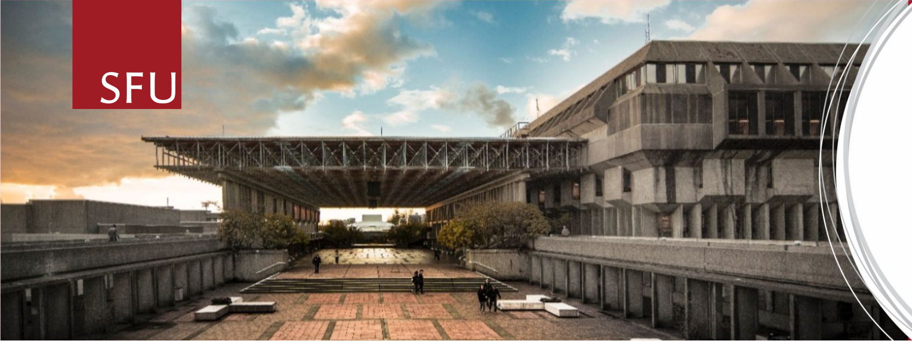

APMA 920
Project Presentation

Neuromechanics of muscle synergies during cycling [1] revisited

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Created on December 13, 2022

Project Details:

The main objective of this project was to revisit the paper *Neuromechanics of Muscle Synergies During Cycling* [1] along with the data collected during the trial and attempt to make new inferences.

Paper Details:

- **Title:** Neuromechanics of Muscle Synergies During Cycling
- **First published:** December 10, 2008
- **Authors:** James M. Wakeling, Tamara Horn
- **Research Location:** School of Kinesiology, Simon Fraser University

Trial Details:

Wakeling, and Horn, conducted an experimental trial with **nine trained cyclists**.

They measure electrical activity (EMG) in **three main synergistic** groups of muscles in one leg (ankle extensors, knee extensors and knee flexors) while cycling on a stationary dynamometer for **nine separate conditions**.

These conditions include varying **cadences** and **torques**, varying the speed the cyclist must pedal, or rather the force applied, respectively, while completing **24 pedal revolutions**.

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Original Hypothesis

The original aim was to test two main hypotheses:

1. that a significant ($> 10\%$) proportion of the patterns of activity is modulated due to the movement mechanics (the load and velocity required during the task), and
2. that activity of muscles within an anatomic group would show a significant ($> 10\%$) uncoupling when the limb was challenged with a range of mechanical conditions.

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Observation Driving Problem Statement

One key observation in their results was focused on the **quadriceps muscles**.

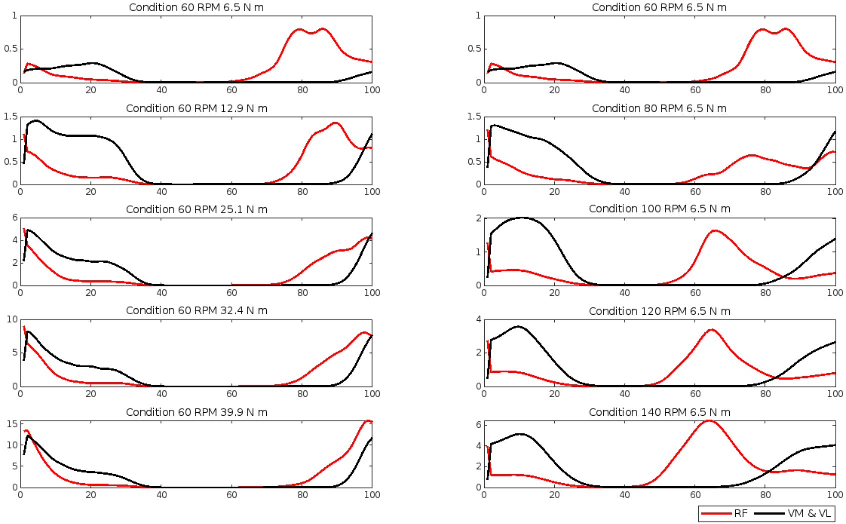
They noted that the **Rectal femoris (RF)** showed a significant phase advance compared to the **Vastus medialis (VM)** and the **Vastus lateralis (VL)** for high cadence trials.

