Evaluation of Cockroach Electromyogram Recordings Over Different Terrains

[redacted]

Background

Cockroaches have been increasingly used in neuromechanics, biomechanics, and physics research for their versatility and ability to correct their locomotion quickly. Cockroaches also exhibit different gaits when traversing different terrains. For example, a cockroach will walk or run on flat terrain, will start climbing on steep terrains, and will begin digging in granular material such as sand. The various cockroach gaits and how they affect cockroach EMG recordings has applications to mammals and even robotics. The following papers were used as the inspiration and motivation for this project:

A comparative approach to closed-loop computation *Roth, Sponberg, & Cowan*

In this paper, Roth et al. lay some groundwork for neural computational analysis. They show how neural computation is fundamentally a closed-loop system because of the feedback of information to the sensory inputs. It is this regulatory feedback that gives biological processes their stability over various perturbations to the environment. They explain a method for testing the effects of multiple sensory inputs by inhibiting individual sensory inputs and measuring the response of the biomechanical state. This process of blocking a sensory input creates an open loop in the system where the motor coordination of an organism is not regulated by information from a sensory feedback.

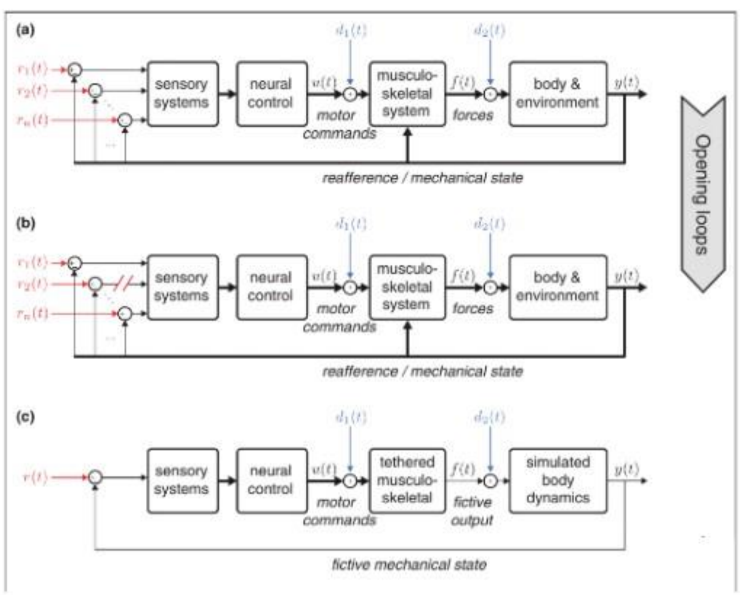

Figure 1: Closed-loop diagram of neural computation with inhibited sensory pathways shown as an opened loop

Neuromechanical response of musculo-skeletal structures in cockroaches during rapid running on rough terrain *Sponberg & Full*

Sponberg & Full constructed an artificial wooden terrain (Figure 2) to stimulate *Blaberus* cockroaches. Their terrain contained a Gaussian distribution of surface heights up to nearly three times the height of the animal. The animal was recorded using two high speed cameras at 500 frames/second and the animal's muscle action potentials (MAP's) were also collected with an acquisition board.

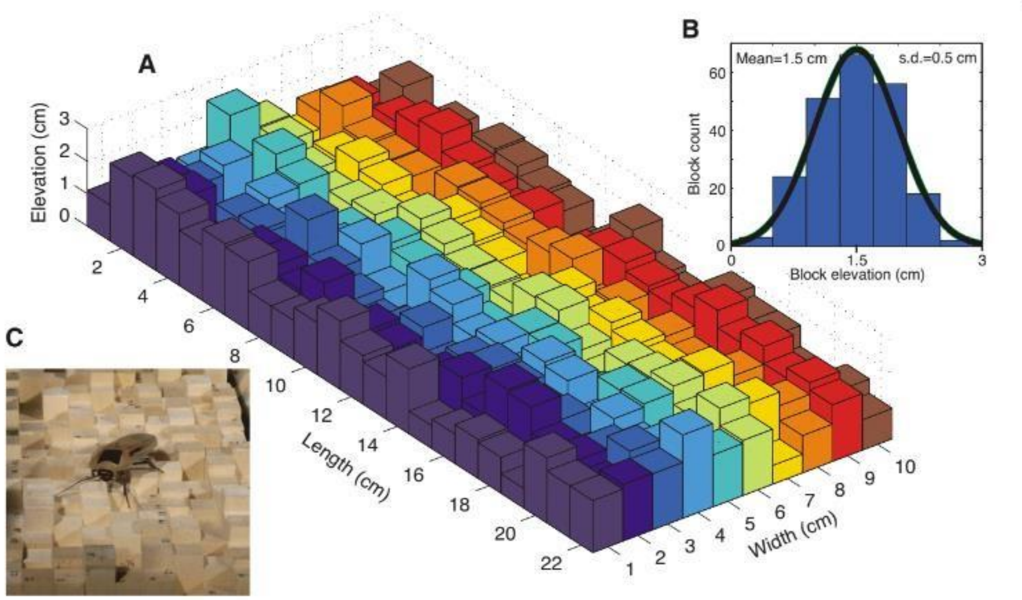

Figure 2: wooden cockroach terrain with a Gaussian distribution of surface heights, *Sponberg & Full*

Sponberg & Full analyzed the number of spikes occurring in each step and the interspike interval (ISI), the time between steps. They also discovered that the surface height perturbations also caused greater variation in the animal's roll, pitch, and yaw. However, the number of MAP's per burst doesn't entirely determine the muscle force and power output. Despite perturbations, the cockroaches recovered with less than a 20% decrease in speed. Sponberg & Full also concluded that duty factor and gait phases did not change, and they did not conclude any significant difference in the distribution of the number of MAP spikes for flat versus rough terrain.

