Grasping Force Variance Amongst Different Stimulation Parameters

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***Abstract*—The long-term goal of this research is to explore the effects of various stimulation parameters on perceived magnitude of the sense. The number of Americans with limb loss is 1 in 190 and expected to double by 2050. Electrical properties of neurons and the basic nerves that communicate sensory information are still present in the residual limb of amputee individuals and can be utilized to restore sensory feedback. Prior work has covered the effects of various stimulation parameters, but has not explore pulse amplitude. Results showed that collective remarks agreed that pulse-amplitude provided improved sensory discrimination compared to pulse-width. Within the results, a charge-balanced stimulation was safely delivered to participants and an RC circuit did mimic an electrode-tissue interface. The results provide a stepping stone in neuroprostheses towards gaining more knowledge of sensory feedback. They may also be applied to adjacent fields, such as other assistive therapies for regaining sensory feedback after events such as strokes**

I. Introduction

Currently, nearly one in 190 Americans live with limb loss. This number is predicted to double by the year 2050 [1]. As the number of individuals with this neurological impairment is likely to grow, it is important that efforts are focused on creating more intuitive tools to help these individuals adjust and improve their quality of life. Current clinical standards of care for these individuals focus on addressing pain treatment, exercise therapy, and educating these patients and their caregivers [2]. Although those aspects are vital, there are limitations when it comes to activities of daily life or leisure activities, and community integration [2]. One vital component to improving traditional prostheses is the incorporation of effective sensory feedback.

Due to the electric spike behavior between the human brain and the body's senses, engineers can take advantage of the electrical communication from the senses to the brain to artificially deliver different sensations to the individuals through electrical stimulation. When a limb is lost, becomes paralyzed, or less functional, the majority of the nerve wiring are still intact and functional [3]. Utilizing these frameworks to deliver sensory information can lead to a variety of helpful applications for individuals of all different neurological impairments.

Previous state-of-the-art research on sensory feedback consists of exploring different ways to electrically stimulate healthy participants and obtain their feedback on the perceived magnitude of the stimulation. Graczyk et al have conducted such an experiment and explored the stimulation parameters of pulse frequency and pulse width. The research found a quantitative way to map the correlations between the stimulation variances and the perceived magnitude [4].

The objective of this paper is to expand upon the work of Graczyk et al by further exploring another stimulation parameter – the current amplitude. As this is parameter had not been explored by Graczyk et al, it will provide more useful insight and more information about sensory feedback and its relation to perceived magnitude. The findings from this paper conclude that a charge-balanced biphasic stimulation can be successfully and safely delivered to the index finger. In addition, an RC circuit with a resistance of 1.46 kΩ and a capacitance of 22.7 nF can effectively mimic the effects of an electrode-tissue interface. Although no statistical significance was found between the perceived magnitude slopes of each participant, positive overall subjective remarks were received that collectively agree that pulse-amplitude provides improved sensory discrimination when compared to pulse-width.

II. Methods

The following section reviews the specifications of this study outlined through a variety of subsections, including participants, stimulation hardware, stimulation parameters, etc.

A. Participants

The research data acquired within this paper was collected through experiments with three participants. The group was 66.67% female and 33.34% male. The participants ages ranged from 21-22 years-old and all participants were considered healthy in terms of neurological condition.

B. Stimulation Hardware

The two primary hardware components that were used in this study were the stimulation box and the surface electrodes that connected the box to the subjects. The electrodes were 3cm in diameter and were placed on the inside of the upper arm, between the bicep and tricep muscles, as shown in Figure 3a. This location was chosen so that participants may push the electrodes deeper between the muscles to target the medial nerve. Stimulating the medial nerve will elicite the grapsing motion of the hand. The stimulation box was a one-channel high-voltage stimulator developed in the University of Utah's NeuroRobotics lab. Its compliance voltage within this experiment was 1 volt.

