Design and Evaluation of a Vibrotactile Sensory Feedback System for Prostheses

by

Tegan J. Thurston

A THESIS

submitted to

Oregon State University

Honors College

in partial fulfillment of

the requirements for the

degree of

Honors Baccalaureate of Science in Bioengineering

(Honors Scholar)

Presented June 29, 2022

Commencement June 2023

AN ABSTRACT OF THE THESIS OF

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Abstract approved:____

V John Mathews

Loss of a limb can severely impact everyday way of life. Prosthetics provide a way to return functionality to the user and improve quality of life. However, most prosthetic systems currently available in the market lack sensory feedback making them comparatively more difficult to use resulting in prosthetic abandonment. Therefore, an important design consideration for prosthetics is sensory feedback to increase their functionality, usability, and ultimately their purpose for the user. Previous development of sensory feedback devices for prosthetics tended to focus on device design with less focus on intentional training methods to teach users to use the device. This thesis presents the design of a vibrotactile sensory feedback system (SFS) to complement a hand prosthesis. The system provides a sense of touch and force to the prosthesis. A sequential training method to teach users to interpret signals from the device was also developed. After undergoing training, users were tested with a force matching task under three conditions: visual feedback only, sensory feedback only, and with both sensory conditions. When sensory feedback was the only form of feedback given users performed comparably worse with less time spent in range and with greater error, but over the course of testing users improved with slightly more time spent within range and with decreased error, providing evidence that given training users can improve their interpretation of the SFS. This work provides a basis for developing more efficient sensory feedback systems to improve usability and retention of prostheses.

Keywords: sensory feedback, prostheses, training methods

Corresponding e-mail address: teganthurston@gmail.com

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project of Tegan Thurston presented on June 29, 2022.

APPROVED:

V John Mathews, Mentor, representing Department of Electrical Engineering and Computer Science

Ravi Balasubramanian, Committee Member, representing Department of Mechanical, Industrial, and Manufacturing Engineering

Raviv Raich, Committee Member, representing Department of Electrical Engineering and Computer Science

Toni Doolen, Dean, Oregon State University Honors College

I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

Tegan Thurston, Author

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I. Introduction

There are an estimated 2.1 million amputees in the United States, of which about 35% are estimated to be upper limb amputees[1]. Of upper limb amputees, about 50% would opt to use a prosthetic arm if given the chance[2].

Myoelectric upper limb prosthetics are controlled from decoded muscle movement that functionally returns the use of a hand to the user. Inherently, myoelectric prostheses lack sensory feedback, such as pressure, temperature, proprioception, etc. The lack of sensory feedback increases the cognitive workload required to operate the prosthetic. Because this increases the difficulty of using the prosthetic, especially when compared to a natural hand, the lack of sensory feedback is one of the primary reasons stated for prosthetic abandonment[3,4]. Consequently, part of building and designing effective and functional myoelectric prosthetics should also involve considerations for including sensory feedback.

Neural stimulation is an effective means of returning sensory feedback to prosthetic users, returning naturalistic sensations that are easier for users to immediately interpret and use. However, the process of incorporating neural stimulation requires invasive surgical methods that lessens the accessibility and appeal of incorporating neural stimulation[5]. Utilizing and incorporating non-invasive methods of returning sensory feedback is more accessible and appealing by comparison.

One of the difficulties with developing non-invasive sensory feedback for prosthetic limbs is teaching users to interpret unnatural signals, such as vibrations, and turning those signals into useful information about the state of the prosthetic, such as if the prosthetic is touching an object. The primary goal of this study is to design a sensory feedback system (SFS) and develop an effective training method for teaching users how to interpret signals from the SFS.

This thesis describes the design, characterization and performance assessment of a vibrotactile sensory feedback system that enhances the ability of prosthetic arm users to better manipulate their prostheses. Chapter 2 overviews the work and progress currently made in the design of sensory feedback systems for prostheses and provides insight into potential progress that has yet to be made. Chapter 3 covers the design of the SFS used in this research followed by Chapter 4 which covers the training and experimental methods used to evaluate how well participants learned to use the SFS. Chapter 5 presents the findings of the evaluation of the SFS. Chapter 6 overlays the conclusions and potential future work of this research.

II. Background

Limbs do more than provide mobility and utility. They also provide important sensory feedback about the environment. Coupled with the loss of a limb is also the loss of important environmental stimulus and information, as object manipulation is largely dependent on tactile feedback in humans[6]. This in turn can result in detrimental consequences for daily activities and quality of life[7,8]. In general, prosthetic limbs do not relay sensory feedback to the user. Without sensory feedback prosthetics require visual or auditory feedback for prosthesis performance, which when compared to using a natural hand creates additional mental workload. The increased mental workload required for using myoelectric prostheses is one of the main reasons for prosthetic abandonment by users [4]. Thus, restoration of sensory feedback for amputees is a critical design concern for developing prosthetics[8].

Ideally, prosthetic sensory feedback would include both exteroception, physical interactions with the environment, and proprioception, sensing the 3D orientation of the body. These sensations parallel the natural sensory abilities of a limb and are relayed by somatic body receptors. Somatic body receptors are divided into three different types: mechanoreceptors, nociceptors, and thermal receptors. These biological sensors relay information about proprioception, pain, temperature, and touch[9]. In the case of amputation, whether sensory feedback is restored invasively or non-invasively, an amputee would need to be taught how to interpret newly restored sensory inputs.

A second consideration for designing sensory feedback systems is if signals should be relayed discretely or continuously, or a mixture of both. The body interprets signals based on discrete events that denote specific tasks, such as touching an object. It is therefore suggested that sensory feedback be provided in a discrete manner to match the body's natural tendencies. Artificial haptic feedback specifically would ideally be delivered within 3-5 milliseconds of the stimulus, almost instantaneously. This would allow the brain to develop fluidity with the prosthetic as part of the body itself[9].