Introduction

This project is a combination of *Sponberg & Full's* experiments and the module 6 experiments with measuring cockroach EMG signals. An EMG signal is "a biomedical signal that measures electrical currents generated in muscles during its contraction representing neuromuscular activities" (*Raez et. al)*. The EMG signal from a muscle is descriptive of the muscle action. We thought it would be insightful to have a granular terrain as the independent variable.

Hypotheses

We hypothesized that decreasing the size of the granules would prompt the cockroach to change gaits from running to walking to digging. We predicted that the change in gait would not only shown visibly but also shown in the EMG data. We also hypothesized that the frequency of bursts of muscle activity would increase as the granular material diameter decreased.

Materials & Methods

Materials

- *Blaberus discoidalis* cockroach
- 3 silver wires
- lighter
- microscope
- forceps set
- insect pins
- Petri dish
- super glue
- 3 smartphones (2 with slow motion cameras)
- amplifier circuit (see Figure 3)
- SpikeGenerator App
- Terrain
    - Cockroach "arena"

- ○ Glass beads with diameters of 25mm, 16mm, 2.7mm, and 1mm

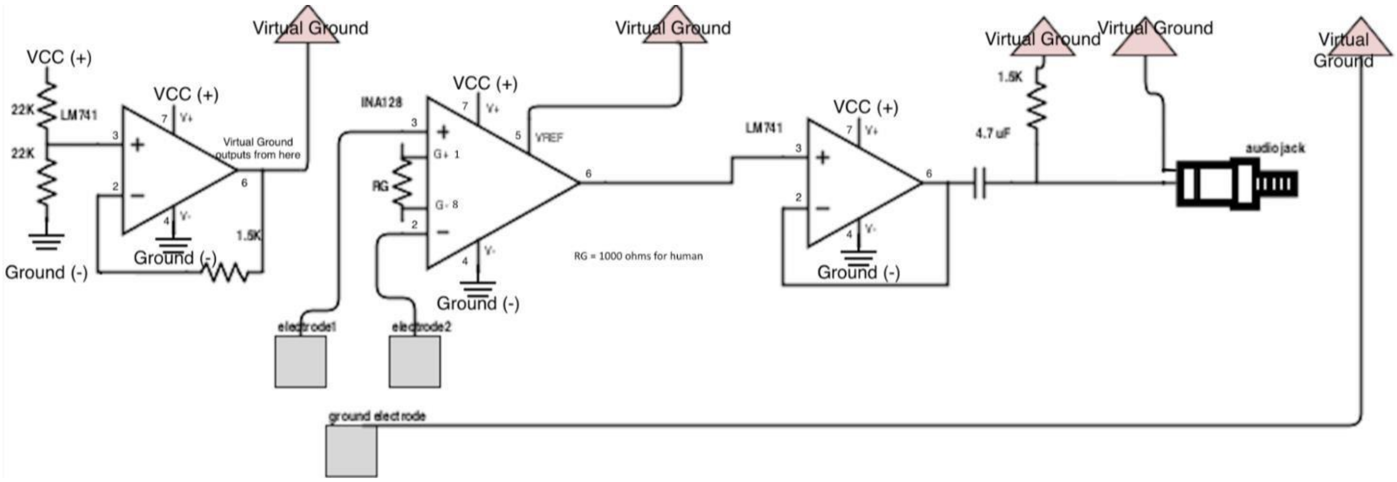

Figure 3: Amplifier Circuit Diagram

Cockroach Wiring

Cockroach wiring followed the procedure outlined in the module 6 plan. Two electrodes were placed on the flexor muscle (Figure 4) and one electrode was placed the ground wire on the cockroach's abdomen.

1. The cockroach was anesthetized in the fridge for ~20 minutes
2. The ends of 3 pieces of silver wire were burned to remove insulation and also to create a small bead about the same diameter as the insect pins
3. The cockroach was pinned to the Petri dish and the insect pins were used to poke 3 holes (2 in the flexor muscle, one in the abdomen)
4. The wires were inserted into the holes and sealed with super glue.
5. The wires were labeled using colored tape to indicate which ones were the ground and muscle electrodes

