

# Motor learnability across posture

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2 Abstract: Z Words, Body: X Words, Pages: Y

## 3 ABSTRACT

4 Learning algorithms applied to tendon-driven limbs are not rigorously tested on  
5 robotic or cadaveric tissues in a way that systematically permutes posture and noise.  
6 Furthermore, the amount of data required to measure the mechanical component of  
7 neuromotor noise is unclear. There exists a gap between the mechanical properties of  
8 cadaveric tendon-driven limbs across realistic positions, and the models that describe  
9 how tendon forces affect the limb's endpoint force behavior. We addressed this  
10 limitation by inventing a tension-to-force experiment that collects data across hundreds  
11 of isometric endpoint postures of any tendon-driven limb controlled by up to 10 newtons  
12 per tendon. We experimented with a bioinspired robotic finger as a stand-in for a  
13 cadaveric finger, attached a six-dimensional force sensor at its fingertip, we wound  
14 tension-controlled strings about its joints in an arbitrary routing. The fingertip fit snugly  
15 in the force sensor, which was affixed to a manipulator—that way, we were able to move  
16 the posture with sub millimeter precision, in under 2 seconds. Using the resultant data  
17 (with 1000 postures along a line and 100 tensions across 7-tendons for each posture)  
18 we (i) characterized static and dynamic components of the tension-to-force relationship,  
19 (ii) identified specific postures that are more challenging to control accurately, (iii)  
20 compared the performance of models from the literature (linear, dynamic, and linear-  
21 cascade), (iv) and evaluated the robustness of results under differing sample size  
22 and noise. Our contribution empowers artificial intelligence experts to develop robust  
23 interpretations of a model's performance atop data from a postural workspace, thereby  
24 enabling biologically-inspired tactile sensing from the muscle properties themselves. In  
25 capturing the variables associated with posture-specific tendon-driven control, we open  
26 a new front for thorough understanding of the biomechanical constraints and pressures  
27 across in learning, health, disease, and in an evolutionary context.

28 Keywords: motor control, force control, neuroscience, tendon-driven systems, isometric, force production, posture

## 1 INTRODUCTION

29 "cable driven flexion and extension" apparatus was built of flexible material, and, importantly, was not aligned with joints specifically  
30 ?. This highlights how our understanding of squishy tendon-driven limbs must take into account that nervous systems are happy to  
31 work with squishiness. Our robotic approach to neuroscience limits us.

32 1.1 Heading Levels

33 1.2 Level 2

34 1.2.1 Level 3

35 1.2.1.1 Level 4

36 1.2.1.1.1 Level 5

## 2 DISCUSSION

37 2.1 Noise in signal

38 where does the noise come from? how would we reduce that? is it important that we reduce that? how does variability/noise in our  
39 muscle forces over time compare to noise in a normal EMG, or normal isometric tendon task.

## CONFLICT OF INTEREST STATEMENT

40 The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be  
41 construed as a potential conflict of interest.

## AUTHOR CONTRIBUTIONS

42 BC and KJ designed the experiment. BAC designed and programmed analytics and served as the lead scientist. KJ implemented the  
43 motor control modules, calibrated sensor equipment, and provided insight into the dynamical response of the limb. FV provided a  
44 thoughtful angle to the implications of this research on the fields of neuroscience, artificial intelligence, and robotics.

