

AWARD NUMBER: W81XWH-15-1-0417

TITLE: Sensory Feedback for Lower Extremity Prostheses Incorporating Targeted Muscle Reinnervation (TMR)

PRINCIPAL INVESTIGATOR: Eric Rombokas, PhD

CONTRACTING ORGANIZATION: Seattle Institute for Biomedical and Clinical Research

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Fort Detrick, Maryland 21702-5012

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14. ABSTRACT This research aims to improve stair descent for lower limb amputees by providing sensory feedback of foot placement. We seek to provide this capability as a robust and widely applicable adjunct to currently used prosthetic hardware. We also seek to leverage emerging of nerve transfer surgeries performed with amputations or as revisions. These surgeries, including Targeted (Sensory) Reinnervation and Regenerative Peripheral Nerve Interfaces (RPNIs) can produce profound sensory effects. Touches at the site of the surgery can feel like they are originating from the amputated limb. This capability is an unprecedented opportunity to provide sensory feedback that is intuitive and useful, but sensory recovery after the surgery is not well understood. The two Specific Aims are to (1) Systematically map and characterize the sensory capabilities of lower extremity Targeted Reinnervation sites under tactile stimulation, and (2) Measure the effects of vibrotactile cues of foot placement on stair descent of transtibial amputees. Over the course of this research we made significant progress in both of these domains. This report summarizes that progress and describe our vision for the future of this line of research.								
15. SUBJECT TERMS Prosthetic Limb, Lower Extremity, Mobility, Locomotion, Stair, Sensory Replacement, Sensory Feedback, Vibrotactile, Haptic, Psychophysics, Targeted Reinnervation, Targeted Muscle Reinnervation, Targeted Sensory Reinnervation								
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Introduction

The purpose of this research has been to improve stair descent for lower limb amputees by providing sensory feedback of foot placement. We seek to provide this capability as a robust and widely applicable adjunct to currently used prosthetic hardware. We also seek to leverage the new emergence of nerve transfer surgeries performed with amputations or as revisions. These surgeries, including Targeted (Sensory) Reinnervation and Regenerative Peripheral Nerve Interfaces (RPNIs) can produce profound sensory effects. Touches at the site of the surgery can feel like they are originating from the amputated limb. This capability is an unprecedented opportunity to provide sensory feedback that is intuitive and useful, but sensory recovery after the surgery is not well understood.

Therefore the two Specific Aims of this project are to (1) Systematically map and characterize the sensory capabilities of lower extremity Targeted Reinnervation (TR) sites under tactile stimulation, and (2) Measure the effects of vibrotactile cues of foot placement on stair descent of transtibial amputees.

Over the course of this research we made significant progress in both of these domains. This document will summarize that progress and describe our vision for the future of this line of research.

Keywords

Prosthetic Limb, Lower Extremity, Mobility, Locomotion, Stair, Sensory Replacement, Sensory Feedback, Vibrotactile, Haptic, Psychophysics, Targeted Reinnervation, Targeted Muscle Reinnervation, Targeted Sensory Reinnervation

Accomplishments

What are the major goals of the project?

Specific Aim 1 is to systematically map and characterize the sensory capabilities of lower extremity Targeted Reinnervation (TR) sites under tactile stimulation. This aim is divided into two Major Tasks:

Major Task 1: Development of Lower-Limb Vibrotactile Stimulation Technologies

Subtask 1: Develop movable vibrotactile stimulator

Subtask 2: Develop 3-tactor vibrotactile array

Subtask 3: Develop mapping procedure to methodically explore TR site and identify sensory capabilities.

Milestone #1: *Manuscript on technology development*

Major Task 2: Mapping and characterization studies of targeted reinnervation (TR) sites

Subtask 1-3: IRB and HRPO approvals

Milestone #2: *All human subjects review approvals received*

Subtask 4: Systematic mapping studies of transtibial amputees having TR procedure

Subtask 5: Systematic mapping studies of transtibial amputees not having TR procedure

Milestone #3: *Manuscript on mapping and characterization of sensory capabilities of TR subjects with respect to vibrotactile stimulation.*

Specific Aim 2: Determine effects of vibrotactile cues of foot placement on stair descent of transtibial amputees.

Major Task 3: Development of integrated motion-capture stair machine for self-selection of speed

Subtask 1: Adaptation of commercially-available stair mill to report stair locations and accept real-time changes to rate

Subtask 2: Algorithms for integrating motion capture of user and stairs to maintain stair descent for varying user speed

Major Task 4: Functional study of feedback for stair descent

Subtask 1-3: Submit documents for VA IRB and HRPO review

Milestone #4 : All human-subjects review approvals (IRB and HRPO) received.

Subtask 4: Stair descent studies of vibrotactile sensory feedback for stair descent of transtibial amputees

Milestone #5: Manuscript on foot placement and self-selected speed given feedback during stair descent

What was accomplished under these goals?

Specific Aim 1 is to systematically map and characterize the sensory capabilities of lower extremity Targeted Reinnervation (TR) sites under tactile stimulation. This aim is divided into two Major Tasks:

Objectives:

Major Task 1: Development of Lower-Limb Vibrotactile Stimulation Technologies

Major Task 2: Mapping and characterization studies of targeted reinnervation (TR) sites

Specific Aim 1 Major Activities and Accomplishments:

We created several generations of vibrotactile stimulation systems tailored to this application. These systems include methods for sensing foot placement and loading forces at the foot, stimulation arrays and “tactors,” and integrated hardware and software. We have produced a versatile and dependable hardware and software solution stack suitable for laboratory or out-of-laboratory, or even potentially take-home, use.

