How are differences in gait quantified?
How is gait data normalized?

Project: recruitment help
You must be a volunteer for another group
(grade % to be determined)

https://wwrichard.net/tag/biomechanics/
- Create consensus trajectory (average)

1. Linear length normalization (LLN)

- Adjust time axis of trajectory to match target (e.g. 1-100%)
  - Resample & interpolation
  - Tricky for fast data

- No alignment of points of interest
Dynamic Time Warping

- shift points to minimize distance b/w test & average

Knee Braced

create consensus then shift points to match

too noisy?

b) After DTW
2. Derivative DTW (DDTW)

→ minimized Δ b/w rates of change of test & target

Sounds careful!
Piecewise LLN (PLLN)
- Split it up!
- ID POI & then align

e) After PLLN

Time (% Gait Cycle)

20

10

0

-10

-20

d) After PDTW

Angle (Degrees)

20

10

0

-10

-20

Time (% Gait Cycle)
Defining Gait Events for use in Normalization:

Subphases: LR MS TS PS ISw MSw TSw
Gait Events: IHS<sup>1</sup> CTO WA CHS ITO THA KA IHS<sup>2</sup>

Sub-phases of Gait:
- Loading Response (LR)
- Mid-Stance (MS)
- Terminal Stance (TS)
- Pre-Swing (PS)
- Initial Swing (ISw)
- Mid-Swing (MSw)
- Terminal Swing (TSw)

Gait Events:
- Ipsilateral Heel Strike (IHS)
- Contralateral Toe-Off (CTO)
- Weight Alignment over Forefoot (WA)
- Contralateral Heel Strike (CHS)
- Ipsilateral Toe-Off (ITO)
- Ipsilateral Toe and Contralateral Heel Alignment (THA)
- Ipsilateral Sagittal Knee and Ankle Alignment (KA)

Helwig et al., J Biomech, 2010; Morris & H-W, 2010
Other means of analyzing data...
- Compare kinematics across all joints

A: Cross correlation analysis
  - Measure of similarity between two signals
  - Rooted in convolution operation

Many applications!
  - Filtering
  - Image analysis

\[ f * g \]

Operation \((1-D)\) implies

\[ f * g = f(a) g(i) + f(b) g(i+1) \]
\[ i = 1 \quad \begin{bmatrix} 3 & 2 & 4 & 1 & 2 & 3 & 4 & 4 & 2 & 1 \end{bmatrix} \]
\[ \frac{1}{2}(3) + \frac{1}{2}(2) = 2.5 \]

\[ i = 2 \quad \begin{bmatrix} 3 & 2 & 4 & 1 & 2 & 3 & 4 & 4 & 2 & 1 \end{bmatrix} \]
\[ \frac{1}{2}(2) + \frac{1}{2}(4) = 3 \]

\[ i = 3 \quad \begin{bmatrix} 3 & 2 & 4 & 1 & 2 & 3 & 4 & 4 & 2 & 1 \end{bmatrix} \]
\[ \frac{1}{2}(4) + \frac{1}{2}(1) = 2.5 \]

\[ g = \begin{bmatrix} 3 & 2 & 4 & 1 & 2 & 3 & 4 & 4 & 2 & 1 \end{bmatrix} \]

\[ f * g = \begin{bmatrix} 2.5 & 3 & 2.5 \end{bmatrix} \]

\[ \text{CONVOLUTION OPERATOR} \]
Image Kernels

Explained Visually

By Victor Powell

An image kernel is a small matrix used to apply effects like the ones you might find in Photoshop or GIMP, such as blurring, sharpening, outlining or embossing. They're also used in machine learning for 'feature extraction', a technique for determining the most important portions of an image. In this context the process is referred to more generally as 'convolution' (see: convolutional neural networks.)

To see how they work, let's start by inspecting a black and white image. The matrix on the left contains numbers, between 0 and 255, which each correspond to the brightness of one pixel in a picture of a face. The large, granulated picture has been blown up to make it easier to see; the last image is the "real" size.

Let's walk through applying the following 3x3 sharpen kernel to the image of a face from above.

\[
\begin{pmatrix}
0 & -1 & 0 \\
-1 & 5 & -1 \\
0 & -1 & 0
\end{pmatrix}
\]

Below, for each 3x3 block of pixels in the image on the left, we multiply each pixel by the corresponding entry of the kernel and then take the sum. That sum becomes a new pixel in the image on the right. Hover over a pixel on either image to see how its value is computed.
How to examine coupling between ipsilateral and contralateral joint motions?

**Cross-correlation analysis**

\[ r_{x,y}(k) = \frac{\sum_{i=1}^{N} (x_i - \bar{x})(y_{i+k} - \bar{y}) + \sum_{i=1}^{N} (x_i - \bar{x})(y_{i-k} - \bar{y})}{\sqrt{\sum_{i=1}^{N} (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^{N} (y_i - \bar{y})^2}} \]

Cross-correlation is a measure of similarity of two waveforms \((x, y)\) as a function of a time-lag applied to one of them.

\((x, y)\) are ipsilateral and contralateral joint angular positions and velocities (RA, RAv, RK, RKv, etc)

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Park et al., Gait & Posture, 2012
Fig. 1: Two time series from left hip and left ankle angular displacement (no brace trial) with a left-ankle time shift of: a) 0% time shift \((k=0)\), b) 10% time shift \((k=10)\), and c) 30% time shift \((k=30)\).
Record maximal cross-correlation and critical phase shift

Maximal cross-correlation ($r_{x,y}^*$) and critical phase shift ($k_{x,y}^*$) values from the cross-correlation function between left hip ($x$) and left ankle angular displacements ($y$) for one subject without bracing.

$$k^* = \left| 50 - k \right|$$

$r^* + k^*$ plotted in characteristic diagram

Write some code to fill it in across all subjects.
Now run some stats to see which boxes are significantly different.
**Knee braced**

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- **motion coupled**
- **Black** ⬇️ **SIG differences**
- **White**: none

← **Ankle braced**

**Not so much**