These muscles are members of the knee extensors anatomic group with the main function being to extend the leg at the knee. It was noted that, at the highest crank torque, the mean EMG intensity of the RF showed greater activity than the VM and VL.

Problem Statement

Can we determine the condition of a pedal cycle based on the relative phase advance of the Rectal femorus (RF) from the Vastus medialis (VM) and the Vastus lateralis (VL) muscles in the raw EMG traces.

Mean RF vs Mean VM & VL values across all 9 conditions and all 9 test subjects.



Key Concepts: Correlation Coefficient

Definition (Pearson Correlation Coefficient)

The population correlation coefficient $\rho_{X,Y}$ between two random variables X and Y with expected values μ_X and μ_Y and standard deviations σ_X and σ_Y is defined as:

$$\rho_{X,Y} = \mathbf{corr}(X,Y) = \frac{\mathbf{cov(X,Y)}}{\sigma_X \sigma_Y} = \frac{E\left[(X-\mu_X)(Y-\mu_Y)\right]}{\sigma_X \sigma_Y}, \quad \text{if} \quad \sigma_X \sigma_Y > 0$$

where E is the expected value operator, **cov** means covariance, and **corr** is a widely used alternative notation for the correlation coefficient.

Within Matlab, the command used for correlation coefficients is `corrcoef(A,B)`. It is defined by

$$\rho(A,B) = \frac{1}{N-1} \sum_{i=1}^{N} \left(\frac{A_i - \mu_A}{\sigma_A}\right)\left(\frac{B_i - \mu_B}{\sigma_B}\right)$$

where N is the number of scalar observations.

Key Concepts: Cross-correlation

Definition (Cross-correlation)

Let (X_t, Y_t) be a pair of random processes, and t be any point in time (t may be an integer for a discrete-time process or a real number for a continuous-time process). Then X_t is the value (or realization) produced by a given run of the process at time t. Suppose that the process has means $\mu_X(t)$ and $\mu_Y(t)$ and variances $\sigma_X^2(t)$ and $\sigma_Y^2(t)$ at time t, for each t. Then the definition of the cross-correlation between times t_1 and t_2 is

$$R_{XY}(t_1, t_2) \triangleq E\left[X_{t_1} \bar{Y_{t_2}}\right]$$

where E is the expected value operator.

Within Matlab, the command used for cross-correlation is `xcorr(x,y)`. It is defined by

$$\hat{R}_{XY}(m) = \left\{ \begin{array}{ll} \sum_{n=0}^{N-m-1} x_{n+m} y_n^*, & m \geq 0 \\ \hat{R}_{YX}(-m), & m < 0 \end{array} \right\}$$

with output vector, c, with elements given by

$$c(m) = \hat{R}_{XY}(m-N), \quad m = 1, 2, ..., 2N-1$$

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1. Average the training data for an individual pedal cycle over all conditions (keeping the RF, VL and VM muscles separate).
2. Compute the cross-correlation vectors of the RF muscle against the average of the VM and VL muscles at each condition.
3. For each test sample, compute the cross-correlation vector for that individual pedal cycle
4. Use the correlation coefficients between the test data and the training cross-correlation vectors to predict which condition the test sample comes from

Algorithm 1 Make Prediction

Input: T, an (m, n) matrix of test data, $C = \{\{c_1\}, ..., \{c_t\}\}$, a cell with 9 averaged cross-correlation vectors for each condition, and $C_{map} = \{\hat{c}_1, ..., \hat{c}_t\}$, a vector with 9 condition maps for each cell in C.

