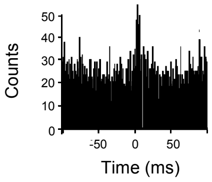
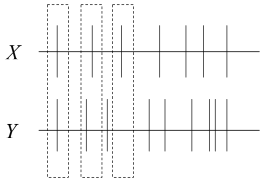
Correlations of neural activity

Correlation analysis of motor neuron activity has been used to determine the organization and connections of neurons that are otherwise inaccessible or difficult to record (Perkel et al. 1967).

Correlation Analysis in the time domain

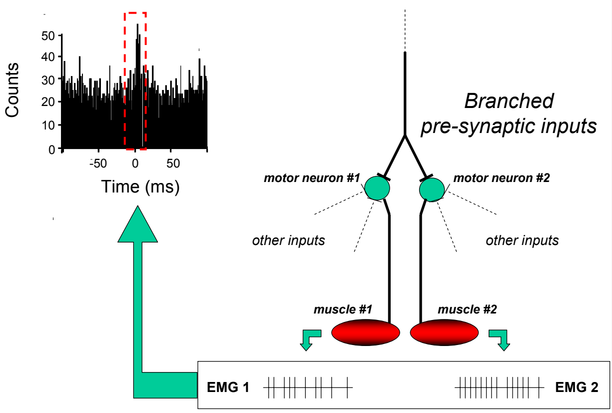
$R_{YX}(\tau) = (1/T)\int y(t)x(t - \tau)dt$





Correlation functions describe the dependence between two signals, *x* and *y*. By representing spike trains by values of **1** at times of spike occurrence and **0** at other times, $R_{YX}(\tau)$ is non-zero when spikes occur in both trains at an interval of τ. The cross-correlation histogram results from summations of the number of spikes in the two trains within a given time interval.

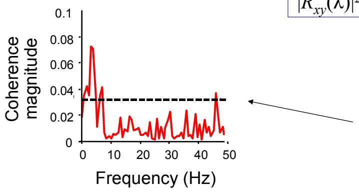
Short-term synchrony



Correlation analysis in the frequency domain

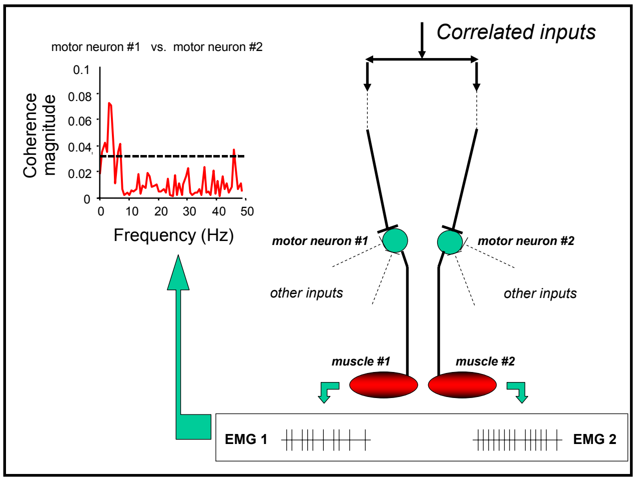
$|R_{xy}(\lambda)|^2 = |f_{xy}(\lambda)|^2 / (f_{xx}(\lambda)f_{yy}(\lambda))$