One method of relaying sensory information to users is with vibrotactile feedback. Vibrotactile feedback consists of vibration indications that can relay a myriad of information to the user, such as touch, grip, and proprioception. This is mainly done through vibration frequency and amplitude, but pulse duration, duty cycle, and shape can also be used to convey various types of information[10,11]. For vibrotactile feedback, it has been shown that utilizing a single element change, such as frequency or amplitude, is interpreted more accurately compared to coordinating changes, such as changing both frequency and amplitude[10].

The use of vibrotactile feedback systems has been shown to improve prosthetic usage and usability by wearers[12,13]. Vibrotactile feedback can also serve as a method to convey hand position, restoring a sense of proprioception to the user[14]. Multiple studies have shown that when vibrotactile feedback is used in conjunction with a myoelectric prosthetic users have an easier time performing given tasks[14–17]. While it is clear that prosthetic users tend to perform tasks better when coupled with some form of sensory feedback, what is still less developed is an effective training mechanism to teach users how to interpret sensations from a SFS. Often, studies focus on training for a single specific task without extra methodology. Subjects are given a training period where they only do that specific task before beginning the ‘actual’ testing portion, training the subject to interpret signals for a specific task instead of training users to interpret signals and apply them to potentially many tasks[12,15,18,19]. The goals of this study are twofold: (1) design a vibrotactile sensory feedback system that can be used to return a sense of touch and pressure to users; and (2) develop an effective and sequential learning mechanism users can follow to learn how to interpret feedback from a SFS after following a training regimen.

III. Design

A modular SFS was designed using an Arduino Mega 2560 for stimulation mapping from a force sensitive resistor (FSR) to a coin vibration motor (VPM2, Solar Robotics) and coded with Matlab (ver. R2022B). Figure 1 outlines a block diagram of the SFS set up.

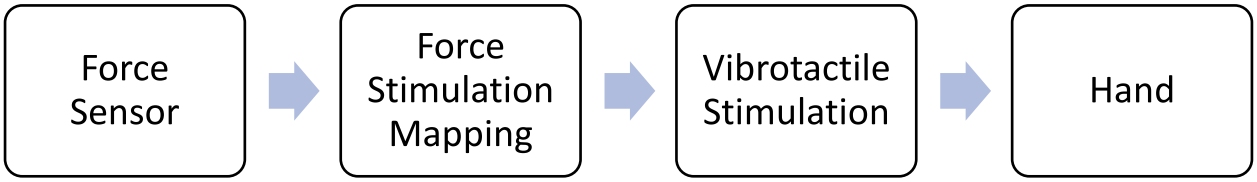

Figure 1: Block flow diagram of the SFS.

The SFS can support five different FSRs and five different coin vibration motors, one sensor per finger, that rest on top of the forearm of the user via a wrist strap. The location of the coin vibration motors on the skin can be changed as necessary. It was combined with a bionic hand, shown in Figure 2, with five degrees of freedom with the FSRs placed on the fingertips of the hand. For the purposes of training users to interpret signals from the sensory system as an initial experiment only a single fingertip was used. While this limits the results of this experiment to a single degree of freedom it will provide a basis to develop the training set further in the same manner. Ideally training would be expanded to all five fingertips and beyond.

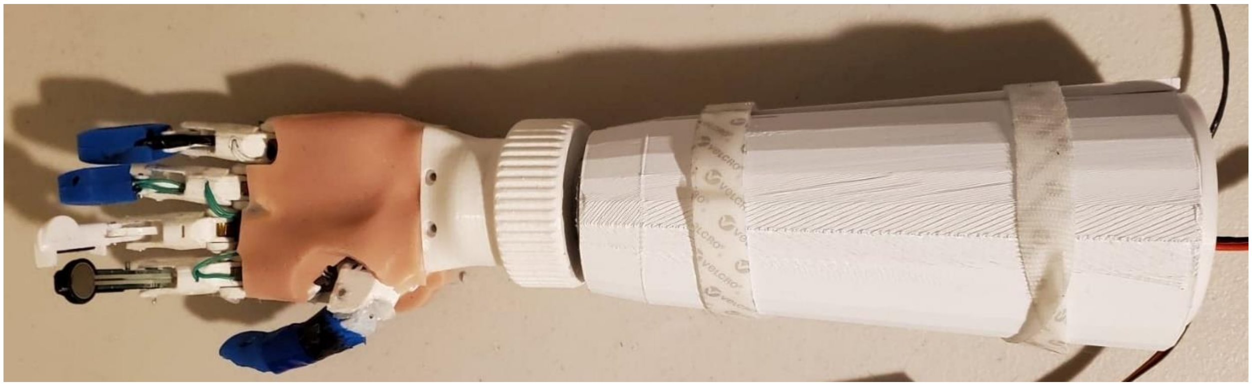

Figure 2: Testing set-up where the index finger has an FSR on the end.

i. Force Sensor Calibration

The force sensitive resistors, when pressed, vary in their detectable output voltage. The detected voltage output was measured using a voltage divider, as pictured in Figure 3.

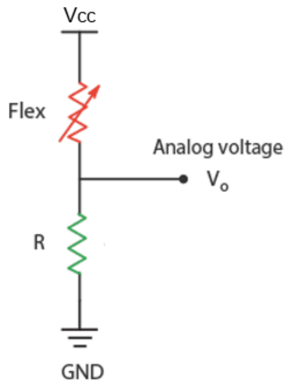

Figure 3: Diagram of the voltage divider circuit for the FSR.

The behavior of the FSR changes depending on the static resistor used across the voltage divider, shown. Equation 1 determines the measured analog voltage based on the voltage divider circuit.

$$V_0 = \frac{V_{cc}}{Flex+R} \tag{1}$$

A 2.2 KOhm resistor was used in the voltage divider as the static resistor. Voltage outputs to the Arduino measured between 0 to 5 V, with 5 V being the upper limit of detection of the sensor. To calibrate the Adafruit FSR sensors to force values in newtons, standard scale weights of 50, 100, 200, and 500 grams were used grams (ranging roughly between 0.5 to 5 N). A single sensor was used to calibrate. For calibration, each weight was placed on the center area of the sensor and measurements of the voltage output V_0 were taken for 10 seconds. These 10 second measurements were recorded and averaged as the correlated voltage output for that force. This was repeated 10 times for each weight at 50, 100, 200, and 500 grams. A logarithmic relationship was observed between the force applied to the FSR and the output voltage V_0, shown in Figure 4.