Extract RF and $V_{M\&L}$ the average of VL and VM muscles from T.
Initialize predictions vector P
for $j = 1 : m$ **do**
  Compute normalized $T_j :=$ **xcorr**$(RF, V_{M\&L})$
  Initialize correlation vector X
  for $k = 1 : 9$ **do**
    Extract $C_k :=$ cross-correlation vector k from C
    Compute $X_k =$ **corrcoef**(T_j, C_k)
  end for
  Set $P_j = C_{map}(m)$,the m'th entry in C_{map} where $X_m = max(X)$
end for
return P

Experiment 1

In order to try and remove any bias from the results, the training set is redefined for each trial, for a total of 100 trials.

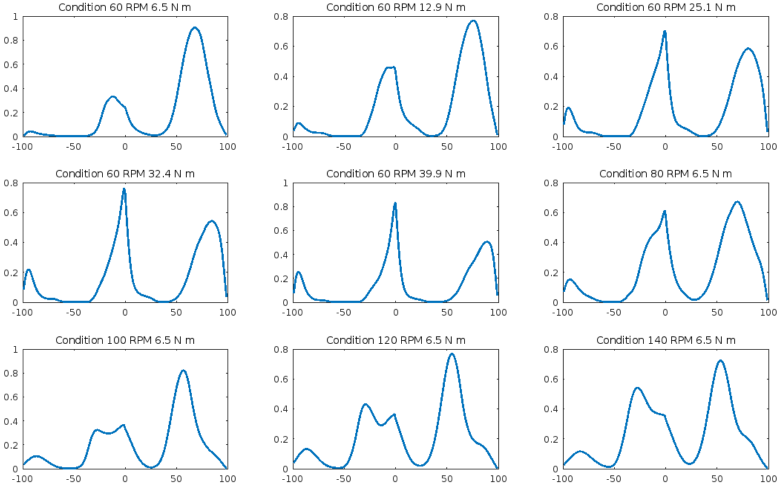
For each trial:

1. remove one random subject from the data
2. take a random subset of the remaining 8 subjects based on the desired training percentage
3. average the RF muscle and the VM and VL muscles over all of the training data for each condition and compute the base cross-correlation vectors. Label the conditions 1-9.
4. Define two test sets, $A =$ the remaining data from the 8 subjects left after randomly removing one, $B =$ all data from the removed subject. Create true condition vectors for each test set to determine accuracy.
5. Use Algorithm 1 to predict the condition and compare against the true conditions.

Cross-Correlation Vectors

3 Experiments

Cross-Correlation Vector for RF muscle vs Mean VM & VL across all 9 conditions all 9 test subjects.



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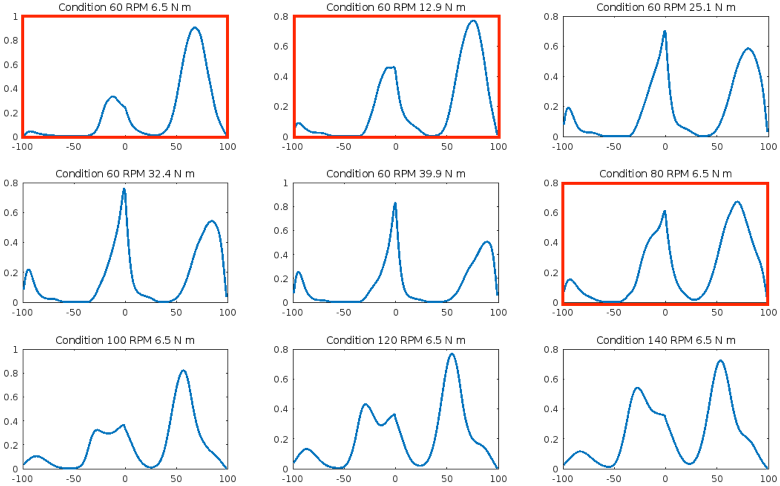