f_{xy} : cross-spectrum
f_{xx} , f_{yy} : auto-spectra



$sig(\alpha) = 1-(1-\alpha)^{1/(L-1)}$

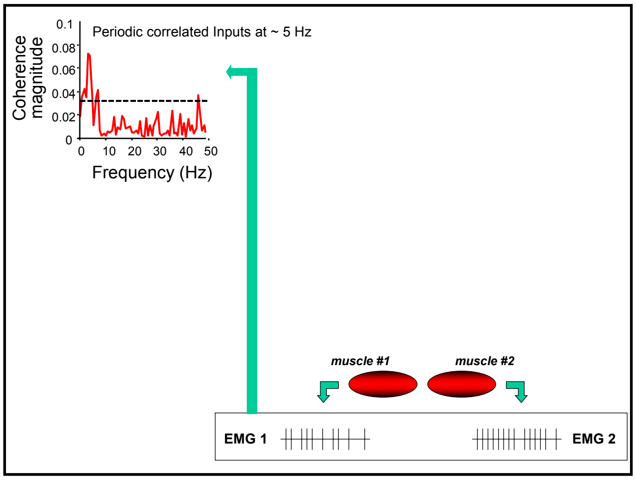
Coherence is a measure used to determine the linear relation between two signals in the frequency domain. Similar to the coefficient of determination (r^2) in linear statistics, the magnitude of coherence at a given frequency is bounded by 0 and 1, indicating that no linear relationship and a perfect linear relationship, respectively, exists at that frequency.

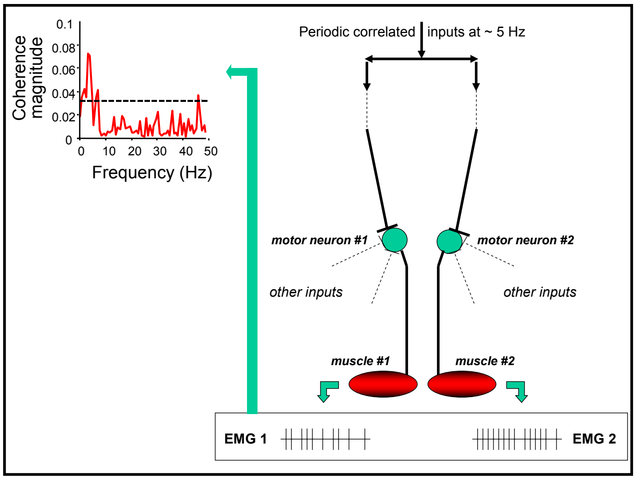


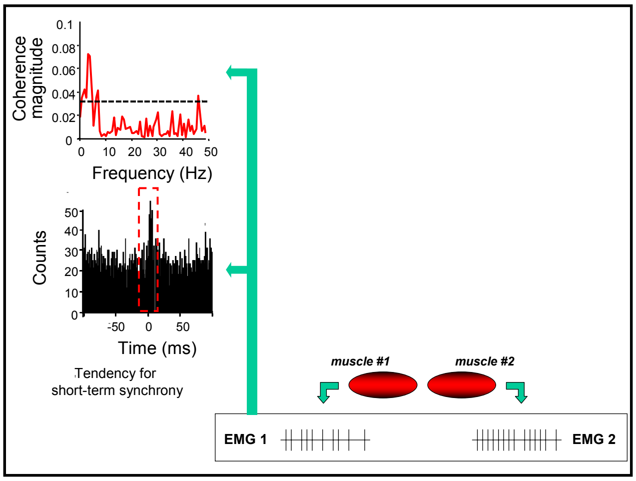
Using Time and Frequency Domain Analysis

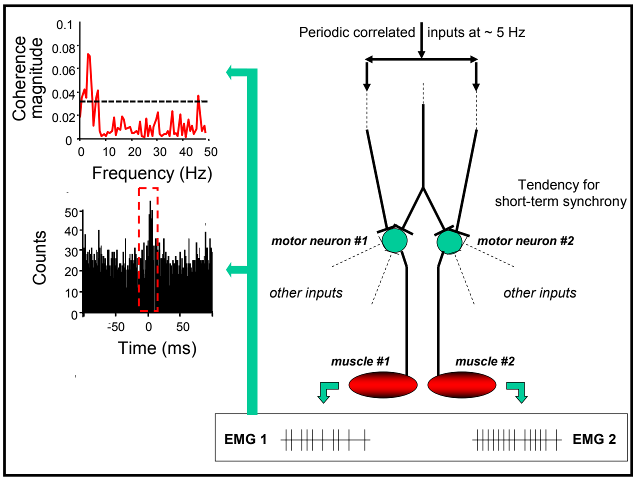
Information obtained by time and frequency domain analysis of motor unit activity is complementary.