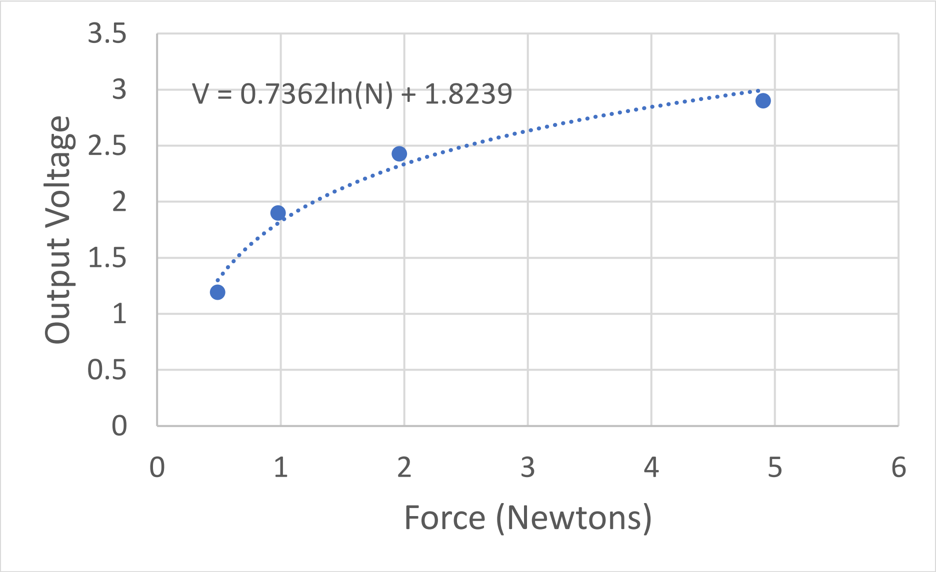

Figure 4: Mapping of force to output voltage of the FSR (Standard deviation bars are present but are too narrow to be visible).

Because the relationship between the force applied to the motor and the output voltage was found to be nonlinear, a nonlinear mapping correlating output voltage of the sensor to the input voltage of the motor was also used for mapping.

ii. Mapping

The force applied to the FSR was then mapped to the motor such that a range of 1-5 N would correlate to the entire operating range of the motor, from 1 – 3.5 V. The final mapping formed an exponential relationship between the force applied to the FSR and the output value of the motor. This was based on findings done in preliminary studies that at higher intensity levels, when more voltage is applied to the motor, the minimum noticeable difference best for users to distinguish changes in intensity is an exponential relationship as shown in Figure 5.

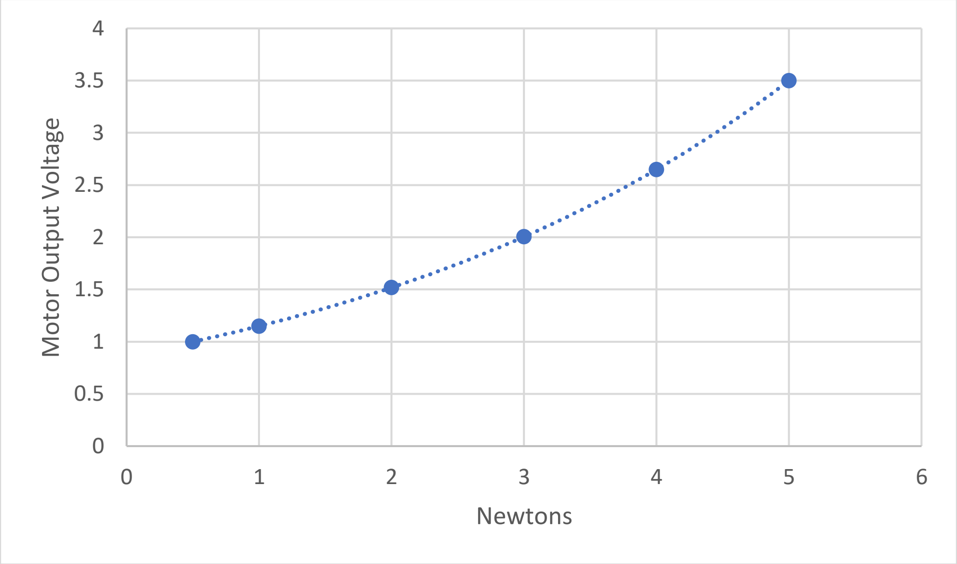

Figure 5: Mapping of force to the motor output voltage between 1 and 3.5 volts.

The mapping was done using the relationship presented in Figure 3 relating the force applied to the FSR in Newtons and the voltage output of the FSR. The voltage output of the FSR was fit using Excel to the voltage input of the coin vibration motor such that the relationship between the force applied to the FSR in Newtons and the output voltage to the motor would match the exponential relationship shown in Figure 5. The resulting regression was used to relate the voltage output of the FSR to the voltage input of the motor.

iii. Coin Motor Calibration

The frequency and amplitude of the coin vibration motors were characterized with an accelerometer (LIS3DH, Adafruit) at a sampling frequency of 700 Hz. The motor was placed underneath the accelerometer as shown in Figure 6 with the accelerometer on top of the vibration motor. This was to emulate the conditions the motor would be operating under when placed inside the armband. Three different VPM2 coin vibration motors were used for calibration so that a single motor was not the sole basis for calibration, designated as motors A, B, and C. Motor A would be run 10 seconds at a time while the accelerometer measured the change in acceleration of the motor in the z-direction only. These 10 second measurements would be repeated 20 times and then motor A would be switched out and replaced with motor B. This was repeated for motor B and motor C, and then another set of 20 measurements were taken for each motor again. Shown in Figure 7, when more voltage is applied to the motor the frequency does not significantly change but the amplitude increases linearly.

