January 2019

Effects Of Locomotion Methods Under Simulated Reduced Gravity Conditions On Muscles And Joints Of The Leg

Sophie Orr

EFFECTS OF LOCOMOTION METHODS UNDER SIMULATED REDUCED GRAVITY CONDITIONS ON MUSCLES AND JOINTS OF THE LEG

by

Sophie Orr
Bachelor of Science, University of California, Davis, 2015

A Thesis
Submitted to the Graduate Faculty

of the

University of North Dakota

In partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota

December
2019

This thesis, submitted by Sophie Orr in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

Dr. Pablo de León

Chairperson

Dr. James Casler

Dr. Jesse Rhoades

This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

Chris Nelson
Associate Dean of the School of Graduate Studies

12/2/19

Date

PERMISSION

Title	Effects of Locomotion Methods Under Simulated Reduced Gravity Conditions on Muscles and Joints of the Leg
Department	Space Studies
Degree	Master of Science

In presenting this thesis in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, I agree that the library of this University shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised my thesis work or, in his absence, by the Chairperson of the department or the dean of the School of Graduate Studies. It is understood that any copying or publication or other use of this thesis or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of North Dakota in any scholarly use which may be made of any material in my thesis.

Sophie Orr
December, 2019

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I wish to convey my tremendous gratitude to those who made this thesis possible. This research would be impossible without the guidance, support and advocacy of Dr. Pablo de León, Dr. James Casler and Dr. Jesse Rhoades. Essential support was also received from the Department of Space Studies, Department of Education, Health and Behavior Studies, The Human Spaceflight Laboratory and the BiPed Laboratory. Partial funding was made possible through the NonReimbursable Space Act Umbrella Agreement between The NASA Lyndon B. Johnson Space Center and University of North Dakota for SAA with UND for Collaborative Research, Technology Transfer, Education and Outreach Activities (doc # SAA-AD-15-19256).

I would also like to thank the North Dakota Space Grant Consortium, specifically Caitlin Nolby and Marissa Saad, for their support of my research and for continuing to provide opportunities like this to a diverse group of students.

Additionally, I would like to acknowledge the ARGOS team at NASA Johnson Space Center for their help in operating the ARGOS during this study.

Finally, I would like to thank Bev Fetter for her unending support and assistance throughout this degree and thesis process.

To Lynn & Connor,

For always being divine.

ABSTRACT

Past research efforts have focused on the energy difference between altered locomotion methods in fractional gravity at different speeds, suggesting that skipping is energetically more efficient than walking and running in these environments. While skipping may be more beneficial from an energy standpoint, the full range of reasons behind the gait transition and locomotion selection have not been researched. This includes damage to the muscles of the leg, which is partially prevented by a transition from walking to running. In a space environment, these factors will play a role in astronaut health and injury prevention. For this study, participants walked, ran and skipped on a treadmill while being supported by an analog for activity on other planets called the Active Response Gravity Offload System (ARGOS). These intervals were performed under 1g, and then under simulated .38g, and .17g conditions to simulate gravity conditions on Mars and the Moon, respectively. Electromyography was used to monitor muscle activation, along with the Vicon motion capture system for 3D motion analysis. Results show that there are significant changes ($p < .05$) in activation energy in the tibialis anterior and medial gastrocnemius under simulated Martian and Lunar gravity conditions, as well as significant changes ($p < .05$) in dorsiflexion and plantar flexion. These findings suggest that there are fundamental changes in the way humans move in these fractional gravity environments, and that the effect these changes have on the body should be included in the development of astronaut training regimen development.

CHAPTER I. INTRODUCTION

The efforts of space exploration have recently turned back to a sustained human presence on the Moon, as well as our first crewed mission to Mars. Shifts in space policy and new commercial ventures have spurred the announcement of the Artemis program, NASA's multi-phase path from the Moon to Mars. Artemis 1 will be the next human mission back to the Moon, will see the first woman step foot on the lunar surface, and is set to land by 2024. With this new push back to the Moon and beyond it is important to reconnect with the lessons learned from Apollo, and how training needs to be updated to reflect the current scientific knowledge base.

One area that has been studied pre and post-Apollo is how humans move around in lower gravity environments, such as on the Moon or Mars. NASA developed a Reduced Gravity Walking Simulator to study human movement and give astronauts the ability to practice moving in reduced gravity before they ever stepped foot on the moon (Hewes, 1969). Though this simulator provided a way for researchers to study possible movement in lunar gravity levels, it restricted movement to forward momentum (Hewes, 1969) and was not used to develop a locomotion training regimen. Later on, video of Apollo astronauts moving on the moon in what appear to be skipping gaits resulted in post-Apollo studies on the efficiency of skipping in these environments. The idea of skipping being the preferred method of locomotion in these environments based on efficiency has dominated subsequent research.

While the energy efficiency of locomotion method is inherently coupled with the gait choice, familiarity and training will undoubtably also play a role in selection. When asked about his locomotion selection on the moon during a Question and Answer session at the Fiske Planetarium located at the University of Colorado, Boulder, Apollo Astronaut Harrison “Jack” Schmitt noted that he selected an apparent skipping gait because it was familiar to him, as it was similar to the leg motions he had become accustomed to as an avid cross-country skier (Schmitt, 2018). He further went on to suggest a study on cross-country movements over skipping in reduced gravity environments. This revelation that it was not necessarily a new gait, but a gait that he had become accustomed to through years of practice and chose to use on Moon, shines light on the importance of training for these missions. Future missions to the Moon and Mars should have locomotion training that takes energy efficiency and biomechanics of locomotion into account.

1.1 Background

1.1.1 Human Locomotion

There are three locomotion methods being explored in this experiment: walking, running and skipping. Walking and running are commonly utilized depending on the speed of the individual, with a preferred transition speed between the two occurring at approximately 4.5 mph for most people (Hreljac, 1995). Skipping is considered a novel gate by most and is usually only observed in children or during play to signify joy. Most people do not consciously think of the mechanical differences between walking and running (or skipping, for that matter), but these differences are essential for both their selection at certain speeds on Earth, understanding their energy expenditures, and for the consideration of locomotion methods on other planets due to reduced or increased gravity levels.

Locomotion methods, or gaits, are differentiated by the difference in stride, step, and stand and swing phases. Figure 1 from Minetti (1998) shows the cadence of walking, running, and skipping, including when either foot is in contact with the ground (rectangles) and when they are in float/flight (no rectangle).

Gait Terms (Enoka, 2002):

- Stride- a full gait cycle, from event on one foot to the same event on the same foot
- Step– half of a stride, a cycle of an event on one foot to the same event on the opposite foot
- Stance phase - when a foot is experiencing support from the ground, beginning at heel strike and ending with toe-off.
- Swing Phase – when a limb is not experiencing support from the ground. This begins with toe-off and ends at heel strike.

1.1.1.1 Walking

As the primary locomotion method for humans on a daily basis, walking is the lowest energy cost locomotion method at these speeds in the 1g environment, as well as being the smoothest locomotion method to reduce jostling of the brain and other tissues (Perry, 1967). Mechanically, walking is characterized by at least one foot being on the ground at a time, which is accomplished by an overlapping of stance time between limbs and is usually utilized at slower speeds compared to running (Olympic style race walking speeds can reach over 12 mph, but this is atypical).

1.1.1.2 Running

Utilized at higher speeds, running involves no overlap of stance phases between limbs and includes a phase where both limbs are entirely off the ground, known as the float or flight phase.

1.2.1.3 Skipping

There are two types of skipping: unilateral and bilateral. Unilateral skipping occurs when a person keeps the same foot forwards during the skip, while bilateral skipping occurs when there is an alternation between the left and right foot skipping. Bilateral skipping is the method we normally think of on Earth (such as skipping children), while unilateral skipping is the observed form in videos of astronauts on the moon (Minetti, 1998). While walking and running have consistent stance and swing phases, skipping alternates between a shorter and longer stance phase with the order of foot contact depending on whether unilateral or bilateral skipping is being employed.

Skipping also has ipsilateral foot-ground contact events, unlike walking and running which have contralateral foot-ground contact events (Ackermann and van den Bogert, 2012). This means that during skipping, each foot has two ground-contact events before the opposite foot touches the ground.

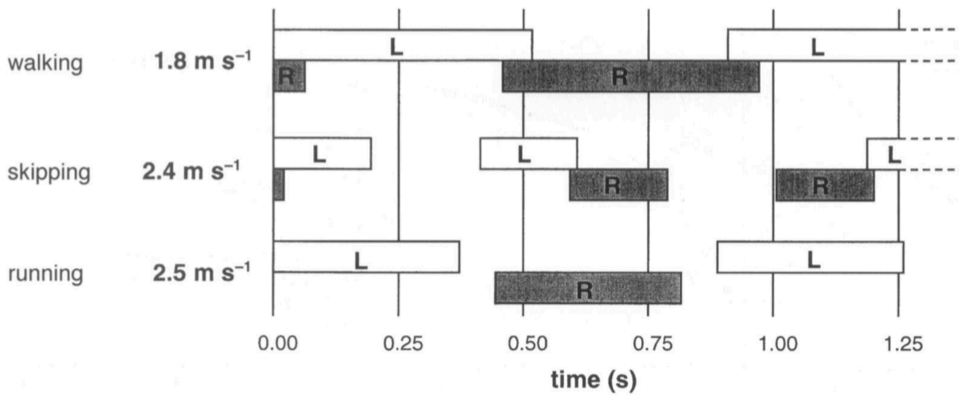


Figure 1. Locomotion Cadences (Minetti 1998)

Depiction of walking, running and skipping cadences. Reprinted from “The Biomechanics of Skipping Gaits: A Third Locomotion Paradigm?” by A.E. Minetti, 1998, *Proceedings: Biological Sciences 265(1402),* 1227-1235

1.1.1.4 Preferred transition speed

When moving from slower to faster speeds, humans switch from walking to running at the cleverly named walk-run transition. This transition occurs at the preferred transition speed, or PTS, when it seems like less effort to run than walk. Whether it is triggered by an actual metabolic reduction or by other biomechanical means is hotly contested, as will be discussed in the literature review. The cause of PTS will be a contributing factor to the selection of gait type on other planets.

1.1.2 Movement

1.1.2.1 Muscles

Muscles are responsible for the movement of the human body. The brain signals the contraction of muscle fibers, which cause the movement of organs and the skeletal system. Of the three types of muscle, two are autonomous (cardiac and smooth muscle), while skeletal muscle is voluntary. Skeletal muscle contractions move limbs by pulling on the muscle attachment point known as the insertion, with help from another muscle attachment point called the origin, which is where the muscle is anchored to the part of the bone that does not move during the contraction.

1.1.2.1.1 Tibialis anterior

The tibialis anterior is the strongest dorsiflexor (extension) muscle and is active during the swing phase, and the heel strike through flat foot section of the stance phase. This activation is used to reduce the slapping impact of the foot on the ground, and to raise the toes to avoid tripping (Brockett & Chapman, 2016). The tibialis anterior is located on the anterior side of the leg (See Image 1)

1.1.2.1.2 Medial gastrocnemius

The gastrocnemius and soleus are responsible for the majority of plantar flexion and come together to form the Achilles tendon. The medial gastrocnemius was selected for this study because the muscle belly had less obstruction for surface EMG electrodes, as the gastrocnemius and Achilles tendon lays between the soleus muscle and the skin (See Image 1). The Medial gastrocnemius was chosen over the lateral gastrocnemius because of the position of the tibialis anterior electrodes, as to avoid crosstalk.

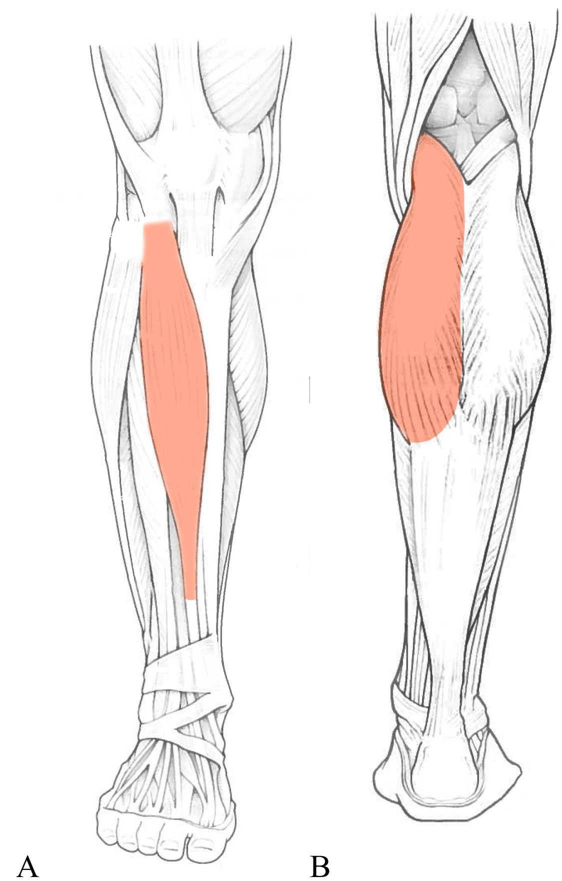


Image 1. Tibialis anterior and medial gastrocnemius muscles

A Tibialis anterior (A), medial gastrocnemius, which lies on the inner side of the leg (C), and a cross-section of where the muscles occur in the leg (B). Adapted from *Netter's Anatomy Coloring* (3-29,3-30), by J.T. Hansen, 2014, Philadelphia, PA: Saunders Elsevier.

1.1.2.1.3 Muscle Activation

Like all muscles, the tibialis anterior and medial gastrocnemius muscles are controlled by nerve impulses. These impulses, also known as muscle fiber action potential in this situation, are based on the rapid changes in electrical potential across the muscle cell membranes. The result of this action potential is the contraction of the muscle, with the intensity of this contraction increasing proportionally to the action potential exhibited upon it. The application of Ohm's law:

$$I = g * V$$

(Equation 1)

where I is the current, g is the conductance and V is the potential difference. As action potential is a change in membrane potential difference, applying Ohm’s law shows that as the action potential increases so does the current associated with it. The potential difference within the muscle itself, not within the associated motor neurons which is caused by increase in current, can be detected by the electrodes used in electromyography (EMG) (Enoka, 2002). Simply put, EMG conveys muscle fiber activity generated as a result of motor neuron activation (Farina et al., 2014).

Studies on muscle activity have demonstrated that muscle activity reductions varied by muscle during different levels of weighting. Mercer et al. (2013) used a lower-body positive treadmill to support the participants during running exercises, simulating a reduction in weight between 50-80% during running trials at three speeds. Gastrocnemius activity reduced in line with the reduction in body weight of the subject, unaffected by speed, while the activity of the tibialis anterior decreased with bodyweight while increasing with speed. They did note that the reduction in activity was not equal to the reduction in weight, suggesting that there is a muscle activation “floor” for running activities. (Mercer et al., 2013).

1.1.2.1.4 Muscle Damage

Muscle damage can be seen in the form of a strain, pull or tear, and can affect a portion of a muscle or the entire muscle and associated tendons (Laumonier and Menetrey, 2016). Muscle injury can cause swelling, bruising, pain, weakness, and complete inability to use the muscle or limb(s) associated with the muscle. This damage can occur due to overuse of a muscle, such as quickly lifting weights too heavy for the comparative strength of the muscle.

1.1.2.1.5 Joints

A joint is a connection between two bones on a human body, consisting of connective tissue, including tendons, ligaments, and cartilage. The bone structure prevents flexing and movement in healthy bone, so a joint is required for the everyday movement of the skeletal system.

1.1.2.1.5.1 Ankle Joints

The ankle is made up of three joints that carry many names among different literature: the subtalar (talocalcaneal) joint, talocrural (tibiotalar or ankle joint proper) joint, and the interior tibiofibular joint, which is often considered a part of the tibiotalar joint. Additionally, some literature claims the transverse-tarsal (talocalcaneonavicular) joint is also part of the ankle (Brockett & Chapman, 2016). The ankle is considered a synovial hinge joint, where the tibia and fibula contact the talus and allow for dorsiflexion and plantarflexion. The two major movements of the ankle that occurs mainly at the tibiotalar joint, though all of these joints play a part in this basic movement (Brockett & Chapman, 2016).

1.1.2.1.5.2 Joint Angles

Joint angles are the degree of extension or flexion from a fixed point, which is usually based on a human standing. When discussing movement of the ankle, the term “dorsiflexion” is used for pointing the foot upwards from 90°, while “plantar flexion” is used to describe pointing the toe downward from 90° (See Image 2). This movement is along the sagittal plane of the foot and includes the tibiotalar and subtalar joints within the ankle. The full range of motion (ROM) of the ankle varies depending on many factors, including the age of a subject, geographical location, cultural influences, daily activity level or foot injuries (Brockett & Chapman, 2016), but is normally between 0-20° for dorsiflexion and from 0-55° for plantar flexion (Nordin & Frankel, 2001). However, the ROM exhibited by the ankle during locomotion is typically lower than the full ROM of the ankle, with average walking dorsiflexion peaking at 10.2° and plantar flexion peaking at 14.2°(Stauffer et al., 1977).

Image 2: Dorsiflexion & plantar flexion.

Dorsiflexion occurs when the foot is pointed upwards, while plantar flexion occurs when the toes are pointed downwards. Adapted from *Netter's Anatomy Coloring* (1-30), by J.T. Hansen, 2014, Philadelphia, PA: Saunders Elsevier.

1.1.2.1.5.3 Joint Injury

Damage at a joint can have long rehabilitation times, varying from short stints of rest and elevation for a strain to surgeries for injuries that involve torn ligaments. Joint injuries include strains, sprains, fractures, and dislocations, and involve joint muscles, ligaments and bones, depending on the injury. Studies of large groups of sports injuries show that ankle and lower limb injuries are extremely common, with ankle ligament injuries being the most common (15% of all NCAA injuries between 1988-2004) and

50% of all injuries involving the lower limbs (Hootman et al., 2007). Another study focusing on high school athletes found that 52.8% of all injuries were lower extremity sports-related injuries, with 50% of those being sprains, 40% of all injuries occurring at the ankle, and 42% of all fractures occurring at the ankle (Fernandez et al., 2007).

1.1.3 Fractional Gravity Environments

The environment that an organism lives in defines the growth and evolution of muscles and the skeletal system, as well as the organ systems that it relies on to survive. In this respect, humans are no different from any other creature. Humans evolved in a 1g environment, where 1g stands for the normal gravitational force equivalent, or g-force, felt per unit mass on the Earth's surface as caused by gravity. This has shaped our locomotion style affected the structure of our bones and the size of our vestibular organs and everything in between. These evolutionary adaptations show that natural selection is working on us, shrinking muscles and bones we do not use until they disappear without consequence, or growing the ones we need until they are optimal for our daily needs. Unfortunately for the future of human space exploration, the force of microgravity, where the pull of gravity is not strong enough for objects to feel like they have a weight, is so far below the 1g felt on Earth that human body functions could vary to an extreme level. One such function is the circulatory system, which exhibits fluid shifts inside the body, changing the distribution of blood upwards (Drummer et al., 2000, Fu et al., 2004,). This change can affect the perception of your surroundings and cause space motion sickness, among other health problems. Other systems that rely on gravity, such as the musculoskeletal system, degrade to levels that render them useless upon returning to Earth. Between 1g and microgravity there are fractional gravity environments, such as the Moon and Mars, with gravity levels of .17 g and .38 g, respectively. The changes to human biological functions are less obvious, as there are few examples of humans in these environments (limited only to Apollo astronauts). Terrestrial analogs for these environments exist, but the time spent in these analogs and the assumptions made leave a question as to their fidelity to fractional gravity environments.

1.1.3.1 Astronaut Training & Simulators

NASA astronauts receive two years of training as Astronaut Candidates before their first launch. While the majority of this training is to ensure skill in their endeavors, much of it is focused on simulating the space environment to test physical compatibility with spaceflight, and to acclimatize them to the general feeling of weightlessness. Astronaut Candidates train in facilities that offer a range of fidelity, with no simulator being a perfect analog for spaceflight. The Neutral Buoyancy Lab (NBL), which has a large pool and a mockup of the ISS where they can practice EVA procedures in an environment that simulates space movement and the bulk of the spacesuits they will be performing them in, (Seedhouse, 2010) but does not offer accurate biomechanics or metabolic rates (Norcross et al., 2010). Other methods, such as parabolic flights, offer seconds of actual weightlessness but pose limits in the number of people and equipment that can be involved in the tests, not to mention the prohibitive length of these weightless periods (Norcross et al., 2010). Additionally, some training and studies are being conducted on reduced gravity simulators such as NASA Johnson Space Center's Active Response Gravity Offload System, or ARGOS, which can simulate the fractional gravity environments between 1g and microgravity for human and robotic testing (NASA 2013, Valle et al., 2011). This provides more prolonged levels of simulated micro or fractional gravity and proximity to testing equipment, as many of these systems are located at space centers. The ARGOS builds on of the Partial Gravity Simulator known as the POGO, which only had forward and up and down abilities (X & Z), while the ARGOS includes a third degree of freedom in the Y plane. Finally, field analogs allow for testing of tools and equipment in realistic EVA locations but are limited to 1g and therefore do not offer a full simulation of biomechanical moment on other planets. (Norcross et al., 2010). The actual differences in fractional gravity will need to be tested and compared to the data collected in studies from ARGOS and other simulators, as the impact of the internal mechanisms of these machines on the movement of the participants is not yet understood at this time, especially given differences in ground reaction force between ARGOS and parabolic flight trials (Crowley et al., 2014).

1.1.3.2 Muscle and Bone Density Loss

Weakness and fatigue occur after just several days in microgravity conditions (Leach and Rambaut, 1983), though the effects can continue to grow the longer they stay in a reduced gravity environment (Adams et al., 2003). In an examination of how contraction methods of muscle fibers were affected by spaceflight Widrick et al. conducted a study comparing muscle shortening velocity and power production in soleus muscle fibers. After a 17-day spaceflight they observed that type I Myosin heavy chain muscle fibers produced less force on average than they had during preflight conditions and that the muscle fibers shortened at a higher velocity (Widrick et al., 1999). As the soleus muscle is used heavily in plantar flexion, this could impact the use of this muscle in gravitational environments, even with reduced gravity levels as low as on the Moon and Mars.

1.2 Problem Statement

Human movement on other planets can have serious implications for the health of astronauts on a long-duration mission. Locomotion methods need to be properly tested in simulated reduced gravity environments to determine how astronauts should be trained before their voyages. The effects of these environments on muscle activation, dorsiflexion and plantar flexion will be fundamental in evaluating locomotion methods and determining the best training regimen.

Chapter II. Literature Review

Human locomotion is hugely complex, so it should come as no surprise that the transition from 1g to lunar or Martian gravity will have a tremendous impact on locomotion. These effects include balance issues due to vestibular system reliance on gravity, changes in locomotion mechanics, and the effect of suits required in these harsh conditions on locomotion methods. The selection of walking, running or skipping will depend on the interaction of these factors.

2.1 Gravity and the Vestibular System

The human vestibular system has evolved to create a stronger sense of balance by increasing the relative size of the anterior and posterior semicircular canals, which are associated with balance in the vertical plane (Day and Fitzpatrick, 2005). The vestibular organs rely significantly on their ability to sense gravity in order to correctly signal the brain as to the intensity and vector of acceleration that is being exerted on the body. This dependence on gravity for balance could prove detrimental in microgravity and reduced gravity as felt during spaceflight and planetary exploration. A 2014 study by Harris et al. discussed the importance of gravity in calculating the perceptual upright, or how the human body assesses what direction is up. Through use of the Oriented Character Recognition Test (OCHART), they were able to establish that humans can begin to correctly assess the perceptual upright at gravity levels as low as 0.15, which is just lower than the 0.17g felt on the surface of the moon (Harris et al., 2014). Though this finding is corroborated by other studies, a previous study by de Winkel et al. (2012) found a wide variation in the gravity needed by individuals to correctly gauge perceptual upright ranging from .03g to .57g. In addition to the wide range, the data they collected show that there was a positive correlation between the age of the participant and their dependence on gravity to establish the perceptual upright, where the older the participant was, the more they relied on it. Due to high amounts of cosmic radiation in space, the first missions to Mars would most likely have older crew members. This would reduce the risk of cancerous masses being the cause of death for said astronauts, as well as offer a reduced chance for reproductive issues as reproduction rates lessen at higher ages. While the visible effects of radiation on older astronauts are lower, the increase of age could have negative ramifications for movement in those environments. There is a difference in testing results between Harris et al. (2014) and de Winkel et al. (2012), but in this case a major contributor is most probably the difference in testing style. The differences in technique are described by Dyde et al. in 2006 indicate that, while the OCHART relies more heavily on the long body axis, the later study relied on the amount that subjective vertical (the identification of a vertical line perpendicular to the ground) depends on gravity (de Winkel et al., 2012). It can, therefore, be suggested that the older an astronaut may be, the more their body depends on the force of gravity to establish what direction is up. This observation hints to the effect of gravity's increased importance in the vestibular system. An older crew might, therefore, have issues with continuous activity on Mars, or in space, without some sort of retraining or rehabilitation device to train/adapt the astronauts to function under reduced gravity for extended periods of time.

The disturbance of the vestibular system function brings up two main dangers. First, the inability to adapt to a new gravitational environment such as that on Mars would leave an astronaut unable to perform mission essential techniques, may require assistance from their crewmates, and could endanger their mission. Nausea and other side effects of severe vestibular pathologies could cause dehydration and malnutrition, endangering the life of the afflicted. Secondly, as the reliance on the vestibular system wanes, the reliance on vision would increase. This will not be an issue for astronauts on a short trip to the moon, but a 6-month spaceflight to Mars puts the astronauts at risk for Spaceflight Associated Neuro-ocular Syndrome (SANS). A NASA Evidence report entitled Risk of Spaceflight Associated Neuro-ocular Syndrome (SANS) suggests that while the vision issues associated with SANS may be acceptable risk for mission success in sub-1-year microgravity missions, but longer missions and planetary missions will require mitigation for these issues (Stenger et al., 2017). Vision impairments may make locomotion difficult if other factors come into play, such as issues with leg biomechanics brought on by changed in gravity levels.

Thought the level of vestibular system disturbance in lunar and Martian gravity levels over long periods will not be truly understood until astronauts experience it, current sensorimotor adaptability training has given modern astronauts the ability to adapt quickly to new gravity environments. NASA and the NSBRI have done extensive testing on the validity of this work, with eyes forward to Martian exploration missions (Bloomberg et al., 2015). By using adaptive treadmill systems that mimic movement differences that could be encountered in the future, Bloomberg et al. were able to train the vestibular systems of the participants to adapt to new environments, using several hand-eye coordination tests to calculate their success. While this training is preventative, once the true distortions felt on Mars are realized the system could be programmed on-site to reduce the transition time. Non-space related organizations have created a variety of vestibular rehabilitation techniques that are able to treat vestibular issues, as opposed to preventative training. A review by Susan J. Herdman has compiled data on the success of vestibular rehabilitation treatments, which were successful in some participants exhibiting vestibular disorders. These rehabilitation techniques utilize gait and balance exercises that could mirror those used in the NASA/NSBRI studies, while others are based on head and eye movements of the patients. Unfortunately, not all patients had the same degree of success, but the treatment was effective on the majority of patients (Herdman 2013).

The effect of gravity on the vestibular system has the possibility of effecting locomotion methods and selection during movement in fractional gravity environments. An assessment of how the different locomotion methods are affected by vestibular perturbations, including base gait stability and the effects of perceived upright on stability during a skipping gait, should be studied before a selection of “optimal” gaits is solidified.

2.2 Gait Selection

Humans spend little to no time thinking about whether they are going to run, walk or skip somewhere. Much of the gait selection calculations happen internally based on a complex and not yet fully understood series of calculations conducted by our central nervous system (CNS) (Croft et al., 2019). Locomotion, at its core, is a means to an end – you walk or run to get somewhere, catch something, or run away from something. With that in mind, it makes sense that the less energy you expend to complete these tasks, the longer you can continue doing them or the more energy you can spend on a more essential task. The evolutionary advantage to lower energy locomotion methods is apparent in the subconscious changes to minimize energetic costs by tweaking frequency of steps and limb movement. A study by Snaterse et al. found that within walking there are two phases of human gait frequency selection: one that occurs quickly in response to changes in speed, occurring under 2 seconds from the speed change, and the second phase of fine-tuning the gait around the 10-second mark. They cite the apparent difference between a pre-programmed response to quickly change speeds in the fast phase and direct optimization of the chosen speed in the slower phase. These processes are used to find the most economical method of walking (Snaterse et al., 2011).

2.2.1 Stability

Human locomotion is a complex movement involving limbs and joints moving and rotating at different speeds. This requires extreme coordination of neurological signals to compensate for this movement, as well as shifts in the center of mass. A lack of stability can cause tripping, falling, or injury of a joint. To be considered as a reliable locomotion method on Earth or in other environments, stability must be confirmed. Gait stability is significantly lowered when the ankle muscles, specifically dorsiflexion, are weakened, especially at higher walking speeds (Whipple et al., 1987). This has implications for muscle degradation during spaceflight with subsequent planetary missions, where adjusting to a novel gravity environment could put astronauts at an increased risk of gait instability.

Studies have shown the connection between the effects of spaceflight on astronauts mirror the degradation of elderly humans on Earth (Goswami, 2017). Just as lessons can be learned about elderly care from spaceflight applications, lessons from rehabilitation and fall prevention in elderly can influence training of astronauts exhibiting muscle atrophy. Weight training of the lower limb counteracts the progression of gaits declining into unstable, fall-prone gaits in elderly women (Persch et al., 2009). This change in gait kinematics may be a precursor for training suggestions for astronauts living in fractional gravity for long periods of time.

2.2.2 The walk-run transition

In 1g human bipedal locomotion has two "normal" methods; walking and running. The switch between the two occurs when the perceived efficiency of walking becomes less than that of running, at a speed known as the preferred transition speed (PTS). This point is typically a gradient of motion, not an abrupt change under either terrestrial

(Hreljac et al., 2008) or reduced gravity conditions (Sylos-Labini et al., 2014). In terrestrial gravity levels, the PTS is close to 2.0 m/s.

Current research on the actual speed at which this transition occurs given variations in height uses a dimensionless value called a Froude Number, represented by the equation:

$$Fr = \frac{v^2}{gL}$$

(Equation 2)

where v = speed of locomotion g = acceleration of gravity and L = characteristic limb length (usually leg length for applications to humans) (Sylos-Labini et al., 2014). The preferred transition is given at Fr = 0.5 (Alexander 1989). This is in contrast with the optimal walking speed of humans which is at Fr=0.25 (Leurs et al., 2011). These transitions can also be applied to locomotion on other planets using the equation:

$$v_{planet} = v_{Earth}\sqrt{\frac{g_{planet}}{g_{Earth}}}$$

(Equation 3)

where v = reference velocity and g= acceleration of gravity (Minetti, 2001). In an attempt to determine if Froude numbers were applicable to locomotion on other planets, Kram et al. performed a study where participants used a reduced gravity simulator and were asked to walk until they reached their PTS, at which point they should run. The results of their data showed that under reduced gravity, there was still a predisposition to transition at a Fr = 0.5, and consequentially the speeds of transition were lower (Kram at al. 1997).

What triggers the walk-run transition is an area up for additional research, though many studies have attempted to answer that question. There is a discrepancy between the optimal walking speed and the transition speed, which shows a decrease in energy efficiency prior to the transition from walking to running (Hreljac, 1993). The speed at which running is more energy-efficient than walking is higher than the actual preferred transition speed of change we observe. Hreljac demonstrated that participants perceived a lower level of exertion while running at the point of preferred transition speed than walking, even though the energetically optimal transition speed was higher than each individual's perceived transition speed (Hreljac, 1993). To address this, Hreljac and a team of researchers conducted a study in 2001 focusing on different muscle systems. This study concluded that the preferred transition speeds were not influenced by the actual metabolic energy output of the participant at that speed but instead were based on the force placed on the dorsiflexor muscles that cause the foot to be pulled towards the shin (Hreljac et al., 2001).

Ankle plantar flexor force production has also been linked to the PTS. A comparison of muscle activation for several muscles of the leg, including the medial gastrocnemius and tibialis anterior, was conducted by Neptune and Sasaki in 2005. They found that the ability of the plantar flexors to generate force during walking at the PTS was hindered by the mechanics of locomotion at that speed. They proposed that the switch to running was to regain the ability of the plantar flexors to generate force, as running at the same speed saw a drastic improvement in force production at the ankle (Neptune and Sasaki in 2005).

2.3 Skipping as an Alternate Locomotion Method

Walk-run transitions have been studied widely in normal gravity levels, but the locomotion paradigms exhibited during the Apollo missions implied that the usage of running might be swapped for skipping. Videos of Apollo astronauts showed skipping motions replaced regular walking during moon EVAs (Jones, 2010). These videos have fascinated researchers, who have studied the cost of skipping in fractional gravity, even proposing a walk-skip transition instead of a walk-run transition (Ackermann and van den Bogert, 2012).

In order to address the walking and running/skipping transitions in space, the energy expenditures of each method in environments other than 1g have been assessed by several studies. The most efficient speed of each movement style can be described by maximum levels of the recovery of mechanical energy (R) during each cycle of movement. This number varies based on locomotion method, speed, and influence of gravity (Cavagna et al., 2000). A study by Cavagna et al. (2000) determined that the highest values of R corresponded with slower speeds in Martian gravity levels, and also suggested that higher gravity levels would show the opposite effect. In addition, they demonstrated that the level of gravity positively correlates with the ability to maintain walking mechanisms, with increased gravity enabling the participant to continue the pendulum motion at higher speeds, but also increased the amount of work needed to do so (Cavagna et al., 2000). As locomotion is optimized to be as low energy as possible, the ability to walk at higher speeds may be a moot point when either running or skipping could reduce that cost.

In order to determine whether the preference for skipping motion exhibited by Apollo astronauts on the moon could continue under Martian gravity conditions, researchers Ackermann and van den Bogert conducted a study using physiological computer modeling simulations to analyze the energy expenditure of walking, running and skipping under Earth, Lunar and Martian gravity levels. As previously mentioned, the analysis of human transitions from walking to running has shown that 2.0 m/s or 4.5 mph is the average preferred transition speed in 1g. Using this as a reference point, Ackermann and van den Bogert analyzed the energy expenditures of all three locomotion types, focusing on the implications for effort and fatigue. Analysis of their data showed that while walking and running are the energy-efficient methods of locomotion on Earth, skipping was the most energy-efficient on the moon and all three means of locomotion had benefits on Mars. Under Martian gravity levels, and at the aforementioned transitional speed of 2.0 m/s, it was less effort to run, but less fatiguing to skip (Ackermann and van den Bogert, 2012). The nuances of the difference between effort and fatigue lies in the difference between energy expenditure (effort) and muscle fatigue (fatigue). They define these three terms in their paper:

Effort cost function:

$$J_e = \frac{1}{\Sigma V_i} \sum_{i=1}^{m} \frac{V_i}{T} \int_0^T a_i^2\,(t)\; dt$$

(Equation 4)

where a is muscle activation and V is the volume of the muscle.

Fatigue cost function:

$$J_f = \left(\sum_{i=1}^{m} \Phi_i^{10} \right)^{1/10} \approx \max_i \Phi_i$$

(Equation 5)

where Φ is a measure of muscle fatigue:

$$\Phi_i = \frac{1}{T} \int_0^T a_i^3(t)\; dt$$

(Equation 6)

with a continuing to represent muscle activation. These equations are based on Crowninshield and Brand's (1981) findings that muscle fatigue is "approximately proportional to the cube of the muscle activation." It is apparent that muscle fatigue levels would be more apparent to changes in muscle activation, given the higher power exhibited in the muscle fatigue equation versus the effort cost equation.

Ackermann and van der Bogert also note that there is a spike in tibialis anterior activation at the 2.0m/s, as the tibialis anterior tendon works to counteract the additional plantar flexion caused by the tendency to land on the back portion of the foot. This activation was apparent in the analysis of fatigue but absent from the effort cost graphs.

The evidence that the cost of movement is not the only factor encouraging an individual's specific preferred locomotion method needs to be taken into account when determining gait selection preferences in fractional gravity environments. A study by Pavei et al. in 2015 came to a similar conclusion regarding skipping and running selection in hypogravity. Their study determined that the metabolic rates of running and skipping were low in simulated Martian and Lunar conditions – about the same as observed in walking gaits in Earth gravity. They determined that the difference between metabolic requirements for running and skipping were negligible at these levels, though skipping was still more costly than running in both novel scenarios. This led their team to determine that non-metabolic reasons were responsible for the preference towards skipping in the Lunar environment shown in Apollo footage, as well as in Ackermann and van den Bogert's 2012 study which was the jumping-off point for their research (Pavei et al. in 2015).

2.4 Suited Effects on Locomotion

Human locomotion is impacted by spacesuit usage due to their mass (including mass distribution), pressurization, and mechanically induced joint stiffness (Carr and Newman, 2005). The mass of the suit causes the center of gravity to be shifted aft compared to terrestrial gravity (Mulugeta et al., 2009) and ultimately alters mobility in the way of muscle force and joint angles (Sridhar et al., 2017) , While the mass of a spacesuit is high, considering the requirements for personal life support systems and layers to protect the astronaut from the harsh environments other planets, the pressurized nature of the suits means that this mass is not necessarily all weighing on the astronaut. Pressurized suits are partially self-supporting in a vacuum, reducing the mass supported by the wearer. Given this reality, and expanding upon the Froude number discussed earlier, Carr and McGee (2009) conducted a study that demonstrated that the walk-run transition occurs at lower Froude numbers in the lunar environment when participants were compared to non-suited conditions. This study introduced a new dimensionless value, the Apollo Number (Ap),

$$Ap = \frac{Fr}{M}$$

(Equation 7)

which took the Froude number and divides it by M, the ratio of human supported to total transported mass. They computed Fr and Ap values by taking anthropometric values from Apollo astronauts and comparing their walk/run/lope velocities during audio and video clips of those astronauts on the lunar surface. They concluded that Ap results in 60% of the reason for the gait transition, though they proposed these numbers could vary based on experiments from Kram et al. (1997) run on NASA's POGO (estimates 38%) or possibly much higher given the sample bias of their tests. Their takeaway was that while this was a significant effect on the walk-run transition, other factors were more likely coming into play, such as metabolic expenditures, muscle force/activation, or stability (Carr and McGee, 2009).

As with injury to the dorsiflexor muscles, the constraints put upon an astronaut by the design of the EVA suit must be taken into account when determining the best gait to use in an environment. Sparrow and Newel posed in a 1998 article that the economy of completing a task was easier to address than the efficiency of those tasks because determining total actual work completed for that task was difficult, if not impossible. They go further to suggest that there are three constraint systems that work against a task being completed: Organism constraints, where the abilities and anatomy of the organism such as muscle force generation, Environmental constraints, including gravitational constraints, where the environment poses additional metabolic energy demands, and Task constraints, where the regulations of the task imposed by either societal or mechanical (such as tool design) constraints determine forced movements or time constraints. These three constraints are involved in defining the movement available to an organism where the efficiency of actions is used to help determine which movement set is ultimately chosen (Sparrow and Newell, 1998). The intersection of these restraints was expanded in Croft et al. (2019), where they concluded that energetic cost of motion was an outcome of the interaction between environmental, organism, and task requirements and constraints. Constraints such as suit and EVA design can impact the efficiency of movements in other planetary environments, even if these movements are optimized for the environment. This impact could increase or decrease stability depending on design interactions with the astronaut.

2.4.1 Skipping, by any other name

A significant issue within the literature at this time is the definition of locomotion methods. While Apollo astronauts are seen making a unilateral skipping pattern, this is often called loping, or just skipping, with little attention given to the difference between the two terms when comparing studies. Crowley at al. describe a "rolling-loping walk (resembling cross-country skiing)," with no definition of what this mainly looks like or how it compares to bilateral or unilateral skipping. It is also worth noting that loping is sometimes used interchangeably with skipping in earlier studies, while loping in colloquial terms just means long, bounding strides and does not necessarily imply a skipping movement. Computer simulations, such as those done by Ackermann and van den Bogert (2012) focused on bilateral skipping, while others focused on unilateral skipping as demonstrated by Apollo astronauts.

In any case, over long periods of time, this change in usage towards skipping could exacerbate the degradation of some bones and muscles, while encouraging growth in others that are typically not used in 1g. This could substantially inhibit the ability of astronauts to walk or complete other movements when they return to Earth gravity and could induce injury and pathologies that could significantly cripple the astronauts.

2.5 Hypothesis

This thesis tackles four hypothesis based on electromyography and motion capture data:

1. Mean activation energy peaks in of the tibialis anterior will vary significantly between Earth gravity and simulated Martian and Lunar gravity levels.

2. Mean activation energy peaks in of the medial gastrocnemius will vary significantly between Earth gravity and simulated Martian and Lunar gravity levels.

3. Mean dorsiflexion peaks will vary significantly between Earth gravity and simulated Martian and Lunar gravity levels.

4. Mean plantar flexion peaks will vary significantly between Earth gravity and simulated Martian and Lunar gravity levels.

CHAPTER III. METHODS

To explore muscle activation and ankle angles in fractional gravity, electromyography of the tibialis anterior and medial gastrocnemius was collected, as well as motion capture data. These were collected at a range of speeds in 1g and under simulated reduced gravity conditions equal to that of Mars and the Moon. Simulated conditions were made possible by the Active Response Gravity Offload System (ARGOS) at NASA's Johnson Space Center. Statistical analysis was performed to determine whether and when significant changes in muscle activation or ankle angles were present, and whether these were higher or lower values.

3.1 Variables

Primary dependent variables include muscle activation, measured in mV, and angles of biomechanical movement, specifically of the ankle, measured in degrees of dorsiflexion or plantar flexion. Independent variables are speed of motion in m/s, and gravity levels in g, with Earth gravity being 1g, simulated Martian and lunar being .38 and .17, respectively.

3.2 Procedures

Participants walked, ran and skipped on a treadmill at 1 MPH increments from 2 to 6 MPH. The tests were repeated for different simulated gravity levels (Lunar and Martian gravity) by connecting the participants to the ARGOS via a gimbal system. The duration of testing was 1 minute per speed per gait, with the last 10 seconds of each speed being used for analysis. This allowed the participant to get used to the speed with the system setup to reduce noise in the data. Speeds and gravitational constants were verified through the VICON system before analysis was conducted.

3.3 Participants

3.3.1 Sample Size

The sample size (n) of this study is 6. This study is attempting to estimate a characteristic of the response measures, and is study is exploratory. This sample size fits within the range discussed within current literature, including other NASA studies, which often feature only three participants.

3.3.2 Participant Selection

Participants were selected based on convenience sampling. Three female participants and three male participants were selected based on availability and ability to perform the exercises required by the study without the risk of adverse health effects. Requirements to ensure the health of our participants were suggested by the NASA IRB office documentation for exercise protocols and included:

* BMI lower than 30
* BMI higher than 19
* No recent smoking history
* No history of lower back pain
* No history of Achilles tendinitis

* Must be able to complete the exercise requirements of this study as listed in the consent form

3.3.3 Institutional Review Board

Institutional Review Board (IRB) approval is required for any study using human participants, including this thesis. IRB Applications were approved by both The University of North Dakota and NASA's Johnson Space Center prior to the recruitment of participant or any participant related testing.

3.3.3.1 Medical Monitor: Level 3

NASA JSC requires medical monitors to be present for any procedures where participants may be injured. Their system uses levels 1-4, with one being the most extreme level of monitoring and 4 being the lowest. The medical monitoring level of this study was level 3, with the following requirements list included in the IRB resources:

* Typically for procedures that carry less risk than Level 2 procedures, for example, those that require sub-maximal aerobic exertion of <85% of maximum predicted heart rate or VO2.
* A physician with current BLS-AED training is available within 15 minutes of notification.
* Two other BLS-AED certified personnel can respond to the test site within two minutes.
* An AED is located nearby and available for use within two minutes.

3.3.3.2 Risk Assessment & Hazard Analysis

Risk assessments and hazard analysis are required for NASA IRB applications and include plans for mitigation of risks and hazards. For this study risks included those associated with exercise and usage of the ARGOS, and mitigations were devised to reduce those risks. Both the Risk Assessment and Hazard analysis are included in the appendix (See Appendix A).

3.3.3.3 Consent Forms

Consent forms outlining the tasks to be performed and the risks were outlines in a consent form that was given to the participants in advance, and then reread and discussed with the participants before their involvement in the study. Participants signed the consent forms before test procedures began and were provided with IRB and PI contact information in the event they had any issues during or after the study tests. These forms were approved by the UND and NASA JSC IRB Boards. The consent forms can be viewed in the Appendix (See Appendix B and C).

3.4 Metrics

3.4.1 Electromyography

There are multiple types of EMG, including intrusive and non-intrusive methods. This study employs surface EMG (sEMG), a non-intrusive method using electrodes that are placed on the skin. This method was chosen as it reduces the risk to the participant caused by piercing the skin and does not require medical training to administer. These electrodes detect muscle activation, which is then used in statistical analysis to determine muscle usage.

3.4.1.1 BIOPAC MP150 System

This hardware system is used to collect data about the human body for research purposes. It allows integration of different data acquisition modules, including the BIOPAC EMG100C unit used in this study, and utilizes channels to allow for multiple sets of data acquisition at once. The system works with BIOPAC AcqKnowledge software for operations, as well as some levels of data, clean up and analysis.

3.4.1.2 BIOPAC EMG100C

The EMG100C amplifies general and skeletal muscle electrical activity. The connection points were non-invasive surface electrodes (no needles or skin penetration - Figure 2) that effectively senses muscle activation and sends the signal to the EMG100C, which then integrates with the main MP150 unit. These electrodes only receive signals; they do not emit signals to the subject. Placement of these electrodes were placed on the leg on the skin above the tibialis anterior and gastrocnemius medialis. The electrodes have a sticker built into them, and conductive gel was used to ensure signal strength. Participants either removed hair from the areas of skin that had the electrodes attached to them, or the PI shaved the areas for them. Ace bandages and tape were used to keep the electrodes in place and illuminate the risk of participants tripping on the lead wires (See Image 3).

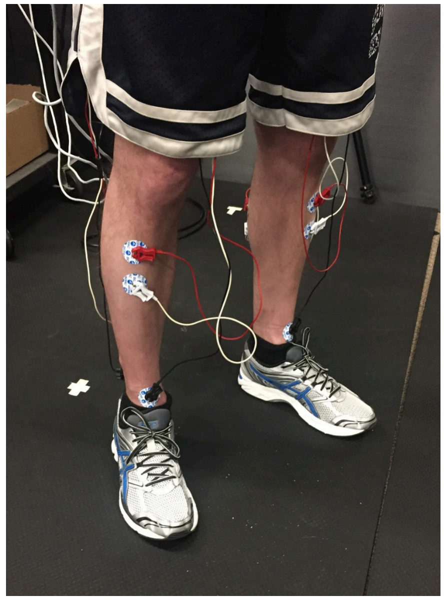


Image 3. EMG Electrode placement.

Placement of surface electrodes before securing them to the participant's legs with Ace bandages.

3.4.1.3 BIOPAC AcqKnowledge

This software is used to control operations of the MP150 and connected units during data acquisition. It is also used to clean up data with filtering algorithms and allows for quick access to mean, standard deviation, and maximum and minimum values for data used in this study.

3.4.1.3.1 Filtering

Raw EMG data are rectified for analysis using the Vicon average rectification filter, a software solution that makes the data easier to analyze. This filter takes the absolute value of the EMG signal, instead of leaving it in positive and negative values, which makes statistical analysis simpler for this application. This is the common approach to cleaning up EMG data for analysis (Enoka, 2002).

3.4.1.3.2 Additional Software

Vicon version 1.8.5 (Vicon, Oxford, UK) Nexus software suite was used for the calibration, data collection, and preliminary data cleanup. Vicon Polygon 4 version 4.0.0 was used for data visualization. Microsoft Excel was used to parse data and organize it for analysis. MATLAB version R2018b (MathWorks, Natick, MA, USA) was used for data analysis, as well as SPSS Statistics version 1.0.0.1131 (IBM, Armonk, NY, USA).

3.4.2 Motion Capture

Motion capture is used to translate movement in 3D space to a data set on a computer that can be processed by relevant software. This allows researchers to precisely measure kinematic data, such as ankle angle, and to extrapolate more complex biomechanics found in kinetic data. This system uses cameras and reflective markers to reduce the data cleanup compared to manual methods.

3.4.2.1 Vicon NEXUS

Vicon NEXUS infrared motion capture analysis system was employed during testing. This system consists of 10 motion-capture cameras mapped the movement of the participants by receiving light shining off of 35 reflective markers placed on key points of the participant's body. These points are standardized as described in Vicon's Plug-in Gait Models, and correct placement is critical for analysis (Vicon Motion Systems Ltd., 2017).

For this study used two posterior superior iliac spine markers instead of a single sacral marker to increase the visibility of the markers due to obstruction from the ARGOS gimbal. This complex system allowed for a comparison between joint angles and overall movement of the participant's body, with the Plug-in Gait model being easily recognized by the system software, as per its design. Each test was recorded and then the data were recorded using the Vicon analysis software (Figure 3), which allowed for analysis of gait variations between tests.

3.4.2.1.1 Hardware

This system consists of 10 infra-red motion-capture cameras that track the movement of the participants by receiving light shining off of reflective markers placed on key points of the participant’s body (these points are standardized) (See Image 4). This allows for a comparison between joint angles and overall movement of the participant’s body.

Image 4: Motion capture reflective marker.

This marker has reflective coating that shines light back in the direction it originated from, allowing the 10-camera system to pick up the movement of the marker.