For example, short-term synchrony may occur with or without correlated periodic inputs.









Analysis of correlated motor unit activity

Time and frequency domain analysis has been extensively used to study motor unit activity and infer neural connectivity patterns.

One of the major themes of motor unit literature is whether correlated neural activity serves a functional purpose for motor behavior. A related question is whether correlated neural activity can be modulated to task demands.

Evidence strongly suggests that corticospinal neurons - underlying the fine control of individual digits (Porter and Lemon, 1993) - constitute the predominant input responsible for synchronous motor unit discharge (e.g., Shinoda et al., 1979, 1981; Fetz and Cheney, 1980; Buys et al. 1986; Mantel and Lemon, 1987; Davey et al., 1990; Farmer et al. 1990; Datta et al., 1991; Farmer et al., 1993).

However, the functional significance of correlated neural input for the control of movement is still being debated.

Two opposite views:

(1) correlated motor unit activity is a mere by-product of other physiological mechanisms (DeLuca et al., 1993), hence devoid of any functional significance.

(2) correlated motor unit activity allows functional coupling of motor units within or across muscles, resulting in coupling of their force output (e.g., Farmer et al. 1998; McAuley and Marsden 2000; Santello and Fuglevand 2004).

There is some evidence in support of task-dependency of correlated neural input in the time domain.

Specifically, grip type and movement direction (Bremner et al. 1991; Huesler et al. 1998) appear to affect the strength of correlated neural input.

More evidence exists in favor of coherence as being a task-dependent mechanism (e.g. Baker et al. 1999; Kakuda et al. 1999; Kilner et al. 2002).

Plastic, long-term changes in correlated neural input have also been reported in the literature, i.e., untrained and strength-trained subjects have higher coherence than subjects with training in fine motor-skills (Semmler et al. 2004).

This evidence indirectly supports the notion of correlated neural input as a mechanism that underlies coupling of motor unit activity, hence forces.

Limitations of previous studies of motor unit activity

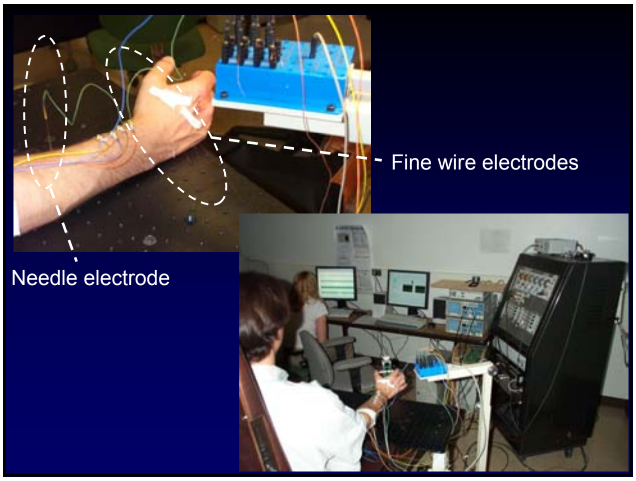
Tasks such as exerting force with one or two digits* against a fixed resistance lack mechanical constraints associated with more natural grasping tasks and are often characterized by laboratory constraints (visual and/or auditory feedback of motor unit firing rate or force, etc.).

In contrast, natural grasping behavior is characterized by modulation of forces that heavily relies on tactile feedback.

*** Bremner et al. (1991a-c); Valero-Cuevas (2000); Keen and Fuglevand (2004); Maier and Hepp-Reymond (1995a-c)**

Analysis of motor unit activity of hand muscles during object hold.

We have used intramuscular EMG and applied time and frequency domain analysis to study the coordination of neural activity associated with holding an object against gravity.