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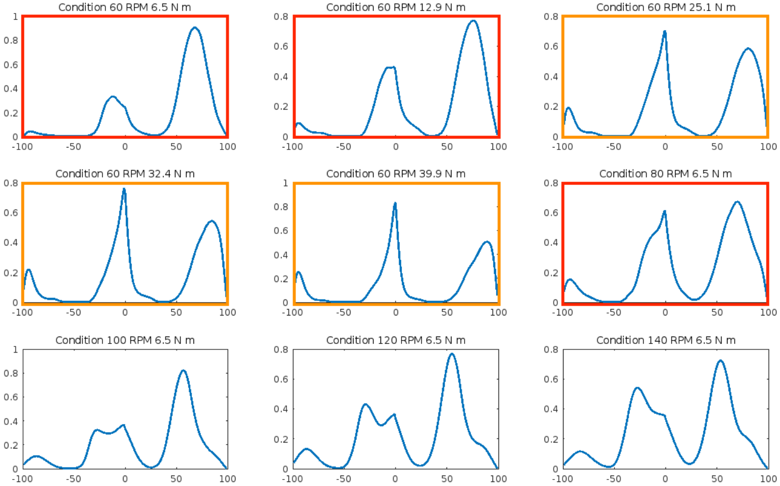

Cross-Correlation Vectors

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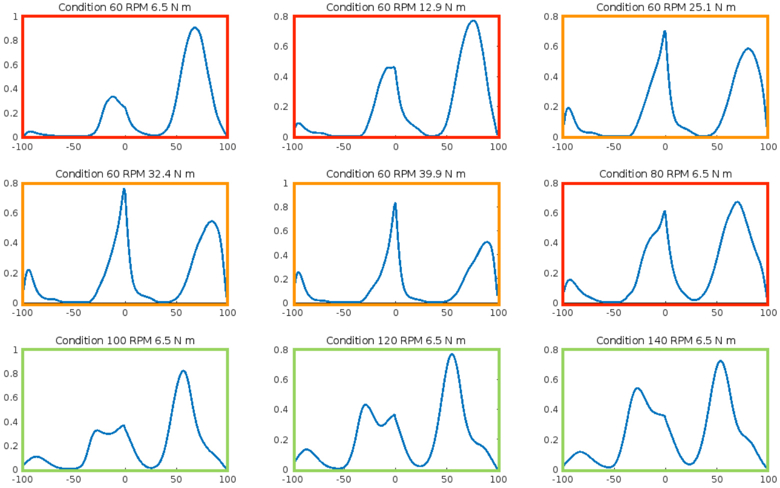

Cross-Correlation Vector Groups

Based on these clear groupings when we average over all the data, it is likely that the performance of this experiment may not be as accurate as desired.

It is possible that Algorithm 1 may not successfully identify the condition of the pedal cycle, but rather predict one of the similar conditions due to variation between subjects.

Correlation Matrix

Let's visualize the correlation coefficients between the cross-correlation vectors

Condition Of Trial	60 RPM 6.5 N m	60 RPM 12.9 N m	60 RPM 25.1 N m	60 RPM 32.4 N m	60 RPM 39.9 N m	80 RPM 6.5 N m	100 RPM 6.5 N m	120 RPM 6.5 N m	140 RPM 6.5 N m
60 RPM 6.5 N m	1	0.8918	0.6575	0.5338	0.3863	0.9057	0.7013	0.5682	0.5011
60 RPM 12.9 N m	0.8918	1	0.9068	0.8241	0.7005	0.935	0.4615	0.3384	0.2989
60 RPM 25.1 N m	0.6575	0.9068	1	0.9852	0.9326	0.8604	0.2993	0.2098	0.1799
60 RPM 32.4 N m	0.5338	0.8241	0.9852	1	0.9794	0.7839	0.2175	0.1426	0.1105
60 RPM 39.9 N m	0.3863	0.7005	0.9326	0.9794	1	0.6832	0.1413	0.0839	0.0487
80 RPM 6.5 N m	0.9057	0.935	0.8604	0.7839	0.6832	1	0.6987	0.5937	0.5475
100 RPM 6.5 N m	0.7013	0.4615	0.2993	0.2175	0.1413	0.6987	1	0.9718	0.9158
120 RPM 6.5 N m	0.5682	0.3384	0.2098	0.1426	0.0839	0.5937	0.9718	1	0.9753
140 RPM 6.5 N m	0.5011	0.2989	0.1799	0.1105	0.0487	0.5475	0.9158	0.9753	1

