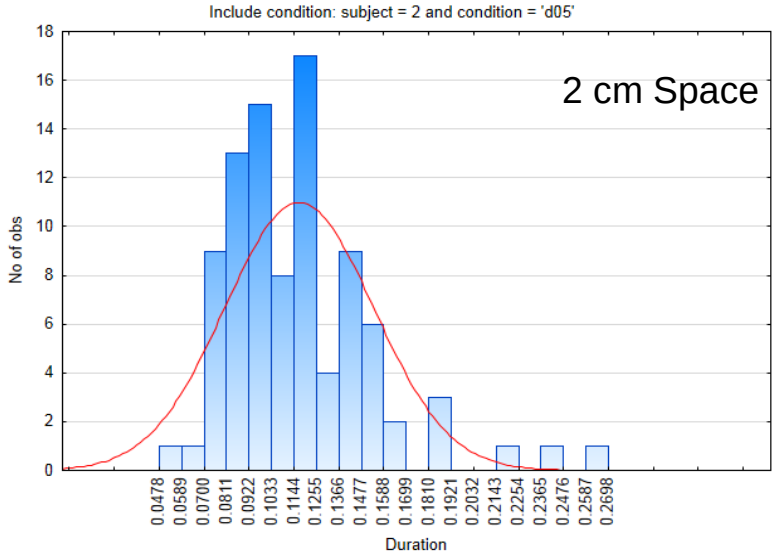



# Results: Stroke Duration

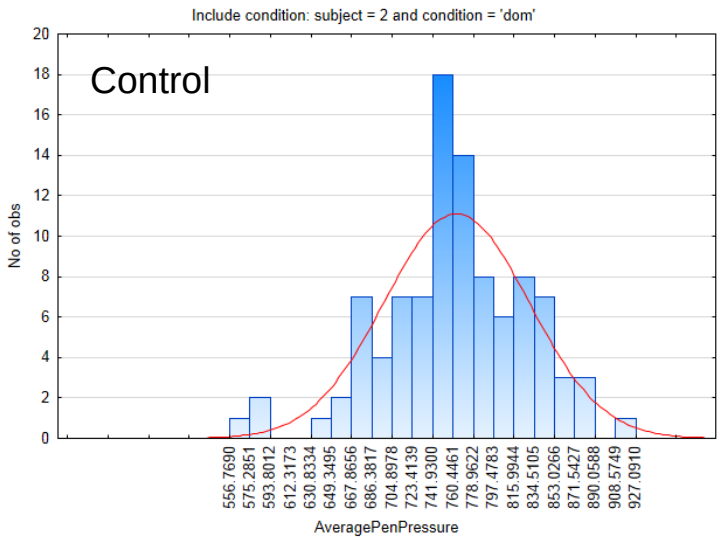


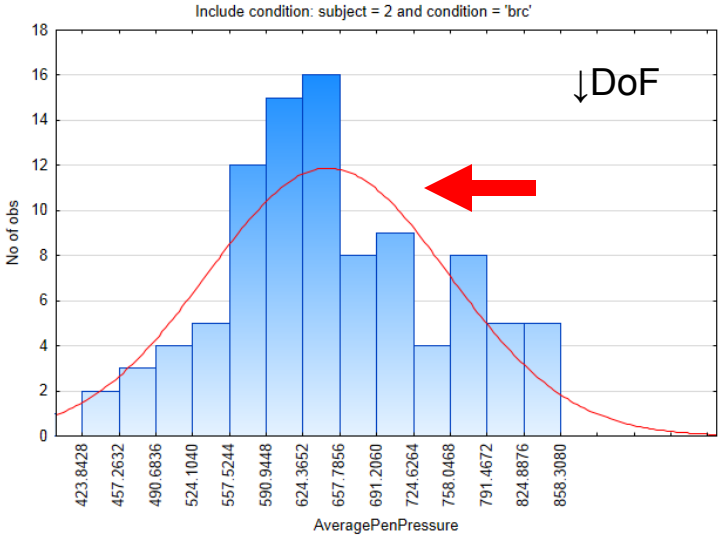



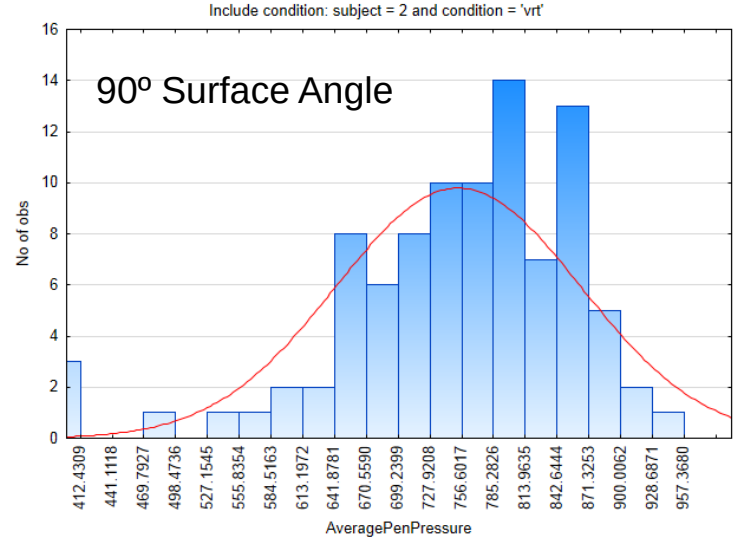



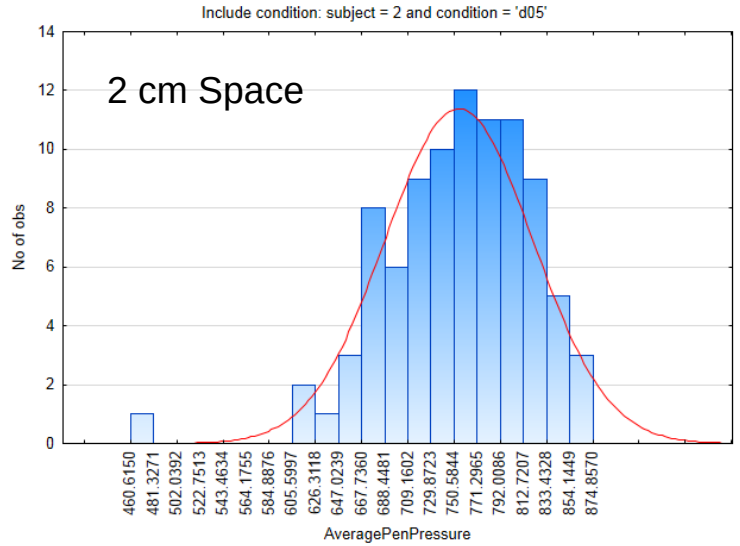



# Results: Pen Pressure

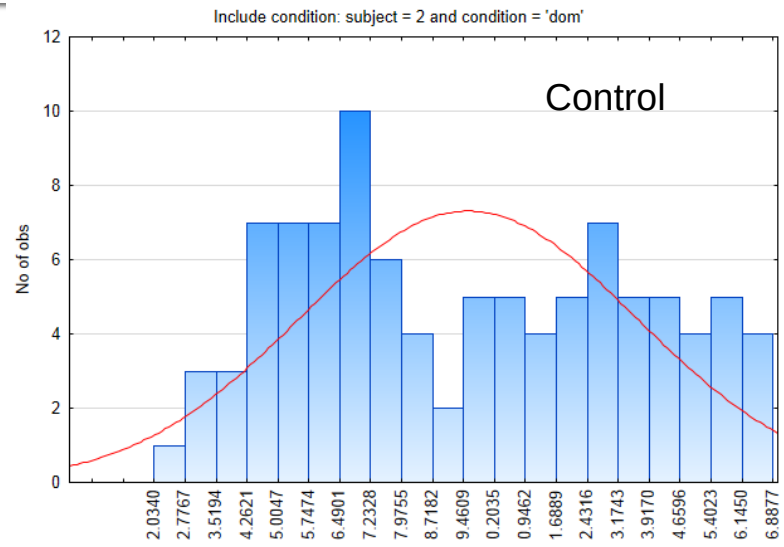


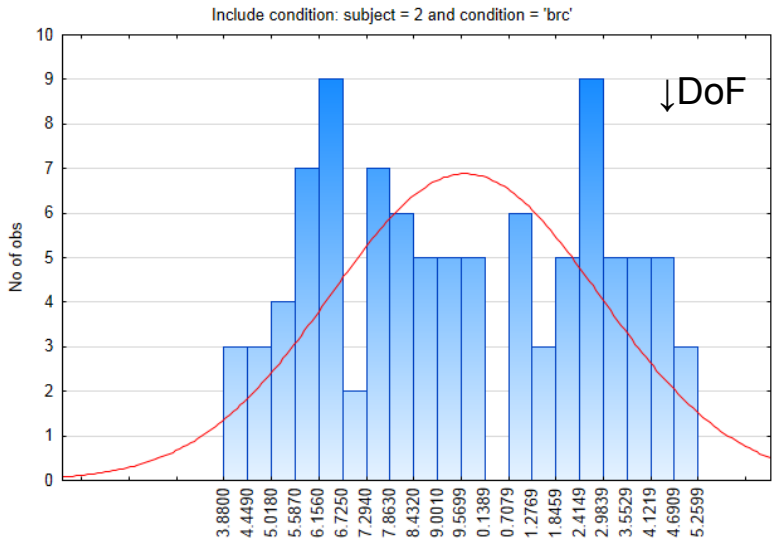