Fine wire electrodes

Needle electrode

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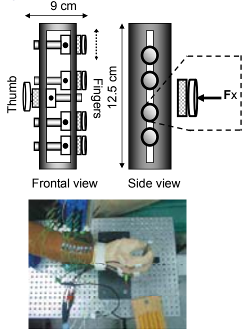
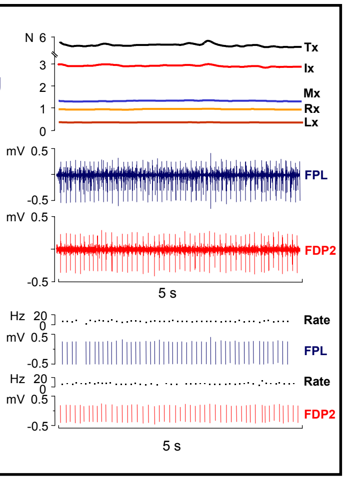
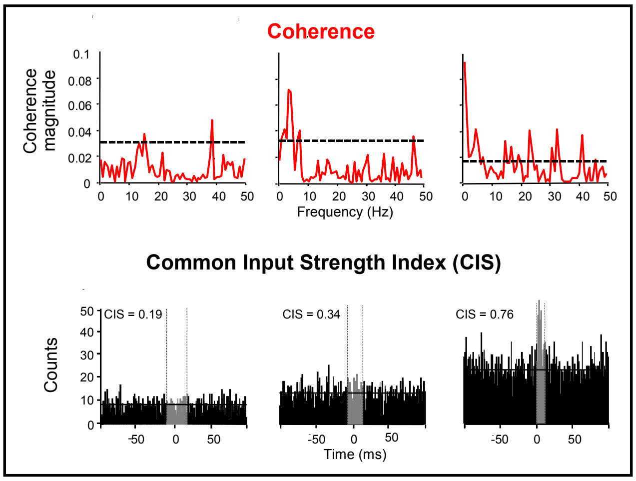
1. Coordination of Motor Unit Activity: 5-Digit Object Hold

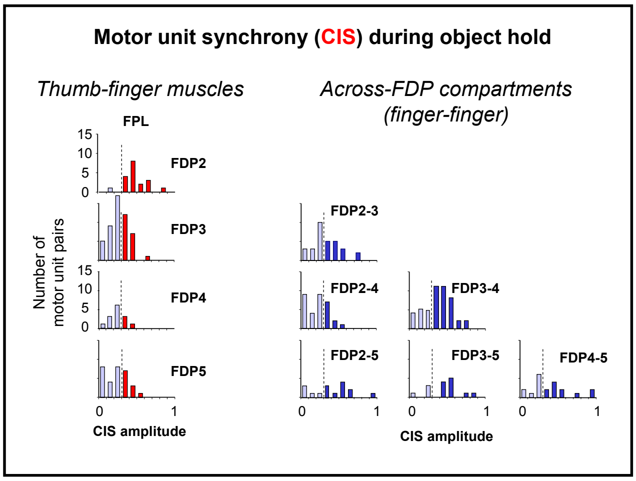
FIVE-DIGIT GRASPING

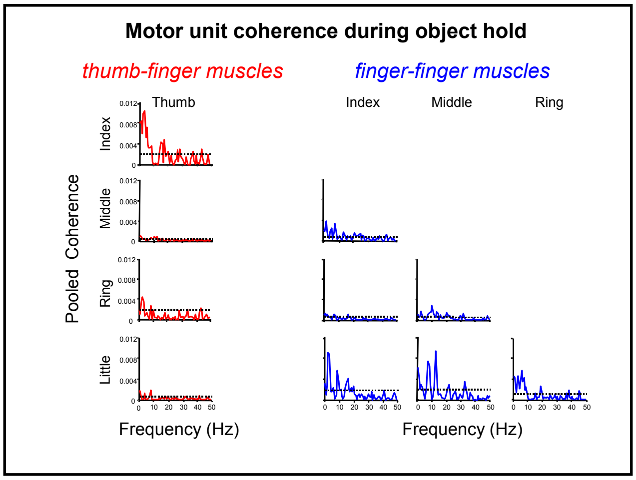
Single motor unit activity of extrinsic finger flexors during **object hold**









