Changes in the Electromyographic Activity and Joint Moments due to the Self-reinnervation of the Lateral Gastrocnemius and Soleus Muscles

A Thesis
Presented to
The Academic Faculty

by

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In Partial Fulfillment
of the Requirements for the Degree
B.S. in Biomedical Engineering with Research Option in the
School of Biomedical Engineering

Georgia Institute of Technology
May 2014

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ACKNOWLEDGEMENTS

I wish to thank Dr. Boris Prilutsky and Dr. Annette Pantall for allowing me to be a research assistant in their lab. Together, their guidance has really helped me not only in the lab, but also in my other coursework. I would also like to thank my academic advisor Paul Fincannon. He has guided me on the right path in order to graduate on time and is always available to talk about any issues I am having, whether they are school-related or not. Finally, I'd like to thank my family to molding me into the person I am today. They've seen me at my best and at my worst, but their unconditional love has picked me up and pushed me into becoming the best person that I can be.

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LIST OF SYMBOLS AND ABBREVIATIONS

Electromyographic	EMG
Lateral gastrocnemius	LG
Soleus	SO
Medial gastrocnemius	MG
Muscle-tendon unit	MTU

SUMMARY

Peripheral nerve injuries can cause serious health problems and result in lifelong disabilities.[1] Although researchers have been studying peripheral nerve injuries, patients may not regain complete function of their muscles even after surgeries to repair their nerves are performed. However, animal studies have shown that after peripheral nerve cut and repair (muscle self-reinnervation), stretch-reflex in the affected muscles does not recover, which may affect the muscle electromyographic (EMG) activity of all muscle synergists, as well as joint kinematics.[2,3] The aim of this study is to determine the effects of the self-reinnervation of the lateral gastrocnemius (LG) and soleus (SO) muscles in the hind limb of felines on the mean EMG activity of the intact synergist medial gastrocnemius (MG), as well as the moments at the knee and ankle joints during different walking conditions: level (0%), downslope (-50%), and upslope (+50%). The EMG activity and joint kinematics were recorded on the three different walking conditions before and 12 weeks after the self-reinnervation of LG and SO when these muscles recovered their activity. The self-reinnervation of the two muscles caused the MG EMG activity to increase for all walking conditions. However, the changes in the knee and ankle moments differed depending on the three different walking conditions. It was concluded that the changes in EMG and joint moments after self-reinnervation could be caused by the absence of stretch-reflex in the affected muscles and/or changes in physiological properties of muscles.

CHAPTER 1

INTRODUCTION

Axons in the peripheral nervous system are able to regenerate after injuries, unlike those found in the central nervous system. However, this regrowth is hampered when peripheral nerve injuries occur, which causes fewer intact axons and larger motor units.[4] The regrowth of the peripheral axon is often delayed because of the distance that axons must travel to reach the target tissues. Therefore, complete regrowth of the axon and regaining full function are often unreachable, which is why peripheral nerve injuries could result in lifelong disabilities.[5] Scientists and doctors have continually been seeking for advancement in existing peripheral nerve injury treatments, with many of these treatments refined during times of war, primarily beginning with World War I. Since approximately 18% of all extremity injuries include damage to peripheral nerves, treatments for peripheral nerve injuries were vastly improved over the course of the war.[6]

Animal Studies

Animal studies have often shown promise in recovery from peripheral nerve injuries since there have often been changes in the EMG activity and joint kinematics shortly after the self-reinnervation of an animal's hind limb muscles. Different methods of reinnervating nerves have been performed and electrical stimulation could decrease the time it takes for a nerve to be completely reinnervated, which has been shown in rats.[7] Other techniques, as well as experiments with other animals have been used to examine how muscles recover from self-reinnervation. A study was performed on a cat's hind limb muscle, which observed how the self-reinnervation of the medial and lateral gastrocnemius muscles would alter the muscle-tendon unit (MTU) length and EMG activity in the cat.[8] Although the MTU length and EMG activity are able to provide a great amount of insight into the self-reinnervation of muscles, there are still areas that the changes in MTU length and EMG activity do not measure, such as the joint kinetics (knee and ankle moments), frequencies of muscles' EMG, and the amount of activity present in muscles surrounding those that were reinnervated.