We created a tactile stimulation wand that allows for careful control of force and frequency of stimulation, and a new cam-follower vibrotactor design (Figure 1.) We demonstrated some novel use cases for this type of design (Figure 2.)

Through design revisions and perceptual and functional tests, this line of research has culminated in a flexible and lightweight system that can be deployed as an aftermarket modification to any prosthetic or orthotic device that can accommodate an insole. (See Figure 5) The system is integrated with commercially available hardware and computing (cellphone) for

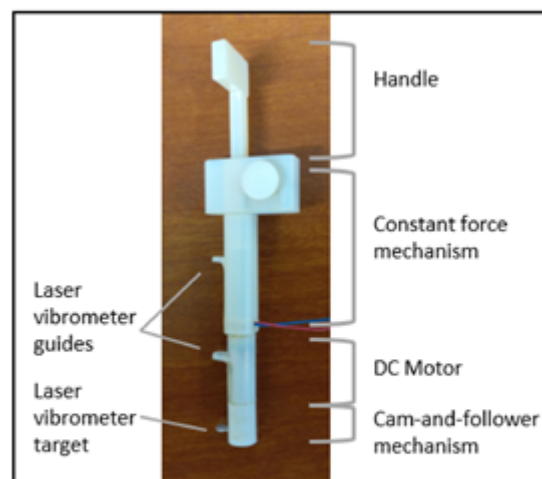


Figure 1: Tactile stimulation wand. The design allows for careful measurement and control of force and frequency.

maximum reliability and minimal custom construction.

We created a quantitative and flexible protocol and associated software for characterization of sensory capabilities. The typical standard for determining the extent and characteristics of sensation is to manually palpate the skin and note verbal responses, such as “it feels like my thumb.” These responses are annotated and sometimes depicted graphically but lack precise quantitative comparability. They also do not typically provide the precision necessary for a high-fidelity sensory display. We developed a Graphical User Interface that allows for the amputee to indicate the

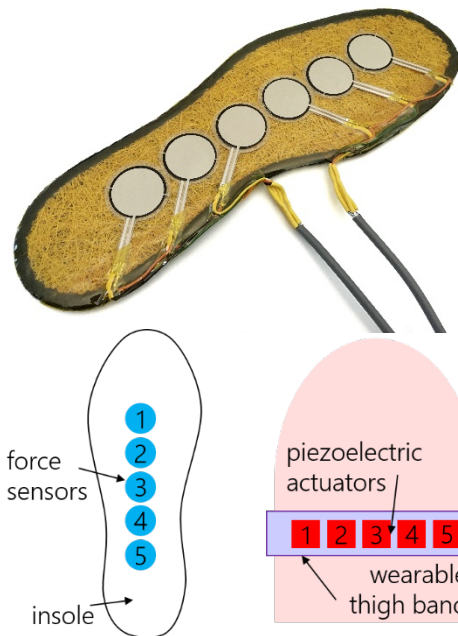


Figure 3: Foot placement sensory feedback scheme. The insole is pictured with exposed sensors but they are typically embedded inside. The wearable factors are pictured in Figure 3.

presence, and apparent origin, of sensory stimuli.

The character of the sensations (eg. “buzzing” or “brushing my skin”) can also be annotated easily. Using this system requires no interpretation by the person administering the stimuli. These fast responses also allow for more repetitions and diversity of stimulation sites.



Figure 2. High Density Cam- design for arrays (left) and integrated with a virtual reality headset (right.)



Figure 4. An array of powerful piezoelectric vibrotactors in custom housings along a thigh band for foot placement cues.

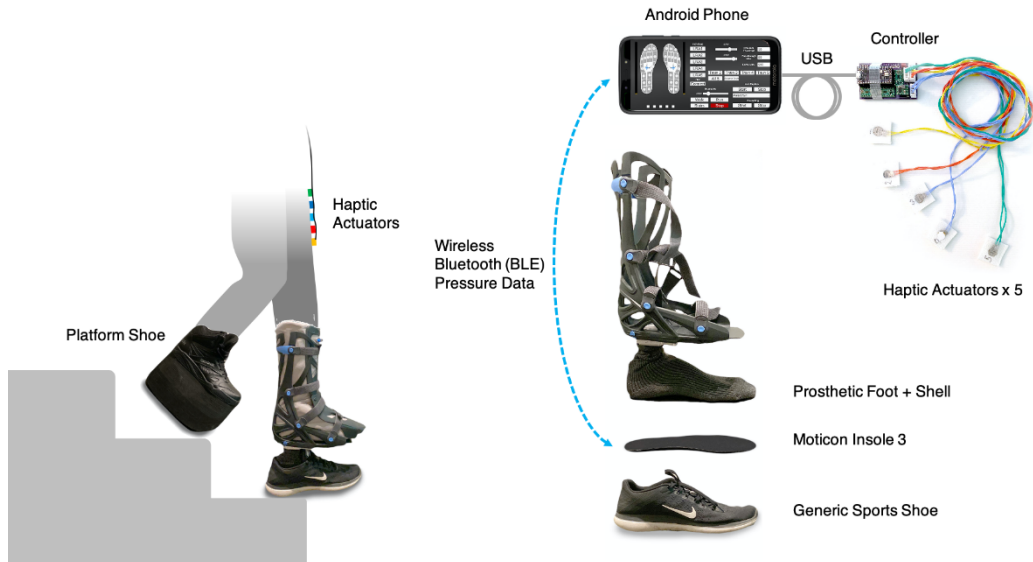


Figure 5. Integrated sensors, computing, and tactile stimulators system. In this case it is depicted with a “bypass” prosthesis. The system can be easily integrated with any prosthetic/orthotic hardware.

