\textbf{Aim 1 - Develop a physiologically relevant hindlimb model of the rat musculature} \par

To accomplish this aim, a three dimensional model was created in Animatlab with attachment points and muscle parameters based on data in the literature. The development of this model includes both the biomechanical setup in Animatlab and the code basis to analyze its motion. This model lacks the neural control aspect critical to the project but serves as a platform for biomechanical analysis and development. The development of this model is developed from fundamental principles with each component expanding on the previous development. \par

This model serves as a development of the work completed by Dr. Alex Hunt in completion of his PhD thesis. In Dr. Hunt's model, a rat model demonstrated locomotory capabilities through neural control of hindlimb muscles. This work developed the process for decomposing biomechanical movements into the motorneuron signals necessary to generate them. However, this work had the benefit of not having to consider the impact of biarticular muscles, a complication which negates the use of a simple one-to-one CPG to musculature system. In the development of a more biologically relevant model, the inclusion of the full hindlimb musculature must be considered. \par

As a first step in developing a full-muscle hindlimb model, the attachment point of every hindlimb muscle was considered. Initially, this work implemented the attachment points derived by Dr. Will Johnson(Johnson 2008) in which he uses 3D mapping to develop xyz-coordinates for muscle attachment points. The implementation of Johnson’s attachment points were presented as part of a project presentation at Living Machines 2018(Young 2018). Johnson’s work was useful from an engineering design standpoint but was unusable for two reasons: the coordinates required hand-tuned scaling in order to map correctly onto the existing bone structures and including only the insertion and origins did not accommodate muscle wrapping via points. For this reason, a more nuanced approach was implemented for the muscle attachment points. \par

Muscle paths were defined based on the descriptions by Greene’s 1953 publication Anatomy of the Rat(Greene 1953), a primer containing diagrams and descriptions of every system in the rat. Based on this information and the identification of bony landmarks in the 3D bone scans, muscle paths were implemented. Animatlab’s muscle objects are not collision-based, meaning they can pass directly through bones. For muscles that pass closely over bones (such as knee extensors like the vastii muscles), muscle paths include via points. These via points are stationary relative to the bone coordinate frames. \par

Once muscle paths were defined for every muscle, muscle parameters were developed. Animatlab uses a linear Hill muscle model which abides by the equation:

Where T is the tension, kse is the XXXX. This model demands explicitly statements for these different variables, a data set that has not been found in the literature. By using muscle parameters examined by Johnson (2011) and Eng(2009), it is possible to develop these muscle parameters. Using the guidance of Zajac (Zajac 1989), these muscle parameters were related to Hill parameters. Individual parameters are discussed individually as follows. \par

Muscle Moment Arms

As a natural progression of analyzing the biomechanics of the model, the development of moment arm profiles during gait was developed. A moment arm calculation process developed from fundamental principles is a useful tool for analyzing the force generating capabilities of specific muscles in the model. This work led to a publication in the Journal of Biomimetics (Young 2019).

Muscle moment arms are developed by projecting muscle paths onto a plane on interest and then measuring the shortest distance from the joint center to the free muscle segment. In the case of 2D walking, the plane of interest is the sagittal plane. Since muscles often contain multiple via points and those via points are often stationary relative to one another, the moment arm was calculated based on the segment of muscle that actively undergoes contraction during walking.