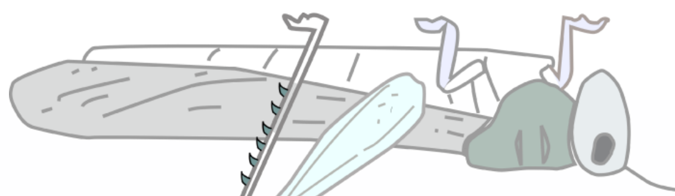

Muscle Forces Developed in the Locust Hind Leg

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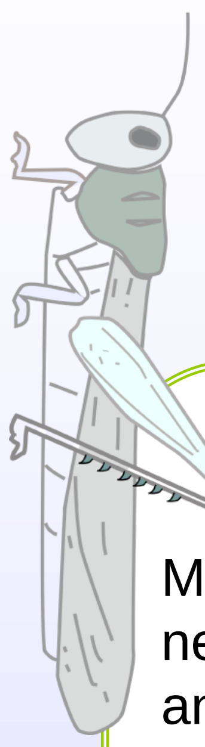
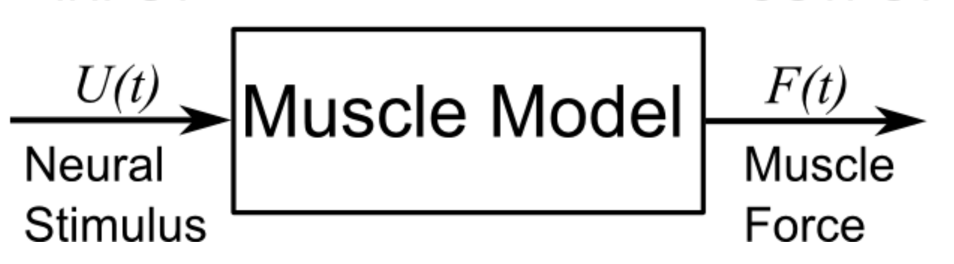


1.Introduction

Muscle models can provide an important step in improving our understanding of neuromuscular systems. Models that integrate motor-neural activation, muscles and body limb mechanics are useful for studying movement control. A good muscle model can also assist in the development of devices to restore function after injury.

The specific aim of this project is to develop a mathematical model of the locust hind leg extensor muscle. The model accounts for the force response of the muscle due to individual stimuli under isometric (constant length) conditions.

2. Muscle Model



A model of the muscle that converts an input, a neural stimulus, into an output, muscle force, is developed. Figure 1 gives an input, output description of the model.

Fig. 1. General form of muscle model

There are various muscle models [1,2]. These indicate the muscles response to an isolated twitch can be modelled as a overdamped fourth-order system. The experimental results are fitted to models of various order.

3. Locust Muscle

The extensor muscle of the locust hind leg is studied. This muscle has a very simple physiology; the muscle is innervated by just two excitatory neurons and one inhibitory neuron. Understanding the behavior of this muscle will help us to understand the behavior of muscle with more complicated physiology, such as human muscle.

When stimulated muscles contract, stimulating the extensor muscle causes the muscle to contract and the tibia to extend (see Fig. 3).