A Challenge: Informed Consent Documentation Lost:

We encountered a challenge in disseminating the results of the sensory characterization and vibrotactile stimulation systems. During a move into new laboratory space, the consent documents for this research were lost. This has prevented us from reporting new findings, and has arrested progress while we resolve the issue. Additional details are included in the annual reports. We anticipate restarting this line of research under new oversight in the new year.



Figure 6: Graphical User Interface for indicating perceived touches.

Unexpected multisensory effects

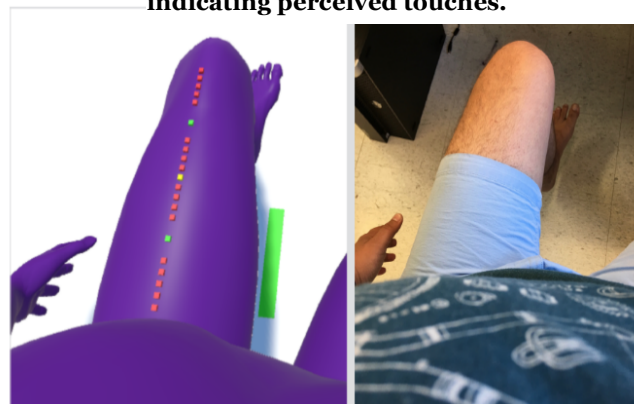
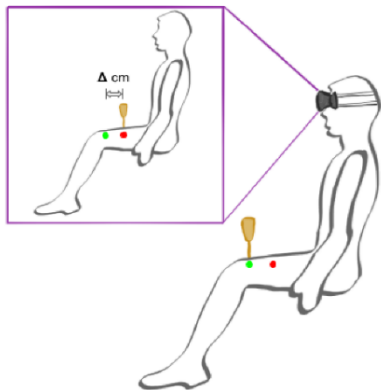


Figure 7: Visual depiction of touch in virtual reality (red dot, left) is delivered with a spatial offset from the actual location of touch (left dot, left.) The two panels on the right side of the figure depict the participants’ view in VR and their real body.

As a result of observations during our tactile stimulation and sensory characterization research, we conducted some fundamental research to better understand multisensory effects on perception. Our observations of sensory acuity were highly variable and context-dependent. However, in order to make a high-fidelity tactile display, it is important to know what “high-fidelity” means. A key factor is how closely spaced an array of tactors would need to be in order to correctly provide information about forces on the foot, or more simply, cues of foot placement. We investigated the role of vision in modulating the apparent perception of the location of tactile stimuli. We developed a visuo-tactile two point discrimination test probe sensory fusion. In a series of experiments we investigated human sensitivity to spatial mismatch between visual and tactile stimuli. See Figures 7 and 8.

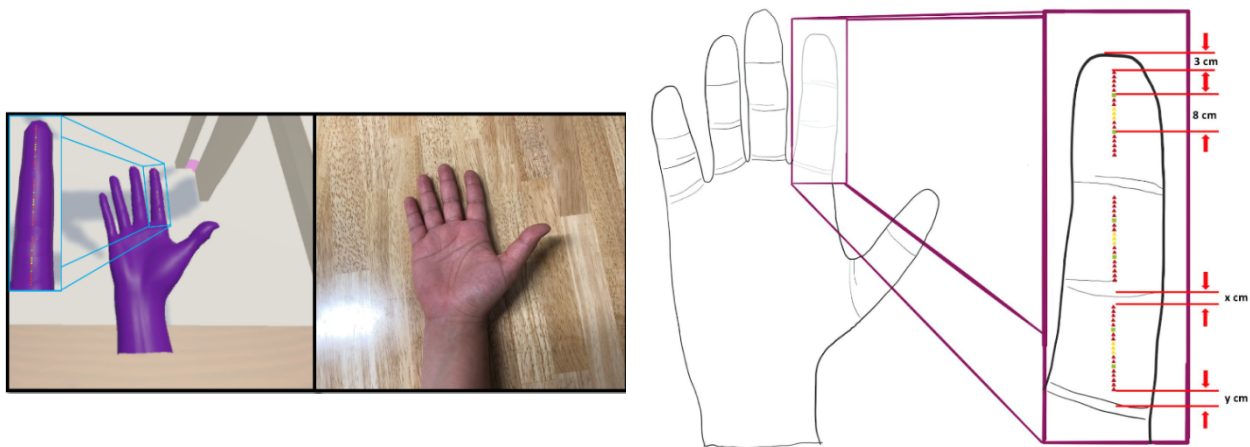


Figure 8: Visual-tactile two point discrimination test. Visual depiction of touch in virtual reality is delivered with a spatial offset from the actual location of touch.

These results have led to further investigations of participants indicating feeling “body ownership” over surrogate virtual, or prosthetic, limbs. These stimuli are similar to those used in mirror therapy for treating phantom limb pain. We are now exploring how these effects could be leveraged for therapy for phantom limb pain, as well as providing the subjective sensation of the prosthesis being a part of the body.