Experiment 2

Define the training and test sets in the same manner as Experiment 1, excluding one subject and taking a certain percentage for training with the remaining being used for testing. Continue with steps 3, 4, & 5 from Experiment 1, but label to conditions based on the below groupings.

$$
\begin{aligned}
\text{Group 1}: \quad & \{c_1 = 60 \text{ rpm and } 6.5 \text{ N m}, c_2 = 60 \text{ rpm and } 12.9 \text{ N m}, \\
& c_6 = 80 \text{ rpm and } 6.5 \text{ N m}\} \\
\text{Group 2}: \quad & \{c_3 = 60 \text{ rpm and } 25.1 \text{ N m}, c_4 = 60 \text{ rpm and } 32.4 \text{ N m}, \\
& c_5 = 60 \text{ rpm and } 39.9 \text{ N m}\} \\
\text{Group 3}: \quad & \{c_7 = 100 \text{ rpm and } 6.5 \text{ N m}, c_8 = 120 \text{ rpm and } 6.5 \text{ N m}, \\
& c_9 = 140 \text{ rpm and } 6.5 \text{ N m}\}
\end{aligned}
$$

Experiment 3

In Experiment 3, we defined a smaller set of cross-correlation vectors by taking the average of the cross-correlation vectors in each group.

The groups used in Experiment 3 are defined slightly differently than in Experiment 2, in order to try and take into consideration the high correlation between conditions 60 rpm and 90 Hz and 60 rpm and 175 Hz. We do this by including condition 2 (60 rpm and 90 Hz) in both Group 1 and Group 2. Thus, we define the 3 cross-correlation vectors by:

$$\begin{aligned}\tilde{c_1} &= \quad mean(c_1, c_2, c_6)\\ \tilde{c_2} &= \quad mean(c_2, c_3, c_4, c_5)\\ \tilde{c_3} &= \quad mean(c_7, c_8, c_9)\end{aligned}$$

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4 Results

Training Percent 60%

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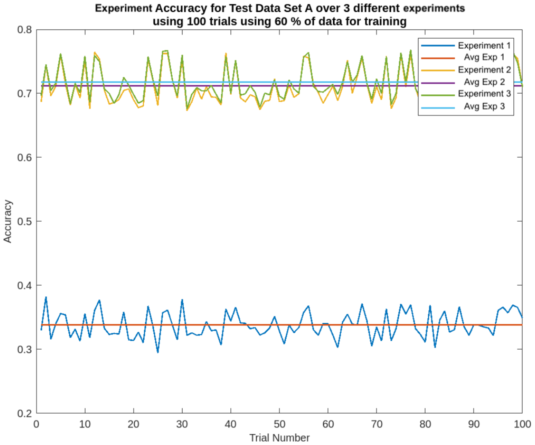

Figure: Accuracy results for test set A with 60% training percentage over 100 trials.

Training Percent 60%

4 Results

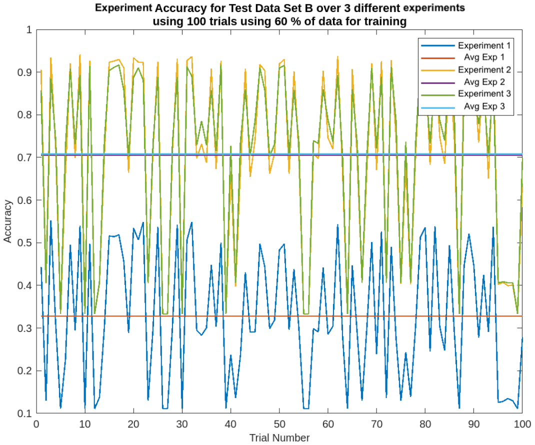

Figure: Accuracy results for test set B with 60% training percentage over 100 trials.