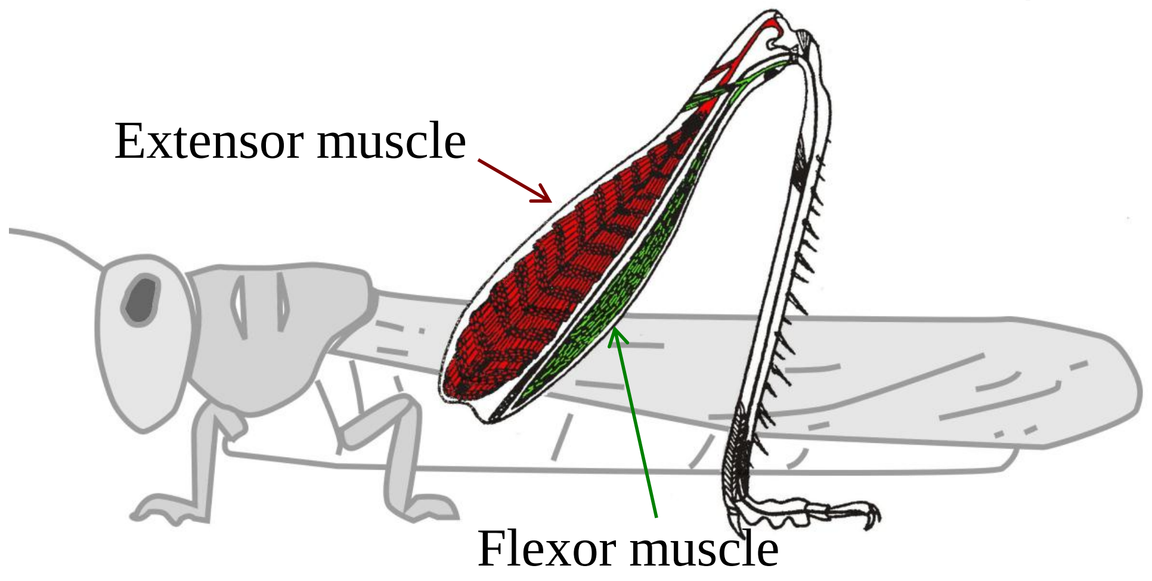


Fig. 2: Location of extensor muscle

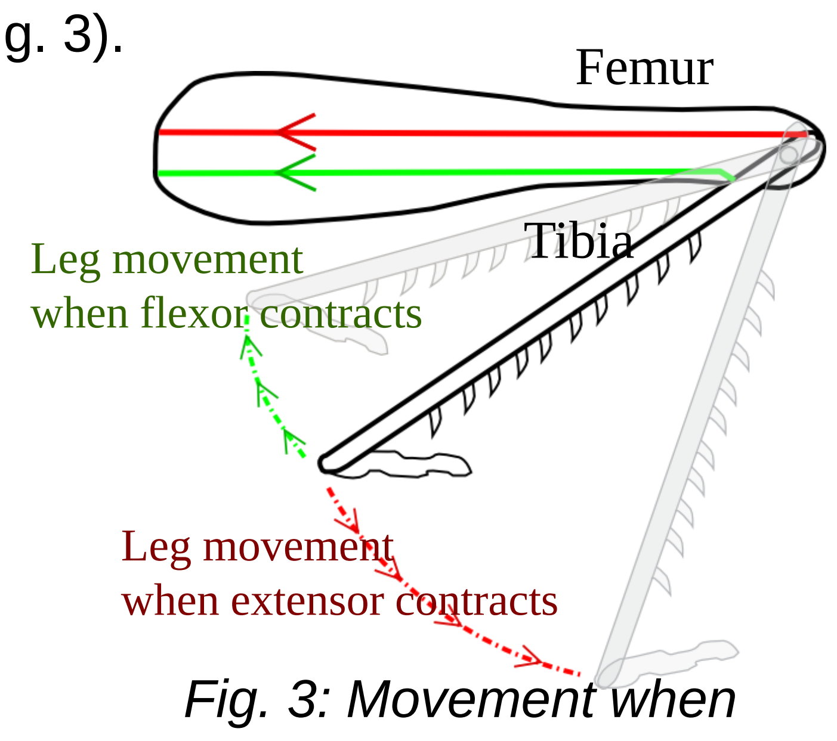


Fig. 3: Movement when muscles stimulated

4. Experimental Method

The extensor muscle was stimulated directly with pulses of 3ms duration and 5V amplitude. The spacing between pulses (interpulse interval – IPI) was varied. Figure 4 gives the experimental set up. Stimulation of the extensor muscle causes it to contract and exert a pushing force on the load cell (see Fig. 4). The load cell measures this pushing force. The force measured by the load cell is converted to a muscle force using knowledge of the joint dimensions.