Specific Aim 2: Determine effects of vibrotactile cues of foot placement on stair descent of transtibial amputees.

Objectives:

Major Task 3: Development of integrated motion-capture stair machine for self-selection of speed

Major Task 4: Functional study of feedback for stair descent

Specific Aim 2 Major Activities and Accomplishments:

We have conducted limited tests of participants using the sensory feedback systems, establishing best practices for tactor placement, outcome testing, sensory discrimination tests, and qualitative feedback. These have ranged from foundational sensory stimulation studies (see Figures 10,11) to the effects of feedback on perception of foot placement (Figures 11,12) to a limited full ambulation study (Figure 13.) We are poised to complete these full studies once restrictions related to the pandemic and institutional oversight are resolved, as described above.

Speed-adapting Stairmill

We developed a speed-adapting stair descent machine. This device is based on a commercially available stair exercise product, but modified to operate in descent mode (opposite the normal direction of an exercise stairmill) and to sense the location of the user in order to adapt the speed of operation. The commercially available device normally uses electromechanical resistance via a transmission system to the steps, intended for use in stair ascent. Our design calls for replacing the alternator with a powered motor for reverse operation (Figure 9). We envision this device being used to establish long-term stair behavior in a way that a short course of only a few steps cannot. The “rise” of the steps is higher than standard ADA-approved steps, however, so it is only appropriate for users who are comfortable with stair descent.



Figure 9: Stair Descent Machine. We have replaced the resistive alternator with a powered motor for reverse direction operation.

Sensory Feedback Studies

We conducted studies to understand and demonstrate how sensory feedback can be used by participants to better estimate the forces on the prosthetic foot, and their foot placement on stairs. We demonstrated that the system provides a marked improvement in their awareness of foot placement relative to the stair edge. Figures 10 and 11 depict results from early hardware revisions.

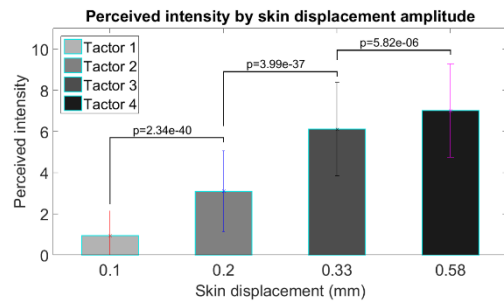


Fig. 8. Perceived touch intensity for different skin displacement amplitudes. The subjective perceived intensity increased with the skin displacement amplitude. Amplitudes are perceived different from each other(all p-values<0.05)

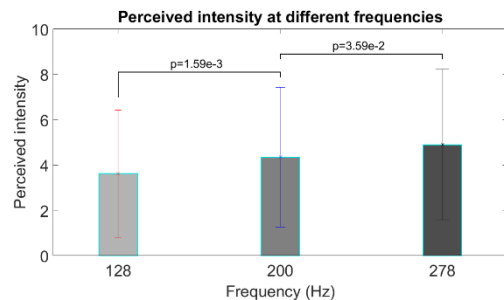


Figure 9. Perceived touch intensity for different frequencies. The subjective perceived intensity increased with frequency. Frequencies are perceived different from each other(all p-values<0.05)

Figure 10: Perceived intensity of the cam-follower vibrotactor for varying frequencies and amplitude.

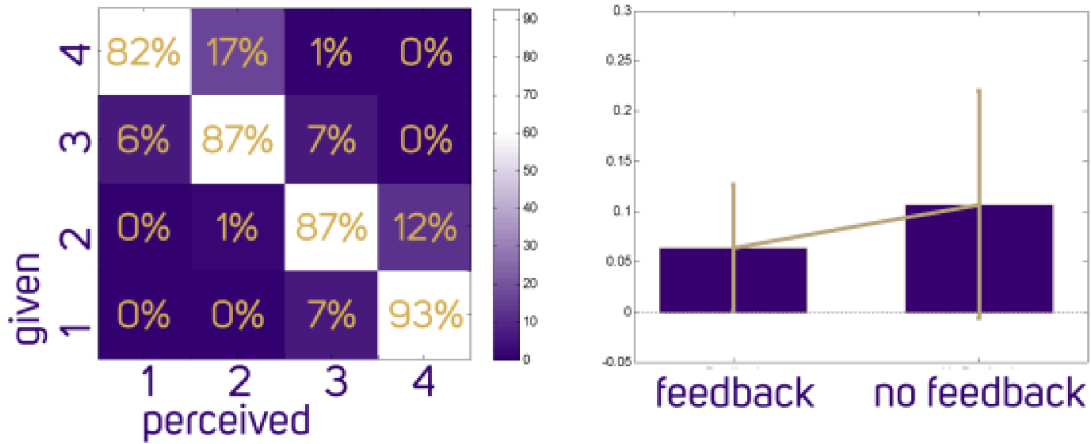


Figure 11. Confusion matrix (left) for discriminating between stimulation at each of the 4 possible sites using the first hardware revision. This demonstrates that subjects can feel the difference between different sites of stimulation. Reduced error (right) when estimating the position of the foot with respect to the edge of a hidden stair step.