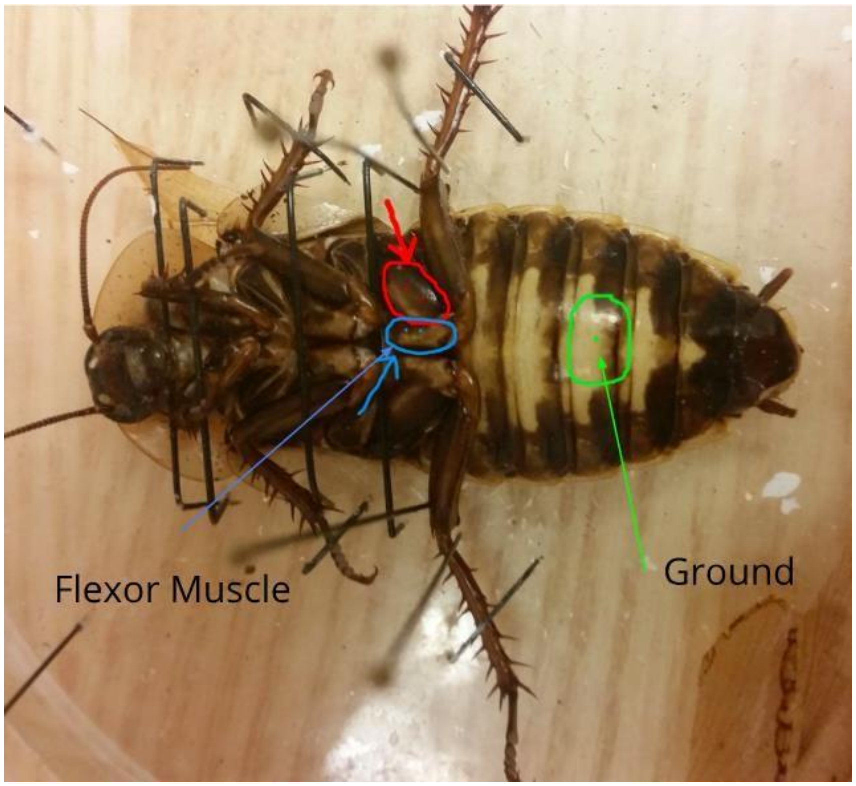

Figure 4: Location of cockroach electrodes

Experiment Procedure

1. The arena was filled with the various glass beads, and the circuit amplifier was hooked up to the phone and balanced on a piece of styrofoam parallel to the ground (Figure 5)
2. The cockroach electrode wires were attached to circuit amplifier and one smartphone with the SpikeGenerator App
3. One phone filmed the cockroach from the top of the terrain (parallel to the ground) and the second phone filmed the cockroach parallel to the side of the terrain and on the same side as the wired flexor muscle.
4. The cockroach was placed into the terrain and allowed to run until it reach the end of the electrode wires. The cockroach was stopped since it couldn’t move forward and so it would not pull out the wires.
5. This procedure was repeated 3-4 times for each iteration of the terrain