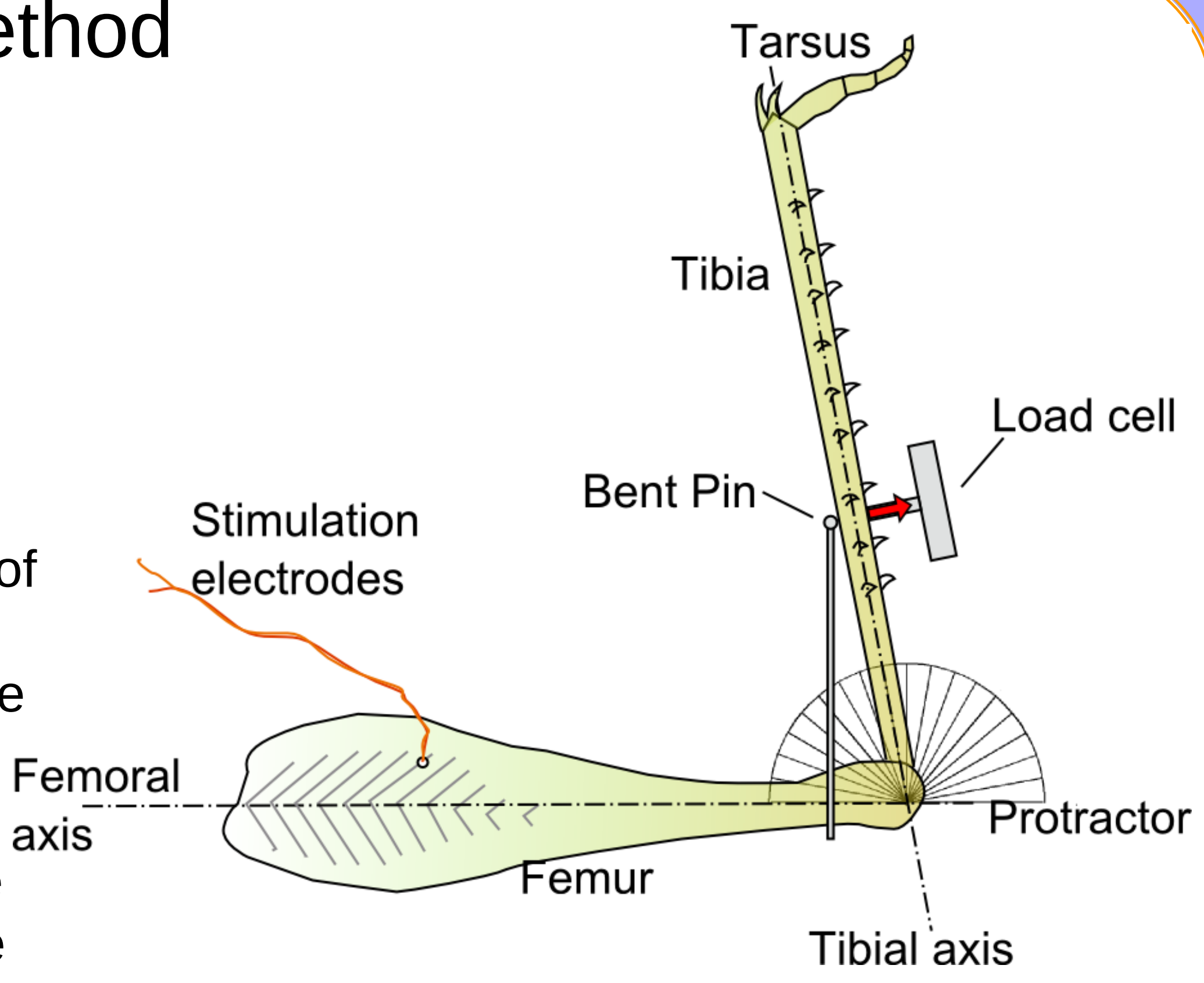


Fig. 4: Schematic of experiments

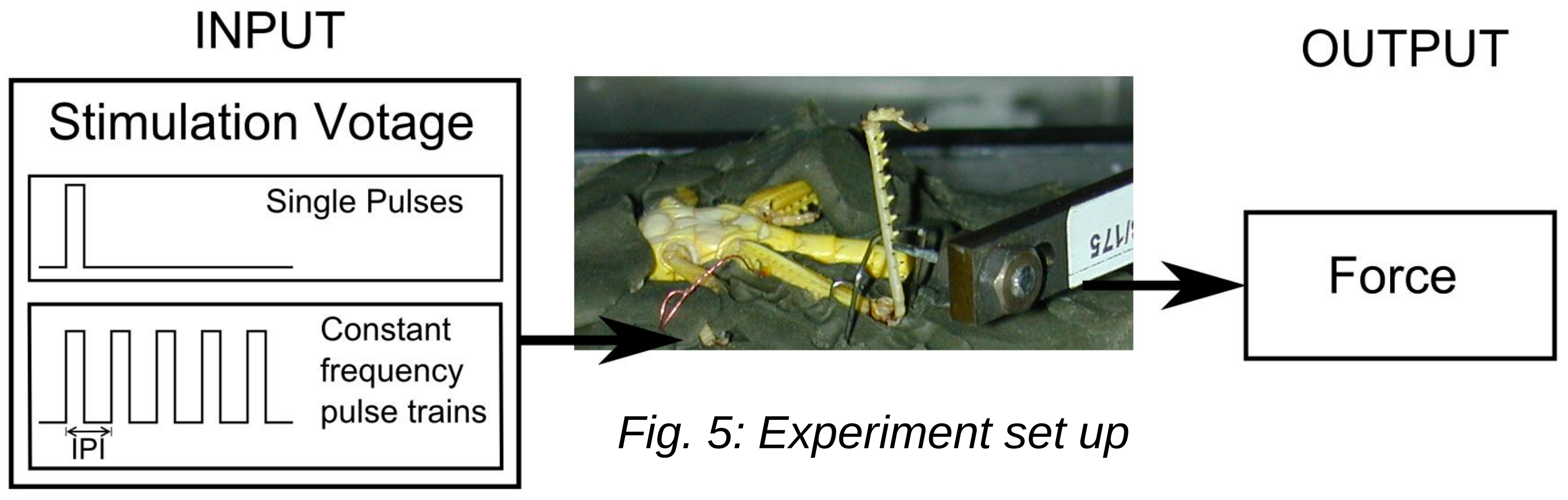


Fig. 5: Experiment set up

[1] Hatze, H., 1977. “A myocybernetic control model of skeletal muscle”. *Biol Cybern*, **25**(2), pp. 103-19.

[2] Ghigliazza, R., and Holmes, P., 2005. “Towards a neuromechanical model for insect locomotion: Hybrid dynamical systems”. *Regular and Chaotic dynamics*, **10**(2), pp. 193-225.

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5. Model Development

5.1 Single Input

In order to replicate the way the muscle transforms a neural input, *u(t),* into a muscle force, *F(t),* parametric models of the muscle were used. The relationship between input, *u(t)* and output, *F(t)* was assumed to be linear and models of various complexities fitted to experimental data. A third-order model was found to give the best fit. Figure 6 shows that a linear third-order model replicates the muscles behaviour in response to an isolated input well.