3.4.2.1.2 Software

Vicon Nexus 1.8 software suite was used for the calibration, data collection, and preliminary data cleanup. Vicon Polygon 4 was used for data visualization. Microsoft Excel was used to parse data and organize it for analysis. MATLAB was used for data analysis, as well as SPSS.

3.4.2.1.3 Calibration

The Vicon T wand is used to calibrate the system. This wand has five 14mm markers, similar to the ones used on the body of the subject. The wand dimensions are prerecorded into the Vicon NEXUS software, and calibration of the test area is performed by manually waving the wand in large circles during a calibration run.

3.4.2.1.4 False Markers & Interference

As this system is participant to the reflectivity of objects in the testing area, a visual sweep for reflective surfaces that appeared in the software window were identified and mitigated. The gimbal system or the treadmill momentarily blocked the view of markers for certain cameras, but the number of cameras employed during this test reduced the amount of marker disappearance.

3.4.2.1.5 Filtering

A 10 hz Woltering filter was applied to the Vicon data. This filter was used to smooth data for processing and was specially designed to be the equivalent to performing a double Butterworth filter on kinematic data (Vicon).

3.4.3 Hexoskin

A Hexoskin Smart Shirt was used to monitor the heart rate of the participants during exercise. This shirt is used in conjunction with an app that receives heart rate data via Bluetooth from the shirt. Participants ages were used to calculate their 85% max heart rate. These rates were used as a basis to stop testing and allow the participants time to rest before resuming.

3.5 Study Design

Exercise protocol that is conducted over a short period of time can have the risk of tiring out the participants, which could skew data. This study scheduled the most energy substantial activities first (Earth-level gravity runs) before the second (Martian) and least (Lunar) intensive runs to reduce this possibility. Participants were also given time to recuperate if they needed it, and there were additional breaks between the gravity conditions due to connecting the participants to the ARGOS gimbal.

3.6 Statistical Analysis

Means and standard deviations were determined from collected data using Microsoft Excel version 16.31. Only one round of testing, with no replications, was competed, as there was limited time to conduct the study due to the ARGOS schedule. Due to the relatively low sample size associated with studies in which an extensive amount of time is necessary for participant preparation and data collection, statistical analysis within this study was limited to non-inferential statistics. This has typically been the case with fractional gravity studies. Low numbers associated with these types of data collection require the application of non-inferential statistics are utilized in determining the extent to which a particular difference or association is of interest for future studies. Primarily, an examination of this nature is utilized to demonstrate possible avenues for future examination and illustrate possible hypotheses for future testing.

This study employed two statistical methods, One-way Analysis of variance (ANOVA) and an Independent Sample Student's T-Tests. ANOVA tests are used to determine the difference in mean values of the samples were significantly different enough to warrant further testing; in our case this is in the form of a T-Test. The main difference between ANOVA and T-Tests is that ANOVA tests are used on three or more sample populations, while T-Tests are only used on two sample populations. Data were grouped into three categories for the ANOVA: walking running and skipping. ANOVAs were performed in SPSS for each speed, and into either channel (for EMG) or left and right leg (for absolute ankle angle). It was essential to separate the ANOVA by speeds as different locomotion methods might be more advantageous at different speeds. This would have incorrectly rejected the null hypothesis, leading to an incorrect assessment of the effect of reduced gravity and made it impossible to determine at what speeds the chances in locomotion were truly different, if at all. The left and right leg were analyzed separately to allow for differences in each leg during unilateral skipping gaits. T-tests were conducted in MATLAB comparing Earth and Martian values, and Earth and lunar values, but not Martian and lunar values. These tests mirrored the setup of the ANOVA in regard to locomotion method and speed.

3.6.1 Hypothesis testing

T-test data will be used to test the hypotheses. P-values will be evaluated based on whether they are equal to or above .05 (hypothesis rejected) or below .05 (hypothesis supported). While these p-values may vary among locomotion methods and speeds, a statistically significant change in any of these sections supports the null hypothesis, as this thesis is looking for changes in overall locomotion, not just at one speed or under one locomotion method.

3.6.2 Bonferroni corrections

When multiple comparisons are made during statistical analysis, corrections are often used to offset the chance of type I and II errors. While the Bonferroni correction has its merits, it is often criticized for overly decreasing the power of performed tests, increasing the likelihood of type II errors (failing to reject the null hypothesis) (Perneger, 1998). As this study is exploratory in nature, and as the n value is already too low to make arguments based on the statistical power of these tests, I have decided to focus on p-values without the Bonferroni correction ($P<.05$). While this is fine for the EMG values, there is some inconsistency with the ankle angle peaks later in this document.

CHAPTER IV. RESULTS

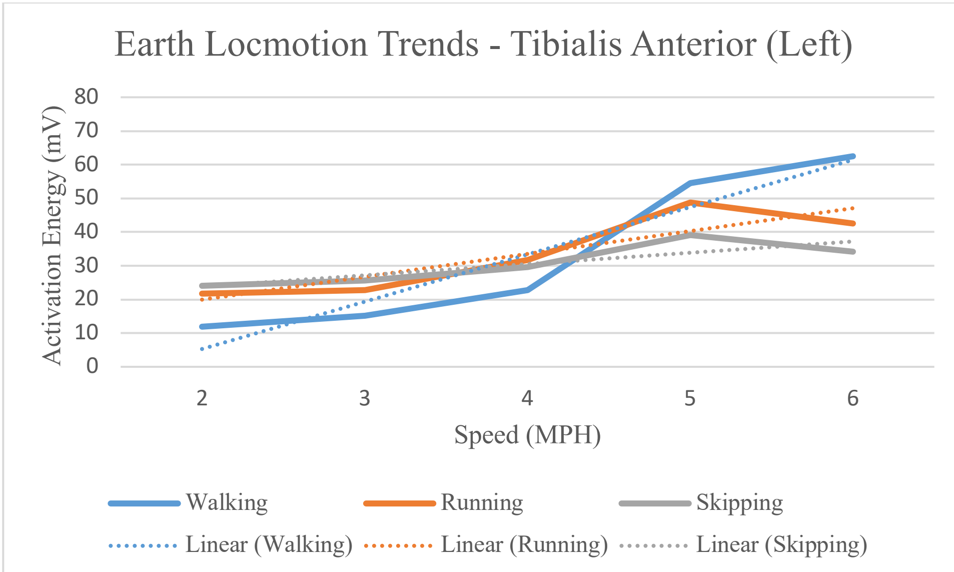
The Study results are displayed in graph form for reader clarity. SPSS ANOVA descriptives and charts, including post hoc Bonferroni corrections, can be found in the Appendix (See Appendix D). Values represented are the averages of participants' activation energy for EMG and the average of peak values for dorsiflexion and planter flexion.

4.1 EMG

4.1.1 Activation Energy Trends by Gravity level

The muscle activation energy of the tibialis anterior in 1g sees upward trends as speed increases, with running and skipping having similar trends under non-Earth conditions (See Figure 2). Walking exhibits higher activation at higher speeds (except for Lunar for the right tibialis anterior) under all conditions. Under Earth conditions, walking starts as a lower activation energy and crosses that threshold between 4 and 5 mph, ending at a higher activation level. This is consistent with the normally demonstrated preferred transition speed where the switch from walking to running occurs. The data corroborates the assumption that energy expenditure of the entire body may not be the cause of the switch from walking to running, but that there is a connection with strain on the dorsiflexor muscles.

The medial gastrocnemius also sees differences in activations among the locomotion methods in 1g (See Figure 5). Walking starts off as less energy and then surpasses that between 4 and 5 MPH for the left leg, with running and skipping being similar patterns. On the right leg the trend was slightly different, with running and skipping having slightly higher values throughout the test, ending at values similar to that of walking at 6MPH. For the medial gastrocnemius there is minimal change in activation between the locomotion methods in non-Earth conditions (See Figures 6 and 7).



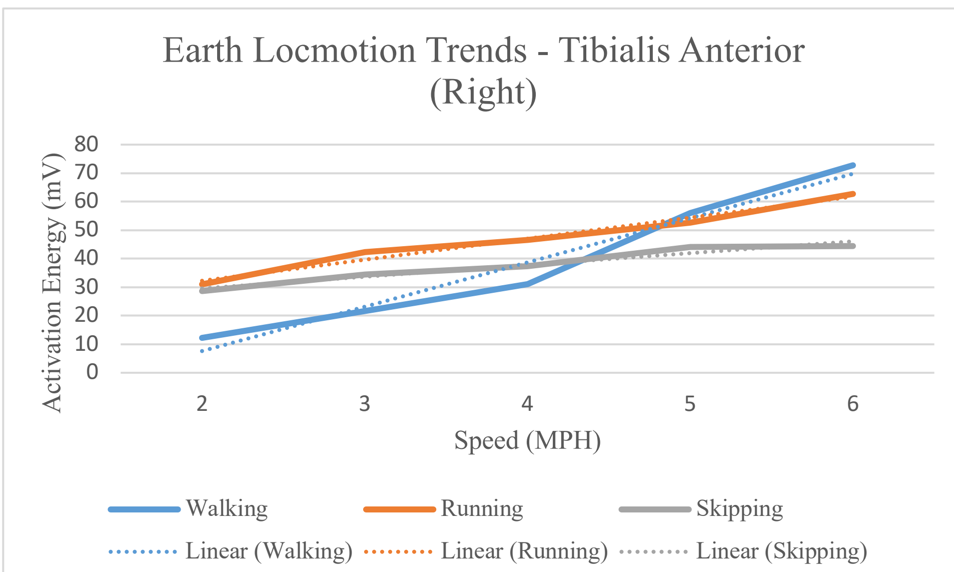
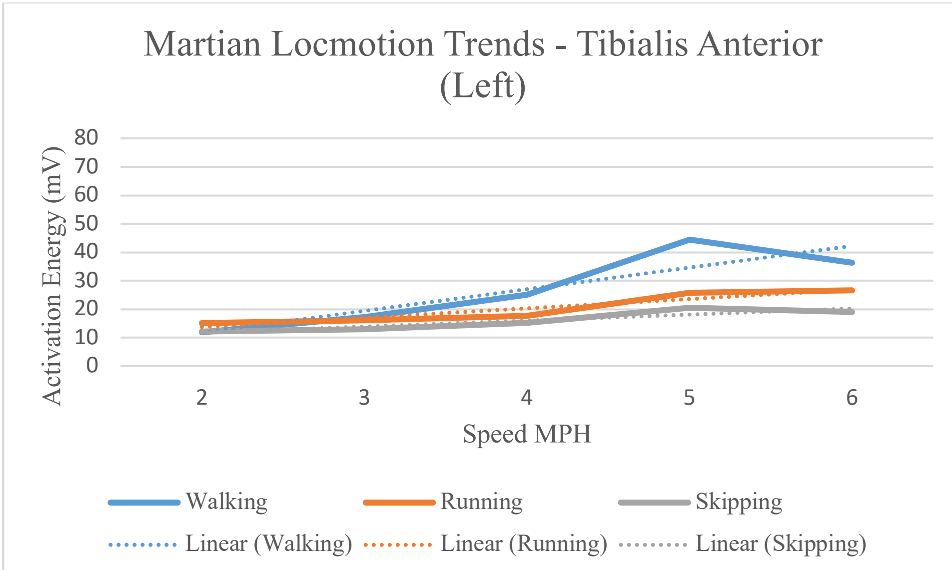


Figure 2. Activation Energy Gravity Trends – Earth - Tibialis anterior



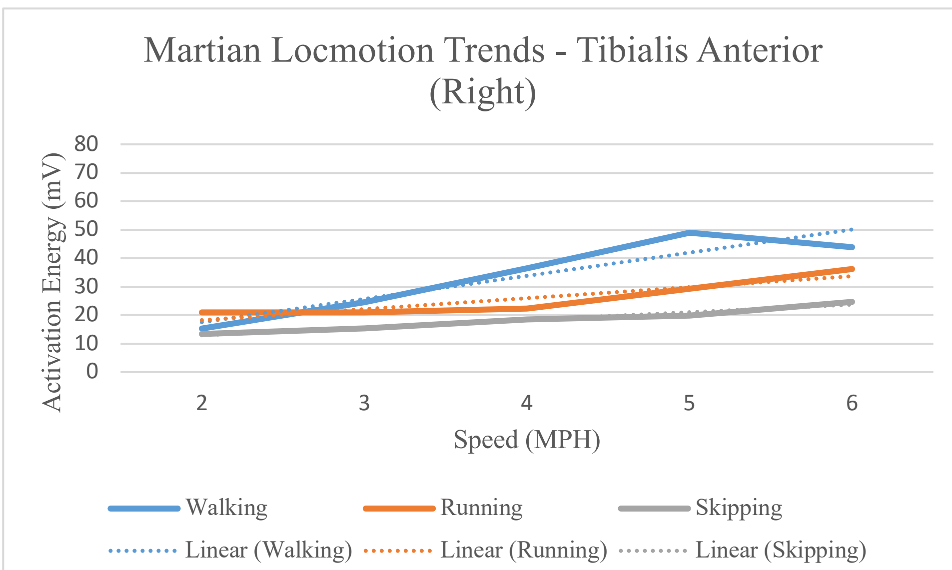
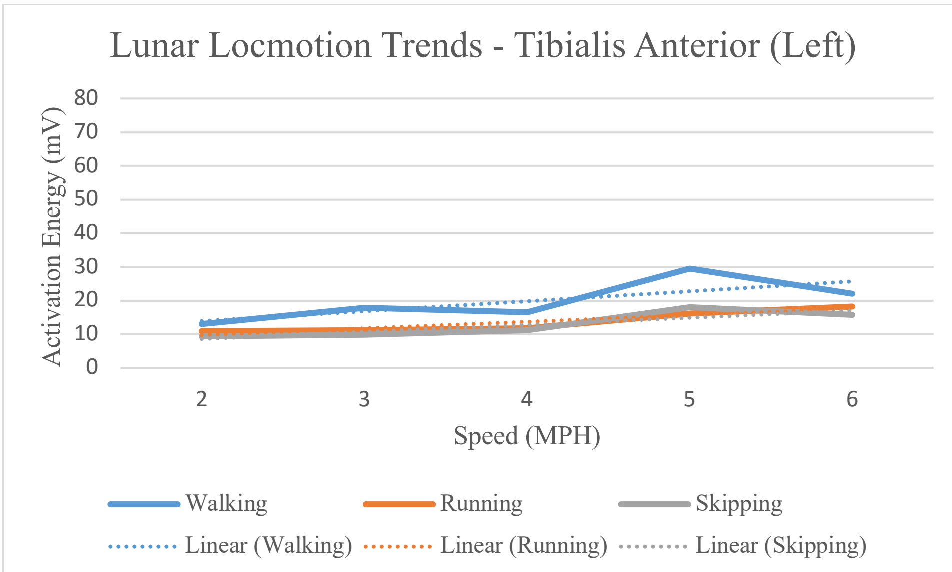


Figure 3. Activation Energy Gravity Trend – Martian – Tibialis anterior



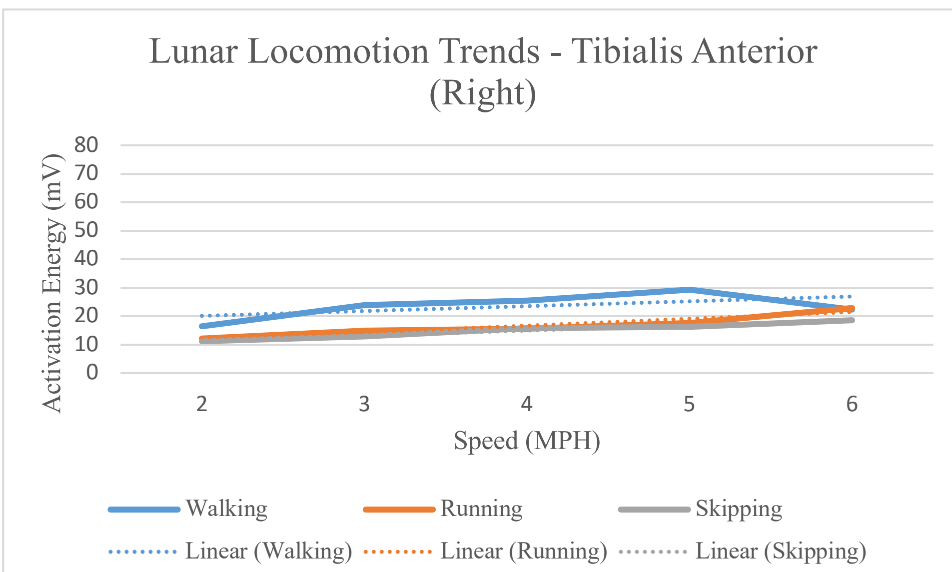
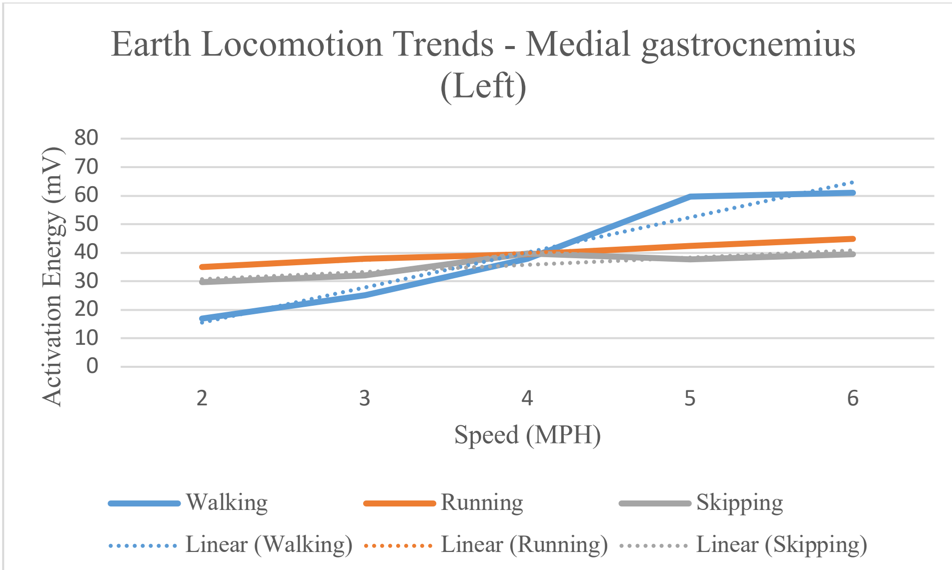


Figure 4. Activation Energy Gravity Trends – Lunar - Tibialis anterior



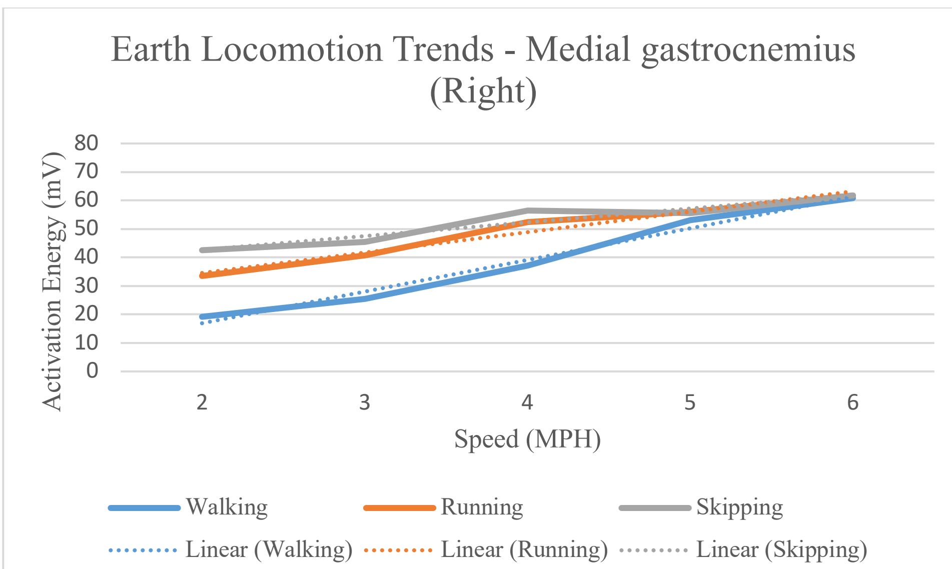
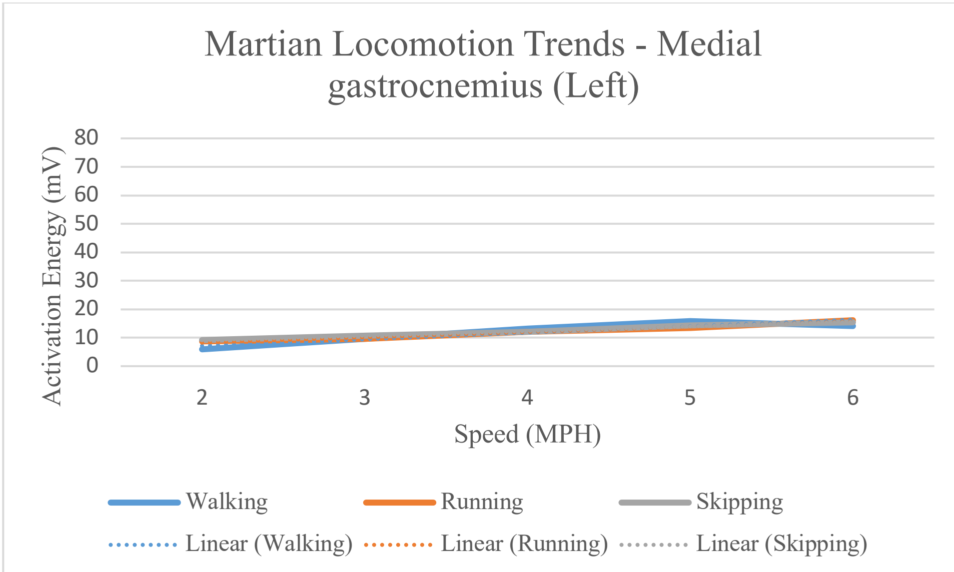


Figure 5. Activation Energy Gravity Trends – Earth – Medial gastrocnemius



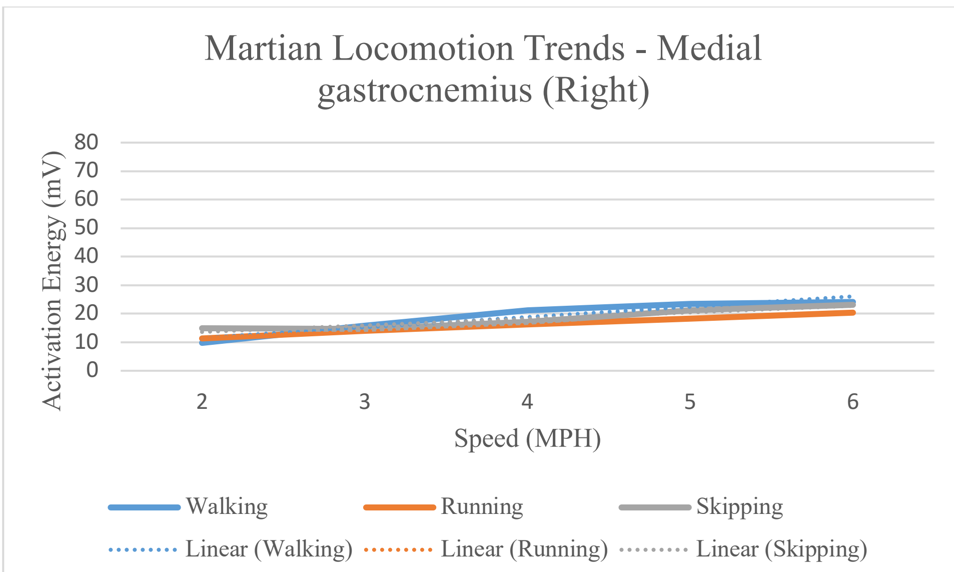
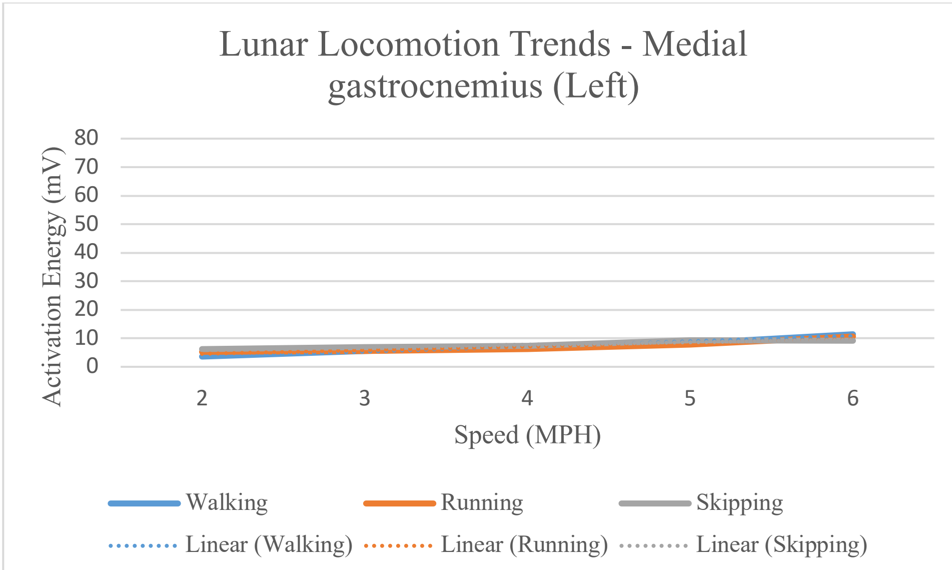


Figure 6. Activation Energy Gravity Trends – Martian – Medial gastrocnemius



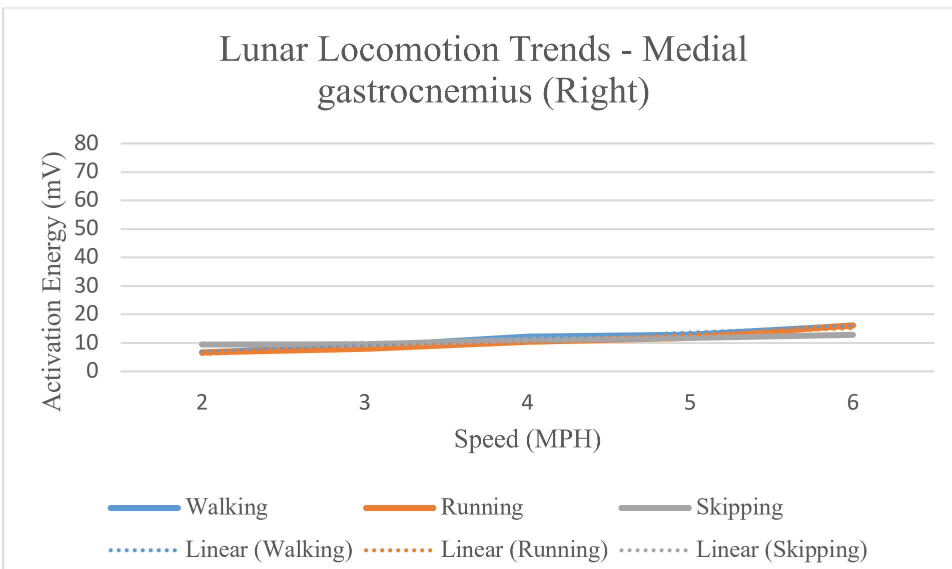
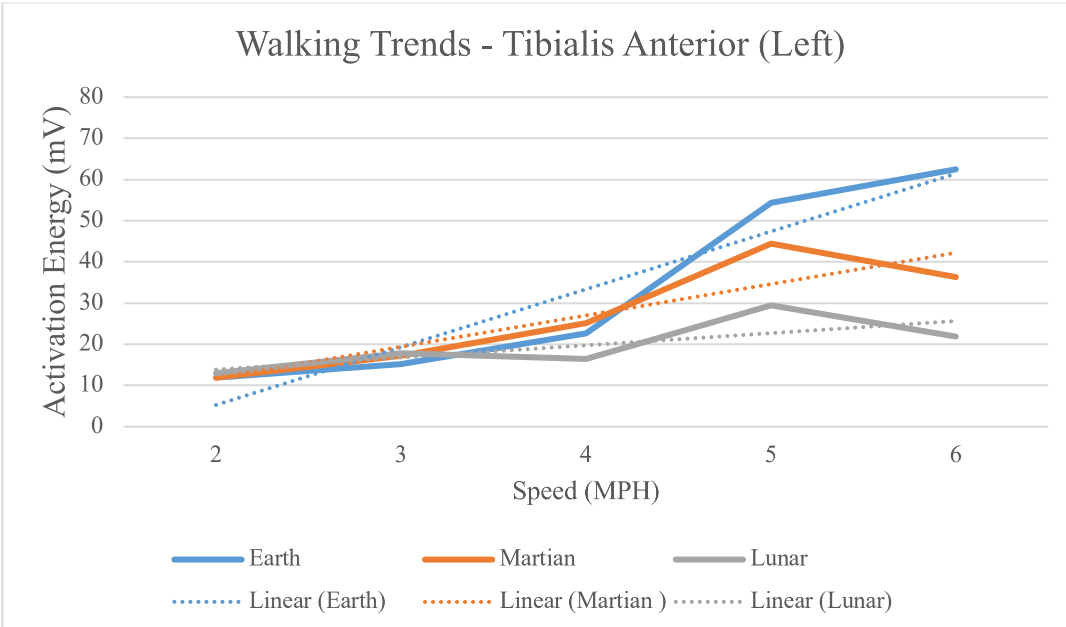


Figure 7. Activation Energy Gravity Trends – Lunar – Medial gastrocnemius



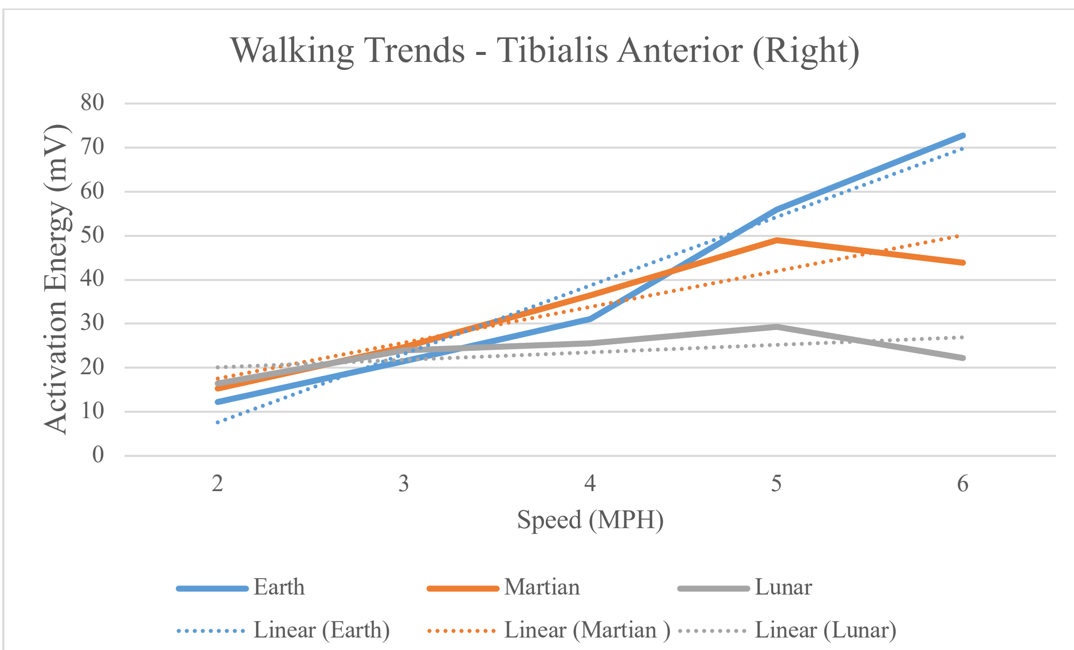
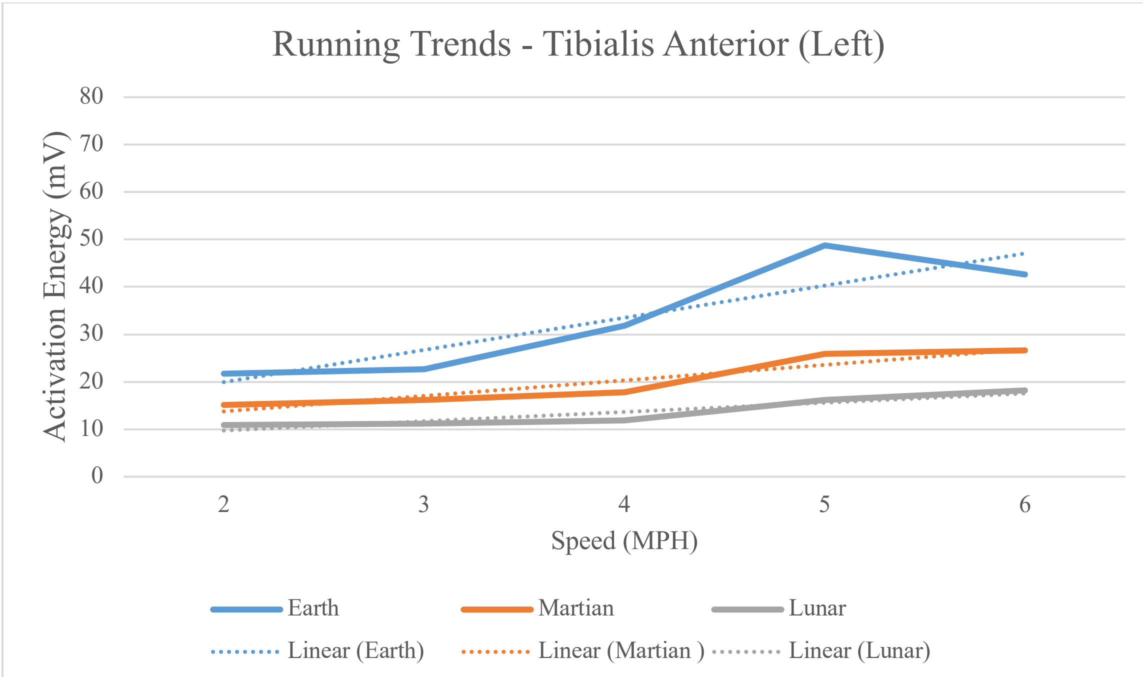


Figure 8. Activation Energy Locomotion Trends – Walking – Tibialis anterior



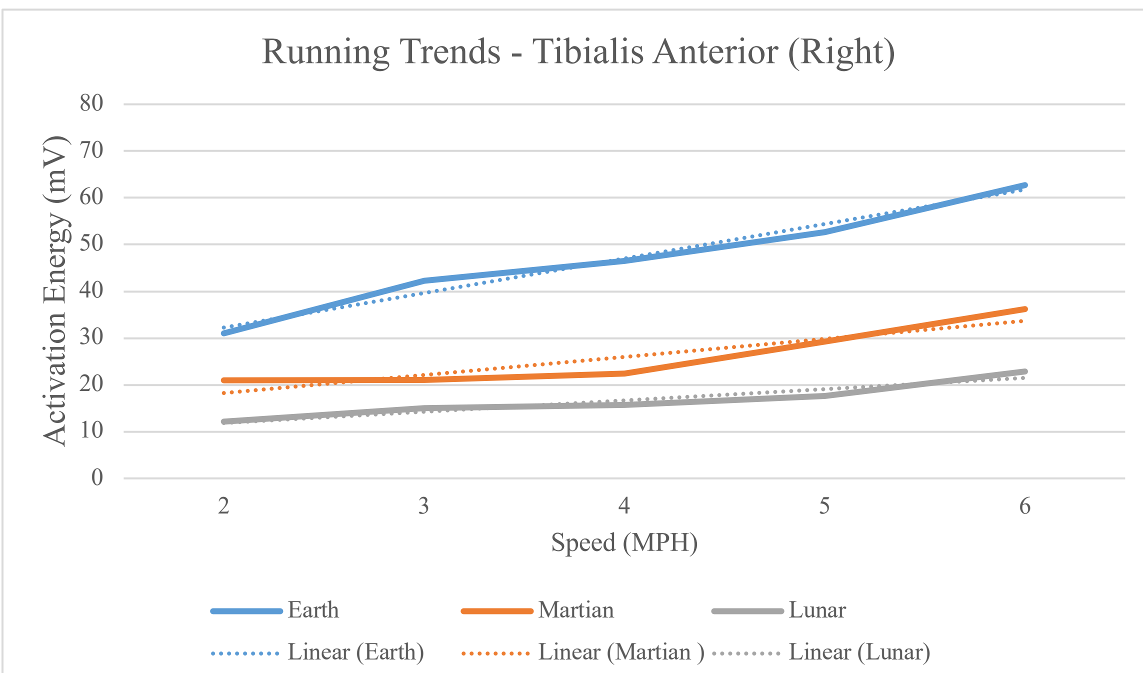
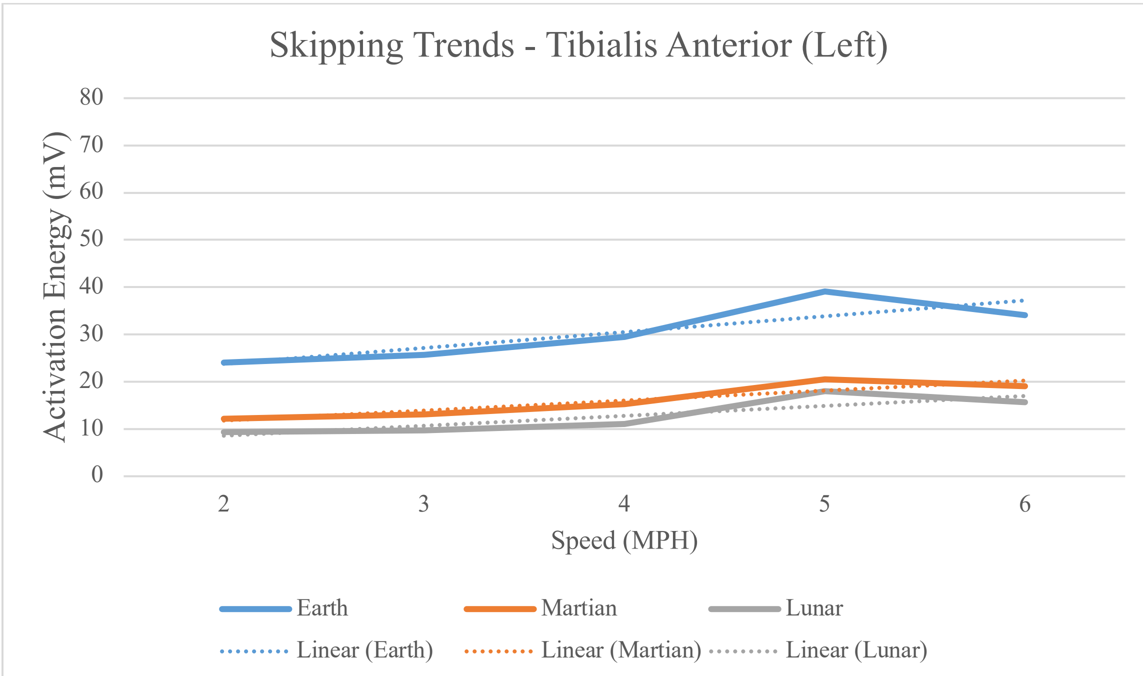


Figure 9. Activation Energy Locomotion Trends – Running – Tibialis anterior



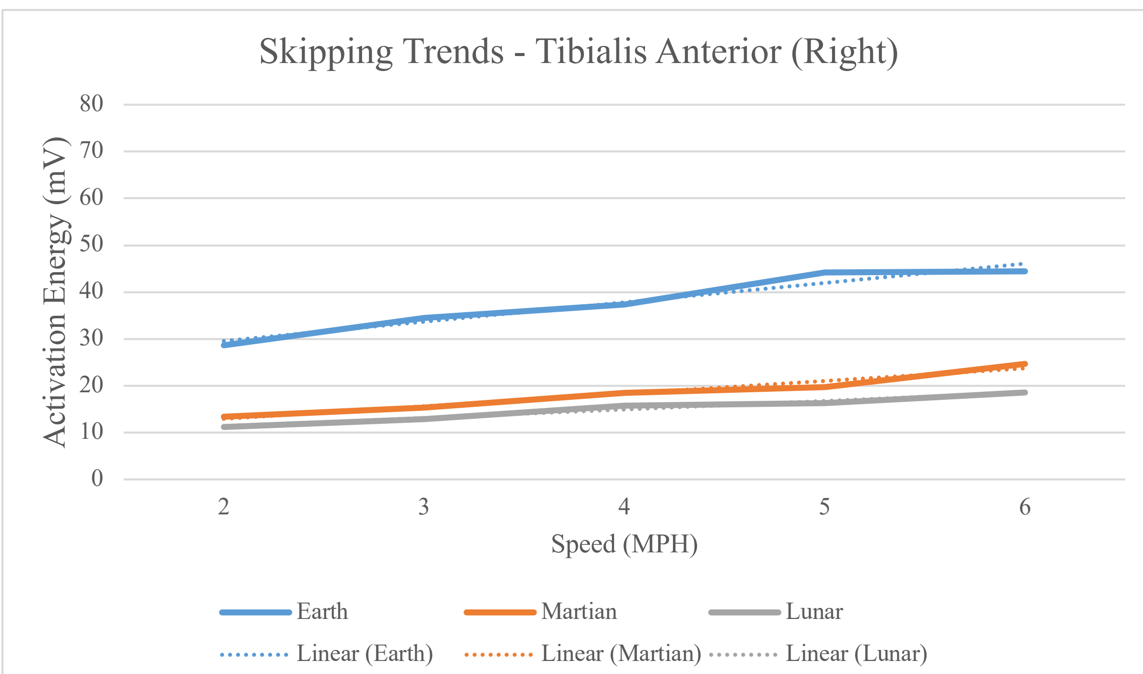
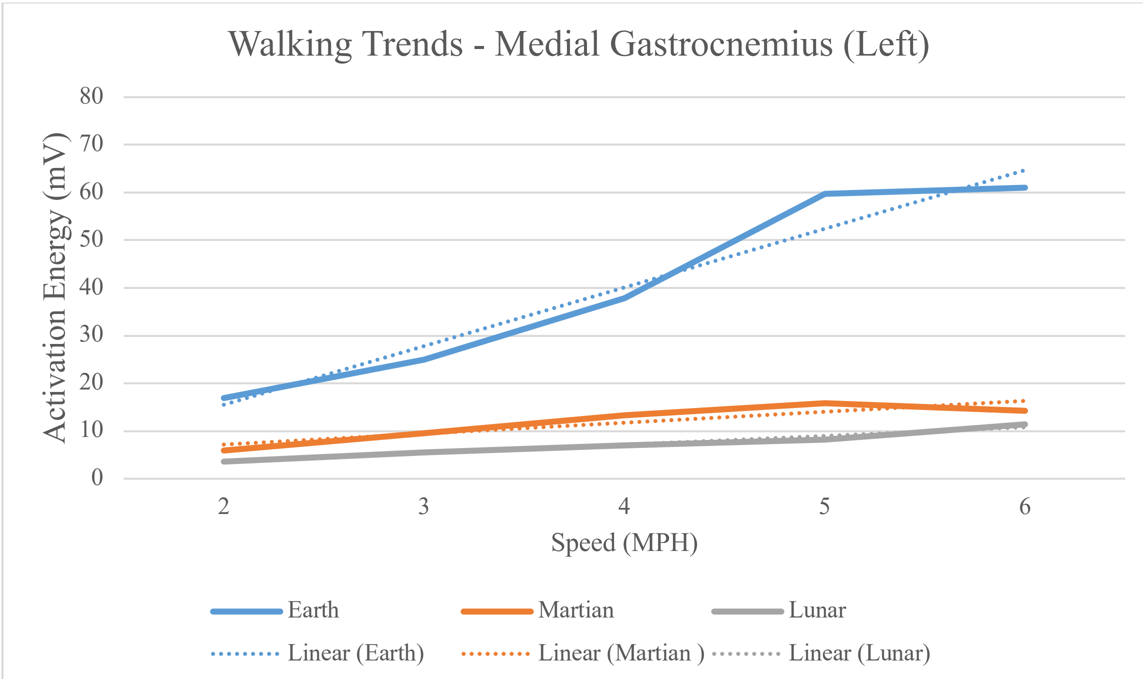


Figure 10. Activation Energy Locomotion Trends – Skipping – Tibialis anterior



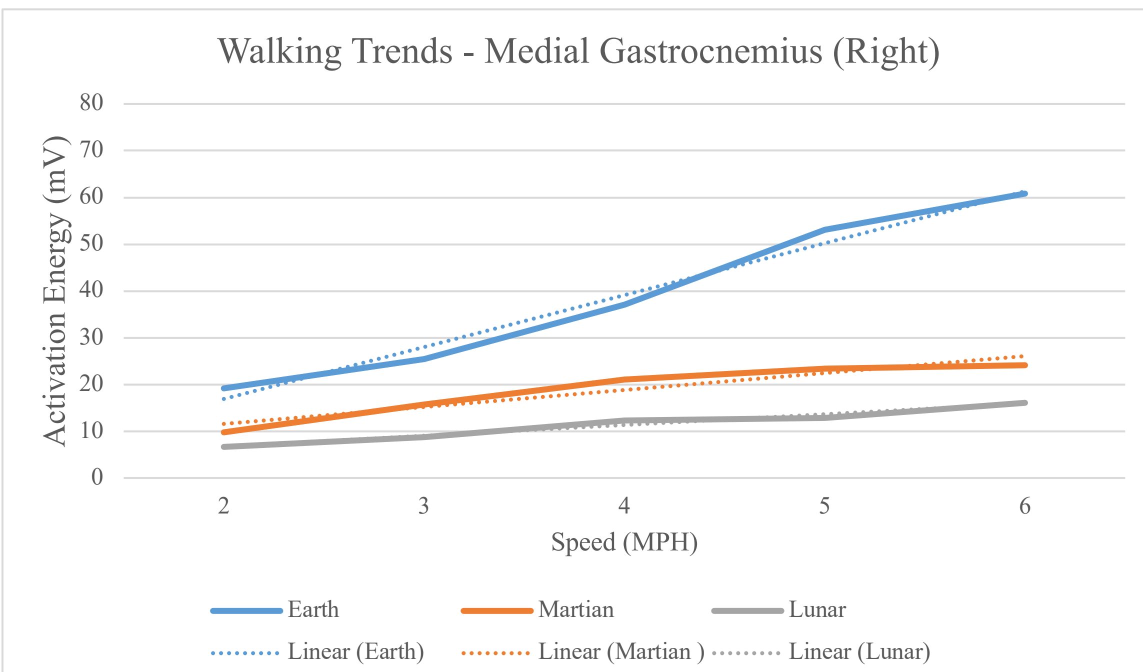
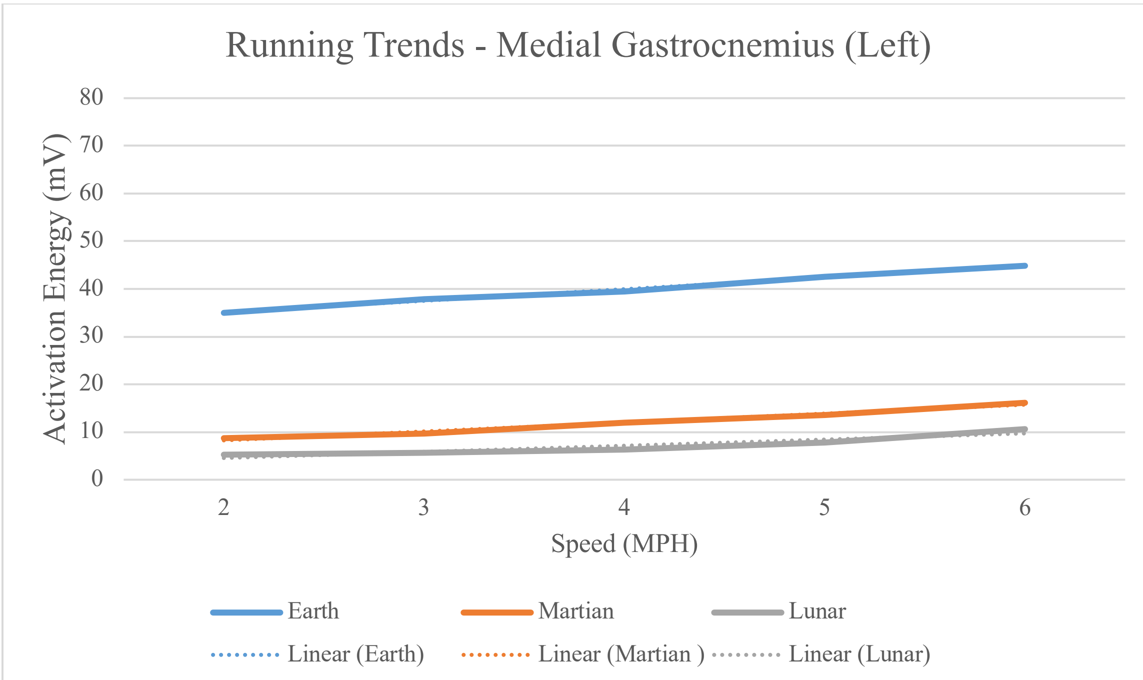


Figure 11. Activation Energy Locomotion Trends – Walking – Medial gastrocnemius



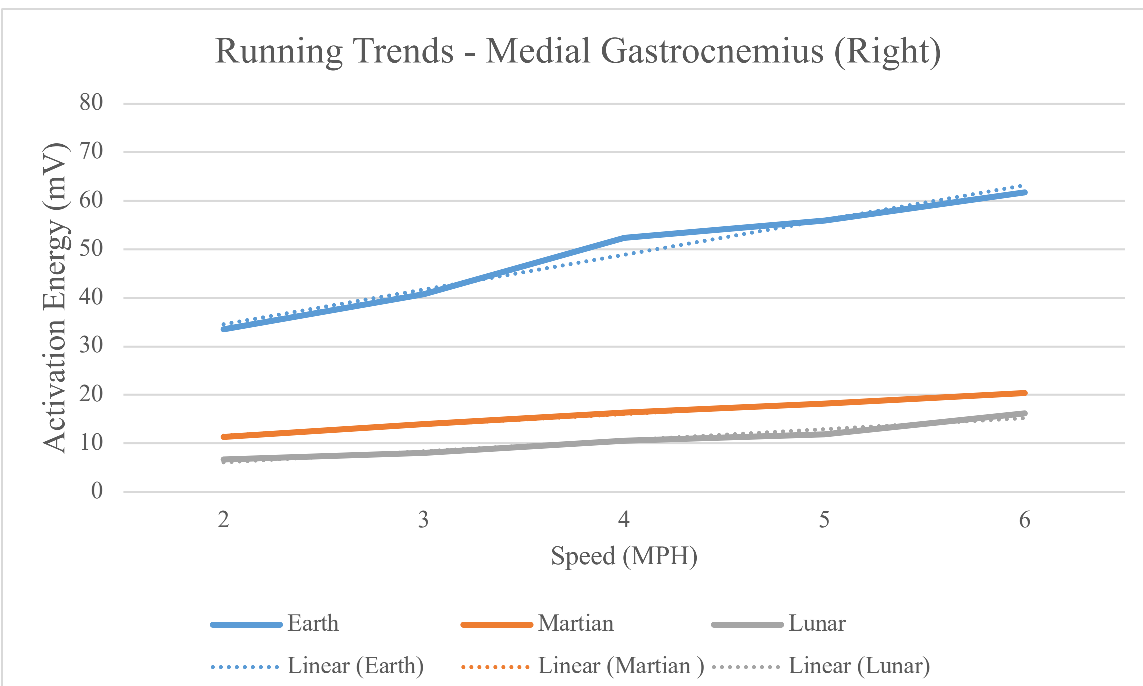
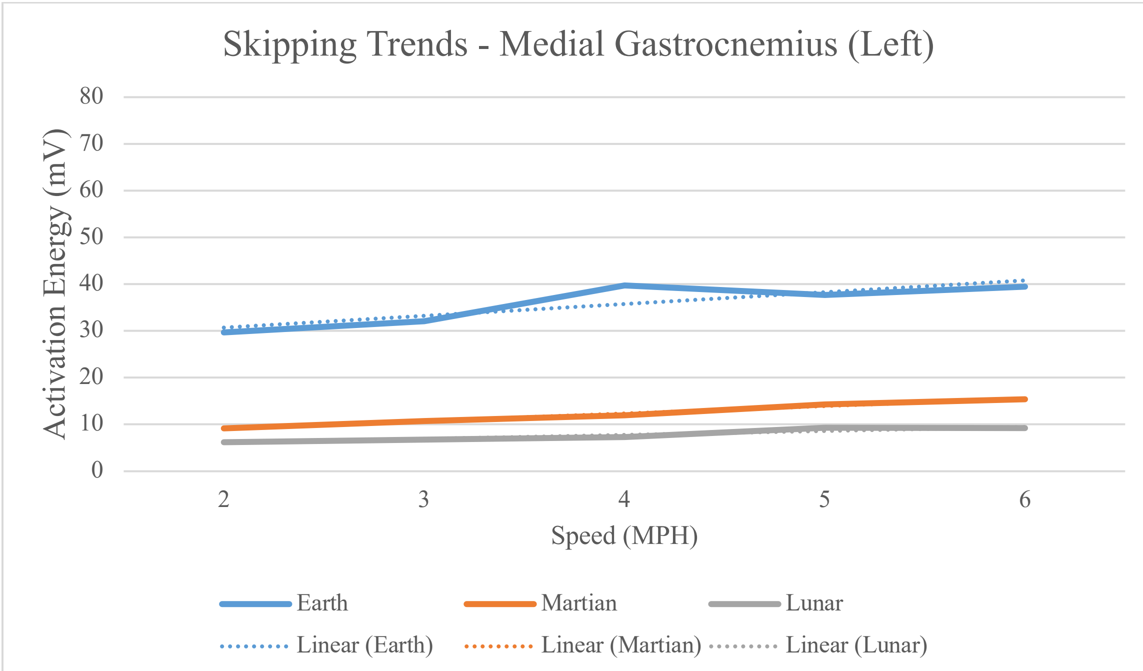


Figure 12. Activation Energy Locomotion Trends – Running – Medial gastrocnemius



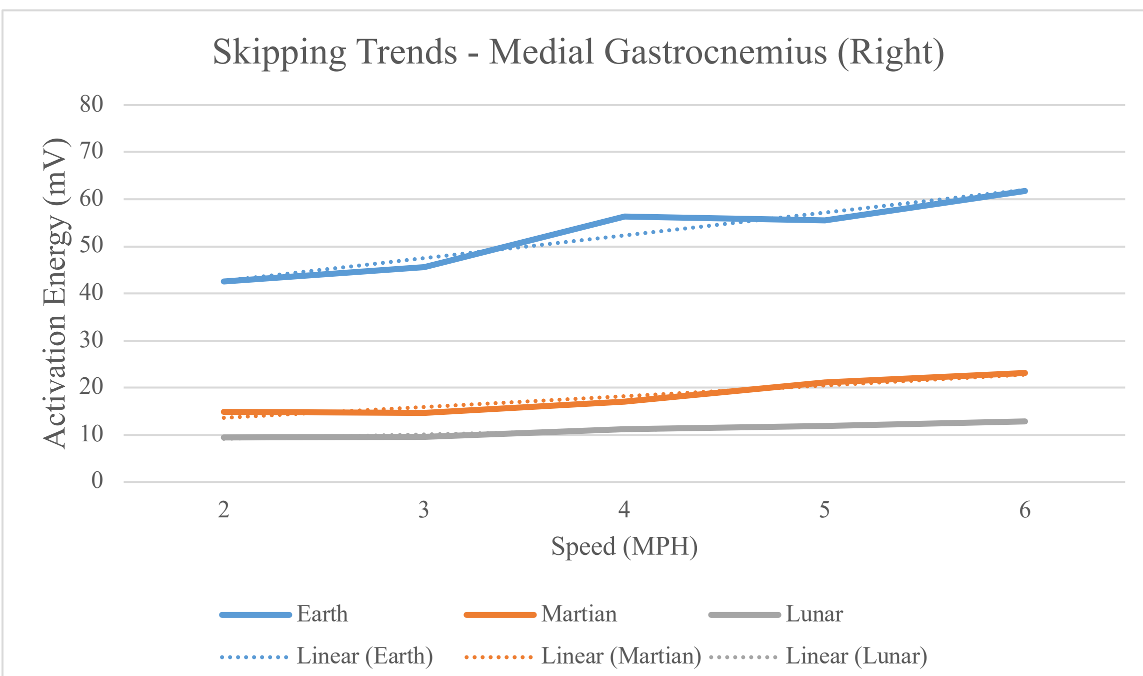


Figure 13. Activation Energy Locomotion Trends – Skipping – Medial gastrocnemius

4.1.2 Activation Energy trends by Locomotion Method

ANOVA Data demonstrates significance in the difference between 1g, .38g and .17 g levels (See Table 1). There is significant difference identified under all speed and locomotion methods.

