# A Computational Model of Muscle Recruitment for Wrist Movements

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## Abstract

In many cases, several muscles may participate in different ways to make the same movement. This creates a problem of redundancy that the motor system must resolve prior to making a movement. Hoffman and Strick (1999) examined the role of several different muscles in the primate while executing two-degree-of-freedom wrist movements. They observed that the muscles were recruited as a function of the movement direction in a roughly cosine-like fashion. In some cases, a muscle was recruited most strongly in directions other than the muscle's direction of action. In this poster, we present an abstract model of wrist muscle recruitment that selects muscles based on their ability to produce the desired movement while minimizing the total effort required to make the movement. These criteria lead to a cosine-like recruitment of muscles similar to that found by Hoffman and Strick.

## Experimental Task (Hoffman and Strick, 1999)

■ Hoffman and Strick (1999) described a task in which a primate moved a manipulandum to control a cursor on a computer screen. The object was to move the cursor from the center to a target lying on a circle.

- radial/ulnar and flexion/extension deviations of the wrist were allowed by the manipulandum

- wrist held in pronation, supination, or midway between the two

■ Peak wrist muscle EMG vs. target direction followed a cosine-like shape (Figure 1).

■ The *preferred direction* of a wrist muscle is defined by the peak of a fitted cosine (long arrow).

- this differed from the *pulling direction* (defined by stimulating the muscle and observing immediate wrist movement) of some muscles

■ as wrist rotated 180⁰, muscle pulling directions rotated between 74⁰ and 130⁰ (Hoffman, 1999).

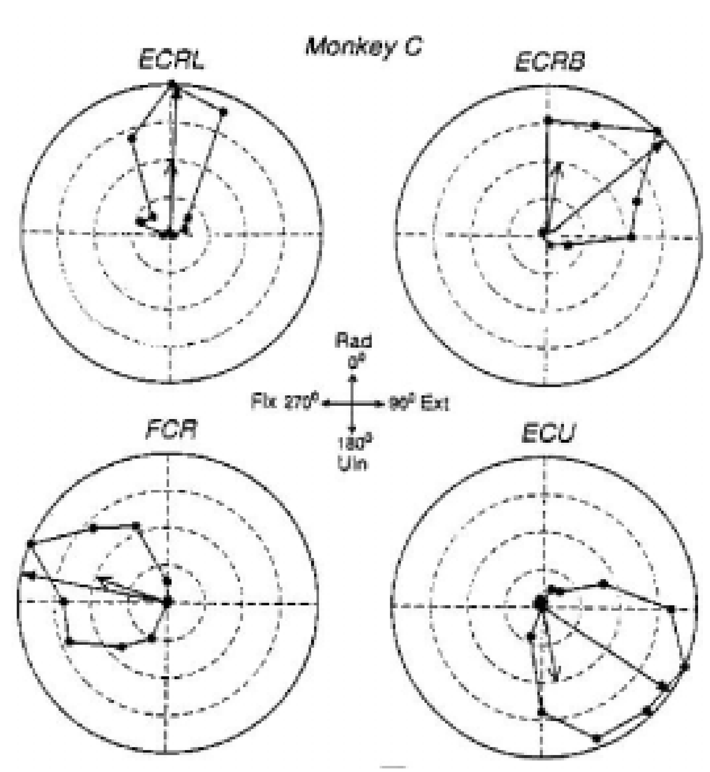


*Figure 1*. EMG vs. target direction for 4 muscles in midrange wrist posture (from Hoffman and Strick , 1999).

## Muscle Selection Model

Individual muscles are assumed to pull the wrist along their pulling directions in a straight line (in joint coordinates) with equal mechanical advantage, as shown in Figure 2.