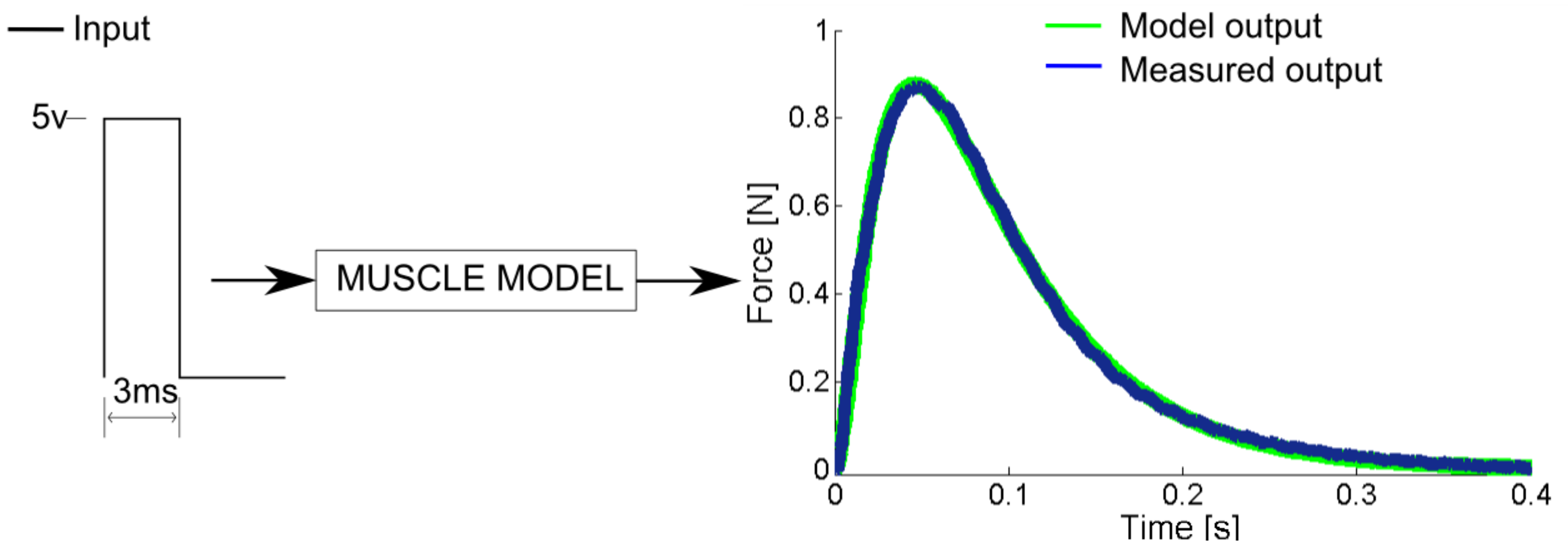

Fig. 6: Measured and modelled force response to single input pulse

5.2 Pulse Train Input

The linear model is used to estimate the force response to a train of inputs. Figure 7 shows that the linear model does not produce a good description of the muscles response to pulse train inputs due to a non-linear summation effect.