ANOVA< .05			
CH1	Walking	Running	Skipping
2	0.864	0.044	0.004
3	0.728	0.026	0.002
4	0.269	0.001	0.002
5	0.539	0.075	0.079
6	0.014	0.025	0.001
CH2			
2	0.001	0.000	0.000
3	0.001	0.000	0.000
4	0.006	0.000	0.000
5	0.002	0.000	0.000
6	0.000	0.000	0.000
CH3			
2	0.031	0.011	0.000
3	0.053	0.007	0.001
4	0.055	0.002	0.001
5	0.010	0.004	0.001
6	0.027	0.010	0.000
CH4			
2	0.692	0.103	0.052
3	0.934	0.151	0.014
4	0.762	0.040	0.026
5	0.472	0.054	0.013
6	0.094	0.080	0.014

Table 1. EMG ANOVA Table

Activation energy with p<.05 in green - CH1 - Left tibialis anterior, CH2 - Left medial gastrocnemius, CH3 - Right medial gastrocnemius, CH4 - left Tibialis anterior

From Figure 14 we see similar values for the same muscles on the left and right leg, which helps corroborate correct placement of the markers. High values of significant change are encouraging, so post hoc analysis was done with Student T-Tests (See Table 2).

MARTIAN	< 0.05			LUNAR			
CH1	Walking	Running	Skipping	CH1	Walking	Running	Skipping
2	0.9977	0.1656	0.012	2	0.6724	0.0304	0.0078
3	0.5283	0.1656	0.0184	3	0.4455	0.0175	0.0038
4	0.6746	0.0134	0.0196	4	0.1492	0.0011	0.004
5	0.6905	0.1841	0.1114	5	0.2861	0.0588	0.0807
6	0.2586	0.1148	0.0069	6	0.9246	0.0155	0.0018
CH2				CH2			
2	0.0114	0.0025	1.55E-04	2	0.0038	0.0011	1.27E-05
3	0.0172	2.83E-04	0.0022	3	0.0046	7.19E-05	5.64E-04
4	0.0397	4.39E-04	0.004	4	0.0134	8.82E-05	0.0014
5	0.0162	4.29E-04	0.0018	5	0.0058	9.52E-05	2.97E-04
6	0.0025	0.0023	8.40E-04	6	0.0016	5.80E-04	7.60E-05
CH3				CH3			
2	0.0681	0.0492	0.0046	2	0.0278	0.0215	1.30E-03
3	0.202	0.0391	0.0126	3	0.0251	0.0156	5.20E-03
4	0.1727	0.0185	0.0106	4	0.0352	0.0082	0.0046
5	0.0609	0.0243	0.0127	5	0.013	0.0107	2.50E-03
6	0.0709	0.0366	0.0048	6	0.0321	0.0233	7.71E-04
CH4				CH4			
2	0.513	0.3175	0.0857	2	0.4277	0.0553	5.32E-02
3	0.731	0.2311	0.0416	3	0.7733	0.1263	2.16E-02
4	0.7216	0.1093	0.046	4	0.6767	0.0452	3.08E-02
5	0.7793	0.1707	0.037	5	0.2541	0.0408	1.85E-02
6	0.2673	0.2036	0.0417	6	0.0368	0.043	1.07E-02

Table 2. EMG Student's T-Tests

Activation with p<.05 shown in green. CH1 - Left tibialis anterior, CH2 - Left medial gastrocnemius, CH3 - Right medial gastrocnemius, CH4 - left Tibialis anterior

Additionally, T-Tests do not tell us whether the values are lower or higher, just that there is a difference. For these EMG values, all the significant values are significantly lower than the Earth values, indicating less activation energy required for the movements.

This analysis indicates that the medial gastrocnemius, acting as a plantar flexor, is exhibiting significantly less activation energy under all locomotion methods in simulated Martian and Lunar conditions (except the medial gastrocnemius of the right leg while walking under Martian conditions).

However, the tibialis anterior muscles, acting as dorsiflexion, have a different pattern. Under Martian conditions, nine of the ten significantly lower values occur during skipping, with one left leg value in running. Under Lunar conditions the majority of running and skipping cause the muscles to exhibit lower activation energy, with the addition of the fastest speed of walking for the right leg. This shows that there may not be a difference in activation energy large enough to matter under Martian gravity conditions, while there is one observed under Lunar conditions. This is in line with the previous experiments assessing the reduced energy expenditure of skipping in lower gravity environments that prompted this thesis experiment.

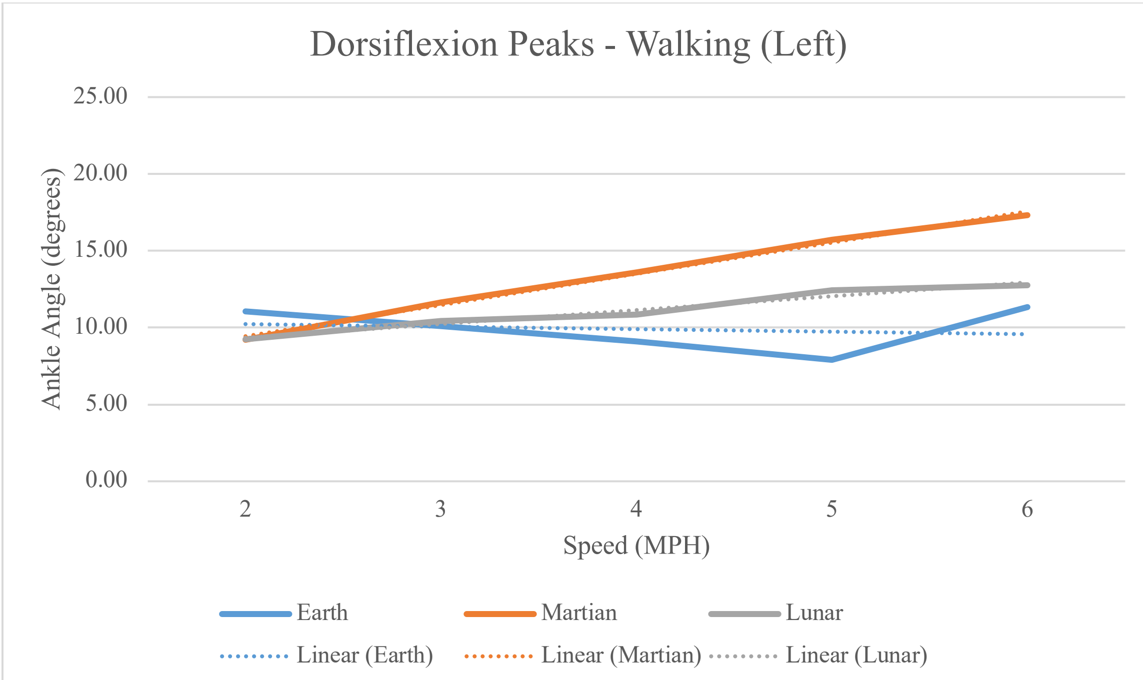
4.2 Motion Capture

4.2.1 Ankle Angle

Absolute Ankle Angle data sets created through the Vicon motion capture system analysis software. This allows us to look at the angles of Dorsiflexion (pointing the toe up) and plantarflexion (pointing the toe down). For this study, peaks were selected out of the 10-second segments and averaged.

4.2.1.1 Dorsiflexion

Dorsiflexion values start off similar walking at 2 MPH but vary as speed increases (See Figure 14) Trend lines (dotted) indicate that as speed increases, so does dorsiflexion angle and difference between angles from Earth, Lunar, and Martian conditions. Though one might expect gravity level to be directly proportionate to dorsiflexion level, here it indicates that Martian gravity conditions may have an increased level of dorsiflexion vs. both Earth and Lunar levels.



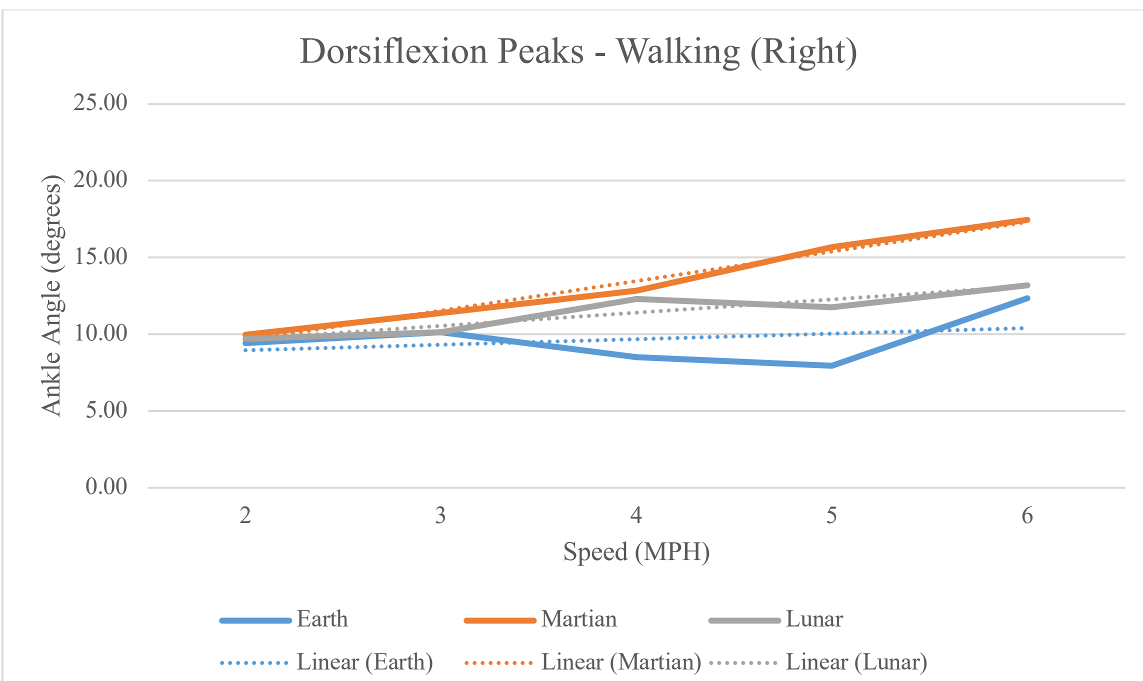


Figure 14. Dorsiflexion Peaks - Walking

For running, Lunar conditions remain the lowest value, starting lower than both Earth and Martian conditions (which start at the same level) and decreasing with speed, while Martian and Earth levels increase with speed (See Figure 15). Here we see that there is a correlation with gravity levels, unlike running trials.

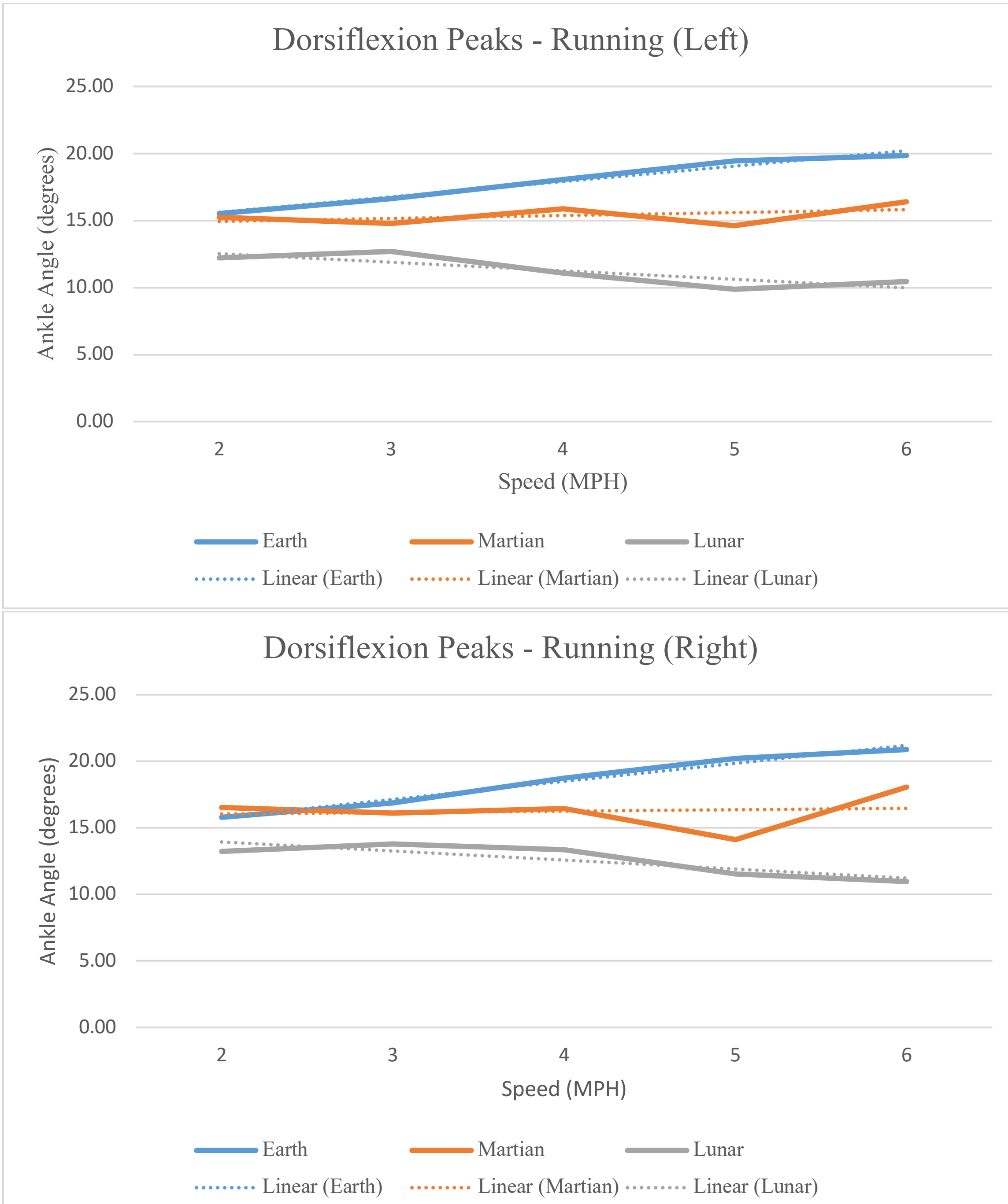
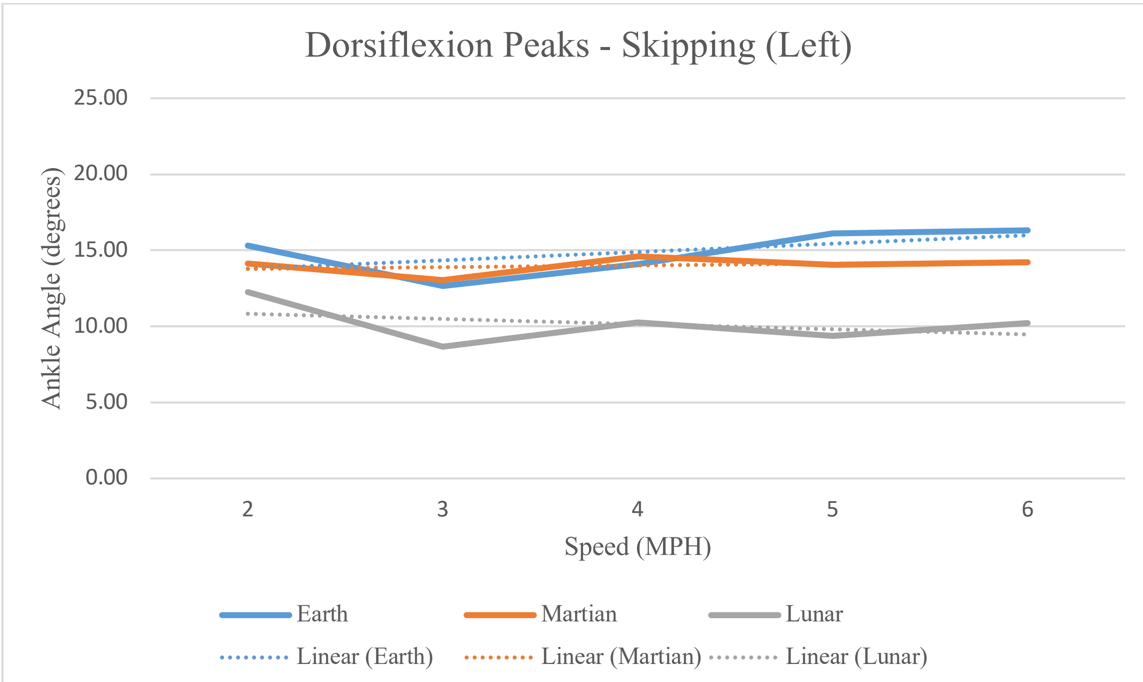


Figure 15. Dorsiflexion Peaks - Running

Skipping dorsiflexion values vary more intensely by leg (See Figure 18). Dorsiflexion best fit lines are flat for the left leg, with Earth and Martian conditions being very similar, while the Lunar conditions show lower levels of dorsiflexion. For the right leg, we see a spike in dorsiflexion degree for low levels in Earth conditions, a dip in dorsiflexion degree at lower speed for Martian levels. Earth levels show a slight decrease in levels as speed increases, while Martian conditions show a slight increase. Lunar levels again show a flat linear fit line close to the same level as the left leg.



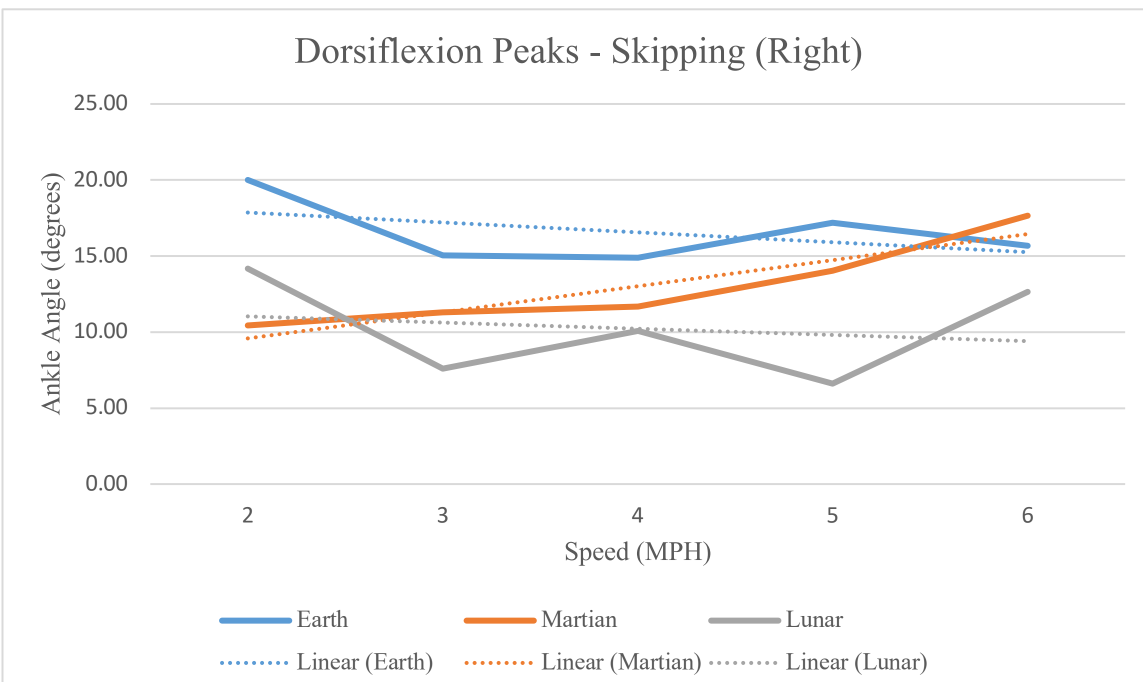
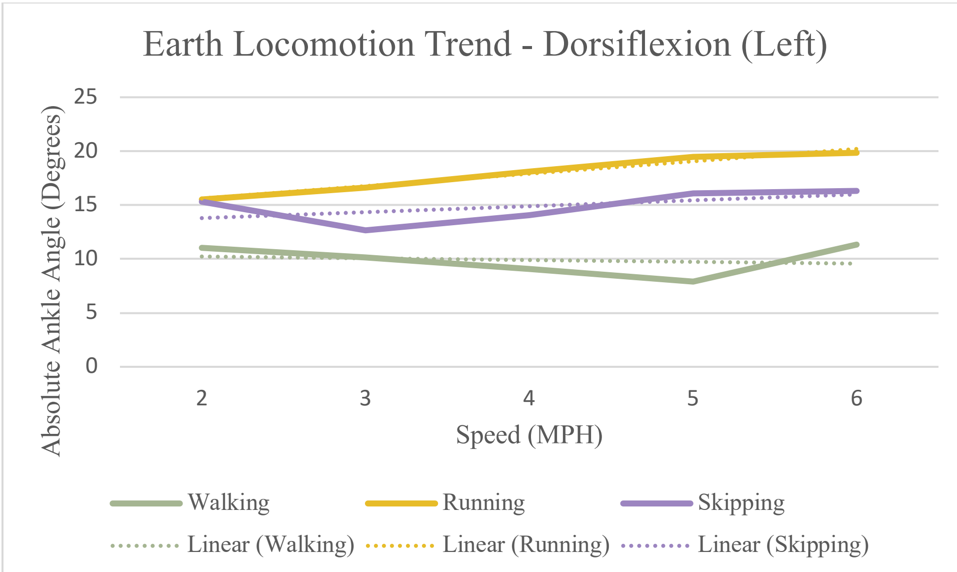


Figure 16. Dorsiflexion Peaks - Skipping

Earth levels have the most variety among the gravity conditions, with distinct trends for each locomotion method (See Figure 19). Walking shows the lowest dorsiflexion values, with running coming in at the highest other than at 2MPH, where we see a spike from skipping. Under simulated Martian gravity levels (See Figure 20), we see the gap close between the locomotion methods, with running values remaining relatively constant, walking remaining a steady slope, and skipping either matching running (left leg) or walking (right leg). We see slightly higher variation between the right and left leg for skipping vs. walking and running in simulated Lunar gravity (See Figure 21), possibly because of skipping being a novel method of movement. This is consistent with all three gravity conditions.



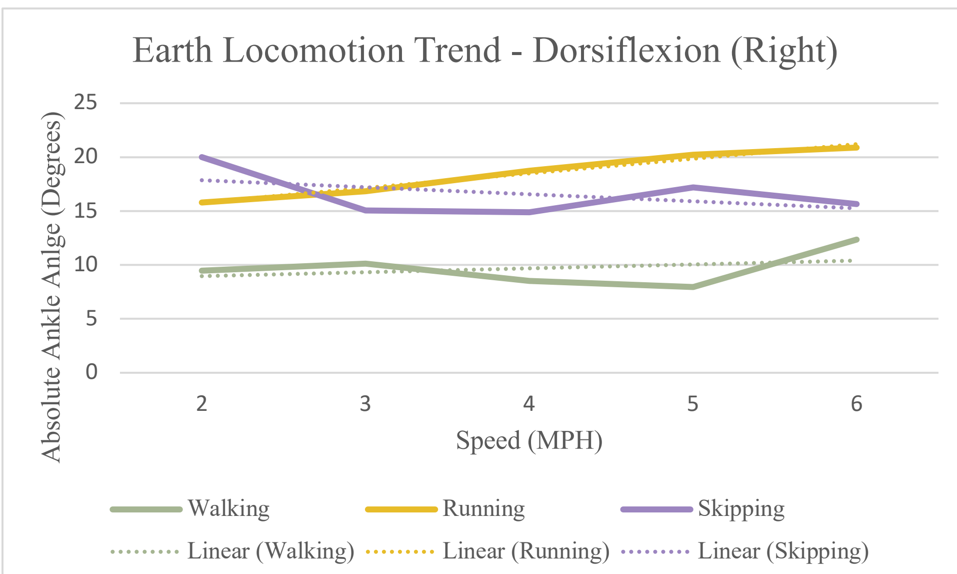
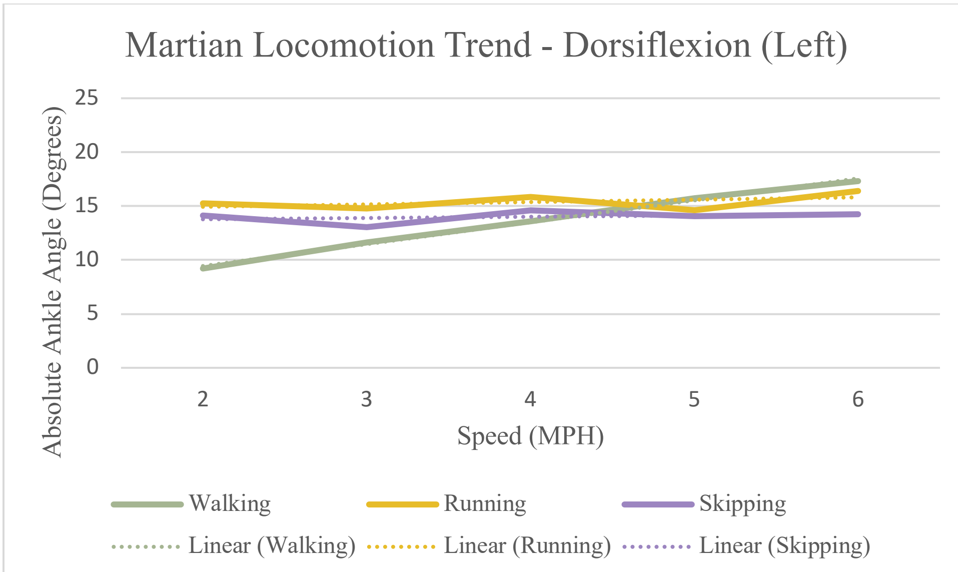


Figure 17. Dorsiflexion Peaks - Earth



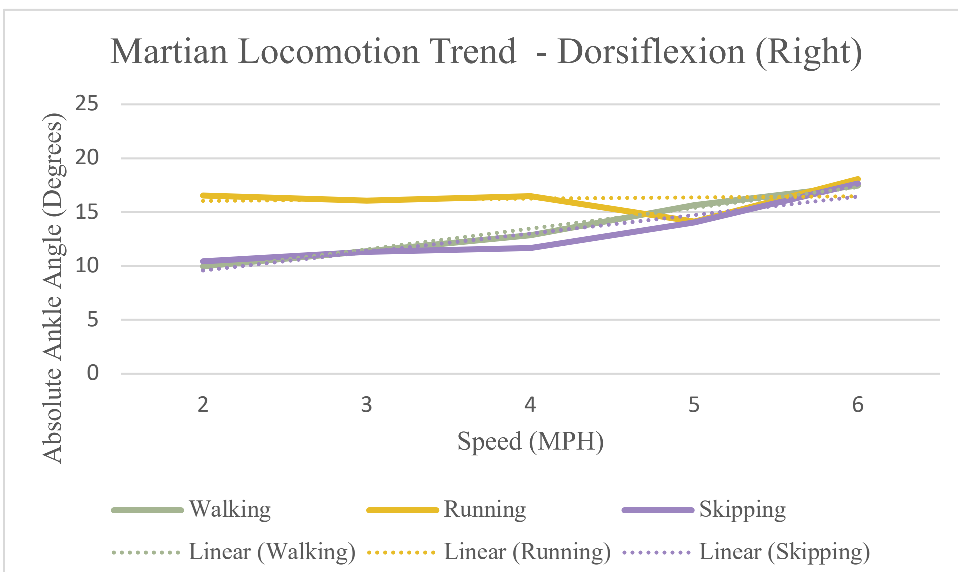
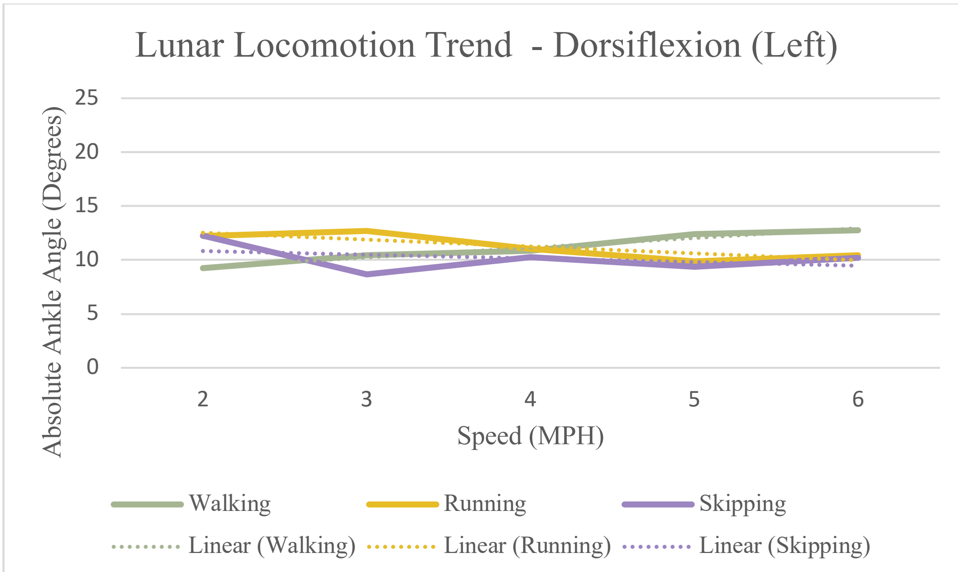


Figure 18. Dorsiflexion Peaks - Martian



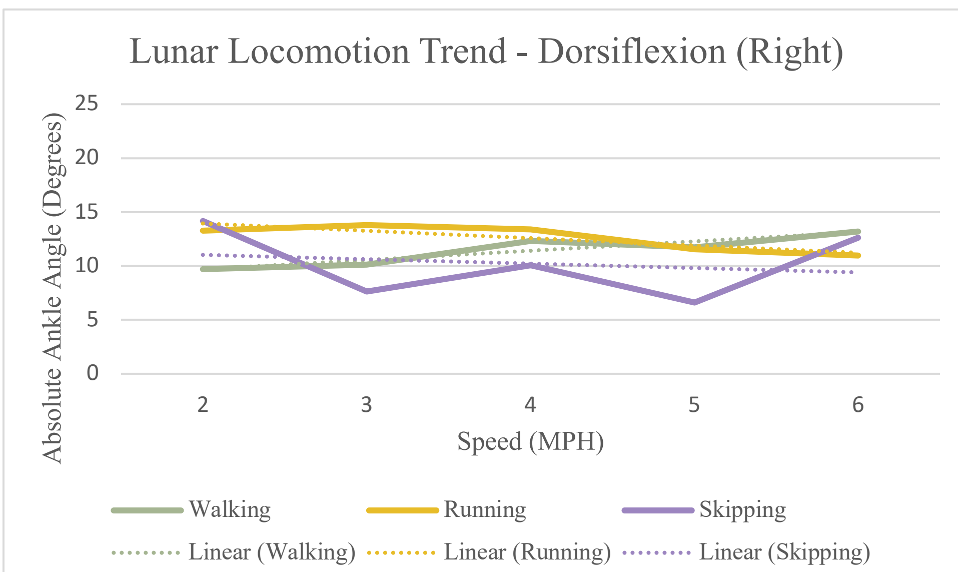


Figure 19. Dorsiflexion Peaks - Lunar

Changes in Dorsiflexion were less significantly different than EMG values, with ANOVA only indicating significance ($p<.05$) at 5 PMH for all locomotion methods, as well as at 6 MPH (See Table 3).

ANOVA < .05			
Left	Walking	Running	Skipping
2	0.637	0.534	0.658
3	0.806	0.4	0.386
4	0.324	0.064	0.405
5	0.056	0.02	0.324
6	0.333	0.006	0.343
Right			
2	0.981	0.336	0.071
3	0.881	0.453	0.106
4	0.192	0.087	0.215
5	0.029	0.003	0.003
6	0.091	0.001	0.661

Table 3. Dorsiflexion Peaks - ANOVA

Dorsiflexion angle values with significant differences $p<.05$ are shown in green.

The $p<.05$ T-Tests show significant amounts of variation, but this does not exactly fit with the ANOVA results, as there are additional significances indicated for running at 3 MPH (See Table 4). This did, however, match the Bonferroni corrected T-Tests (See Appendix E). It is possible that the difference between the ANOVA and T-Tests can be a result of different degrees of freedom (T-test *dof* is 10, while ANOVA was

17) and small sampling size of 6. In this case there are very few instances of significant differences after the correction, though the fast running speeds still see that difference.

MARTIAN	< .05			LUNAR			
Left	Walking	Running	Skipping	Left	Walking	Running	Skipping
2	0.3507	0.9152	0.73	2	0.4747	0.3503	0.3891
3	0.5626	0.5108	0.9023	3	0.8813	0.1882	0.2598
4	1.78E-01	0.3412	0.8744	4	0.4299	0.0473	0.2799
5	0.0259	0.0797	0.6535	5	0.1137	0.0137	0.1088
6	0.2074	0.1704	0.6388	6	0.7484	0.0064	0.1495
Right				Right			
2	0.8238	0.7001	0.0604	2	0.9328	0.3074	0.2024
3	0.6619	0.7132	0.2254	3	0.9897	0.268	0.0395
4	1.47E-01	0.3818	0.2563	4	0.073	3.98E-02	0.0752
5	0.0298	0.0266	0.1887	5	0.1724	6.50E-04	0.0014
6	0.0876	0.2694	0.7634	6	0.7124	5.73E-04	0.2298

Table 4. Dorsiflexion Peaks - T-Tests

Ankle angle values with significant differences (p<.05) are shown in green.

There were high and lower mean values of dorsiflexion peaks, though the majority of changes indicated lower dorsiflexion (See Table 5).

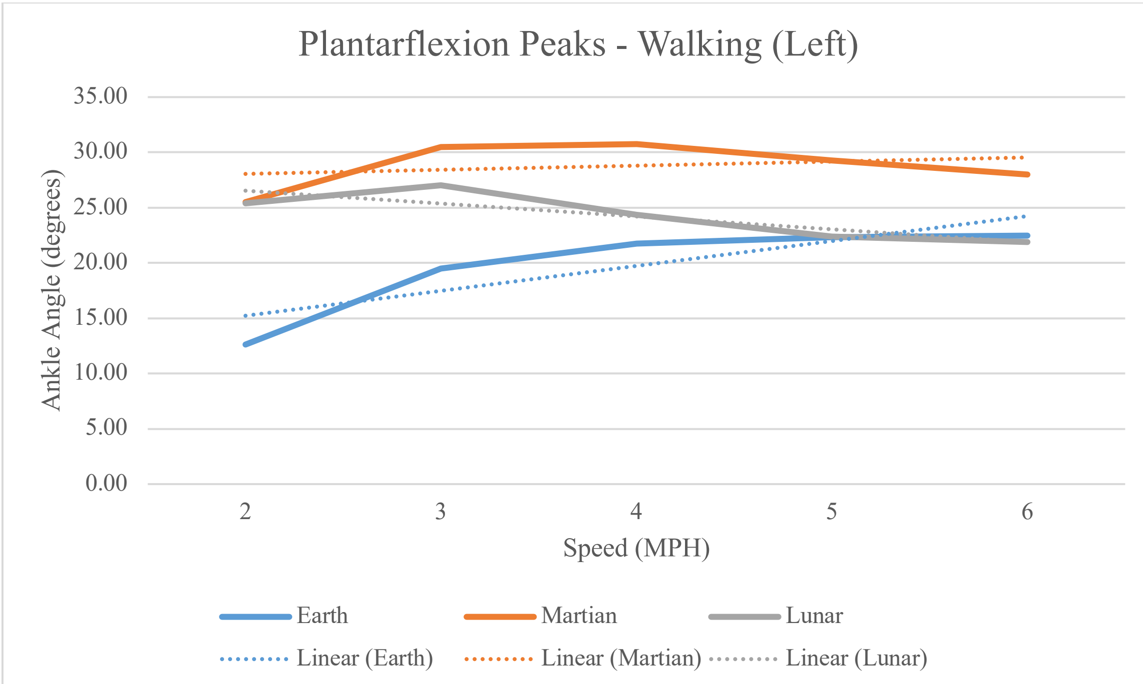
MARTIAN	< .05			LUNAR			
Left	Walking	Running	Skipping	Left	Walking	Running	Skipping
2	0.3507	0.9152	0.73	2	0.4747	0.3503	0.3891
3	0.5626	0.5108	0.9023	3	0.8813	0.1882	0.2598
4	1.78E-01	0.3412	0.8744	4	0.4299	0.0473	0.2799
5	0.0259	0.0797	0.6535	5	0.1137	0.0137	0.1088
6	0.2074	0.1704	0.6388	6	0.7484	0.0064	0.1495
Right				Right			
2	0.8238	0.7001	0.0604	2	0.9328	0.3074	0.2024
3	0.6619	0.7132	0.2254	3	0.9897	0.268	0.0395
4	1.47E-01	0.3818	0.2563	4	0.073	3.98E-02	0.0752
5	0.0298	0.0266	0.1887	5	0.1724	6.50E-04	0.0014
6	0.0876	0.2694	0.7634	6	0.7124	5.73E-04	0.2298

Table 5. Dorsiflexion T-Test Value Comparisons

Student's T-test chart with indication of higher (red) or lower (green) ankle dorsiflexion

4.2.1.2. Plantar flexion

In walking on the Earth, plantar flexion starts at a much lower degree than for Martian or Lunar conditions and slowly converges with lunar degrees, which fall in value as speed increases (See Figure 20). Planter flexion in Martian conditions stay at a higher degree, increases until halfway through the speeds, and slightly dips back down. Degree values in running follow similar trends to each other under simulated Martian conditions, with Earth values starting lower than Martian and Lunar values but ending in a convergence of all three values at 6MPH (See Figure 21). Skipping demonstrates the same slope in each gravity condition, with Earth values being consistently significantly lower than Martian and Lunar values and never converging with them (See Figure 22). It is interesting that in walking, there are distinct differences between the trends for each gravity condition, but that running and skipping show Martian and Lunar trends to be extraordinarily similar and different from the Earth values. The mechanical differences seen between the differences in gravity may happen at a much lower gravity difference than that seen between Earth (1g) and Mars (.38g).