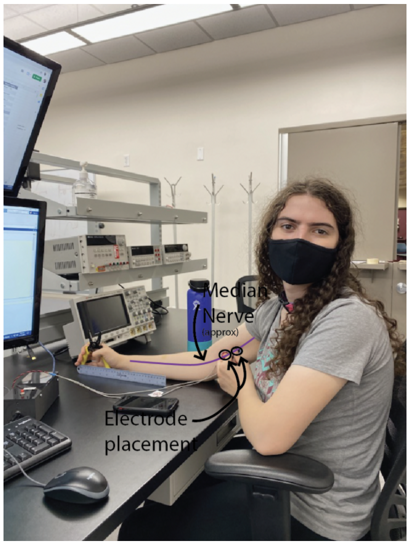


Fig. 1. Overview of the experiment and stimulation interface. (a) Electrode placement on the median nerve. (b) The evoked grasping movement used to squeeze a wire cutter. Force is proportional to the how far the wire cutter's handles get squeezed together.

C. Stimulation Parameters

The two stimulation parameters used for independent exploration in this study were the stimulation waveform's pulse width and current amplitude. Generally, the pulse width was measured by looking at the time that elapsed during the anodic or cathodic phase. Either phase can be used in this case since we are utilizing a charge-balanced biphasic waveform. The current amplitude was measured by observing the peak-to-peak voltage within the waveform and following Ohm's law to obtain the current. In practice, both stimulation parameters were updated manually through a MATLAB script that generated commands to the stimulation box.

D. Strength-Duration Curve

Due to the variance between participants, an individual range of values was determined for each participant, for each stimulation parameter. For each participant, the minimum threshold was determined by the smallest value that could still elicit a grasping movement. The values were increased by 0.5 until it became uncomfortable for the participant. The maximum value was set to the one before it became uncomfortable. The individual ranges were then divided into equal intervals for the four trials. This data was normalized prior to analysis. The activation movement was measured using a wire cutter tool as a form of resistance to the grasping force. As seen in Figure 3, the tool was placed in the hand prior to stimulation. The elicited stimulation would close the hand grasp. A stronger grasp means a stronger force, which will be visualized through the hand being able to squeeze the tool's handles more. This observation was quantified by measuring the distance between the tool's handles. The simulations were started and stopped manually after the length of closure was measured using a ruler. The reaction to the stimulation was rather immediate, so there wasn't a large lag time to determine if a movement had occurred. Four trials were done at different parameter values. Each trial had three samples to verify consistency between results.

E. Chronaxie and Rheobase

F. Experimental Design and Metrics

For each participant, each stimulation parameter had a series of four trials per round, therefore, four different values for the stimulation parameter were tested on each round. The performance metric used was the distance measurement between the handles of the wire cutter tool. The distances were measured in centimeters. The individual simulations were present until the distance measurement was obtained. There were a total or three rounds to ensure results over multiple samples. The parameter value ranges varied based on participant, however, the values within their range were stimulated in increasing order per each round, since stimulation order was not an important factor within this experiment.

The pulse-width stimulation parameter covered a range of 75μsec - 225μsec, at different amplitudes that were comfortable for each participant. The four discrete values tested were $[75, 125, 175, 225]$ at amplitudes of $[4mA, 3.6mA, 6mA]$. The current amplitude stimulation parameter covered an individualized range per participant. The four discrete values for each participant were $[3, 3.5, 4, 4.5]$, $[2.75, 3.3, 3.6, 4]$, $[5, 5.5, 6, 6.5]$. We contribute these variances in ranges to various causes, such as skin resistance, muscle definition, distance to medial nerve, etc.