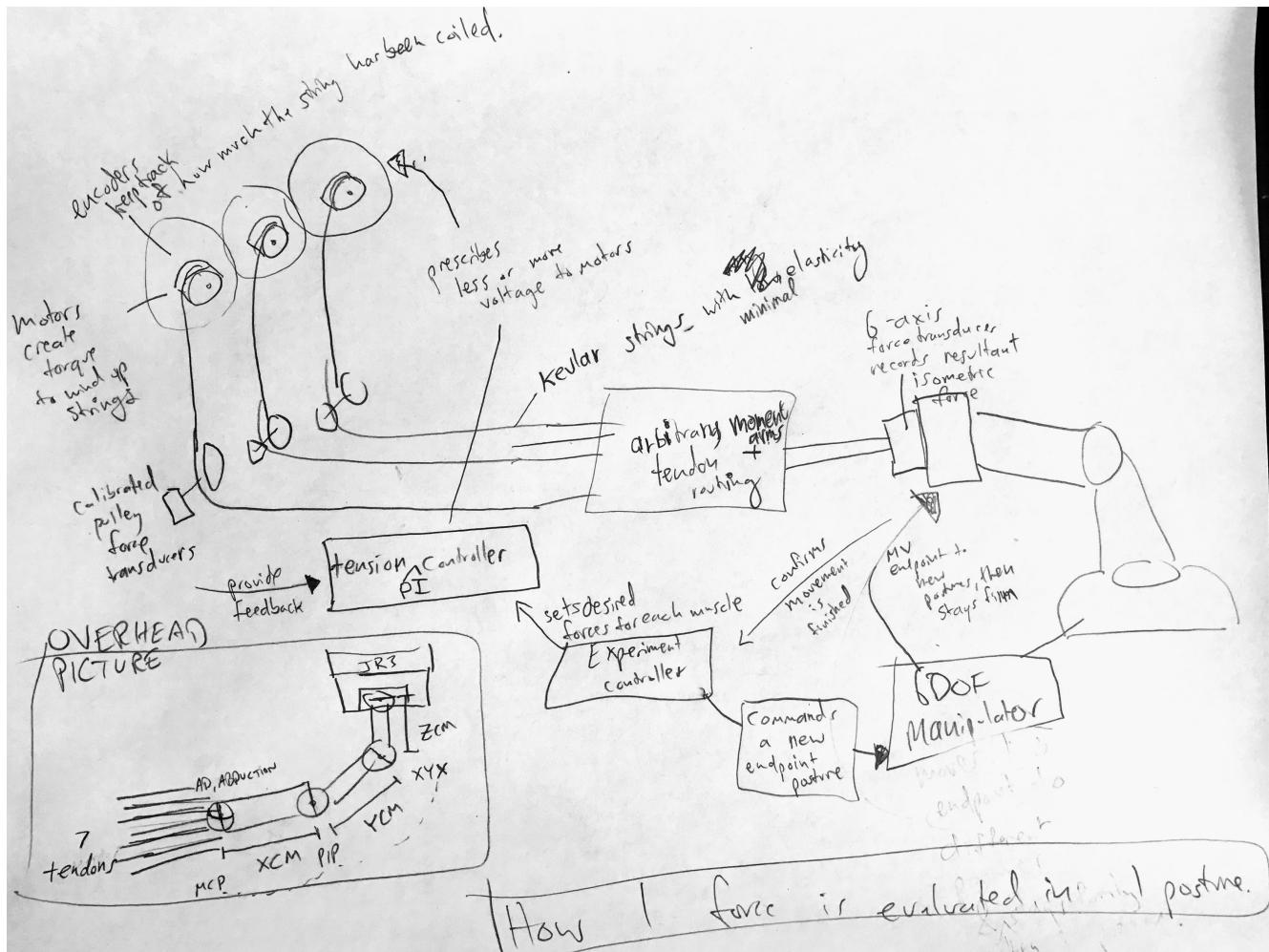
## FUNDING

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48 the official views of the NIH or NSF.