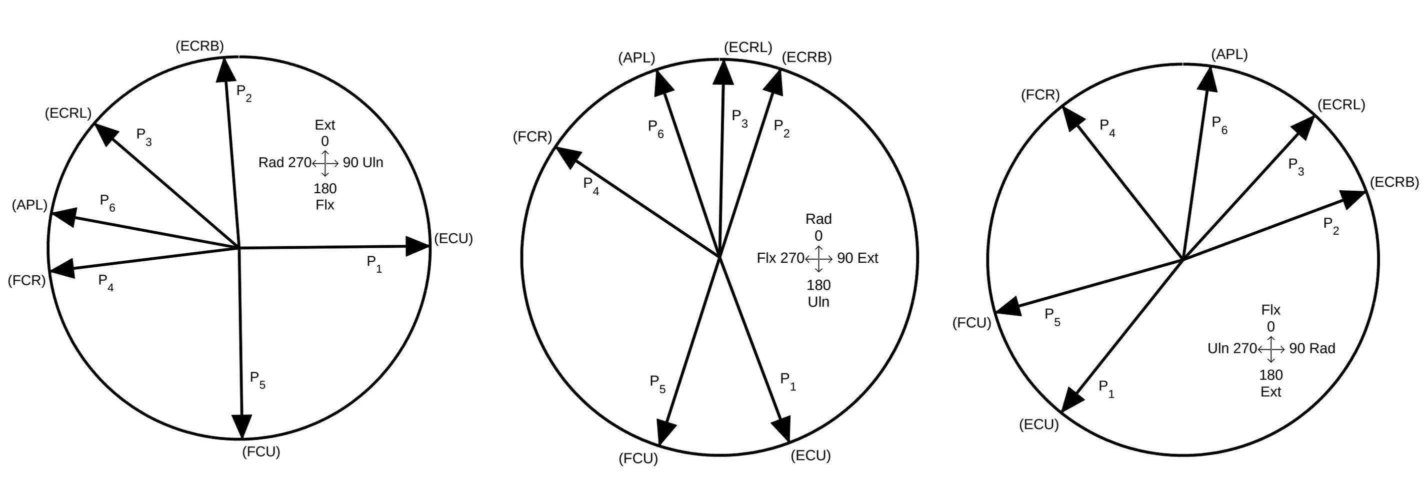


*Figure 2.* Pulling directions of 6 muscles for pronation (left), midway (center), and supination (right) (data from Hoffman, 1999).

The pulling direction is expressed as a column vector $\mathbf{P}_i^\rho$, where $i$ is the muscle index and $\rho$ is the wrist posture (pro, mid, or sup). If the activation level of muscle $i$ is $a_i$ and the set of muscles is $A$, then the wrist movement endpoint (including direction and magnitude) $\mathbf{x}$ is described as follows:

$$\mathbf{x} = \sum_{i \in A} \mathbf{P}_i^\rho a_i .$$

With 6 muscles controlling a two-degree-of-freedom motion, there is a redundancy that allows an infinite number of solutions. We use three performance criteria in selecting the muscle activations:

1) Minimize error between implemented movement and target
2) All muscle activations $a_i$ must be positive
3) Minimize total muscle activation

Criteria 1) and 3) are summarized in the following error function:

$$E = \frac{1}{2}\left\| \mathbf{x}_t - \sum_{i \in A} \mathbf{P}_i^\rho a_i \right\|^2 + \frac{\lambda}{2}\|\mathbf{a}\|^2 ,$$

where $\mathbf{x_t}$ is the target location, $\lambda$ is a regularization parameter set to 0.02, and $\mathbf{a}$ is the muscle activation vector. Similar optimization criteria that minimize total squared muscle force have been used with favorable results in other studies dealing with redundancy and muscle recruitment (Pedotti, 1978; Collins, 1995).

## Results

We applied a gradient descent method minimizing the error term (and flooring all $a_i$ to 0) independently for 12 targets lying on a circle and for the 3 wrist postures (for a total of 36 distinct conditions). For each wrist posture, muscle activation values as a function of target position were fitted to a cosine function to determine the preferred directions of the muscles. Figure 3 shows the muscle activation patterns as a function of target direction as calculated by the model. Note the qualitative similarities with Figure 1.