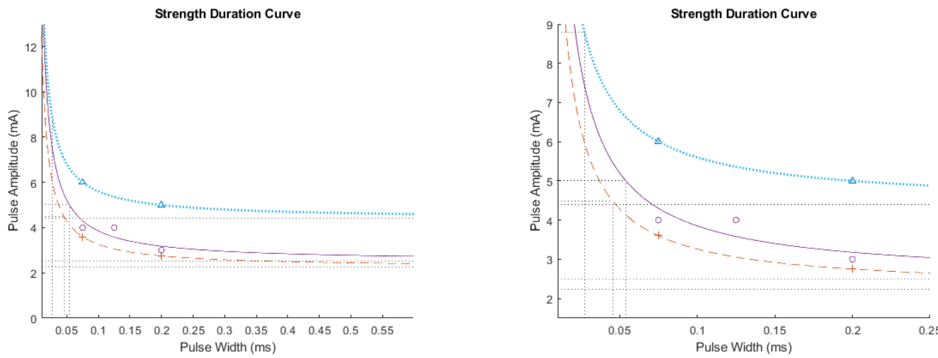
G. Statistical Analysis

To begin the statistical analysis, the data was tested to detect any outliers and remove them when necessary. Then, a test of normality was conducted on the cleaned data and the data was determined to not be normally distributed. The data was considered to be paired as multiple of the same trials were conducted again on the same participant. There was a sample size of 18 per parameter per individual.

III. Results

A. A charge-balanced biphasic stimulation was successfully delivered to the index finger.

The stimulation was performed by placing two electrodes on the top and bottom of the index finger on the right hand, as shown in Fig. **??**a. The pulse-width stimulation parameter was measured by viewing how long the anodic or cathodic phase were active. The amplitude stimulation parameter was measured by obtaining the peak-to-peak voltage amplitude and dividing by the resistance, according to Ohms law. The biggest difference between the programmed and measured outputs were the waveform shapes. Although they had similar characteristics, as expected, the measured output certainly had a capacitative component introduced by the skin that the measured output did not, clearly visible in Fig. 4. More information about the stimulation waveform characteristics may be found in Table 1.



a. Clear representation of rheobase markers. b. Clear representation of chronaxy markers.

Fig. 2. Strength-Duration Curve. The same plot is shown in with different axis limits in part a and b, to more clearly visualize the rheobase and chronaxy markers. The data was linearized by replacing the explanatory variable with 1/pulse width. Then, the line of least squares was found for each person and converted back to the non-linear version. Rheobase was the intercept of the fit lines. Chronaxy was found using the Chronaxy equation for each line.

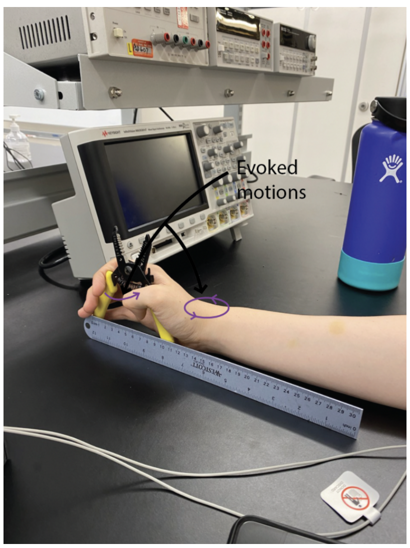


Fig. 3. The functional task to determine the activation movement. A wire cutter tool was used as a form of resistance to the grasping force. The distance between the wire cutter tool's handles was measured using a ruler.

B. The RC equivalent circuit had a resistance of 1.46 kΩ and a capacitance of 22.7 nF.

The equivalent circuit was structured using an RC circuit with a current source. The resistance and capacitance values were calculated using node-voltage circuit analysis and the appropriate capacitance and resistance equations. As seen in Fig. **??**, the capacitance and resistance values were 22.7 nF 1.46 kΩ, respectively. The time constant was evaluated to be 33.3 μsec.

C. No statistical significance was found between the slopes of each participant.

The two stimulation parameters that were varied were the pulse-width and the current amplitude. The pulse-width range took on the following values: $[200, 215, 230, 245, 260, 275]$. The current amplitude range covered the following values: $[1.3, 1.4, 1.5, 1.6, 1.7, 1.8]$. When analyzing perceived magnitude plots in Fig. **??**, the best fit lines for the pulse-width and amplitude parameters could be described with $y = 0.0387x - 6.0688$ and $y = 11.905x - 14.286$, respectively. Based on individual slope analysis, as seen in Fig. **??**, there was no statistical significance between any of the individuals.

