

Final Year Project: Investigating Human Walking

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Finding a relationship between foot pressure and leg muscle activity during human walking is valuable as the data could be useful in developing a model of human walking which potentially can be used in spinal injury rehabilitation research. A connection could determine which muscles need to be stimulated using electrical muscle stimulation (EMS) to re-train a correct walking pattern in an injured patient. The data could also be used in robotics in the development of humanoid robots with movement based on human walking.

Introduction

Analysis of human walking is a significant area of research in which measurements of muscle activity using electromyography (EMG) have often been used. However, the relationship between foot pressure and leg muscle activity has never been researched before.

The aim of this project was to determine if there is a correlation between foot pressure and leg muscle activity. The specific tasks that were carried out include:

- Design and development of an insole with embedded force sensors and an appropriate amplifier to allow it to be fitted into shoes.
- Building of a pre-amplifier to accurately measure the leg muscle electromyograms (EMG). This will be connected to the USB-DUX data acquisition device along with the insole.
- Recruitment of test subjects for experimentation on a treadmill.
- Measurements taken on a treadmill and recording of foot pressure and leg muscle EMG.
- Analysis and digital filtering of the data and comparison with other experimental data from other walking research.
- Determination of a correlation between muscle activity and foot pressure and if possible, the forward/inverse transfer functions.

Background in Research

The idea for the project came from observation of the RunBot. RunBot is a biped robot which operates through reflexes without a central pattern generator. On development the robot exhibited a natural walking pattern, which suggested that the way it operates is comparable to how human walking is generated. RunBot

uses touch information to drive motors in the legs, when one foot touches the ground motors drive the other leg forward and so on [2]. The project aimed to investigate whether human walking is generated in a similar way but with motors replaced by muscle activity in each leg.

The Experiment

To determine whether there is a correlation between leg muscle activity and foot pressure during human walking, electromyography (EMG) was performed on four different leg muscles and an insole containing Force Sensing Resistors (FSR) was developed for heel pressure measurement. Measuring foot pressure and EMG should be performed without obstructing the test subjects walking. A device was developed to measure EMG and foot pressure which was small and could easily be attached to the test subject's waist during a treadmill experiment. An insole was made for in-shoe pressure measurement of the heel during walking. Readings were taken using a USB-DUX data acquisition device connected to a laptop running the Comedirecord program, allowing raw data to be collected for later analysis.

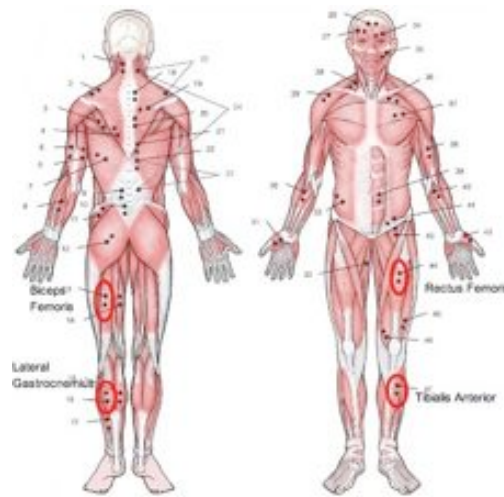


Figure 1: SEMG Chart showing correct positioning of surface EMG electrodes [3]. Circled are the muscles selected for measurement in this project.

Experimentation involved recruiting five test subjects and performing test runs on a treadmill based in the Centre for Rehabilitation Engineering at the University of Glasgow. The test subjects were informed of the aims of the project and what would be expected of them. They each filled in ethical consent forms, as required by the ethical approval granted by the University Faculty of Biomedical & Life Sciences and given an information sheet to keep. Each of the subjects were male, in the age range of 21 to 23, fit and healthy and had, at the time of experimentation, no leg or foot injury which would cause significant interference to walking. Their identities have been protected and they are referred to as subject A, B, C, D or E.

