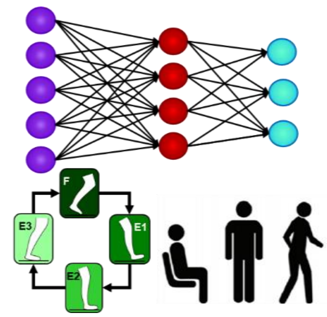
RESEARCH PROGRAM

The overall goal of my research is to improve the lives of people with disabilities using neural interfaces and prostheses. My research focus has 3 major thrusts: neural and artificial control of walking, implanted neural interfaces, and neuromodulation, utilizing my experience in both animal and human models. Much of my research also includes applying machine learning techniques to solve problems in neural engineering and rehabilitation.

Control of Walking

Movement disorders affect thousands of Canadians. Much of my PhD work at the University of Alberta aimed to restore walking in a model of spinal cord injury (SCI) using an implant called intraspinal microstimulation (ISMS). ISMS targets the motoneuron pools in the lumbar enlargement to produce movements in the leg muscles. Control strategies for neurotechnologies such as ISMS should predict and adapt to the user's intentions during walking in an intuitive manner. I developed two controllers that utilized machine learning for use in a hemisection SCI model in anaesthetized cats. Both controllers used information from external sensors on one hindlimb to control the movements of the other hindlimb using ISMS. One controller used supervised learning to predict the speed of walking, and using that prediction adapted the control strategy to improve walking at faster speeds. The other controller used reinforcement learning to learn predictions during walking, which were used by a control method called Pavlovian control. Pavlovian control is inspired by classical conditioning, whereby predictions of a sensory stimulus (movements from one limb) were used to produce a fixed response (stimulation output). The Pavlovian controller did not need tuning of its settings between different experiments and with variable walking patterns, demonstrating that it can automatically adapt to different subjects during walking.

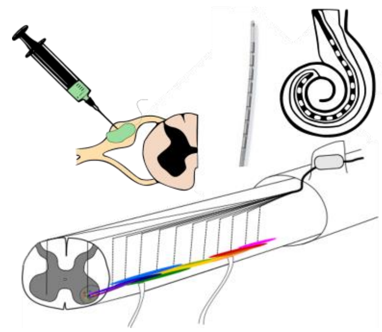


Ex. Using machine learning to predict the gait cycle and transitions

Research Plan: I will build on these control strategies to improve walking in movement disorders using an exoskeleton and electrical stimulation. My immediate research focus will use supervised learning to predict different gait types such as walking, stand-to-sit transfers, slopes, etc. in healthy controls. I hypothesize that gait types, and the transitions between them, can be predicted using body-worn sensors such as insoles (forces), electromyography (EMG; muscle activity), and goniometers (limb position, joint angle). The subsequent study will aim to predict gait types in people with movement disorders. These studies will identify key parameters for defining and transitioning to different gait types in people with movement disorders, and how they differ from intact controls. I also aim to develop the Pavlovian controller for an exoskeleton for movement disorders. The controller can be easily modified to include many feedback signals, and it has phenomenal online adaptation capabilities. This makes it an ideal controller to translate to existing devices and has large clinical potential. This work is attractive to CIHR, NSERC, and the NIH, as well as the Rick Hansen Foundation and the Heart and Stroke Foundation.

Implanted Neural Interfaces

Implanted neural interfaces, medical devices, and materials can be used throughout the body to restore functions. Chronic *in vivo* testing is key to screening and assessing their performance prior to clinical translation. During my PhD, I worked on a study investigating ISMS safety in minipigs. We tracked their walking recovery for several weeks following intraoperative stimulation using ISMS. This study laid the groundwork for translating ISMS to human trials.



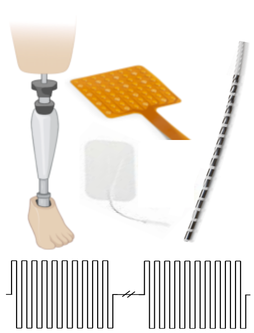
Ex. Implanted neural interfaces I have used in vivo: Injectrode, spinal cord stimulation, cochlear implant, and intraspinal microstimulation.

My postdoctoral work at the Bionics Institute consisted of chronic cochlear implant studies in rats, guinea pigs, and cats. I evaluated electrode coating materials using electrochemical methods to determine their reliability for chronic stimulation. I also performed electrochemical testing in high charge density trials, which were designed to investigate stimulation safety limits for cochlear stimulation. At the University of Pittsburgh and now at Carnegie Mellon University, I used an injectable electrode (Injectrode) to stimulate the dorsal root ganglion (DRG) in cats. The Injectrode was developed by Neuronoff, Inc., and is a polymer that cures inside the body minutes. I compared the recruitment properties of the Injectrode with a clinical-like electrode. I am also a part of the research team conducting the early feasibility testing of the Stentrode brain-computer interface (BCI) in people with ALS.

Research Plan: I will continue to build relationships with industry partners and lead research efforts to test novel electrode materials and implantable devices in acute and chronic *in vivo* experiments. Specifically, I will lead functional testing including measuring recruitment properties, electrochemical performance, and material integrity. This work will systematically evaluate the viability of materials and devices for chronic use and the mechanisms of action of the therapy. I will attain funding through industrial partners and from CIHR, NSERC, and the NIH.

Neuromodulation

Neuromodulation alters neural activity using electrical stimulation. I am part of a team at the University of Pittsburgh that uses spinal cord stimulation (SCS) to restore sensation in the phantom limb of lower-limb amputees. Specifically, I am looking at the reflex responses evoked in muscles during sensory-SCS while walking. I am also exploring non-invasive neuromodulation methods because they are more easily tested and translated. I obtained pilot funding to use transcutaneous spinal cord stimulation (tSCS) to reduce phantom limb pain in lower-limb amputees. tSCS uses surface electrodes to stimulate the same structures as SCS (the dorsal roots). In my pilot study, I will determine if spinal reflex modulation is altered after limb amputation, and if tSCS can be used to restore normal reflex modulation and reduce phantom pain. I am also conducting experiments comparing the recruitment properties of different waveforms that are commonly used for tSCS, including a high frequency (10 kHz) waveform. This work will increase the understanding of how tSCS excites the spinal cord and help determine which stimulation parameters are most useful for neuromodulation applications.



Ex. Using neuromodulation and high-density EMG to improve lives of amputees

Research Plan: My immediate plan is to build on the results from the pilot study investigating tSCS as a method for reducing phantom limb pain in a larger clinical trial. I will also investigate whether tSCS can improve balance and gait stability lower limb amputees, because they are at a greater risk of falling due to lack of sensation and impaired spinal cord reflex modulation. Furthermore, I also plan to explore the use of tSCS for improving walking in stroke, since it has shown great success in people with SCI. This research thrust has the potential to attract funding from CIHR, the NIH, and the Heart and Stroke Foundation.