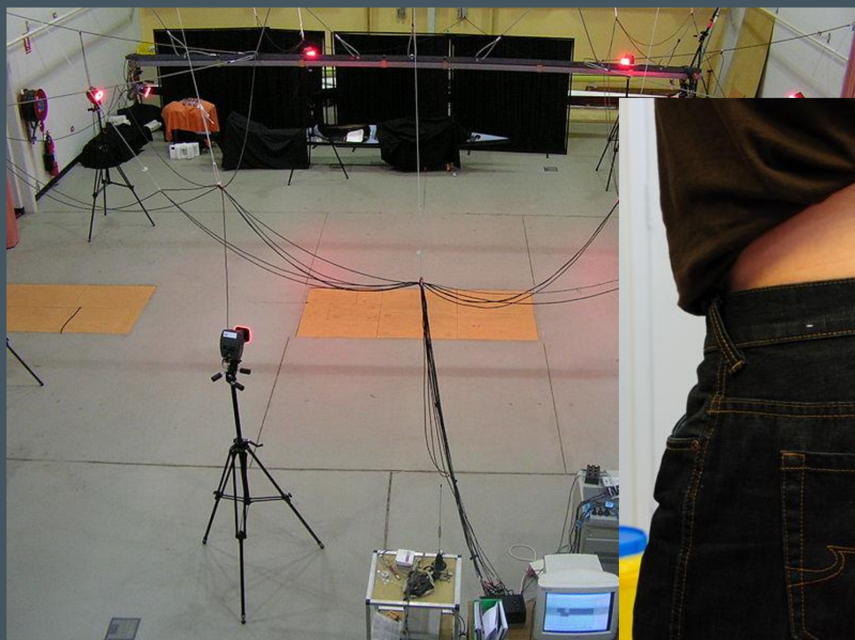
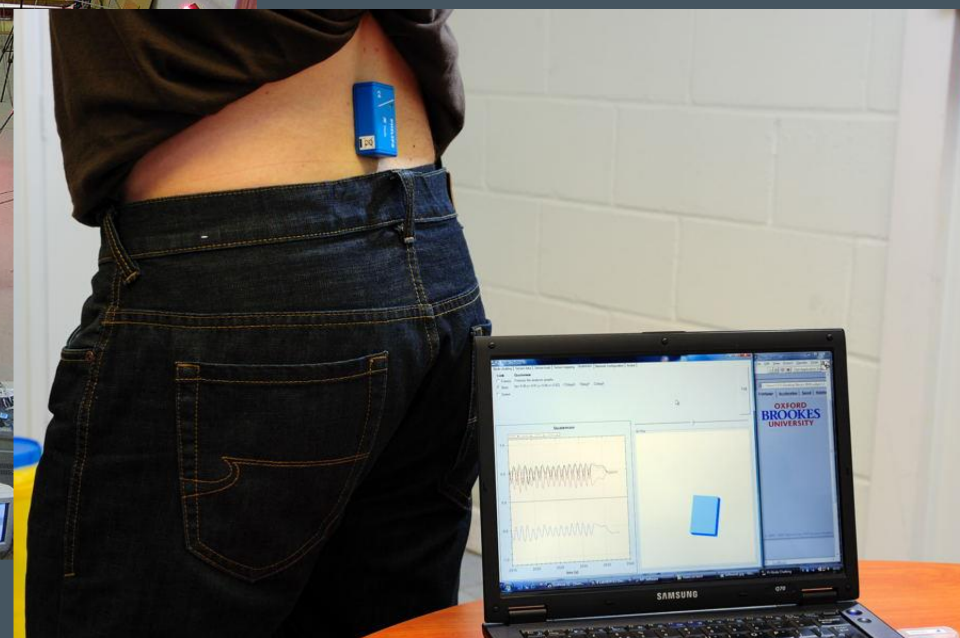
Objective Gait Assessments
‘*in a box*’





Dr Patrick Esser
Research Lead Movement Science Group
Centre for Movement, Occupation and Rehabilitation Sciences

How can we objectively measure Gait?

Facts (Toro B. et al, 2003)

23.1% of patients are measured in gait labs:

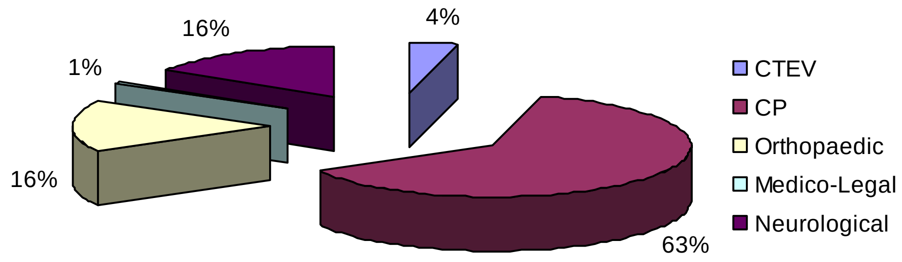
Reasons:

- 41.8% current method time consuming
- 38.8% current method is expensive
- 27 % lack of technical knowledge

Oxford Gait Laboratory:

Total patients last 12 months: 338

1.3 measurements a day



Objective Measures of Gait

- Is there a need? -

Own questionairre

69.3% performing any kind of gait analyses

Reasons:

52% Budget constrains

39% Time constrains

9 % Lack of technical knowledge

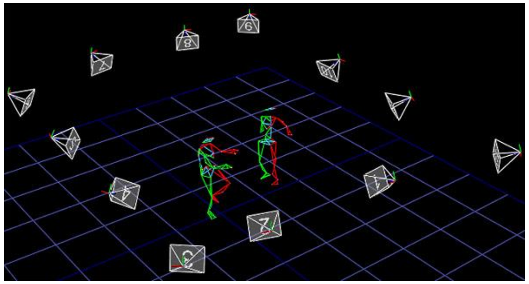
Other comments:

‘ I sometimes use a paper walk way if I feel I need to look at step/stride length and width of walking base’

‘ Wanting to use some movement analysis software (silicon coach) which was bought by the managers but we don’t have the right camera to use it!!’