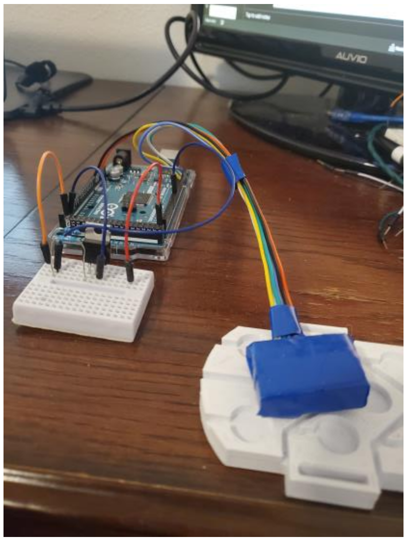

Figure 6: Testing set-up for coin motor calibrations.

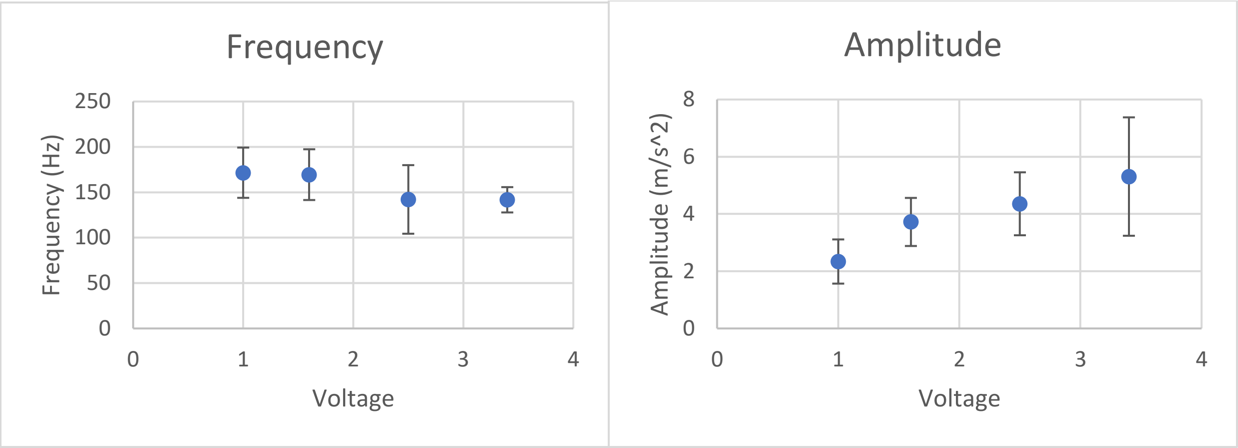

Figure 7: Voltage versus frequency and amplitude of the coin vibration motors.

Prior work has largely focused on how variation in frequency of vibrotactile devices like the VPM2 coin vibration motors is a useful indicator for users to interpret sensory information[9]. However, with the VPM2 motor only the amplitude can be adjusted. Experimental results presented later provide evidence that amplitude changes alone provide sufficient feedback for users to be able to perceive differences in stimulation.

IV. Methods

The evaluation of the SFS took place in three stages designed to gradually introduce participants to the sensations from the coin vibration motors and evaluate their interpretation of the signals, as shown in Figure 8. After receiving International Review Board approval (IRB-2021-1153) from the review board at Oregon State University and informed consent from all participants, they were trained to recognize and use five discrete force levels during the training regimen, corresponding to intensities ranging from 1-5 Newtons.

Figure 8: Training regimen to evaluate the SFS.

i. Calibration

The first stage was a calibration stage that evaluated the sensitivity of the participant to the different intensity levels of the coin vibration motor. The goal of this stage was to determine the minimum noticeable difference (MND) required for participants to differentiate the intensities of the five force levels, 1 through 5, corresponding to 1 through 5 newtons of force. The participants were asked to wear the armband pictured in Figure 9 with the coin vibration motor placed over the center of their forearm of their non-dominant hand. The armband remained on the non-dominant arm of the participant for the remainder of the study.

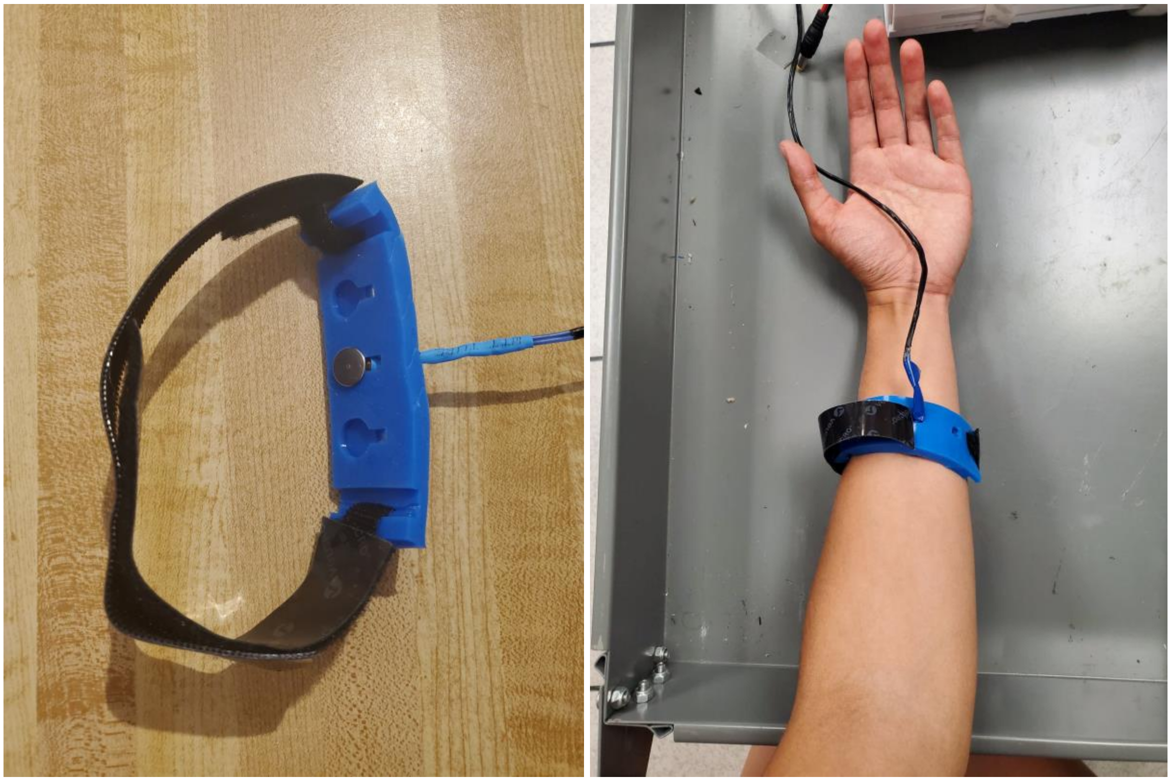

Figure 9: Armband worn by participants to hold the coin vibration motor in place.