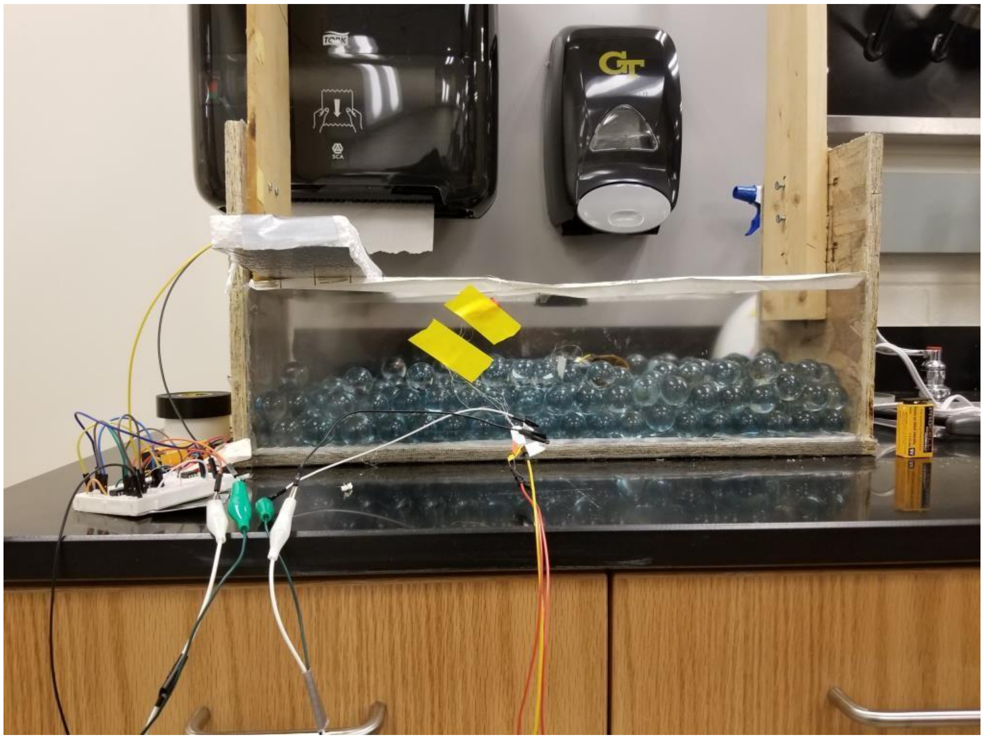

Figure 5a: Cockroach arena filled with 25mm glass beads, side view

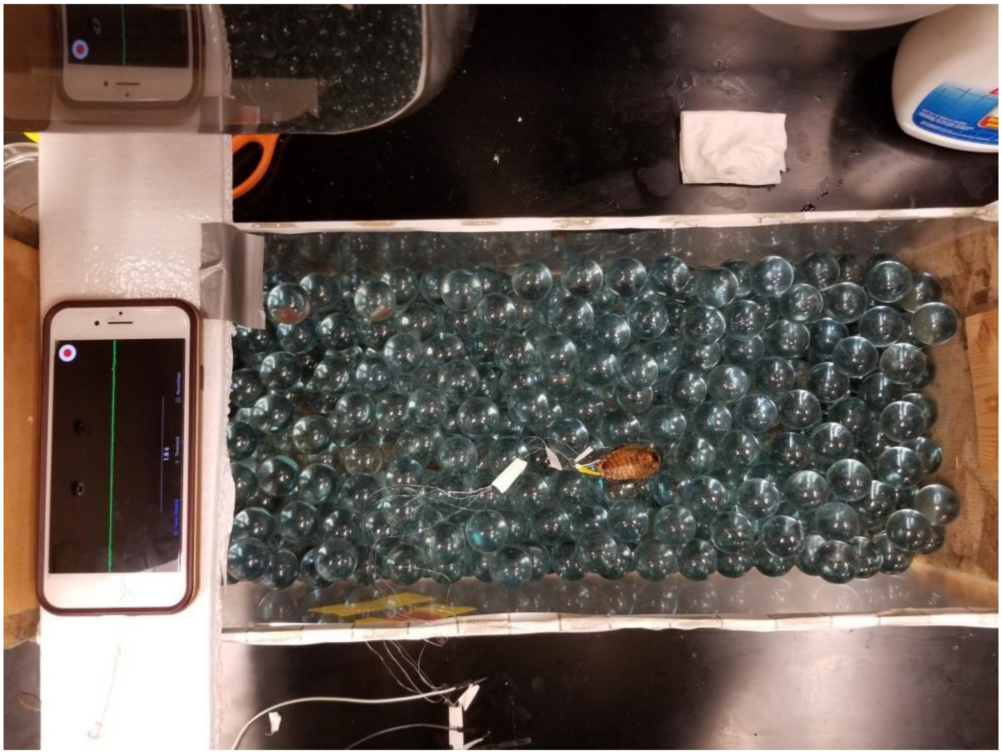

Figure 5b: Cockroach arena filled with 25mm glass beads, top view

Results

We collected the following EMG signals from the cockroach's bottom left flexor muscle and took slow motion videos (hyperlinked below) of each trial from the top and side of the arena.

Terrain 1: 25mm Diameter Beads ***Video***

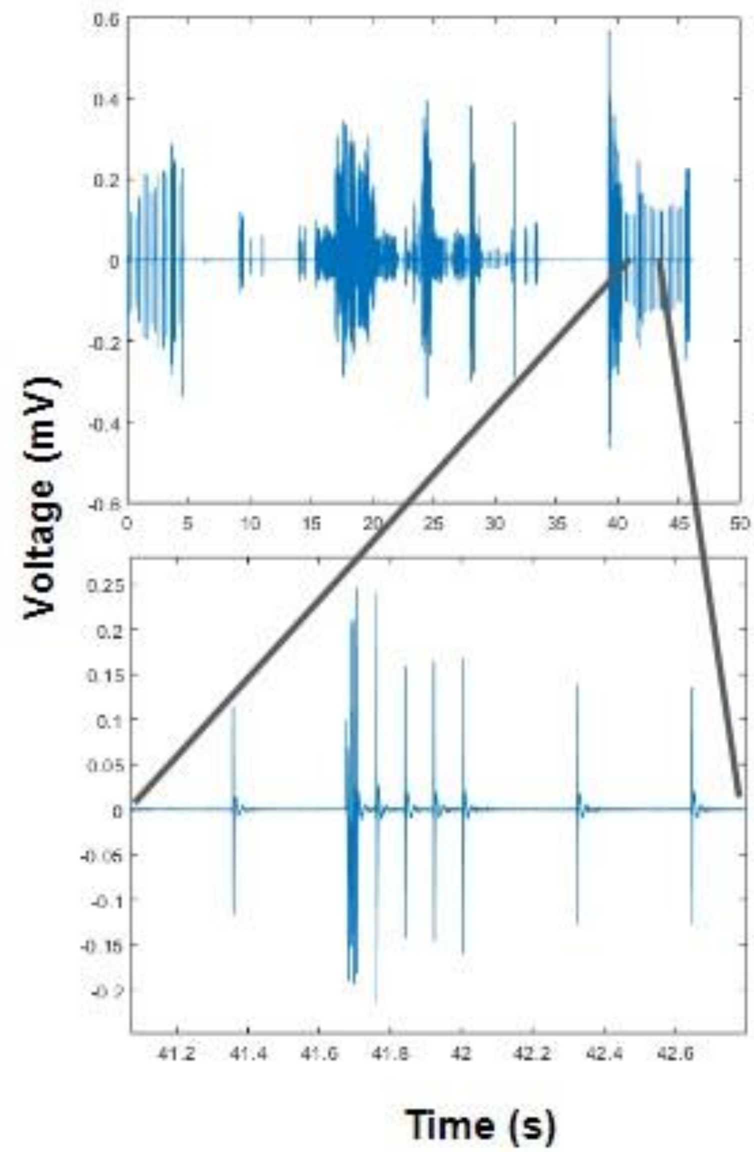

Figure 6a: EMG signal of the cockroach in terrain 1 with a zoomed in view on a segment when the cockroach is moving

Terrain 2: 16mm Diameter Beads [Video]