Objective Measures of Gait

- Measurement Tools -

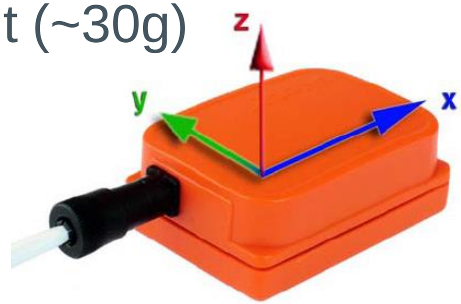


<u>Optical motion camera system</u>

- Relatively expensive and time consuming
- Restricted measurement volume
- Gold standard

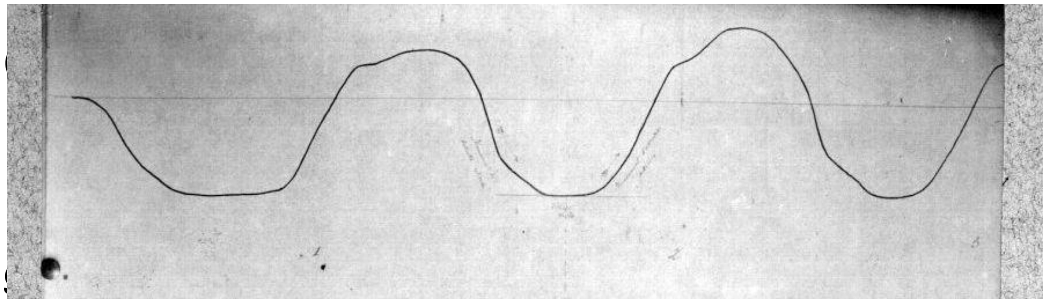
<u>Our system is based on Accelerometry (IMU)</u>

- Micro Electric-Mechanical System (MEMS)
    - Tri axial Accelerometer, Gyroscope, Magnetonometer
- Lightweight (~30g)
- Wireless



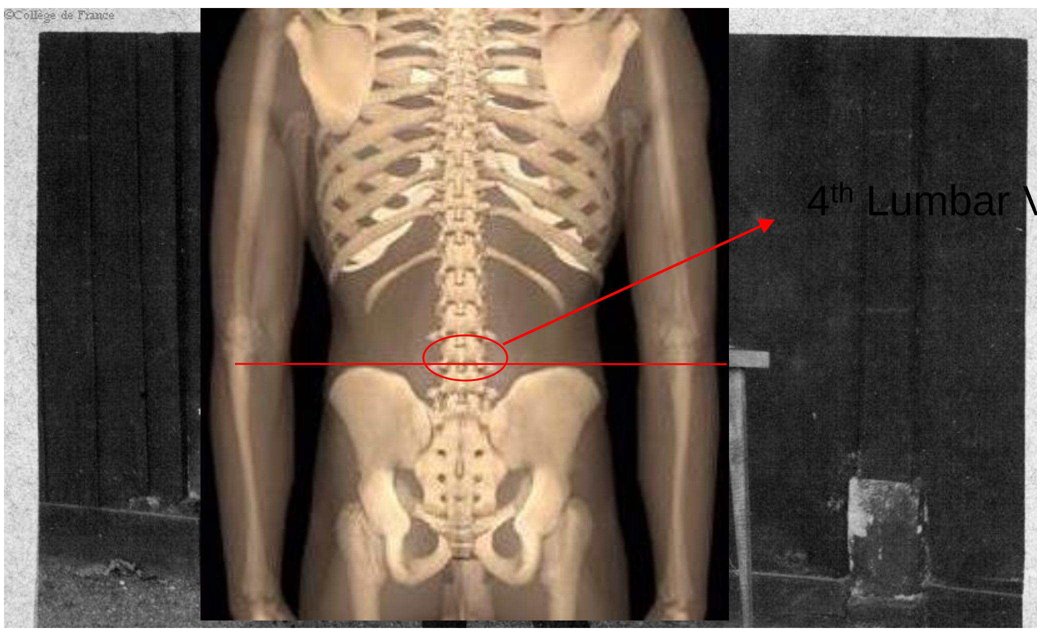
Objective Measures of Gait

- Centre of Mass -



…he resultant of the

…ss' (Dempster 1955)