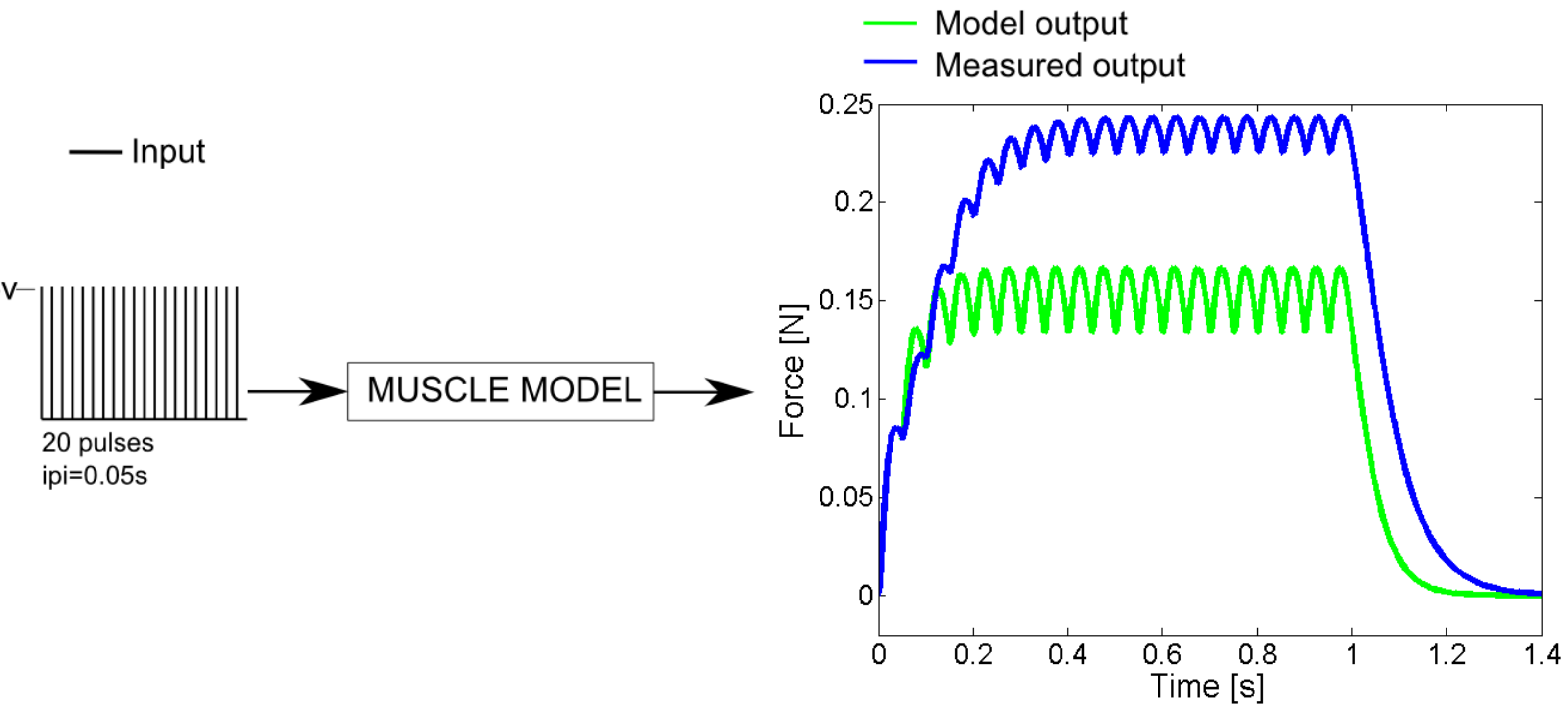

Fig. 7: Measured and modelled force response to pulse train input

5.3 Force Contributed by Second Stimulus

The force contributed by a second stimulus is calculated by subtracting the response due to one pulse from the response due to two, as shown in Fig. 8.

