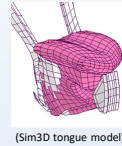


## Introduction

We are interested in modelling the articulation of the tongue at the neuromuscular level. We have built an interactive software platform for building 3D biomechanical models. We are pursuing the idea that saccadic eye movement, fast limb movement and lingual speech articulation share a similar neuromuscular control concept. We have built a simple 4-muscle 2-joint limb model to develop and test whether our pulsatile control concept produces established experimental behaviour.



(Sim3D tongue model)

## Proposal

1. A reaching gesture consists of two volitional final position instructions,

- an initial launch **pulse** towards a distant equilibrium point that determines velocity and initial direction optionally followed by another pulse or
- a landing **step** defining the resting target equilibrium point

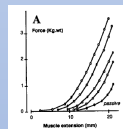
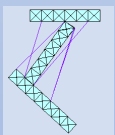
- Spinal interneurons stagger the activation of individual muscles, reducing joint interaction torques, jerk, and in doing so, straighten the trajectory of the launch pulse.
- Timing of the pulse-step transition is controlled to avoid undershoot or overshoot.
- Curved trajectories occur when launch pulse direction differs from target direction.

Proposals 1 & 2 are investigated here.

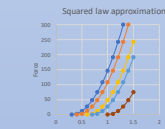
## Method

Biomechanical simulation is based on muscle motoneurons having descending excitation with Ia afferent excitation.  $\lambda$  sets descending excitation level (= nominal muscle length with no load). Afferent Ia stretch feedback ( $I + \Delta l$ ) of muscle length ( $l$ ) and stretch speed ( $\Delta l$ ) provide reflexive excitation.

$$\text{where force} = (l + \Delta l - \lambda)^2 \quad l + \Delta l > \lambda \quad \text{force} = 0 \text{ for } l + \Delta l \leq \lambda$$



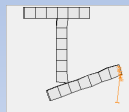
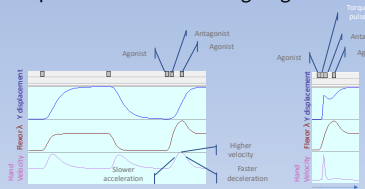
Force-length curves for different voltages (0V, 2V, 3V, 4V, 5V) of 70Hz square wave (0.1ms pulse duration) of the cerebellar nucleus (cat) at different levels of motor command activity (Feldman and Orin, 1972)



$$F = k * (\Delta l)^2$$

## Single joint simulation results

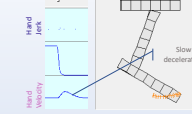
Force arm to target and release just after reach is initiated -> arm moving back towards start position before reaching target. This is due to staggered muscle activation.



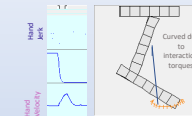
Angular displacement from Bizzi et al 1984

## Two joint simulation results

(1). Reach – single equilibrium point (EP) at target (i.e. pulse EP = Step EP)

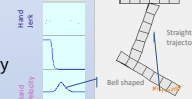


(2). Reach – pulse to EP beyond target followed by step to EP at target Joint interaction torques so - target reached via curved path with jerk.



Note : Higher peak velocity and faster deceleration

(3) Same pulse step EP as (2) but staggered activation of each muscle (generated manually by trial and error) Target reached by straighter path, reduced jerk and bell shaped velocity profile.



Note1: Pattern of muscle delays needed for straight path matches phasic EMG pattern  
Note2: Muscle activation order depends on direction.  
Note3: Movement velocity control does not require increased stiffness

## Discussion

Simulation indicates that a reach can be broken down into an initial pulsed launch towards the target followed by a corrective step to land on the target. The initial pulse generate higher interaction torques which can be mitigated by staging of activation of neuromuscular components of that command. In these simulations the  $\lambda$  commands are staggered as we have not yet developed a spinal network for this purpose.

## Conclusion

The single joint and two joint pulse step EP control (i.e. two stage final position control) has not disproved the concept.

## REFS

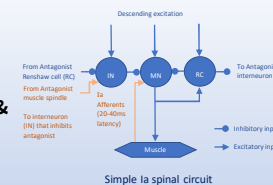
BIZZI, E., ACCORNERO, N., CHAPPLE, W. and HOGAN, N., 1984. Posture control and trajectory formation during arm movement. Journal of Neuroscience, 4(11), pp. 2738-2744.

## Future

We are currently investigating a model based on selection and timing of 2 final position equilibrium points where dynamics of interaction torques are regulated by spinal interneuron circuits. **Buhrmann & Di Paolo (2014)** describe a similar model where “tuned” spinal circuitry compensates for interaction torques. Their model adheres to EPH tenets where central commands comprise of monotonic shifts in equilibrium point that control trajectory and the amount of co-contraction of agonist antagonist pairs controls velocity. **Tsianos & Loeb (2014)** also describe a spinal circuit model. They train their interneuron network using a cost minimisation based on squared deviation from kinematic target and energy consumed by each muscle. It resulted in phasic muscle activity and straight paths.

**Barto, Fagg, Sitkov & Houk (1999)** proposed a pulse-step EP model but damping in their model prevented Equilibrium point targets being reached.

We are attempting to determine how the spinal network generates the phasic response.



## Cerebellum-based positional error correction