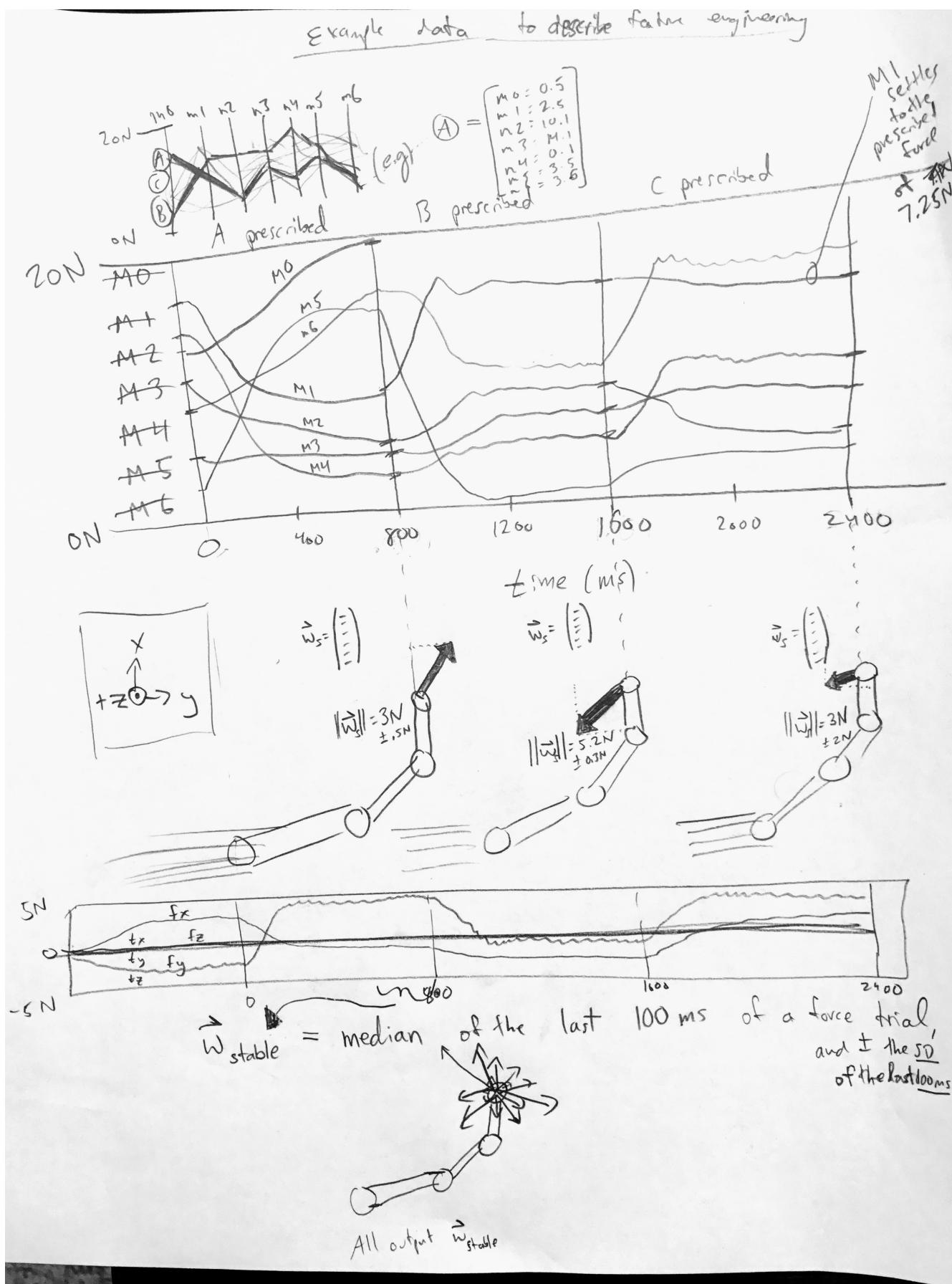
## ACKNOWLEDGMENTS

49 We thank ;KIAN TODO Add Posture Dependency Interns; M Ishikawa, T Strooboscher, and B Miura for their instrumental support in  
50 mechanical and electrical engineering, as well as support with analytics reviews and documentation.