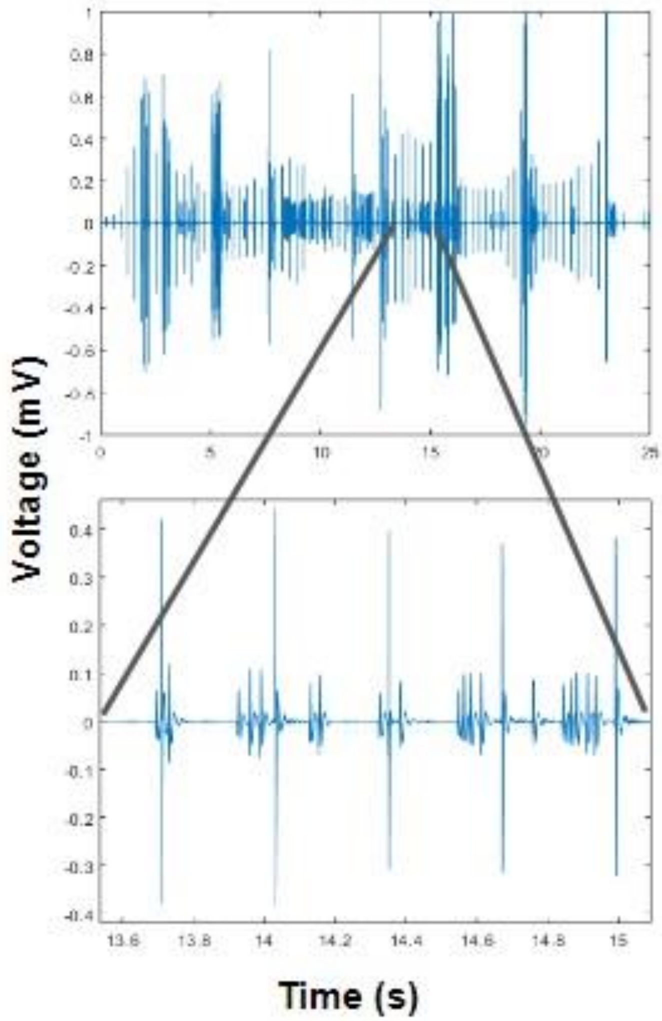

Figure 6b: EMG signal of the cockroach in terrain 2 with a zoomed in view on a segment when the cockroach is moving

Terrain 3: 2.7mm Diameter Beads [Video]

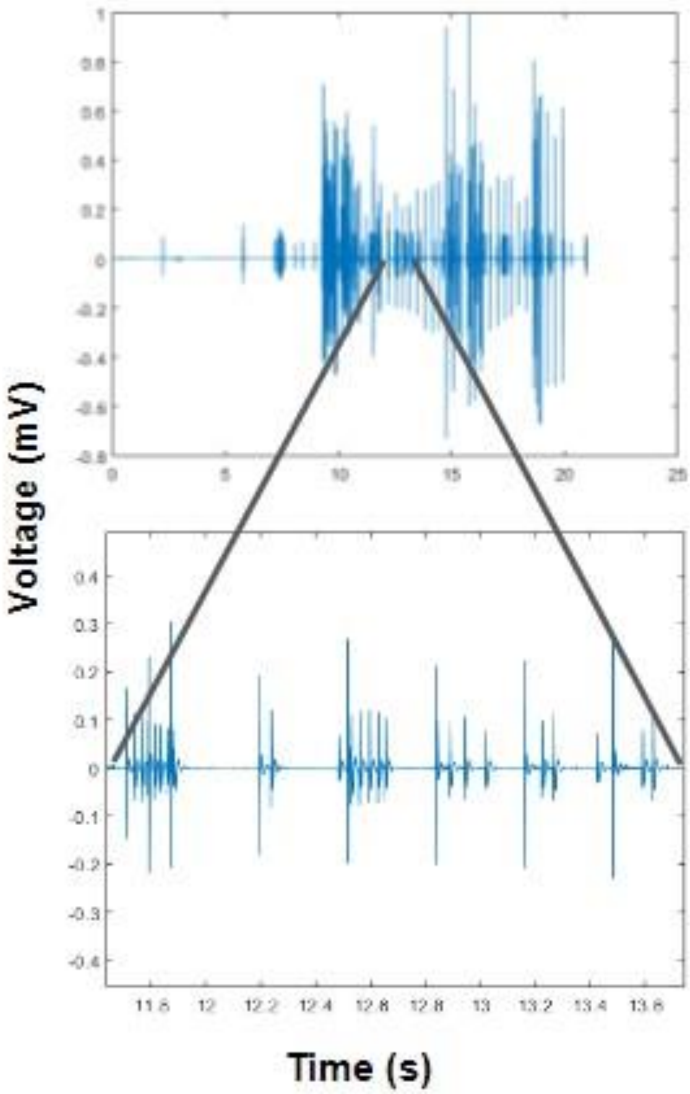

Figure 6c: EMG signal of the cockroach in terrain 3 with a zoomed in view on a segment when the cockroach is moving