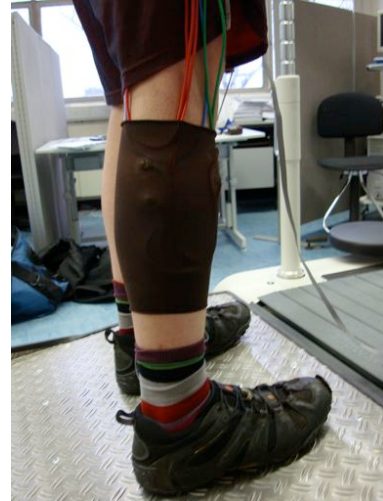
Every effort was made to keep the conditions constant between each treadmill experiment recording in order to produce consistent results. Each test subject walked on a treadmill set to the average human walking speed of 4kmph for a 1 minute duration. Each test subject wore the adjustable waist strap holding the enclosure containing the EMG pre-amplifier and the FSR circuitry fastened securely around their waist. The FSR insole was placed in the right shoe under the heel of the foot (calcaneus) and the electrodes were connected to the pre-determined muscles of the right leg. Guidance on how to find these muscles and correctly attach the pre-gelled surface EMG (SEMG) electrodes was given by researchers at the Scottish Centre for Innovation in Spinal Cord Injury (SCISCI) at the Southern General Hospital in Glasgow.



(a) Electrodes connected to the leg muscles to measure EMG.



(b) Electrodes connected to the leg muscles to measure EMG.



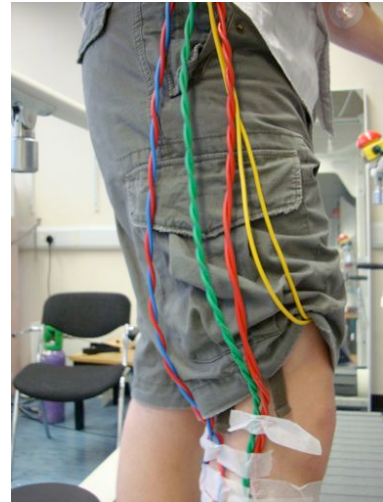
(c) An elastic sleeve made from tights used to hold electrode leads still during the walking experiment. Using tights helped reduce the amount of D.C drift in the results.



(d) An elastic sleeve helps secure the electrodes to the skin allowing a good measurement of EMG to be taken.

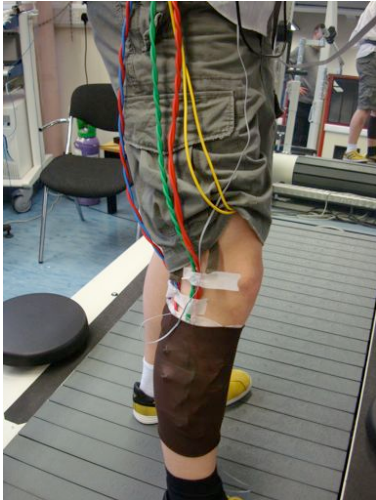


(e) Medical tape was used along with the elastic sleeve to reduce the amount of D.C drift in the EMG measurements.



(f) As there are two electrodes for each muscle, the leads were twisted together to reduce movement which results in noise in the EMG.

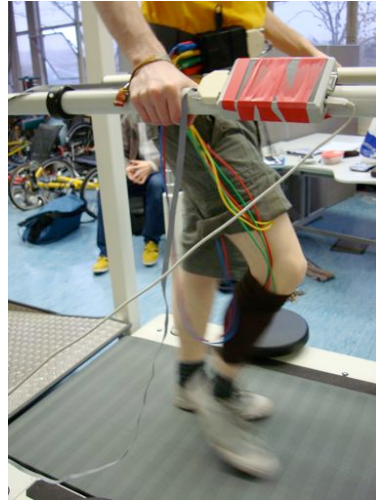
Figure 2: Photographs of the experimental set-up.



(a) Complete electrode and lead attachment. The FSR insole is placed inside the shoe and the wire connecting it to the enclosure round the subject's waist is secured by the elastic sleeve along with the electrode leads.



(b) The enclosure containing all the circuitry is securely attached around the subject's waist, wires are connected to the electrodes on the leg muscles and to a ground connection on the left arm.



(c) The USB-DUX board was securely taped to the side of the treadmill and connected to the box round the subject's waist via ribbon cable. Each test subject walked on the treadmill at average human walking speed of 4kmph.



