NEUROMODULATION CHANGES THE BIOMECHANICS AND CAPABILITIES OF THE *APLYSIA* FEEDING MUSCLE I2

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INTRODUCTION

Neuromodulation is often used by the nervous system to change a muscle's response to nervous system stimulation. Invertebrate preparations are well suited for study of neuromodulation because of their experimentally tractable nervous systems and biomechanics. The *Aplysia* smooth muscle I2 is a good model for neuromodulation because it is a muscle with known behavioral correlates [1], and it responds to serotonergic neuromodulation [2]. During two feeding behaviors, biting and swallowing, I2 moves the grasping structure toward the jaws [1]. During swallowing behaviors, the I2 muscle is sufficiently strong to move the grasper throughout the grasper's full range of motion, but, during biting, an unmodulated I2 is insufficiently strong to generate the full motion of the grasper [3]. We used *in vitro* studies of I2's response to serotonin to show that serotonergic neuromodulation can sufficiently strengthen I2 to allow the I2 to generate biting behaviors.

METHODS

Aplysia californica were anesthetized by injection of 60% body mass of 333 mM $MgCl_2$ and the feeding apparatus (the buccal mass) was removed. The I2 was dissected out of the buccal mass, and the I2 nerve was suctioned and attached to a stimulus isolation unit (WPI A360). I2's length was controlled by a serovomotor system (Aurora Scientific, 300B-LR).

In order to characterize how I2's mechanical properties would change in response to serotonergic neuromodulation, we measured the descending limb of I2's length-tension curve in response to increasing concentrations of serotonin. I2's maximum contractile force and rate of contraction were both recorded.

The changes in I2's contractile properties were then programmed into a kinetic model of the feeding apparatus [3] to predict whether these changes in biomechanics were sufficient to allow the I2 to produce biting behaviors.

RESULTS AND DISCUSSION

In response to serotonin application, I2's maximal contractile force increased as a function of serotonin concentration and length (3 concentrations are shown in **Figure 1**). At longer lengths, both lower and higher concentrations of serotonin caused a near doubling of I2's maximum contractile strength. In contrast, at shorter lengths, lower concentrations of serotonin had little effect, while higher concentrations of serotonin caused a tripling of I2's maximum contractile force. Serotonin did not cause a significant change in the speed of I2 activation (data not shown).

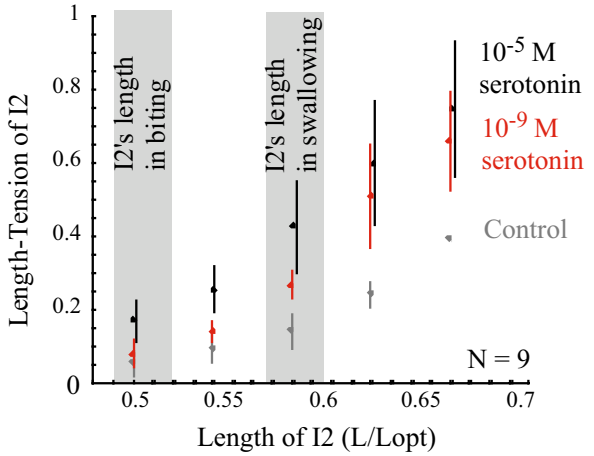

Figure 1: I2's length-tension curve in response to different concentrations of serotonin

It has been previously shown that tripling of I2's maximal contractile force is sufficient to allow I2 to generate biting behaviors [3]. To achieve this increase of I2's contractile force, however, the serotonin concentration had to be quite high (10^{-5} M). In a different *Aplysia* feeding muscle (I5), stimulation of a serotonergic neuron (the metacerebral cell) has been observed to cause the same change in muscle contraction as application 10^{-9} M serotonin [4], suggesting that, while serotonergic neuromodulation can strengthen I2 sufficiently to allow I2 to generate biting behaviors, the amount of serotonin needed to do so is greater than the concentration that is biologically observed.

When this change in contractile strength is programmed into the kinetic model of the feeding apparatus, the model predicts that 10^{-5} M serotonin would be required to strengthen the I2 sufficiently to generate biting behaviors.

CONCLUSIONS

Serotonergic neuromodulation is sufficient to strengthen the I2 enough to allow I2 to generate biting behaviors. This does, however, require the nervous system to apply a very large amount of serotonin to the muscle. Serotonergic strengthening of a muscle represents a concrete example of a neuromodulating neuron (the metacerebral cell) acting to change the biomechanics of a muscle (I2). It is probable that another mechanism assists I2 with moving the grasper. These data are consistent with a complimentary hypothesis that another muscle (I1/I3) assists I2 with moving the grasper [3].

REFERENCES

1. Hurwitz I, et al. *J. Neurophysiology* **75**(4):1309-1326, 1996.
2. Hurwitz I, et al. *J Neurophysiology* **84**(6):2810-2820, 2000.
3. Sutton GP, et al. *Biol. Cybernetics* **91**(5): 333-345, 2004.
4. Weiss KR, et al. *Brain Research* **99**, 381-386, 1975.