Two pulses of vibrations were sent through the motor for one-second intervals with a one-second pause in-between. There was a chance these two pulses differed in voltage such that the mapped newtons of force when applied to the FSR would be approximately 0.15 N either above or below the initial force value, or that the two pulses were exactly the same. Because the threshold value was randomly above or below the initial force value, participants were also evaluated on the MND if the threshold was increased or decreased from the initial force value.

For a single initial force value participants would be tested six times, two where the initial force value and threshold were the same, two where the threshold was above the initial force value, and two where the threshold was below the initial force value. For the MND for the increased and decreased thresholds, this was evaluated only including the two events where the threshold value was the same as the initial force value and the two events where the threshold value was either above or below the initial force value. Because the vibration of the motor also generated a noise that could help users distinguish if pulses were different, ambient music was played in the background over the course of this and the following stages. The order of the vibrations, the initial force value or the threshold, were played in random order. All initial force values were tested in the same testing set. If participants could correctly identify from 5 out of the 6 pulses whether the pulses were the same or different that initial force value was removed from the testing pool and the threshold value was increased by another 0.15 N. This continued until all initial force values were accurately interpreted or until the threshold value increased to 1 newton. At that threshold, all initial force value values would be overlapping and it could no longer be considered an MND.

ii. Training

The purpose of the training stage was to teach users to correctly identify five different force values corresponding to force values between 1-5 newtons from the motor. To do this, users were trained under three different difficulty levels to gradually introduce the force values to them. These difficulty levels were easy, medium, and hard. The easy difficulty had only two force levels, the medium three, and the hard five, all corresponding to the scale outlined in Table 1.

Table 1: Force values in newtons for the easy, medium, and hard levels.

Mode	**Pulse**
Easy	1,5
Medium	1,3,5
Hard	1,2,3,4,5

For the training stage, participants were asked to identify what force value was sent through the motor. As with the calibration stage, music was played in the background to hide the sound of the motor. This continued at each difficulty until participants reached 80% accuracy in their identification or until there was no more improvement in accuracy. Within the difficulty levels each intensity was guaranteed to show up randomly in the set five times, such that the easy level had 10 trials, the medium 15, and the hard 25.

iii. Testing

For the final stage, the testing stage, users were asked to squeeze the FSR on the fingertip of the hand with their dominant hand and match a random force value from the hard level users trained on in the training stage. The purpose of this stage was to evaluate how well users learned and retained their ability to recognize the five distinct force values after the training stage. This emulates the environment that users would undergo when learning to control a bionic hand with sensory feedback, where users must learn to control the pressure applied to the hand for a variety of tasks, even if they are not familiar tasks. There were three different feedback conditions users were given to match the force with: with visual feedback only, with vibrotactile feedback only, and with both visual and vibrotactile feedback. This was to provide a comparison for the common condition that prosthetic users interpret sensory feedback, solely with visual feedback by looking at the prosthetic, to natural states where sensory feedback can be interpreted without visual input. If the haptic feedback only results are comparable to the visual only and visual with haptic results this provides evidence that the SFS is an effective means to return sensory feedback to prosthetic users.

During visual feedback users could view the force they were applying to the finger in real-time on a screen while the trial was ongoing without the motor vibrating. During vibrotactile feedback only users were only allowed to use the vibrations from the motor to determine the force they were applying to the finger. During the condition with both vibrotactile and visual feedback users could see how much force they were applying to the finger in real-time on the screen while the motor was also vibrating.

The three feedback environments were applied equally but appeared randomly over the course of 45 different trials. Each of the five force levels were guaranteed to randomly show up nine times over the 45 trials, five times for each level. Participants were instructed to reach and hold the requested force value for 10 seconds by squeezing the FSR sensor on the finger of the bionic hand. With the vibrotactile feedback condition, participants were allowed to look at the visual component after they had completed the trial for feedback. Metrics used to evaluate participant performance were the time it took to reach an acceptable range within the requested force, which was set to ± 0.5 N, the total time spent within the range over the whole 10 second trial, the time spent in range after first reaching the range and before leaving the range (indicated as time in range after first reach), the overall RMSE of the 10 second trial, the RMSE of the total seconds in range, the RMSE of time spent in range before leaving the range, and the RMSE of seconds 7-9 of the trial. The RMSE was calculated using Equation 2 below. Seconds 7-9 of each trial were chosen because some users would stop squeezing the finger shortly before 10 seconds had passed in anticipation of the end of the trial.

$$RMSE = \sqrt{\frac{\Sigma_i^N (x_i - \hat{x}_i)^2}{N}} \tag{2}$$

V. Results and Discussion

Table 2: Participant data.