51 The resultant equation for the linear fit of  $t_{rise}$  as a function of  $\delta a$  is  $t_{rise}$

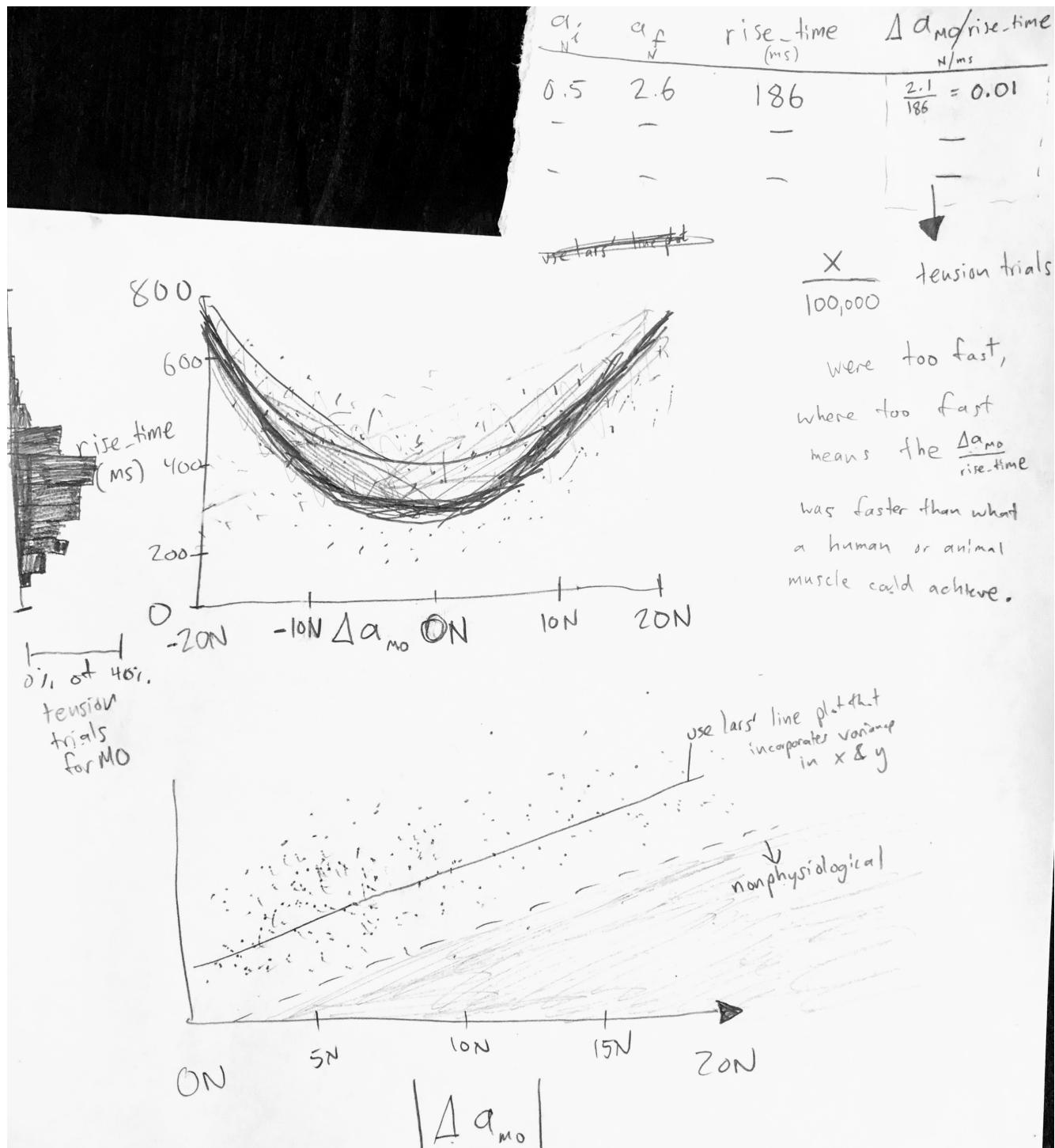


**Figure 1.** Experimental paradigm for all posture dependency experiments.

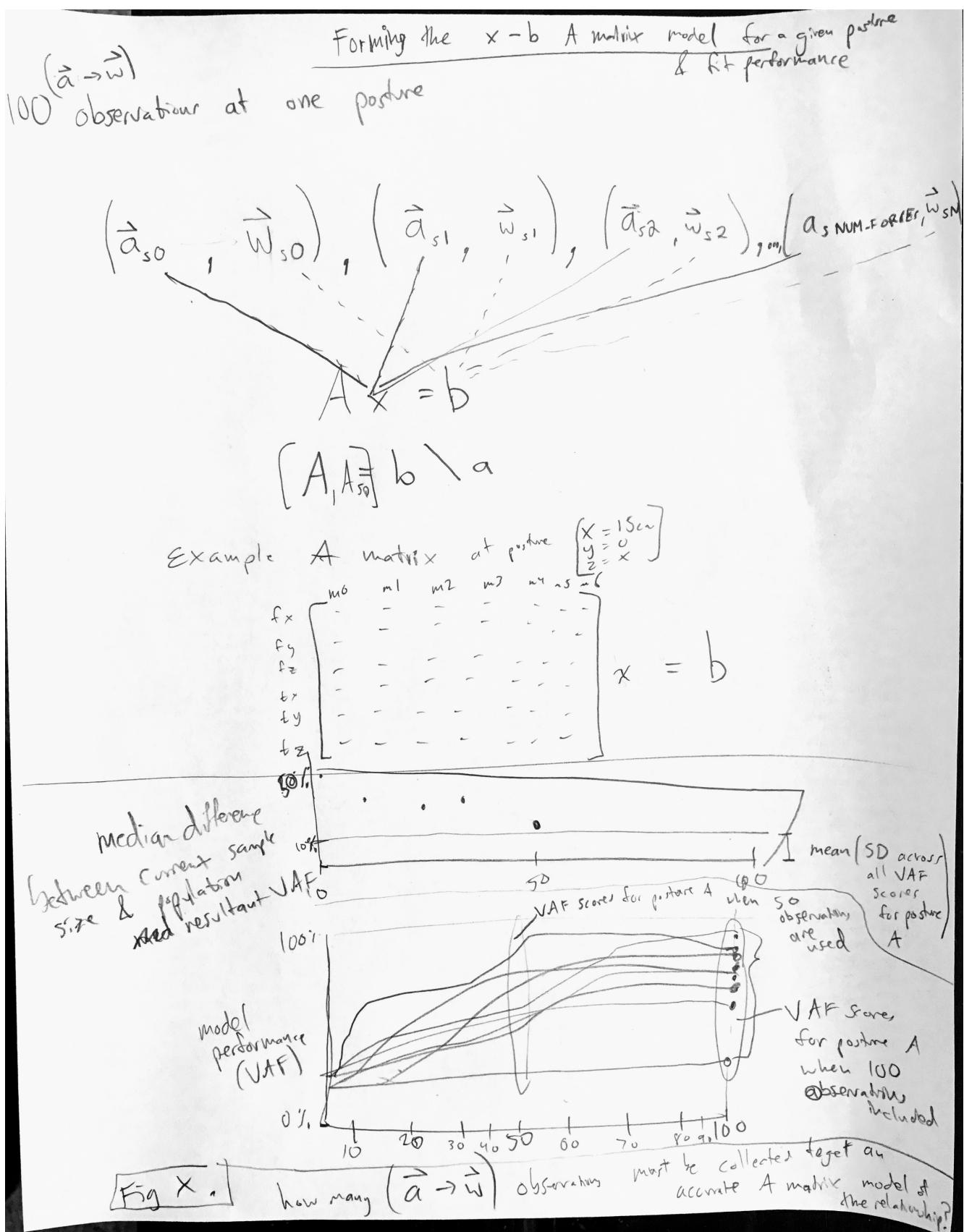


**Figure 2.** Description of the data and signals recorded for this analysis. In viewing the SD of measured force once the signal has stabilized (by extracting only the last 100ms) we found the max, first quartile, median, third quartile, and max of SD were X,Y,Z,A,B, respectively.