Terrain 4: 1mm Diameter Beads ***Video***

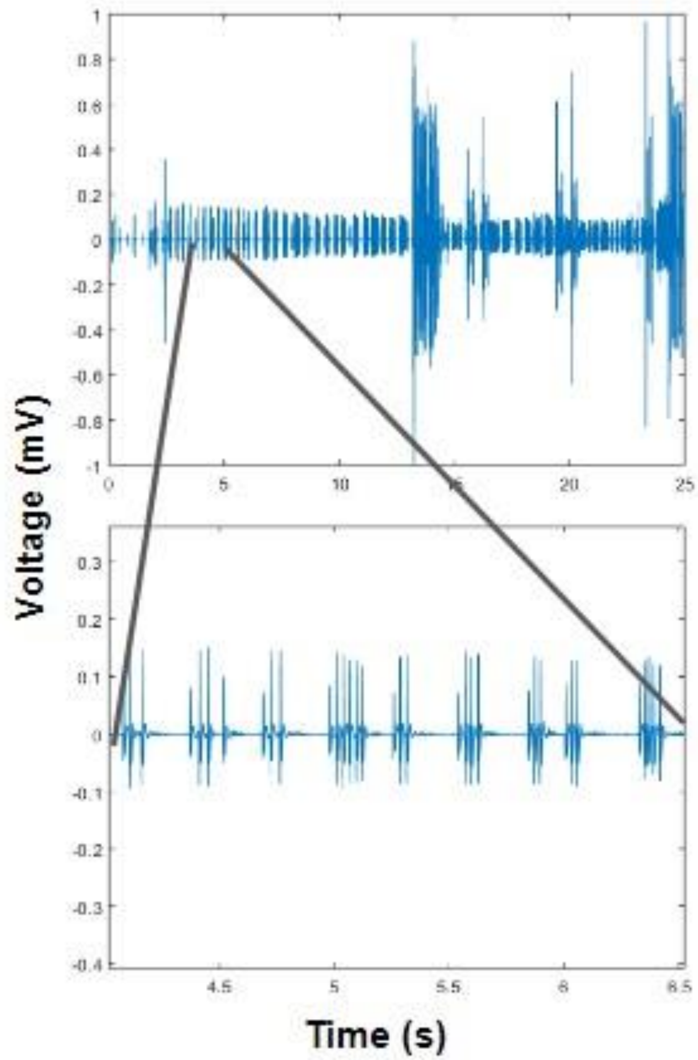

Figure 6d: EMG signal of the cockroach in terrain 4 with a zoomed in view on a segment when the cockroach is moving

Calculations

We collected and calculated the following data. This information was collected from the same cockroach so it's possible that there are errors due to cockroach fatigue. In addition, we did not account for any missteps or instances where the cockroach ran into the glass wall. The waveforms collected appear visually similar to the data collected in *Sponberg & Full*.

Spikes per Burst

Using the SpikeGenerator App on our smartphones and reading the .wav file in MATLAB, we tallied the number of spikes for each burst, and we calculated the average spikes per burst for each terrain trial.

Terrain	**Maximum Spikes per Burst**	**Average Spikes per Burst**
1: 25 mm Diameter Beads	5	1.6
2: 16 mm Diameter Beads	6	1.8
3: 2.7 mm Diameter Beads	7	3.86
4: 1 mm Diameter Beads	6	5.67

The average spikes per burst increased as the diameter of the glass beads decreased. We also created figures showing the proportion of bursts that have certain number of spikes (Figure 7).