4^{th} Lumbar Vertebra

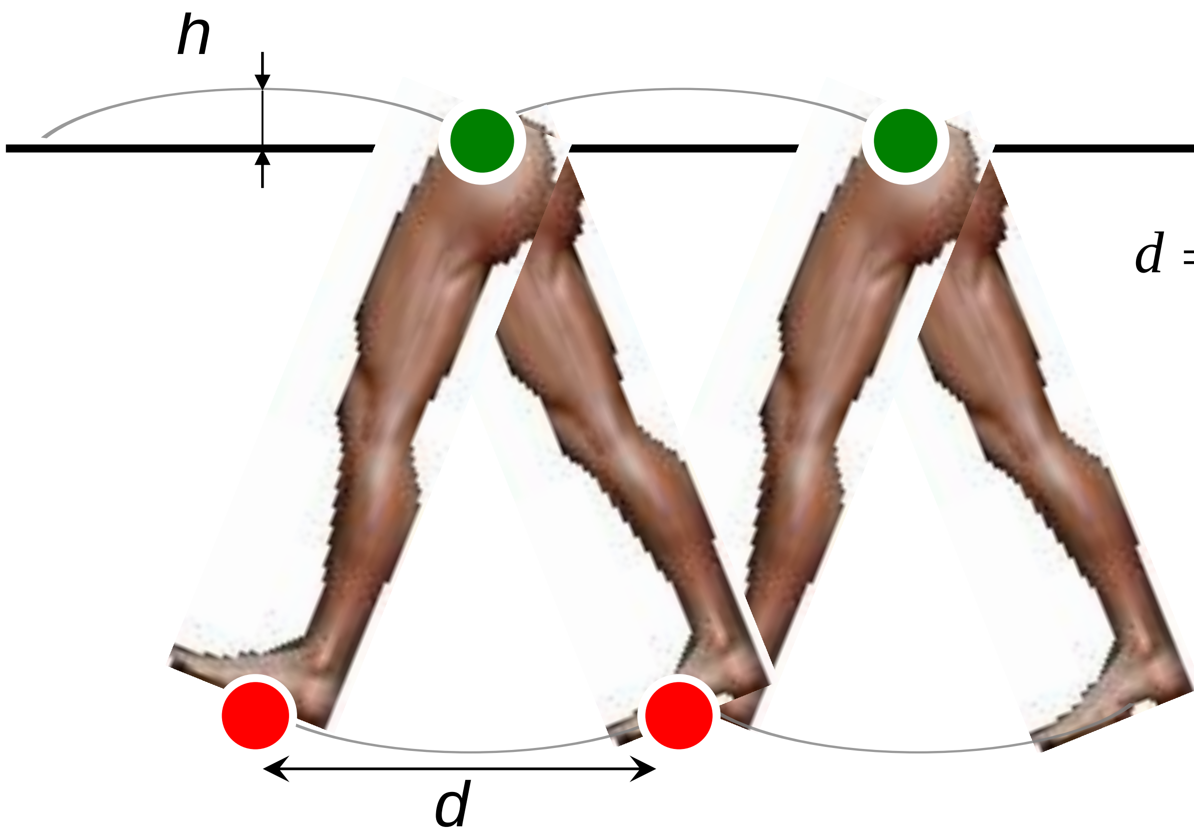
Marey, Etienne-Jules

1882-1886

Pendulum Mechanics

$$E_K = \frac{1}{2}mv^2$$

$$E_P = mgh$$



$$d = 2\sqrt{2Lh - h^2}$$

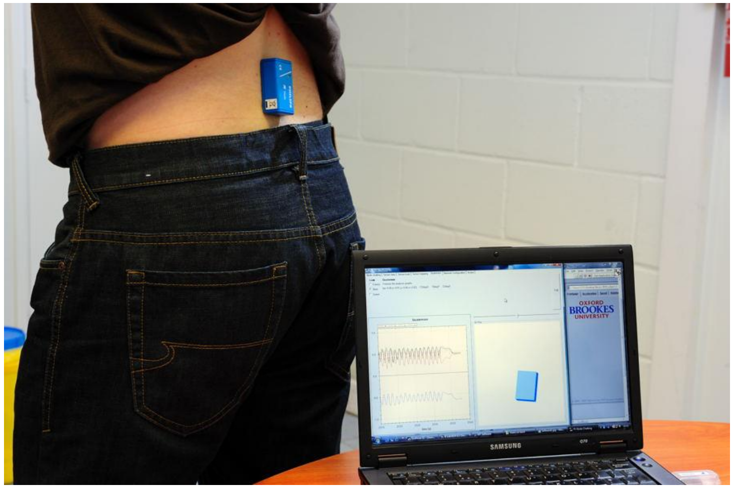
Objective Measures of Gait
- Walking Protocol -

Clinical standardised tests

- 10 metre walk
- 2 minute walk

Single Sensor Approach

- Placed over CoM
- 100Hz
- Wireless



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$$\begin{bmatrix} C_{1,1}=\sigma_1^2 & C_{1,2} & & C_{1,N} \\ C_{2,1} & C_{2,2}=\sigma_2^2 & & \\ & & \ddots & \vdots \\ C_{N,1} & & \cdots & C_{N,N}=\sigma_N^2 \end{bmatrix}$$

$$\bar{x}_0 = H\bar{z}_0$$

$$P_0 = \begin{bmatrix} \varepsilon & 0 \\ 0 & \varepsilon \end{bmatrix}$$

$$\bar{x}_k = \bar{x}_k^- + K(\bar{z}_k - H\bar{x}_k^-)$$

$$P_k = (I - KH)P_k^-$$

actual

$$\mathbf{x}_k = \mathbf{A}\mathbf{x}_{k-1} + \mathbf{B}\mathbf{u}_k + \mathbf{w}_{k-1}$$