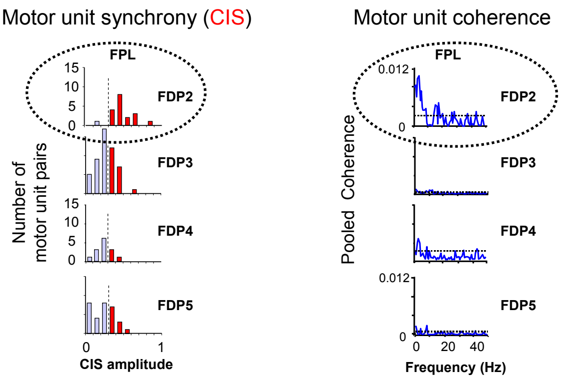


Both time and frequency domain analyses revealed a heterogeneous distribution of common input to the extrinsic flexors of the digits.

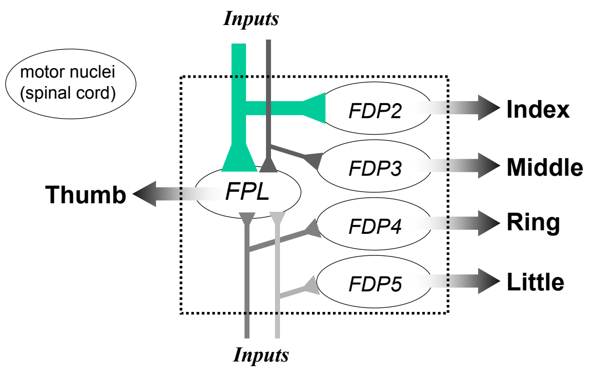
Of particular interest was the finding that muscles controlling flexion of the thumb and index finger were characterized by a stronger, periodic neural common input than muscle pairs controlling any other thumb-finger or finger-finger combination.

Winges and Santello, *J Neurophys* (2004)
Johnston, Winges and Santello, *J Neurophys* (2005)

Thumb-finger muscles



Is this organization of neural common input *fixed* ?

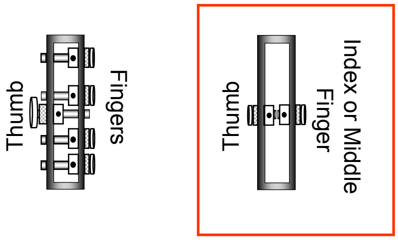


To examine the extent to which correlated neural input can be modulated to task demands, we asked subjects to grasp an object with two digits.

The rationale for this experimental condition was:

(1) Two- and five-digit grasp elicit different force (hence muscle) coordination patterns across thumb and digit(s)

(2) Grip type has been found to affect the magnitude of correlated neural input (Huesler et al. 1998), although this was tested in a force production task (no gravity effect).



A different distribution of common neural input between the two grip types would suggest that coupling of activity of motor nuclei of hand muscles can be modulated to changes in muscle coordination patterns.

2. Coordination of Motor Unit Activity: 5- vs. 2-Digit Object Hold

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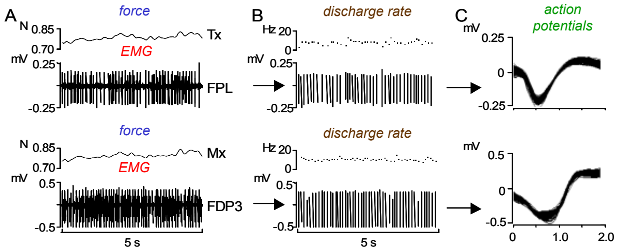
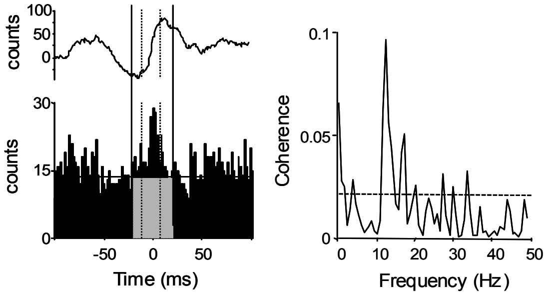
Object hold with thumb and middle finger

