**DROP FOOT AND AFOs**

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PhD Mini-Proposal

**MOTIVATION\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**

**Definition**

Drop foot (also known as “foot drop”) is a condition that results when the muscles in the lower leg and ankle are weak or paralyzed and thus are unable to properly lift the foot. This can affect one or both feet, and it results in the toes dragging during gait. In order to compensate for the dragging toes, sufferers will often lift their knee on the affected leg higher. This gait pattern places them at increased risk for arthritis due to a heightened joint-loading occurring in the knee. The cause of drop foot is widespread and includes, but is not limited to the following:

1. Stroke
2. Cerebral palsy
3. M.S.
4. A.L.S.
5. Trauma to the cerebrum

* Source: National Institute of Neurological Disorders and Stroke (branch of NIH)

**Project specifics: Post-stroke drop foot**

For the purpose of this project, we will focus on drop foot that occurs as a result of a stroke. During a stroke, a person may suffer damage to the motor cortex or the area of the spinal tract containing the cerebral cortex. This leads to lasting effects of contralateral weakness conditions like drop foot. (\* source: Kluding, et. al.)

We choose to focus our efforts on the stroke cause of drop foot for wide array of reasons. According to the Centers for Disease Control and Prevention, more than 795,000 strokes are reported annually in the U.S. alone, with around 610,000 of these being first strokes. For survivors over 65 years old, more than fifty-percent of them have lasting mobility issues, making strokes the leading cause of mobility impairment. Finally, strokes annually cost the U.S. an estimated $33 billion in medical care and absence from work due to remaining effects. (\*source: CDC)

By focusing our efforts on post-stroke drop foot, we will work to improve a treatment option known as an “ankle-foot orthosis” (AFO) through modeling the subject-device interface, the effect of stiffness on the efficacy of the AFO, toe position, and ankle angle.

**Relevant studies (in no particular order)**

1. “The influence of ankle-foot orthosis stiffness on walking performance in individuals with lower-limb impairments.” Harper, Esposito, Wilken, Neptune.
   1. Goals: To investigate the effect of passive dynamic selective laser sintering AFOS (SLS manufactured PD-AFOs) on walking performance in individuals with lower-limb neuromuscular and musculoskeletal impairments.
   2. Predictions: As PD-AFO stiffness decreases, 1.) sagittal plane ankle RoM will increase, 2.) knee joint extensor moments and work and muscular contributions will increase to compensate to for reduced stiffness in the AFO, and 3.) hip extensor moments and work and muscular contribution will decrease as the PD-AFO contribution to forward propulsion increases.
   3. Methods: Each subject was given an AFO with the prescribed stiffness, as well as one that was 20% more stiff and another that was 20% more compliant.
   4. Results: 1.) Ankle RoM increased but no significant change in the ankle joint moments or work, 2.) medial gastrocnemius muscle activity increased which is thought to have compensated for the decreased stiffness of the AFO. It seems as though the knee joint extensor moments increased only for subjects who are lower limb amputees, who do not have fully functional gastrocnemius muscles, 3.) There is a decrease in the gluteus medius activity.
   5. Limitations: 1.) The SLS manufactured strut may not have all the functional characteristics of the CF strut, even though a study showed there aren’t many differences in the biomechanical gait measures. 2.) The contribution of the AFO to the ankle joint moments and work could not be separated from the biological contribution. Future work should try to quantify the AFO contribution to the total joint moment in order to understand the mechanisms used to compensate. 3.) The acclimation period was not strictly controlled but should be considered since previous studies showed that changes in muscle activities were almost immediate and did not continue over time. 4.) Since the subject population was of active military individuals who were in good physical condition, the population is not representative of the general population.
2. “Foot drop stimulation vs. ankle foot orthosis after stroke.” Kluding, Dunning, O’Dell, Wu, Ginosian, Feld, Mcbride.
   1. Goals: Known as the Functional Ambulation: Standard Treatment vs. Electrical Stimulation Therapy (FASTEST), the experiment was designed to compare ankle foot orthosis treatment with electrical stimulation in the treatment of foot drop still persisting 3 months after a stroke with a gait speed of less than 0.8 m/s.
   2. Predictions: After 30 weeks of treatment, subjects undergoing the foot drop stimulation procedure would have greater improvement in gait speed.
   3. Methods: Subjects were randomized into either a treatment group (who wore an FDS device) or a control group (who wore an AFO device) for 30 weeks. At 30 weeks, the AFO group began receiving FDS treatment. Both groups continued treatment for the next 12 weeks.
   4. Results: No significant difference in characteristics measured: gait speed, steps per day, etc. There was a higher user satisfaction in the FDS group, and it is theorized that the lack of mobility from AFO may not be ideal. Not a lot of data on the efficacy of AFO alone in treating foot-drop in subjects after a stroke, though some kinematic studies have shown a biomechanical advantage to placing the device on certain joints. The improvements using the AFO could be attributed to strengthening of lower-limb muscles, neural plasticity, or improved cardiopulmonary conditioning.
   5. Limitations: 1.) This experiment did not only investigate AFO alone, but the control group also received a TENS treatment when they did physical therapy. Since previous studies show that TENS is effective is increasing gait speed when in combination with gait training, it is impossible to say whether the improvement in gait speed was due to the AFO alone or the combination of TENS and AFO. 2.) This is experiment also only investigated one stiffness level of the AFO, so it did not give the subjects a chance to actually improve muscle strength and contribution. In general, limitations of AFOs include: comfort, aesthetics, difficulty standing from a sitting position due to immobility of ankle.
3. “Physical interface dynamics alter how robotic exosuits alter human movement: implications for optimizing wearable assistive devices.” Yandell, Quinlivan, Popov, Walsh, Zelik.
   1. Goals: Use typical motion capture techniques and force measurements to estimate interface power and quantify how a soft robotic exosuit interacts and transfers power to the body during motion.
   2. Methods: The subject wore a backpack that contained an actuator and a controller. A Bowden cable transmits the actuator power down to the ankle. There was an inner Bowden cable that attached the outer Bowden’s cable to the shank. Finally, there is a modified boot that connects the the inner Bowden’s cable to the foot by way of a carbon fiber beam in order to provide plantarflexion assistance. Forces were measured in the Bowden’s cable in the end effector and the displacement of the Bowden’s cable was also measured. The interface power was also measured- this refers to power absorbed into the shank and foot surfaces due to deformation of the devices and influence of soft tissues. Augmentation power was estimated- i.e. the power that actually contributes to the goal (ankle plantarflexion). The contributions to augmentation power are broken into components of biological vs. exosuit. This is compared to ideal augmentation power in which nothing is lost to the soft tissues.
   3. Results: A lot of power was absorbed during exosuit loading (time in which increased force is applied by the exosuit). This is evidenced by the ankle augmentation power of roughly 4.7 J, and the cable-end-effector work was roughly 10.6 J. Therefore, approx. 5.9 J was absorbed. During exosuit unloading, the ankle augmentation work was approx. 5.4 J, with cable-end-effector work approx. 1.6 J. The remaining 3.8 J was returned into the system contributing to augmentation work by the interface (it was absorbed during the loading phase). They found that it is impossible to ignore interface power absorption when 75% of the cable-end-effector work is augmented by the absorption-return mechanism. During the exosuit loading phase, 55% of the CEE work was absorbed into the soft tissues and 45% went to ankle augmentation power. During the exosuit unloading phase, the interface returned most of the absorbed power and contributed to the ankle plantarflexion. The majority of ankle augmentation work occurred during the exosuit unloading phase and this subsequently caused a time lag in the augmentation power relative to the CEE power.
   4. Limitations: Stiffer devices could reduce power absorption. Larger surface areas of devices could also reduce power absorption. Devices should be designed to more firmly hold to the body and reduce error due to slippage of skin. This study only involved one subject, one joint, and one soft exosuit. It would be worth it to have an intersubject variety, try this on multiple joints, and extend the work into a hard exoskeleton. The effects were broken into interface vs. biological contributions, but the effects due to the interface were not further divided into those due to textile stretching, skin slippage, etc. This study did not account for device migration or the effects of shearing or compression on the biological tissues.