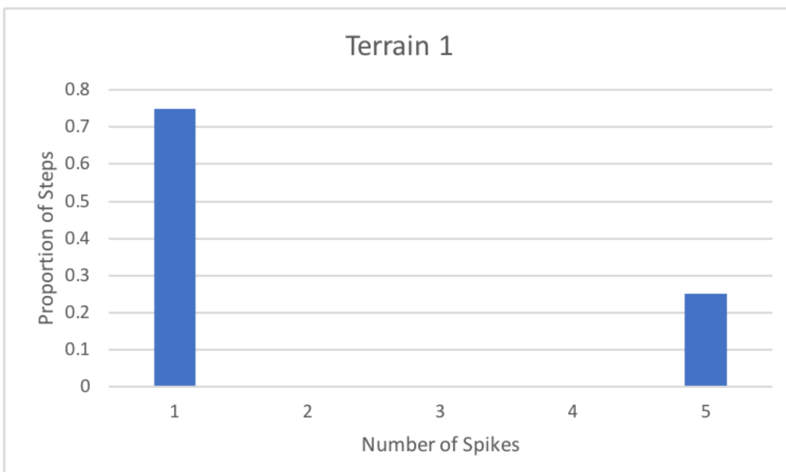

Figure 7a: Terrain 1 Number of Spikes vs Proportion of Steps

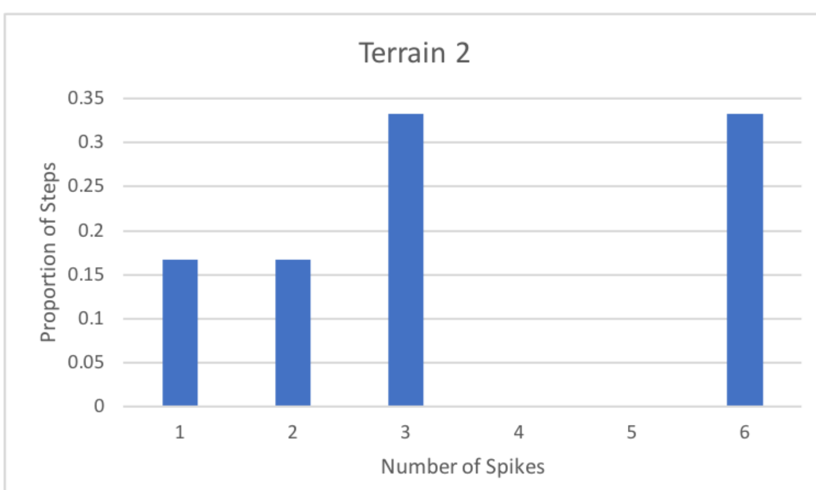

Figure 7b: Terrain 2 Number of Spikes vs Proportion of Steps

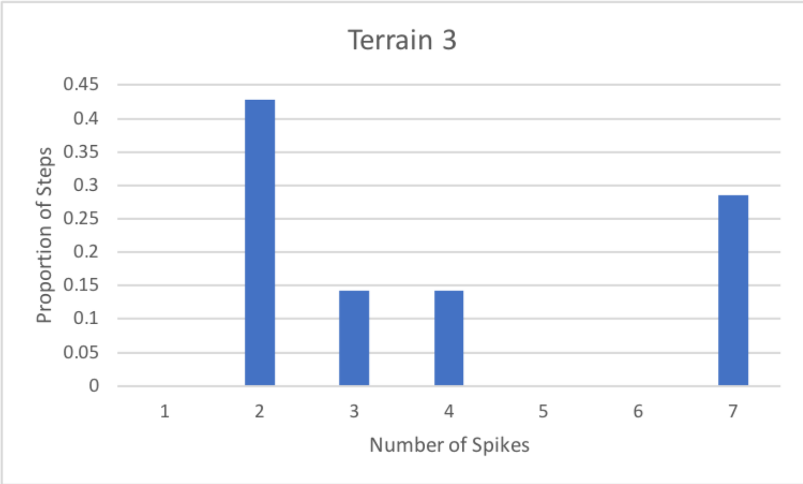

Figure 7c: Terrain 3 Number of Spikes vs Proportion of Steps

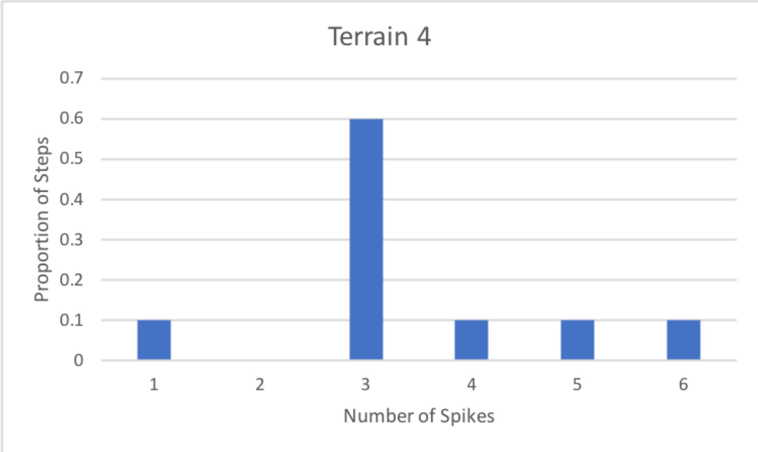

Figure 7d: Terrain 4 Number of Spikes vs Proportion of Steps

Frequency of Interspike Burst Intervals

The frequency spectrum of the cockroach EMG signal is analyzed using the fast fourier transform. A window of the time domain signal is selected for when the cockroach is moving and then using the FFT function in MATLAB, the power spectral density plot is generated.