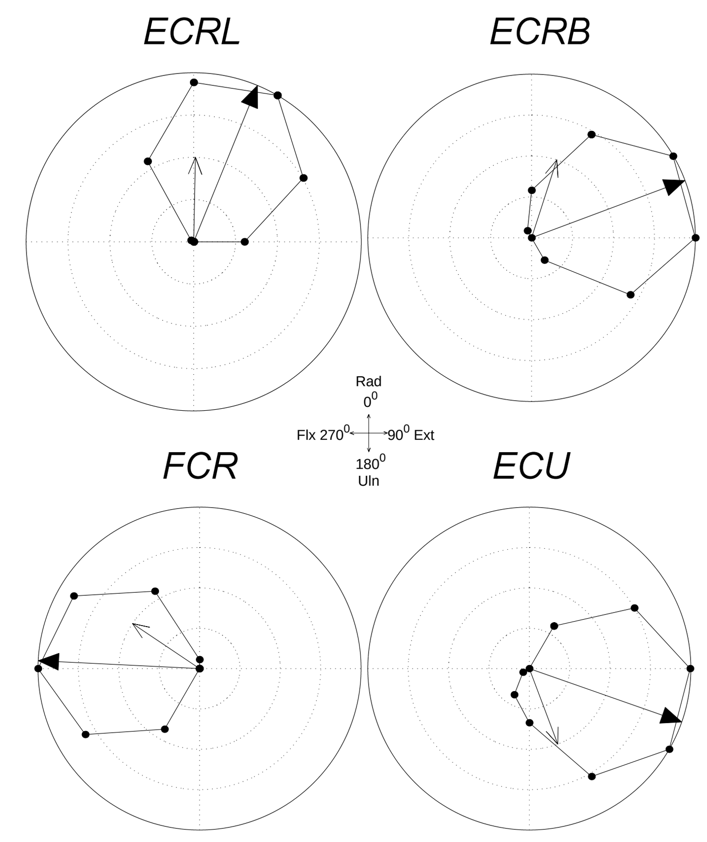


*Figure 3*. Muscle activation vs. target direction for 4 muscles in midrange wrist posture, as calculated by the model.

## Preferred versus Pulling Directions

The difference between the preferred and pulling directions of some muscles is a result of the uneven distribution of the pulling directions. If there is a large gap between the pulling directions of two muscles, then the muscles have to devote some force to pulling against each other in order to reach a target located in the gap. Thus, the preferred direction of a muscle will tend towards this gap.

Figure 4 summarizes for all 36 conditions the difference between a muscle's preferred direction and its pulling direction as a function of its pulling direction. Each set of three connected points represents a single muscle, denoted by a circle for when the wrist is in pronation, a dot for midrange, and a square for supination.

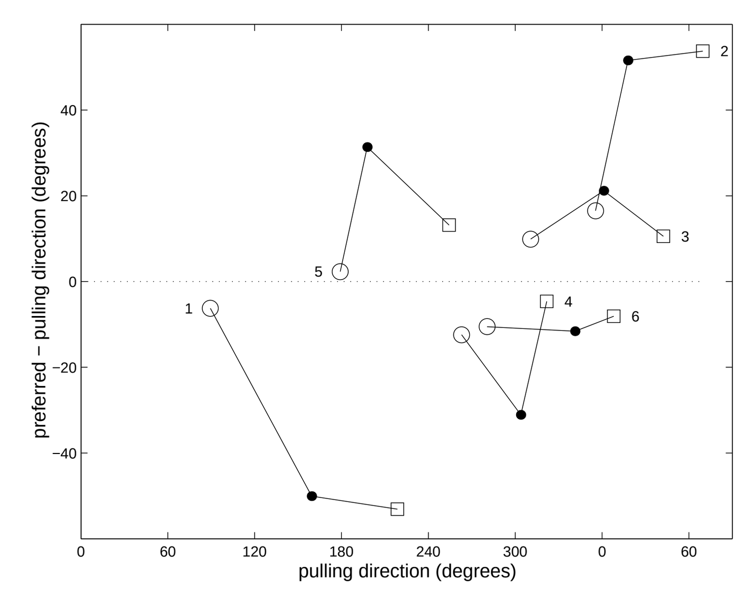


*Figure 4*. Difference in preferred directions and pulling directions for muscles as a function of pulling directions for the muscles.