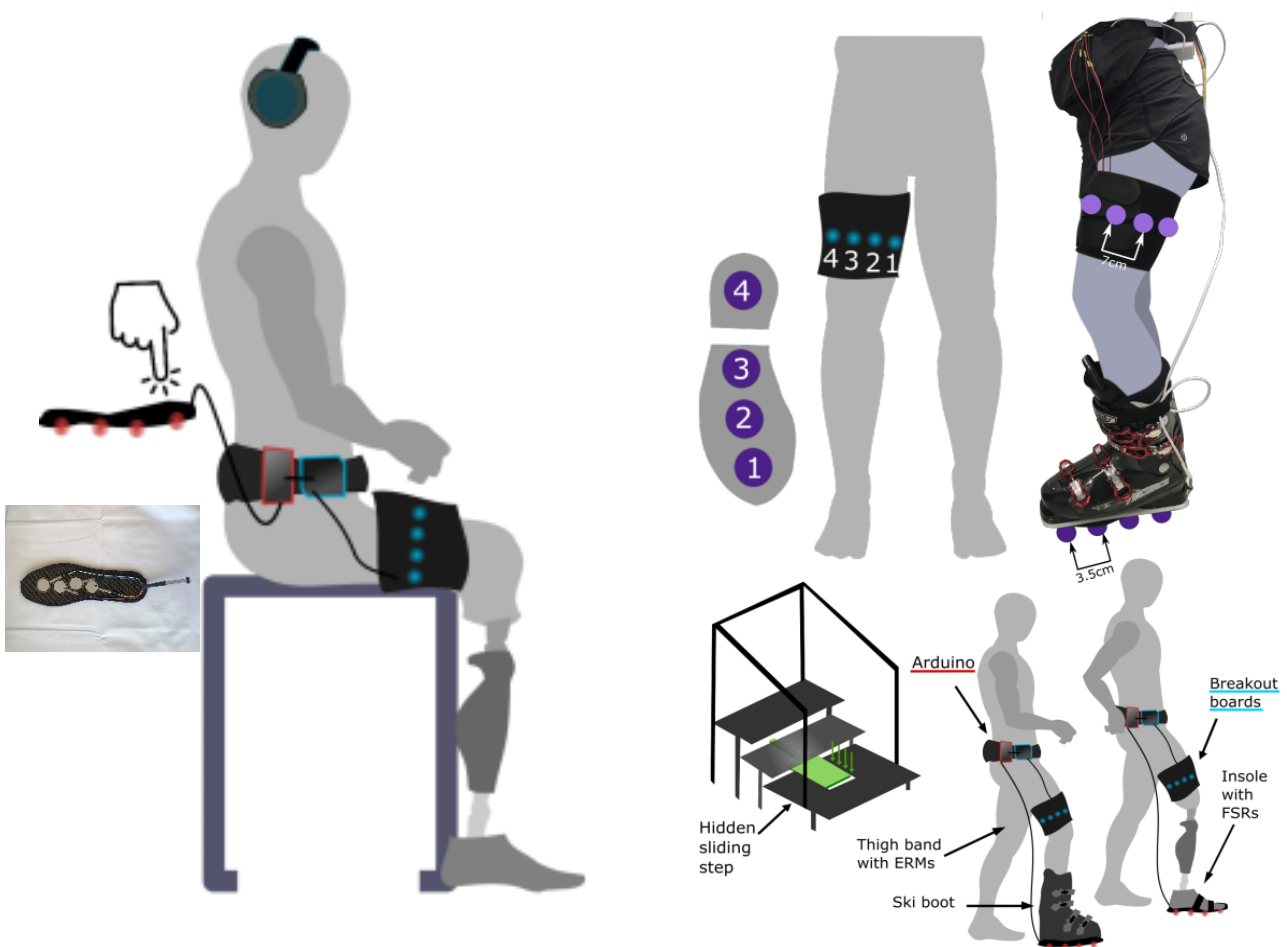


Figure 12. Revised Sensory Feedback System. Ability to discriminate among different stimulation locations (left) and ability to estimate foot placement on a hidden step (right) was tested for 12 control participants wearing a ski boot and 2 below-knee prosthesis users using their regular prosthesis (right).

These positive results were also confirmed using revised hardware and software in a foot placement discrimination experiment. Figures 12 and 13 depict the experimental apparatus, results for discrimination of sensory stimuli, and improvements in accuracy in the presence of the feedback.

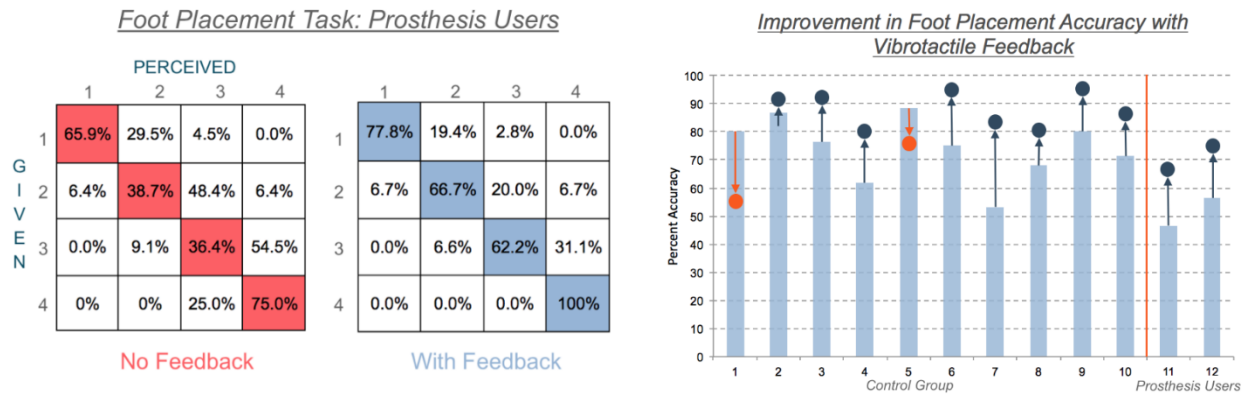


Figure 13: Improvement in awareness of foot placement relative to the stair edge while using the sensory feedback system. On the left are the “confusion matrices” for estimation of foot position. Percentages along the diagonal are correct. The blue diagonal, with feedback, consists of higher accuracy percentages than the red, without feedback. The panel on the right depicts the individual performance, as simple percentage accuracies.