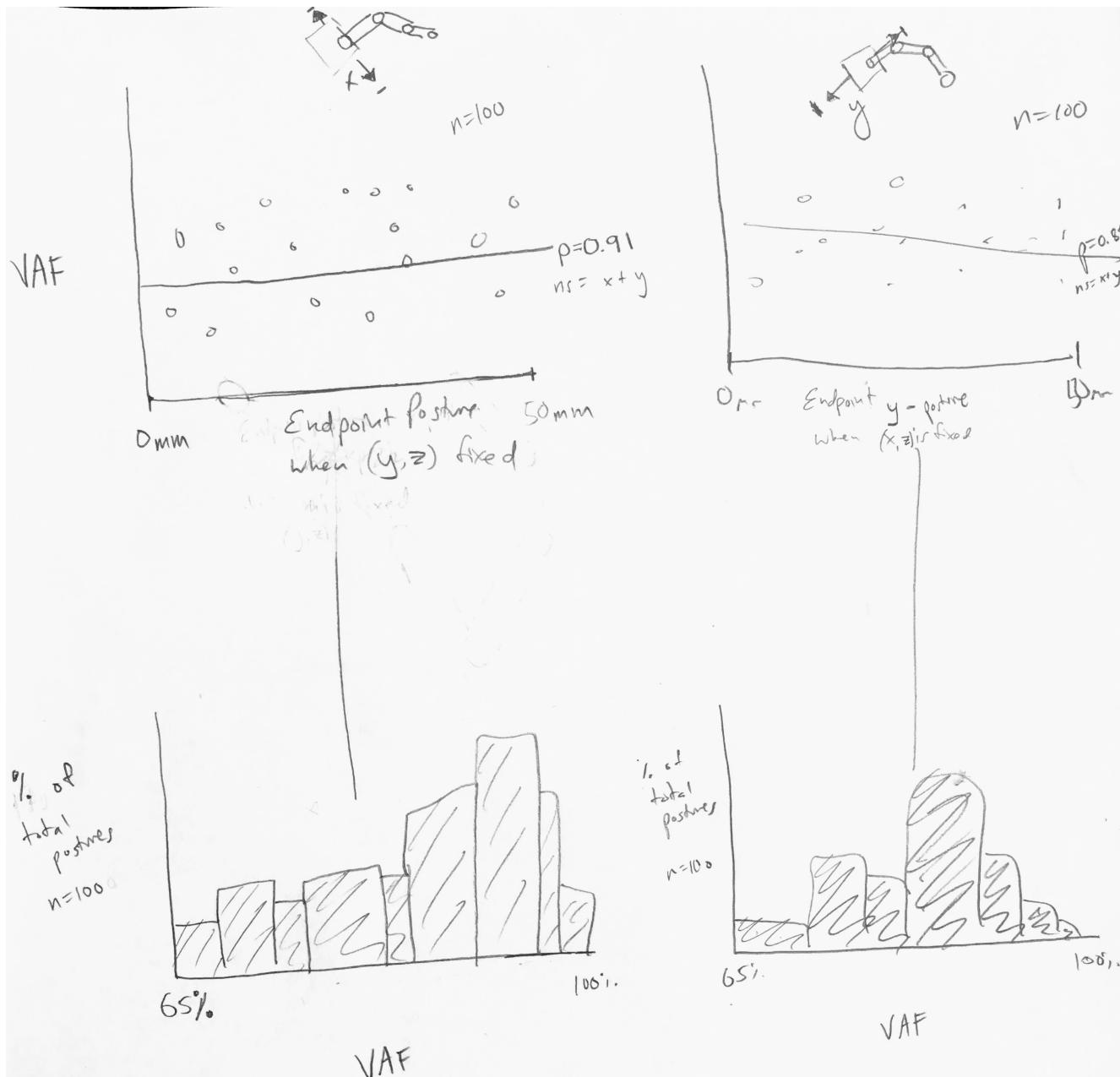
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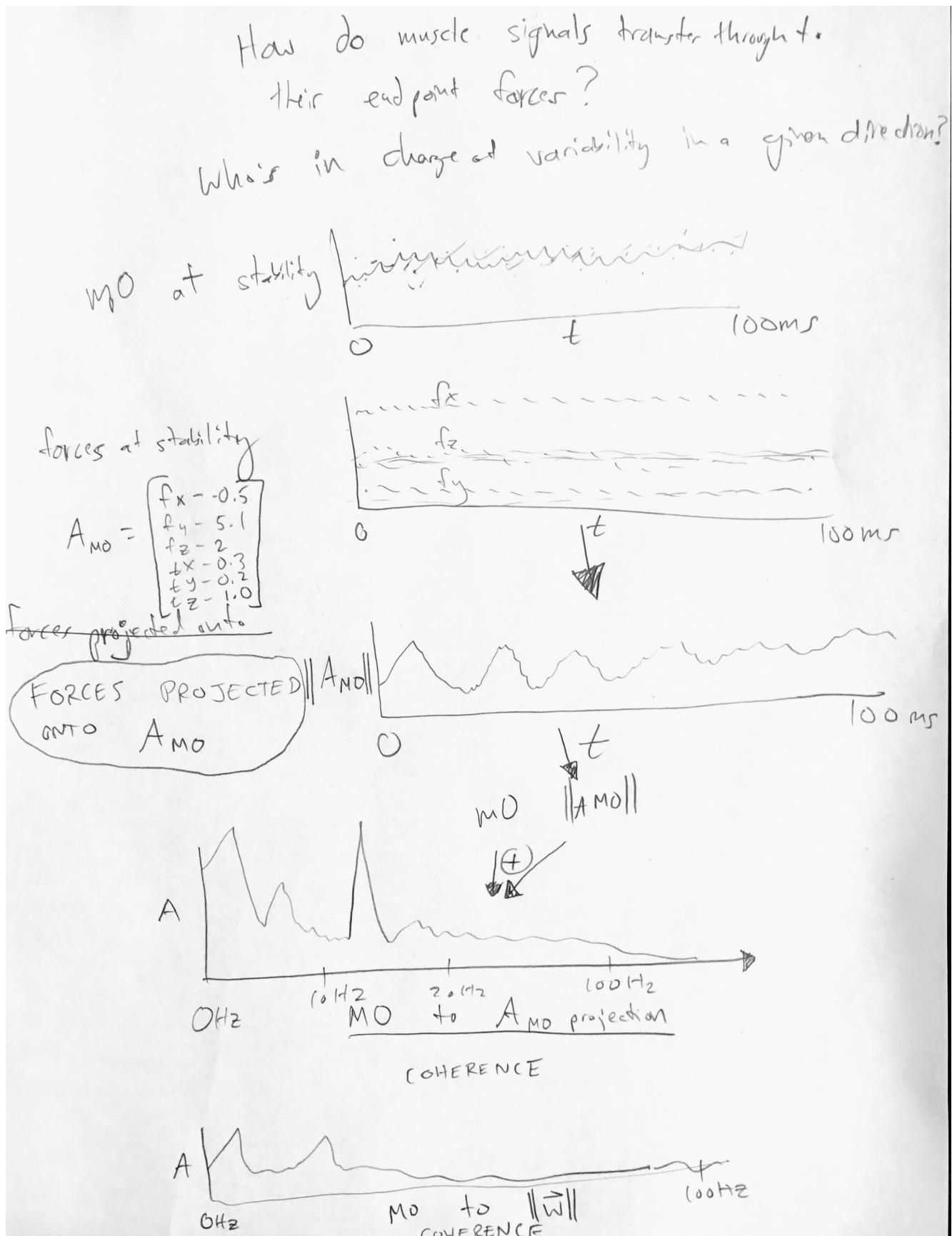
**Figure 3.** Rise time and how the change in activation changes the settling time.