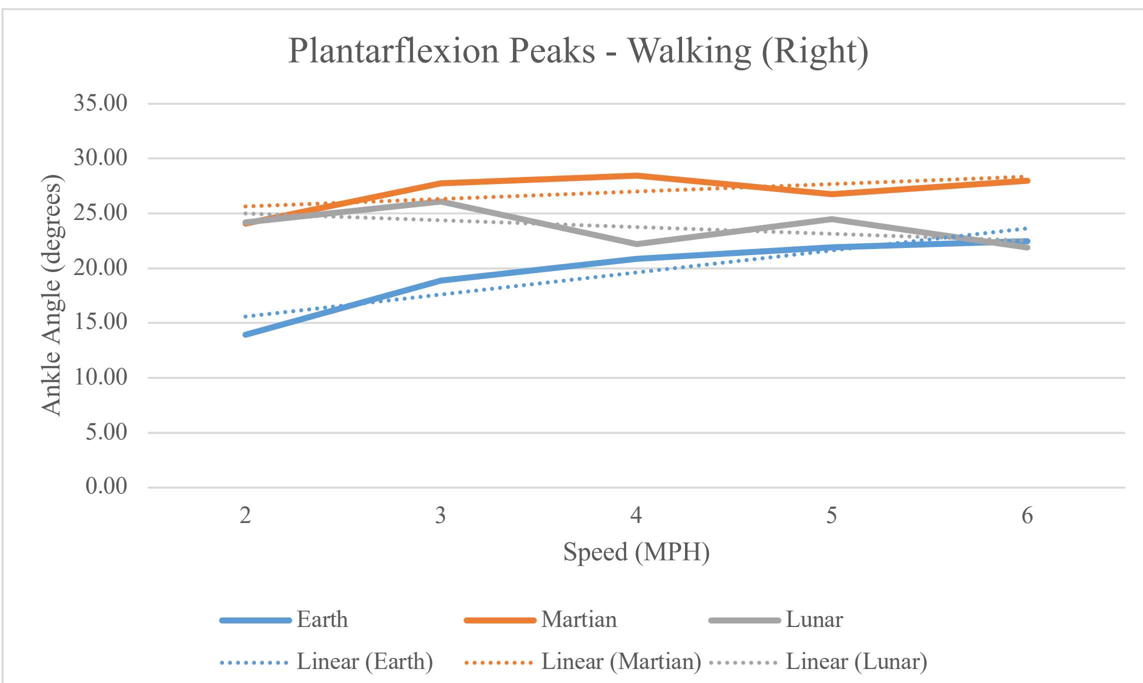
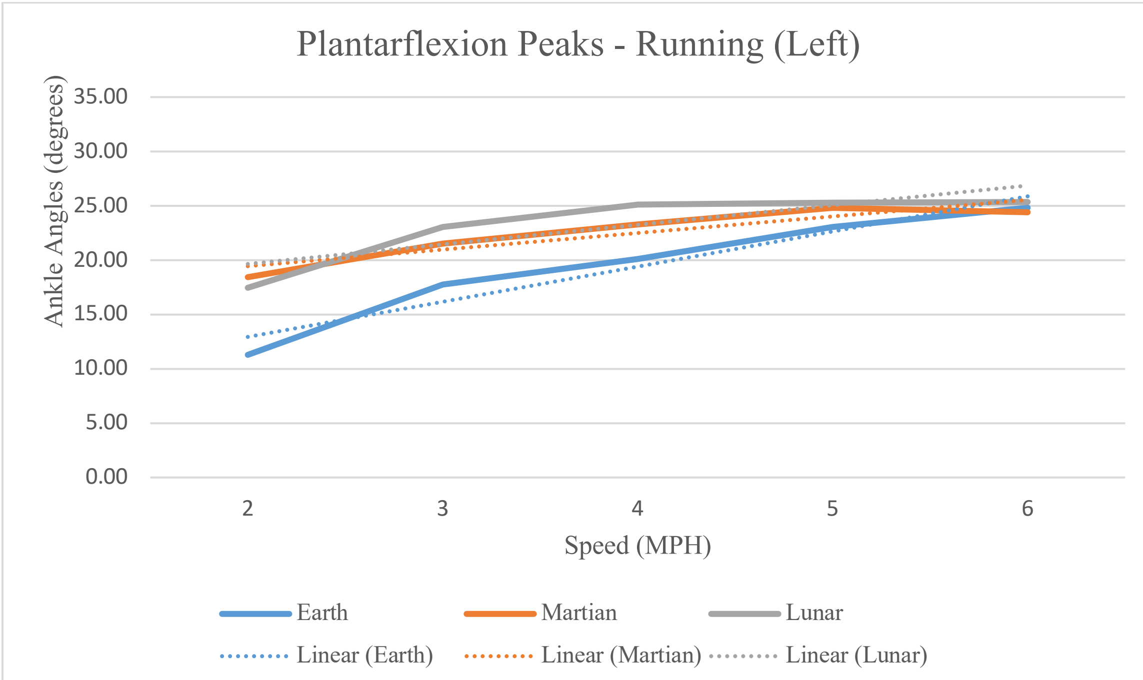


Figure 20. Plantar Flexion - Walking



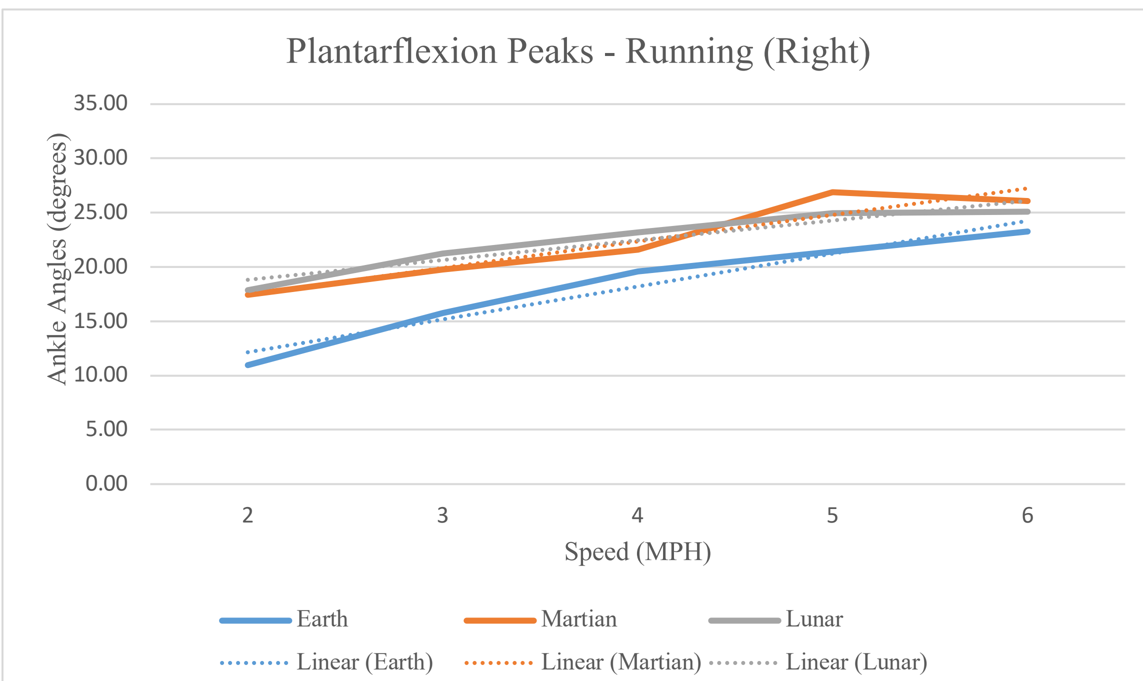


Figure 21. Plantar Flexion - Running

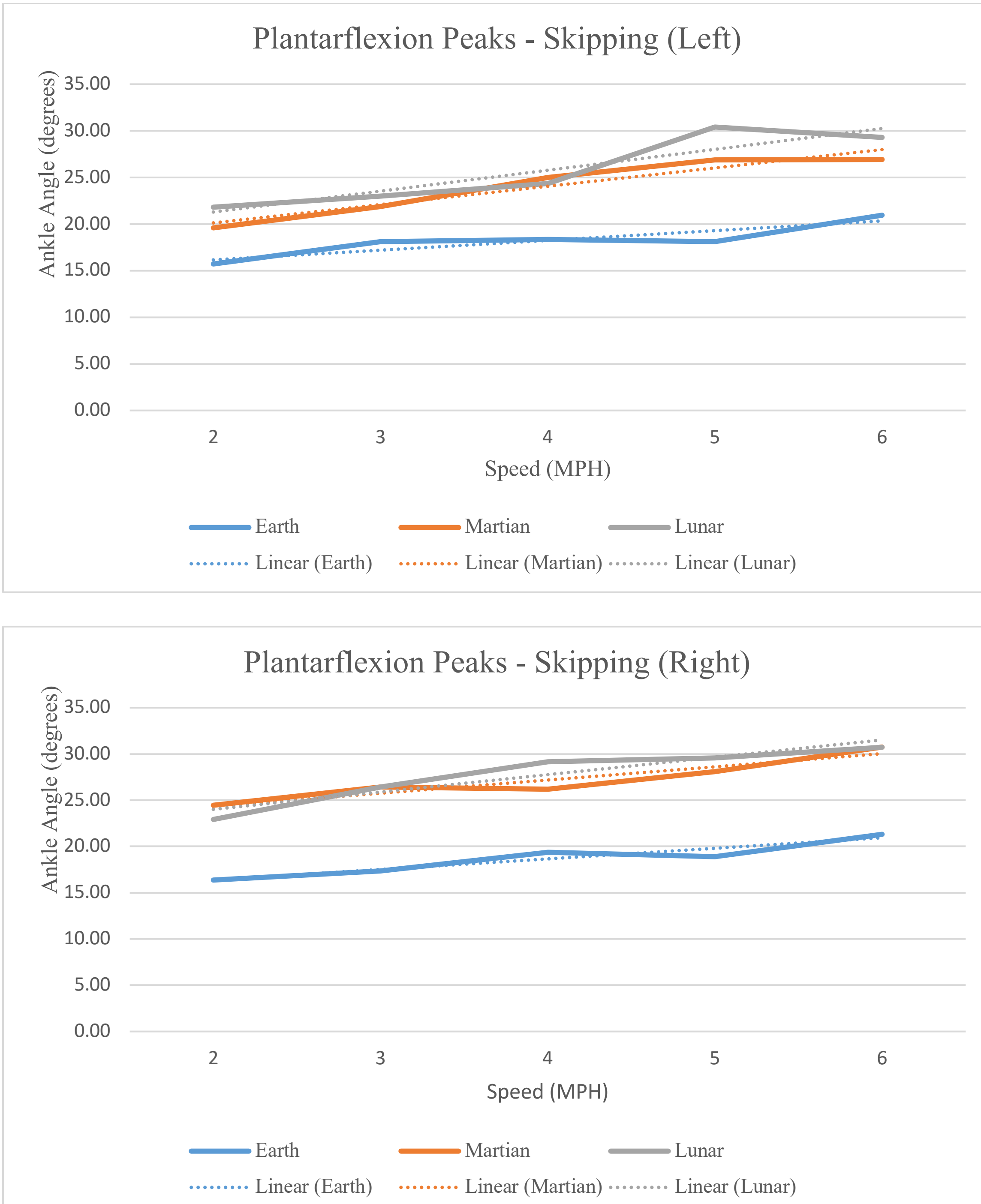
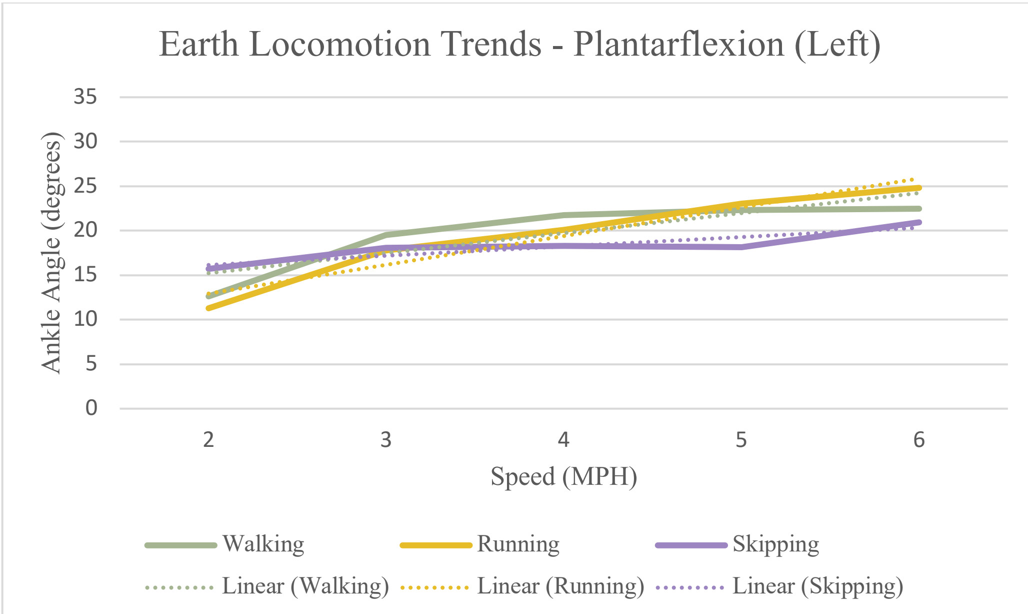


Figure 22. Plantar Flexion - Skipping



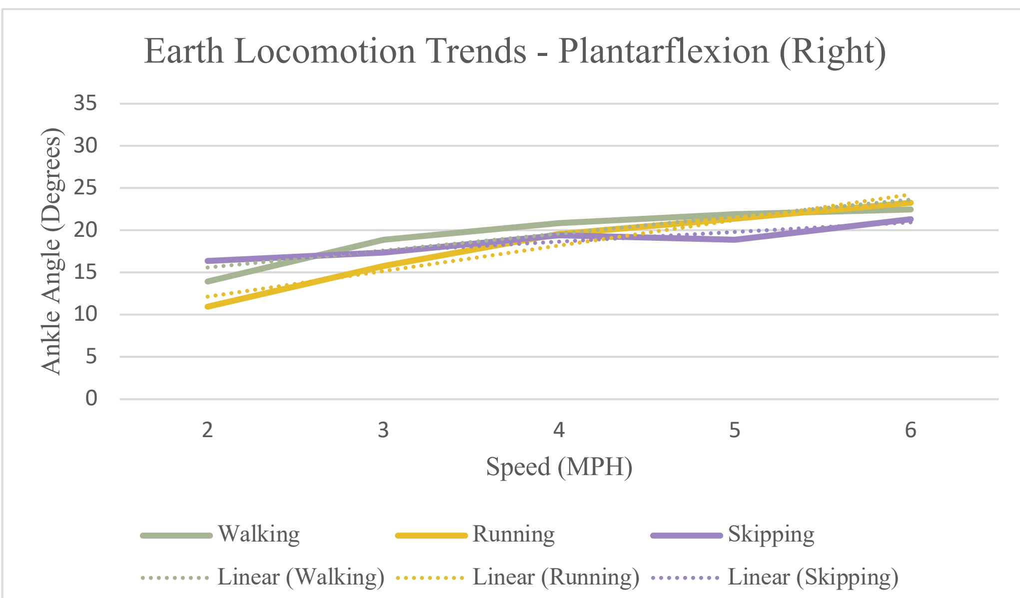
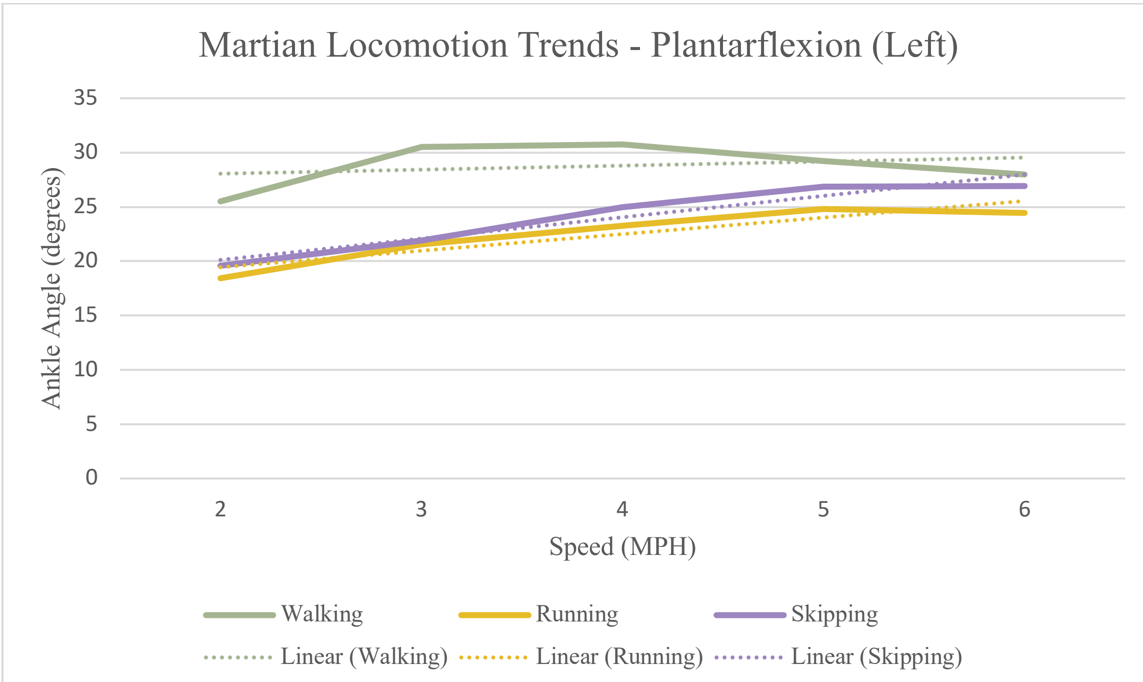


Figure 23. Plantar Flexion - Earth



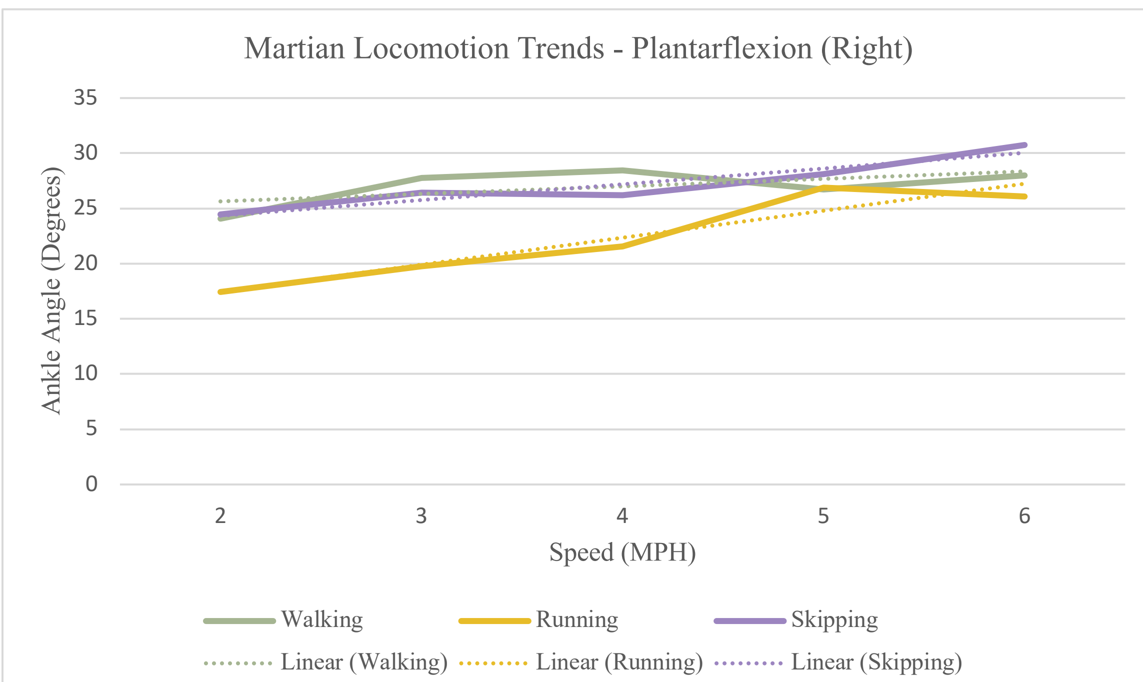
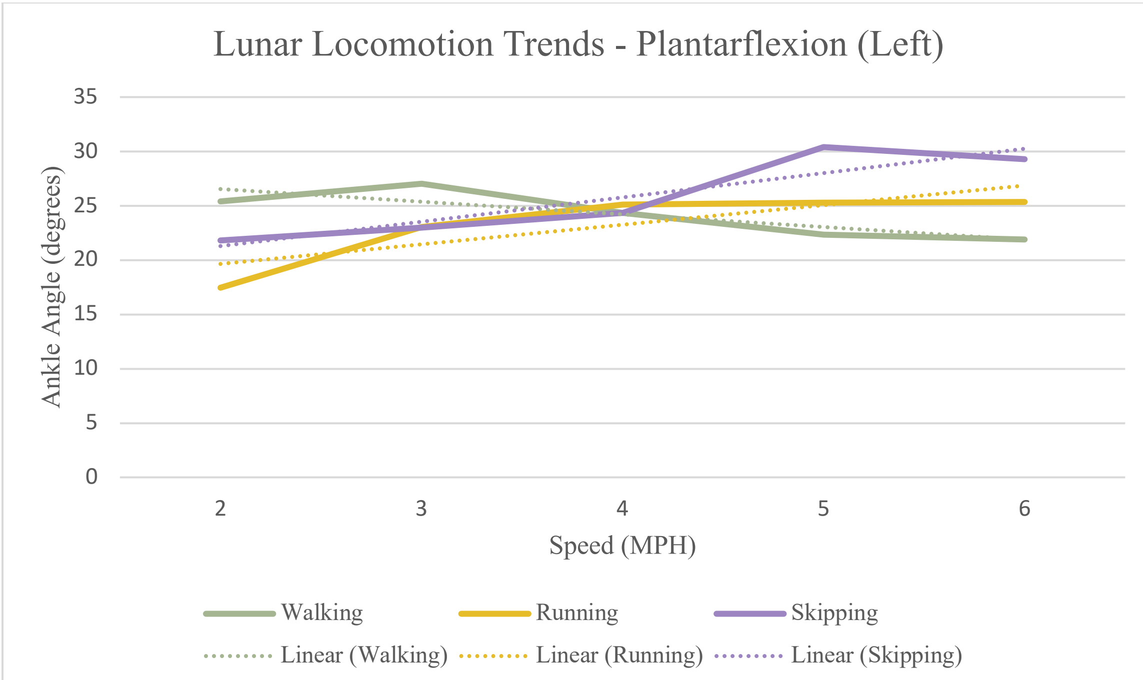


Figure 24. Plantar Flexion - Martian



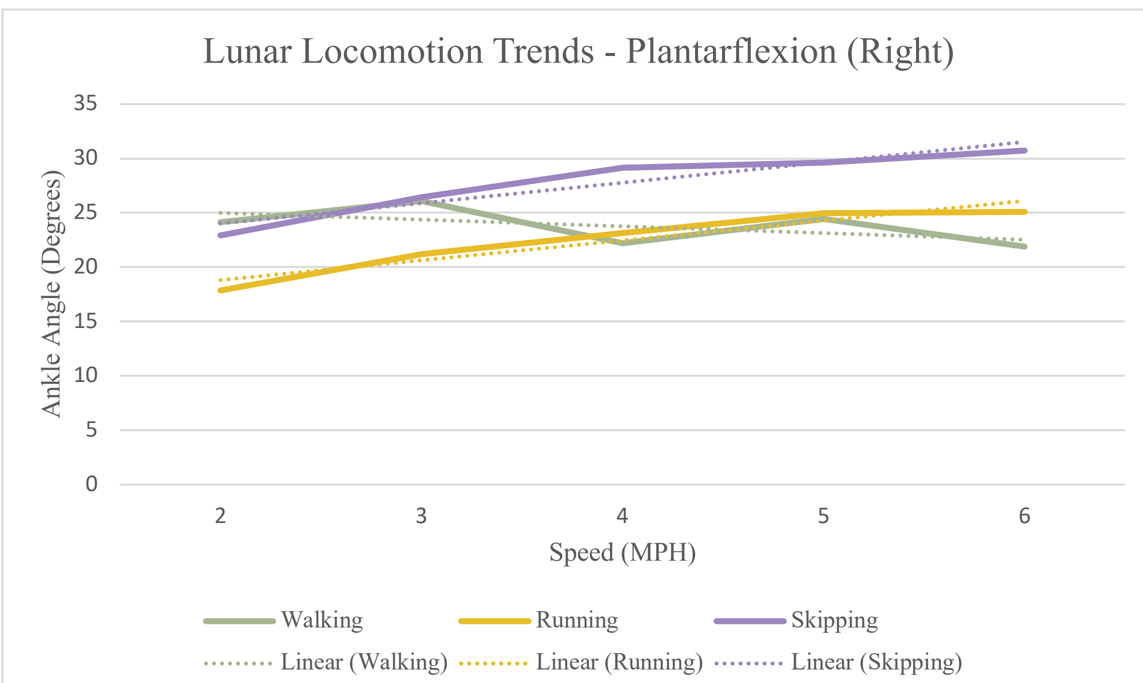


Figure 25. Plantar Flexion - Lunar

ANOVA results indicated that running had a very consistent amount of plantar flexion between gravity conditions, with variations being the most obvious in skipping and walking (See Table 6). The pattern for plantar flexion does not follow the same theme as dorsiflexion, with only walking at 2MPH and skipping at 5 MPH, showing any suggestion of significance.

ANOVA< .05			
Left	Walking	Running	Skipping
2	0.017	0.292	0.544
3	0.057	0.544	0.546
4	0.093	0.556	0.199
5	0.196	0.859	0.016
6	0.85	0.982	0.077
Right			
2	0.043	0.435	0.355
3	0.075	0.579	0.133
4	0.159	0.789	0.151
5	0.515	0.712	0.04
6	0.576	0.864	0.086

Table 6. Plantar Flexion Peaks - ANOVA

Plantar flexion angle values with significant differences p<.05 are shown in green.

We see that T-Test and ANOVA discrepancies still exist as they did in dorsiflexion (See Table 7). All mean differences in Martian and Lunar conditions were higher than the Earth level.

MARTIAN	< .05			LUNAR			
Left	Walking	Running	Skipping	Left	Walking	Running	Skipping
2	0.0236	0.1377	0.4911	2	0.0049	0.1582	0.2109
3	0.0392	0.4028	0.4146	3	0.1154	0.2694	0.2175
4	2.80E-02	0.461	0.1499	4	0.5262	0.2489	0.0291
5	0.0258	0.6639	0.0288	5	0.9931	0.5873	0.0049
6	0.3241	0.9291	0.1131	6	0.9182	0.9121	0.0191
Right				Right			
2	0.0482	0.2637	0.1052	2	0.0101	0.2286	0.3059
3	0.0545	0.3516	0.0558	3	0.0427	0.3519	0.1045
4	3.19E-02	0.6496	0.1608	4	0.7619	4.97E-01	0.0518
5	0.172	0.4158	0.056	5	0.5751	5.38E-01	0.0141
6	0.2586	0.4655	0.0523	6	0.9246	7.63E-01	0.0602

Table 7. Plantar Flexion Peaks - T-Tests

Plantar flexion angle values with significant differences (p<.05) are shown in green.

CHAPTER V ANALYSIS & DISCUSSION

5.1 Analysis

5.1.1 Implications of EMG data

5.1.1.1 Tibialis Anterior

There are two ways to compare the data collected: a comparison of each locomotion method across one level of gravity, or a comparison of one locomotion method across all three gravity levels. Both styles have been presented here, as they contain fascinating insights into the movement in these conditions.

5.1.1.1.1 Gravity Trends

These data mirror the setup of the ANOVA and T-Test for the tibialis anterior: significant differences between walking, running, and skipping were observed between 1g and Martian and lunar gravities in the ANOVA, prompting the T-Test. In the T-Test, significant differences were seen between 1g and Martian skipping conditions, where there was less activation energy to skip in most Martian conditions than in 1g (at 2, 3, 4, and 6MPH for the left leg, 3-6 MPH for right leg), and also in one of the running conditions at the 4 MPH speed for the left tibialis anterior. Additionally, there were significant changes from Lunar g to 1g, with walking at 6 MPH (right) Skipping from 2-5 and 6 (left) and 4-6MPH (right) and running from 2-5 and 6 MPH (left) and 3-6 MPH (right). While the significance of these values is represented in the chart, a graphical view of the values makes comparisons to 1g possible, an allows for comparisons to the PTS research to evaluate whether activation energy levels are high or low enough to speak to locomotion method selection.

The collected activation energy data of the tibialis anterior in normal Earth conditions are consistent with the frequently demonstrated PTS from current literature. There is a point between 4 and 5 MPH where the activation energy of the tibialis anterior during walking intersects with running, after which running prompts less activation. This value was between 40-50 mV (See Figure 2). There is a difference in activation values from left and right legs, with the right leg having higher activation at the same time for the same locomotion method. This could be due to the preferred handedness of the individuals or the mechanics of novel skipping gaits.

Tibialis anterior activation in simulated Martian conditions sees a change from 1g, with the activation energy of running and skipping staying well below their values for the same speed in Earth gravity. Walking has a similar activation curve in Martian gravity compared to 1g, though there is a marked decrease in activation between 5 and 6 MPH. These values are close to the PTS values seen in 1g, while the 5MPH Martian levels are beyond the crossover point seen in 1g. Skipping and running activation levels start close to that of walking but remain low while walking increases. Skipping EMG values also remain lower than running throughout the entire range of speeds.

Lunar gravity activation levels also have walking with higher activation energy levels than running and skipping. Activation levels for walking peak at the same level exhibited while walking between 3 and 4 MPH in 1g. Running and skipping have almost identical values, peaking under the activation required for both methods at 2 MPH in 1g.

5.1.1.1.2 Locomotion Trends

Activation levels start the same for walking across all gravity levels but start to differentiate after the 3 MPH mark. The trends continue as would be expected, with 1g levels requiring the most activation, Martian levels requiring less and Lunar levels requiring the least amount of the three. Similar activation levels are seen between walking and running, with the levels of activation energy being the highest at 1g and lowest at lunar gravity, with Martian in the middle. The difference here from walking is that the values do not start at the same level. Skipping follows the running trends, but the skipping values between lunar and Martian are incredibly similar. The levels of activation energy in fractional gravity environments never crosses that seen at the PTS in 1g under any of the locomotion methods. From this perspective, it is unlikely that muscle fatigue from the tibialis would impact the movement selection on other planets.

5.1.1.2 Medial Gastrocnemius

5.1.1.2.1 Gravity Trends:

Again, these data mirror the ANOVA and T-Test tables. The left medial gastrocnemius was wholly different at all speeds and locomotion levels for the left leg, and in all conditions except walking at 3 and 4 MPH on the right leg. The T-Test data showed that both Martian and Lunar gravity levels were significantly different from 1g levels for the left leg, and that also was the case in the right leg, except for walking in Martian gravity levels, which were not statistically different from 1g.

Activation of the medial gastrocnemius is different between left and right legs in 1g. There was a crossover event just above 4 PMH for walking with running and skipping for the left leg, while this intersection did not occur until 5 PMH on the right leg. Right leg activation levels were much higher for running and skipping than in the left leg, reaching a plateau around 4 PMH that continues to 6 MPH.

5.1.1.2.2 Locomotion Trends

1g activation levels of the medial gastrocnemius are much higher than those of Martian and lunar gravity levels for all locomotion methods, with the latter two methods being very similar. Medial gastrocnemius activation starts low and reaches a high at 6 MPH, while lunar and Martian levels have a small slope and barely reach the level of activation seen at 2 MPH in 1g. Activation levels start at a medium range for running in 1g, while Martian and lunar levels remain much lower in Martian and lunar levels, and never reach a level exhibited in 1g. Skipping levels are very similar to running, with a medium level of activation in 1g and shallow level of activation in Martian and lunar levels. Martian and lunar values are indistinguishable from each other and are at the same activation as 2 MPH values for walking in 1g. Given these results it is unlikely that activation of the medial gastrocnemius impacts locomotion choice in Martian or Lunar gravity levels, as there would be no energy advantage for any method.

5.1.2 Implications of AAA data

5.1.2.1 Dorsiflexion

Dorsiflexion shows less significant changes in ANOVA and T-Tests compared to EMG data, but under reduced gravity conditions some practical significance is apparent (See Tables 3 and 4).

5.1.2.1.1 Walking

Dorsiflexion values for walking are higher in lunar and Martian gravity, respectively, though lunar levels are close to those seen on Earth at 6 MPH. This is in contrast to the EMG data from this study that show a positive correlation between activation energy at specific speeds and gravity levels. This implies a change to the mechanism of movement, as opposed to the straight scaling of movement across gravity levels. This should be expanded upon in future studies.

5.1.2.1.2 Running

Dorsiflexion levels decrease under Martian and lunar gravity levels compared to 1g. Dorsiflexion of running increases in both Martian and 1g but decreases in Earth gravity. These mirror what is shown in the EMG data, where the difference between Martian and 1g is less significant, but the difference between lunar and 1g are significant at higher speeds.

5.1.2.1.3 Skipping

Dorsiflexion remains consistent on the left leg between 1g and Martian conditions, with the average peaks remaining similar across all speeds. In lunar gravity, however, dorsiflexion begins and ends at a lower value. This is in contrast with the EMG data, which shows that 1g conditions are significantly different from Martian and lunar conditions, with Martian and Lunar conditions being very close in value. Again, this implies a change in movement across gravity levels, not a straight scaling of movement.

Unlike the other two locomotion methods, in skipping we see an erratic difference between dorsiflexion of the left and right foot, which could be explained by skipping being a locomotion method not actively practiced by the participants , leading to differences in usage of legs (favoring the dominant leg, as you would handedness, is a possibility that comes to mind that is often seen in people who participate in sports, though the jury is still out on the effect of leg preference on muscle activation (Vaisman et al., 2017, Carpes et al., 2010).

5.1.2.2 Plantar flexion

Significant changes to plantar flexion levels are observed during several sets of conditions, most notably in walking from 2-5 MPH with the left leg in Martian gravity and at 2 MPH in lunar gravity, as well as skipping at 5 MPH in Martian gravity and from 4-6 MPH in lunar gravity (See Tables 6 and 7). The right leg shows significance in 2 and

3 MPH walking between 1g and Martian gravity, as well as 2-3 MPH walking and 5 MPH skipping in lunar gravity.

5.1.2.2.1 Walking

The level of medial gastrocnemius activation is consistent with some of the changes seen in plantar flexion during walking, but not at all points. Low activation occurred under almost all scenarios, except for walking under lunar conditions. However, T-Test show that significantly increased plantarflexion occurred during walking (Martian left 2-5MPH and right 2 & 4 MPH, Lunar Left at 2 MPH and right at 2&3 MPH)

5.1.2.2.2 Running

There was no significant change in plantar flexion found during T-Tests between the gravity environments. However, comparing the graphs of running in the different gravity levels shows a higher starting plantarflexion angle for Martian and lunar conditions than 1g. These levels even out as the participant approaches 6 MPH.

5.1.2.2.3 Skipping

T-Tests show significant increases in plantar flexion for the left leg in Martian gravity at 5 MPH, and the left and right legs at 4-6 MPH and 5 MPH, respectively. Graphs of the mean peaks demonstrate that Martian and Lunar gravity exhibits higher plantarflexion values across the entire speed range.

5.1.2.2.4 Gravity Levels

Plantar flexion remained very similar between all locomotion methods in 1g, with each method showing similar levels of plantar flexion in each leg. However, Changes can be seen in Martian and Lunar conditions. Under Martian conditions walking levels seem might higher than skipping and running at the beginning of the tests for the left leg, but skipping starts at a higher level, similar to running on the right leg. These values converge near the 5 and 6 MPH mark. The difference in left and right leg plantarflexion during skipping again might suggest handedness preferences that reflect on gait characteristics. Similarly, we see that walking and running plantar flexion levels remain the same between left and right legs in Lunar gravity, with skipping plantar flexion levels varying greatly between the two. Walking begins at higher levels but has a negative slope, crossing running's plantar flexion line around the 4 MPH mark. Skipping starts high on the left leg and lower on the right leg.

5.2 Discussion

The data collected support the rejection of all four null hypotheses, as there are p-values $<.05$ present in simulated Martian and lunar gravity conditions. This rejection shines a light on areas for exploration, such as the role of the tibialis anterior and medial gastrocnemius in fractional gravity environments, potential for injury or pathology development, and training regimen development.

5.2.1 Plantar Flexion

Though plantar flexion values increased in these conditions, the medial gastrocnemius EMG T-Test data shows that there is reduced activation for all conditions except walking in Martian gravity levels. There are two probable reasons for these changes. First, that while the gastrocnemius is a major contributor to plantar flexion, this study only focused on the medial gastrocnemius activation energy, where the differences in activation energy and plantar flexion could be due to participation of lateral gastrocnemius or other plantar flexors, such as the soleus. Alternatively, might suggest another change in the mechanics of movement on other planets at a variety of speeds.

The increase in plantar flexion in walking and skipping may increase the chance of tripping or injury. Mistiming of movements of the foot can cause injury, especially if muscles are weakened (Baker et al., 2016), such as in an individual who has been living in reduced gravity conditions. Plantar flexion also increases the instability of the ankle joint (Mansfield and Neumann, 2019), increasing the likelihood of a rolled ankle and sprains (Farr et al., 2018) unless mitigated. This could be solved by spacesuit boot design, but joints are restricted can also account for mistimed movements (Baker et al., 2016) which could cause injury. Mobility and restriction and their effects on the ankle joint and gait stability will end up being an important trade study for future suit design.

5.2.2 Asymmetrical Gaits

While bilateral skipping is a symmetric gait, unilateral skipping, as seen in Apollo astronaut footage is an asymmetrical gait. Walking and running are inherently symmetric gaits, as the human body is symmetric. This ensures that the muscles on either side of the body are more or less equal in size and strength. Asymmetrical gaits, on the other hand, will use different muscles on either leg, altering the muscle development between the two. A study by LaRoche et al. (2012) explored how strength asymmetry (>20% strength in one leg verses the other) in the legs affected gait asymmetry and variability in an older population. They saw that these variables were positively correlated and noted that all three variables are related to fall risks in older adults (LaRoche et al, 2012). If strength asymmetry can be caused by unilateral skipping methods, it could increase the likelihood of falls in astronauts that are already dealing with the deleterious effects of living in micro/fractional gravity environments over long periods of time. This could be combated with an alteration in exercise or countermeasure regimen but could exacerbate the problems with muscle and bone degradation unnecessarily.

As the growth and degradation of muscles would be unknown in a unilateral skipping scenario, i.e., which muscles would grow in either leg or which would diminish, it is impossible to assess the effects of this change in movement. The human body is extremely resilient and develops solutions to return to equilibrium, meaning that it often overcompensates in one area to fill a void in another. Jeon et al. discovered that, in the event of ankle strengths asymmetry, a counterbalance of knee strength increase is observed in what can be determined as an attempt to maintain the body's center of mass (Jeon et al., 2016). This is just one example of an unknown consequence of astronauts developing muscle asymmetry because of a unilateral skipping gait. It is well understood that while there are muscles acting on the ankle, knee and hip joints during locomotion, other muscle groups are actively engaging during locomotion. One such muscle group is the abdominal muscles which provide trunk stability and protection of the spine throughout the jarring leg movements necessary to propel yourself forward. Changes could affect these muscles, which could result in full-body problems that can be a major risk factor for mission success and astronaut health.

5.2.3 Training Implications

Astronauts spend two years preparing for their first spaceflight, with many of those months spent in simulators acclimatizing them to movement in fractional gravity environments. The addition of a skipping gait into these training sessions would be effortless, especially considering that the ARGOS was utilized for this study and is suspected to be an essential training tool for astronaut training for future missions. The success of this study using current ARGOS hardware, as well as a collection of base mean and standard deviation data from this study that will allow for the development of future testing and follow-on studies, would create a natural starting point for this training and subsequent locomotion training development.

A change in locomotion mechanics can have a negative effect, even if it is "better" in the long run. With this in mind we have to focus on the fact that skipping, whether in 1g environments or on other celestial bodies, is a novel gait. As discussed in Olin and Gutierrez (2013) transitioning from one style of locomotion to another, in their case shoed heel-strike running to barefoot toe-trike running, has an effect on muscle activation and forces felt in the body. Their study saw increased EMG values for the medial gastrocnemius and peak tibial shock while transitioning to this new method of running, even though it has been touted as a healthier way to run given the evolution of humans to moving without shoes (Olin & Gutierrez, 2013). The creation of a gradual training method was suggested, and the switch from walking or running to skipping in non-terrestrial gravity levels should undergo the same amount of attention. Considering long-duration missions to the Moon or Mars are (seemly fast) approaching, and that current studies focused on days are not minutes or hours of exercise, a more extended duration study into the effect of skipping on muscles and joints of the leg and hip should be conducted. These studies should focus on suited and shirt-sleeve locomotion, as equipment will also affect the running mechanics.

5.2.4 Suit Design

Just as changes in foot-strike can impact muscle forces, changes in exterior conditions, i.e., shoes, can change the muscle activation and forces exerted on the body. In a 2003 study, Tscharner et al. discovered that the tibialis anterior responds to the addition of shoes as compared to barefoot running. Shoes act as dampeners to movement across a plane (Tscharner et al., 2003), and one of the functions of the tibialis anterior muscle (and other dorsiflexors) is to prevent the impacts of the foot on the ground. By incorporating this into shoe design, foot and leg health is improved.

Similarly, designing spacesuits and boots to benefit the wearer instead of counting on the already existing mechanics of a suit to determine locomotion methods is paramount. While the pressure of the suit might make skipping mechanically less energy, that does not mean the suit was designed, so that would be a primary function or benefit. Current suits cause mobility restriction (Carr and McGee, 2009) which could aid or hinder astronauts depending on the gravity-based predisposition for changes in ankle angle. Working leg health and locomotion mechanics into the next iterations of spacesuit design will benefit the argument for or against skipping as the suggested movement in fractional gravity environments.

5.3 Limitations

5.3.1 ARGOS

As with any gimbal system, the ARGOS has a possible limitation from humans "gaming" the system by leaning forward to regain some semblance of a normal gravity environment. This may have affected the fidelity of microgravity simulation but would be extremely hard to observe and quantify during this study. Also, the gimbal system obstructed the view of the reflective markers during some movements, reducing the data collected for extrapolating hip movement. While the ankle data were the main focus of this study, a workaround for this should be developed for studies looking into knee and hip mechanics. Finally, the speed of the treadmill does not always represent the speed the participants are going during the tests – the force of the participant's body hitting the treadmill may have caused a slowing of the belt, or the high variation of the treadmill might mean more precise values may be slightly off.

5.3.2 Length of Time

The cost of operating the machine and time to complete the trials was prohibitive, as the sample size was forced to remain small, so testing would not last more than three days. Additional testing where the participants traversed for more extended periods of time to get used to the treadmill, equipment, and gimbal system. Additional replications of the experiment tests would have been ideal for the statistical analysis but were unrealistic for the time allotted. Long-term testing will be necessary to corroborate current mechanical simulations regarding their similarity to muscle degradation during long-duration missions to other celestial bodies.

5.3.3 Sample Size

Though typical for this type of study, the small relative sample size of this study prohibited a higher statistical power that would have been ideal.

5.3.4 Skipping

The assumption was made that participants would understand what skipping was from previous experience. There was one participant who began the study not knowing what skipping was and was trained on it after signing their necessary forms and before their tests began, but the introduction of a novel gait so soon before the study may have impacted the trials themselves. Also, both bilateral and unilateral skipping methods were demonstrated for all participants, with the suggestion that they practice both and then pick the one that seemed more natural before the 10-second data collection periods. Five of the six participants proceeded to perform bilateral skipping as their selected movement, while one proceeded to use unilateral. How the differences in locomotion affected the data acquisition, or how shifting of weight was impacted by the ARGOS remains unknown.

5.3.5 Participants

One participant was unable to walk at high speeds on the treadmill, so the data from their walking conditions were not included in the ANOVA or T-Tests. The inclusion of that data may have influenced the p-values gained through that analysis. A correlation between leg length and fastest speed that can be achieved through walking should be considered before participant selection in future studies. Additionally, data was missing from two of the subjects while walking a 6 MPH (one subject under earth conditions, one under lunar conditions). The resulting n=5 for walking conditions.

CHAPTER VI. FUTURE RESEARCH & CONCLUSIONS

6.1 Future Research

6.1.1 Verification

These experiments are limited by the fractional gravity simulators and computer programs available to terrestrial researchers. These methods and those from other biomechanics and locomotion studies should be performed on the Moon and Mars upon the first trips to/ back to these bodies. By validating the results, or by showing the inconsistencies, a more realistic fractional analog can be created, and a more robust training regimen can be devised.

6.1.2 Other Kinematic and Kinetic Factors

Further research into the lower leg and ankle muscle moments and force could be conducted from these trials, as they were another set of factors that were indicated as the main contributor to the run-walk transition is the muscle moment of the ankle in a study by Hreljac et al., in 2008.

6.1.3 Gaits & Gerontology

Continuing to apply gerontology to spaceflight situations (and vice versa) can expand upon both fields of study. A study comparing the step length of astronauts under different levels of gravity and locomotion styles could be compared to gerontology data about the incidents of falls and gait stability explored in papers such as Pavol et al. (1999).

6.1.4 Suited Applications

The next logical step forward is suited testing with the same testing procedure. While this study focused on general locomotion as would be exhibited in a habitat, such as in exercise capacity, EVA research will require the same tests be reproduced with a suited participant to further assess the impact of skipping in fractional gravity environments.

6.1.5 Spacesuit Design

After suited trials are performed, suit and boot design iterations can include data from those trials as a branching off point for future designs. Continued design and testing will ensure that the restriction of the suit does not negatively impact astronaut movement or health, and actively supports them instead.

6.1.6 Training Design

A synthesis of past locomotion research should be conducted to determine whether unilateral or bilateral skipping is better for movement in fractional gravity environments, or if there is a preference. Once this is conducted, additional information from gerontological and spacesuit design should be included in a trade study that ultimately suggests the type of locomotion best suited for fractional gravity exploration. This should be used to create a training regimen for Astronaut Candidates. It may be too risky to do this as a study, as not properly training or improperly training Astronaut Candidates could result in injury in those environments. The usage of bed rest studies and continued utilization of the ARGOS or other simulators could inform this decision.

6.2 Conclusion

Human locomotion on other planets will be a major issue requiring preventative training due to the changes in mechanics and muscle usage. The change in dorsiflexion and plantar flexion values indicates an increased rate of trips and falls, especially with exacerbation of muscle degradation exhibited in micro and reduced gravity. The reduced muscle activation between Earth, Martian and Lunar gravity levels indicates that locomotion method selection will not rely on energy expenditure but will instead depend on training and suit design. Skipping does not show an obvious benefit in unsuited methods above walking and running considering the similar values of all locomotion methods in those environments. Secondly, unilateral skipping offers the possibility of additional harm, resulting in asymmetrical strength which can lead to further injury. Astronauts will need to be properly trained, but this training will need to be developed with the deleterious effects of asymmetrical movement in mind. Without this training, astronauts could suffer injuries that endanger their mission success and put them at risk for long-lasting pathologies.

WORKS CITED

Active Response Gravity Offload System. (January 22, 2013). *Integrated Environments.* Retrieved from https://www.nasa.gov/centers/johnson/engineering/integrated_environments/active_response_gravity/

Plug-in Gait Reference Guide. (2017). Vicon Motion Systems Ltd.

Ackermann, M., & van den Bogert, A. J. (2012). Predictive simulation of gait at low gravity reveals skipping as the preferred locomotion strategy. *Journal of Biomechanics, 45*(7), 1293-1298. doi:10.1016/j.jbiomech.2012.01.029

Adams, G. R., Caiozzo, V. J., & Baldwin, K. M. (2003). Skeletal muscle unweighting: spaceflight and ground-based models. *Journal of Applied Physiology, 95*(6), 2185-2201. doi:10.1152/japplphysiol.00346.2003

Alexander, R. M. (1989). Optimization and gaits in the locomotion of vertebrates. *Physiol Rev, 69*(4), 1199-1227.

Alkner, B. A., & Tesch, P. A. (2004). Knee extensor and plantar flexor muscle size and function following 90 days of bed rest with or without resistance exercise. *Eur J Appl Physiol, 93*(3), 294-305. doi:10.1007/s00421-004-1172-8

Baker, M., Mullally, E., Blenkinsop, O., Perrin, N., & Brewer, J. (2016). *Pocket Anatomy of the Moving Body: The Compact Guide to the Science of Human Locomotion*. London, UK: Barrons Educational Series.

Bertram, J. E. A., & Hasaneini, S. J. (2013). Neglected losses and key costs: tracking the energetics of walking and running. *Journal of Experimental Biology, 216*(6), 933-938. doi:10.1242/jeb.078543

Bloomberg, J. J., Peters, B. T., Cohen, H. S., & Mulavara, A. P. (2015). Enhancing astronaut performance using sensorimotor adaptability training. *Frontiers in Systems Neuroscience, 9*, 129. doi:10.3389/fnsys.2015.00129

Brockett, C. L., & Chapman, G. J. (2016). Biomechanics of the ankle. *Orthopaedics and Trauma, 30*(3), 232-238. doi:10.1016/j.mporth.2016.04.015

Carpes, F. P., Diefenthaeler, F., Bini, R. R., Stefanyshyn, D., Faria, I. E., & Mota, C. B. (2010). Does leg preference affect muscle activation and efficiency? *Journal of Electromyography and Kinesiology, 20*(6), 1230-1236. doi:https://doi.org/10.1016/j.jelekin.2010.07.013

Carr, C., & Newman, D. (2005). When is Running More Efficient Than Walking in a Space Suit? *SAE Technical Papers*. doi:10.4271/2005-01-2970

Carr, C. E., & McGee, J. (2009). The Apollo Number: Space Suits, Self-Support, and the Walk-Run Transition. *PLoS One, 4*(8), e6614. doi:10.1371/journal.pone.0006614

Cavagna, G. A., Willems, P. A., & Heglund, N. C. (2000). The role of gravity in human walking: pendular energy exchange, external work and optimal speed. *J Physiol, 528*(Pt 3), 657-668.

Cowley, M., Harvill, L., & Rajulu, S. (2014). *Human Performance in Simulated Reduced Gravity Environments*. Paper presented at the 25th Congress for the International Society of Biomechanics, Glasgow; United Kingdom. ntrs.nasa.gov/search.jsp?R=20140017135

Croft, J. L., Schroeder, R. T., & Bertram, J. E. A. (2019). The Landscape of Movement Control in Locomotion: Cost, Strategy, and Solution. *Frontiers in Psychology, 10*, 716. doi:10.3389/fpsyg.2019.00716

Crowninshield, R. D., & Brand, R. A. (1981). A physiologically based criterion of muscle force prediction in locomotion. *Journal of Biomechanics, 14*(11), 793-801. doi:https://doi.org/10.1016/0021-9290(81)90035-X

Day, B. L., & Fitzpatrick, R. C. (2005). The vestibular system. *Current Biology, 15*(15), R583-R586. doi:http://dx.doi.org/10.1016/j.cub.2005.07.053

de Winkel, K. N., Clément, G., Groen, E. L., & Werkhoven, P. J. (2012). The perception of verticality in lunar and Martian gravity conditions. *Neurosci Lett, 529*(1), 7-11. doi:10.1016/j.neulet.2012.09.026

De Witt, J. K., Edwards, W. B., Scott-Pandorf, M. M., Norcross, J. R., & Gernhardt, M. L. (2014). The preferred walk to run transition speed in actual lunar gravity. *J Exp Biol, 217*(18), 3200.

Drummer, C., Gerzer, R., Baisch, F., & Heer, M. (2000). Body fluid regulation in μ-gravity differs from that on Earth: an overview. *Pflügers Archiv, 441*(1), R66-R72. doi:10.1007/s004240000335

Dyde, R. T., Jenkin, M. R., & Harris, L. R. (2006). The subjective visual vertical and the perceptual upright. *Experimental Brain Research, 173*(4), 612-622. doi:10.1007/s00221-006-0405-y

Enoka, R. M. (2002). *Neuromechanics of human movement* (6th ed.). Champaign, IL: Human Kinetics.

Farina, D., Merletti, R., & Enoka, R. M. (2014). The extraction of neural strategies from the surface EMG: an update. *J Appl Physiol (1985), 117*(11), 1215-1230. doi:10.1152/japplphysiol.00162.2014

Farr, B. K., Nguyen, D., Stephenson, K., Rogers, T., Stevens, F. R., & Jasko, J. J. (2018). 39 - Ankle Sprains. In C. E. Giangarra & R. C. Manske (Eds.), *Clinical Orthopaedic Rehabilitation: a Team Approach (Fourth Edition)* (pp. 255-272.e251). Philadelphia: Content Repository Only!

Fernandez, W. G., Yard, E. E., & Comstock, R. D. (2007). Epidemiology of Lower Extremity Injuries among U.S. High School Athletes. *Academic Emergency Medicine, 14*(7), 641-645. doi:10.1111/j.1553-2712.2007.tb01851.x

Fu, Q., Arbab-Zadeh, A., Perhonen, M. A., Zhang, R., Zuckerman, J. H., & Levine, B. D. (2004). Hemodynamics of orthostatic intolerance: implications for gender differences. *American Journal of Physiology - Heart and Circulatory Physiology, 286*(1), H449-H457. doi:10.1152/ajpheart.00735.2002

Goswami, N. (2017). Falls and Fall-Prevention in Older Persons: Geriatrics Meets Spaceflight! *Frontiers in Physiology, 8*(603). doi:10.3389/fphys.2017.00603

Hansen, J. T. (2014). *Netter's Anatomy Coloring Book* (2nd ed.). Philadelphia, PA: Saunders Elsevier.