Participant	**Gender**	**Age**	**Dominant Arm**
P1	Male	22	Right
P2	Male	25	Right
P3	Female	57	Right
P4	Male	57	Right
P5	Female	22	Right
P6	Female	22	Right
P7	Female	21	Right
P8	Female	22	Right
P9	Male	26	Left
P10	Female	63	Right

Ten participants with fully intact arms were recruited, four male and six female, between the ages of 21 to 63 for inclusion in the study as outlined in Table 2. All participants were right hand dominant except for one.

i. Calibration

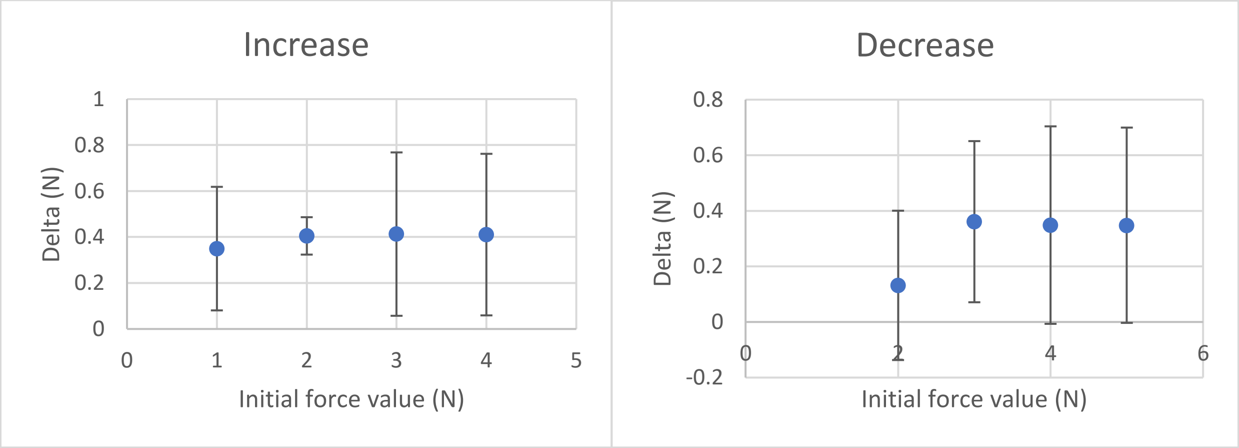

Figure 10: Minimum noticeable difference at each initial force value level for both increased and decreased threshold values with standard deviation bars.

The MND for each initial force value remained unchanged as the initial force value increased, as shown in Figure 10. All initial force value levels had large variation among participants. For the increasing threshold values two participants were found to be outliers in their minimum noticeable differences for the 2 N initial force value so their data was omitted for that point, leaving N = 8 for that value only. The results of Figure 10 support the rationale for mapping the newtons to the output of the motor in an exponential fashion, as the MND for each force value was relatively unchanged, meaning that users could detect the five different force values with the same distinction. This is desirable because it means the force values, though distinct in detection, are not noticeably different in the difficulty required to distinguish them.

The results of the calibration portion indicate that as the intensity of the vibration increases, a greater change is required for users to recognize that the intensity has shifted. This provides an important implication for the design of sensory feedback systems based on the physiological limitations of the users. This means that a discrete feedback design is limited by the range of vibration that the motor can output and if additional levels are desired to be included, they should be sufficiently spread apart so that the MNDs between the force values do not overlap.

ii. Training

The accuracy for the training portion was calculated in relation to how close a participant's guess was to the actual initial force value, as shown in Equation 3, where a guess further away from the actual force value contributes more to the error.

$$Accuracy = 1 - \frac{\sum\left|\frac{Guess - Actual}{5}\right|}{\#\ of\ Trials} \tag{3}$$

All participants except for one did three trials of the hard mode during the training stage. The excluded participant did exceptionally well during the first trial and was deemed trained enough to move onto the next stage. Results are presented in Figure 11. The easy and medium modes were done by all participants only once. Accuracy increased overall between the first and final trial as expected, but only slightly. A single factor ANOVA was performed on the data and the resulting p-value was 0.60, indicating that the results were not significantly different.

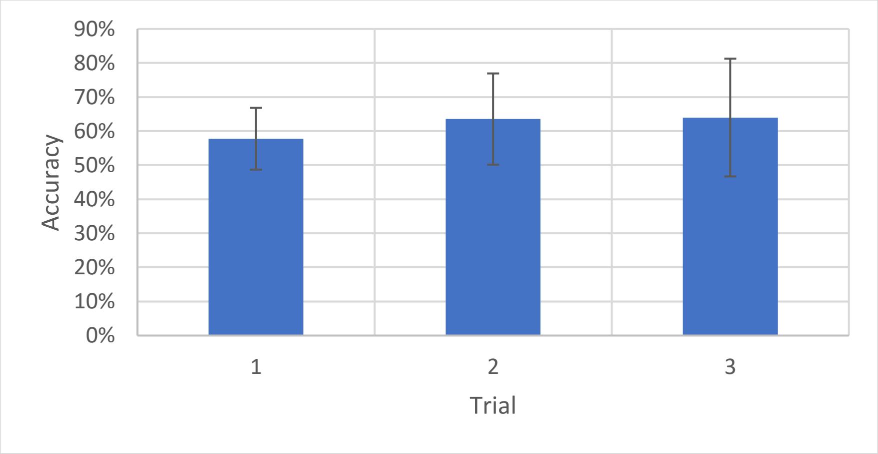

Figure 11: Overall accuracy of the hard mode during the training stage with standard deviation bars, P = 0.60.

Participants were able to learn how to recognize different stimulation levels in a relatively short period of time during a single training session that lasted less than two hours. The ability of the user to clearly identify different stimulation levels improved only marginally with additional iterations during the same session. However, it is anticipated that the users will improve their abilities substantially over long-term use of the sensory feedback system. Additional studies are needed to validate this hypothesis as the findings were not found to be significant but can provide evidence of possible trends while training users to interpret signals from an SFS.

iii. Testing

Table 3: Descriptive metrics of the testing stage for all participants. $P < 0.05$ for all metrics except for the first time in range.