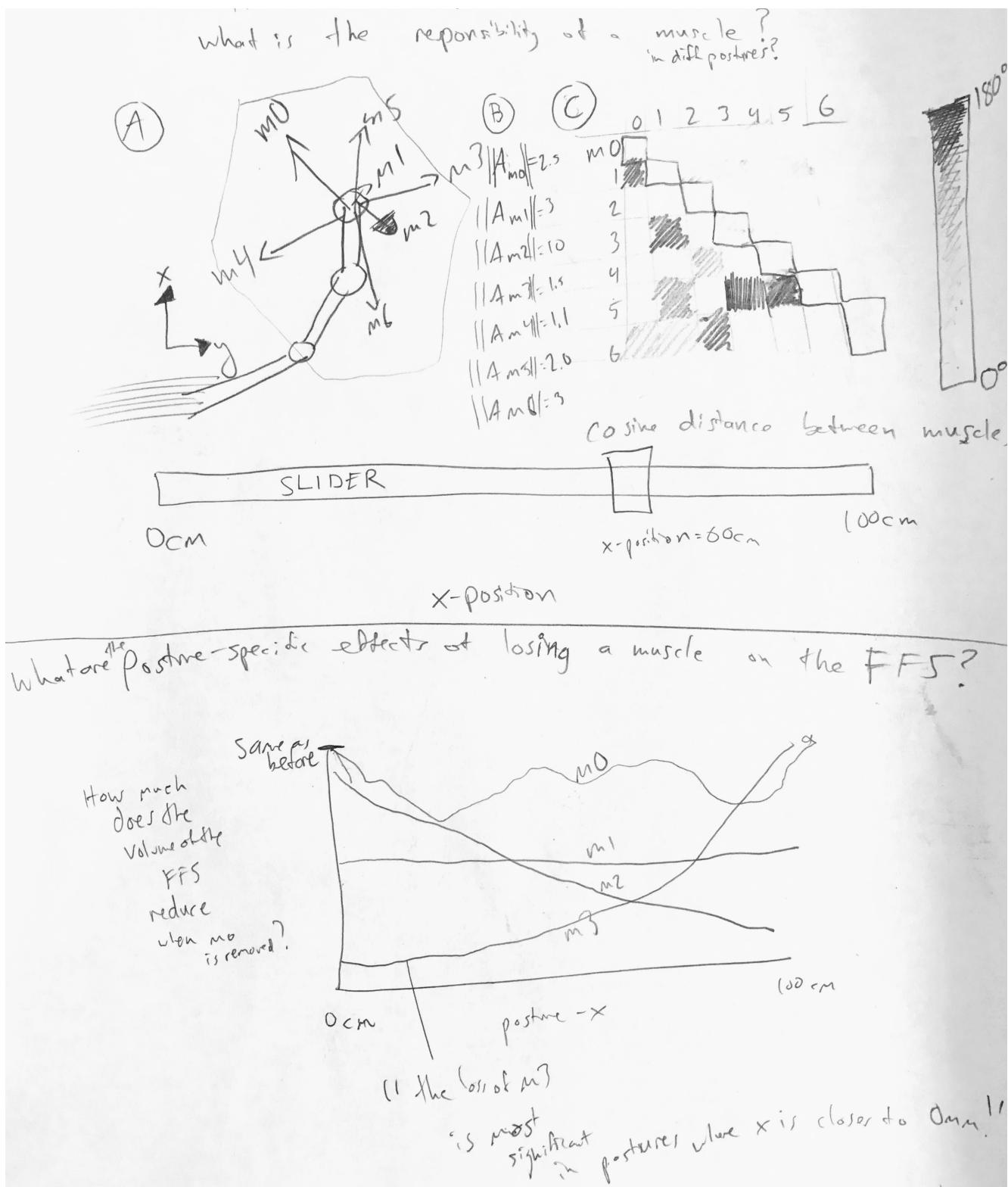
**Figure 4.** Application of linear modeling to tension-to-force relationships