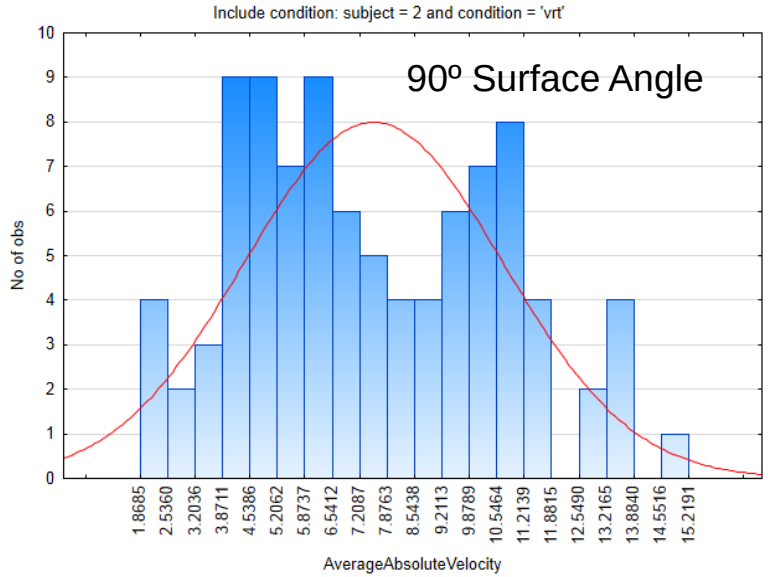



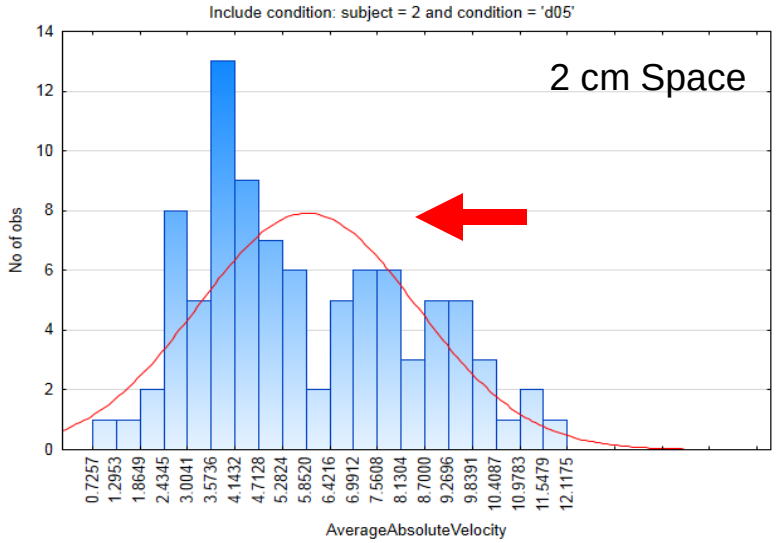



# Results: Stroke Velocity



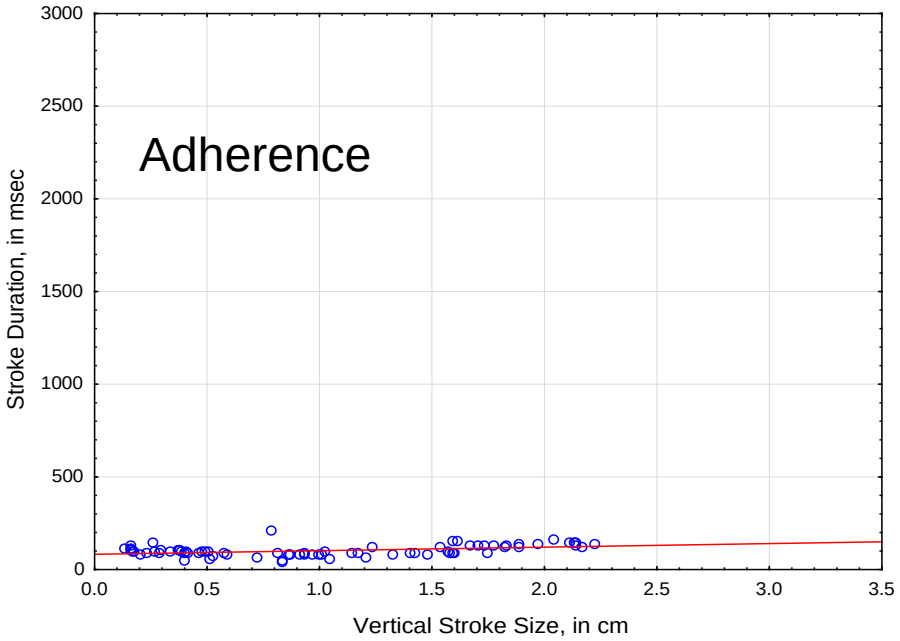



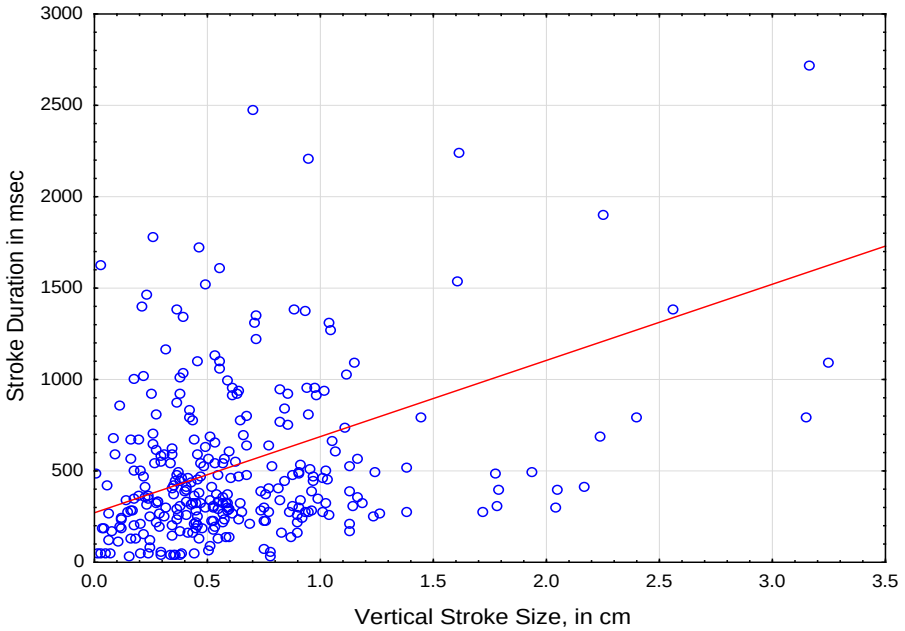



# Calculating Isochrony for Signatures

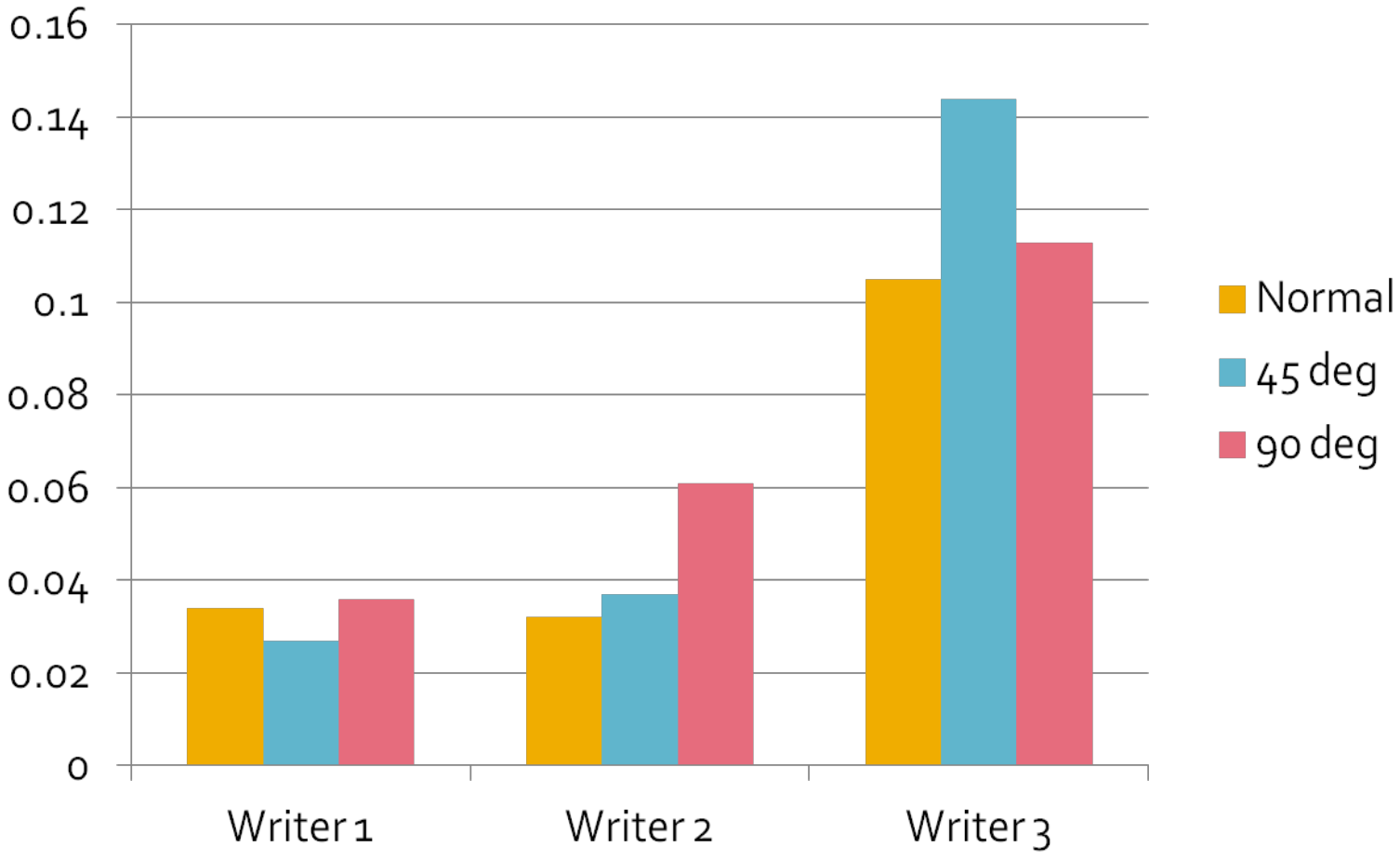
Slope Coefficient = 0.019



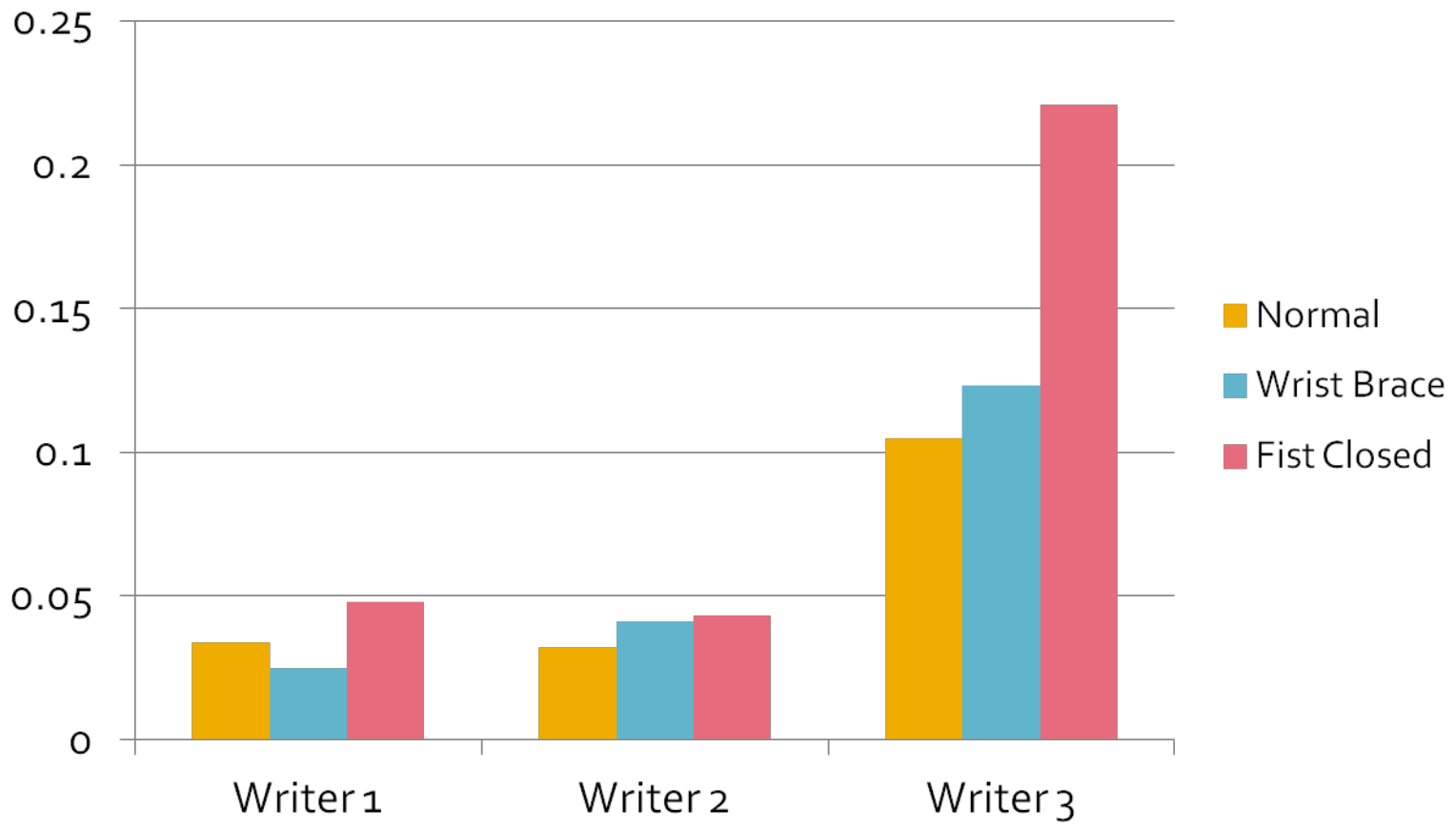