$$K = P_k^- H^T \left(HP_k^- H^T + R\right)^{-1}$$

$$x_k = x_k^- + K\left(z_k - Hx_k^-\right)$$

$$P_k = (I - KH)P_k$$

$$K(t_3) = \frac{\sigma^2(t_3^-)}{\sigma^2(t_3^-) + \sigma_3^2}$$

$$\bar{x}_k^- = A\bar{x}_{k-1}$$

$$P_k^- = AP_{k-1}A^T$$

$$\mathbf{P}_k^- = E[\mathbf{e}_k^- \mathbf{e}_k^{-T}]$$

$$\mathbf{P}_k = E[\mathbf{e}_k \mathbf{e}_k^T]$$

$$\hat{x}(t_3) = \hat{x}(t_3^-) + K(t_3)(z_3 - \hat{x}(t_3^-))$$

$$E[\mathbf{x}] = \bar{\mathbf{x}} = [\bar{x}_1, \cdots \bar{x}_n]^T$$

$$\begin{bmatrix} x_k \\ y_k \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_{k-1} \\ y_{k-1} \end{bmatrix} + \begin{bmatrix} \sim x_{k-1} \\ \sim y_{k-1} \end{bmatrix}$$

state $\bar{x}_k$ state transition A state $\bar{x}_{k-1}$

$$\sigma^2 = E[(x - \bar{x})^2] = \frac{1}{N}\sum^N (x_i - \bar{x})^2$$

$$C_{ij} = \frac{1}{N}\sum_{k=1}^{N} (x_{ik} - \bar{x}_i)(x_{jk} - \bar{x}_j)$$

$$\begin{bmatrix} u_k \\ v_k \end{bmatrix} = \begin{bmatrix} H_x & 0 \\ 0 & H_y \end{bmatrix} \begin{bmatrix} x_k \\ y_k \end{bmatrix} + \begin{bmatrix} \sim u_k \\ \sim v_k \end{bmatrix}$$

$$Q = E\{\overline{w} * \overline{w}^T\} = \begin{bmatrix} Q_{xx} & 0 \\ 0 & Q_{yy} \end{bmatrix}$$

measure mnt H

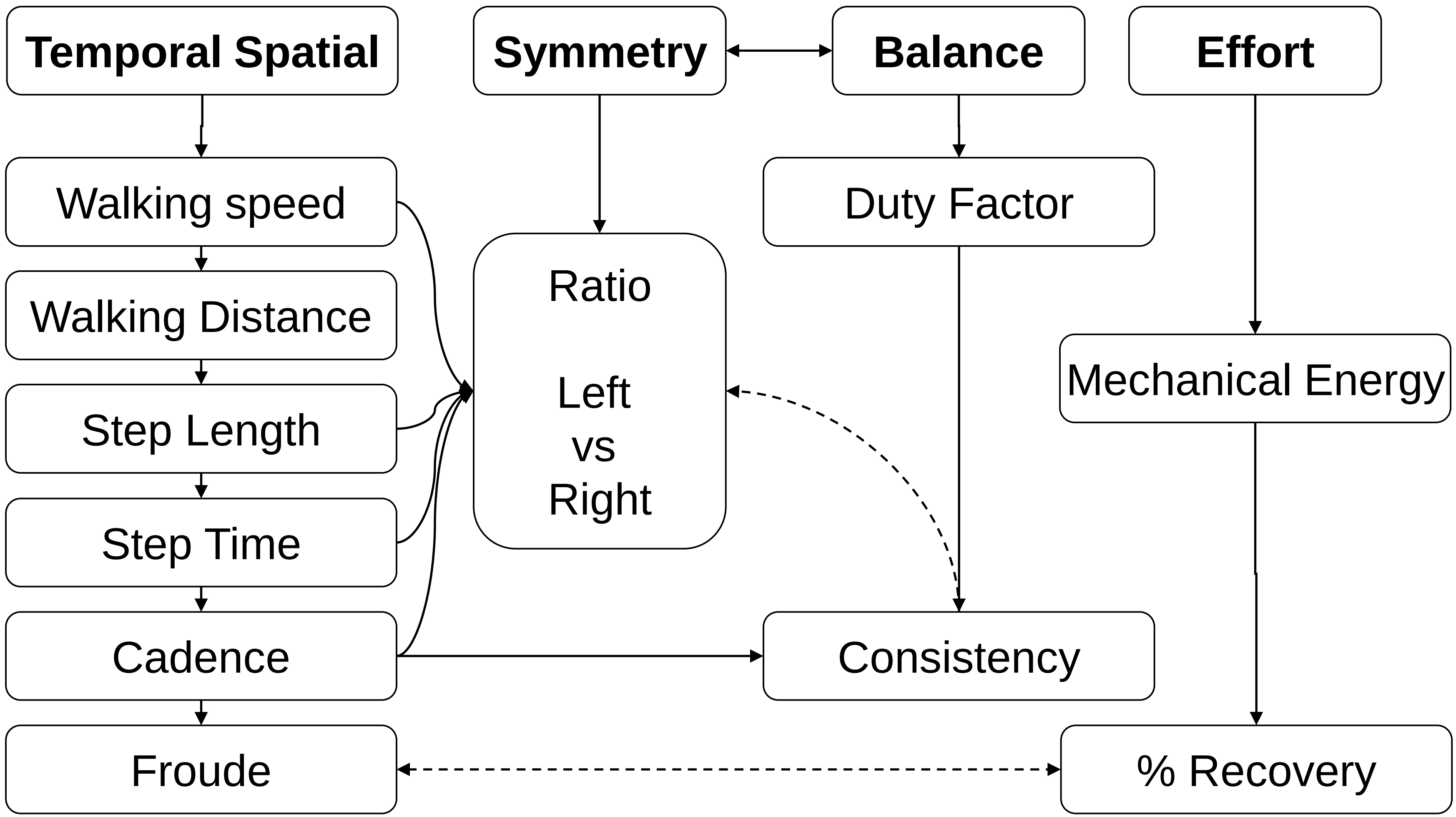
$$R = E\{\overline{v} * \overline{v}^T\} = \begin{bmatrix} R_{xx} & 0 \\ 0 & R_{yy} \end{bmatrix} \quad \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