CHAPTER 2

MATERIALS AND METHODS

One adult cat was trained under operant conditioning methods with food rewards for walking along an enclosed walkway. The walkway was surrounded with Plexiglas and consisted of three force plates embedded on the surface of the walkway. The slope of the walkway was changed to allow for three different walking conditions: level (0%), upslope (+50%), and downslope (-50%). After training was complete, the cat underwent the first surgery: the implantation of EMG electrodes in the right hind limb. The electrodes were implanted in the nine different muscles of the hind limb, but only one muscle was analyzed for this study - the MG. Once the cat recovered from surgery, the initial set of data collection could begin

Reflective markers, whose positions were recorded by the Vicon camera system, were placed at specific locations on the cat. As the cat walked along the walkway, the Vicon camera would record each trial. For each trial, the ground reaction forces, EMG data, and joint position data was collected. After pre-reinnervation data were collected, the cat was ready for the second surgery: the self-reinnervation of the SO and LG muscles of the right hind limb. The nerves innervating the SO and LG muscles were cut, realigned, and repaired with fibrin glue. After the cat recovered from surgery, the next set of data collection could begin, which used the same procedures as the ones used before self-reinnervation. The EMG activity and joint kinematics were recorded weekly for 12 weeks after the self-reinnervation surgery. Collected marker positions and ground reaction forces were used to compute the resultant muscle moments at the ankle and knee joints.[9] Recorded EMG signals were analyzed using a wavelet analysis to determine the mean frequency and magnitude of EMG signals.[10] A two-sample *t*-test was performed to analyze the results from pre-reinnervation and 12 weeks after the self-reinnervation surgery and to determine which conditions were statistically significant.

CHAPTER 3

RESULTS

Effects of LG and SO self-reinnervation on mean EMG activity of MG

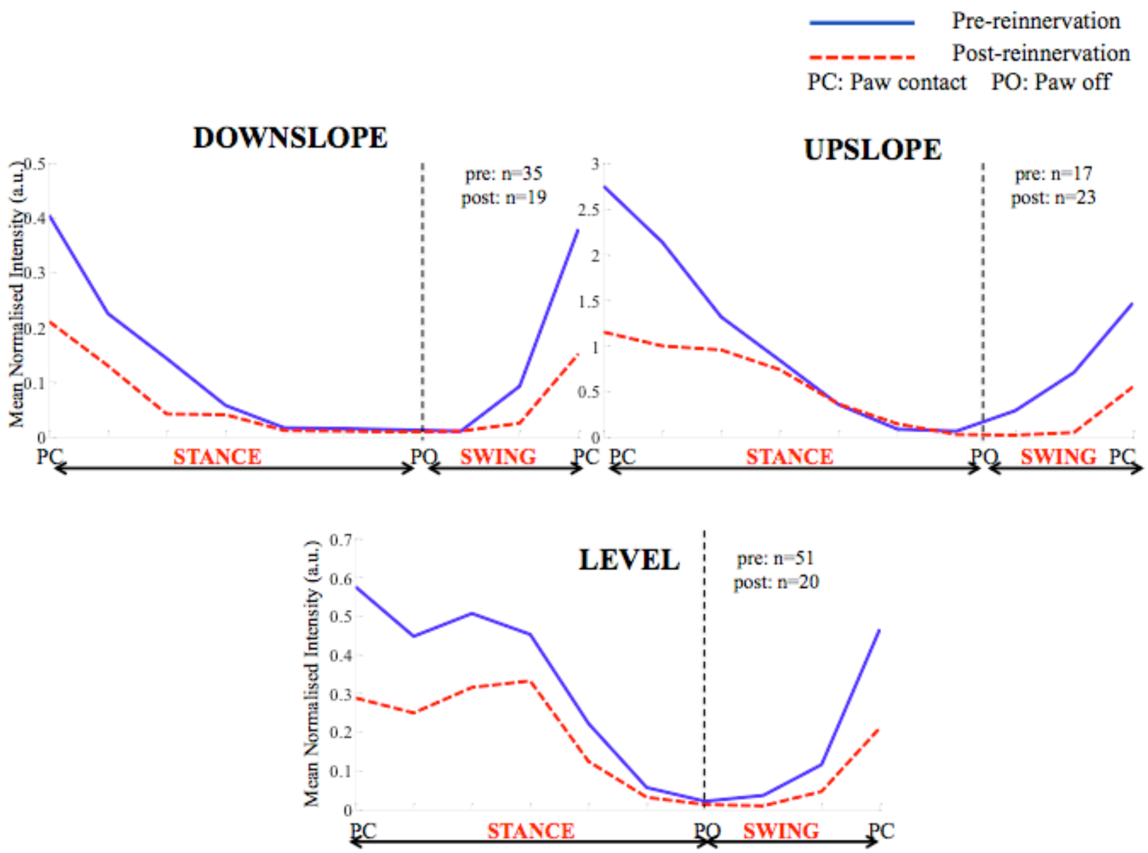

Figure 1. Mean EMG of medial gastrocnemius for all three walking conditions prior to and 12 weeks after the self-reinnervation of the soleus and lateral gastrocnemius muscles in a cat's right hind limb.

The mean EMG activity of MG significantly decreased for all three walking conditions 12 weeks following the self-reinnervation surgery ($p<0.05$). For all walking conditions, there were steeper negative slopes during the stance phase and steeper positive slopes during the swing phase after self-reinnervation when compared with that of pre-reinnervation.