Stair Ambulation Test

Based on these promising results, we have prepared full stair ambulation tests. We performed a full systems test, with a non-amputee wearing a ski boot prosthetic limb surrogate, of the sensory feedback system on real stairs. We measured stimulation vs. no-stimulation performance, body kinematics (joint angles from XSENS wearable motion tracking system), foot placement, and eye tracking (Pupil Labs, Inc.) to understand the cognitive load associated with visual confirmation of foot placement location. Based on this test we have performed system improvements required to translate the feedback system to fully dynamic stair ambulation. See Figure 14.



Figure 14: Full stair ambulation test including full body kinematic recordings and eye gaze tracking for quantification of performance changes under stimulation.

Collaboration with surgeons performing nerve revision surgeries

We have been collaborating with local surgeons Dr. Dennis Kao and surgical resident Dr. Katie Liu, who are performing TR and RPNI procedures at the University of Washington, as well as surgeons and researchers in Michigan, Dr. Deanna Gates and Dr. Ted Kung, who are performing primarily Regenerative Peripheral Nerve Interface procedures. We have explored the high prevalence of “referral of sensation” in residual limbs (typically described as occurring after TR surgery), but have found that referral of sensation occurs often even without TR surgery. This presents an unexpected opportunity to create custom feedback arrays based on the resultant sensory maps and increases the impact that sensory feedback arrays could have. We are exploring the use of custom maps of cutaneous referred sensation for haptic feedback upon recommencement of research.

Opportunities for training and professional development

Nothing to report. The grants funds for this project were not awarded to provide training and professional development opportunities.

How were results disseminated to communities of interest?

Nothing to report. All dissemination was standard for research project activities without specialized outreach.

Plans for next reporting period

This is the final report for the funded research under this grant. Pending resolution of research oversight and pandemic-related challenges, we will continue this line of research, submit proposals for continued work, and complete publication targets that are in review and preparation.

Impact

Impact on the principal discipline of the project

This research has demonstrated the first sensory feedback system for stair ambulation. It has established basic principles for vibrotactile stimulation paradigm, including tactor placement, stimulation parameters, and novel tactor designs. This research has also produced a protocol and software for sensory characterization following amputation that is fast, repeatable, and minimizes bias. The research supported by this award also catalyzed foundational explorations of human multisensory processes that could be key in the future for design and implementation of sensory augmentation systems.

Impact on other disciplines

Nothing to report.

Impact on technology transfer

The revised technical systems developed for these experiments are significantly more robust and reliable than those available before this research. Once proven in more functional experiments, they may constitute a package suitable for technology transfer. There are no inventions to report at this time.

Impact on society

Nothing to report.

Changes / Problems

Changes in approach

Nothing to report.

Problems or delays

We encountered a challenge in disseminating the results of the sensory characterization and vibrotactile stimulation systems (Specific Aim 1). During a move into new laboratory space, the consent documents for this research were lost. This has prevented us from reporting new findings, and has arrested progress while we resolve the issue. Additional details are included in the prior annual reports. We anticipate restarting this line of research under new oversight in the new year.

Impacts on expenditures

The delays discussed above resulted in grant funds remaining at the end of the project. A final FFR will be submitted reflecting the balance and unused funds returned to the Government.

Significant changes in use or care of human subjects, vertebrate animals, biohazards, or select agents

Nothing to report.

Products

Publications, conference papers, and presentations

Journal Publications

Caballero D, Sternad D, Hogan N, and Rombokas E “Sensory contribution to dynamic primitives” (In Preparation)

Caballero D, and Rombokas E “Sensitivity to conflict between visual touch and haptic touch in the hand: a computational perspective.” (In Preparation)

Astrini Sie, Maxim Karrenbach, Charlie Fisher, Shawn Fisher, Nathaniel Wieck, Callysta Caraballo, Elisabeth Case, David Boe, and Eric Rombokas “Descending 13 Real World Steps: A Dataset and Analysis of Stair Descent. (In Review)

Caballero D and Rombokas E “Sensitivity to conflict between visual touch and tactile touch”, IEEE Transactions on Haptics, 25 July 2018, DOI: 10.1109/TOH.2018.2859940

Peer-reviewed Conference Publications (note: engineering conferences are peer-reviewed, full publications, not abstracts as typical in medical conferences)

Sie A, Fisher C, Karrenbach M, Caraballo C, Case E, Muir B, and Rombokas E “Wearable Cues for Walking: Assessment of Haptic Timing for Stride Adjustments.” (In Review)

Rokhmanova N, and Rombokas E “ Vibrotactile Feedback Improves Foot Placement Perception on Stairs for Lower-Limb Prosthesis Users” 2019 IEEE 16th International Conference on Rehabilitation Robotics (ICORR), June 24-28, 2019, Toronto, Canada

Sie A , Boe, D, and Rombokas E “ Design and Evaluation of a Wearable Haptic Feedback System for Lower Limb Prostheses during Stair Descent” IEEE International Conference on Biomedical Robotics and Biomechatronics – Biorob2018, Enschede, Netherlands.