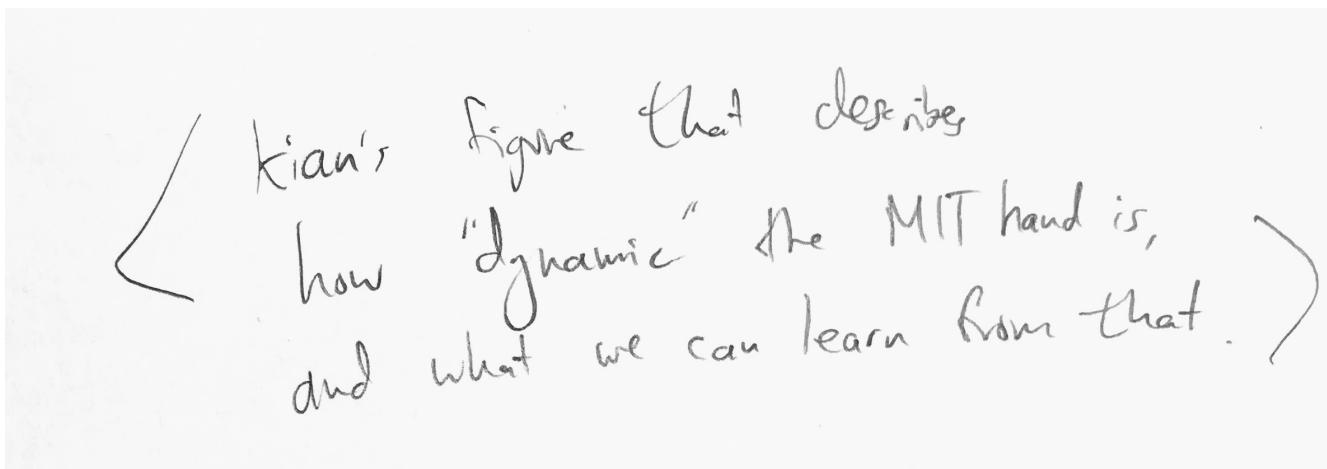
**Figure 5.** Model fit for a linear matrix in different postures. Fit across the Y posture line (while X and Z were fixed), and the X posture line (while Y and Z were fixed), showed no significant areas of higher or lower model fit ( $p=0.X$ ,  $p=0.7$ , respectively).



**Figure 6.** Tension-to-force coherence across different muscles, and with respect to the linear model's observed tendon contribution



**Figure 7.** Responsibility of a muscle in output force space



**Figure 8.** KIAN TODO