Harris, L. R., Herpers, R., Hofhammer, T., & Jenkin, M. (2014). How much gravity is needed to establish the perceptual upright? *PLoS One, 9*(9), e106207. doi:10.1371/journal.pone.0106207

Herdman, S., & Clendaniel, R. A. (2014). *Vestibular Rehabilitation: Contemporary perspectives in rehabilitation* (S. Herdman Ed. 3rd ed.). Philadelphia, PA: F.A. Davis Company.

Hootman, J. M., Dick, R., & Agel, J. (2007). Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *Journal of athletic training, 42*(2), 311-319.

Hreljac, A. (1993). Determinants of the gait transition speed during human locomotion: kinetic factors. *Gait & Posture, 1*(4), 217-223. doi:https://doi.org/10.1016/0966-6362(93)90049-7

Hreljac, A. (1995). Determinants of the gait transition speed during human locomotion: Kinematic factors. *Journal of Biomechanics, 28*(6), 669-677. doi:http://dx.doi.org/10.1016/0021-9290(94)00120-S

Hreljac, A., Arata, A., Ferber, R., Mercer, J. A., & Row, B. S. (2001). An Electromyographical Analysis of the Role of Dorsiflexors on the Gait Transition during Human Locomotion. *Journal of Applied Biomechanics, 17*(4), 287-296. doi:doi:10.1123/jab.17.4.287

Hreljac, A., Imamura, R. T., Escamilla, R. F., Edwards, W. B., & MacLeod, T. (2008). The Relationship Between Joint Kinetic Factors and the Walk--Run Gait Transition Speed During Human Locomotion. *Journal of Applied Biomechanics, 24*(2), 149-157.

Jeon, K., Chun, S., & Seo, B. (2016). Effects of muscle strength asymmetry between left and right on isokinetic strength of the knee and ankle joints depending on athletic performance level. *J Phys Ther Sci, 28*(4), 1289-1293. doi:10.1589/jpts.28.1289

Jones, E. M. (1995-2001, 2 November 2010). Lunar Gaits. *Apollo 11 Lunar Surface Journal.* Retrieved from http://www.hq.nasa.gov/office/pao/History/alsj/a11/a11.gaits.html

Kram, R., Domingo, A., & Ferris, D. P. (1997). Effect of reduced gravity on the preferred walk-run transition speed. *J Exp Biol, 200*(Pt 4), 821-826.

Laroche, D. P., Cook, S. B., & Mackala, K. (2012). Strength asymmetry increases gait asymmetry and variability in older women. *Med Sci Sports Exerc, 44*(11), 2172-2181. doi:10.1249/MSS.0b013e31825e1d31

Laumonier, T., & Menetrey, J. (2016). Muscle injuries and strategies for improving their repair. *Journal of experimental orthopaedics, 3*(1), 15-15. doi:10.1186/s40634-016-0051-7

Leonard, J. I., Leach, C. S., & Rambaut, P. C. (1983). Quantitation of tissue loss during prolonged space flight. *Am J Clin Nutr, 38*(5), 667-679.

Leurs, F., Ivanenko, Y. P., Bengoetxea, A., Cebolla, A.-M., Dan, B., Lacquaniti, F., & Cheron, G. A. (2011). Optimal walking speed following changes in limb geometry. *J Exp Biol, 214*(13), 2276. doi:10.1242/jeb.054452

Mansfield, P. J., & Neumann, D. A. (2019). Chapter 11 - Structure and Function of the Ankle and Foot. In P. J. Mansfield & D. A. Neumann (Eds.), *Essentials of Kinesiology for the Physical Therapist Assistant (Third Edition)* (pp. 311-350). St. Louis (MO): Mosby.

Mercer, J. A., Applequist, B. C., & Masumoto, K. (2013). Muscle Activity While Running at 20%–50% of Normal Body Weight. *Research in Sports Medicine, 21*(3), 217-228. doi:10.1080/15438627.2013.792084

Minetti, A. E. (1998). The Biomechanics of Skipping Gaits: A Third Locomotion Paradigm? *Proceedings: Biological Sciences, 265*(1402), 1227-1235.

Minetti, A. E. (2001). Invariant aspects of human locomotion in different gravitational environments. *Acta Astronautica, 49*(3), 191-198. doi:https://doi.org/10.1016/S0094-5765(01)00098-4

Mulugeta, L., Chappell, S. P., & Skytland, N. G. (2009). *The Effect of Center of Gravity and Anthropometrics on Human Performance in Simulated Lunar Gravity*. https://doi.org/10.4271/2009-01-2561

Neptune, R. R., & Sasaki, K. (2005). Ankle plantar flexor force production is an important determinant of the preferred walk-to-run transition speed. *Journal of Experimental Biology, 208*(5), 799. doi:10.1242/jeb.01435

Norcross, J. R., Chappell, S. P., & Gernhardt, M. L. *Lessons Learned from Performance Testing of Humans in Spacesuits in Simulated Reduced Gravity*. Paper presented at the HRP Investigators' Workshop, Houston, TX; United States.

Nordin, M., & Frankel, V. H. (2001). *Basic Biomechanics of the Musculoskeletal System*: Lippincott Williams & Wilkins.

Olin, E. D., & Gutierrez, G. M. (2013). EMG and tibial shock upon the first attempt at barefoot running. *Human Movement Science, 32*(2), 343-352. doi:https://doi.org/10.1016/j.humov.2012.11.005

Pavei, G., Biancardi, C. M., & Minetti, A. E. (2015). Skipping vs. running as the bipedal gait of choice in hypogravity. *Journal of Applied Physiology, 119*(1), 93-100. doi:10.1152/japplphysiol.01021.2014

Pavol, M., Owings, T., Foley, K., & Grabiner, M. (1999). Gait Characteristics as Risk Factors for Falling From Trips Induced in Older Adults. *Journal of Gerontology: MEDICAL SCIENCES, 54*, M583-590. doi:10.1093/gerona/54.11.M583

Perneger, T. V. (1998). What's wrong with Bonferroni adjustments. *BMJ, 316*(7139), 1236-1238. doi:10.1136/bmj.316.7139.1236

Perry, J. (1967). The mechanics of walking: a clinical interpretation. *Physical therapy, 47*(9), 778-801.

Persch, L. N., Ugrinowitsch, C., Pereira, G., & Rodacki, A. L. F. (2009). Strength training improves fall-related gait kinematics in the elderly: A randomized controlled trial. *Clinical Biomechanics, 24*(10), 819-825. doi:https://doi.org/10.1016/j.clinbiomech.2009.07.012

Rader, A. A., Newman, D. J., & Carr, C. E. (2007). *Loping: A Strategy for Reduced Gravity Human Locomotion?* Paper presented at the International Conference On Environmental Systems, Chicago, Illinois. https://doi.org/10.4271/2007-01-3134

Schmitt, H. J. (2018). Walking on the Moon: Apollo 17 Exploration and Beyond.

Seedhouse, E. (2010). *Prepare for Launch*. New York, NY: Praxis.

Snaterse, M., Ton, R., Kuo, A. D., & Donelan, J. M. (2011). Distinct fast and slow processes contribute to the selection of preferred step frequency during human walking. *Journal of Applied Physiology, 110*(6), 1682-1690. doi:10.1152/japplphysiol.00536.2010

Sparrow, W. A., & Newell, K. M. (1998). Metabolic energy expenditure and the regulation of movement economy. *Psychonomic Bulletin & Review, 5*(2), 173-196. doi:10.3758/bf03212943

Sridhar, S., Stetz, E., McFarland, S., & Schaffner, G. (2017). *Space Suit and Portable Life Support System Center of Gravity Influence on Astronaut Kinematics, Exertion and Efficiency*.

Stauffer, R. N., Chao, E. Y., & Brewster, R. C. (1977). Force and motion analysis of the normal, diseased, and prosthetic ankle joint. *Clinical orthopaedics and related research*(127), 189-196.

Stenger, M. B., Tarver, W. J., Brunstetter, T., Gibson, R. C., Laurie, S. S., Lee, S. M. C., . . . Zwart, S. R. (2017). *Evidence Repot: Risk of Spaceflight Associated Neuro-ocular Syndrome (SANS)*. Retrieved from Houston, Texas:

Sylos-Labini, F., Lacquaniti, F., & Ivanenko, Y. P. (2014). Human locomotion under reduced gravity conditions: biomechanical and neurophysiological considerations. *Biomed Res Int, 2014*, 547242. doi:10.1155/2014/547242

Vaisman, A., Guiloff, R., Rojas, J., Delgado, I., Figueroa, D., & Calvo, R. (2017). Lower Limb Symmetry: Comparison of Muscular Power Between Dominant and Nondominant Legs in Healthy Young Adults Associated With Single-Leg-Dominant Sports. *Orthopaedic journal of sports medicine, 5*(12), 2325967117744240-2325967117744240. doi:10.1177/2325967117744240

Valle, P., Dungan, L., Lieberman, A., & Poncia, D. (2011). *Active Response Gravity Offload System* (MSC-24815-1/24-1). Retrieved from NASA Tech Briefs, September 2011: https://ntrs.nasa.gov/search.jsp?R=20120000452

Vicon. FAQS FOR SOFTWARE. Retrieved from https://www.vicon.com/support/faqs/?q=what-are-the-details-of-the-woltring-filter

von Tscharner, V., Goepfert, B., & Nigg, B. M. (2003). Changes in EMG signals for the muscle tibialis anterior while running barefoot or with shoes resolved by non-linearly scaled wavelets. *Journal of Biomechanics, 36*(8), 1169-1176. doi:10.1016/S0021-9290(03)00086-1

Watkins, J., & Mathieson, I. (2009). Chapter 7 - Structure and function of the foot. In J. Watkins & I. Mathieson (Eds.), *The Pocket Podiatry Guide: Functional Anatomy* (pp. 227-301). Edinburgh: Churchill Livingstone.

Whipple, R. H., Wolfson, L. I., & Amerman, P. M. (1987). The Relationship of Knee and Ankle Weakness to Falls in Nursing Home Residents: An Isokinetic Study. *Journal of the American Geriatrics Society, 35*(1), 13-20. doi:10.1111/j.1532-5415.1987.tb01313.x

Widrick, J. J., Knuth, S. T., Norenberg, K. M., Romatowski, J. G., Bain, J. L. W., Riley, D. A., . . . Fitts, R. H. (1999). Effect of a 17 day spaceflight on contractile properties of human soleus muscle fibres. *The Journal of Physiology, 516*(Pt 3), 915-930. doi:10.1111/j.1469-7793.1999.0915u.x

Winter, D. A. (1991). *The Biomechanics and Motor Control of Human Gait: Normal, Elderly and Pathalogical* (2nd ed.). Waterloo, Ontario, Canada: University of Waterloo Press.

APPENDICES

APPENDIX A: Integrated Hazard Analysis for Electromyography and Motion Capture Systems in ARGOS

Integrated Hazard Analysis for Electromyography and Motion Capture Systems in ARGOS

Engineering Directorate
Software, Robotics, and Simulation Division

Baseline
Date: October 2017

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058-3696

Appendix A – Integrated Hazard Analysis for Electromyography and Motion Capture Systems in ARGOS

SOFTWARE, ROBOTICS, AND SIMULATION DIVISION
NASA – LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TEXAS

Integrated Hazard Analysis for North Dakota Experimental 2 (NDX-2) Lower Torso Assembly in ARGOS

Doc. No. SRSD-17-002 Date: October 2017

Prepared By: ______________________ Date ____________ Michael T. Amoroso, ARGOS Document Manager	
Prepared By: ______________________ Date: ____________ Sophie Orr, University of North Dakota	
Approved By: ______________________ Date: ____________ David Read, Chief, Dynamic Systems Test Branch	
Approved By: ______________________ Date: ____________ Neill Long, JETS Safety Representative	
Approved By: ______________________ Date: ____________ Art Knell, NS Safety Representative	
Approved By: ______________________ Date: ____________ Pablo de Leon, Director of UND Human Spaceflight Laboratory	
Release Authorized By: ______________________ Date: ____________ Robert O. Ambrose, Chief, Software, Robotics, and Simulation Division	

Appendix A – Integrated Hazard Analysis for Electromyography and Motion Capture Systems in ARGOS

Document Change Log For: SRSD-17-002			Page: 1 of 1
Revision Letter Date	Reason for Change	Pages Affected	Brief Description Of Change
Oct. 2017	Baseline	All	Initial Release

Verify that this is the correct version before use.

Table of Contents

INTRODUCTION/PURPOSE

This report is the Integrated Hazard Analysis for using the BIOPACK MP150 system and EMG100C amplifiers in the Gen 2b Active Response Gravity Offload System (ARGOS) for testing. The use of the system includes, but is not limited to, characterization of the system, characterization of humans, and test specific objectives. This hazard analysis is specific to the testing to be performed and approved by the test specific Test Readiness Review.

All hazards that have the potential for harming test personnel (test team and test participant) are compiled into this integrated hazard analysis.

The purpose of this document is to identify potential hazards involved in operating the Gen 2b ARGOS assembly, control system, support hardware, and human interaction with the system and support hardware, as well as the integrated use of the BIOPACK MP150 system and EMG100C amplifiers with these systems. This includes all mockups, tools, and equipment that the test participant will interact with. The document analyzes the use of the hardware provided by the Software, Robotics and Simulation Division (SR&SD/ER). A “hazard” is defined as any condition that has the potential for harming personnel or equipment.

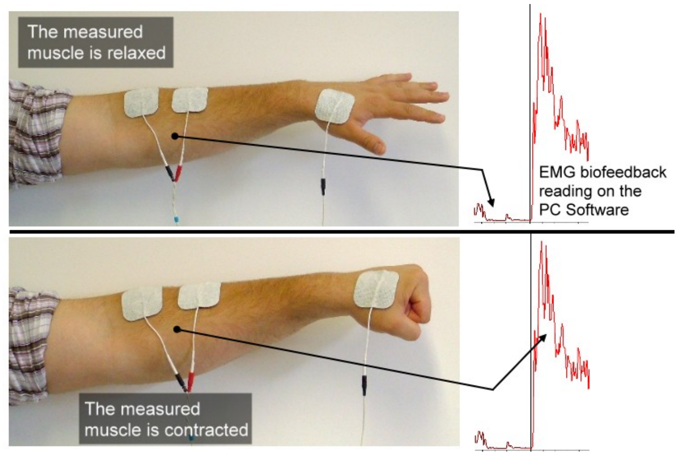
The process for approving ARGOS for Human in the Loop testing is documented in the ARGOS Project Management Plan, SRSD-14-004. This process includes a System Acceptance Review and oversight by an Independent Review Team.

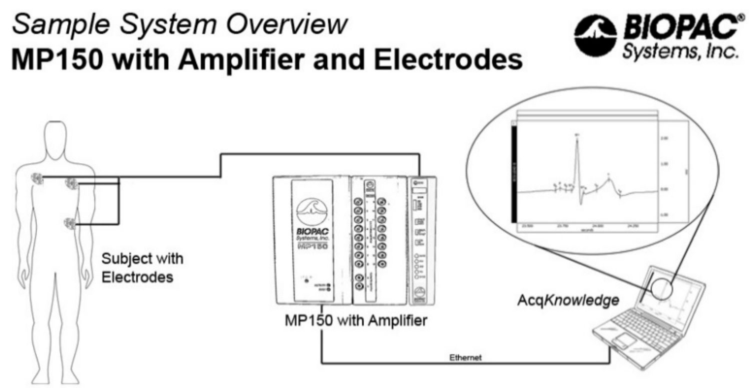
The hardware, mockups and risk will be evaluated before the TRR using the ARGOS Pre-TRR process as defined in SRSD-16-002. The Pre-TRR Risk Review Board will make a recommendation and present any dissenting opinions at the TRR.

BIOPAC MP150 and EMG100C Hardware

The subjects will be connected to the BIOPAC MP150 data acquisition and analysis system with the EMG100C Electromyogram Amplifier attachment. The EMG100C amplifies general and skeletal muscle electrical activity. The connection points will be electrodes that effectively senses muscle activation and send the signal to the EMG100C, which then integrates with the main MP150 unit. These electrodes only receive signals, they do not emit signals to the subject. The operating voltage of the unit is 10 V. Placement of these electrodes will be on the leg on the skin above the tibialis anterior and medial gastrocnemius medialis. The electrodes have a sticker built into them, and conductive gel will also be used to ensure signal strength. These are surface electrodes and do not penetrate the skin in any way. Specialized tape will be used to ensure electrodes do not move during movement during testing. This data will later be analyzed with the BIOPAC Acq*Knowledge* software to compare the activation energy the tibialis anterior and gastrocnemius medialis muscles exhibited during the tests. The BIOPAC system is currently used by UND and other universities as a research tool, and is not intended to be used as a medical device.

Appendix A – Integrated Hazard Analysis for Electromyography and Motion Capture Systems in ARGOS





Motion Capture System

In addition to the BIOPAC system, the Vicon infrared motion capture analysis system will be employed during testing. This consists of 10 motion capture cameras that will map the movement of the subjects by receiving light shining off of reflective markers placed on key points of the subject's body (these points are standardized). This allows for a comparison between joint angles and overall movement of the subject's body. Each test will be recorded and then the data will be recorded using the Vicon Nexus software, which will allow for analysis of gait changes between tests. Subjects will not be involved in the placement or operation of the cameras.

Appendix A – Integrated Hazard Analysis for Electromyography and Motion Capture Systems in ARGOS

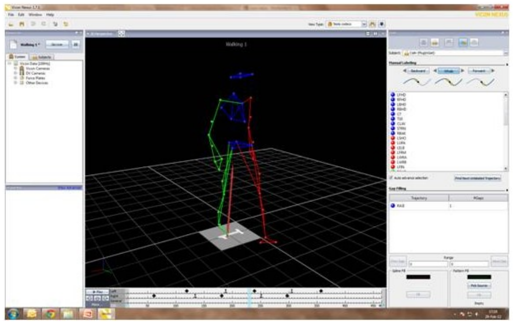


Figure 3. Data from the Vicon motion capture camera system will be represented in 3D form and used for analysis.

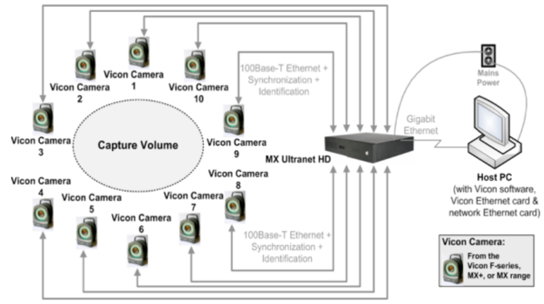


Figure 4. 10 Vicon infrared cameras will be set up around the testing area.

Hexoskin Smart Shirt

These will allow the study staff to monitor the subjects' heart rate (via an ECG channel) and breathing rate. This device is comprised of a shirt and data collection device which can connect to a computer or cellular device to show real time data. This data will be monitored to ensure that subjects have not overexerted themselves. The power is provided by a 3.7V battery pack.

2.0 SCOPE

This Hazard Analysis covers the specific tasks of using BIOPAC Electromyography equipment in the Gen 2b Active Response Gravity Offload System (ARGOS) for human in the loop testing. The analysis covers custom horizontal system, the custom z-axis system, system operations with a human participant or robotic system, Gen 2b ARGOS provided support hardware, and Gen 2b ARGOS control rack. A human test subject provides an input into the ARGOS (through attachment to system via harness and/or by providing an external force to system). Each test will require a test specific integrated hazard analysis. A detailed description of the ARGOS is available in SRSD-15-014 ARGOS System Description Document.

The equipment assessed in this integrated HA is as follows:

ARGOS System (Vertical, Horizontal, and Structure)
Emergency Extraction Equipment (Ladders, Sky Genie)
Horizontal gimbal and harness
Vertical gimbal and harness
BIOPAC MP 150 and BIOPAC EMG100C hardware
Hexoskin Smart Shirt and hardware
Donning table (no hazards)
Vicon Motion Capture Cameras, stands and flashlights (no hazards)

3.0 HAZARD IDENTIFICATION CRITERIA

This Report is prepared in accordance with JPR1700.1 Rev J JSC Safety and Health Handbooks.
The "hazards" or "potential hazards" identified in this analysis came from the following sources:
Facility "walk-through" inspections
Hardware inspections
System Design Drawings
Vendor Manuals
Discussion with Facility, Safety, and Project Engineers
Lessons Learned from ARGOS Generation 1 and 2a testing

The hardware, mockups and risk will be evaluated before the TRR using the ARGOS Pre-TRR process as defined in SRSD-16-002. The Pre-TRR Risk Review Board will make a recommendation and present any dissenting opinions at the TRR.
Each of the potential hazards identified from these criteria are documented on the attached Hazard Analysis Worksheets. Each worksheet identifies a potential hazard, lists what causes that hazard to exist and states what measures have been taken to control or minimize that hazard. It gives a numerical representation of what level or degree of severity the hazard is rated by the analyzer and also lists the probability of the occurrence.
Signatures on the Signature Sheet of this document indicate that all hazard worksheets listed in Appendix A – Hazard Analysis Worksheets have been reviewed and that the risk is accepted by the appropriate authority for the level of risk. Any hazard with a RAC of 3 after controls requires a division chief signature for acceptance. Any hazard with a RAC of 4, 5, or 6 after controls requires a branch chief signature for acceptance.

3.01. Hazard Definitions

The following definitions are vital to an understanding of the requirements contained in this document:

a. Hazard – An unsafe or unhealthy condition that could lead to a mishap if it is not corrected.

b. Consequence – The subjective estimate of worst credible outcome in terms of potential personnel injury, equipment/facility damage and monetary losses. Consequence is further defined by severity classifications. Consequence severity classes are defined as follows:

1. Class I – Catastrophic. A condition that may cause death or permanently disabling injury, facility destruction on the ground.

2. Class II – Critical. A condition that may cause severe injury or occupational illness, or major property damage to facilities, systems, equipment, or flight hardware.

3. Class III – Moderate. A condition that may cause minor injury or occupational illness, or minor property damage to facilities, systems, equipment, or flight hardware.

4. Class IV – Negligible. A condition that could cause the need for minor first-aid treatment but would not adversely affect personal safety or health; damage to facilities, equipment, or flight hardware more than normal wear and tear level.

c. Likelihood – The relative likelihood a hazard may occur. The complete probability range is separated into intervals for additional classification. It is important to note that even though quantitative probability intervals are listed in this document they are only for numeric comparison and that the actual probability is derived by subjective estimation of a qualitative nature. The hazard probability categories are defined as follows:

1. Likelihood A. Likely to occur.

2. Likelihood B. Probably will occur.

3. Likelihood C. May occur.

4. Likelihood D. Unlikely to occur.

5. Likelihood E. Improbable.

d. Risk Assessment Code (RAC) – The Risk Assessment Code is the numerical value that represents the hazard risk associated with a given task, project, test, or equipment and is the point of intersection of the consequence severity estimate and the probability estimate on the RAC matrix.

e. Risk Assessment Code (RAC) Matrix – A matrix made up of probability estimates, severity estimates and risk assessment codes. The matrix is used to derive the risk assessment code once the severity and probability have been determined.

f. Hazard Disposition – The status of a hazard after controls are in place. Hazard Dispositions are utilized in this analysis, documented at the bottom of each hazard analysis worksheet, to supplement the risk assessment codes and to further describe the control or status of the hazard. The disposition criteria are defined as follows:

Open / No action – A hazard exists in the system, and no controlling equipment or procedures have been implemented to minimize the hazard

Closed/Controlled – A hazard exists in the system, and appropriate mechanical/electrical procedural actions have been taken to reduce the hazard to a minimal level

Closed/Eliminated – A hazard that is no longer in the system because it has been eliminated

Closed/Accepted – A hazard of RAC 2 or 3 after controls whose risk has been accepted by NASA management.

g. Hazard Summary – A list of the hazard categories with before and after control RACs.

h. Verification – The validation method or process that confirms the hazard control. Verifications of the hazard controls are identified via review of test procedures, equipment operating instructions and checklists, test system drawings and schematics, personnel training records, applicable JSC, EA, Division and Branch work instructions and operating procedures, inspection of test equipment/area and interviews with facility engineers, technicians, test directors, and management.

i. Hazard Analysis Work Sheet (HAWS) – The Form which documents the system or process that is being analyzed, the system location, hazard description, before and after controls RACs, causes, controls, verifications and disposition status.

j. The RAC matrix is defined as follows:

	LIKELIHOOD ESTIMATE				
CONSEQUENCE CLASS	A	B	C	D	E
I	1	1	2	3	4
II	1	2	3	4	5
III	2	3	4	5	6
IV	3	4	5	6	7

k. The table below specifies the required action(s) for each RAC:

RAC	Action
1	Unacceptable – All operations must cease immediately until the hazard is corrected or until temporary controls are in place and permanent controls are in work. A safety or health professional must stay at the scene at least until temporary controls are in place. RAC 1 hazards have the highest priority for hazard controls.
2	Undesirable – All operations must cease immediately until the hazard is corrected or until temporary controls are in place and permanent controls are in work. RAC2 hazards are next in priority after RAC1 hazards for control. Program Manager (Directorate Level), Organizational Director, or equivalent
3	Acceptable with Controls – Division Chief or equivalent management is authorized to accept the risk with adequate justification

4-7	Acceptable with Controls – Branch Chief or equivalent management is authorized to accept the risk with adequate justification

A APPLICABLE DOCUMENTS

Document Number	Revision	Date	Document Title
192-120102N15			Compax3S Installation Manual
88-022337-01G			ACR9000 Series Hardware Installation Guide
AWI 1.11	Rev. B	Apr. 2016	Active Response Gravity Offload (ARGOS) Training Work Instruction
AWI 1.14	Rev M.4	Oct 2017	Gen2 ARGOS Operating Procedure for Facility Operation
AWI 1.30	C	May 2016	Active Response Gravity Offload System (ARGOS) Maintenance Plan
AWI 1.31	Baseline	May 2016	ARGOS Lockout Tagout Plan
EA-WI-017	Rev. A	May 2007	Engineering Directorate Control of Hazardous Energy (Lockout Tagout) Process
ESCG-4450-10-STAN-DOC-0032			ARGOS Eyebolt Assessment
ESCG-4450-10-STAN-DOC-0064			Strength Assessment of Heavy Lift Z-Axis Assembly
ESCG-4450-12-STAN-DOC-0067			Strength and Fracture Assessment of the Versatile Neutral Capability Horizontal Interface (VNCHI) Gimbal Assembly of the ARGOS
ESTA-TH-7B198	Baseline	4/9/2015	EDU Bank Build and Test
http://irb.nasa.gov/			IRB Web Page
JETS-JE32-13-SMA-DOC-0013	Rev. B		Strength Assessment of the ARGOS EMU Gimbal Assembly
JETS-JE32-14-SMA-DOC-0105			Strength Assessment of the ARGOS Gen2 Unsuited Gimbal (ARGOSGUE500)
JETS-JE32-14-SMA-DOC-0111			Strength Assessment of the ARGOS VNCHI Gimbal Assembly (ARGOSHGE710)

JETS-JE32-15-SMA-DOC-0013A			Strength Assessment of the ARGOS Top Level Y-Axis Assembly (ARGOSYAE552)
JETS-JE32-15-SMA-DOC-0036			Strength Assessment of the ARGOS Gen2B Hoist Assembly (ARGOSZAE600)
JPR1700.1	Rev. K	Nov. 2013	JSC Safety and Health Handbook
SRSD-16-007	Rev. D	October 2017	Integrated Hazard Analysis for EMU in ARGOS

B ACRONYMS

ACFM	Actual Cubic Feet per Minute
ARGOS	Active Response Gravity Offload System
ATP	Acceptance Test Procedure
AWI	ARGOS Work Instruction
BACC	Breathing Air Compressor Cart
COTS	Commercial Off The Shelf
dB	Decibel
EMU	Extravehicular Mobility Unit
ESTA	Energy Systems Test Area
EVA	Extravehicular Activity
FMEA	Failure Modes and Effects Analysis
FOD	Foreign Object Debris
GSE	Ground Support Equipment
HA	Hazard Analysis
HUT	Hard Upper Torso
IRB	Institutional Review Board
JSC	Johnson Space Center
LTA	Lower Torso Assembly
MAWP	Maximum Allowable Working Pressure

MLI	Multi Layer Insulation
NASA	National Aeronautics and Space Administration
NBL	Neutral Buoyancy Laboratory
NFPA	National Fire Protection Association
PPE	Personal Protective Equipment
PSID	Pounds per square inch, Differential
PSIG	Pounds per Square inch, Gage
PTC	Passive Thermal Control
QD	Quick Disconnect
RAC	Risk Assessment Code
RITF	Receiving Inspection and Test Facility
SAR	System Acceptance Review
SRSD	Software, Robotics, and Simulation Division
TRR	Test Readiness Review
UND	University of North Dakota
VNCHI	Versatile Neutral Capability Horizontal Interface
WAD	Work Authorizing Document

6.0 HAZARD SUMMARY

#	Potential Hazard	Subsystem	Severity/Probability/RAC	
			Before Controls	**After Controls**
1	Test Subject Discomfort/Injury	Hexoskin Smart Shirt	1/C/3	I/C/4
3	Electrical Hazards	BIOPAC MP150 System	II/D/4	II/E/5

Appendix A - HAZARD ANALYSIS WORKSHEETS

Appendix A – Integrated Hazard Analysis for Electromyography and Motion Capture Systems in ARGOS

ARGOS HAZARD ANALYSIS WORKSHEET

Title Test Subject Discomfort/Injury		**No.** 1	**Date** October 2017	
System	**Subsystem** Hexoskin Smart Shirt	**Severity/Probability/RAC Before Hazard Controls** II/C/3	**Severity/Probability/RAC After Hazard Controls** II/D/4	

Hazard Description:
Testing activities that leads to the test subjects discomfort or injury including, dizziness, nausea, headaches, orthostatic intolerance and unconsciousness.

Hazard Causes:
1. 1 Test subject physical condition
2. Test subject anxiety or overexertion
3. Improper thermal regulation

Hazard Control:
1a. Test subject will be selected based on specific physical characteristics and requirements.
1b. Subject will be monitored during all testing phases for physical or emotional discomfort by specified team members and the project leader.
1c. The project leader will be directing the test subject during testing and will maintain open communication.
1d. Medical assistance plan to deal with urgent situations will be taught and discussed with all team members.
2a, 3a. Subjects are actively monitored by specific team members at all times for physical and emotional discomfort.
2b. Subjects will be wearing Hexoskin Smart Shirt as a monitoring device for heart and breathing rates.
2c. Open communication between test subject, project leader, and team are maintained at all times.
2d. Subject will have time prior to testing to familiarize with ARGOS movement.
3b. Heart rate will remain below 85% of max while testing procedure are under way.

Additional Hazard Control Constants:
- Subject can terminate the test at any time as per AWI 1.14 Section 7.
- Testing will be terminated if any parameters fall below acceptable levels for testing as per AWI 1.14 Section 7 and UND 1.1 Section 3.5.

Hazard Control Verifications:
1a. These requirements are outlined by the NASA IRB guidelines and Test Subject Selection criteria on exercise protocol.
1b. UND 1.1 Test Plan, AWI 1.1
1c. UND 1.1 Test Plan Section 4.1, 4.2
1d. UND 1.1, AWI 1.14 Section 9.4 and 9.7
2a, 3a . UND 1.1 Test Plan Section 3.3
2b. UND 1.1 Test Plan Sections 1.3, 4.5
2c. UND 1.1 Test Plan, AWI 1.14 section 7.

2d. UND 1.1 Test Plan Section 4.6
3b. UND 1.1 Test Plan Section 3.5

Remarks:
- The Hexoskin Smart Shirt is a wireless COTS telemetric data device that can be worn under the subject's clothing and cooling devices.

Hazard Disposition: Closed/Accepted

Appendix A – Integrated Hazard Analysis for Electromyography and Motion Capture Systems in ARGOS

ARGOS HAZARD ANALYSIS WORKSHEET

Title	**No.**	**Date**
Electrical Hazards	3	October 2017

System	**Subsystem**	**Severity/Probability/RAC Before Hazard Controls**	**Severity/Probability/RAC After Hazard Controls**
	BIOPAC MP150 System and Hexoskin Smart Shirt	II/D/4	II/E/5

Hazard Description:
Exposure to electrical current resulting in personal injury and hardware damage.

Hazard Causes:

1. Electromyography system component failure
2. Facility electrical failure
3. Test support hardware electrical failure

Hazard Control:
1a. The electromyography system is inspected and tested prior to use per the BIOPAC MP150 System Product Sheet.
1b. The power supplied to the electromyography unit is in a low voltage application (10V) and conforms to Low Voltage Directive 73/23/EEC and 2014/35/EU following EN 60950-1 Standards.
1c. Electromyography system is created by company that conforms to ISO 9001:2008 standards
2a. Facility power has a circuit breaker and is grounded.
2b. Electrical components and terminals are not exposed under normal conditions.
2c. Electrical systems have been worked on and manipulated by qualified personnel and inspected prior to use and testing will be terminated if these standards are not met
3a. Support hardware will be functionally tested prior to use.
3b. Systems are powered off during connection and disconnection times.

Additional Hazard Control Constants:
- Project leader and testing team are trained and practiced in emergency egress scenarios.
- Subject will be monitored by project leader and testing team at all times during the test.
- Emergency procedures and safety briefings are provided prior to the commencement of any testing.
- ARGOS Personnel are trained in emergency procedures AWI 1.14.

Hazard Control Verifications:
1a.UND 1.1 Section 4.4
1b. UND 1.1 Section 2.1, BIOPAC MP150 EC Declaration of Conformity, BIOPAC MP150 Hardware specifications sheet
1c. UND 1.1 Section 2.1, ISO Certification document # 45311-IS2
2a, b. AWI 1.14, section 3
2c. AWI 1.14
3a. UND 1.1, AWI 1.14
3b. UND 1.1 Section 4

Remarks:
BIOPAC MP150 system, Hexoskin units and all related equipment are COTS.

Hazard Disposition: Closed/Accepted

APPENDIX B: NASA Informed Consent Form

NASA INSTITUTIONAL REVIEW BOARD (IRB)
CONSENT TO BE A PART OF A RESEARCH STUDY

NOTE: Any alterations to this consent document will invalidate the test subjects' consent unless the changes are approved in advance by the IRB.

ABOUT THIS RESEARCH CONSENT FORM

You may be eligible to take part in a research study.

A research study is carefully planned and designed to increase scientific knowledge.

This NASA IRB Consent form describes important information related to participation in a research study including the purpose, planned procedures, and potential risks.

Please take time to review this information carefully. Talk to the researchers about the study and ask any questions you have. **Make sure you fully understand what will be expected of you and the risks associated with participating in this study.** You may also wish to talk to others (for example, your friends, family, or doctors) about your participation in this study. If and when you decide to be a participant, you will be asked to sign this form and you will be given a copy.

Taking part in this study is completely **voluntary**. The decision to participate is yours. You may also leave the study at any time. If you leave the study before it is finished, there will be no penalty to you.

This NASA IRB Consent form provides a detailed description regarding essential information including, but not limited to, **how, when, where**, and **by whom** a signed informed consent will be obtained.

Note: Failure to disclose pre-existing medical conditions may place you at greater risk for injury or other adverse events resulting from your participation in this study.

1. GENERAL INFORMATION

1.1 Your study title is: **Effects of locomotor gaits under simulated reduced gravity conditions on muscles of the leg**

1.2 Your study team includes a Principal Investigator, Co-Investigator, Key-Personnel (names, degrees, affiliations):

PI: Sophie Orr, University of North Dakota
B.S. Anthropology
Currently a M.S. Space Studies Student at the University of North Dakota
Co-Investigator: Pablo de Leon, University of North Dakota
PhD History (Science and Technology)
B.S. Aeronautical Engineering

Key-Personnel:
Jesse Rhoades, University of North Dakota
PhD Pedagogical Kinesiology,
M.S. in Exercise Science (Biomechanics)
B.S in Physical Education,
Paul Valle, NASA Johnson Space Center
ARGOS Project Manager
B.S. in Mechanical Engineering

1.3 This study is sponsored or funded by: **The University of North Dakota Department of Space Studies**

2. PURPOSE OF THIS STUDY (History and Background)

2.1 You are being asked to join this study because:

You are invited to be in a research study about the effect of simulated gravity on the locomotion patterns of humans, as well as the impact of such locomotion on muscles of the leg. You have been chosen because you meet the basic selection criteria needed to fit the equipment associated with this study and are available during the testing schedule.

The purpose of this experiment is to suggest a preferred locomotion method to train astronauts in for future trips to the moon and Mars. The result of this study will help reduce the possibility of harmful training or a misunderstood aspect of living in fractional gravity. This is in line with the risk reduction strategy for performance effects put forth in NASA's Human Research Roadmap. This study will serve as a basis for future research.

3. STUDY PARTICIPANTS

3.1 In order to be eligible to participate, you may be asked to undergo the following screening tests or procedures:

Screening physicians will evaluate subject eligibility for exercise protocols based on age, fitness level, and history of pre-existing medical conditions or other pertinent other medical history.

Failure to disclose pre-existing medical conditions may place them at greater risk for injury or other adverse events resulting from participation in the study.

This study requires physical exercise on a treadmill with speeds up to 6 miles per hour. To ensure the health and safety of the test subjects the following criteria apply:

- Must be able to complete exercise requirements of this study listed in this document.
- BMI lower than 30
- BMI higher than 19
- No recent smoking history
- No history of lower back pain
- No history of Achilles tendinitis

3.2 You are one of 6 Subjects.

4. STUDY PROCEDURES

4.1 The checked boxes below indicate that you will be informed and/or provided the following:

_x__ Chart or calendar as a possible addition to the explanation of the tests;

_x__ Duration of the study, and when the study is completed;

_x__ Amount of time for each test, frequency of testing, and whether testing is continuous or intermittent;

___ Need for follow-up examinations or tests;

_x__ Location of the testing;

___ The amount of blood, urine, saliva, other biological samples and/or tissue to be taken and how often;

_x_ Detailed explanation of each test, including what data will be collected;

_x_ Whether joining this study limits your chance to join other studies;

_x_ Whether "standard" medical procedures are included in the study;

_x_ How your other activities may be affected by the study (exercise, diet, medications, physical activities, etc.).

_x__ **Check here if Section 4.2 is Not Applicable**

4.2 You are being told if the study you are joining includes one of the following categories:

___ *"Randomized"* means that you are put into a group by chance (e.g., like flipping a coin). Neither you nor the principal investigator will choose what group you will be in. You will have a chance of being placed in any group.

___ *"Blinded"* means you (blinded) will not know what group you are in.

___ *"Double-Blinded"* means that neither you nor the Principal Investigator (double-blinded) will know what group you are in.

___ *"Placebo"* means a pill with no medicine. In a placebo-controlled study, you may be given a study medication and it will contain either (name of drug) or placebo (pills with no medicine).

___ *"Observational"* means a chart or record-based study that examines previously collected data.

4.3 Study description
This study will occur at Johnson Space Center in Houston, TX

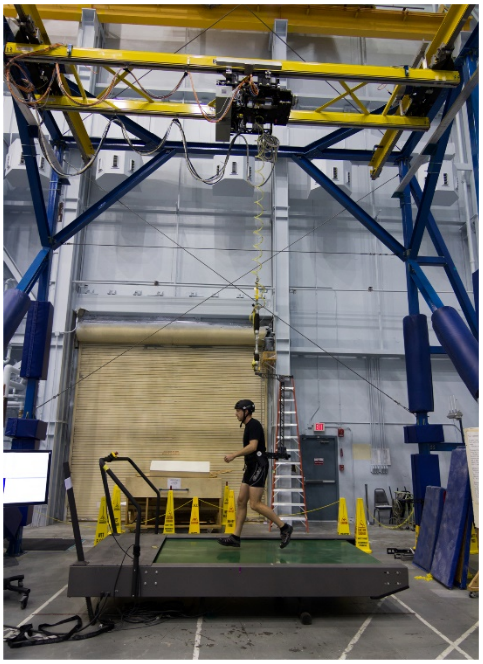


***Figure 1**. ARGOS (Active Response Gravity Offload System). The ARGOS is designed to simulate reduced gravity environments, such as on the Moon or Mars, and can even simulates microgravity (free floating) conditions.*

The PI will go over study procedures and all items covered in this document. You will be given the chance to ask questions about the procedure, and will be asked to sign this informed consent form. Once you have signed the informed consent form, testing will be scheduled.

Experiment Test at Johnson Space Center
This study will take place at Johnson Space Center. You will be connected to the ARGOS via a gimbal and harness system, where you will walk, run and skip on a treadmill at different speeds. The tests will be repeated for different simulated gravity levels (Lunar and Martian gravity), totaling 3 runs per subject. The duration of testing is 1 minute per speed with the last 10 seconds of each speed for analysis. This will allow you to get used to the speed with the system setup to reduce noise in the data. This will be repeated several times to reduce noise in the data. Total time for testing is approximately 90 minutes.

***Figure 3.** BIOPAC MP150 System. This is hardware used to collect data about the human body for research purposes. It can have different types of attachments, with this experiment utilizing the EMG100C unit that collects electromyography data.*

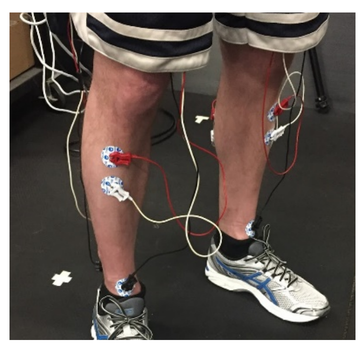


***Figure 4.** EMG Electrode Placement. The electrodes will be placed on the front and back of the lower leg to collect data about your muscle activity.*

During testing:

You will be connected to the BIOPAC MP150 data acquisition and analysis system [See Figure 3] with the EMG100C Electromyogram Amplifier attachment. The EMG100C amplifies general and skeletal muscle electrical activity, a process known as "electromyography" or EMG. The connection points will be electrodes that effectively senses muscle activation and send the signal to the EMG100C amplifiers, which then integrates with the main MP150 unit. These electrodes only receive signals; they do not emit signals to you. Placement of these electrodes will be on the shin and the calf of both legs [See Figure 4]. The electrodes have a sticker build into them, and conductive gel will also be used to ensure signal strength. You will be asked to remove hair from the areas of skin that will have the electrodes attached to them. You can do this yourself or the PI will shave the areas for you. Specialized tape will be used to ensure electrodes do not move during movement during testing.

In addition to the BIOPAC system, the motion capture camera system will be employed during testing. This consists of several motion capture cameras that will map your movement by receiving light reflected from reflective markers placed on key points of your body. Each test will be recorded and then the data will be uploaded to the Ariel Performance Analysis System (APAS) which will allow for analysis of gait alterations between tests.

The electrodes will remain on you between testing runs, as electrode movement would be possible. You are expected to be available for your allotted testing time, but are not required to be present for tests of the other subjects if your schedule does not allow for it The data collected, including electromyography and 3d motion capture data, will be used in Sophie Orr's master's thesis. This experiment will involve videotaping, photography and interviews in order to allow a full picture of the experiment process be available to interested parties and available for use in the written thesis document. Finally, experiments and activities that occur at UND and/or at NASA facilities are used for UND/NASA public relation stories. This includes, but is not limited to, UND/NASA websites, news sources and social media accounts. The sharing of your video, photos and quotes helps spread the work about this research and the institutions that help make it possible.

5. DRUGS, BIOLOGICS, and MEDICAL DEVICES

_x_ **Check here if Section 5.1 is Not Applicable**

5.1 You will be told if the study uses drugs, blood or blood components, allergenic substances, vaccines, medical devices or other similar products used to investigate human anatomy or physiology, or to prevent or treat disease or injury.

Is a study drug or biologic used?

___ No

___ Yes, the study drug or biologic is ________________________________.

___ This drug or biologic is FDA approved.

___ This is an investigational drug or biologic, with the FDA IND number: __________________________________.

Is a study medical device used?

___ No

___ Yes, the study medical device is ___________________.

___ This medical device is FDA approved.

___ This is an investigational medical device, with the FDA IDE number ___________________________________.

___ This is an investigational non-significant risk device, with IRB approval for use. A document providing full and informed disclosure is provided for your review.

6. INFORMATION ABOUT RISKS AND HAZARDS

6.1 You are joining a study that is:

___ "Minimal risk" means that the probability and magnitude of harm or discomfort anticipated in the research is not greater in and of themselves than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests.

_x_ "Greater than minimal risk" means that the probability and magnitude of harm or discomfort anticipated in the research is greater in and of themselves than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests, but that the risks of harm or discomfort are considered to be acceptable when weighed against the anticipated benefits and the importance of the knowledge to be gained from the research.

6.2 You are told that the risks of joining the study and the steps taken to protect against harm include:

- The ARGOS system and test winch system will suspend you from the ground. While the suspension is minimal (these tests are focused on the individuals being able to physically touch the ground), a fall is possible. To mitigate the risk of this occurring, you will be closely monitored for the entire time you are secured into any system related to the study in case unforeseen circumstances arise.
- You will be running on a treadmill, where you could trip and fall off of the treadmill. You will, however, be suspended, which could mitigate the chance of falling off the treadmill. To further mitigate chances of this occurring, treadmill speeds will be within normal walking and running speeds. You will also be closely monitored for the entire time you are secured into any system related to the study in case unforeseen circumstances arise.
- The EMG equipment in use is a non-invasive research grade biological sensing device. It is possible that the gel or stickers used to attach the device to the skin might cause mild discomfort (similar to putting a piece of tape or sticker on the skin). To mitigate the risk of this occurring shaving the areas where the adhesives will contact the skin.
- As with any physical exercise, you may experience some physical injuries. These are expected to be mild and any severe injury will end the study and immediate medical attention will be supplied. Some possible injuries during this study may include minor cuts, minor bruising, headaches, nausea, dizziness, fatigue, or other unforeseen minor injuries. To mitigate the possibility of any injury, treadmill speeds will be within normal walking and running speeds and will not exceed speeds above those associated with moderate exercise. You will also be closely monitored for the entire time you are secured into any system related to the study in case unforeseen circumstances arise. Subjects must also pass certain physical requirements to participate in research, further mitigating the chances of this occurring.

  During this study you may be seen by bystanders, causing an unintended breach in privacy. JSC is a government facility, and as such the key personnel of this study do not have the ability to determine who will be at the facility during testing time, nor will the key personnel know who else will be in the facility before, during or after the tests. You may contact the PI, Sophie Orr, at any time with concerns and if needed the PI will assist and fund the participant in locating counseling service to discuss your concerns.
- Electric shock from the BIOPAC MP150 system is possible though extremely unlikely. To mitigate this hazard the hardware will be tested in compliance with the hardware user manual prior to testing.

6.3 You are told that the hazards and the steps used to minimize the hazards include:

- The ARGOS system and test winch system will suspend you from the ground. While the suspension is minimal (these tests are focused on the individuals being able to physically touch the ground), a fall is possible. To mitigate chances of this occurring, you will not be suspended higher than is required to simulate the gravity levels being assessed in this study.
- You will be running on a treadmill, where you could trip and fall off of the treadmill. You will, however, be suspended, which could mitigate the chance of falling off the treadmill. To mitigate chances of this occurring, treadmill speeds will be within normal

walking and running speeds. You will be allowed to familiarize yourself with movement while connected to the ARGOS gimbal and harness.

- The EMG equipment in use is a non-invasive research grade biological sensing device. It is possible that the gel or stickers used to attach the device to the skin might cause mild discomfort (similar to putting a piece of tape or sticker on the skin). This will be mitigated by shaving the areas where the adhesives will contact the skin, reducing adhesion points that could cause discomfort.
- As with any physical exercise, you may experience some physical injuries. These are expected to be mild and any severe injury will end the study and immediate medical attention will be supplied. Some possible injuries during this study may include minor cuts, minor bruising, headaches, nausea, dizziness, fatigue, or other unforeseen minor injuries. To mitigate the possibility of any injury, treadmill speeds will be within normal walking and running speeds and will not exceed speeds above those associated with moderate exercise.
- During this study you may be seen by bystanders, causing an unintended breach in privacy. JSC is a government facility, and as such the key personnel of this study do not have the ability to determine who will be at the facility during testing time, nor will the key personnel know who else will be in the facility before, during or after the tests. You may contact the PI, Sophie Orr, at any time with concerns and if needed the PI will assist and fund the participant in locating counseling service to discuss your concerns.

_x__ **Check here if Section 6.4 is Not Applicable**

6.4 You are told if you are flying as part of the Reduced Gravity Parabolic Aircraft and informed of the following information:

___ "Since the Reduced Gravity Parabolic Flight Aircraft and other NASA sponsored aircraft are considered to be public aircraft within the meaning of the Federal Aviation Act of 1958, as amended, and as such do not hold a current airworthiness certificate issued by the Federal Aviation Administration, any individual manifested to board the Reduced Gravity Parabolic Flight Aircraft or other NASA sponsored aircraft should determine before boarding whether their personal life or accident insurance provides coverage under such condition."

7. TREATMENT, INJURY AND COMPENSATION INFORMATION

7.1 Even though researchers have taken steps to minimize the risks, you may experience problems or side effects. In the event of physical injury resulting from this study, NASA will provide or cause to be provided, the necessary immediate action or treatment. NASA will pay for any claims of injury, loss of life or property damage to the extent required by the Federal Employees Compensation Act or the Federal Tort Claims Act. Your agreement to participate shall not be construed as a release of NASA or any third party from any future liability, which may arise from, or in connection with, the test procedures.

_x_ **Check here if Section 7.2 is Not Applicable**

7.2 For International Partner subjects**:**

___ In the event of injury resulting from this study, I understand that I will receive medical attention and available treatment. I also understand that I will be compensated for any injuries to the extent permitted under current **__(insert agency name)__** laws and regulations and the provisions of the contract between me and **(insert agency name)__** . My agreement to participate shall not be construed as a release of **(insert agency name)____** or any third party liability which may arise from, or in connection with, the above procedures.