$$E[x] = \bar{x} = \frac{1}{N}\sum_1^N x_i$$

$$H = \frac{\partial z}{\partial x} = \begin{bmatrix} \frac{x_k^-}{\sqrt{(x_k - x_b)^2 + (y_k - y_b)^2}} & \frac{y_k^-}{\sqrt{(x_k - x_b)^2 + (y_k - y_b)^2}} & 0 \end{bmatrix}$$

Objective Measures of Gait

- Outcome Parameters -



Objective Measures of Gait

- Outcome Parameters -

More advanced parameters:

Walk Ratio [mm/(steps/min)] = steplength [mm] / cadence [steps/min]

- Ratio should stay constant independent of speed
- Shown to be 6.2 [mm/(steps/min)] in TDA (Sekiya, 1998)
- MS reduced to 5.2 [mm/(steps/min)] (Rota, 2011)
- Measure of neuromotor gait control
  - Combines both temporal & spatial parameters

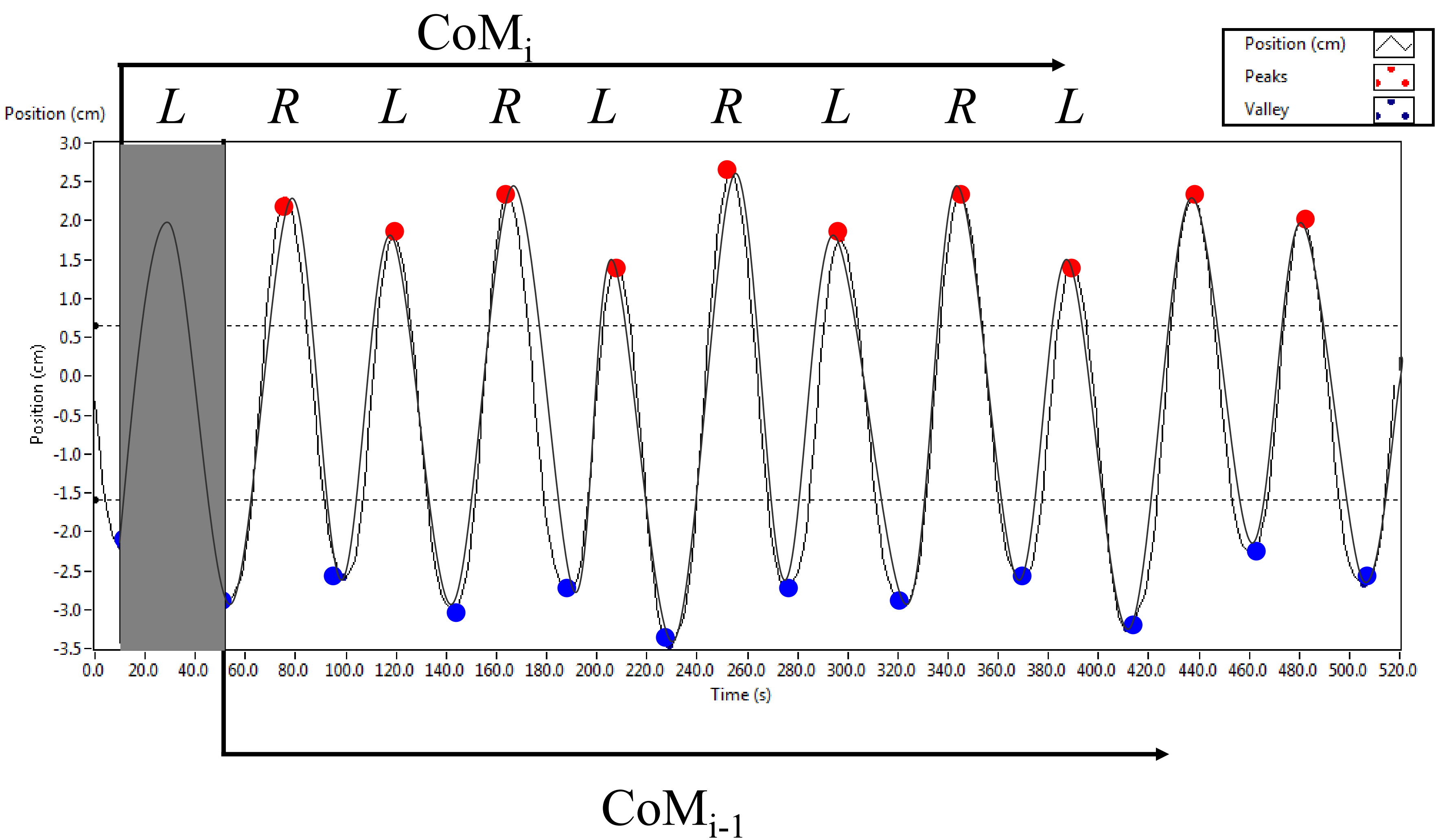
Phase Plot Analysis

- Measure of gait variability based on CoM vertical Movement

(Esser et al, Gait&Posture, 2013; Collet et al, J Neur Rehab, 2013)