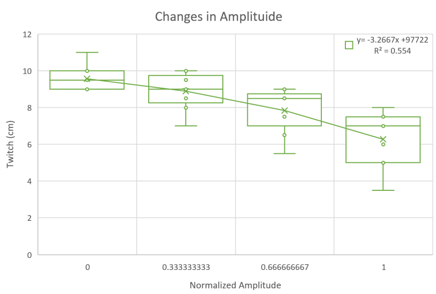
D. Positive overall subjective remarks were received.

A disclaimer should be stated that remarks mentioned are subjective, but can still be useful information for the improvement of future experiments. With this in mind, generally positive feedback was received about the experiments. Collectively, participants agreed that it was much easier to discriminate sensations using the amplitude parameter than it was using the pulse-width parameter. Some of the pulse-width parameter values seemed indistinguishable to most of the participants.

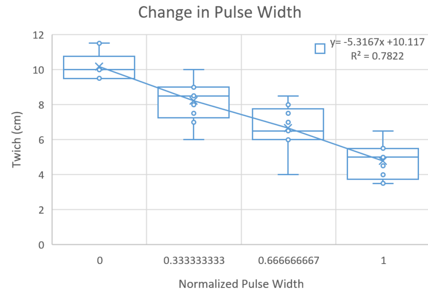
IV. Discussion

This paper's objective was to expand upon the work of Graczyk et al by further exploring the current amplitude as a new stimulation parameter. The findings from this paper concluded that a charge-balanced biphasic stimulation can be successfully and safely delivered to the index finger. In addition, an RC circuit, with a resistance of 1.46 kΩ and a capacitance of 22.7 nF, can effectively mimic the effects of an electrode-tissue interface. Although no statistical significance was found between the perceived magnitude slopes of each participant, collective remarks agreed that pulse-amplitude provided improved sensory discrimination when compared to pulse-width.

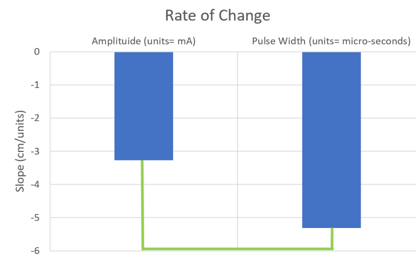
Prior work has shown that there is in fact a direct relationship between certain stimulation parameters, such as pulse-width and pulse-frequency, and perceived magnitude. Prior work has also shown that these factors can be characterized by a single computational term to help predict perceived magnitude [4]. In contrast, here we show that there are other parameters, specifically the pulse-amplitude, that may also



a. Box Plot for Amplitude.



b. Box Plot for Pulse Width.



c. Bar Plot of statistical comparison.

Fig. 4. Statistical Analysis performed on acquired data. Ultimately, as seen in part c, results were statistically insignificant, with p=0.2.

have an impact on perceived magnitude and may be stronger than those considered in the prior work.

The work presented here builds off of prior work by exploring a parameter that had not yet been explored by Graczyk et al, which provides more useful insight and more information about sensory feedback and its relation to perceived magnitude. Also novel from this work is its method for statistically analyzing its results using a comparison between perceived magnitude plot slopes.

Future work should replicate these findings with additional participants to ensure that the statistical analysis of no statistical difference is accurate. In addition, future work should expand the range of values for the pulse-width in an effort to improve the perceived magnitude with this parameter.

This paper's work has a direct impact on the field of neuroprostheses by contributing more knowledge of sensory feedback for perceived magnitude. The findings may also be applied to adjacent fields, such as the development of other assistive devices in therapies for regaining sensory feedback after events such as strokes. Clinically speaking, the development of this work provides a foundation for improvements in prostheses and their grasping sensitivity. Improvements in prostheses can significantly impact the quality of life for amputees, providing a better approach for daily tasks and independence.

V. Author Contributions

All authors contributed to the experiment design and parameter decisions. EW, and GS were involved in participant data collection. PTZ developed the performance metric. PTZ, EW, and GS conducted parameter range selection. GS created the strength-duration curve. HK performed statistical analysis.

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