motor unit activity

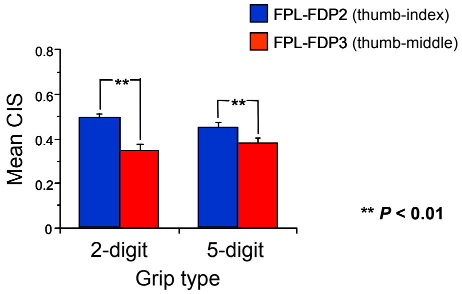


Object hold with thumb and middle finger

Time and frequency domain correlations

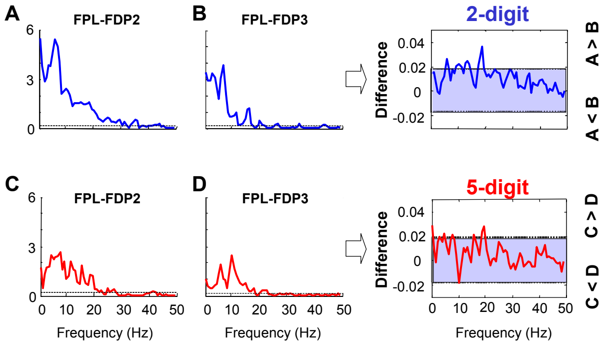


Motor unit synchrony from thumb and index finger flexors was stronger than that from thumb and middle finger flexors **in both 2- and 5-digit grips**.

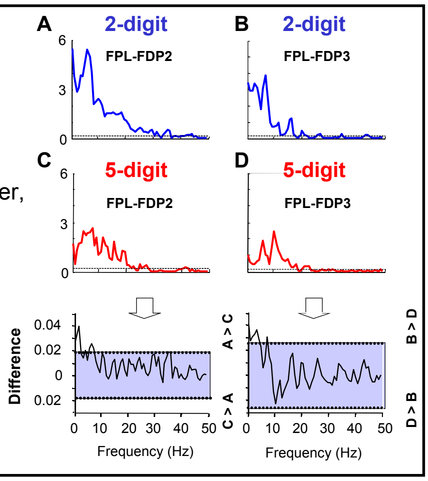


** *P* < 0.01

Motor unit coherence was also stronger across thumb and index finger flexors than across thumb and middle finger flexors **in both grip types**.



Unlike motor unit synchrony, however, coherence was stronger during 2- than 5-digit grip.



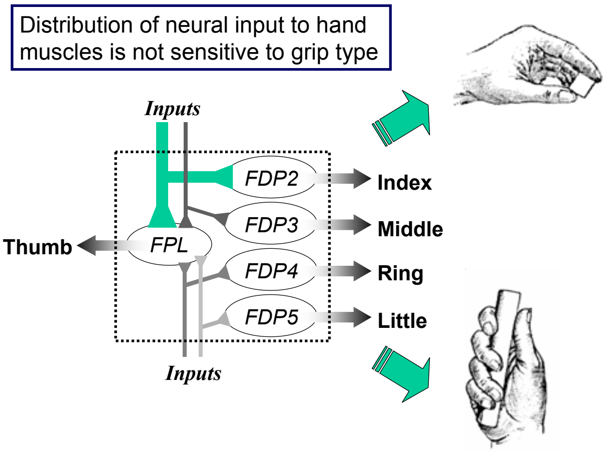
These results:

(1) Extend and confirm previous observations from 5-digit grasping that the distribution of common neural input is **muscle pair-specific** as both synchrony and coherence were stronger in FPL-FDP2 than in FPL-FPD3 regardless of grip type.