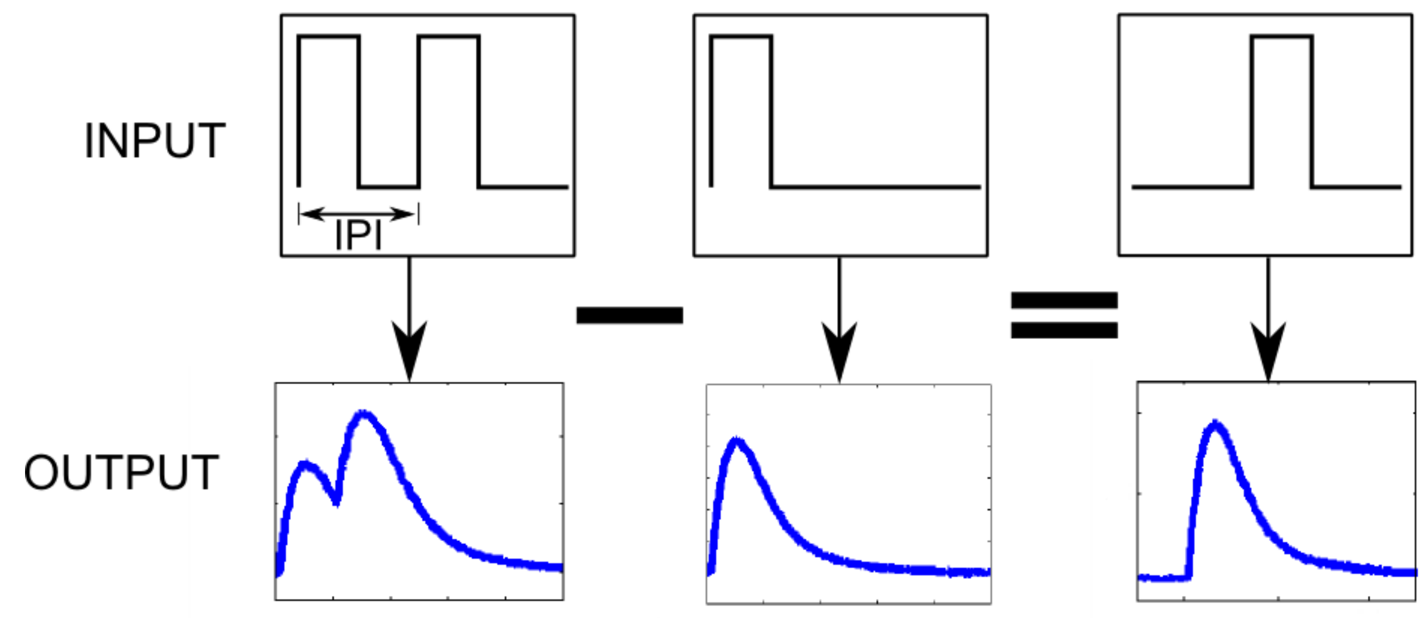

Fig. 8: How force contributed by second stimulus is calculated

For a linear system the response due to the second pulse should be the same as the response due to the first pulse. Figure 9 shows this is not the case, the muscle behaves non-linearly.
If the model parameters are allowed to vary from pulse to pulse the linear model provides a good fit to the force contributed by a second stimulus.

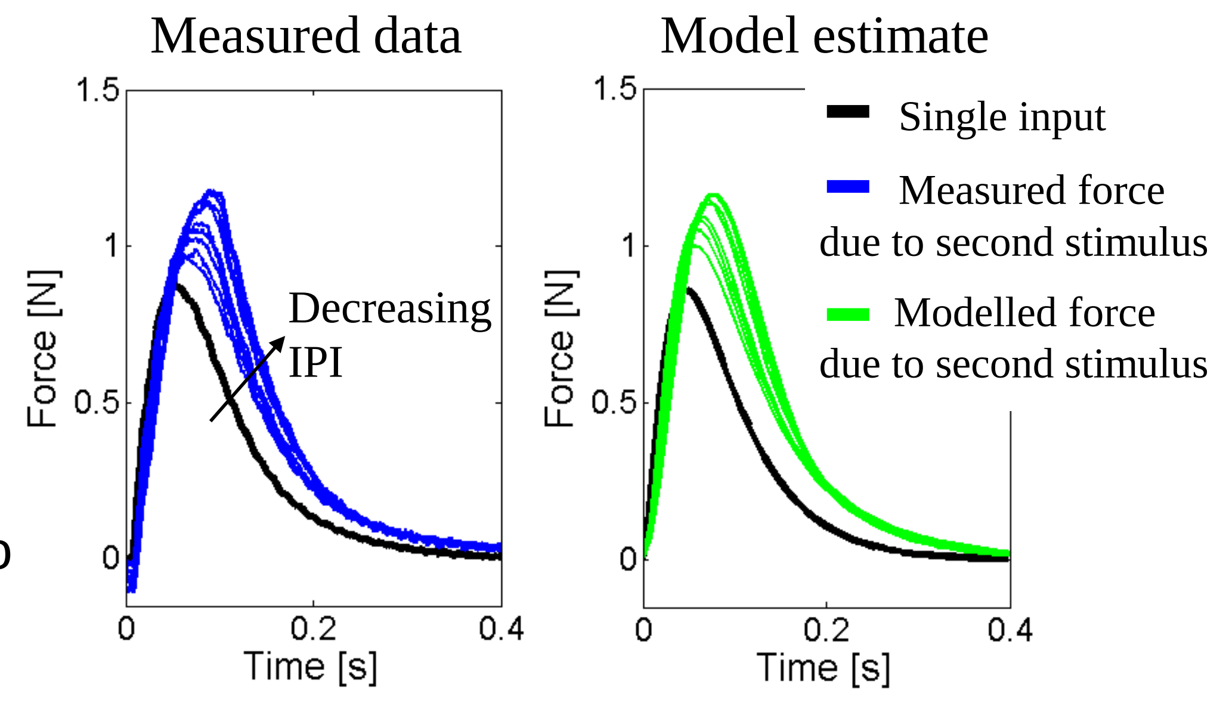

Fig. 9: Force contributed by second stimulus compared to first.

6. Conclusions and Future Work

The muscle behaves non-linearly when the responses due to individual stimuli sum. A linear third-order model provides a good description of the force response of the muscle to isolated inputs. This is different to [1,2] where a fourth order model is used.

The next step is to develop a model that applies to pulse train inputs, and then to develop a model applicable to physiological inputs (actual neural inputs).