Slope Coefficient = 0.417



# Results: Isochrony
## Writing Surface

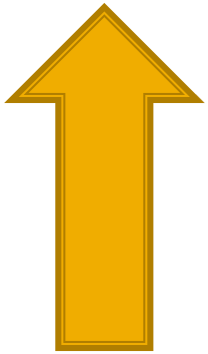


# Results: Isochrony
## Degrees of Freedom



# Summary of Findings

- **Invariant Features**
  - Stroke Duration
  - Isochrony
- **"Plastic" Features**
  - Vertical Size
  - Stroke Velocity
  - Pen Pressure



Timing Features

# Conclusions
## Motor Control Perspective

- Kinematic analyses of signature writing within an individual supports the theory of motor equivalence
- Timing appears to be a highly programmed feature of the motor system; unaffected by spatial, musculoskeletal, or postural constraints

# Conclusions
## FDE Perspective

- FDEs should remember that
  - hand and finger movements are highly flexible with multiple degrees of freedom and can attain single trajectories using multiple solutions.
  - a flexibly organized motor system is capable of producing large variability in the **metrics** of movements to attain a goal.
  - timing features such as stroke duration and possibly letter spacing appear to exhibit individual invariance

# Conclusions
## FDE Perspective

- Finally, because timing invariance (i.e. motor equivalence) allows movement parameters such as torque, trajectory, speed, and distance to be reliably repeated, evaluating the authenticity of signatures written under **different conditions** poses unique challenges.