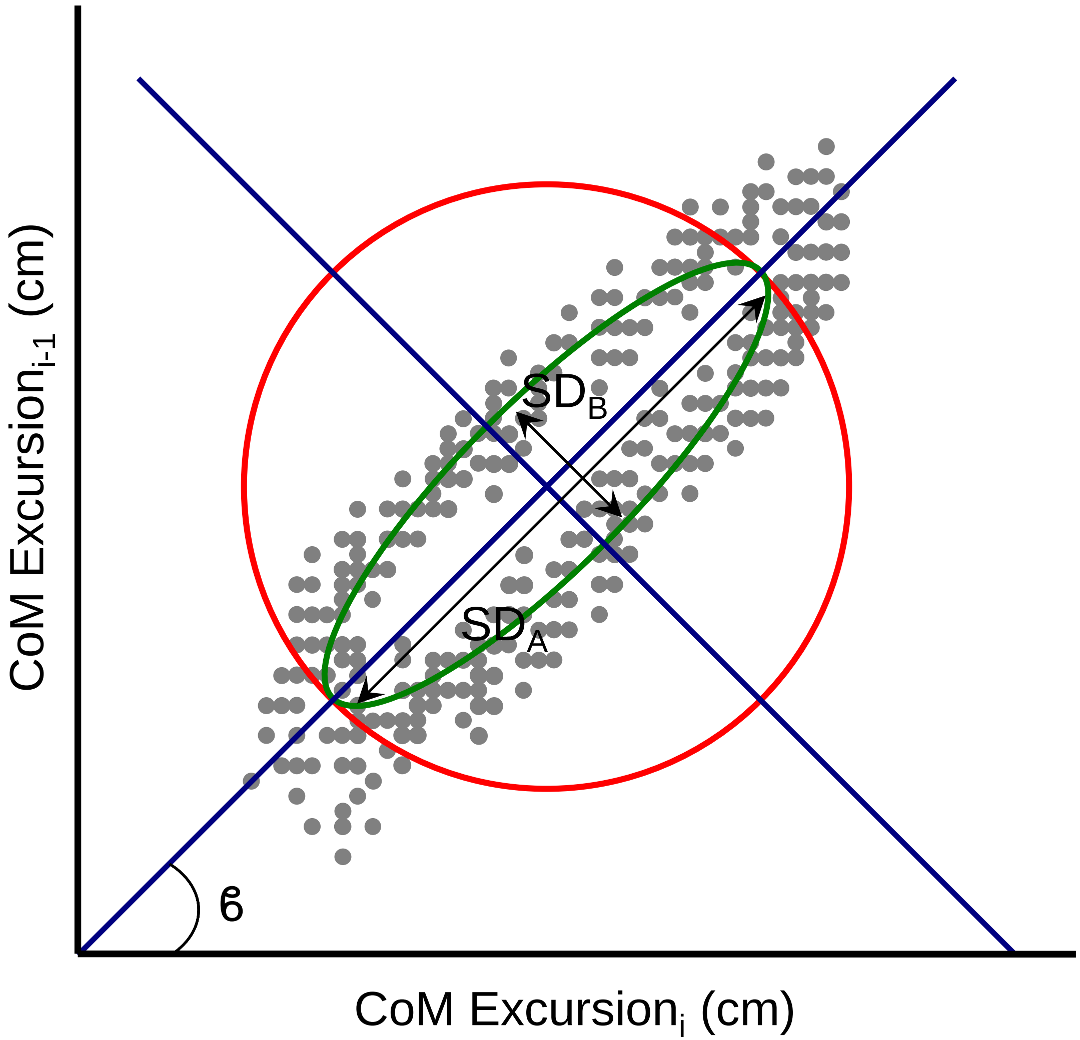
Objective Measures of Gait

- Phase Plot Analysis Explained



Objective Measures of Gait

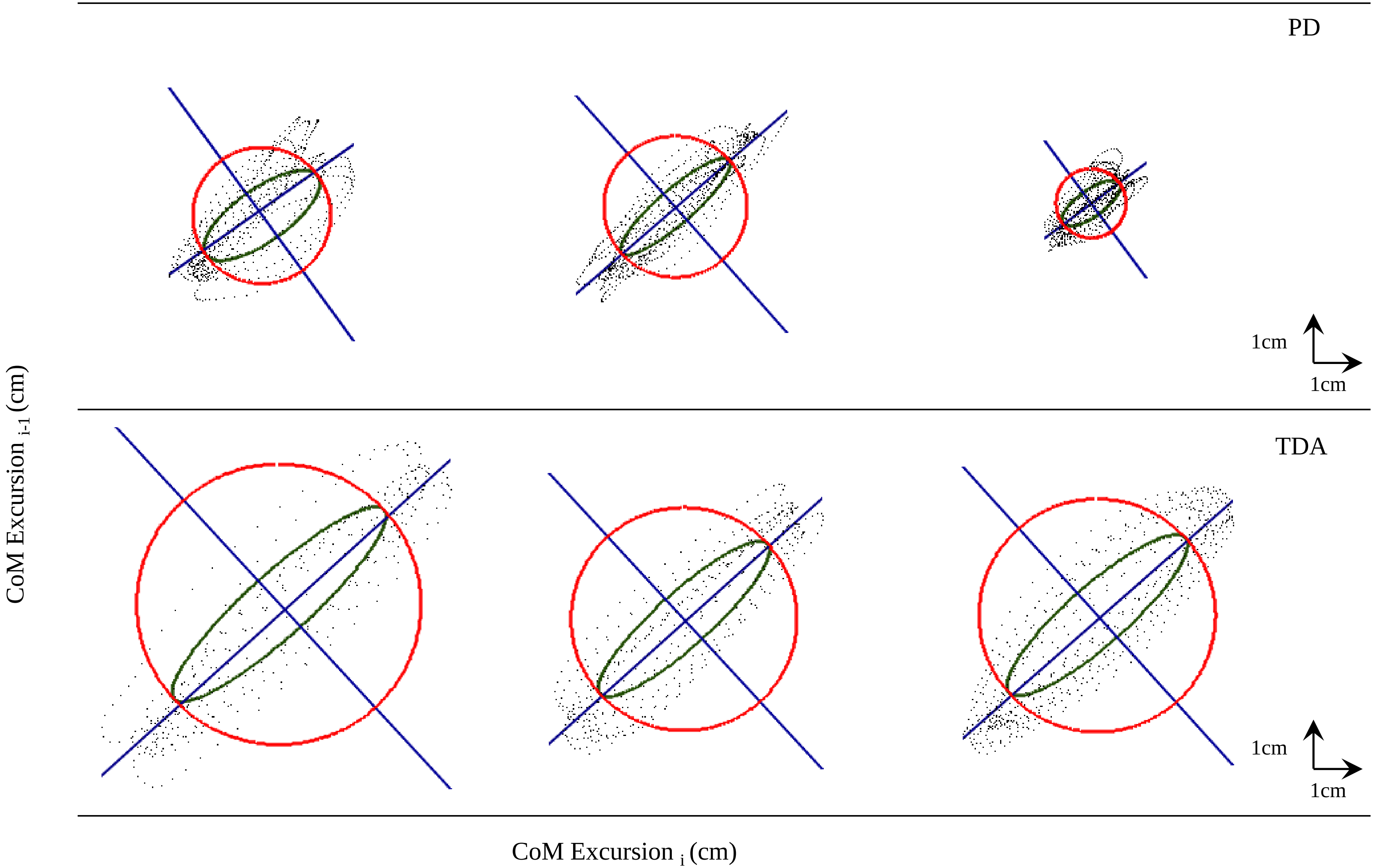
- Outcome parameters -



SD_A	change in step frequency and step length
SD_B	change in step frequency