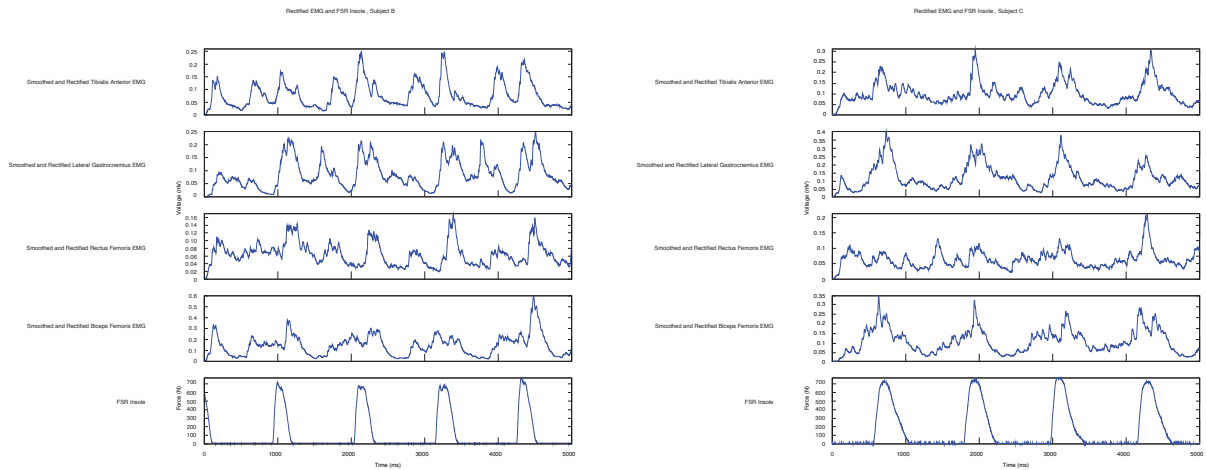
(d) Test subject walking on the treadmill in the Centre for Rehabilitation Engineering at Glasgow University.

Figure 3: Photographs of the walking experiment on 26/3/2009

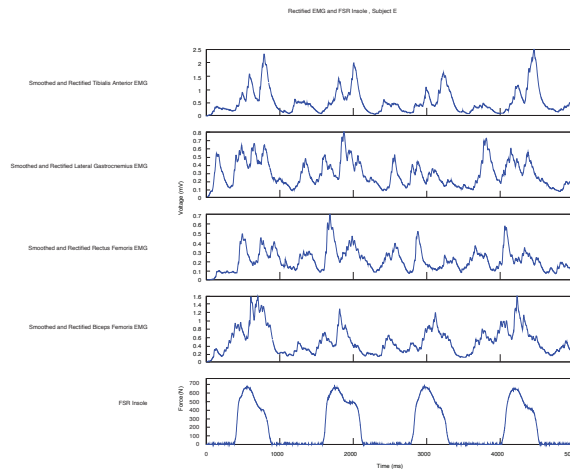
Analysis of Raw Data

On analysis of the experimental data out of the five test subjects, two produced EMG data which had saturated and was thus unusable. The reason for this was bad electrode connection to the leg for measuring EMG, due to excessive leg hair making it difficult to get good contact with the skin.

After these results had been discounted, three good sets of results remained from test subjects B, C and E. Digital filtering was conducted on the EMG data using the Octave program and the graphs used to determine if a correlation was evident between foot pressure and leg muscle activity.



(a) EMG signals of the four leg muscles as well as the FSR insole force data of subject B. (b) EMG signals of the four leg muscles as well as the FSR insole force data of subject C.



(c) EMG signals of the four leg muscles as well as the FSR insole force data of subject E.

Figure 4: EMG signals of the four leg muscles and FSR insole force data for each of the three test subjects. A pattern in the EMG recordings can clearly be seen.

Interpretation of Results

Positive correlations between heel pressure and leg muscle activity were found in three out of the four leg muscles measured. This was determined through visual analysis of the graphs and through finding the correlation coefficients in Octave. Octave takes in the FSR data as one argument and the EMG of one leg muscle as another. The resultant number, if close or equal to ± 1 suggests a strong correlation whereas a result near to or equalling zero suggests no correlation, the results can be seen in fig.5.