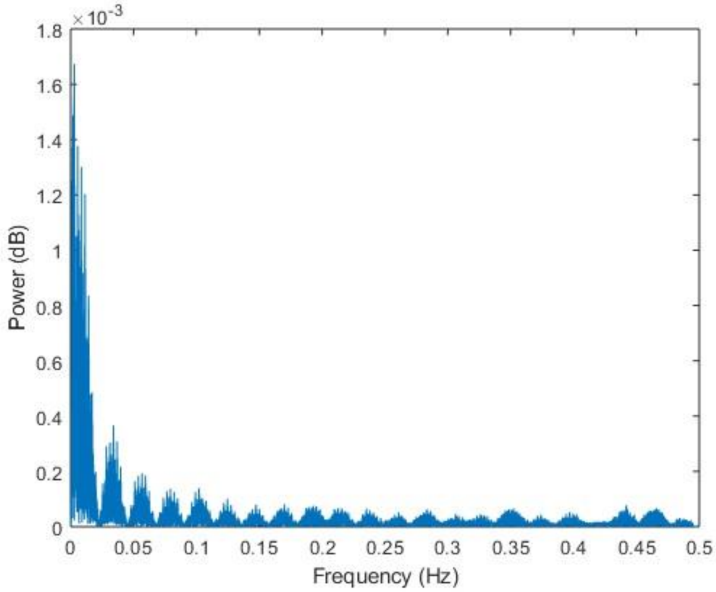

Figure 8a: Power spectral density of the cockroach EMG signal from terrain 1

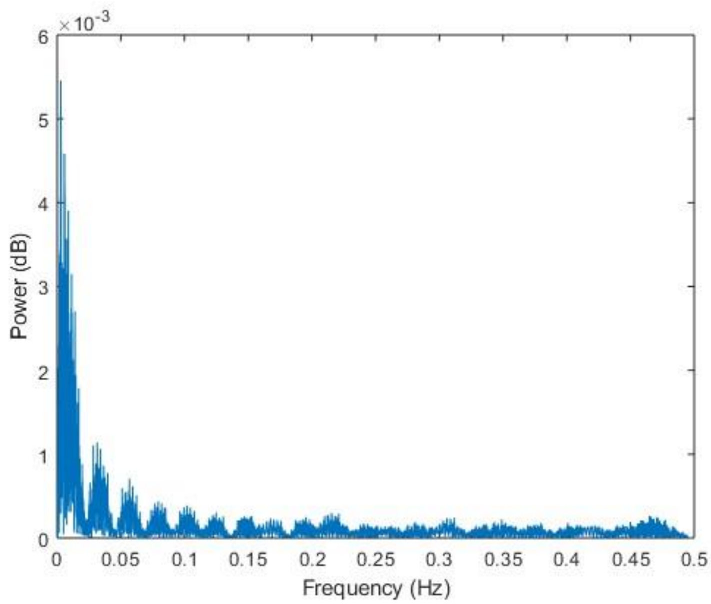

Figure 8b:Power spectral density of the cockroach EMG signal from terrain 2

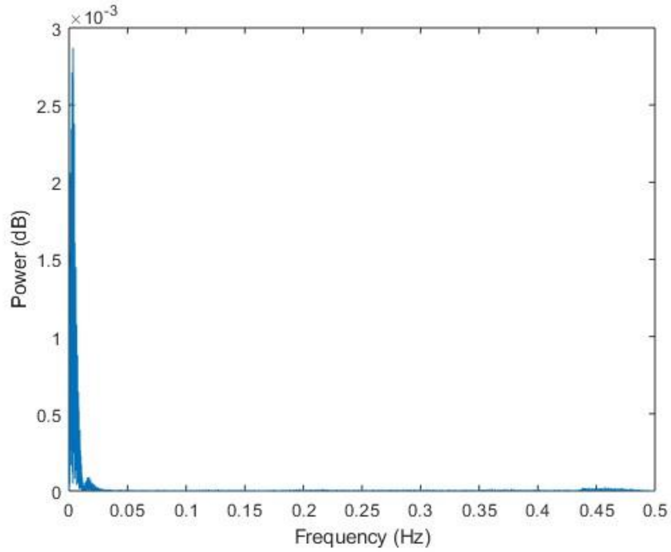

Figure 8c: Power spectral density of the cockroach EMG signal from terrain 3

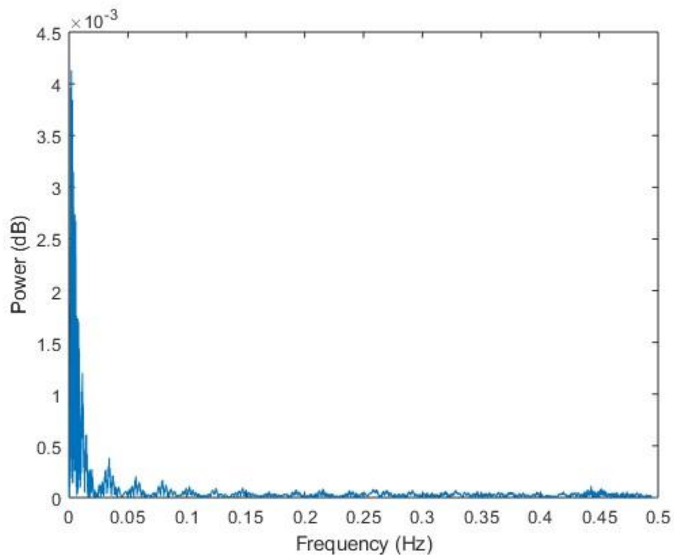

Figure 8d: Power spectral density of the cockroach EMG signal from terrain 4

Observations from the Videos

The cockroach had more trouble traversing Terrain 1 and treated the large glass beads (which were only slightly smaller than the cockroach itself) more like steps than a granular material. There are a few scenarios, seen in the videos, where the cockroach struggles to climb over a bead. Since the beads are randomly spread out in the arena, the cockroach must quickly adjust from ascending to descending. In addition, the glass beads have a low coefficient of friction which could have caused the cockroach to struggle walking across the terrain.

In Terrain 4, the cockroach can be seen digging into the bed glass beads. The cockroach's range is constrained by the electrodes attached to its leg and once it reaches the end of the line, it keeps trying to move forward while stuck in place. This causes it to start to dig into the 1 mm diameter glass beads.

Conclusion

The results clearly show that cockroaches behave differently as the glass beads decreases in size. As the terrain changes from being more of a rough terrain into a granular terrain, the cockroach muscles experience a higher level of activity, since the bursts are more frequent. The amplitude of the bursts also decreases as the size of the granular material decreases; however, other studies such as *Raez et. al* have shown that amplitude of EMG spikes does not directly relate to force as there are anatomical and physiological variables to consider. Like *Sponberg & Full*, we predict that there isn't a significant difference in MAPs between the different terrains; however, it is clear from the videos and the preliminary data that there is a definite difference in cockroach behavior while subjected to locomotion in different sizes of granular material. Due to our small number of trials, we do not have enough data to conclude significance of MAPs from these results.

Further Steps

We can take this project further by evaluating the EMG signals from the other 5 legs as well as from the extensor muscle instead of a single flexor muscle. Other parameters to change include the material of the granular substance, or change the terrain from a granular substance to a more uniform substance, and the angle of the terrain. In addition, having a larger arena and with more slack on the electrode wires will allow the cockroach to move more freely and without restraint. Another way to improve this project is to increase the amount of trials per terrain and to run this experiment on different cockroaches. We can also use higher speed cameras to track other parameters such as cockroach velocity and acceleration in the ground plane and we can sync up the cockroach steps in the video to the respective EMG recording, which will make it easier to identify missteps.

References

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