___ Include the HRMRB Multinational consent form

8. BENEFITS INFORMATION

8.1 Participation in NASA studies generally result in no direct benefit to you as an individual. It is hoped that the information learned from this research study will help NASA learn more about human physiological and psychological changes for future space flight missions.

9. NEW FINDINGS

9.1 If new information is obtained during the study after you have joined, you will be informed. You may change your mind about continuing in the study. You may be asked to sign a new consent form that includes the new information.

10. STUDY WITHDRAWAL and/or TERMINATION

10.1 You may withdraw from the study at any time. If you decide to leave before the study is finished, please tell the investigator or study staff. Your refusal will be honored, except in cases when the responsible physician's opinion is that study termination could have undesired consequences for your health and/or the health of other subjects. You will be told if there could be any harm to you if you decide to leave before the study is finished. If you tell the researchers your reasons for leaving the study, that information will be part of the study record.

10.2 Your withdrawal or refusal to participate in the study will not result in any penalty or loss of benefits to which you are otherwise entitled.

10.3 If you decide not to join the study, you may be eligible to participate in other studies.

10.4 Researchers may need to stop your participation in the study even if you want to continue participation. Some examples of this scenario include: (Check applicable boxes)

_x_ The researcher believes that it is not in your best interest to stay in the study

_x_ There is any problem with following study related instructions

___ There is any problem with following hospital, clinic, or laboratory policies and procedures

_x_ There is any serious complication during the study

_x_ There is inappropriate behavior

_x_ The study is suspended or canceled

_x_ The subject's information is or becomes unusable for any reason

_x_ Events beyond NASA's control occur, for example: fire, explosion, disease, weather, floods, terrorism, wars, insurrection, civil strife, riots, government action, or failure of utilities

___ Existing data reveal answers earlier than expected

11. COST and FINANCIAL INFORMATION

11.1 There are no costs or bills to you for participation in this study.

12. PAYMENT and REIMBURSEMENT

___ **Check here if Section 12.1 is Not Applicable**

12.1 You will be paid to participate in the study as follows:

___ Is the total dollar amount for the study, including pro-rating (if you do not complete the study or if there is a bonus payment at the end of the study).

_x_ No payment if you are a NASA, non-NASA, federal civil servant employee, contractor, or International Partner crewmember participating in ESA, JAXA, CSA, or NASA-sponsored studies.

13. SUBJECT RECORD CONFIDENTIALITY AND AUTHORIZATION TO RELEASE PROTECTED HEALTH INFORMATION (PHI)

13.1 Your privacy and the confidentiality of data collected as a part of this research study will be protected from unauthorized disclosure according to applicable federal law.

13.2 Your protected health information may be used or shared with others during the research. This may include:

- Existing medical records;
- Video and photographic materials;
- New information created from study-related tests, procedures, visits, and/or questionnaires.

13.3 Your protected information may be used or shared by NASA offices of research oversight or quality assurance, medical monitors, and researchers for the reasons below:

- To conduct and oversee the research;
- To make sure the research meets NASA requirements;
- To conduct monitoring activities (including situations where you or others may be at risk of harm or reporting of adverse events);
- To become part of your medical record, if necessary, for your medical care;
- To review the safety of the research.
- To support "NASA Clinical Summit" activities where clinical experts evaluate relevant medical and research data to recommend clinical practice guidelines specifically for astronauts. These data will not include names or other information that explicitly link the information to you.

13.4 Every effort will be made to maintain the confidentiality of your study records. There are many reasons why information about you may be used or seen by the researchers or others during or after this study. Examples include:

- The researchers may need the information to make sure you can take part in the study.
- NASA and other government officials may need the information to make sure that the study is done in a safe and proper manner. These agencies may include the Department of Health and Human Services (DHHS), the Food and Drug Administration (FDA), the National Institutes of Health (NIH), and/or the Office for Human Research Protections (OHRP) or other domestic or foreign government bodies if required by law and/or necessary for oversight purposes.

- The FDA may need to review the information if the study involves the use of an experimental drug or device.
- Safety monitors, medical personnel, or safety committees may review your research data and/or medical records for the purposes of medical safety or for verification of research procedures.
- A data and safety monitoring board (DSMB) may oversee the research, if applicable.
- The results may be used by the research team and possibly be presented/published at scientific conferences and/or in an article, but would not include information that would identify you without your consent.

13.5 You have the right to withdraw your consent for the researchers to use or share your protected health information. The researchers will not be able to withdraw all the information that already has been used or shared with others to carry out related activities such as oversight, or to ensure quality of the study. To withdraw your consent, you must do so in writing by contacting the researcher.

13.6 You have the right to request access to your study records after the study is completed. To request this information, you must do so in writing by contacting the researcher.

13.7 If physiologic data (including but not limited to standard measures, laboratory data, psychological, or physiological measurements) are obtained from you for this study, they may become the property of NASA's Life Science Data Archive. These data may be used in this research, may be used in other research, and may be shared with other organizations. All federal regulations concerning the privacy and confidentiality of these data will be followed. Records stored in this archive will not include names, registration numbers, or other information that explicitly links the information to you.

14. CONTACT INFORMATION

14.1 You may contact the Principal Investigator to:

- Obtain more information about the study;
- Ask a question about the study procedures;
- Report an illness, injury, or other problem;
- Leave the study before it is finished;
- Express a concern about the study.

Principal Investigator and Study Coordinator: Sophie Orr

Email Address: Sophie.orr@und.edu

Mailing Address:

Department of Space Studies

Clifford Hall, Room 512

4149 University Ave Stop 9908

Grand Forks, ND 58202-9008

Phone: (65070 799-5638

Study Co-Investigator and Faculty Advisor: Pablo de Leòn

Email Address deleon@space.edu

Mailing Address: Department of Space Studies

Clifford Hall, Room 512

4149 University Ave Stop 9908

Grand Forks, ND 58202-9008

You may express a concern about this study by contacting the NASA JSC Institutional Review Board (IRB) listed below:

Office of Research Assurance: Research Integrity & Protection of Human Subjects

2101 NASA Parkway

Mail Code SA

Houston, Texas 77058

Telephone: (281) 204-1650

E-mail: NASA-IRB@nasa.gov

15. RECORD of INFORMATION PROVIDED

15.1 Your signature in the next section means that you have received copies of all of the following documents:

___ This NASA IRB "Consent to be Part of a Research Study" document

___ Other (specify): ________________________________

16. SIGNATURES

___ **Check here if the study will NOT utilize video, audio or still photography**

Video, Audio, and Photo:

I understand that this study will utilize video and/or still photography to analyze study results and I consent for the use of these materials.

___ I accept

___ I do not accept

Signature: ______________________________

I give consent for my quotes to be used for this study; however, I will not be identified.

___ I accept

___ I do not accept

Signature: ______________________________

Research Subject:

I understand the information printed on this form. I have discussed this study, its risks and potential benefits, and my other choices with __________________________. My questions so far have been answered. I understand that if I have more questions or concerns about the study or my participation as a research subject, I may contact the study team. I understand that I will receive a copy of this form at the time I sign it and later upon request.

Signature of Subject: ___________________________________ Date: ________________

Name (Print legal name): ____

Principal Investigator (or Designee):

I have given this subject information about this study. I believe this to be accurate and complete. The subject has indicated that he or she understands the nature of the risks and benefits of participating in this study.

Name: Sophie Orr Title: Principal Investigator

Signature: __________________________________ Date: ____________________________

Witness (optional):

I observed the above subject sign this consent document.

Name: ________________________________

Signature: ____________________________ Date: _________________________

APPENDIX C: UND Informed Consent Form

THE UNIVERSITY OF NORTH DAKOTA
CONSENT TO PARTICIPATE IN RESEARCH

TITLE: Effects of locomotor gaits under simulated reduced gravity conditions on muscles of the leg

PROJECT DIRECTOR: Sophie Orr

PHONE: (650) 799-5638

DEPARTMENT: Space Studies

STATEMENT OF RESEARCH

A person who is to participate in the research must give his or her informed consent to such participation. This consent must be based on an understanding of the nature and risks of the research. This document provides information that is important for this understanding. Research projects include only subjects who choose to take part. Please take your time in making your decision as to whether to participate. If you have questions at any time, please ask.

WHAT IS THE PURPOSE OF THIS STUDY?

You are invited to be in a research study about the effect of simulated gravity on the locomotion patterns of humans, as well as the impact of such locomotion on muscles of the leg. You have been chosen because you meet the basic selection criteria needed to fit the equipment associated with this study and are enrolled as a graduate student within the John D. Odegard School of Aerospace Sciences.

The purpose of this experiment is to suggest a preferred locomotion method to train astronauts in for future trips to the moon and Mars. The result of this study will help reduce the possibility of harmful training or a misunderstood aspect of living in fractional gravity. This is in line with the risk reduction strategy for performance effects put forth in NASA's Human Research Roadmap. This study will serve as a basis for future research.

HOW MANY PEOPLE WILL PARTICIPATE?

Approximately three people will take part in this study at the University of North Dakota and NASA's Johnson Space Center in Houston, TX.

HOW LONG WILL I BE IN THIS STUDY?

Your participation in the study will last approximately 3 hours total time.

WHAT WILL HAPPEN DURING THIS STUDY?

This study will take place at Johnson Space center in Houston, TX.

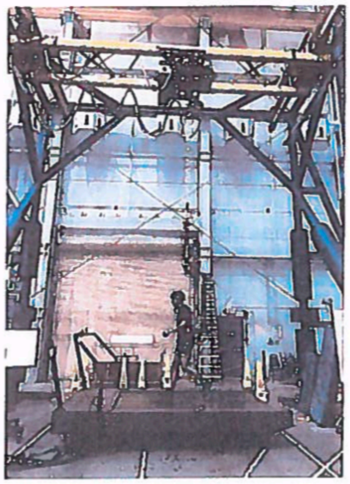


Figure 1. ARGOS (Active Response Gravity Offload System). The ARGOS is designed to simulate reduced gravity environments, such as on the Moon or Mars, and can even simulates microgravity (free floating) conditions.

The PI will go over study procedures and all items covered in this document. You will be given the chance to ask questions about the procedure, and will be asked to sign this informed consent form. Once you have signed the informed consent form, testing will be scheduled.

Experiment Test at Johnson Space Center

This study will take place at Johnson Space Center. You will be connected to the ARGOS via a gimbal and harness system, where you will walk, run and skip on a treadmill at different speeds. The tests will be repeated for different simulated gravity levels (Lunar and Martian gravity), totaling 3 runs per subject. The duration of testing is 1 minute per speed with the last 10 seconds of each speed for analysis. This will allow you to get used to the speed with the system setup to reduce noise in the data. This will be repeated several times to reduce noise in the data. Total time for testing is approximately 90 minutes.

During testing:

You will be connected to the BIOPAC MP150 data acquisition and analysis system [See Figure 3] with the EMG100C Electromyogram Amplifier attachment. The EMG100C amplifies general and skeletal muscle electrical activity, a process known as "electromyography" or EMG. The connection points will be electrodes that effectively senses muscle activation and send the signal

Approval Date: FEB 15 2018
Expiration Date: OCT 10 2018
University of North Dakota IRB

to the EMG100C amplifiers, which then integrates with the main MP150 unit. These electrodes only receive signals; they do not emit signals to you. Placement of these electrodes will be on the shin and the calf of both legs [See Figure 4]. The electrodes have a sticker build into them, and conductive gel will also be used to ensure signal strength. You will be asked to remove hair from the areas of skin that will have the electrodes attached to them. You can do this yourself or the PI will shave the areas for you. Specialized tape will be used to ensure electrodes do not move during movement during testing.

Figure 3. BIOPAC MP150 System. This is hardware used to collect data about the human body for research purposes. It can have different types of attachments, with this experiment utilizing the EMG100C unit that collects electromyography data.

Figure 4. EMG Electrode Placement. The electrodes will be placed on the front and back of the lower leg to collect data about your muscle activity.

In addition to the BIOPAC system, the motion capture camera system will be employed during testing. This consists of several motion capture cameras that will map your movement by receiving light reflected from reflective markers placed on key points of your body. Each test will be recorded and then the data will be uploaded to the Ariel Performance Analysis System (APAS) which will allow for analysis of gait alterations between tests.

The electrodes will remain on you between testing runs, as electrode movement would be possible. You are expected to be available for your allotted testing time, but are not required to be present for tests of the other subjects if your schedule does not allow for it

The data collected, including electromyography and 3d motion capture data, will be used in Sophie Orr's master's thesis. This experiment will involve videotaping, photography and interviews in order to allow a full picture of the experiment process be available to interested

Approval Date: FEB 15 2018
Expiration Date: OCT 18 2018
University of North Dakota IRB

parties and available for use in the written thesis document. Finally, experiments and activities that occur at UND and/or at NASA facilities are used for UND/NASA public relation stories. This includes, but is not limited to, UND/NASA websites, news sources and social media accounts. The sharing of your video, photos and quotes helps spread the work about this research and the institutions that help make it possible.

WHAT ARE THE RISKS OF THE STUDY?

- The ARGOS system and test winch system will suspend you from the ground. While the suspension is minimal (these tests are focused on the individuals being able to physically touch the ground), a fall is possible. To mitigate chances of this occurring, you will be closely monitored for the entire time you are secured into any system related to the study in case unforeseen circumstances arise.
- You will be running on a treadmill, where you could trip and fall off of the treadmill. You will, however, be suspended, which could mitigate the chance of falling off the treadmill. To mitigate chances of this occurring, treadmill speeds will be within normal walking and running speeds. You will also be closely monitored for the entire time you are secured into any system related to the study in case unforeseen circumstances arise.
- The EMG equipment in use is a non-invasive medical grade biological sensing device. It is possible that the gel or stickers used to attach the device to the skin might cause mild discomfort (similar to putting a piece of tape or sticker on the skin). This will be mitigated by shaving the areas where the adhesives will contact the skin.
- As with any physical exercise, you may experience some physical injuries. These are expected to be mild and any severe injury will end the study and immediate medical attention will be supplied. Some possible injuries during this study may include minor cuts, minor bruising, headaches, nausea, dizziness, fatigue, or other unforeseen minor injuries. To mitigate the possibility of any injury, treadmill speeds will be within normal walking and running speeds and will not exceed speeds above those associated with moderate exercise. You will also be closely monitored for the entire time you are secured into any system related to the study in case unforeseen circumstances arise.
- During this study you may be seen by bystanders, causing an unintended breach in privacy. JSC is a government facility, and as such the key personnel of this study do not have the ability to determine who will be at the facility during testing time, nor will the key personnel know who else will be in the facility before, during or after the tests. You

may contact the PI, Sophie Orr, at any time with concerns and if needed the PI will assist and fund the participant in locating counseling service to discuss your concerns.

WHAT ARE THE BENEFITS OF THIS STUDY?

You may not benefit personally from being in this study. However, we hope that you might be able to include this on a resume or gain experience not normally found in academics. In the future other people might benefit from this study's data and create more viable training measures for future human planetary exploration.

WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

It will not cost you anything to be part of this study.

WILL I BE PAID FOR PARTICIPATING?

There is no compensation offered for this study.

WHO IS FUNDING THE STUDY?

This is a graduate level thesis project with North Dakota Space Grant Consortium funding.

CONFIDENTIALITY

The records of this study will be kept private to the extent permitted by law. In any report about this study that might be published, you will not be identified. Your study record may be reviewed by Government agencies and the University of North Dakota Institutional Review Board.

Any information that is obtained in this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by the Principal Investigator, Sophie Orr, and she will lock any paper data within locked cabinets stored in locked rooms. Data located on computers or files will be stored under password protection and these computers are located with locked offices. You will be given a coded identifier, and this identifier will be used on any and all data forms. The identifier key will be locked in the Human Spaceflight Laboratory. Only the Principal

Approval Date: FEB 15 2018
Expiration Date: OCT 18 2018
University of North Dakota IRB

Investigator, research advisors, and people who audit IRB files will have access to your data and any requests for access will be reviewed by the PI and UND's Institutional Review Board.

If we write a report or article about this study, we will describe the study results in a summarized manner so that you cannot be identified.

You have the right to review any of your written, collected, or recorded data prior to submission and may request access from the PI to your specific data after submission.

Though videos, photographs and quotes will be collected during the testing by key personnel and UND/NASA reporting agencies, data from the study will not be attributed to you in any way.

COMPENSATION FOR INJURY

In the event that this research activity results in an injury, treatment will be available including first aid, emergency treatment and follow-up care as needed. Payment for any such treatment is to be provided by you (you will be billed) or your third-party payer, if any (such as health insurance, Medicare, etc.) No funds have been set aside to compensate you in the event of injury. Also, the study staff cannot be responsible if you knowingly and willingly disregard the directions they give you.

IS THIS STUDY VOLUNTARY?

Your participation is voluntary. You may choose not to participate or you may discontinue your participation at any time without penalty or loss of benefits to which you are otherwise entitled. Your decision whether or not to participate will not affect your current or future relations with the University of North Dakota.

If you decide to leave the study early, we ask that you contact the PI so that she may perform a close out visit and ensure that you do have any concerns prior to leaving the study site.

If circumstances arise that threaten the safety of you or other participants the PI and study support crew have been trained on hazard detection and given instructions on when to terminate the study.

Approval Date: FEB 15 2018
Expiration Date: OCT 18 2018
University of North Dakota IRB

Appendix C – UND Informed Consent Form

CONTACTS AND QUESTIONS?

The researchers conducting this study is Sophie Orr. You may ask any questions you have now. If you later have questions, concerns, or complaints about the research please contact the PI Sophie Orr or her advisor Dr. Pablo de Leòn.

Sophie Orr:	(650) 799-5638	sophie.orr@und.edu
Pablo de Leòn:	(701)777-2369	deleon@space.edu

If you have questions regarding your rights as a research subject, you may contact The University of North Dakota Institutional Review Board at **(701) 777-4279.**

- You may also call this number about any problems, complaints, or concerns you have about this research study.
- You may also call this number if you cannot reach research staff, or you wish to talk with someone who is independent of the research team.
- General information about being a research subject can be found by clicking "Information for Research Participants" on the web site: http://und.edukesearch/resources/human-subjects/research-participants.cfm

I give consent to be audiotaped during this study.

Please initial: ______ Yes______ No

I give consent to be photographed during this study.

Please initial: ______ Yes______ No

I give consent for my quotes to be used; however I will not be identified.

Please initial: ______ Yes______ No

Approval Date: FEB 15 2018
Expiration Date: OCT 18 2018
University of North Dakota IRB

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

____________________________________ ________________________

Subjects Name Date

____________________________________ ________________________

Signature of Subject Date

I have discussed the above points with the subject or, where appropriate, with the subject's legally authorized representative.

____________________________________ ________________________

Signature of Person Who Obtained Consent Date

Approval Date: FEB 15 2018
Expiration Date: OCT 18 2018
University of North Dakota IRB

APPENDIX D: ANOVA Descriptives & Charts

Appendix D – ANOVA Descriptives & Charts

EMG Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
CH1W2	1.0	6	0.0119017	0.00240264	0.00098087	0.0093803	0.0144231	0.00827	0.01487
	2.0	6	0.0118967	0.00336430	0.00137347	0.0083661	0.0154273	0.00828	0.01810
	3.0	6	0.0130083	0.00574129	0.00234387	0.0069832	0.0190334	0.00657	0.02321
	Total	18	0.0122689	0.00387442	0.00091321	0.0103422	0.0141956	0.00657	0.02321
CH1R2	1.0	6	0.0217167	0.00943205	0.00385062	0.0118183	0.0316150	0.01259	0.03743
	2.0	6	0.0151267	0.00524365	0.00214071	0.0096238	0.0206295	0.00790	0.02351
	3.0	6	0.0108933	0.00466404	0.00190409	0.0059987	0.0157879	0.00555	0.01766
	Total	18	0.0159122	0.00785176	0.00185068	0.0120076	0.0198168	0.00555	0.03743
CH1S2	1.0	6	0.0240483	0.00863427	0.00352493	0.0149872	0.0331094	0.01086	0.03494
	2.0	6	0.0121650	0.00399277	0.00163004	0.0079748	0.0163552	0.00618	0.01841
	3.0	6	0.0093383	0.00658955	0.00269017	0.0024230	0.0162536	0.00441	0.02212
	Total	18	0.0151839	0.00907728	0.00213954	0.0106699	0.0196979	0.00441	0.03494
CH1W3	1.0	6	0.0152467	0.00400368	0.00163450	0.0110451	0.0194483	0.01057	0.02122
	2.0	6	0.0172117	0.00618400	0.00252461	0.0107220	0.0237014	0.01047	0.02601
	3.0	6	0.0178767	0.00705357	0.00287961	0.0104744	0.0252789	0.00703	0.02712
	Total	18	0.0167783	0.00564937	0.00133157	0.0139690	0.0195877	0.00703	0.02712
CH1R3	1.0	6	0.0226683	0.00915209	0.00373633	0.0130638	0.0322729	0.01363	0.03803
	2.0	6	0.0161750	0.00541569	0.00221095	0.0104916	0.0218584	0.00834	0.02330
	3.0	6	0.0112100	0.00372102	0.00151910	0.0073050	0.0151150	0.00844	0.01837
	Total	18	0.0166844	0.00778724	0.00183547	0.0128119	0.0205569	0.00834	0.03803
CH1S3	1.0	6	0.0257067	0.01004610	0.00410130	0.0151639	0.0362494	0.01253	0.04094
	2.0	6	0.0130700	0.00448861	0.00183247	0.0083595	0.0177805	0.00748	0.02004
	3.0	6	0.0097433	0.00287973	0.00117564	0.0067212	0.0127654	0.00480	0.01332
	Total	18	0.0161733	0.00938704	0.00221255	0.0115053	0.0208414	0.00480	0.04094

CH1W4	1.0	6	0.0227217	0.00637772	0.00260369	0.0160287	0.0294147	0.01329	0.02877
	2.0	6	0.0252033	0.01252528	0.00511342	0.0120589	0.0383478	0.01210	0.04369
	3.0	6	0.0165033	0.00736964	0.00300864	0.0087694	0.0242373	0.00901	0.02893
	Total	18	0.0214761	0.00939455	0.00221432	0.0168043	0.0261479	0.00901	0.04369
CH1R4	1.0	6	0.0317917	0.01012375	0.00413300	0.0211674	0.0424159	0.02095	0.04330
	2.0	6	0.0177367	0.00541138	0.00220918	0.0120578	0.0234156	0.00808	0.02204
	3.0	6	0.0118067	0.00390641	0.00159478	0.0077071	0.0159062	0.00789	0.01784
	Total	18	0.0204450	0.01084485	0.00255616	0.0150520	0.0258380	0.00789	0.04330
CH1S4	1.0	6	0.0295233	0.01143577	0.00466863	0.0175222	0.0415244	0.01610	0.04287
	2.0	6	0.0153100	0.00516194	0.00210735	0.0098929	0.0207271	0.00868	0.02087
	3.0	6	0.0111000	0.00403110	0.00164569	0.0068696	0.0153304	0.00654	0.01727
	Total	18	0.0186444	0.01081036	0.00254803	0.0132686	0.0240203	0.00654	0.04287
CH1W5	1.0	6	0.0544283	0.04579759	0.01869679	0.0063667	0.1024900	0.02448	0.14518
	2.0	6	0.0444450	0.03821618	0.01560169	0.0043396	0.0845504	0.02096	0.11911
	3.0	6	0.0294717	0.02906874	0.01186726	-0.0010341	0.0599774	0.01058	0.08612
	Total	18	0.0427817	0.03750125	0.00883913	0.0241327	0.0614306	0.01058	0.14518
CH1R5	1.0	6	0.0487600	0.03633883	0.01483527	0.0106247	0.0868953	0.02343	0.11818
	2.0	6	0.0258433	0.01508373	0.00615791	0.0100139	0.0416727	0.00985	0.05236
	3.0	6	0.0161200	0.00927535	0.00378664	0.0063861	0.0258539	0.00798	0.03140
	Total	18	0.0302411	0.02605479	0.00614117	0.0172844	0.0431979	0.00798	0.11818
CH1S5	1.0	6	0.0390983	0.02436821	0.00994828	0.0135255	0.0646712	0.02065	0.08666
	2.0	6	0.0205133	0.00926660	0.00378307	0.0107886	0.0302380	0.01087	0.03751
	3.0	6	0.0179983	0.01066976	0.00435591	0.0068011	0.0291956	0.00659	0.03310
	Total	18	0.0258700	0.01808719	0.00426319	0.0168755	0.0348645	0.00659	0.08666
CH1W6	1.0	5	0.0614740	0.01270649	0.00568252	0.0456968	0.0772512	0.04588	0.08112
	2.0	6	0.0373167	0.01629788	0.00665358	0.0202131	0.0544202	0.02596	0.06470
	3.0	5	0.0260220	0.01401661	0.00626842	0.0086181	0.0434259	0.01309	0.04230
	Total	16	0.0413363	0.02009478	0.00502370	0.0306285	0.0520440	0.01309	0.08112
CH1R6	1.0	6	0.0425733	0.01878268	0.00766800	0.0228621	0.0622845	0.02511	0.06802
	2.0	6	0.0266333	0.01257081	0.00513201	0.0134411	0.0398256	0.01085	0.04342
	3.0	6	0.0181950	0.00825109	0.00336849	0.0095360	0.0268540	0.00917	0.02787
	Total	18	0.0291339	0.01668684	0.00393313	0.0208357	0.0374321	0.00917	0.06802
CH1S6	1.0	6	0.0341150	0.00903987	0.00369051	0.0246282	0.0436018	0.02541	0.05035
	2.0	6	0.0190017	0.00612571	0.00250081	0.0125731	0.0254302	0.01363	0.02896
	3.0	6	0.0157183	0.00581206	0.00237276	0.0096189	0.0218177	0.00961	0.02265
	Total	18	0.0229450	0.01062843	0.00250514	0.0176596	0.0282304	0.00961	0.05035

CH2W2	1.0	6	0.0169100	0.00861211	0.00351588	0.0078721	0.0259479	0.00976	0.03225
	2.0	6	0.0059117	0.00132557	0.00054116	0.0045206	0.0073028	0.00445	0.00753
	3.0	6	0.0035867	0.00123990	0.00050619	0.0022855	0.0048879	0.00223	0.00522
	Total	18	0.0088028	0.00765074	0.00180330	0.0049982	0.0126074	0.00223	0.03225
CH2R2	1.0	6	0.0349883	0.01595278	0.00651269	0.0182469	0.0517297	0.02159	0.06059
	2.0	6	0.0087100	0.00152852	0.00062401	0.0071059	0.0103141	0.00681	0.01036
	3.0	6	0.0052500	0.00228443	0.00093262	0.0028526	0.0076474	0.00364	0.00953
	Total	18	0.0163161	0.01624086	0.00382801	0.0082397	0.0243925	0.00364	0.06059
CH2S2	1.0	6	0.02969000	0.006818853	0.002783785	0.02253405	0.03684595	0.018800	0.036190
	2.0	6	0.00917150	0.005155409	0.002104687	0.00376123	0.01458177	0.000519	0.016260
	3.0	6	0.00620500	0.002468933	0.001007938	0.00361401	0.00879599	0.002810	0.009100
	Total	18	0.01502217	0.011778748	0.002776278	0.00916473	0.02087960	0.000519	0.036190
CH2W3	1.0	6	0.0249950	0.01289812	0.00526563	0.0114593	0.0385307	0.00956	0.04675
	2.0	6	0.0095083	0.00327642	0.00133759	0.0060699	0.0129467	0.00514	0.01413
	3.0	6	0.0055633	0.00226401	0.00092428	0.0031874	0.0079393	0.00320	0.00883
	Total	18	0.0133556	0.01131654	0.00266733	0.0077280	0.0189831	0.00320	0.04675
CH2R3	1.0	6	0.0379083	0.01215678	0.00496299	0.0251506	0.0506661	0.02407	0.05339
	2.0	6	0.0096350	0.00263844	0.00107714	0.0068661	0.0124039	0.00630	0.01316
	3.0	6	0.0056550	0.00121136	0.00049454	0.0043838	0.0069262	0.00364	0.00709
	Total	18	0.0177328	0.01625546	0.00383145	0.0096491	0.0258164	0.00364	0.05339
CH2S3	1.0	6	0.0321400	0.01212124	0.00494848	0.0194195	0.0448605	0.01595	0.04747
	2.0	6	0.0108000	0.00409819	0.00167308	0.0064992	0.0151008	0.00394	0.01549
	3.0	6	0.0068167	0.00300600	0.00122719	0.0036621	0.0099713	0.00376	0.01064
	Total	18	0.0165856	0.01347950	0.00317715	0.0098824	0.0232888	0.00376	0.04747
CH2W4	1.0	6	0.0378633	0.02511884	0.01025472	0.0115027	0.0642239	0.00867	0.08139
	2.0	6	0.0132667	0.00435421	0.00177760	0.0086972	0.0178361	0.00827	0.01876
	3.0	6	0.0069783	0.00237683	0.00097034	0.0044840	0.0094727	0.00304	0.00882
	Total	18	0.0193694	0.01951571	0.00459990	0.0096645	0.0290744	0.00304	0.08139
CH2R4	1.0	6	0.0395033	0.01274804	0.00520436	0.0261251	0.0528816	0.02215	0.05609
	2.0	6	0.0119850	0.00309873	0.00126505	0.0087331	0.0152369	0.00883	0.01586
	3.0	6	0.0063083	0.00190781	0.00077886	0.0043062	0.0083105	0.00440	0.00856
	Total	18	0.0192656	0.01655926	0.00390305	0.0110308	0.0275003	0.00440	0.05609
CH2S4	1.0	6	0.03973667	0.017707723	0.007229148	0.02115355	0.05831978	0.022620	0.067090
	2.0	6	0.01202333	0.004575678	0.001868013	0.00722145	0.01682521	0.005260	0.017070
	3.0	6	0.00729850	0.004064877	0.001659479	0.00303267	0.01156433	0.000621	0.012620
	Total	18	0.01968617	0.017889025	0.004216484	0.01079016	0.02858217	0.000621	0.067090

CH2W5	1.0	6	0.0597267	0.03611314	0.01474313	0.0218282	0.0976251	0.01209	0.12269
	2.0	6	0.0158333	0.00903119	0.00368697	0.0063557	0.0253110	0.00881	0.03306
	3.0	6	0.0082017	0.00209020	0.00085332	0.0060081	0.0103952	0.00500	0.01142
	Total	18	0.0279206	0.03089816	0.00728277	0.0125553	0.0432858	0.00500	0.12269
CH2R5	1.0	6	0.0424983	0.01342356	0.00548014	0.0284112	0.0565855	0.02059	0.05751
	2.0	6	0.0135050	0.00311446	0.00127147	0.0102366	0.0167734	0.00963	0.01856
	3.0	6	0.0078283	0.00211958	0.00086531	0.0056040	0.0100527	0.00474	0.01023
	Total	18	0.0212772	0.01735717	0.00409113	0.0126457	0.0299087	0.00474	0.05751
CH2S5	1.0	6	0.0377483	0.01258228	0.00513669	0.0245440	0.0509526	0.02426	0.05778
	2.0	6	0.0143433	0.00517374	0.00211217	0.0089138	0.0197728	0.00849	0.02109
	3.0	6	0.0093033	0.00274058	0.00111884	0.0064273	0.0121794	0.00578	0.01206
	Total	18	0.0204650	0.01480776	0.00349022	0.0131013	0.0278287	0.00578	0.05778
CH2W6	1.0	5	0.0549640	0.02059373	0.00920979	0.0293935	0.0805345	0.03073	0.08539
	2.0	6	0.0180167	0.01235221	0.00504277	0.0050538	0.0309795	0.00947	0.04129
	3.0	5	0.0116980	0.00254203	0.00113683	0.0085417	0.0148543	0.00942	0.01559
	Total	16	0.0275881	0.02315814	0.00578953	0.0152480	0.0399282	0.00942	0.08539
CH2R6	1.0	6	0.0448583	0.01675253	0.00683919	0.0272776	0.0624390	0.01761	0.06146
	2.0	6	0.0161300	0.00456917	0.00186535	0.0113350	0.0209250	0.01010	0.02393
	3.0	6	0.0106100	0.00261155	0.00106616	0.0078693	0.0133507	0.00596	0.01349
	Total	18	0.0238661	0.01814840	0.00427762	0.0148411	0.0328911	0.00596	0.06146
CH2S6	1.0	6	0.0394983	0.01141463	0.00466000	0.0275194	0.0514773	0.02509	0.05077
	2.0	6	0.0153983	0.00523497	0.00213717	0.0099046	0.0208921	0.00941	0.02214
	3.0	6	0.0092067	0.00177416	0.00072430	0.0073448	0.0110685	0.00721	0.01202
	Total	18	0.0213678	0.01510297	0.00355980	0.0138572	0.0288783	0.00721	0.05077
CH3W2	1.0	6	0.0191817	0.00983321	0.00401439	0.0088623	0.0295010	0.00843	0.03083
	2.0	6	0.0097783	0.00549397	0.00224290	0.0040128	0.0155439	0.00457	0.01886
	3.0	6	0.0066617	0.00673814	0.00275083	-0.0004096	0.0137329	0.00322	0.02037
	Total	18	0.0118739	0.00898091	0.00211682	0.0074078	0.0163400	0.00322	0.03083
CH3R2	1.0	6	0.0335100	0.02406968	0.00982641	0.0082504	0.0587696	0.01853	0.08141
	2.0	6	0.0113350	0.00317499	0.00129618	0.0080031	0.0146669	0.00658	0.01572
	3.0	6	0.0066900	0.00176730	0.00072150	0.0048353	0.0085447	0.00410	0.00876
	Total	18	0.0171783	0.01786881	0.00421172	0.0082924	0.0260643	0.00410	0.08141
CH3S2	1.0	6	0.0425483	0.01814252	0.00740665	0.0235089	0.0615877	0.02362	0.06598
	2.0	6	0.0147100	0.00447726	0.00182783	0.0100114	0.0194086	0.01035	0.02162
	3.0	6	0.0094433	0.00278104	0.00113536	0.0065248	0.0123619	0.00620	0.01301
	Total	18	0.0222339	0.01812044	0.00427103	0.0132228	0.0312450	0.00620	0.06598

CH3W3	1.0	6	0.0254033	0.01373752	0.00560832	0.0109867	0.0398200	0.00999	0.04457
	2.0	6	0.0157967	0.01040549	0.00424802	0.0048768	0.0267166	0.00569	0.03328
	3.0	6	0.0087733	0.00712143	0.00290731	0.0012999	0.0162468	0.00440	0.02314
	Total	18	0.0166578	0.01230707	0.00290080	0.0105376	0.0227779	0.00440	0.04457
CH3R3	1.0	6	0.0407617	0.02734129	0.01116203	0.0120687	0.0694546	0.01471	0.09236
	2.0	6	0.0140167	0.00387432	0.00158168	0.0099508	0.0180825	0.00704	0.01798
	3.0	6	0.0080533	0.00319674	0.00130506	0.0046986	0.0114081	0.00441	0.01351
	Total	18	0.0209439	0.02101157	0.00495247	0.0104951	0.0313927	0.00441	0.09236
CH3S3	1.0	6	0.0455517	0.02458431	0.01003650	0.0197520	0.0713513	0.02168	0.08141
	2.0	6	0.0146567	0.00413663	0.00168877	0.0103155	0.0189978	0.00983	0.02196
	3.0	6	0.0095633	0.00329797	0.00134639	0.0061023	0.0130243	0.00523	0.01323
	Total	18	0.0232572	0.02130050	0.00502057	0.0126647	0.0338497	0.00523	0.08141
CH3W4	1.0	6	0.0370567	0.02301728	0.00939676	0.0129015	0.0612118	0.01121	0.06314
	2.0	6	0.0210950	0.01337373	0.00545980	0.0070601	0.0351299	0.00874	0.04443
	3.0	6	0.0123167	0.00949316	0.00387557	0.0023542	0.0222791	0.00466	0.03049
	Total	18	0.0234894	0.01860054	0.00438419	0.0142396	0.0327393	0.00466	0.06314
CH3R4	1.0	6	0.0524233	0.03100360	0.01265717	0.0198870	0.0849596	0.01979	0.09549
	2.0	6	0.0162983	0.00564168	0.00230321	0.0103778	0.0222189	0.00758	0.02248
	3.0	6	0.0105033	0.00401509	0.00163916	0.0062897	0.0147169	0.00642	0.01639
	Total	18	0.0264083	0.02571064	0.00606006	0.0136227	0.0391939	0.00642	0.09549
CH3S4	1.0	6	0.0563617	0.03019181	0.01232575	0.0246773	0.0880460	0.02708	0.09387
	2.0	6	0.0170917	0.00546475	0.00223097	0.0113568	0.0228266	0.00924	0.02362
	3.0	6	0.0112017	0.00378170	0.00154387	0.0072330	0.0151703	0.00632	0.01480
	Total	18	0.0282183	0.02658068	0.00626513	0.0150001	0.0414366	0.00632	0.09387
CH3W5	1.0	6	0.0531133	0.03211754	0.01311193	0.0194080	0.0868186	0.01978	0.09431
	2.0	6	0.0233450	0.01269391	0.00518227	0.0100236	0.0366664	0.00929	0.04073
	3.0	6	0.0129100	0.00597364	0.00243873	0.0066410	0.0191790	0.00456	0.02108
	Total	18	0.0297894	0.02585535	0.00609416	0.0169319	0.0426470	0.00456	0.09431
CH3R5	1.0	6	0.0559283	0.03422347	0.01397167	0.0200130	0.0918437	0.02045	0.10163
	2.0	6	0.0181983	0.00666818	0.00272227	0.0112005	0.0251962	0.00912	0.02655
	3.0	6	0.0118233	0.00472586	0.00192932	0.0068638	0.0167828	0.00709	0.01956
	Total	18	0.0286500	0.02766300	0.00652023	0.0148935	0.0424065	0.00709	0.10163
CH3S5	1.0	6	0.0554533	0.02636162	0.01076208	0.0277885	0.0831182	0.03214	0.09236
	2.0	6	0.0211617	0.00860432	0.00351270	0.0121320	0.0301914	0.01253	0.03580
	3.0	6	0.0118533	0.00423154	0.00172752	0.0074126	0.0162941	0.00721	0.01710
	Total	18	0.0294894	0.02456854	0.00579086	0.0172718	0.0417071	0.00721	0.09236

CH3W6	1.0	5	0.0569360	0.02784887	0.01245439	0.0223571	0.0915149	0.03814	0.10394
	2.0	6	0.0270767	0.01712097	0.00698960	0.0091093	0.0450440	0.01235	0.05294
	3.0	5	0.0166960	0.00896187	0.00400787	0.0055684	0.0278236	0.00940	0.03133
	Total	16	0.0331638	0.02489041	0.00622260	0.0199006	0.0464269	0.00940	0.10394
CH3R6	1.0	6	0.0617317	0.04144189	0.01691858	0.0182411	0.1052223	0.02463	0.13471
	2.0	6	0.0203800	0.00677882	0.00276744	0.0132661	0.0274939	0.01351	0.03040
	3.0	6	0.0161933	0.00453841	0.00185280	0.0114306	0.0209561	0.00868	0.02086
	Total	18	0.0327683	0.03117536	0.00734810	0.0172652	0.0482715	0.00868	0.13471
CH3S6	1.0	6	0.0617617	0.02472691	0.01009472	0.0358124	0.0877110	0.03322	0.08642
	2.0	6	0.0231267	0.00880946	0.00359645	0.0138817	0.0323716	0.01441	0.03741
	3.0	6	0.0128517	0.00474788	0.00193831	0.0078691	0.0178343	0.00661	0.02072
	Total	18	0.0325800	0.02605277	0.00614070	0.0196243	0.0455357	0.00661	0.08642
CH4W2	1.0	6	0.0122367	0.00720036	0.00293953	0.0046804	0.0197930	0.00666	0.02642
	2.0	6	0.0152983	0.00839111	0.00342566	0.0064924	0.0241043	0.00543	0.02756
	3.0	6	0.0164450	0.01018123	0.00415647	0.0057605	0.0271295	0.00669	0.03288
	Total	18	0.0146600	0.00835381	0.00196901	0.0105057	0.0188143	0.00543	0.03288
CH4R2	1.0	6	0.0310150	0.01988062	0.00811623	0.0101516	0.0518784	0.01190	0.06682
	2.0	6	0.0209717	0.01230355	0.00502290	0.0080599	0.0338835	0.00621	0.03978
	3.0	6	0.0121383	0.00769154	0.00314006	0.0040666	0.0202101	0.00453	0.02263
	Total	18	0.0213750	0.01552859	0.00366012	0.0136528	0.0290972	0.00453	0.06682
CH4S2	1.0	6	0.0286433	0.01778412	0.00726034	0.0099800	0.0473066	0.01300	0.05682
	2.0	6	0.0133967	0.00821812	0.00335503	0.0047723	0.0220211	0.00519	0.02462
	3.0	6	0.0112017	0.00798053	0.00325804	0.0028266	0.0195767	0.00369	0.02225
	Total	18	0.0177472	0.01397579	0.00329413	0.0107972	0.0246972	0.00369	0.05682
CH4W3	1.0	6	0.0215400	0.01301658	0.00531400	0.0078799	0.0352001	0.01063	0.03855
	2.0	6	0.0246600	0.01725161	0.00704294	0.0065555	0.0427645	0.01068	0.05600
	3.0	6	0.0239950	0.01559583	0.00636697	0.0076282	0.0403618	0.00623	0.05034
	Total	18	0.0233983	0.01451937	0.00342225	0.0161780	0.0306186	0.00623	0.05600
CH4R3	1.0	6	0.0422050	0.03920230	0.01600427	0.0010647	0.0833453	0.01296	0.11522
	2.0	6	0.0210867	0.01045148	0.00426680	0.0101185	0.0320548	0.01155	0.03730
	3.0	6	0.0150050	0.00767901	0.00313494	0.0069464	0.0230636	0.00786	0.02566
	Total	18	0.0260989	0.02540348	0.00598766	0.0134660	0.0387317	0.00786	0.11522
CH4S3	1.0	6	0.0344300	0.01859180	0.00759007	0.0149191	0.0539409	0.01796	0.06860
	2.0	6	0.0153633	0.00733107	0.00299290	0.0076699	0.0230568	0.00610	0.02517
	3.0	6	0.0129200	0.00547585	0.00223550	0.0071735	0.0186665	0.00601	0.02271
	Total	18	0.0209044	0.01497311	0.00352920	0.0134585	0.0283504	0.00601	0.06860

Appendix D – ANOVA Descriptives & Charts

CH4W4	1.0	6	0.0310333	0.01875409	0.00765633	0.0113521	0.0507145	0.01568	0.06126
	2.0	6	0.0363983	0.03055505	0.01247405	0.0043328	0.0684639	0.01277	0.09250
	3.0	6	0.0255233	0.02521689	0.01029475	-0.0009402	0.0519868	0.00753	0.07301
	Total	18	0.0309850	0.02420611	0.00570544	0.0189476	0.0430224	0.00753	0.09250
CH4R4	1.0	6	0.0465400	0.03234190	0.01320353	0.0125993	0.0804807	0.01748	0.09359
	2.0	6	0.0223700	0.00941049	0.00384182	0.0124943	0.0322457	0.01094	0.03501
	3.0	6	0.0156550	0.00686893	0.00280423	0.0084465	0.0228635	0.00897	0.02575
	Total	18	0.0281883	0.02310464	0.00544582	0.0166987	0.0396780	0.00897	0.09359
CH4S4	1.0	6	0.0374200	0.01812442	0.00739926	0.0183996	0.0564404	0.02203	0.06776
	2.0	6	0.0184450	0.00939651	0.00383611	0.0085840	0.0283060	0.00999	0.03513
	3.0	6	0.0157033	0.01093972	0.00446612	0.0042228	0.0271839	0.00637	0.03678
	Total	18	0.0238561	0.01601597	0.00377500	0.0158916	0.0318207	0.00637	0.06776
CH4W5	1.0	6	0.0559100	0.04521317	0.01845820	0.0084617	0.1033583	0.02453	0.14518
	2.0	6	0.0489667	0.03801742	0.01552055	0.0090698	0.0888635	0.02116	0.11911
	3.0	6	0.0293050	0.02926544	0.01194757	-0.0014072	0.0600172	0.00889	0.08612
	Total	18	0.0447272	0.03758546	0.00885898	0.0260364	0.0634180	0.00889	0.14518
CH4R5	1.0	6	0.0525967	0.03521746	0.01437747	0.0156382	0.0895551	0.01946	0.11818
	2.0	6	0.0292133	0.01628332	0.00664764	0.0121250	0.0463016	0.01425	0.05236
	3.0	6	0.0176767	0.00934522	0.00381517	0.0078695	0.0274839	0.00970	0.03140
	Total	18	0.0331622	0.02630400	0.00619991	0.0200816	0.0462429	0.00970	0.11818
CH4S5	1.0	6	0.0441483	0.02255671	0.00920874	0.0204765	0.0678202	0.02665	0.08666
	2.0	6	0.0197817	0.01033607	0.00421968	0.0089346	0.0306287	0.00955	0.03751
	3.0	6	0.0163117	0.00895930	0.00365762	0.0069095	0.0257139	0.00790	0.03310
	Total	18	0.0267472	0.01916009	0.00451608	0.0172191	0.0362753	0.00790	0.08666
CH4W6	1.0	5	0.0721760	0.02991433	0.01337809	0.0350325	0.1093195	0.03929	0.11032
	2.0	6	0.0558433	0.04221636	0.01723476	0.0115400	0.1001467	0.02491	0.12474
	3.0	5	0.0373800	0.03622528	0.01620044	-0.0075996	0.0823596	0.01105	0.09772
	Total	16	0.0551775	0.03721184	0.00930296	0.0353487	0.0750063	0.01105	0.12474
CH4R6	1.0	6	0.0627183	0.03991823	0.01629655	0.0208267	0.1046099	0.02348	0.13174
	2.0	6	0.0362050	0.02618271	0.01068905	0.0087279	0.0636821	0.01211	0.08010
	3.0	6	0.0228600	0.01352586	0.00552191	0.0086655	0.0370545	0.01080	0.04552
	Total	18	0.0405944	0.03185372	0.00750799	0.0247540	0.0564349	0.01080	0.13174
CH4S6	1.0	6	0.0444350	0.01648853	0.00673141	0.0271314	0.0617386	0.02958	0.07517
	2.0	6	0.0246700	0.01257591	0.00513409	0.0114724	0.0378676	0.01409	0.04790
	3.0	6	0.0185683	0.01175775	0.00480008	0.0062293	0.0309073	0.00767	0.04046
	Total	18	0.0292244	0.01721027	0.00405650	0.0206660	0.0377829	0.00767	0.07517

Appendix D – ANOVA Descriptives & Charts

EMG ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
CH1W2	Between Groups	0.000	2	0.000	0.147	0.864
	Within Groups	0.000	15	0.000		
	Total	0.000	17			
CH1R2	Between Groups	0.000	2	0.000	3.874	0.044
	Within Groups	0.001	15	0.000		
	Total	0.001	17			
CH1S2	Between Groups	0.001	2	0.000	8.190	0.004
	Within Groups	0.001	15	0.000		
	Total	0.001	17			
CH1W3	Between Groups	0.000	2	0.000	0.324	0.728
	Within Groups	0.001	15	0.000		
	Total	0.001	17			
CH1R3	Between Groups	0.000	2	0.000	4.682	0.026
	Within Groups	0.001	15	0.000		
	Total	0.001	17			
CH1S3	Between Groups	0.001	2	0.000	9.869	0.002
	Within Groups	0.001	15	0.000		
	Total	0.001	17			
CH1W4	Between Groups	0.000	2	0.000	1.435	0.269
	Within Groups	0.001	15	0.000		
	Total	0.002	17			
CH1R4	Between Groups	0.001	2	0.001	12.897	0.001
	Within Groups	0.001	15	0.000		
	Total	0.002	17			
CH1S4	Between Groups	0.001	2	0.001	9.659	0.002
	Within Groups	0.001	15	0.000		
	Total	0.002	17			
CH1W5	Between Groups	0.002	2	0.001	0.645	0.539
	Within Groups	0.022	15	0.001		
	Total	0.024	17			
CH1R5	Between Groups	0.003	2	0.002	3.094	0.075
	Within Groups	0.008	15	0.001		
	Total	0.012	17			

Appendix D – ANOVA Descriptives & Charts

CH1S5	Between Groups	0.002	2	0.001	3.013	0.079
	Within Groups	0.004	15	0.000		
	Total	0.006	17			
CH1W6	Between Groups	0.003	2	0.002	7.766	0.006
	Within Groups	0.003	13	0.000		
	Total	0.006	15			
CH1R6	Between Groups	0.002	2	0.001	4.766	0.025
	Within Groups	0.003	15	0.000		
	Total	0.005	17			
CH1S6	Between Groups	0.001	2	0.001	11.324	0.001
	Within Groups	0.001	15	0.000		
	Total	0.002	17			
CH2W2	Between Groups	0.001	2	0.000	11.769	0.001
	Within Groups	0.000	15	0.000		
	Total	0.001	17			
CH2R2	Between Groups	0.003	2	0.002	18.167	0.000
	Within Groups	0.001	15	0.000		
	Total	0.004	17			
CH2S2	Between Groups	0.002	2	0.001	37.186	0.000
	Within Groups	0.000	15	0.000		
	Total	0.002	17			
CH2W3	Between Groups	0.001	2	0.001	10.421	0.001
	Within Groups	0.001	15	0.000		
	Total	0.002	17			
CH2R3	Between Groups	0.004	2	0.002	35.633	0.000
	Within Groups	0.001	15	0.000		
	Total	0.004	17			
CH2S3	Between Groups	0.002	2	0.001	19.320	0.000
	Within Groups	0.001	15	0.000		
	Total	0.003	17			
CH2W4	Between Groups	0.003	2	0.002	7.315	0.006
	Within Groups	0.003	15	0.000		
	Total	0.006	17			
CH2R4	Between Groups	0.004	2	0.002	32.285	0.000
	Within Groups	0.001	15	0.000		
	Total	0.005	17			

