The transition between muscle coordination patterns is context dependent

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INTRODUCTION

The mechanical constraints for the production of finger motion and static force differ, thus joint torques and muscle coordination patterns to produce them should also differ [1]. We hypothesize that the transition between those coordination patterns should depend on the accuracy of the task. To test this hypothesis we investigated finger tapping: the abrupt transitions from motion to static force. We find that the coordination patterns for motion and force differed. Modeling the transition of the coordination patterns as a sigmoid function shows that the initiation is advanced in time when the task requires greater accuracy. This is the first study to show the tuning of complete muscle coordination patterns during a skillful everyday task.

METHODS

Eight consenting and healthy young adults rapidly transitioned from accurately moving the fingertip towards a flat target surface to producing an isometric force against it (i.e., tapping) while wearing a thimble defining a point contact [2]. Subjects tapped the horizontal surface of two pedestals: “smooth” (polished steel) and “small” (5 mm diameter) vs. “rough” (300-grit sandpaper) and “large” (11 mm diameter). The former required greater accuracy for both fingertip motion and force. Each trial consisted of 4 brief preparatory taps, followed by a tap-ramp-and-hold task where subjects ramped force magnitude and held it at maximal voluntary magnitude.

We simultaneously recorded fine wire EMG from all seven muscles of the index finger during the task [2]; and characterized the coordination pattern as the time varying 7-D unit vector of muscle forces estimated from the full-wave rectified, band-pass filtered, normalized (by MVC) EMGs weighted by physiological cross sectional areas. The temporal evolution of the coordination pattern vectors was quantified by the alignment (included angle) with respect to the reference coordination pattern defined during 80 ms of maximal static force [1]. Fig. 1 shows the evolution of the alignment from -500 to +500 ms before and after contact, respectively, for a sample trial.

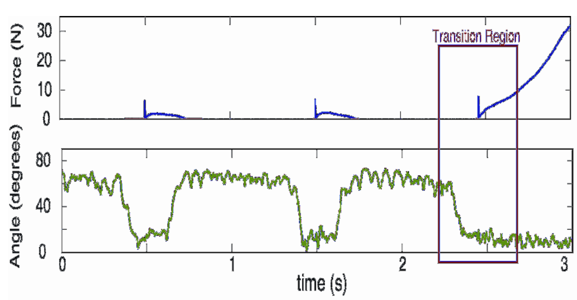

Figure 1: Coordination pattern alignment during a complete trial: preliminary taps and the tap-ramp-and-hold task.

RESULTS AND DISCUSSION

The coordination patterns for motion and force production were distinct, as shown by changes in coordination pattern (i.e., unit vector) alignment by >60 degrees (Fig. 1).

A sigmoid function characterizes and fits well the coordination pattern transition, normalized by the included angles at -500 ms and +500 ms. The average coefficient of determination ± SE was r^2 = 0.76±0.2, N=36 trials. When considering the constraints set by target texture and size, the model fits the rough-large case significantly better (average r^2 of 0.84±0.14), than the smooth-small case (r^2= 0.68±0.2), p<0.05. Fig. 2 shows the sigmoids fitted to each trial.

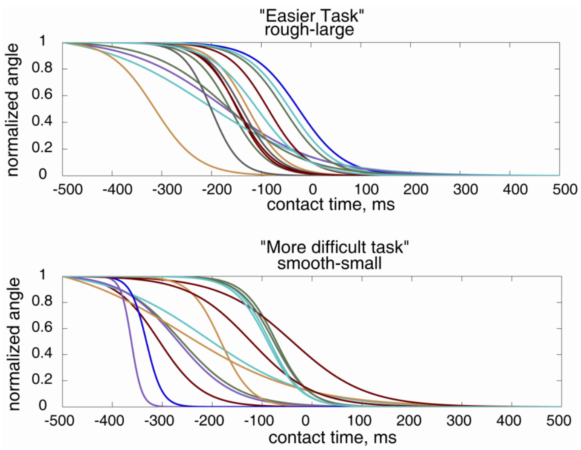

Figure 2: Fitted sigmoid for transition.

We find the transition between coordination patterns begins before contact, but the transition for the more difficult surface condition began around -300 ms, compared to -200 ms for the easier surface constraints (p< 0.05). Fig. 3 shows the average temporal trends of the normalized transitions, which do not overlap until ca. -230 ms.

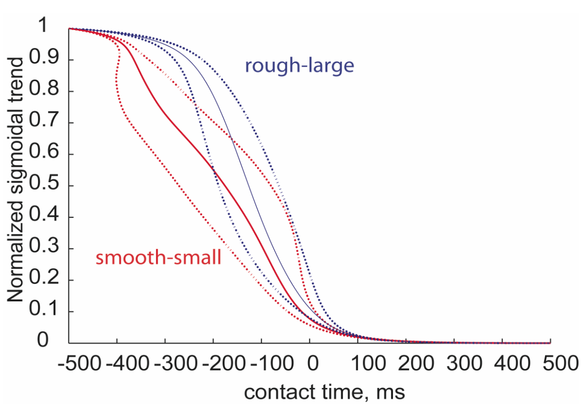

Figure 3: Normalized average sigmoidal trends (± SE) indicating an earlier transition onset for the more difficult task constraints.

SUMMARY/CONCLUSIONS

The muscle coordination patterns that produce motion and force are distinctly different, and the transition between them is well described by a sigmoid function—likely the low-pass filtering of a step change in the latent neural command by muscle activation-contraction dynamics.

The directional accuracy of force production was comparable across conditions, in spite of one having a more slippery surface. The >90% completion of the transition at contact time may signify a preference for force accuracy over motion accuracy (Fig. 3). Also, the context dependent initiation of the transition (sooner for the more difficult task) may allow time for transients in neural and muscle dynamics to die down before contact. Interestingly, however, the sigmoidal trends for the more difficult condition were less stereotypical (lower r^2 and higher residuals, p<0.05), suggesting a more active regulation of the coordination pattern during the transition for the task with smaller margin of error for motion and force. Mathematically speaking, the corrections for more difficult tasks likely occur in the null space of the mechanical output, and suggest that muscle redundancy may enable the nervous system to produce accurate manipulation function even when switching coordination strategies during *real world* tasks such as tapping.

REFERENCES

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