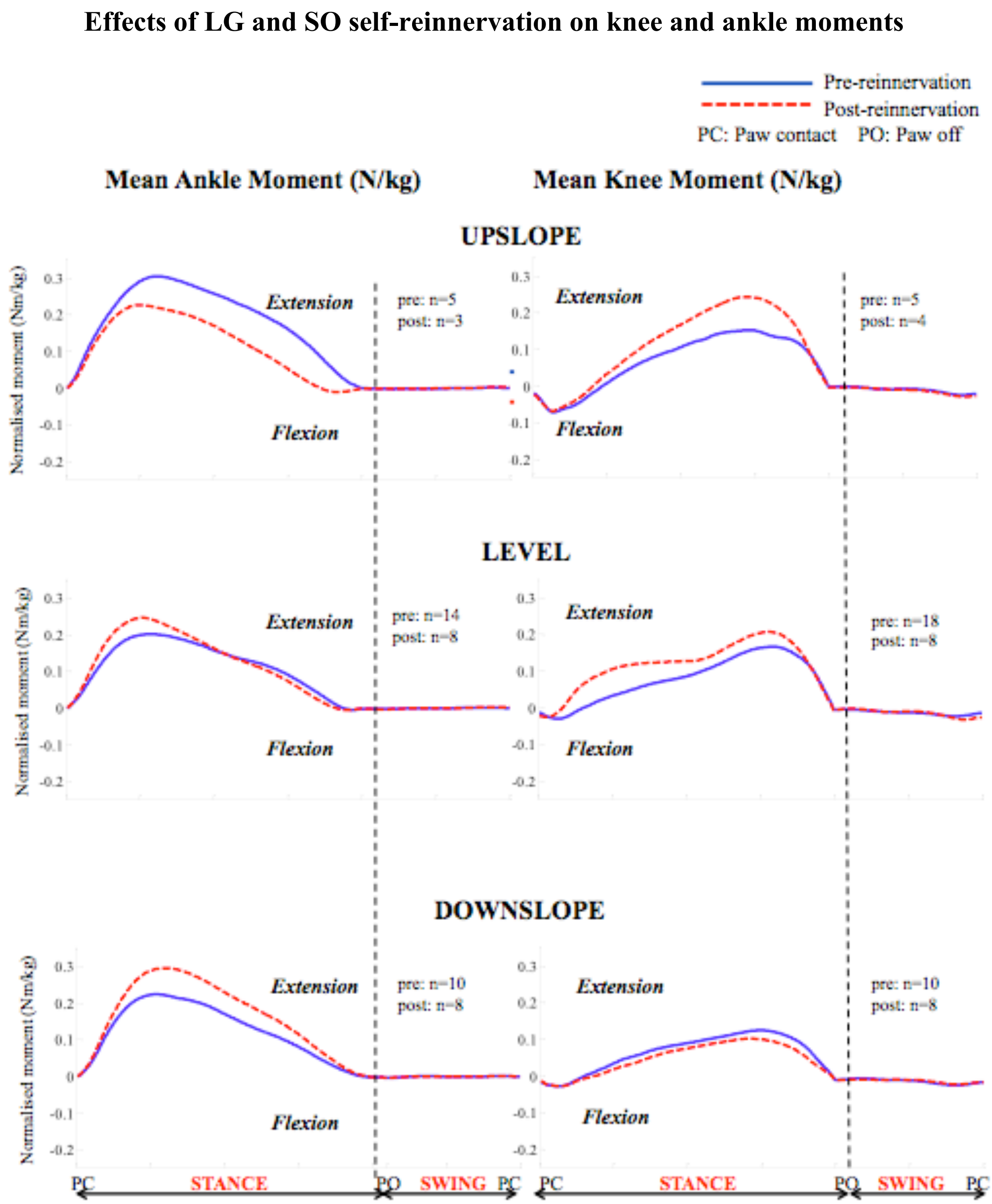

Figure 2. Mean ankle and knee moments for all three walking conditions before and 12 weeks after the self-reinnervation of the soleus and lateral gastrocnemius muscles in a cat's right hind limb.

In some of the knee and ankle moments for each walking condition, significant differences were observed. For the upslope condition, there was a decrease in ankle moment and an increase in knee moment. However, due to the small sample size, a t-test could not be performed since conditions were not satisfied, indicating that neither of these results was significant. A significant decrease was observed in the ankle moment of the downslope condition ($p<0.05$). In the level walking condition, there was no significant difference in either the ankle or knee moments following reinnervation.