(2) Indicate that within a muscle pair-specific distribution of correlated neural input, **coherence, but not synchrony, can be modulated to task demands**. Hence, the periodicity of common input to motor neurons of hand muscles is sensitive to grip type.

Winges, Johnston and Santello, *J Neurophys* (2006)

Distribution of neural input to hand muscles is not sensitive to grip type



However, the validity of the notion of a muscle pair specific distribution of neural inputs to hand muscles may suffer from the following limitations:

(1) The task conditions we tested might not have been sufficient to elicit a change in the distribution of common neural input, and/or

(2) Our results were obtained from muscles/muscle compartments (FPL and FDP2-5) that share similar mechanical actions and anatomical features, i.e., they are all flexors and they are all extrinsic.

To overcome these limitations, we designed a third study where we focused our attention on:

(1) a task that required fine modulation in the degree of co-activation of two muscles,

(2) intrinsic muscles with opposite mechanical actions

Coordination of Motor Unit Activity:
3. Effect of object center of mass

Neural common input to ***intrinsic muscles*** has been extensively studied.

However, the vast majority of this work has focused on *within-muscle* common input, hence they cannot be used to understand how this mechanism might be used or modulated during tasks that require the coordination of two muscles.

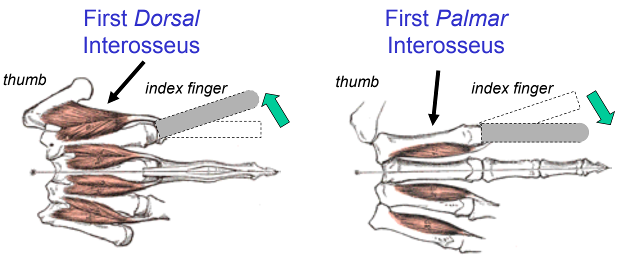
Intrinsic vs. Extrinsic muscles

Intrinsic muscles generate significantly less force than extrinsic muscles and appear to be particularly important for modulating the direction of forces at the digits.

We focused on two intrinsic muscles of the Index finger: **M. First Dorsal Interosseus** (FDI) and **M. First Palmaris Interosseus** (FPI).

FDI **abducts** the index finger

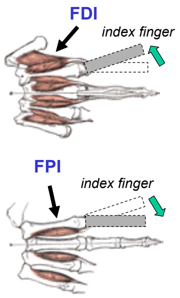
FPI **adducts** the index finger



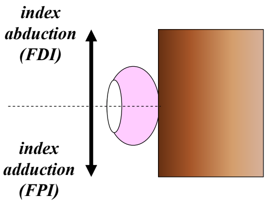
Dorsal aspect

Palmar aspect

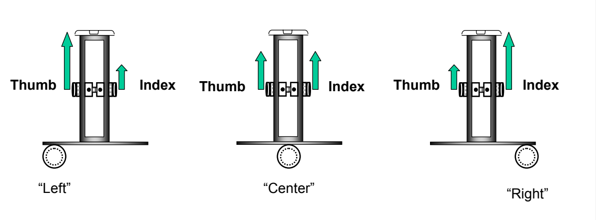
Activation of FDI and FPI also results in index finger flexion or extension when the finger is flexed or extended, respectively, at the metacarpal joint, even though this contribution is fairly small compared to their primary mechanical actions of abductors and adductors (Brand and Hollister 1999).



FDI and FPI play a crucial role during object hold as fine coordination of their activity directly affects the magnitude of the tangential (vertical) force at the index finger.



We used an object hold task against external torques to change the relative force contribution of these two antagonist muscles towards the net *tangential force produced by the index finger* necessary to maintain the object aligned with the vertical.



We expected co-activation of FDI and FPI across all CM conditions.

However, modulation of index finger tangential force as a function of object CM should have also required a modulation of the *relative force contribution* of each muscle as they have ***opposite mechanical actions*** on the index finger.