**METHODS**\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

1. Three studies
   1. Stiffness of AFO
      1. In the Harper, et. al. article, I would like to expand upon limitation in which we focus the effort here on quantifying the AFO contribution to the ankle joint moment to better understand the mechanism by which the muscles compensate for the decreasing stiffness in the device.
   2. Surface area of device and augmentation power
      1. In the Zelik, et. al. article, I would like to investigate how the interface power absorption is dependent on the the surface area of the device, and if increasing the surface area of the AFO could increase the augmentation power.
   3. Ankle angle
      1. Not sure where to go with this, but possible investigate if there is a minimum angle the ankle needs to be at in order to refrain from affecting the gait?
2. Execution (I definitely would say this is the part that I am not sure of the most. I would like to develop a clearer picture of how exactly this is going to work.)
   1. Developmental model
      1. Stiffness of AFO
         1. 3D print a device of specific stiffness
         2. Collect data
      2. Surface area of device and augmentation power
         1. Since most of the soft tissue for an AFO is on the leg where the cuff connects, could we possibly increase the width of the cuff to find out if we lose less power to the soft tissues than before?
      3. Ankle angle
   2. Simulation and prediction
   3. Optimization and validation

The biomech factors that contribute to ankle dorsiflexion in normal gait and drop foot gait in individuals with post-stroke gait

Stanford dissertation **Saryn Goldberg** Biomechanical Factors...knee flexion

**Melanie Fox** dissertation stiff knee (understanding biomechanical causes and functional mechanism of treatment for stiff knee gait for cerebral palsy)

**Jill Higginson** stroke (post-stroke gait) (Analysis of muscle coordination during post-stroke hemiparetic gait)

Burdham musculoskeletal diseases

Drop foot in CP vs. Stroke

* + - As best as I can tell, drop foot is actually a rare gait pattern in people with CP, as it results from hypotonia (which affects only about 1% of the CP population). Source: Cerebral Palsy Gait, Clinical Importance (from NCBI)

# In a stroke, about 75% of survivors partially recover, and about 20% of them have drop foot. (source: The Orthotic Effect of Functional Electrical Stimulation on the Improvement of Walking in Stroke Patients with a Dropped Foot: A Systematic Review).

* + - 1.5-4 babies per 1000 are born with at least some sign of CP. Taking the worst case, that is 4/1000. With ~ 4 million births each year in the US (CDC), that means that approximately every year about 16,000 people will be born that show signs of cerebral palsy, with about 160 of them exhibiting a drop foot. Every year, 795,000 strokes are reported in the US. Approx. 600,000 will partially recover, and thus ~ 120,000 will have a resultant drop foot.
* I realize this may not be the best analysis, but it at least provides an idea about how much more prevalent the condition is for strokes vs. CP.