CHAPTER 4

DISCUSSION

Significant results were observed in mean EMG activity of the MG, ankle, and knee moments, which are all slope dependent. For all walking conditions, there was a decrease in the mean EMG activity of the neurologically intact synergist MG, which could be caused by numerous factors, such as different motor control strategies or implantation sites when compared with other cats. Since each cat is unique, the implantation site could differ from one another, which could result in different EMG readings. Along with these differing factors, the decrease in EMG activity could be caused by the increase in SO and LG muscle activity, which would compensate for the decrease in MG activity. The absence of stretch-reflex in the affected muscles will also cause changes in the EMG activity, as well as the joint moments after self-reinnervation.

Looking at the results for the ankle and knee moments, compensation of different joints could be the reason why some joint moments increase, while others decrease after self-reinnervation. In the upslope walking condition, there was an increase in knee moment, but a decrease in ankle moment. This could be due to the knee moment compensating for a smaller ankle moment. Since only one cat was observed in this study, it is difficult to draw concrete conclusions based on these results. Based on the results of this and previous animal studies, there is promise in advancing the current peripheral nerve injuries that exist. However, more cats need to be studied to determine the general mean EMG activity and joint kinematic trends after self-reinnervation of different muscles.

REFERENCES

1. Scholz, T., Krichevsky, A., Sumarto, A., Jaffurs, D., Wirth, G., Paydar, K., & Evans, G. (2009). Peripheral nerve injuries: an international survey of current treatments and future perspectives. Journal Of Reconstructive Microsurgery, 25(6), 339-344.

2. Cope, T.C., S.J. Bonasera, T.R. Nichols (1994) Re- innervated muscles fail to produce stretch reflexes. J Neurophysiology *71:* 817–820.

3. Maas, H., Prilutsky, B., Nichols, T., & Gregor, R. (2007). The effects of self-reinnervation of cat medial and lateral gastrocnemius muscles on hindlimb kinematics in slope walking. Experimental Brain Research. Experimentelle Hirnforschung. Expérimentation Cérébrale, 181(2), 377-393.

4. Gaudet, A.D., Popovich, P.G., Ramer, M.S. (2011) Wallerian degeneration: gaining perspective on inflammatory events after peripheral nerve injury. Journal of Neuroinflammation, 8 (110).

5. Zochodne, D. W. (2012). The challenges and beauty of peripheral nerve regrowth. Journal Of The Peripheral Nervous System, 17(1), 1-18. doi:10.1111/j.1529-8027.2012.00378.x

6. Woodhall B, Beebe G: *Peripheral Nerve Regeneration: A Follow-Up Study of 3,656 World War II Injuries*. Washington, DC: US Government Printing Office; 1956.

7. Brushart, T., Hoffman, P., Royall, R., Murinson, B., Witzel, C., & Gordon, T. (2002). Electrical stimulation promotes motorneuron regeneration without increasing its speed or conditioning the neuron. The Journal Of Neuroscience: The Official Journal Of The Society For Neuroscience, 22(15), 6631-6638.

8. Maas, H., Gregor, R., Hodson-Tole, E., Farrell, B., English, A., & Prilutsky, B. (2010). Locomotor changes in length and EMG activity of feline medial gastrocnemius muscle following paralysis of two synergists. Experimental Brain Research. Experimentelle Hirnforschung. Expérimentation Cérébrale, 203(4), 681-692.

9. Gregor RJ, Smith DW, Prilutsky BI. Mechanics of slope walking in the cat: quantification of muscle load, length change, and ankle extensor EMG patterns. J Neurophysiol. 2006 Mar;95(3):1397-409.

10. Hodson-Tole EF, Pantall A, Maas H, Farrell B, Gregor RJ, Prilutsky BI. Task-dependent activity of motor unit populations in feline ankle extensor muscles. J Exp Biol. 2012 Nov 1;215(Pt 21):3711-22.

11. Maas, H., Gregor, R., Hodson-Tole, E., Farrell, B., & Prilutsky, B. (2009). Distinct muscle fascicle length changes in feline medial gastrocnemius and soleus muscles during slope walking. Journal Of Applied Physiology (Bethesda, Md.: 1985), 106(4), 1169-1180.

12. Prilutsky B, Maas H, Bulgakova M, Hodson-Tole EF, Gregor RJ: Short-Term Motor Compensations to Denervation of Feline Soleus and Lateral Gastrocnemius Result in Preservation of Ankle Mechanical Output during Locomotion. Cells Tissues Organs 2011;193:310-324 (DOI: 10.1159/000323678)

VITA

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Wendy Wang was born in Columbus, Ohio. She attended public school in Lilburn, Georgia, where she earned her high school diploma before coming to the Georgia Institute of Technology in Atlanta. At Georgia Tech, she is currently pursuing a bachelor's degree in Biomedical Engineering, with the Research Option. She is also working on her research in the Applied Physiology department. When she is not studying or working on her research, Wendy enjoys relaxing with family and friends, as well as going figure skating, which she has been doing for 14 years.