Training Percent 70%

4 Results

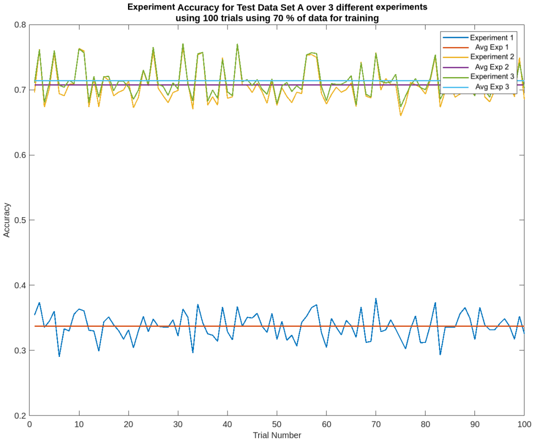

Figure: Accuracy results for test set A with 70% training percentage over 100 trials.

Training Percent 70%

4 Results

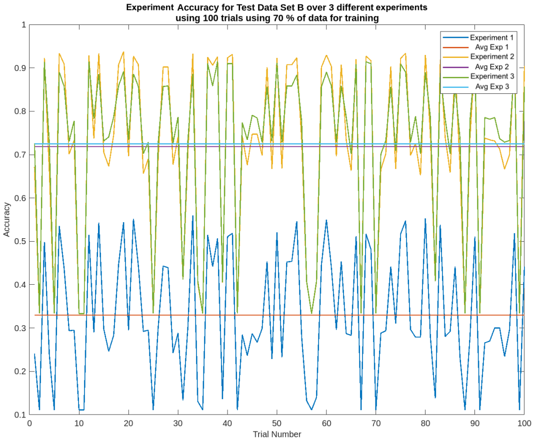

Figure: Accuracy results for test set B with 70% training percentage over 100 trials.

Experiment 1 Accuracy

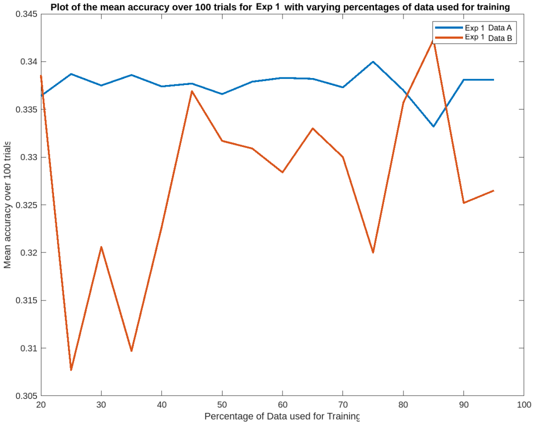

Figure: Mean accuracy over 100 trials for increasing training percentage for Experiment 1.

Experiment 2 & 3 Accuracy

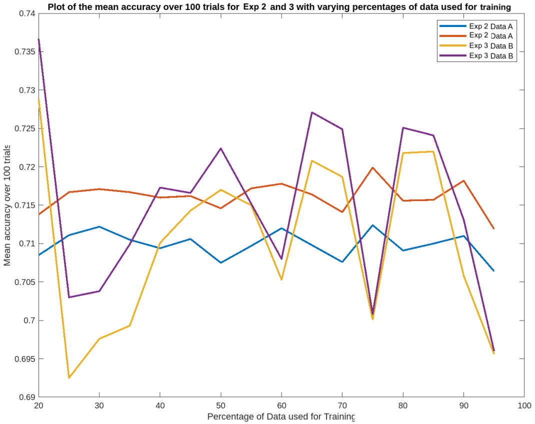

Figure: Mean accuracy over 100 trials for increasing training percentage for Experiment 2 and 3.

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In **Experiment 1**, we have low accuracy around **30%.**

Once conditions were grouped in **Experiments 2 and 3**, we see a great improvement for both test set A and test set B. The model is able to predict the pedal cycle condition group for both data types with an average of approximately **71%** accuracy.

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Q&A

Thank you for listening!

James M. Wakeling and Tamara Horn.
Neuromechanics of muscle synergies during cycling.
Journal of Neurophysiology, 101(2):843–854, 2009.