## Implications of the Model

■ Cosine-like pattern of muscle activation is not explicitly represented, but results from minimizing total muscle activity.

■ This minimization criterion discourages a few muscles from having large activations and prefers to distribute the responsibility of the movement across many muscles.

■ The optimization method empirically yields unique solutions for each of the 36 conditions.

■ Altering the "mechanical advantage" of a certain muscle changes the behavior of the preferred directions of neighboring muscles. However, the behavior of the preferred direction of the altered muscle is relatively unchanged. See Figure 5.

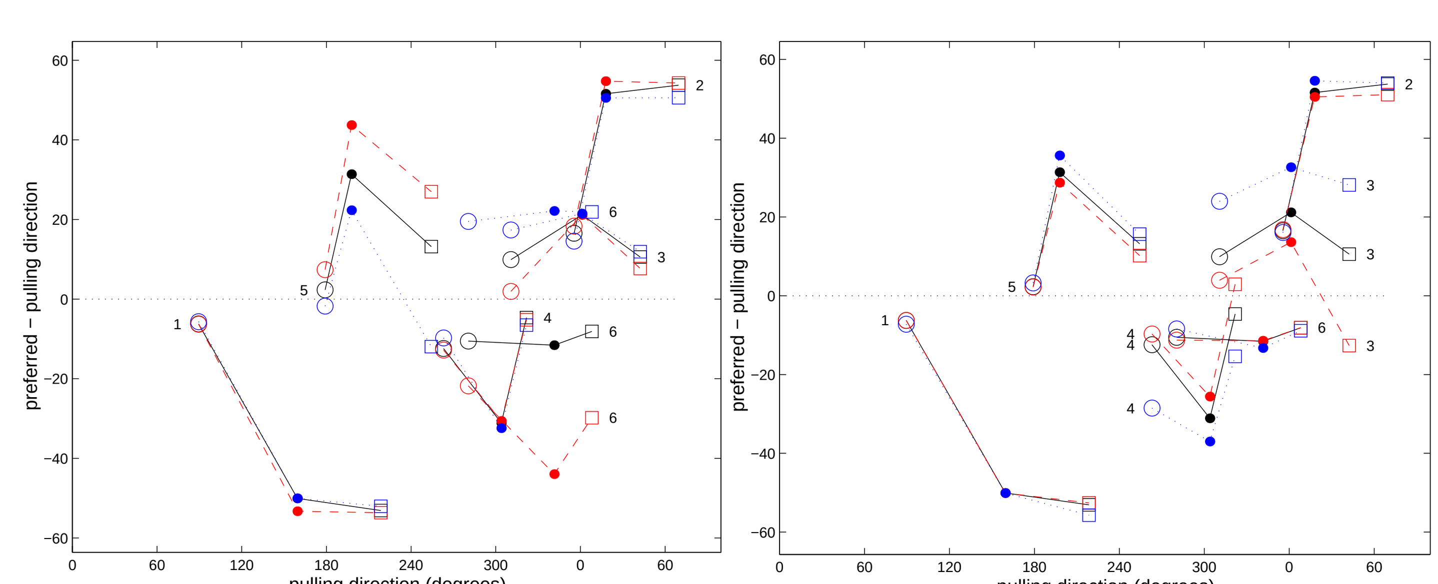


*Figure 5*. Changes in muscle preferred directions due to alterations in the pulling strength of muscles 4 (left) and 6 (right), Muscle and wrist posture notation same as in Figure 4. Solid black line segments represent the original pulling strength; red dashed line for half pulling strength; blue dotted line for double pulling strength.

## References

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