ϐ	change in step length
∀	*Ratio between SD_A and SD_B*

Objective Measures of Gait

- Visualisation Parkinson's -



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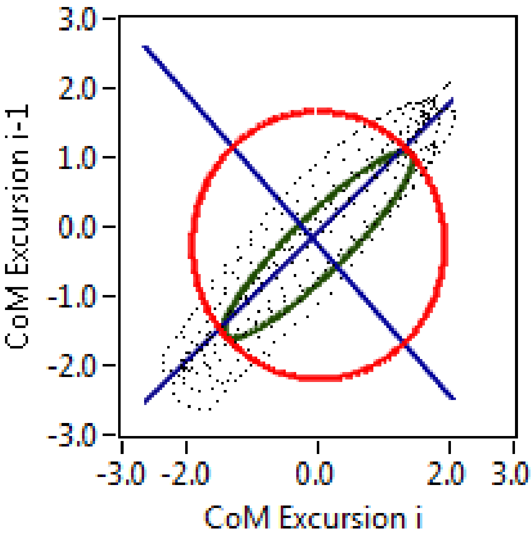
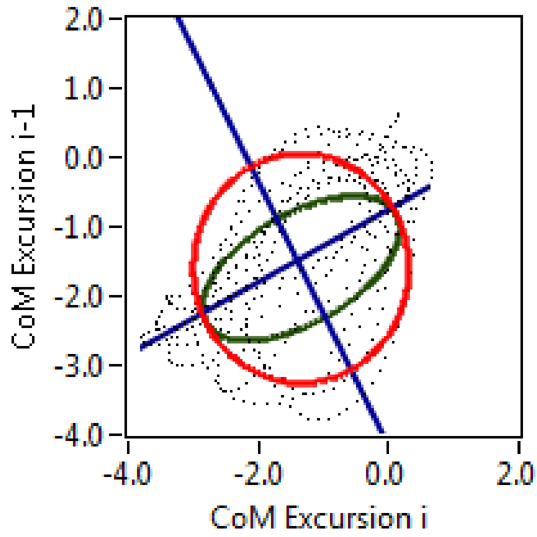
Objective Measures of Gait

