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
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.
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 in stroke size and shape. This is the principle of isochrony.
Samples from two blindfolded writers

Right hand

motor equivalence  motor equivalence

Left hand

motor equivalence  motor equivalence

Right mirror (reversed)

motor equivalence  motor equivalence

Left mirror (reversed)

motor equivalence  motor equivalence

Teeth

motor equivalence

a  b

Lashley, 1942
Others followed........

Bernstein 1947

Raibert, 1977
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:
Some cortical areas active during both finger and toe signing:

1. Dorsal Premotor Area
2. Intraparietal Sulcus
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.
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
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

Control

↓DoF

90° Surface Angle

2 cm Space
Results: Stroke Duration

Control

90° Surface Angle

↓DoF

2 cm Space
Results: Pen Pressure

Control

↓DoF

90° Surface Angle

2 cm Space
Results: Stroke Velocity

- Control
- 90° Surface Angle
- 2 cm Space
Calculating Isochrony for Signatures

Slope Coefficient = 0.019

Slope Coefficient = 0.417

Adherence
Results: Isochrony
Writing Surface

- **Writer 1**
  - Normal: 0.03
  - 45 deg: 0.02
  - 90 deg: 0.04

- **Writer 2**
  - Normal: 0.04
  - 45 deg: 0.03
  - 90 deg: 0.05

- **Writer 3**
  - Normal: 0.12
  - 45 deg: 0.14
  - 90 deg: 0.10
Results: Isochrony
Degrees of Freedom

- **Writer 1**
  - Normal: 0.04
  - Wrist Brace: 0.03
  - Fist Closed: 0.05

- **Writer 2**
  - Normal: 0.03
  - Wrist Brace: 0.04
  - Fist Closed: 0.05

- **Writer 3**
  - Normal: 0.15
  - Wrist Brace: 0.17
  - Fist Closed: 0.24
Summary of Findings

- **Invariant Features**
  - Stroke Duration
  - Isochrony

- **“Plastic” Features**
  - Vertical Size
  - Stroke Velocity
  - Pen Pressure

- **Timing Features**
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.
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.
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.