Appendix D – ANOVA Descriptives & Charts

CH2S4	Between Groups	0.004	2	0.002	15.748	0.000
	Within Groups	0.002	15	0.000		
	Total	0.005	17			
CH2W5	Between Groups	0.009	2	0.005	10.013	0.002
	Within Groups	0.007	15	0.000		
	Total	0.016	17			
CH2R5	Between Groups	0.004	2	0.002	32.022	0.000
	Within Groups	0.001	15	0.000		
	Total	0.005	17			
CH2S5	Between Groups	0.003	2	0.001	21.532	0.000
	Within Groups	0.001	15	0.000		
	Total	0.004	17			
CH2W6	Between Groups	0.006	2	0.003	14.541	0.000
	Within Groups	0.002	13	0.000		
	Total	0.008	15			
CH2R6	Between Groups	0.004	2	0.002	19.738	0.000
	Within Groups	0.002	15	0.000		
	Total	0.006	17			
CH2S6	Between Groups	0.003	2	0.002	28.662	0.000
	Within Groups	0.001	15	0.000		
	Total	0.004	17			
CH3W2	Between Groups	0.001	2	0.000	4.439	0.031
	Within Groups	0.001	15	0.000		
	Total	0.001	17			
CH3R2	Between Groups	0.002	2	0.001	6.241	0.011
	Within Groups	0.003	15	0.000		
	Total	0.005	17			
CH3S2	Between Groups	0.004	2	0.002	15.958	0.000
	Within Groups	0.002	15	0.000		
	Total	0.006	17			
CH3W3	Between Groups	0.001	2	0.000	3.608	0.053
	Within Groups	0.002	15	0.000		
	Total	0.003	17			
CH3R3	Between Groups	0.004	2	0.002	7.068	0.007
	Within Groups	0.004	15	0.000		
	Total	0.008	17			

Appendix D – ANOVA Descriptives & Charts

CH3S3	Between Groups	0.005	2	0.002	10.795	0.001
	Within Groups	0.003	15	0.000		
	Total	0.008	17			
CH3W4	Between Groups	0.002	2	0.001	3.545	0.055
	Within Groups	0.004	15	0.000		
	Total	0.006	17			
CH3R4	Between Groups	0.006	2	0.003	9.203	0.002
	Within Groups	0.005	15	0.000		
	Total	0.011	17			
CH3S4	Between Groups	0.007	2	0.004	11.352	0.001
	Within Groups	0.005	15	0.000		
	Total	0.012	17			
CH3W5	Between Groups	0.005	2	0.003	6.378	0.010
	Within Groups	0.006	15	0.000		
	Total	0.011	17			
CH3R5	Between Groups	0.007	2	0.003	8.262	0.004
	Within Groups	0.006	15	0.000		
	Total	0.013	17			
CH3S5	Between Groups	0.006	2	0.003	12.061	0.001
	Within Groups	0.004	15	0.000		
	Total	0.010	17			
CH3W6	Between Groups	0.004	2	0.002	5.855	0.015
	Within Groups	0.005	13	0.000		
	Total	0.009	15			
CH3R6	Between Groups	0.008	2	0.004	6.392	0.010
	Within Groups	0.009	15	0.001		
	Total	0.017	17			
CH3S6	Between Groups	0.008	2	0.004	16.824	0.000
	Within Groups	0.004	15	0.000		
	Total	0.012	17			
CH4W2	Between Groups	0.000	2	0.000	0.377	0.692
	Within Groups	0.001	15	0.000		
	Total	0.001	17			
CH4R2	Between Groups	0.001	2	0.001	2.651	0.103
	Within Groups	0.003	15	0.000		
	Total	0.004	17			

Appendix D – ANOVA Descriptives & Charts

CH4S2	Between Groups	0.001	2	0.001	3.630	0.052
	Within Groups	0.002	15	0.000		
	Total	0.003	17			
CH4W3	Between Groups	0.000	2	0.000	0.068	0.934
	Within Groups	0.004	15	0.000		
	Total	0.004	17			
CH4R3	Between Groups	0.002	2	0.001	2.152	0.151
	Within Groups	0.009	15	0.001		
	Total	0.011	17			
CH4S3	Between Groups	0.002	2	0.001	5.814	0.014
	Within Groups	0.002	15	0.000		
	Total	0.004	17			
CH4W4	Between Groups	0.000	2	0.000	0.277	0.762
	Within Groups	0.010	15	0.001		
	Total	0.010	17			
CH4R4	Between Groups	0.003	2	0.002	4.019	0.040
	Within Groups	0.006	15	0.000		
	Total	0.009	17			
CH4S4	Between Groups	0.002	2	0.001	4.693	0.026
	Within Groups	0.003	15	0.000		
	Total	0.004	17			
CH4W5	Between Groups	0.002	2	0.001	0.789	0.472
	Within Groups	0.022	15	0.001		
	Total	0.024	17			
CH4R5	Between Groups	0.004	2	0.002	3.577	0.054
	Within Groups	0.008	15	0.001		
	Total	0.012	17			
CH4S5	Between Groups	0.003	2	0.001	5.952	0.013
	Within Groups	0.003	15	0.000		
	Total	0.006	17			
CH4W6	Between Groups	0.003	2	0.002	1.111	0.359
	Within Groups	0.018	13	0.001		
	Total	0.021	15			
CH4R6	Between Groups	0.005	2	0.002	3.009	0.080
	Within Groups	0.012	15	0.001		
	Total	0.017	17			

CH4S6	Between Groups	0.002	2	0.001	5.791	0.014
	Within Groups	0.003	15	0.000		
	Total	0.005	17			

EMG ANOVA Post Hoc - Bonferroni

Dependent Variable	(I) V1	(J) V1	Mean Difference (I-J)	Std. Error	Sig.	97.5% Confidence Interval Lower Bound	Upper Bound
CH1W2	1.0	2.0	0.00000500	0.00235829	1.000	-0.0071554	0.0071654
		3.0	-0.00110667	0.00235829	1.000	-0.0082671	0.0060538
	2.0	1.0	-0.00000500	0.00235829	1.000	-0.0071654	0.0071554
		3.0	-0.00111167	0.00235829	1.000	-0.0082721	0.0060488
	3.0	1.0	0.00110667	0.00235829	1.000	-0.0060538	0.0082671
		2.0	0.00111167	0.00235829	1.000	-0.0060488	0.0082721
CH1R2	1.0	2.0	0.00659000	0.00391880	0.340	-0.0053086	0.0184886
		3.0	0.01082333	0.00391880	0.044	-0.0010752	0.0227219
	2.0	1.0	-0.00659000	0.00391880	0.340	-0.0184886	0.0053086
		3.0	0.00423333	0.00391880	0.891	-0.0076652	0.0161319
	3.0	1.0	-0.01082333	0.00391880	0.044	-0.0227219	0.0010752
		2.0	-0.00423333	0.00391880	0.891	-0.0161319	0.0076652
CH1S2	1.0	2.0	.01188333*	0.00385739	0.023	0.0001712	0.0235955
		3.0	.01471000*	0.00385739	0.005	0.0029979	0.0264221
	2.0	1.0	-.01188333*	0.00385739	0.023	-0.0235955	-0.0001712
		3.0	0.00282667	0.00385739	1.000	-0.0088855	0.0145388
	3.0	1.0	-.01471000*	0.00385739	0.005	-0.0264221	-0.0029979
		2.0	-0.00282667	0.00385739	1.000	-0.0145388	0.0088855
CH1W3	1.0	2.0	-0.00196500	0.00339974	1.000	-0.0122876	0.0083576
		3.0	-0.00263000	0.00339974	1.000	-0.0129526	0.0076926
	2.0	1.0	0.00196500	0.00339974	1.000	-0.0083576	0.0122876
		3.0	-0.00066500	0.00339974	1.000	-0.0109876	0.0096576
	3.0	1.0	0.00263000	0.00339974	1.000	-0.0076926	0.0129526
		2.0	0.00066500	0.00339974	1.000	-0.0096576	0.0109876

CH1R3	1.0	2.0	0.00649333	0.00375554	0.313	-0.0049095	0.0178962
		3.0	.01145833*	0.00375554	0.024	0.0000555	0.0228612
	2.0	1.0	-0.00649333	0.00375554	0.313	-0.0178962	0.0049095
		3.0	0.00496500	0.00375554	0.618	-0.0064379	0.0163679
	3.0	1.0	-.01145833*	0.00375554	0.024	-0.0228612	-0.0000555
		2.0	-0.00496500	0.00375554	0.618	-0.0163679	0.0064379
CH1S3	1.0	2.0	.01263667*	0.00379128	0.014	0.0011253	0.0241481
		3.0	.01596333*	0.00379128	0.002	0.0044519	0.0274747
	2.0	1.0	-.01263667*	0.00379128	0.014	-0.0241481	-0.0011253
		3.0	0.00332667	0.00379128	1.000	-0.0081847	0.0148381
	3.0	1.0	-.01596333*	0.00379128	0.002	-0.0274747	-0.0044519
		2.0	-0.00332667	0.00379128	1.000	-0.0148381	0.0081847
CH1W4	1.0	2.0	-0.00248167	0.00529013	1.000	-0.0185440	0.0135807
		3.0	0.00621833	0.00529013	0.774	-0.0098440	0.0222807
	2.0	1.0	0.00248167	0.00529013	1.000	-0.0135807	0.0185440
		3.0	0.00870000	0.00529013	0.363	-0.0073623	0.0247623
	3.0	1.0	-0.00621833	0.00529013	0.774	-0.0222807	0.0098440
		2.0	-0.00870000	0.00529013	0.363	-0.0247623	0.0073623
CH1R4	1.0	2.0	.01405500*	0.00404191	0.010	0.0017826	0.0263274
		3.0	.01998500*	0.00404191	0.001	0.0077126	0.0322574
	2.0	1.0	-.01405500*	0.00404191	0.010	-0.0263274	-0.0017826
		3.0	0.00593000	0.00404191	0.489	-0.0063424	0.0182024
	3.0	1.0	-.01998500*	0.00404191	0.001	-0.0322574	-0.0077126
		2.0	-0.00593000	0.00404191	0.489	-0.0182024	0.0063424
CH1S4	1.0	2.0	.01421333*	0.00439282	0.017	0.0008755	0.0275512
		3.0	.01842333*	0.00439282	0.002	0.0050855	0.0317612
	2.0	1.0	-.01421333*	0.00439282	0.017	-0.0275512	-0.0008755
		3.0	0.00421000	0.00439282	1.000	-0.0091279	0.0175479
	3.0	1.0	-.01842333*	0.00439282	0.002	-0.0317612	-0.0050855
		2.0	-0.00421000	0.00439282	1.000	-0.0175479	0.0091279
CH1W5	1.0	2.0	0.00998333	0.02211809	1.000	-0.0571734	0.0771401
		3.0	0.02495667	0.02211809	0.831	-0.0422001	0.0921134
	2.0	1.0	-0.00998333	0.02211809	1.000	-0.0771401	0.0571734
		3.0	0.01497333	0.02211809	1.000	-0.0521834	0.0821301
	3.0	1.0	-0.02495667	0.02211809	0.831	-0.0921134	0.0422001
		2.0	-0.01497333	0.02211809	1.000	-0.0821301	0.0521834

Appendix D – ANOVA Descriptives & Charts

CH1R5	1.0	2.0	0.02291667	0.01347451	0.329	-0.0179958	0.0638291
		3.0	0.03264000	0.01347451	0.086	-0.0082724	0.0735524
	2.0	1.0	-0.02291667	0.01347451	0.329	-0.0638291	0.0179958
		3.0	0.00972333	0.01347451	1.000	-0.0311891	0.0506358
	3.0	1.0	-0.03264000	0.01347451	0.086	-0.0735524	0.0082724
		2.0	-0.00972333	0.01347451	1.000	-0.0506358	0.0311891
CH1S5	1.0	2.0	0.01858500	0.00938985	0.199	-0.0099252	0.0470952
		3.0	0.02110000	0.00938985	0.120	-0.0074102	0.0496102
	2.0	1.0	-0.01858500	0.00938985	0.199	-0.0470952	0.0099252
		3.0	0.00251500	0.00938985	1.000	-0.0259952	0.0310252
	3.0	1.0	-0.02110000	0.00938985	0.120	-0.0496102	0.0074102
		2.0	-0.00251500	0.00938985	1.000	-0.0310252	0.0259952
CH1W6	1.0	2.0	0.02415733	0.00882270	0.051	-0.0032550	0.0515697
		3.0	.03545200*	0.00921501	0.006	0.0068207	0.0640833
	2.0	1.0	-0.02415733	0.00882270	0.051	-0.0515697	0.0032550
		3.0	0.01129467	0.00882270	0.669	-0.0161177	0.0387070
	3.0	1.0	-.03545200*	0.00921501	0.006	-0.0640833	-0.0068207
		2.0	-0.01129467	0.00882270	0.669	-0.0387070	0.0161177
CH1R6	1.0	2.0	0.01594000	0.00802008	0.196	-0.0084112	0.0402912
		3.0	.02437833*	0.00802008	0.025	0.0000271	0.0487296
	2.0	1.0	-0.01594000	0.00802008	0.196	-0.0402912	0.0084112
		3.0	0.00843833	0.00802008	0.928	-0.0159129	0.0327896
	3.0	1.0	-.02437833*	0.00802008	0.025	-0.0487296	-0.0000271
		2.0	-0.00843833	0.00802008	0.928	-0.0327896	0.0159129
CH1S6	1.0	2.0	.01511333*	0.00412342	0.007	0.0025935	0.0276332
		3.0	.01839667*	0.00412342	0.001	0.0058768	0.0309165
	2.0	1.0	-.01511333*	0.00412342	0.007	-0.0276332	-0.0025935
		3.0	0.00328333	0.00412342	1.000	-0.0092365	0.0158032
	3.0	1.0	-.01839667*	0.00412342	0.001	-0.0309165	-0.0058768
		2.0	-0.00328333	0.00412342	1.000	-0.0158032	0.0092365
CH2W2	1.0	2.0	.01099833*	0.00293377	0.006	0.0020906	0.0199061
		3.0	.01332333*	0.00293377	0.001	0.0044156	0.0222311
	2.0	1.0	-.01099833*	0.00293377	0.006	-0.0199061	-0.0020906
		3.0	0.00232500	0.00293377	1.000	-0.0065827	0.0112327
	3.0	1.0	-.01332333*	0.00293377	0.001	-0.0222311	-0.0044156
		2.0	-0.00232500	0.00293377	1.000	-0.0112327	0.0065827

CH2R2	1.0	2.0	.02627833*	0.00539595	0.001	0.0098947	0.0426620
		3.0	.02973833*	0.00539595	0.000	0.0133547	0.0461220
	2.0	1.0	-.02627833*	0.00539595	0.001	-0.0426620	-0.0098947
		3.0	0.00346000	0.00539595	1.000	-0.0129236	0.0198436
	3.0	1.0	-.02973833*	0.00539595	0.000	-0.0461220	-0.0133547
		2.0	-0.00346000	0.00539595	1.000	-0.0198436	0.0129236
CH2S2	1.0	2.0	.020518500*	0.002965929	0.000	0.01151310	0.02952390
		3.0	.023485000*	0.002965929	0.000	0.01447960	0.03249040
	2.0	1.0	-.020518500*	0.002965929	0.000	-0.02952390	-0.01151310
		3.0	0.002966500	0.002965929	0.999	-0.00603890	0.01197190
	3.0	1.0	-.023485000*	0.002965929	0.000	-0.03249040	-0.01447960
		2.0	-0.002966500	0.002965929	0.999	-0.01197190	0.00603890
CH2W3	1.0	2.0	.01548667*	0.00449966	0.011	0.0018244	0.0291489
		3.0	.01943167*	0.00449966	0.002	0.0057694	0.0330939
	2.0	1.0	-.01548667*	0.00449966	0.011	-0.0291489	-0.0018244
		3.0	0.00394500	0.00449966	1.000	-0.0097172	0.0176072
	3.0	1.0	-.01943167*	0.00449966	0.002	-0.0330939	-0.0057694
		2.0	-0.00394500	0.00449966	1.000	-0.0176072	0.0097172
CH2R3	1.0	2.0	.02827333*	0.00416621	0.000	0.0156235	0.0409231
		3.0	.03225333*	0.00416621	0.000	0.0196035	0.0449031
	2.0	1.0	-.02827333*	0.00416621	0.000	-0.0409231	-0.0156235
		3.0	0.00398000	0.00416621	1.000	-0.0086698	0.0166298
	3.0	1.0	-.03225333*	0.00416621	0.000	-0.0449031	-0.0196035
		2.0	-0.00398000	0.00416621	1.000	-0.0166298	0.0086698
CH2S3	1.0	2.0	.02134000*	0.00438122	0.001	0.0080374	0.0346426
		3.0	.02532333*	0.00438122	0.000	0.0120207	0.0386260
	2.0	1.0	-.02134000*	0.00438122	0.001	-0.0346426	-0.0080374
		3.0	0.00398333	0.00438122	1.000	-0.0093193	0.0172860
	3.0	1.0	-.02532333*	0.00438122	0.000	-0.0386260	-0.0120207
		2.0	-0.00398333	0.00438122	1.000	-0.0172860	0.0093193
CH2W4	1.0	2.0	0.02459667	0.00853466	0.034	-0.0013170	0.0505103
		3.0	.03088500*	0.00853466	0.008	0.0049713	0.0567987
	2.0	1.0	-0.02459667	0.00853466	0.034	-0.0505103	0.0013170
		3.0	0.00628833	0.00853466	1.000	-0.0196253	0.0322020
	3.0	1.0	-.03088500*	0.00853466	0.008	-0.0567987	-0.0049713

		2.0	-0.00628833	0.00853466	1.000	-0.0322020	0.0196253
CH2R4	1.0	2.0	.02751833*	0.00441908	0.000	0.0141008	0.0409359
		3.0	.03319500*	0.00441908	0.000	0.0197774	0.0466126
	2.0	1.0	-.02751833*	0.00441908	0.000	-0.0409359	-0.0141008
		3.0	0.00567667	0.00441908	0.655	-0.0077409	0.0190942
	3.0	1.0	-.03319500*	0.00441908	0.000	-0.0466126	-0.0197774
		2.0	-0.00567667	0.00441908	0.655	-0.0190942	0.0077409
CH2S4	1.0	2.0	.027713333*	0.006245207	0.001	0.00875112	0.04667555
		3.0	.032438167*	0.006245207	0.000	0.01347595	0.05140038
	2.0	1.0	-.027713333*	0.006245207	0.001	-0.04667555	-0.00875112
		3.0	0.004724833	0.006245207	1.000	-0.01423738	0.02368705
	3.0	1.0	-.032438167*	0.006245207	0.000	-0.05140038	-0.01347595
		2.0	-0.004724833	0.006245207	1.000	-0.02368705	0.01423738
CH2W5	1.0	2.0	.04389333*	0.01242797	0.009	0.0061585	0.0816282
		3.0	.05152500*	0.01242797	0.003	0.0137902	0.0892598
	2.0	1.0	-.04389333*	0.01242797	0.009	-0.0816282	-0.0061585
		3.0	0.00763167	0.01242797	1.000	-0.0301032	0.0453665
	3.0	1.0	-.05152500*	0.01242797	0.003	-0.0892598	-0.0137902
		2.0	-0.00763167	0.01242797	1.000	-0.0453665	0.0301032
CH2R5	1.0	2.0	.02899333*	0.00464739	0.000	0.0148825	0.0431041
		3.0	.03467000*	0.00464739	0.000	0.0205592	0.0487808
	2.0	1.0	-.02899333*	0.00464739	0.000	-0.0431041	-0.0148825
		3.0	0.00567667	0.00464739	0.722	-0.0084341	0.0197875
	3.0	1.0	-.03467000*	0.00464739	0.000	-0.0487808	-0.0205592
		2.0	-0.00567667	0.00464739	0.722	-0.0197875	0.0084341
CH2S5	1.0	2.0	.02340500*	0.00462592	0.000	0.0093594	0.0374506
		3.0	.02844500*	0.00462592	0.000	0.0143994	0.0424906
	2.0	1.0	-.02340500*	0.00462592	0.000	-0.0374506	-0.0093594
		3.0	0.00504000	0.00462592	0.879	-0.0090056	0.0190856
	3.0	1.0	-.02844500*	0.00462592	0.000	-0.0424906	-0.0143994
		2.0	-0.00504000	0.00462592	0.879	-0.0190856	0.0090056
CH2W6	1.0	2.0	.03694733*	0.00837220	0.002	0.0109347	0.0629599
		3.0	.04326600*	0.00874447	0.001	0.0160967	0.0704353
	2.0	1.0	-.03694733*	0.00837220	0.002	-0.0629599	-0.0109347
		3.0	0.00631867	0.00837220	1.000	-0.0196939	0.0323313

	3.0	1.0	-.04326600*	0.00874447	0.001	-0.0704353	-0.0160967
		2.0	-0.00631867	0.00837220	1.000	-0.0323313	0.0196939
CH2R6	1.0	2.0	.02872833*	0.00585325	0.001	0.0109562	0.0465005
		3.0	.03424833*	0.00585325	0.000	0.0164762	0.0520205
	2.0	1.0	-.02872833*	0.00585325	0.001	-0.0465005	-0.0109562
		3.0	0.00552000	0.00585325	1.000	-0.0122521	0.0232921
	3.0	1.0	-.03424833*	0.00585325	0.000	-0.0520205	-0.0164762
		2.0	-0.00552000	0.00585325	1.000	-0.0232921	0.0122521
CH2S6	1.0	2.0	.02410000*	0.00422751	0.000	0.0112641	0.0369359
		3.0	.03029167*	0.00422751	0.000	0.0174558	0.0431276
	2.0	1.0	-.02410000*	0.00422751	0.000	-0.0369359	-0.0112641
		3.0	0.00619167	0.00422751	0.491	-0.0066442	0.0190276
	3.0	1.0	-.03029167*	0.00422751	0.000	-0.0431276	-0.0174558
		2.0	-0.00619167	0.00422751	0.491	-0.0190276	0.0066442
CH3W2	1.0	2.0	0.00940333	0.00437516	0.145	-0.0038809	0.0226876
		3.0	0.01252000	0.00437516	0.036	-0.0007642	0.0258042
	2.0	1.0	-0.00940333	0.00437516	0.145	-0.0226876	0.0038809
		3.0	0.00311667	0.00437516	1.000	-0.0101676	0.0164009
	3.0	1.0	-0.01252000	0.00437516	0.036	-0.0258042	0.0007642
		2.0	-0.00311667	0.00437516	1.000	-0.0164009	0.0101676
CH3R2	1.0	2.0	0.02217500	0.00811414	0.046	-0.0024618	0.0468118
		3.0	.02682000*	0.00811414	0.014	0.0021832	0.0514568
	2.0	1.0	-0.02217500	0.00811414	0.046	-0.0468118	0.0024618
		3.0	0.00464500	0.00811414	1.000	-0.0199918	0.0292818
	3.0	1.0	-.02682000*	0.00811414	0.014	-0.0514568	-0.0021832
		2.0	-0.00464500	0.00811414	1.000	-0.0292818	0.0199918
CH3S2	1.0	2.0	.02783833*	0.00629754	0.001	0.0087172	0.0469594
		3.0	.03310500*	0.00629754	0.000	0.0139839	0.0522261
	2.0	1.0	-.02783833*	0.00629754	0.001	-0.0469594	-0.0087172
		3.0	0.00526667	0.00629754	1.000	-0.0138544	0.0243878
	3.0	1.0	-.03310500*	0.00629754	0.000	-0.0522261	-0.0139839
		2.0	-0.00526667	0.00629754	1.000	-0.0243878	0.0138544
CH3W3	1.0	2.0	0.00960667	0.00621565	0.429	-0.0092658	0.0284791
		3.0	0.01663000	0.00621565	0.052	-0.0022425	0.0355025
	2.0	1.0	-0.00960667	0.00621565	0.429	-0.0284791	0.0092658
		3.0	0.00702333	0.00621565	0.829	-0.0118491	0.0258958

	3.0	1.0	-0.01663000	0.00621565	0.052	-0.0355025	0.0022425
		2.0	-0.00702333	0.00621565	0.829	-0.0258958	0.0118491
CH3R3	1.0	2.0	0.02674500	0.00926628	0.034	-0.0013900	0.0548800
		3.0	.03270833*	0.00926628	0.009	0.0045733	0.0608434
	2.0	1.0	-0.02674500	0.00926628	0.034	-0.0548800	0.0013900
		3.0	0.00596333	0.00926628	1.000	-0.0221717	0.0340984
	3.0	1.0	-.03270833*	0.00926628	0.009	-0.0608434	-0.0045733
		2.0	-0.00596333	0.00926628	1.000	-0.0340984	0.0221717
CH3S3	1.0	2.0	.03089500*	0.00838237	0.007	0.0054438	0.0563462
		3.0	.03598833*	0.00838237	0.002	0.0105371	0.0614396
	2.0	1.0	-.03089500*	0.00838237	0.007	-0.0563462	-0.0054438
		3.0	0.00509333	0.00838237	1.000	-0.0203579	0.0305446
	3.0	1.0	-.03598833*	0.00838237	0.002	-0.0614396	-0.0105371
		2.0	-0.00509333	0.00838237	1.000	-0.0305446	0.0203579
CH3W4	1.0	2.0	0.01596167	0.00942085	0.333	-0.0126427	0.0445660
		3.0	0.02474000	0.00942085	0.057	-0.0038644	0.0533444
	2.0	1.0	-0.01596167	0.00942085	0.333	-0.0445660	0.0126427
		3.0	0.00877833	0.00942085	1.000	-0.0198260	0.0373827
	3.0	1.0	-0.02474000	0.00942085	0.057	-0.0533444	0.0038644
		2.0	-0.00877833	0.00942085	1.000	-0.0373827	0.0198260
CH3R4	1.0	2.0	.03612500*	0.01058916	0.012	0.0039733	0.0682767
		3.0	.04192000*	0.01058916	0.004	0.0097683	0.0740717
	2.0	1.0	-.03612500*	0.01058916	0.012	-0.0682767	-0.0039733
		3.0	0.00579500	0.01058916	1.000	-0.0263567	0.0379467
	3.0	1.0	-.04192000*	0.01058916	0.004	-0.0740717	-0.0097683
		2.0	-0.00579500	0.01058916	1.000	-0.0379467	0.0263567
CH3S4	1.0	2.0	.03927000*	0.01030485	0.005	0.0079815	0.0705585
		3.0	.04516000*	0.01030485	0.002	0.0138715	0.0764485
	2.0	1.0	-.03927000*	0.01030485	0.005	-0.0705585	-0.0079815
		3.0	0.00589000	0.01030485	1.000	-0.0253985	0.0371785
	3.0	1.0	-.04516000*	0.01030485	0.002	-0.0764485	-0.0138715
		2.0	-0.00589000	0.01030485	1.000	-0.0371785	0.0253985
CH3W5	1.0	2.0	0.02976833	0.01168264	0.067	-0.0057035	0.0652401
		3.0	.04020333*	0.01168264	0.011	0.0047315	0.0756751
	2.0	1.0	-0.02976833	0.01168264	0.067	-0.0652401	0.0057035
		3.0	0.01043500	0.01168264	1.000	-0.0250368	0.0459068

	3.0	1.0	-.04020333*	0.01168264	0.011	-0.0756751	-0.0047315
		2.0	-0.01043500	0.01168264	1.000	-0.0459068	0.0250368
CH3R5	1.0	2.0	.03773000*	0.01172862	0.017	0.0021186	0.0733414
		3.0	.04410500*	0.01172862	0.006	0.0084936	0.0797164
	2.0	1.0	-.03773000*	0.01172862	0.017	-0.0733414	-0.0021186
		3.0	0.00637500	0.01172862	1.000	-0.0292364	0.0419864
	3.0	1.0	-.04410500*	0.01172862	0.006	-0.0797164	-0.0084936
		2.0	-0.00637500	0.01172862	1.000	-0.0419864	0.0292364
CH3S5	1.0	2.0	.03429167*	0.00935043	0.007	0.0059011	0.0626822
		3.0	.04360000*	0.00935043	0.001	0.0152094	0.0719906
	2.0	1.0	-.03429167*	0.00935043	0.007	-0.0626822	-0.0059011
		3.0	0.00930833	0.00935043	1.000	-0.0190822	0.0376989
	3.0	1.0	-.04360000*	0.00935043	0.001	-0.0719906	-0.0152094
		2.0	-0.00930833	0.00935043	1.000	-0.0376989	0.0190822
CH3W6	1.0	2.0	0.02985933	0.01174303	0.074	-0.0066265	0.0663452
		3.0	.04024000*	0.01226519	0.018	0.0021318	0.0783482
	2.0	1.0	-0.02985933	0.01174303	0.074	-0.0663452	0.0066265
		3.0	0.01038067	0.01174303	1.000	-0.0261052	0.0468665
	3.0	1.0	-.04024000*	0.01226519	0.018	-0.0783482	-0.0021318
		2.0	-0.01038067	0.01174303	1.000	-0.0468665	0.0261052
CH3R6	1.0	2.0	0.04135167	0.01407906	0.031	-0.0013964	0.0840997
		3.0	.04553833*	0.01407906	0.017	0.0027903	0.0882864
	2.0	1.0	-0.04135167	0.01407906	0.031	-0.0840997	0.0013964
		3.0	0.00418667	0.01407906	1.000	-0.0385614	0.0469347
	3.0	1.0	-.04553833*	0.01407906	0.017	-0.0882864	-0.0027903
		2.0	-0.00418667	0.01407906	1.000	-0.0469347	0.0385614
CH3S6	1.0	2.0	.03863500*	0.00889175	0.002	0.0116371	0.0656329
		3.0	.04891000*	0.00889175	0.000	0.0219121	0.0759079
	2.0	1.0	-.03863500*	0.00889175	0.002	-0.0656329	-0.0116371
		3.0	0.01027500	0.00889175	0.798	-0.0167229	0.0372729
	3.0	1.0	-.04891000*	0.00889175	0.000	-0.0759079	-0.0219121
		2.0	-0.01027500	0.00889175	0.798	-0.0372729	0.0167229
CH4W2	1.0	2.0	-0.00306167	0.00501014	1.000	-0.0182739	0.0121505
		3.0	-0.00420833	0.00501014	1.000	-0.0194205	0.0110039
	2.0	1.0	0.00306167	0.00501014	1.000	-0.0121505	0.0182739

		3.0	-0.00114667	0.00501014	1.000	-0.0163589	0.0140655
	3.0	1.0	0.00420833	0.00501014	1.000	-0.0110039	0.0194205
		2.0	0.00114667	0.00501014	1.000	-0.0140655	0.0163589
CH4R2	1.0	2.0	0.01004333	0.00820417	0.719	-0.0148669	0.0349535
		3.0	0.01887667	0.00820417	0.108	-0.0060335	0.0437869
	2.0	1.0	-0.01004333	0.00820417	0.719	-0.0349535	0.0148669
		3.0	0.00883333	0.00820417	0.896	-0.0160769	0.0337435
	3.0	1.0	-0.01887667	0.00820417	0.108	-0.0437869	0.0060335
		2.0	-0.00883333	0.00820417	0.896	-0.0337435	0.0160769
CH4S2	1.0	2.0	0.01524667	0.00705141	0.142	-0.0061634	0.0366567
		3.0	0.01744167	0.00705141	0.077	-0.0039684	0.0388517
	2.0	1.0	-0.01524667	0.00705141	0.142	-0.0366567	0.0061634
		3.0	0.00219500	0.00705141	1.000	-0.0192151	0.0236051
	3.0	1.0	-0.01744167	0.00705141	0.077	-0.0388517	0.0039684
		2.0	-0.00219500	0.00705141	1.000	-0.0236051	0.0192151
CH4W3	1.0	2.0	-0.00312000	0.00888369	1.000	-0.0300934	0.0238534
		3.0	-0.00245500	0.00888369	1.000	-0.0294284	0.0245184
	2.0	1.0	0.00312000	0.00888369	1.000	-0.0238534	0.0300934
		3.0	0.00066500	0.00888369	1.000	-0.0263084	0.0276384
	3.0	1.0	0.00245500	0.00888369	1.000	-0.0245184	0.0294284
		2.0	-0.00066500	0.00888369	1.000	-0.0276384	0.0263084
CH4R3	1.0	2.0	0.02111833	0.01376397	0.437	-0.0206730	0.0629096
		3.0	0.02720000	0.01376397	0.200	-0.0145913	0.0689913
	2.0	1.0	-0.02111833	0.01376397	0.437	-0.0629096	0.0206730
		3.0	0.00608167	0.01376397	1.000	-0.0357096	0.0478730
	3.0	1.0	-0.02720000	0.01376397	0.200	-0.0689913	0.0145913
		2.0	-0.00608167	0.01376397	1.000	-0.0478730	0.0357096
CH4S3	1.0	2.0	0.01906667	0.00690720	0.044	-0.0019055	0.0400389
		3.0	.02151000*	0.00690720	0.021	0.0005378	0.0424822
	2.0	1.0	-0.01906667	0.00690720	0.044	-0.0400389	0.0019055
		3.0	0.00244333	0.00690720	1.000	-0.0185289	0.0234155
	3.0	1.0	-.02151000*	0.00690720	0.021	-0.0424822	-0.0005378
		2.0	-0.00244333	0.00690720	1.000	-0.0234155	0.0185289
CH4W4	1.0	2.0	-0.00536500	0.01461057	1.000	-0.0497268	0.0389968
		3.0	0.00551000	0.01461057	1.000	-0.0388518	0.0498718
	2.0	1.0	0.00536500	0.01461057	1.000	-0.0389968	0.0497268

		3.0	0.01087500	0.01461057	1.000	-0.0334868	0.0552368
	3.0	1.0	-0.00551000	0.01461057	1.000	-0.0498718	0.0388518
		2.0	-0.01087500	0.01461057	1.000	-0.0552368	0.0334868
CH4R4	1.0	2.0	0.02417000	0.01145881	0.156	-0.0106222	0.0589622
		3.0	0.03088500	0.01145881	0.050	-0.0039072	0.0656772
	2.0	1.0	-0.02417000	0.01145881	0.156	-0.0589622	0.0106222
		3.0	0.00671500	0.01145881	1.000	-0.0280772	0.0415072
	3.0	1.0	-0.03088500	0.01145881	0.050	-0.0656772	0.0039072
		2.0	-0.00671500	0.01145881	1.000	-0.0415072	0.0280772
CH4S4	1.0	2.0	0.01897500	0.00772058	0.080	-0.0044669	0.0424169
		3.0	0.02171667	0.00772058	0.039	-0.0017252	0.0451585
	2.0	1.0	-0.01897500	0.00772058	0.080	-0.0424169	0.0044669
		3.0	0.00274167	0.00772058	1.000	-0.0207002	0.0261835
	3.0	1.0	-0.02171667	0.00772058	0.039	-0.0451585	0.0017252
		2.0	-0.00274167	0.00772058	1.000	-0.0261835	0.0207002
CH4W5	1.0	2.0	0.00694333	0.02197478	1.000	-0.0597783	0.0736650
		3.0	0.02660500	0.02197478	0.734	-0.0401167	0.0933267
	2.0	1.0	-0.00694333	0.02197478	1.000	-0.0736650	0.0597783
		3.0	0.01966167	0.02197478	1.000	-0.0470600	0.0863833
	3.0	1.0	-0.02660500	0.02197478	0.734	-0.0933267	0.0401167
		2.0	-0.01966167	0.02197478	1.000	-0.0863833	0.0470600
CH4R5	1.0	2.0	0.02338333	0.01330309	0.298	-0.0170086	0.0637753
		3.0	0.03492000	0.01330309	0.057	-0.0054719	0.0753119
	2.0	1.0	-0.02338333	0.01330309	0.298	-0.0637753	0.0170086
		3.0	0.01153667	0.01330309	1.000	-0.0288553	0.0519286
	3.0	1.0	-0.03492000	0.01330309	0.057	-0.0753119	0.0054719
		2.0	-0.01153667	0.01330309	1.000	-0.0519286	0.0288553
CH4S5	1.0	2.0	0.02436667	0.00879336	0.043	-0.0023325	0.0510658
		3.0	.02783667*	0.00879336	0.019	0.0011375	0.0545358
	2.0	1.0	-0.02436667	0.00879336	0.043	-0.0510658	0.0023325
		3.0	0.00347000	0.00879336	1.000	-0.0232291	0.0301691
	3.0	1.0	-.02783667*	0.00879336	0.019	-0.0545358	-0.0011375
		2.0	-0.00347000	0.00879336	1.000	-0.0301691	0.0232291
CH4W6	1.0	2.0	0.01633267	0.02236849	1.000	-0.0531668	0.0858321
		3.0	0.03479600	0.02336313	0.481	-0.0377938	0.1073858
	2.0	1.0	-0.01633267	0.02236849	1.000	-0.0858321	0.0531668

		3.0	0.01846333	0.02236849	1.000	-0.0510361	0.0879628
	3.0	1.0	-0.03479600	0.02336313	0.481	-0.1073858	0.0377938
		2.0	-0.01846333	0.02236849	1.000	-0.0879628	0.0510361
CH4R6	1.0	2.0	0.02651333	0.01653934	0.389	-0.0237048	0.0767315
		3.0	0.03985833	0.01653934	0.088	-0.0103598	0.0900765
	2.0	1.0	-0.02651333	0.01653934	0.389	-0.0767315	0.0237048
		3.0	0.01334500	0.01653934	1.000	-0.0368731	0.0635631
	3.0	1.0	-0.03985833	0.01653934	0.088	-0.0900765	0.0103598
		2.0	-0.01334500	0.01653934	1.000	-0.0635631	0.0368731
CH4S6	1.0	2.0	0.01976500	0.00794614	0.075	-0.0043617	0.0438917
		3.0	.02586667*	0.00794614	0.016	0.0017399	0.0499934
	2.0	1.0	-0.01976500	0.00794614	0.075	-0.0438917	0.0043617
		3.0	0.00610167	0.00794614	1.000	-0.0180251	0.0302284
	3.0	1.0	-.02586667*	0.00794614	0.016	-0.0499934	-0.0017399
		2.0	-0.00610167	0.00794614	1.000	-0.0302284	0.0180251

*. The mean difference is significant at the 0.025 level.

Ankle Angle - Descriptives

						95% Confidence Interval for Mean			
		N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
PLeftW2	1.0	6	11.05152	3.70931	1.51432	7.15883	14.94421	6.96000	17.16730
	2.0	6	9.20886	2.73791	1.11775	6.33560	12.08212	4.90257	13.24900
	3.0	6	9.24317	4.66878	1.90602	4.34359	14.14275	3.84100	14.99433
	Total	18	9.83452	3.66700	0.86432	8.01096	11.65807	3.84100	17.16730
PLeftR2	1.0	6	15.51959	4.22964	1.72674	11.08086	19.95833	11.12830	21.07730
	2.0	6	15.23052	4.91284	2.00566	10.07481	20.38623	9.81785	21.18570
	3.0	6	12.20160	7.13667	2.91353	4.71213	19.69108	2.63420	22.79930
	Total	18	14.31724	5.45206	1.28506	11.60599	17.02848	2.63420	22.79930
PLeftS2	1.0	6	15.29254	5.79193	2.36454	9.21428	21.37079	7.34918	21.70317
	2.0	6	14.13723	5.47962	2.23705	8.38672	19.88774	7.28150	20.95520
	3.0	6	12.25487	5.89542	2.40679	6.06801	18.44173	4.54830	22.78400
	Total	18	13.89488	5.52989	1.30341	11.14493	16.64483	4.54830	22.78400
PLeftW3	1.0	6	10.11462	3.48326	1.42204	6.45915	13.77008	6.86867	16.49163

	2.0	6	11.63894	5.17127	2.11116	6.21203	17.06585	4.20429	17.59500
	3.0	6	10.43645	3.78951	1.54706	6.45961	14.41330	5.48990	16.37350
	Total	18	10.73000	4.01412	0.94614	8.73383	12.72618	4.20429	17.59500
PLeftR3	1.0	6	16.63269	4.47132	1.82541	11.94032	21.32505	11.41755	22.22518
	2.0	6	14.76509	5.00222	2.04215	9.51558	20.01460	10.18455	21.38457
	3.0	6	12.69458	5.16226	2.10748	7.27712	18.11203	8.10567	21.32756
	Total	18	14.69745	4.88025	1.15029	12.27056	17.12434	8.10567	22.22518
PLeftS3	1.0	6	12.65761	4.42524	1.80660	8.01361	17.30162	6.53643	19.04886
	2.0	6	13.04446	6.09128	2.48676	6.65205	19.43688	4.74600	19.10970
	3.0	6	8.66513	6.88760	2.81185	1.43703	15.89322	1.02880	21.14150
	Total	18	11.45573	5.89698	1.38993	8.52323	14.38823	1.02880	21.14150
PLeftW4	1.0	6	9.09632	2.95136	1.20489	5.99906	12.19359	5.13210	14.08775
	2.0	6	13.60528	7.03060	2.87023	6.22712	20.98345	5.96167	24.28000
	3.0	6	10.84460	4.28868	1.75084	6.34391	15.34529	4.95450	18.35540
	Total	18	11.18207	5.11446	1.20549	8.63871	13.72543	4.95450	24.28000
PLeftR4	1.0	6	18.07534	4.21609	1.72121	13.65083	22.49986	14.10617	23.51942
	2.0	6	15.85320	3.44754	1.40745	12.23522	19.47117	12.87044	20.65400
	3.0	6	11.05943	6.32605	2.58260	4.42065	17.69821	4.05857	22.40288
	Total	18	14.99599	5.43778	1.28170	12.29184	17.70014	4.05857	23.51942
PLeftS4	1.0	6	14.08296	4.84087	1.97628	9.00278	19.16314	8.75856	20.98213
	2.0	6	14.60302	6.18608	2.52546	8.11113	21.09492	6.68583	22.07730
	3.0	6	10.25396	6.63139	2.70725	3.29475	17.21318	-0.68730	19.45271
	Total	18	12.97998	5.92143	1.39569	10.03532	15.92464	-0.68730	22.07730
PLeftW5	1.0	6	7.90302	3.92625	1.60288	3.78267	12.02337	4.49650	14.90764
	2.0	6	15.73296	6.19965	2.53100	9.22683	22.23910	9.63992	24.14070
	3.0	6	12.41604	5.02672	2.05215	7.14082	17.69125	7.17170	21.89150
	Total	18	12.01734	5.84581	1.37787	9.11029	14.92439	4.49650	24.14070
PLeftR5	1.0	6	19.46479	4.27151	1.74384	14.98211	23.94747	14.05242	25.00892
	2.0	6	14.61629	4.33943	1.77157	10.06233	19.17024	6.20140	18.46060
	3.0	6	9.87043	6.61212	2.69939	2.93144	16.80942	2.80625	21.49657
	Total	18	14.65050	6.32525	1.49087	11.50503	17.79597	2.80625	25.00892
PLeftS5	1.0	6	16.10789	5.48848	2.24066	10.34809	21.86770	9.57013	22.43788
	2.0	6	14.05030	9.41073	3.84191	4.17434	23.92625	-0.04840	27.44444
	3.0	6	9.37471	7.59117	3.09908	1.40827	17.34116	1.56750	23.53840
	Total	18	13.17763	7.76272	1.82969	9.31732	17.03794	-0.04840	27.44444
PLeftW6	1.0	5	11.33548	8.79304	3.93237	0.41748	22.25349	1.29440	25.31300

	2.0	6	17.31744	6.92286	2.82624	10.05234	24.58253	9.96742	28.56200
	3.0	6	12.75807	5.37857	2.19579	7.11361	18.40253	8.54580	23.38536
	Total	17	13.94885	7.08998	1.71957	10.30352	17.59418	1.29440	28.56200
PLeftR6	1.0	6	19.84979	4.66102	1.90285	14.95835	24.74124	13.49533	26.19800
	2.0	6	16.40053	3.31374	1.35283	12.92298	19.87809	12.29000	21.99200
	3.0	6	10.43093	4.82936	1.97158	5.36283	15.49903	5.69360	19.08900
	Total	18	15.56042	5.70160	1.34388	12.72508	18.39576	5.69360	26.19800
PLeftS6	1.0	6	16.31538	7.33345	2.99387	8.61940	24.01136	8.70713	27.94313
	2.0	6	14.21610	7.68716	3.13827	6.14891	22.28328	3.45925	24.65000
	3.0	6	10.20204	6.18092	2.52335	3.71557	16.68851	5.35850	22.50471
	Total	18	13.57784	7.15855	1.68729	10.01797	17.13771	3.45925	27.94313
PRightW2	1.0	6	9.44898	4.61483	1.88400	4.60601	14.29195	1.97900	16.30929
	2.0	6	9.97336	3.20582	1.30877	6.60906	13.33766	6.58183	13.95533
	3.0	6	9.70521	5.59629	2.28468	3.83226	15.57816	1.82483	18.35457
	Total	18	9.70918	4.30654	1.01506	7.56759	11.85078	1.82483	18.35457
PRightR2	1.0	6	15.79248	3.08903	1.26109	12.55074	19.03422	11.08782	19.37964
	2.0	6	16.54885	3.50645	1.43150	12.86906	20.22865	10.76811	21.18670
	3.0	6	13.24290	4.91689	2.00731	8.08295	18.40286	8.74200	22.26350
	Total	18	15.19475	3.95615	0.93247	13.22740	17.16209	8.74200	22.26350
PRightS2	1.0	6	20.00245	9.99560	4.08069	9.51271	30.49219	10.33486	38.57300
	2.0	6	10.43370	4.76800	1.94653	5.42998	15.43741	1.00583	14.22525
	3.0	6	14.17140	3.11170	1.27035	10.90587	17.43694	10.21040	19.07970
	Total	18	14.86918	7.43880	1.75334	11.16995	18.56841	1.00583	38.57300
PRightW3	1.0	6	10.15139	3.56142	1.45394	6.41391	13.88887	5.85644	14.42813
	2.0	6	11.38978	5.71352	2.33254	5.39380	17.38575	2.67933	18.03800
	3.0	6	10.11674	5.36192	2.18899	4.48975	15.74373	1.05883	15.57057
	Total	18	10.55264	4.70733	1.10953	8.21174	12.89354	1.05883	18.03800
PRightR3	1.0	6	16.86211	3.33903	1.36315	13.35801	20.36620	13.80850	21.78464
	2.0	6	16.08958	3.72594	1.52111	12.17945	19.99972	10.02527	20.04600
	3.0	6	13.79127	5.47474	2.23505	8.04589	19.53666	7.91130	23.03350
	Total	18	15.58099	4.24015	0.99941	13.47241	17.68956	7.91130	23.03350
PRightS3	1.0	6	15.03391	3.74642	1.52947	11.10228	18.96554	8.44340	20.08763
	2.0	6	11.30431	5.99561	2.44770	5.01230	17.59632	2.71155	18.68780
	3.0	6	7.60749	6.70891	2.73890	0.56692	14.64806	-1.83611	17.65567
	Total	18	11.31524	6.13773	1.44668	8.26302	14.36746	-1.83611	20.08763
PRightW4	1.0	6	8.51549	3.56349	1.45479	4.77584	12.25514	3.82010	14.09410

	2.0	6	12.85428	5.73877	2.34284	6.83181	18.87675	6.20764	18.77867
	3.0	6	12.29804	2.94853	1.20373	9.20374	15.39233	8.81064	16.14740
	Total	18	11.22260	4.46235	1.05179	9.00353	13.44168	3.82010	18.77867
PRightR4	1.0	6	18.71592	4.67099	1.90693	13.81401	23.61783	15.11131	25.85940
	2.0	6	16.45988	3.82925	1.56329	12.44132	20.47843	9.41700	19.93088
	3.0	6	13.36237	2.94042	1.20042	10.27659	16.44815	9.44873	17.68480
	Total	18	16.17939	4.28628	1.01028	14.04787	18.31090	9.41700	25.85940
PRightS4	1.0	6	14.88738	3.85736	1.57476	10.83933	18.93543	9.84070	21.54913
	2.0	6	11.65394	5.32782	2.17508	6.06273	17.24515	4.57582	17.61613
	3.0	6	10.05684	4.54457	1.85531	5.28761	14.82607	3.91620	15.03029
	Total	18	12.19939	4.80361	1.13222	9.81061	14.58817	3.91620	21.54913
PRightW5	1.0	6	7.95261	6.02580	2.46002	1.62892	14.27631	1.76800	18.21238
	2.0	6	15.67765	4.42470	1.80638	11.03421	20.32109	8.17469	20.72730
	3.0	6	11.75103	1.94357	0.79346	9.71137	13.79068	9.34754	13.80256
	Total	18	11.79376	5.29913	1.24902	9.15857	14.42896	1.76800	20.72730
PRightR5	1.0	6	20.21627	3.39852	1.38744	16.64974	23.78280	15.92850	24.63400
	2.0	6	14.11733	4.63718	1.89312	9.25090	18.98375	8.32300	19.11189
	3.0	6	11.54551	2.73121	1.11501	8.67928	14.41174	7.60650	15.91533
	Total	18	15.29304	5.09066	1.19988	12.76151	17.82456	7.60650	24.63400
PRightS5	1.0	6	17.18942	2.02343	0.82606	15.06596	19.31289	15.10163	20.18430
	2.0	6	14.01910	5.12032	2.09036	8.64566	19.39255	9.53290	23.13920
	3.0	6	6.60667	5.55447	2.26760	0.77761	12.43572	-0.97138	13.72840
	Total	18	12.60506	6.22991	1.46840	9.50700	15.70313	-0.97138	23.13920
PRightW6	1.0	5	12.35313	7.10723	3.17845	3.52834	21.17792	4.37500	20.27415
	2.0	6	17.46136	5.08716	2.07683	12.12271	22.80001	8.96700	22.95236
	3.0	6	13.19485	2.37049	0.96775	10.70718	15.68253	10.11890	16.04518
	Total	17	14.45312	5.27606	1.27963	11.74041	17.16582	4.37500	22.95236
PRightR6	1.0	6	20.88636	4.14420	1.69186	16.53729	25.23543	15.49650	25.99717
	2.0	6	18.06311	4.21968	1.72268	13.63482	22.49139	10.47725	21.83225
	3.0	6	10.96609	2.61972	1.06950	8.21686	13.71532	7.88400	13.63457
	Total	18	16.63852	5.54508	1.30699	13.88101	19.39603	7.88400	25.99717
PRightS6	1.0	6	15.66869	3.28031	1.33918	12.22622	19.11116	10.98033	19.28800
	2.0	6	17.65290	15.36810	6.27400	1.52507	33.78073	2.94267	46.21980
	3.0	6	12.63688	4.79172	1.95621	7.60827	17.66548	9.20443	20.37750
	Total	18	15.31949	9.15898	2.15879	10.76484	19.87414	2.94267	46.21980
PPLeftW2	1.0	6	12.62139	5.72428	2.33693	6.61412	18.62866	5.59717	21.59313