Sie A, Realmuto J, and Rombokas E. “A Lower Limb Prosthesis Haptic Feedback System for Stair Descent.” Frontiers in Biomedical Devices, BIOMED - 2017 Design of Medical Devices Conference, DMD 2017

Websites or other Internet Sites

Nothing to report.

Technologies or techniques

Nothing to report.

Inventions, Patent Applications, and/or Licenses

Nothing to report. See discussion in “Impact on Technology Transfer”

Other Products

Nothing to report.

Participants and Other Collaborating Organizations

Information provided for: (1) PI; and (2) each person who has worked at least one person month per year on the project during the reporting period of 9/30/2015-9/29/2020 regardless of the source of compensation; calculated by the sum of all effort divided by a 5-year reporting period (to find those with at least one person month per year on average).

Nearest person month worked = Sum of all calendar months effort for the period from 9/30/2015-9/29/2020.

Name: Eric Rombokas
Project Role: PI
Researcher Identifier (e.g. ORCID ID):
Nearest person month worked: 12
Contribution to Project: Unchanged
Funding Support: Unchanged

Name: David Boe
Project Role: Research Specialist
Researcher Identifier (e.g. ORCID ID):
Nearest person month worked: 26
Contribution to Project: Unchanged
Funding Support: Unchanged

Name: Luke K. Johnson
Project Role: Research Assistant
Researcher Identifier (e.g. ORCID ID):
Nearest person month worked: 12
Contribution to Project: Unchanged
Funding Support: Unchanged

Name: David Caballero
Project Role: Research Assistant
Researcher Identifier (e.g. ORCID ID):
Nearest person month worked: 24
Contribution to Project: Unchanged
Funding Support: Unchanged

Name: Huiwen Guo
Project Role: Research Assistant
Researcher Identifier (e.g. ORCID ID):
Nearest person month worked: 5
Contribution to Project: Unchanged
Funding Support: Unchanged

Name: Lalit Palve
Project Role: Research Assistant
Researcher Identifier (e.g. ORCID ID):
Nearest person month worked: 14

Contribution to Project: Unchanged
Funding Support: Unchanged

Name: Nataliya Rohkmanova
Project Role: Research Assistant
Researcher Identifier (e.g. ORCID ID):
Nearest person month worked: 12
Contribution to Project: Unchanged
Funding Support: Unchanged

Name: Astrini Sie
Project Role: Research Assistant
Researcher Identifier (e.g. ORCID ID):
Nearest person month worked: 19
Contribution to Project: Unchanged
Funding Support: Unchanged

Changes in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period

Revised Other Support Attached.

Other organizations involved as partners

Nothing to report.

Special Reporting Requirements

Quad chart

See attachments

Nonexpendable personal property acquired with award funds

Report cumulative listing of nonexpendable personal property acquired with award funds for which title has not been vested to the recipient: Not applicable. Tangible personal property acquired in whole or in part with award funds is considered to be exempt property in accordance with 2 CFR Parts 200.312 and 200.313. Title to all such exempt property vested in SIBCR (as the recipient) upon acquisition without further obligation to the Federal Government, except that the USAMRAA Grants Officer could require title be transferred to the Federal Government or to a third party if the project or program for which the equipment was purchased were transferred to a third party. This grant was not transferred to a third party.

Residual Inventory

There is not a residual inventory of unused supplies exceeding \$5,000 in total aggregate value.

Appendices

Revised Other Support for PI.

Sensory Feedback for Lower Extremity Incorporating TMR

MR140172 Neuromusculoskeletal Injuries Research Award

Funding Opportunity Number: W81XWH-14-DMRDP-CRMRP-NMSIR



PI: Eric Rombokas

Org: Seattle Institute for Biomedical and Clinical Research Award Amount: 1.5M

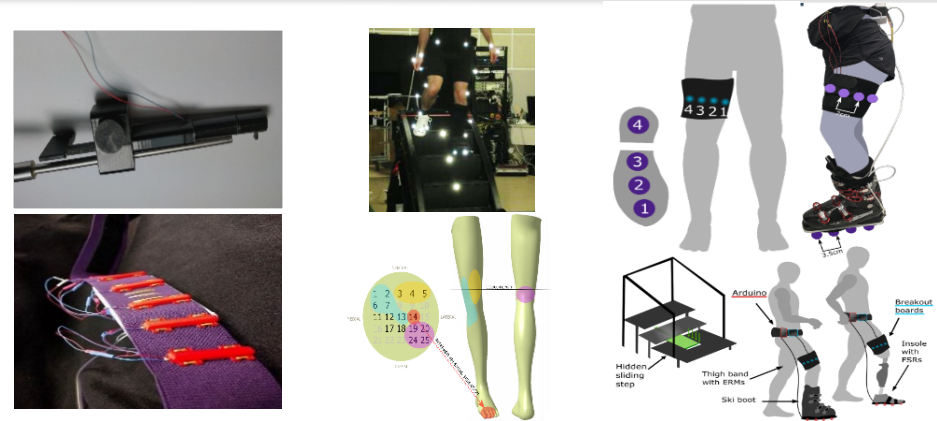
Study Aims

- Map and characterize the sensory capabilities of lower extremity Targeted Reinnervation (TR) sites under vibrotactile stimulation.
- Measure the effects of vibrotactile cues of foot placement on stair descent of transtibial amputees.