- Visualisation Huntington's disease -

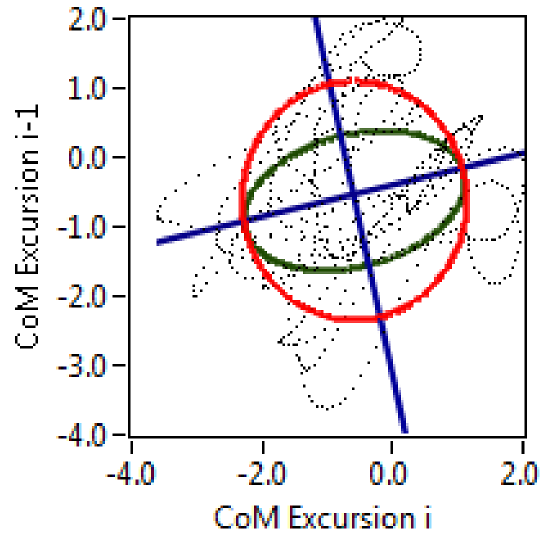
TDA



Pre-sym



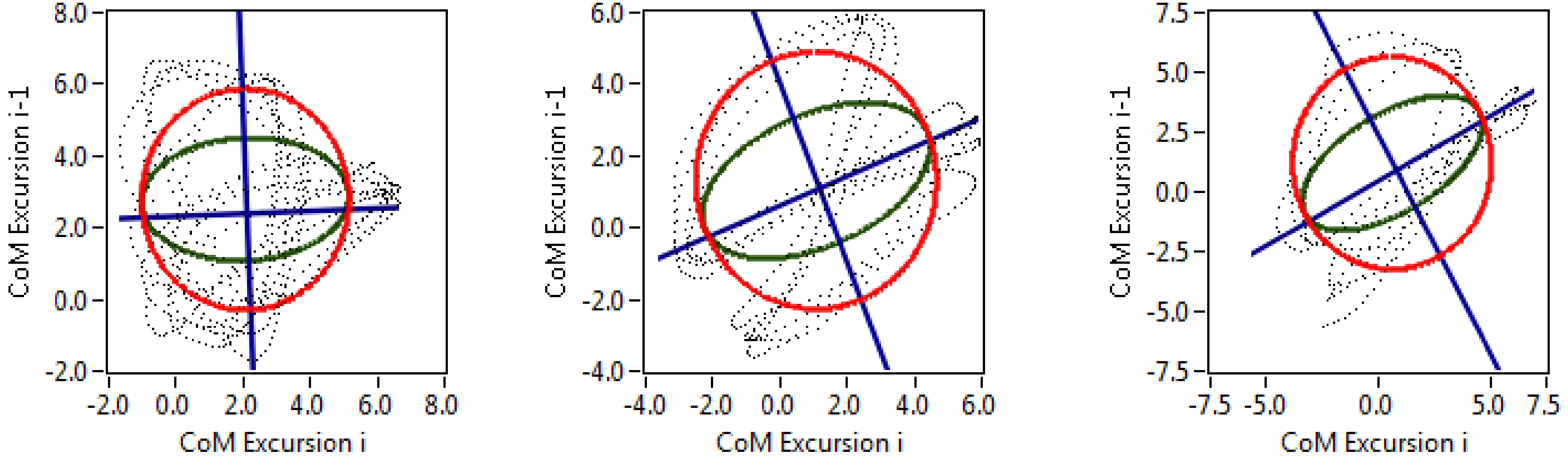
Symp



Objective Measures of Gait

- Visualisation Stroke -

#1 #2 #3



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Whitehall II (Oxford Cohort)

An on-going, prospective cohort study, recruited 10 308 non-industrial civil servants across a range of employment grades in 1985–1988

N=178; 75% male; 69(5.1)yrs

Core Outcomes (gait focussed)

↑ age = ↓ walking speed & ↓ stride time

↑ stride length = ↑ TMT-A & ↑ Boston Naming Test

↑ educational level = ↑ walking speed & ↓ stride time

MSK history = ↓ walking speed & ↓ stride length

Females = ↓ stride time & ↓ double stance [%]

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journal homepage: www.elsevier.com/locate/gaitpost

ELSEVIER

Association between gait and cognition in an elderly population based sample

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Table 1
Demographic and clinical characteristics of the sample.

Variable	Summary
N	178
Age (y), mean (SD)	69 (5.1)
Male, n (%)	134 (75)
Ethnicity white, n (%)	175 (98)
Social class, n (%)	
Higher	29 (17)
Middle	130 (76)
Lower	12 (7)
Years of full-time education (y), median (IQR)	15 (5)
FSIQ (estimated from TOPF), mean (SD)	116.4 (6.9)
Height (m), mean (SD)	1.73 (0.1)
Weight (kg), mean (SD)	78.1 (13.8)
Leg length(cm), mean (SD)	95.1 (5.8)
BMI, median (IQR)	(4)

MRC Insight 46

Insight46 is a neuroscience sub-study of the Medical Research Council (MRC) National Survey of Health and Development (NSHD), consisting of 502 participants of the original NSHD, who were active during the 24th follow-up in 2014-2015 (68-69y, n=2,689)

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N=331; 50% male; 60-64yrs

Core Outcomes (gait focussed)

Females = ↓ walking speed compared to men

↑ healthier lifestyle = ↑ walking speed

↑ HEI score (10pts) = ↑ walking speed for women

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Diet quality in late midlife is associated with faster walking speed in later life in women, but not men: findings from a British birth cohort

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Manuscripts submitted to Journal of Gerontology: Medical Sciences

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