Metric	**Visual**	**Vibrotactile**	**Both**
First time in range (s)	1.12 ± 0.47	1.20 ± 0.64	1.27 ± 0.33
Total time spent in range (s)	8.62 ± 0.58	4.19 ± 0.85	7.73 ± 0.54
Time spent in range after first reach (s)	6.60 ± 3.81	2.41 ± 3.18	5.96 ± 3.91
Overall RMSE	0.74 ± 0.45	1.08 ± 0.32	0.78 ± 0.24
RMSE of total seconds in range	0.15 ± 0.02	0.26 ± 0.05	0.22 ± 0.01
RMSE of time spent in range after first reach	0.17 ± 0.10	0.30 ± 0.10	0.21 ± 0.11
RMSE of seconds 7-9	0.21 ± 0.22	0.78 ± 0.29	0.32 ± 0.09

Table 3 outlines descriptive metrics for the testing stage. From a single factor ANOVA, all differences were found to be significant ($P < 0.05$) for all metrics except for the first time in range. Overall, for all three feedback conditions the time spent to get within the range was about 1 second. The total time spent in range was comparable between visual and both feedback conditions, at 8.62 and 7.73 seconds respectively. The time spent in range during the vibrotactile condition was roughly half that, at 4.19 seconds. Similar results for the time spent in range after first reaching the range, where visual and both were 6.60 and 5.96 seconds respectively while the vibrotactile condition was significantly lower at 2.41 seconds. Notably, the variation for the vibrotactile condition was very high at 3.18 seconds. The overall RMSE for visual and vibrotactile conditions were also similar at 0.74 and 0.78 respectively. For the vibrotactile condition the overall RMSE was slightly higher comparably, at 1.08. This trend was similar for the RMSE of other metrics as well, where the vibrotactile condition only had a comparably higher error.

For all three feedback conditions the time it took users to reach within range for the first time was around 1 second and the difference between the feedback conditions was not found to be significant, providing evidence that training did teach adequate recognition in users to achieve initial control over the SFS. However, the time users spent in range during the vibrotactile only feedback condition was about half the time spent in range with visual feedback only for both the total time spent in range and the time spent in range after first reach, indicating that more training will likely be necessary to teach users to have short-term control of the SFS. The RMSE of the seconds users spent in range with the visual and both feedback conditions were comparable for all metrics, with the RMSE for the vibrotactile only condition being significantly higher. Overall, users spent less time in range during the vibrotactile condition and had greater error during the time they were in range overall.

Each feedback condition was tested fifteen times. This was split up into three groups of five and evaluated over the course of the testing stage. A Jarque-Bera test of normality indicated that the data was not normal. Because of this, significance tests were done using Kruskal-Wallis one-way ANOVAs. Figures 12 and 13 compare the groupings for each of the major metrics.

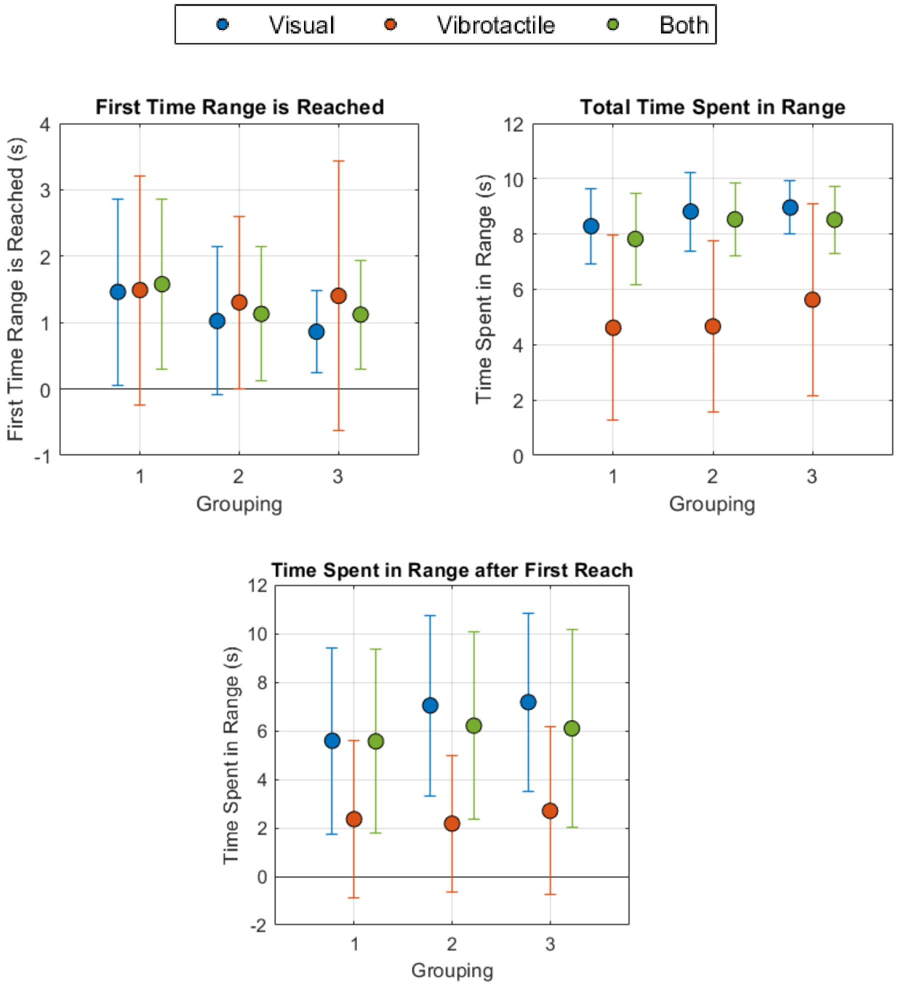

Figure 12: Comparison of time evaluation metrics for groupings of five (N = 5 for each grouping) for all feedback conditions with standard deviation bars. All variation was significant (P < 0.05) for all metrics except for the first time in range where P = 0.2.