Approach

Assess sensory consequences of TR in lower extremity via Semmes-Weinstein monofilament exam, then use hand-held vibrotactile stimulator to measure for the vibrotactile haptic modality that would actually be used in an integrated sensorized prosthetic system.

Measure the effects of providing vibrotactile feedback of foot placement on self-selected speed of transtibial amputees performing stair descent. Subjects will descend integrated motion-capture speed-adaptive escalator.



Vibrotactile stimulator and worn array (left). Vibrotactile sensory feedback can deliver sensation of forces and foot events to the lower extremity amputee. Users having targeted reinnervation feel these sensations as if they are originating at the absent limb. Users report different subjective intensity and apparent origin (middle, bottom) given different stimuli. We are testing using a speed-adapting stairmill (middle, top). Users of the system demonstrate an improved ability to locate their foot on a hidden stair (right).

Timeline and Cost

Activities	CY	16	17	18	19	20
Develop Vibrotactile Actuators		█				
Develop automatic stair machine		█				
Sensory mapping of TR sites		█				█
Stair Descent with feedback		█				█
Estimated Budget (\$K)		\$496	\$498	\$497	\$0	\$0

Goals/Milestones

- Hidden step experiments with revised sensory feedback hardware
- Stair descent experiments with sensory feedback
- TR sensory assessment

Budget Update:

- Projected Expenditure: \$1.49M/5 years
- Actual Expenditure: \$1,327,480

Active/Pending/Completed Support

Eric Rombokas, PhD

Active

Title: COLLABORATIVE RESEARCH: NRI: INT: An Open-Source Framework for Continuous Torque Control of Intuitive Robotic Prosthetic Legs

Role: PI

Source of Support: National Science Foundation

Total Award Amount: \$560K

Location of Project: University of Washington, Seattle, WA

This project seeks to establish an open-source framework for closed-loop torque control of robotic prosthetic legs to achieve customizable behaviors that are continuously cued by the human body.

Title: "Interdisciplinary Center for Analysis of Motion and Performance in Humans and Machines"

Source: University of Washington Strategic Research Initiatives Program 2016

Role: Co-PI

Using a rich sensor suite (high-speed motion capture/videography, instrumented treadmills/force plates, and wearable devices) and mechanical infrastructure (bodyweight support system, heterogeneous terrain), researchers will conduct studies that advance our understanding of human and robot movement.

Title: VA Center of Excellence for Limb Loss Prevention and Prosthetic Engineering

Source: Department of Veterans Affairs, Rehabilitation Research and Development Service (A9243C)

Role: Investigator

The VA RR&D Center for Limb Loss and Mobility is dedicated to prevent limb loss in the veteran population and to enhance comfort and mobility for those veterans who do undergo amputation.

Pending / In Review

Title: Improving Veterans' Rehabilitation Outcomes After Stroke Using an Advanced Upper Extremity Robotic Exoskeleton

Role: Investigator

Location: VA Puget Sound Health Care System, Seattle, WA

We have recently developed a next-generation robotic therapy platform to enhance recovery following stroke. We will compare improvements in upper extremity outcome measures following 3-weeks of intensive inpatient therapy between a robotic therapy group and non-robotic therapy group. We will also determine if robotic therapy leads to long-term (>52 weeks post-stroke) improvements in outcomes.

Completed Research Support

Title: "Sensory Feedback for Lower Extremity Prostheses Incorporating Targeted Muscle Reinnervation (TMR)"

Source: Department of Defense, Defense Medical Research and Development Program, Clinical and Rehabilitative Medicine Research Program, 01/2015, W81XWH-15-1-0417, MR140172

Role: PI

This research will first characterize the sensory recovery of people with amputations who have a nerve transfer surgery called Targeted Reinnervation. This is a novel surgery wherein nerves serving the amputated limb are redirected to remaining tissue. These sensory characterizations will be used to best deliver tactile stimulation to improve the safety and speed of stair descent using a sensorized prosthetic lower limb.

Title: "Optimizing the virtual body experience: Bishop's Hand"

Source: Sponsored Research Agreement with Oculus Research

Role: PI

We are developing a variety of technologies that can alter or replace multimodal sensory experiences. We study how vision, proprioception, and haptic sensation are fused by the brain to create a unified experience of self situated in the body. We use virtual reality to probe how the feeling of body ownership can be extended to virtual avatars.

Title: "Acquisition of a Objet500 Connex3 3D Printer"

Source: Department of Veteran Affairs "Sheep" Equipment Grant, 02/2015

Role: Co-Investigator

This VA equipment grant will supply an advanced 3D printer for use in several collaborative research programs. I will be leading an effort to create a robotic biomechanics testbed for soft tissues and tendon-bone interactions, but there will also be collaborations for exciting orthotic and laboratory applications.

Title: Integrated Task Board with Adjustable Dynamics

Source: National Science Foundation Engineering Research Center for Sensorimotor Neural Engineering Seed Grant – NSF 62-2526 Award Period: 12/2011 - 12/2012

Role: PI

This goal of this work was to build an adjustable and richly instrumented "Task Board" suitable for the study of human solutions to manipulation tasks or evaluating the performance of robotic hand controllers. The completed device was used in studies of robotic hand manipulation.