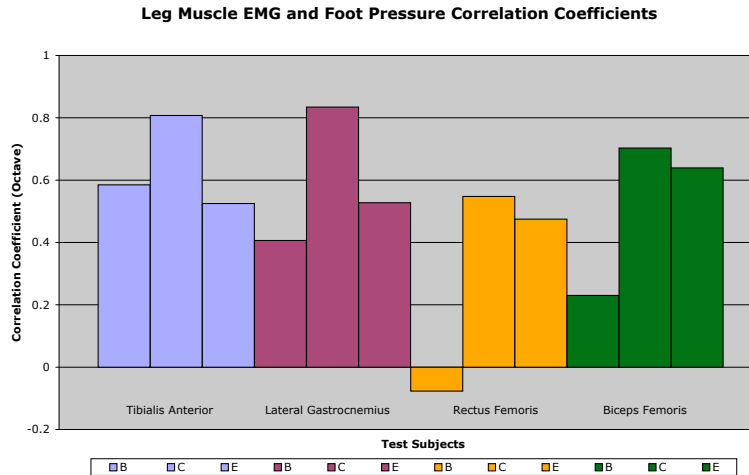


Figure 5: Correlation Coefficient values for muscle EMG and foot pressure for each of the three test subjects, found using the ‘corrcoef’ command in Octave. The muscle with most correlation to foot pressure is the tibialis anterior (blue) as all three test subjects gave a positive correlation coefficient.

The average rise and fall times of the tension in each muscles were determined by using graph matching. The characteristic shape of a muscle tension (the muscle twitch) closely matches the impulse-response time curve of a damped second-order system [4]. Where the electrical stimulus can be considered as an impulse, the signal sent from the nerves to drive the muscles and the mechanical response as a longer length twitch. By graph matching, the data is matched visually so the equation is a close representation of the actual muscle activity. This information can be used to find the transfer function for each muscle’s activity during human walking which would be useful in creation of a model of human walking. Knowledge of the rise and fall times is also useful in determining how long muscles have to be stimulated to produce the muscle activity observed in a normal walking pattern.

Further Research

Overall the project was successful in determining a correlation between leg muscle activity and foot pressure, however there are some improvements which could have produced better results. Creating an insole with a greater amount of FSR sensors could have shown the foot pressure in different areas of the foot, not just in the heel. From this data it could be determined whether the muscle which did not correlate to heel pressure in this experiment is correlated to touch information from a different part of the foot.

Increasing the number of test subjects, age ranges and using both male and females could also prove interesting in research. By using more test subjects the collected data could be analysed to a greater extent and by using subjects of a wider age range it could be investigated whether age affects gait (walking pattern) and leg muscle EMG and whether it could be corrected. A combination of female and male subjects might also be of interest to study as it has been documented that due to differences in anatomy there is a difference in walking patterns which might produce a variation in results.

This results observed in this project mean that further research could be done to investigate whether the activity of other muscles in the legs are also correlated.

Relevance of Results

The results could be used in electrical muscle stimulation (EMS) of spinal injury patients to retrain a normal walking pattern in rehabilitation. In other research, Functional Muscle Stimulation (FMS) has been used to stimulate muscles in the thigh to produce a pedaling motion which is used to provide cycling exercise to injured patients [1]. This is successful in driving a tricycle but could also be adapted to re-train human walking by taking into consideration the natural movement of the foot. From this project investigation, it has been found that the muscles in the lower leg have more correlation with foot pressure than those measured in the thigh, suggesting stimulation of the lower leg muscles might produce a more natural walking pattern than just stimulation of the upper leg muscles. Touch information from the foot could determine which muscles need to be stimulated at the correct time to produce a normal gait pattern.

By finding the rise and fall times of muscle tension in each of the measured muscles the information is useful in determining how long muscles have to be stimulated to produce the muscle activity observed in a normal walking pattern.

Conclusion

The research conducted in this project has not previously been investigated. The results have demonstrated that there is a correlation between heel pressure and leg muscle EMG. The project has shown that the way human walking is generated is similar to the RunBot's operation. The outcome is that touch information from ground contact can be used to stimulate the major muscles used in walking.

The FSR insole was successful in measuring foot force during walking and the data provides useful parameters in determining the human gait pattern. The results produced in this project could be used in the development of rehabilitation methods for patients with spinal cord injuries and the determined transfer functions can be used in the development of humanoid robots and in the modeling of human walking.

References

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