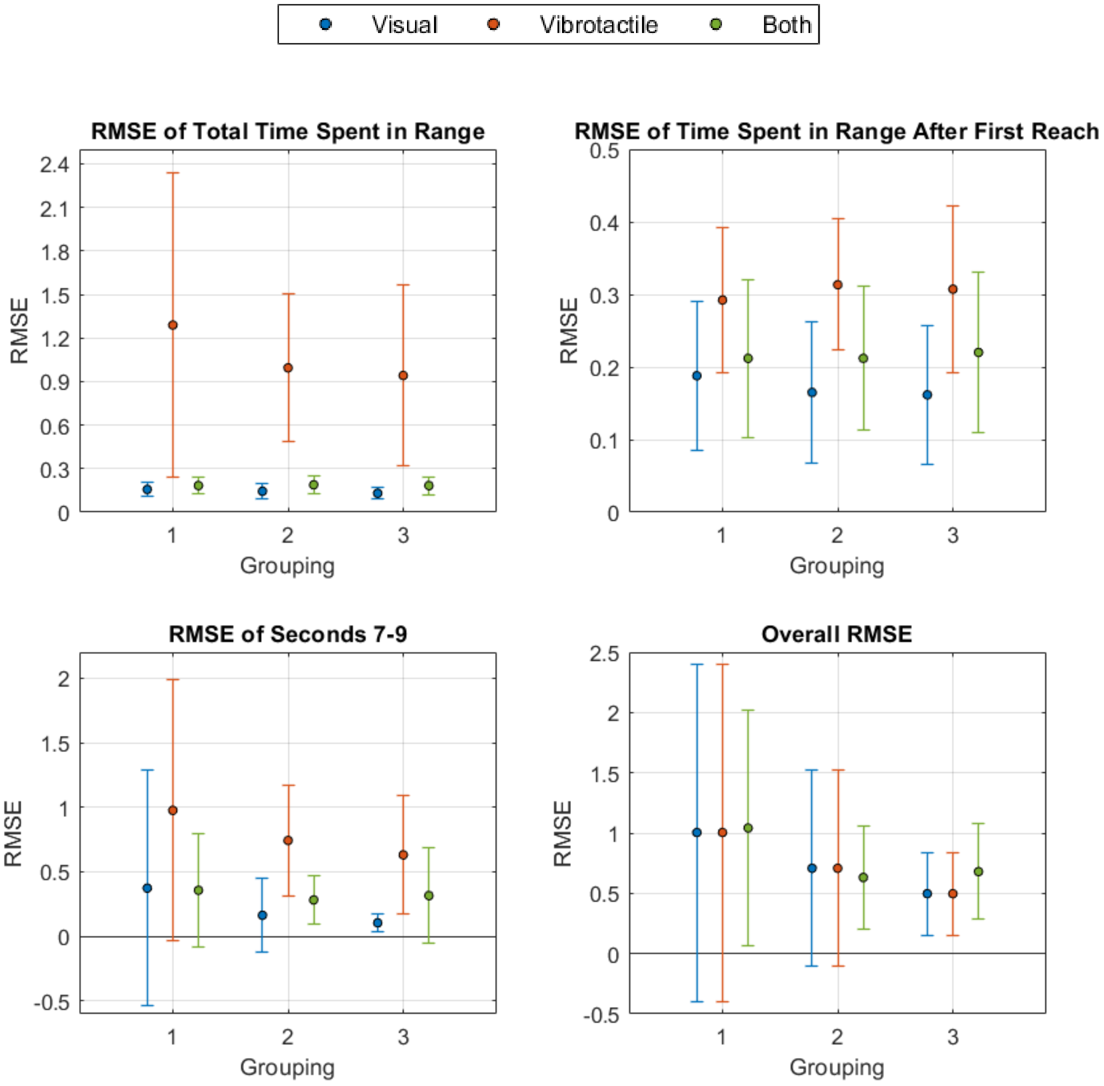

Figure 13: Comparison of time evaluation metrics for groupings of five (N = 5 for each grouping) for all feedback conditions with standard deviation bars. All variation was significant (P < 0.05) for all metrics except for Overall RMSE where P = 0.68.

In Figure 12 over the course of testing users slightly improved in the time they spent in range for the vibrotactile feedback condition only. In Figure 13 the RMSE of the total time spent in range and of seconds 7-9 of the trial also decreased over the course of testing for all three feedback conditions. For all metrics except for the overall RMSE the vibrotactile only feedback condition had much larger RMSE than visual and both feedback conditions and this remained higher as the trials continued. The overall RMSE was similar within each group for the three feedback conditions and gradually decreased as the trials progressed.

The results of the testing stage indicates that users can quickly get within range of desired force values but when holding force values steady visual feedback still provides important information that vibrotactile alone does not. However, while vibrotactile feedback alone is not comparable to visual feedback alone or when paired with visual feedback, users were able to complete the given tests and also showed improvement with in slightly increased time spent in range and lower RMSE values as the trials progressed. Because users showed improvement over time when tested with vibrotactile feedback only condition, this provides evidence that although users are interpreting a relatively unnatural sensation they can improve with training and practice at specific tasks.

Additionally, other sources of error may be at play, such as the inherent vibration of the motor generating difficulty keeping a hand steady when pressing on the FSR in addition to the learning curve required to reliably interpret the vibrations of the motor. For sensory design considerations, it may be preferable to work on the lower end of intensities to avoid creating possible difficulty with movement and control due to the motor vibrating at high amplitudes.

VI. Conclusions

Prosthetic abandonment is a common problem, especially with myoelectric prostheses. Part of the stated reasons for abandonment is difficulty of use. Inherently, myoelectric prostheses lack sensory feedback. When compared to a natural arm and hand this creates an increase in difficulty for the user due to lack of feedback about the whereabouts of the position and strength output of the prosthetic. When sensory feedback systems are combined with prostheses there is improvement in user performance when completing tasks, but there is not a regular and methodological training method for teaching users how to interpret sensory feedback signals. In this study a sensory feedback device was developed using a force sensitive resistor and a coin vibration motor. Ten participants were recruited to participate in a study to evaluate the design of the system and to determine a method to how best to teach users to use the system. After users completed a calibration stage and a training stage, users were tested on their ability to interpret sensations from the sensory feedback device. It was found that the vibrotactile feedback alone from the sensory feedback device performed worse compared to providing visual feedback alone and both visual and vibrotactile feedback, but that over the course of the test users demonstrated increased time in their time spent within the desired force level range during the trials and with decreased error. This provides evidence that users can improve their interpretation of the signals from the sensory feedback device given training and practice. This work provides the basis for developing more effective sensory feedback systems and the training method used to teach users how to interpret signals from them.

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