	2.0	6	25.50624	10.35211	4.22623	14.64237	36.37011	11.81125	42.17433
	3.0	6	25.38397	6.54491	2.67195	18.51551	32.25243	17.70588	35.60343
	Total	18	21.17053	9.61519	2.26632	16.38901	25.95206	5.59717	42.17433
PPLeftR2	1.0	6	11.28356	3.72196	1.51948	7.37760	15.18952	6.83200	15.60600
	2.0	6	18.43170	10.19472	4.16198	7.73299	29.13040	11.59820	38.56100
	3.0	6	17.45492	9.18619	3.75025	7.81461	27.09524	7.82933	34.36583
	Total	18	15.72339	8.37057	1.97296	11.56081	19.88598	6.83200	38.56100
PPLeftS2	1.0	6	15.71176	5.55209	2.26663	9.88520	21.53832	8.43700	22.54800
	2.0	6	19.58562	12.05919	4.92314	6.93028	32.24097	4.91670	35.24600
	3.0	6	21.80541	9.68886	3.95546	11.63757	31.97324	8.80825	37.97900
	Total	18	19.03426	9.28234	2.18787	14.41826	23.65026	4.91670	37.97900
PPLeftW3	1.0	6	19.50165	8.92988	3.64561	10.13031	28.87299	11.39175	33.82144
	2.0	6	30.49681	7.02170	2.86660	23.12799	37.86563	22.06922	43.14663
	3.0	6	27.02536	5.87496	2.39844	20.85997	33.19075	20.06080	34.47213
	Total	18	25.67461	8.39087	1.97775	21.50193	29.84729	11.39175	43.14663
PPLeftR3	1.0	6	17.75864	4.95381	2.02238	12.55993	22.95734	10.44486	25.11867
	2.0	6	21.54113	9.37662	3.82799	11.70097	31.38129	12.19210	38.58725
	3.0	6	23.05066	9.91713	4.04865	12.64327	33.45805	10.98670	37.90840
	Total	18	20.78348	8.20056	1.93289	16.70543	24.86152	10.44486	38.58725
PPLeftS3	1.0	6	18.11349	3.75934	1.53474	14.16831	22.05868	12.35760	23.27350
	2.0	6	21.88695	10.18909	4.15968	11.19416	32.57974	6.06320	35.06680
	3.0	6	22.97707	8.23533	3.36206	14.33462	31.61952	9.67300	34.14660
	Total	18	20.99251	7.69651	1.81409	17.16512	24.81989	6.06320	35.06680
PPLeftR4	1.0	6	20.12113	3.55764	1.45240	16.38762	23.85464	15.58425	25.50640
	2.0	6	23.26329	9.38836	3.83278	13.41081	33.11578	12.57690	38.60100
	3.0	6	25.10757	9.32044	3.80505	15.32637	34.88877	11.77800	39.37325
	Total	18	22.83066	7.72552	1.82092	18.98885	26.67247	11.77800	39.37325
PPLeftS4	1.0	6	18.31498	2.81799	1.15044	15.35768	21.27227	15.10160	23.53529
	2.0	6	24.97033	10.06549	4.10922	14.40725	35.53341	11.87890	38.15840
	3.0	6	24.35260	5.08355	2.07535	19.01774	29.68746	19.46040	32.63660
	Total	18	22.54597	7.01990	1.65461	19.05505	26.03688	11.87890	38.15840
PPLeftW5	1.0	6	22.32072	4.46963	1.82472	17.63013	27.01130	15.73890	29.15643
	2.0	6	29.24637	4.70283	1.91992	24.31104	34.18169	21.35520	35.90760
	3.0	6	22.36263	10.73648	4.38315	11.09538	33.62987	6.77310	33.99800
	Total	18	24.64324	7.58301	1.78733	20.87229	28.41418	6.77310	35.90760
PPLeftR5	1.0	6	23.02842	5.06906	2.06943	17.70877	28.34807	17.06440	29.39030

	2.0	6	24.80820	8.31370	3.39406	16.08350	33.53290	15.34533	36.31611
	3.0	6	25.29902	8.52387	3.47986	16.35377	34.24427	15.02889	38.27067
	Total	18	24.37855	7.08966	1.67105	20.85294	27.90415	15.02889	38.27067
PPLeftS5	1.0	6	18.11655	3.35068	1.36791	14.60023	21.63287	13.40275	23.74914
	2.0	6	26.88167	7.72301	3.15290	18.77687	34.98647	16.25120	38.12520
	3.0	6	30.40066	7.66291	3.12837	22.35893	38.44240	22.98014	40.99400
	Total	18	25.13296	8.14638	1.92012	21.08186	29.18406	13.40275	40.99400
PPLeftW6	1.0	5	22.67948	2.86736	1.28232	19.11918	26.23978	19.12020	26.54430
	2.0	6	25.50107	4.19314	1.71184	21.10064	29.90149	20.21180	32.32067
	3.0	6	23.18958	10.40526	4.24793	12.26994	34.10923	7.49140	34.56467
	Total	17	23.85537	6.55729	1.59038	20.48392	27.22682	7.49140	34.56467
PPLeftR6	1.0	6	24.82014	5.43825	2.22016	19.11304	30.52724	18.42080	30.78833
	2.0	6	24.42313	9.17383	3.74520	14.79579	34.05046	12.51588	37.32556
	3.0	6	25.34853	10.06165	4.10765	14.78947	35.90758	15.11830	38.68767
	Total	18	24.86393	7.96108	1.87644	20.90498	28.82288	12.51588	38.68767
PPLeftS6	1.0	6	20.94338	4.01804	1.64036	16.72670	25.16006	15.82863	27.55589
	2.0	6	26.91977	7.41142	3.02570	19.14195	34.69758	17.70950	37.12140
	3.0	6	29.29316	6.13312	2.50383	22.85684	35.72947	22.99600	40.35580
	Total	18	25.71877	6.71076	1.58174	22.38159	29.05595	15.82863	40.35580
PPRightW2	1.0	6	13.93791	4.99905	2.04085	8.69173	19.18409	6.67633	20.91871
	2.0	6	24.07637	9.84502	4.01921	13.74465	34.40808	13.54943	38.16986
	3.0	6	24.16601	6.13777	2.50573	17.72482	30.60721	14.57700	31.92875
	Total	18	20.72676	8.44622	1.99079	16.52656	24.92697	6.67633	38.16986
PPRightR2	1.0	6	10.95678	6.85280	2.79765	3.76520	18.14836	3.02390	19.85444
	2.0	6	17.43725	11.51905	4.70263	5.34875	29.52575	3.96522	35.88471
	3.0	6	17.86174	11.26811	4.60019	6.03658	29.68689	2.93983	34.76280
	Total	18	15.41859	10.03760	2.36589	10.42701	20.41017	2.93983	35.88471
PPRightS2	1.0	6	16.37339	6.75605	2.75815	9.28334	23.46343	8.74488	28.29214
	2.0	6	24.46286	8.83601	3.60728	15.19004	33.73568	11.90840	37.02000
	3.0	6	22.92578	13.25145	5.40988	9.01924	36.83233	8.18200	37.43089
	Total	18	21.25401	10.05302	2.36952	16.25476	26.25326	8.18200	37.43089
PPRightW3	1.0	6	18.87688	5.31393	2.16940	13.30025	24.45350	12.97367	26.57222
	2.0	6	27.75891	8.46384	3.45535	18.87665	36.64116	19.22350	40.45763
	3.0	6	26.08448	5.44103	2.22129	20.37447	31.79449	16.82411	31.75511
	Total	18	24.24009	7.33518	1.72892	20.59239	27.88779	12.97367	40.45763
PPRightR3	1.0	6	15.77299	5.87098	2.39682	9.61178	21.93420	11.06769	25.38280

	2.0	6	19.75496	8.07563	3.29686	11.28011	28.22982	9.57044	32.87863
	3.0	6	21.21740	12.33100	5.03411	8.27681	34.15799	5.21983	37.94800
	Total	18	18.91512	8.92439	2.10350	14.47712	23.35311	5.21983	37.94800
PPRightS3	1.0	6	17.33686	6.88080	2.80907	10.11591	24.55781	9.78371	28.94400
	2.0	6	26.43148	7.66374	3.12871	18.38888	34.47408	17.51283	35.99880
	3.0	6	26.45500	10.44826	4.26548	15.49023	37.41977	14.48000	37.13144
	Total	18	23.40778	9.10051	2.14501	18.88220	27.93336	9.78371	37.13144
PPRightW4	1.0	6	20.88828	4.46046	1.82098	16.20731	25.56925	14.77811	26.12833
	2.0	6	28.44946	5.94872	2.42855	22.20666	34.69226	20.43978	35.79678
	3.0	6	22.19507	9.26267	3.78147	12.47450	31.91565	6.18400	33.61100
	Total	18	23.84427	7.28170	1.71631	20.22317	27.46537	6.18400	35.79678
PPRightR4	1.0	6	19.57989	4.86439	1.98588	14.47503	24.68475	14.37200	26.86767
	2.0	6	21.58962	9.31972	3.80476	11.80917	31.37007	7.91067	33.63878
	3.0	6	23.16565	11.47116	4.68308	11.12740	35.20390	11.44729	38.02520
	Total	18	21.44505	8.57252	2.02056	17.18204	25.70806	7.91067	38.02520
PPRightS4	1.0	6	19.38132	5.33522	2.17809	13.78235	24.98029	13.02150	28.53650
	2.0	6	26.18431	9.62124	3.92785	16.08744	36.28118	16.32200	39.84980
	3.0	6	29.14500	9.43036	3.84993	19.24844	39.04156	15.20644	40.69320
	Total	18	24.90354	8.91322	2.10087	20.47110	29.33599	13.02150	40.69320
PPRightW5	1.0	6	21.91091	5.42536	2.21490	16.21734	27.60447	13.16264	27.61427
	2.0	6	26.72955	5.90943	2.41251	20.52799	32.93111	18.42042	34.11109
	3.0	6	24.45752	9.29677	3.79539	14.70116	34.21388	10.81500	34.62989
	Total	18	24.36599	6.96065	1.64064	20.90454	27.82744	10.81500	34.62989
PPRightR5	1.0	6	21.41908	5.96707	2.43604	15.15703	27.68113	15.97931	29.07764
	2.0	6	26.88875	14.61271	5.96561	11.55365	42.22384	9.05233	49.29775
	3.0	6	24.96083	12.21162	4.98537	12.14551	37.77614	7.81450	40.42120
	Total	18	24.42288	11.07105	2.60947	18.91738	29.92839	7.81450	49.29775
PPRightS5	1.0	6	18.89695	6.09293	2.48743	12.50281	25.29109	12.45625	29.33711
	2.0	6	28.11337	8.48340	3.46333	19.21060	37.01615	17.77127	40.11650
	3.0	6	29.60328	6.40661	2.61549	22.87996	36.32661	22.23380	38.93325
	Total	18	25.53787	8.24000	1.94219	21.44022	29.63552	12.45625	40.11650
PPRightW6	1.0	5	22.47317	3.99582	1.78699	17.51170	27.43464	16.81469	26.82620
	2.0	6	27.98879	8.58850	3.50624	18.97572	37.00187	16.37369	41.67443
	3.0	6	21.89339	12.77769	5.21647	8.48403	35.30275	4.62727	35.16756
	Total	17	24.21523	9.29376	2.25407	19.43683	28.99364	4.62727	41.67443
PPRightR6	1.0	6	23.26861	6.40104	2.61321	16.55113	29.98609	17.50033	31.20208

	2.0	6	26.08964	6.47757	2.64446	19.29185	32.88743	16.93520	36.03522
	3.0	6	25.09318	12.90277	5.26753	11.55255	38.63381	6.42600	40.91800
	Total	18	24.81714	8.64880	2.03854	20.51620	29.11809	6.42600	40.91800
PPRightS6	1.0	6	21.31962	6.74474	2.75353	14.24145	28.39779	11.42878	31.51988
	2.0	6	30.75088	8.03567	3.28055	22.31797	39.18380	21.03800	40.91800
	3.0	6	30.73097	8.54060	3.48669	21.76816	39.69379	18.14650	42.20200
	Total	18	27.60049	8.64350	2.03729	23.30218	31.89881	11.42878	42.20200

Ankle Angles - ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
PLeftW2	Between Groups	13.333	2	6.667	0.465	0.637
	Within Groups	215.263	15	14.351		
	Total	228.597	17			
PLeftR2	Between Groups	40.534	2	20.267	0.654	0.534
	Within Groups	464.790	15	30.986		
	Total	505.324	17			
PLeftS2	Between Groups	28.211	2	14.105	0.430	0.658
	Within Groups	491.643	15	32.776		
	Total	519.854	17			
PLeftW3	Between Groups	7.746	2	3.873	0.218	0.806
	Within Groups	266.177	15	17.745		
	Total	273.924	17			
PLeftR3	Between Groups	46.567	2	23.284	0.975	0.400
	Within Groups	358.319	15	23.888		
	Total	404.887	17			
PLeftS3	Between Groups	70.536	2	35.268	1.016	0.386
	Within Groups	520.628	15	34.709		
	Total	591.165	17			
PLeftW4	Between Groups	62.017	2	31.009	1.216	0.324
	Within Groups	382.663	15	25.511		
	Total	444.680	17			

Appendix D – ANOVA Descriptives & Charts

PLeftR4	Between Groups	154.282	2	77.141	3.321	0.064
	Within Groups	348.399	15	23.227		
	Total	502.681	17			
PLeftS4	Between Groups	67.692	2	33.846	0.961	0.405
	Within Groups	528.385	15	35.226		
	Total	596.077	17			
PLeftW5	Between Groups	185.355	2	92.677	3.514	0.056
	Within Groups	395.595	15	26.373		
	Total	580.949	17			
PLeftR5	Between Groups	276.166	2	138.083	5.127	0.020
	Within Groups	403.983	15	26.932		
	Total	680.149	17			
PLeftS5	Between Groups	142.861	2	71.430	1.215	0.324
	Within Groups	881.555	15	58.770		
	Total	1024.416	17			
PLeftW6	Between Groups	110.740	2	55.370	1.118	0.355
	Within Groups	693.545	14	49.539		
	Total	804.286	16			
PLeftR6	Between Groups	272.497	2	136.249	7.295	0.006
	Within Groups	280.144	15	18.676		
	Total	552.641	17			
PLeftS6	Between Groups	115.785	2	57.893	1.150	0.343
	Within Groups	755.378	15	50.359		
	Total	871.163	17			
PRightW2	Between Groups	0.825	2	0.413	0.020	0.981
	Within Groups	314.462	15	20.964		
	Total	315.288	17			
PRightR2	Between Groups	36.004	2	18.002	1.174	0.336
	Within Groups	230.065	15	15.338		
	Total	266.069	17			
PRightS2	Between Groups	279.065	2	139.532	3.163	0.071
	Within Groups	661.643	15	44.110		
	Total	940.708	17			
PRightW3	Between Groups	6.311	2	3.155	0.128	0.881
	Within Groups	370.391	15	24.693		
	Total	376.702	17			

PRightR3	Between Groups	30.618	2	15.309	0.835	0.453
	Within Groups	275.023	15	18.335		
	Total	305.641	17			
PRightS3	Between Groups	165.456	2	82.728	2.613	0.106
	Within Groups	474.963	15	31.664		
	Total	640.419	17			
PRightW4	Between Groups	66.884	2	33.442	1.847	0.192
	Within Groups	271.629	15	18.109		
	Total	338.513	17			
PRightR4	Between Groups	86.690	2	43.345	2.881	0.087
	Within Groups	225.637	15	15.042		
	Total	312.327	17			
PRightS4	Between Groups	72.680	2	36.340	1.706	0.215
	Within Groups	319.590	15	21.306		
	Total	392.270	17			
PRightW5	Between Groups	179.045	2	89.523	4.501	0.029
	Within Groups	298.329	15	19.889		
	Total	477.374	17			
PRightR5	Between Groups	237.987	2	118.993	8.812	0.003
	Within Groups	202.565	15	13.504		
	Total	440.551	17			
PRightS5	Between Groups	353.980	2	176.990	8.681	0.003
	Within Groups	305.820	15	20.388		
	Total	659.800	17			
PRightW6	Between Groups	85.846	2	42.923	1.671	0.223
	Within Groups	359.543	14	25.682		
	Total	445.389	16			
PRightR6	Between Groups	313.500	2	156.750	11.238	0.001
	Within Groups	209.215	15	13.948		
	Total	522.715	17			
PRightS6	Between Groups	76.579	2	38.290	0.426	0.661
	Within Groups	1349.497	15	89.966		
	Total	1426.076	17			
PPLeftW2	Between Groups	657.835	2	328.918	5.399	0.017
	Within Groups	913.847	15	60.923		
	Total	1571.683	17			

Appendix D – ANOVA Descriptives & Charts

PPLeftR2	Between Groups	180.271	2	90.136	1.338	0.292
	Within Groups	1010.857	15	67.390		
	Total	1191.129	17			
PPLeftS2	Between Groups	114.134	2	57.067	0.634	0.544
	Within Groups	1350.619	15	90.041		
	Total	1464.752	17			
PPLeftW3	Between Groups	379.102	2	189.551	3.477	0.057
	Within Groups	817.811	15	54.521		
	Total	1196.913	17			
PPLeftR3	Between Groups	89.183	2	44.592	0.635	0.544
	Within Groups	1054.054	15	70.270		
	Total	1143.237	17			
PPLeftS3	Between Groups	78.163	2	39.082	0.631	0.546
	Within Groups	928.854	15	61.924		
	Total	1007.017	17			
PPLeftR4	Between Groups	76.278	2	38.139	0.610	0.556
	Within Groups	938.344	15	62.556		
	Total	1014.622	17			
PPLeftS4	Between Groups	162.256	2	81.128	1.802	0.199
	Within Groups	675.488	15	45.033		
	Total	837.744	17			
PPLeftW5	Between Groups	190.705	2	95.352	1.818	0.196
	Within Groups	786.831	15	52.455		
	Total	977.536	17			
PPLeftR5	Between Groups	17.128	2	8.564	0.153	0.859
	Within Groups	837.347	15	55.823		
	Total	854.475	17			
PPLeftS5	Between Groups	480.220	2	240.110	5.558	0.016
	Within Groups	647.960	15	43.197		
	Total	1128.181	17			
PPLeftW6	Between Groups	25.823	2	12.912	0.273	0.765
	Within Groups	662.146	14	47.296		
	Total	687.969	16			
PPLeftR6	Between Groups	2.586	2	1.293	0.018	0.982
	Within Groups	1074.852	15	71.657		
	Total	1077.439	17			

Appendix D – ANOVA Descriptives & Charts

PPLeftS6	Between Groups	222.138	2	111.069	3.066	0.077
	Within Groups	543.445	15	36.230		
	Total	765.583	17			
PPRightW2	Between Groups	414.821	2	207.410	3.899	0.043
	Within Groups	797.936	15	53.196		
	Total	1212.756	17			
PPRightR2	Between Groups	179.710	2	89.855	0.879	0.435
	Within Groups	1533.099	15	102.207		
	Total	1712.809	17			
PPRightS2	Between Groups	221.472	2	110.736	1.110	0.355
	Within Groups	1496.601	15	99.773		
	Total	1718.073	17			
PPRightW3	Between Groups	267.288	2	133.644	3.096	0.075
	Within Groups	647.396	15	43.160		
	Total	914.684	17			
PPRightR3	Between Groups	95.273	2	47.636	0.568	0.579
	Within Groups	1258.689	15	83.913		
	Total	1353.962	17			
PPRightS3	Between Groups	331.706	2	165.853	2.312	0.133
	Within Groups	1076.221	15	71.748		
	Total	1407.928	17			
PPRightW4	Between Groups	195.993	2	97.997	2.084	0.159
	Within Groups	705.400	15	47.027		
	Total	901.393	17			
PPRightR4	Between Groups	38.761	2	19.381	0.240	0.789
	Within Groups	1210.535	15	80.702		
	Total	1249.296	17			
PPRightS4	Between Groups	300.752	2	150.376	2.149	0.151
	Within Groups	1049.823	15	69.988		
	Total	1350.575	17			
PPRightW5	Between Groups	69.733	2	34.867	0.694	0.515
	Within Groups	753.929	15	50.262		
	Total	823.662	17			
PPRightR5	Between Groups	92.356	2	46.178	0.348	0.712
	Within Groups	1991.304	15	132.754		
	Total	2083.660	17			

Appendix D – ANOVA Descriptives & Charts

PPRightS5	Between Groups	403.576	2	201.788	4.032	0.040
	Within Groups	750.682	15	50.045		
	Total	1154.258	17			
PPRightW6	Between Groups	132.958	2	66.479	0.745	0.493
	Within Groups	1249.024	14	89.216		
	Total	1381.982	16			
PPRightR6	Between Groups	24.560	2	12.280	0.148	0.864
	Within Groups	1247.068	15	83.138		
	Total	1271.629	17			
PPRightS6	Between Groups	355.045	2	177.523	2.910	0.086
	Within Groups	915.027	15	61.002		
	Total	1270.072	17			

Ankle Angle ANOVA Post Hoc - Bonferroni

Dependent Variable	(I) ^	(J) ^				97.5% Confidence Interval	
			Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
PLeftW2	1.0	2.0	1.842660470085470	2.187150343175110	1.000	-4.798147422683180	8.483468362854120
		3.0	1.808351190476190	2.187150343175110	1.000	-4.832456702292460	8.449159083244840
	2.0	1.0	-1.842660470085470	2.187150343175110	1.000	-8.483468362854120	4.798147422683180
		3.0	-0.034309279609275	2.187150343175110	1.000	-6.675117172377920	6.606498613159380
	3.0	1.0	-1.808351190476190	2.187150343175110	1.000	-8.449159083244840	4.832456702292460
		2.0	0.034309279609275	2.187150343175110	1.000	-6.606498613159380	6.675117172377920
PLeftR2	1.0	2.0	0.289074462574458	3.213822865142870	1.000	-9.469001983975720	10.047150909124600
		3.0	3.317991414141420	3.213822865142870	0.955	-6.440085032408760	13.076067860691600
	2.0	1.0	-0.289074462574458	3.213822865142870	1.000	-10.047150909124600	9.469001983975720
		3.0	3.028916951566960	3.213822865142870	1.000	-6.729159494983210	12.786993398117100
	3.0	1.0	-3.317991414141420	3.213822865142870	0.955	-13.076067860691600	6.440085032408760
		2.0	-3.028916951566960	3.213822865142870	1.000	-12.786993398117100	6.729159494983210
PLeftS2	1.0	2.0	1.155308080808090	3.305359463932540	1.000	-8.880699404921200	11.191315566537400
		3.0	3.037671969696970	3.305359463932540	1.000	-6.998335516032320	13.073679455426300
	2.0	1.0	-1.155308080808090	3.305359463932540	1.000	-11.191315566537400	8.880699404921200
		3.0	1.882363888888880	3.305359463932540	1.000	-8.153643596840410	11.918371374618200
	3.0	1.0	-3.037671969696970	3.305359463932540	1.000	-13.073679455426300	6.998335516032320

		2.0	-1.882363888888880	3.305359463932540	1.000	-11.918371374618200	8.153643596840410
PLeftW3	1.0	2.0	-1.524322156084660	2.432088588119280	1.000	-8.908831932604400	5.860187620435070
		3.0	-0.321836243386251	2.432088588119280	1.000	-7.706346019905990	7.062673533133480
	2.0	1.0	1.524322156084660	2.432088588119280	1.000	-5.860187620435070	8.908831932604400
		3.0	1.202485912698410	2.432088588119280	1.000	-6.182023863821320	8.586995689218150
	3.0	1.0	0.321836243386251	2.432088588119280	1.000	-7.062673533133480	7.706346019905990
		2.0	-1.202485912698410	2.432088588119280	1.000	-8.586995689218150	6.182023863821320
PLeftR3	1.0	2.0	1.867601731601730	2.821817146135990	1.000	-6.700234327078170	10.435437790281600
		3.0	3.938112746512740	2.821817146135990	0.549	-4.629723312167170	12.505948805192600
	2.0	1.0	-1.867601731601730	2.821817146135990	1.000	-10.435437790281600	6.700234327078170
		3.0	2.070511014911010	2.821817146135990	1.000	-6.497325043768900	10.638347073590900
	3.0	1.0	-3.938112746512740	2.821817146135990	0.549	-12.505948805192600	4.629723312167170
		2.0	-2.070511014911010	2.821817146135990	1.000	-10.638347073590900	6.497325043768900
PLeftS3	1.0	2.0	-0.386849353886879	3.401398807720800	1.000	-10.714459487891100	9.940760780117380
		3.0	3.992489748677230	3.401398807720800	0.776	-6.335120385327030	14.320099882681500
	2.0	1.0	0.386849353886879	3.401398807720800	1.000	-9.940760780117380	10.714459487891100
		3.0	4.379339102564110	3.401398807720800	0.652	-5.948271031440150	14.706949236568400
	3.0	1.0	-3.992489748677230	3.401398807720800	0.776	-14.320099882681500	6.335120385327030
		2.0	-4.379339102564110	3.401398807720800	0.652	-14.706949236568400	5.948271031440150
PLeftW4	1.0	2.0	-4.508961574074080	2.916097320878670	0.429	-13.363058945569800	4.345135797421600
		3.0	-1.748280723905730	2.916097320878670	1.000	-10.602378095401400	7.105816647589950
	2.0	1.0	4.508961574074080	2.916097320878670	0.429	-4.345135797421600	13.363058945569800
		3.0	2.760680850168350	2.916097320878670	1.000	-6.093416521327340	11.614778221664000
	3.0	1.0	1.748280723905730	2.916097320878670	1.000	-7.105816647589950	10.602378095401400
		2.0	-2.760680850168350	2.916097320878670	1.000	-11.614778221664000	6.093416521327340
PLeftR4	1.0	2.0	2.222144360269380	2.782481154848550	1.000	-6.226256488011440	10.670545208550200
		3.0	7.015913474025990	2.782481154848550	0.070	-1.432487374254830	15.464314322306800
	2.0	1.0	-2.222144360269380	2.782481154848550	1.000	-10.670545208550200	6.226256488011440
		3.0	4.793769113756610	2.782481154848550	0.316	-3.654631734524210	13.242169962037400
	3.0	1.0	-7.015913474025990	2.782481154848550	0.070	-15.464314322306800	1.432487374254830
		2.0	-4.793769113756610	2.782481154848550	0.316	-13.242169962037400	3.654631734524210
PLeftS4	1.0	2.0	-0.520064760702253	3.426643505127520	1.000	-10.924324945907700	9.884195424503220
		3.0	3.828998677248680	3.426643505127520	0.844	-6.575261507956800	14.233258862454100
	2.0	1.0	0.520064760702253	3.426643505127520	1.000	-9.884195424503220	10.924324945907700
		3.0	4.349063437950930	3.426643505127520	0.671	-6.055196747254540	14.753323623156400
	3.0	1.0	-3.828998677248680	3.426643505127520	0.844	-14.233258862454100	6.575261507956800

		2.0	-4.349063437950930	3.426643505127520	0.671	-14.753323623156400	6.055196747254540
PLeftW5	1.0	2.0	-7.829942195767190	2.964961395501670	0.056	-16.832404737239300	1.172520345704950
		3.0	-4.513016498316490	2.964961395501670	0.446	-13.515479039788600	4.489446043155660
	2.0	1.0	7.829942195767190	2.964961395501670	0.056	-1.172520345704950	16.832404737239300
		3.0	3.316925697450710	2.964961395501670	0.843	-5.685536844021440	12.319388238922900
	3.0	1.0	4.513016498316490	2.964961395501670	0.446	-4.489446043155660	13.515479039788600
		2.0	-3.316925697450710	2.964961395501670	0.843	-12.319388238922900	5.685536844021440
PLeftR5	1.0	2.0	4.848503793428800	2.996230244316920	0.379	-4.248899829097980	13.945907415955600
		3.0	9.594361257353775*	2.996230244316920	0.018	0.496957634826988	18.691764879880600
	2.0	1.0	-4.848503793428800	2.996230244316920	0.379	-13.945907415955600	4.248899829097980
		3.0	4.745857463924970	2.996230244316920	0.402	-4.351546158601820	13.843261086451800
	3.0	1.0	-9.594361257353775*	2.996230244316920	0.018	-18.691764879880600	-0.496957634826988
		2.0	-4.745857463924970	2.996230244316920	0.402	-13.843261086451800	4.351546158601820
PLeftS5	1.0	2.0	2.057597619047630	4.426072454633920	1.000	-11.381211917945300	15.496407156040500
		3.0	6.733180357142850	4.426072454633920	0.447	-6.705629179850030	20.171989894135700
	2.0	1.0	-2.057597619047630	4.426072454633920	1.000	-15.496407156040500	11.381211917945300
		3.0	4.675582738095230	4.426072454633920	0.923	-8.763226798897650	18.114392275088100
	3.0	1.0	-6.733180357142850	4.426072454633920	0.447	-20.171989894135700	6.705629179850030
		2.0	-4.675582738095230	4.426072454633920	0.923	-18.114392275088100	8.763226798897650
PLeftW6	1.0	2.0	-5.981954292929300	4.261956958186840	0.547	-19.060959351313000	7.097050765454360
		3.0	-1.422586175861170	4.261956958186840	1.000	-14.501591234244800	11.656418882522500
	2.0	1.0	5.981954292929300	4.261956958186840	0.547	-7.097050765454360	19.060959351313000
		3.0	4.559368117068130	4.063616516606090	0.842	-7.910973910654550	17.029710144790800
	3.0	1.0	1.422586175861170	4.261956958186840	1.000	-11.656418882522500	14.501591234244800
		2.0	-4.559368117068130	4.063616516606090	0.842	-17.029710144790800	7.910973910654550
PLeftR6	1.0	2.0	3.449260398860380	2.495078087776950	0.561	-4.126503338683800	11.025024136404600
		3.0	9.418866727716724*	2.495078087776950	0.006	1.843102990172540	16.994630465260900
	2.0	1.0	-3.449260398860380	2.495078087776950	0.561	-11.025024136404600	4.126503338683800
		3.0	5.969606328856340	2.495078087776950	0.091	-1.606157408687840	13.545370066400500
	3.0	1.0	-9.418866727716724*	2.495078087776950	0.006	-16.994630465260900	-1.843102990172540
		2.0	-5.969606328856340	2.495078087776950	0.091	-13.545370066400500	1.606157408687840
PLeftS6	1.0	2.0	2.099288065175560	4.097094073662540	1.000	-10.340649933003300	14.539226063354400
		3.0	6.113342261904760	4.097094073662540	0.469	-6.326595736274070	18.553280260083600
	2.0	1.0	-2.099288065175560	4.097094073662540	1.000	-14.539226063354400	10.340649933003300
		3.0	4.014054196729200	4.097094073662540	1.000	-8.425883801449630	16.453992194908000
	3.0	1.0	-6.113342261904760	4.097094073662540	0.469	-18.553280260083600	6.326595736274070

		2.0	-4.014054196729200	4.097094073662540	1.000	-16.453992194908000	8.425883801449630
PRightW2	1.0	2.0	-0.524377380952378	2.643492962986420	1.000	-8.550770714112050	7.502015952207300
		3.0	-0.256227436507935	2.643492962986420	1.000	-8.282620769667610	7.770165896651740
	2.0	1.0	0.524377380952378	2.643492962986420	1.000	-7.502015952207300	8.550770714112050
		3.0	0.268149944444444	2.643492962986420	1.000	-7.758243388715230	8.294543277604120
	3.0	1.0	0.256227436507935	2.643492962986420	1.000	-7.770165896651740	8.282620769667610
		2.0	-0.268149944444444	2.643492962986420	1.000	-8.294543277604120	7.758243388715230
PRightR2	1.0	2.0	-0.756372575757569	2.261098007126420	1.000	-7.621706519948360	6.108961368433220
		3.0	2.549579461279460	2.261098007126420	0.832	-4.315754482911330	9.414913405470250
	2.0	1.0	0.756372575757569	2.261098007126420	1.000	-6.108961368433220	7.621706519948360
		3.0	3.305952037037030	2.261098007126420	0.493	-3.559381907153770	10.171285981227800
	3.0	1.0	-2.549579461279460	2.261098007126420	0.832	-9.414913405470250	4.315754482911330
		2.0	-3.305952037037030	2.261098007126420	0.493	-10.171285981227800	3.559381907153770
PRightS2	1.0	2.0	9.568749867724860	3.834472087845850	0.074	-2.073793400974950	21.211293136424700
		3.0	5.831040608465600	3.834472087845850	0.447	-5.811502660234210	17.473583877165400
	2.0	1.0	-9.568749867724860	3.834472087845850	0.074	-21.211293136424700	2.073793400974950
		3.0	-3.737709259259260	3.834472087845850	1.000	-15.380252527959100	7.904834009440540
	3.0	1.0	-5.831040608465600	3.834472087845850	0.447	-17.473583877165400	5.811502660234210
		2.0	3.737709259259260	3.834472087845850	1.000	-7.904834009440540	15.380252527959100
PRightW3	1.0	2.0	-1.238384259259260	2.868956891777590	1.000	-9.949349936758770	7.472581418240240
		3.0	0.034652447089941	2.868956891777590	1.000	-8.676313230409560	8.745618124589440
	2.0	1.0	1.238384259259260	2.868956891777590	1.000	-7.472581418240240	9.949349936758770
		3.0	1.273036706349200	2.868956891777590	1.000	-7.437928971150300	9.984002383848710
	3.0	1.0	-0.034652447089941	2.868956891777590	1.000	-8.745618124589440	8.676313230409560
		2.0	-1.273036706349200	2.868956891777590	1.000	-9.984002383848710	7.437928971150300
PRightR3	1.0	2.0	0.772524851074870	2.472167460605890	1.000	-6.733675733565530	8.278725435715270
		3.0	3.070835120435130	2.472167460605890	0.700	-4.435365464205270	10.577035705075500
	2.0	1.0	-0.772524851074870	2.472167460605890	1.000	-8.278725435715270	6.733675733565530
		3.0	2.298310269360260	2.472167460605890	1.000	-5.207890315280140	9.804510854000660
	3.0	1.0	-3.070835120435130	2.472167460605890	0.700	-10.577035705075500	4.435365464205270
		2.0	-2.298310269360260	2.472167460605890	1.000	-9.804510854000660	5.207890315280140
PRightS3	1.0	2.0	3.729597979797980	3.248804912595000	0.807	-6.134693870530990	13.593889830127000
		3.0	7.426421759259250	3.248804912595000	0.112	-2.437870091069720	17.290713609588200
	2.0	1.0	-3.729597979797980	3.248804912595000	0.807	-13.593889830127000	6.134693870530990
		3.0	3.696823779461270	3.248804912595000	0.819	-6.167468070867700	13.561115629790200
	3.0	1.0	-7.426421759259250	3.248804912595000	0.112	-17.290713609588200	2.437870091069720

		2.0	-3.696823779461270	3.248804912595000	0.819	-13.561115629790200	6.167468070867700
PRightW4	1.0	2.0	-4.338793602693600	2.456867376289370	0.293	-11.798538798016000	3.120951592628790
		3.0	-3.782547979797980	2.456867376289370	0.433	-11.242293175120400	3.677197215524410
	2.0	1.0	4.338793602693600	2.456867376289370	0.293	-3.120951592628790	11.798538798016000
		3.0	0.556245622895622	2.456867376289370	1.000	-6.903499572426770	8.015990818218010
	3.0	1.0	3.782547979797980	2.456867376289370	0.433	-3.677197215524410	11.242293175120400
		2.0	-0.556245622895622	2.456867376289370	1.000	-8.015990818218010	6.903499572426770
PRightR4	1.0	2.0	2.256044447681930	2.239231631834970	0.989	-4.542896988067520	9.054985883431390
		3.0	5.353548698523690	2.239231631834970	0.091	-1.445392737225770	12.152490134273100
	2.0	1.0	-2.256044447681930	2.239231631834970	0.989	-9.054985883431390	4.542896988067520
		3.0	3.097504250841760	2.239231631834970	0.560	-3.701437184907700	9.896445686591210
	3.0	1.0	-5.353548698523690	2.239231631834970	0.091	-12.152490134273100	1.445392737225770
		2.0	-3.097504250841760	2.239231631834970	0.560	-9.896445686591210	3.701437184907700
PRightS4	1.0	2.0	3.233442340067340	2.664958036847800	0.731	-4.858125036734250	11.325009716868900
		3.0	4.830535714285720	2.664958036847800	0.270	-3.261031662515870	12.922103091087300
	2.0	1.0	-3.233442340067340	2.664958036847800	0.731	-11.325009716868900	4.858125036734250
		3.0	1.597093374218380	2.664958036847800	1.000	-6.494474002583210	9.688660751019960
	3.0	1.0	-4.830535714285720	2.664958036847800	0.270	-12.922103091087300	3.261031662515870
		2.0	-1.597093374218380	2.664958036847800	1.000	-9.688660751019960	6.494474002583210
PRightW5	1.0	2.0	-7.725038461538470	2.574786568480690	0.027	-15.542819721759900	0.092742798682983
		3.0	-3.798412678062690	2.574786568480690	0.482	-11.616193938284100	4.019368582158760
	2.0	1.0	7.725038461538470	2.574786568480690	0.027	-0.092742798682983	15.542819721759900
		3.0	3.926625783475770	2.574786568480690	0.444	-3.891155476745680	11.744407043697200
	3.0	1.0	3.798412678062690	2.574786568480690	0.482	-4.019368582158760	11.616193938284100
		2.0	-3.926625783475770	2.574786568480690	0.444	-11.744407043697200	3.891155476745680
PRightR5	1.0	2.0	6.098942180504650	2.121658438811300	0.035	-0.343013741813605	12.540898102822900
		3.0	8.670756410256402*	2.121658438811300	0.003	2.228800487938140	15.112712332574700
	2.0	1.0	-6.098942180504650	2.121658438811300	0.035	-12.540898102822900	0.343013741813605
		3.0	2.571814229751750	2.121658438811300	0.733	-3.870141692566510	9.013770152070010
	3.0	1.0	-8.670756410256402*	2.121658438811300	0.003	-15.112712332574700	-2.228800487938140
		2.0	-2.571814229751750	2.121658438811300	0.733	-9.013770152070010	3.870141692566510
PRightS5	1.0	2.0	3.170322107984610	2.606915417315400	0.728	-4.745011436922220	11.085655652891400
		3.0	10.582758134920638*	2.606915417315400	0.003	2.667424590013810	18.498091679827500
	2.0	1.0	-3.170322107984610	2.606915417315400	0.728	-11.085655652891400	4.745011436922220
		3.0	7.412436026936030	2.606915417315400	0.037	-0.502897517970795	15.327769571842900
	3.0	1.0	-10.582758134920638*	2.606915417315400	0.003	-18.498091679827500	-2.667424590013810

		2.0	-7.412436026936030	2.606915417315400	0.037	-15.327769571842900	0.502897517970795
PRightW6	1.0	2.0	-5.108227359307370	3.068648615949610	0.355	-14.525232543583400	4.308777824968700
		3.0	-0.841720867650888	3.068648615949610	1.000	-10.258726051927000	8.575284316625180
	2.0	1.0	5.108227359307370	3.068648615949610	0.355	-4.308777824968700	14.525232543583400
		3.0	4.266506491656480	2.925841654848210	0.501	-4.712255654282540	13.245268637595500
	3.0	1.0	0.841720867650888	3.068648615949610	1.000	-8.575284316625180	10.258726051927000
		2.0	-4.266506491656480	2.925841654848210	0.501	-13.245268637595500	4.712255654282540
PRightR6	1.0	2.0	2.823257300569780	2.156207296774960	0.630	-3.723598739551160	9.370113340690720
		3.0	9.920267710622700*	2.156207296774960	0.001	3.373411670501760	16.467123750743600
	2.0	1.0	-2.823257300569780	2.156207296774960	0.630	-9.370113340690720	3.723598739551160
		3.0	7.097010410052917*	2.156207296774960	0.015	0.550154369931977	13.643866450173900
	3.0	1.0	-9.920267710622700*	2.156207296774960	0.001	-16.467123750743600	-3.373411670501760
		2.0	-7.097010410052917*	2.156207296774960	0.015	-13.643866450173900	-0.550154369931977
PRightS6	1.0	2.0	-1.984215079365080	5.476205820080670	1.000	-18.611526935587900	14.643096776857800
		3.0	3.031813293650790	5.476205820080670	1.000	-13.595498562572000	19.659125149873600
	2.0	1.0	1.984215079365080	5.476205820080670	1.000	-14.643096776857800	18.611526935587900
		3.0	5.016028373015870	5.476205820080670	1.000	-11.611283483207000	21.643340229238700
	3.0	1.0	-3.031813293650790	5.476205820080670	1.000	-19.659125149873600	13.595498562572000
		2.0	-5.016028373015870	5.476205820080670	1.000	-21.643340229238700	11.611283483207000
PPLeftW2	1.0	2.0	-12.884850000000000	4.506408538901910	0.036	-26.567582641842800	0.797882641842858
		3.0	-12.762579563492100	4.506408538901910	0.038	-26.445312205334900	0.920153078350772
	2.0	1.0	12.884850000000000	4.506408538901910	0.036	-0.797882641842858	26.567582641842800
		3.0	0.122270436507915	4.506408538901910	1.000	-13.560462205334900	13.805003078350800
	3.0	1.0	12.762579563492100	4.506408538901910	0.038	-0.920153078350772	26.445312205334900
		2.0	-0.122270436507915	4.506408538901910	1.000	-13.805003078350800	13.560462205334900
PPLeftR2	1.0	2.0	-7.148138095238120	4.739567408018980	0.457	-21.538807099632900	7.242530909156700
		3.0	-6.171366111111100	4.739567408018980	0.638	-20.562035115505900	8.219302893283730
	2.0	1.0	7.148138095238120	4.739567408018980	0.457	-7.242530909156700	21.538807099632900
		3.0	0.976771984127023	4.739567408018980	1.000	-13.413897020267800	15.367440988521800
	3.0	1.0	6.171366111111100	4.739567408018980	0.638	-8.219302893283730	20.562035115505900
		2.0	-0.976771984127023	4.739567408018980	1.000	-15.367440988521800	13.413897020267800
PPLeftS2	1.0	2.0	-3.873862698412700	5.478480391989690	1.000	-20.508080799162000	12.760355402336600
		3.0	-6.093646031746030	5.478480391989690	0.851	-22.727864132495300	10.540572069003300
	2.0	1.0	3.873862698412700	5.478480391989690	1.000	-12.760355402336600	20.508080799162000
		3.0	-2.219783333333340	5.478480391989690	1.000	-18.854001434082600	14.414434767416000
	3.0	1.0	6.093646031746030	5.478480391989690	0.851	-10.540572069003300	22.727864132495300

		2.0	2.219783333333340	5.478480391989690	1.000	-14.414434767416000	18.854001434082600
PPLeftW3	1.0	2.0	-10.995163425925900	4.263047508607940	0.063	-23.938983054398900	1.948656202547030
		3.0	-7.523714417989410	4.263047508607940	0.294	-20.467534046462400	5.420105210483550
	2.0	1.0	10.995163425925900	4.263047508607940	0.063	-1.948656202547030	23.938983054398900
		3.0	3.471449007936520	4.263047508607940	1.000	-9.472370620536440	16.415268636409500
	3.0	1.0	7.523714417989410	4.263047508607940	0.294	-5.420105210483550	20.467534046462400
		2.0	-3.471449007936520	4.263047508607940	1.000	-16.415268636409500	9.472370620536440
PPLeftR3	1.0	2.0	-3.782494642857150	4.839774020892890	1.000	-18.477419304736700	10.912430019022400
		3.0	-5.292026984126980	4.839774020892890	0.874	-19.986951646006500	9.402897677752550
	2.0	1.0	3.782494642857150	4.839774020892890	1.000	-10.912430019022400	18.477419304736700
		3.0	-1.509532341269840	4.839774020892890	1.000	-16.204457003149400	13.185392320609700
	3.0	1.0	5.292026984126980	4.839774020892890	0.874	-9.402897677752550	19.986951646006500
		2.0	1.509532341269840	4.839774020892890	1.000	-13.185392320609700	16.204457003149400
PPLeftS3	1.0	2.0	-3.773459126984130	4.543258089848480	1.000	-17.568077442134500	10.021159188166300
		3.0	-4.863575529100530	4.543258089848480	0.904	-18.658193844250900	8.931042786049860
	2.0	1.0	3.773459126984130	4.543258089848480	1.000	-10.021159188166300	17.568077442134500
		3.0	-1.090116402116400	4.543258089848480	1.000	-14.884734717266800	12.704501913034000
	3.0	1.0	4.863575529100530	4.543258089848480	0.904	-8.931042786049860	18.658193844250900
		2.0	1.090116402116400	4.543258089848480	1.000	-12.704501913034000	14.884734717266800
PPLeftR4	1.0	2.0	-3.142161111111120	4.566407978522370	1.000	-17.007069044852200	10.722746822630000
		3.0	-4.986438888888900	4.566407978522370	0.876	-18.851346822630000	8.878469044852180
	2.0	1.0	3.142161111111120	4.566407978522370	1.000	-10.722746822630000	17.007069044852200
		3.0	-1.844277777777780	4.566407978522370	1.000	-15.709185711518900	12.020630155963300
	3.0	1.0	4.986438888888900	4.566407978522370	0.876	-8.878469044852180	18.851346822630000
		2.0	1.844277777777780	4.566407978522370	1.000	-12.020630155963300	15.709185711518900
PPLeftS4	1.0	2.0	-6.655349801587280	3.874382666157000	0.319	-18.419072889626300	5.108373286451730
		3.0	-6.037619907407400	3.874382666157000	0.420	-17.801342995446400	5.726103180631610
	2.0	1.0	6.655349801587280	3.874382666157000	0.319	-5.108373286451730	18.419072889626300
		3.0	0.617729894179885	3.874382666157000	1.000	-11.145993193859100	12.381452982218900
	3.0	1.0	6.037619907407400	3.874382666157000	0.420	-5.726103180631610	17.801342995446400
		2.0	-0.617729894179885	3.874382666157000	1.000	-12.381452982218900	11.145993193859100
PPLeftW5	1.0	2.0	-6.925650793650780	4.181523022188350	0.355	-19.621938991758900	5.770637404457340
		3.0	-0.041912367724848	4.181523022188350	1.000	-12.738200565833000	12.654375830383300
	2.0	1.0	6.925650793650780	4.181523022188350	0.355	-5.770637404457340	19.621938991758900
		3.0	6.883738425925930	4.181523022188350	0.362	-5.812549772182190	19.580026624034000
	3.0	1.0	0.041912367724848	4.181523022188350	1.000	-12.654375830383300	12.738200565833000

		2.0	-6.883738425925930	4.181523022188350	0.362	-19.580026624034000	5.812549772182190
PPLeftR5	1.0	2.0	-1.779777777777780	4.313665105745950	1.000	-14.877286767220400	11.317731211664800
		3.0	-2.270595767195780	4.313665105745950	1.000	-15.368104756638400	10.826913222246800
	2.0	1.0	1.779777777777780	4.313665105745950	1.000	-11.317731211664800	14.877286767220400
		3.0	-0.490817989418002	4.313665105745950	1.000	-13.588326978860600	12.606691000024600
	3.0	1.0	2.270595767195780	4.313665105745950	1.000	-10.826913222246800	15.368104756638400
		2.0	0.490817989418002	4.313665105745950	1.000	-12.606691000024600	13.588326978860600
PPLeftS5	1.0	2.0	-8.765123412698400	3.794617045173620	0.107	-20.286655483987700	2.756408658590900
		3.0	-12.284113095238101*	3.794617045173620	0.017	-23.805645166527400	-0.762581023948805
	2.0	1.0	8.765123412698400	3.794617045173620	0.107	-2.756408658590900	20.286655483987700
		3.0	-3.518989682539700	3.794617045173620	1.000	-15.040521753829000	8.002542388749600
	3.0	1.0	12.284113095238101*	3.794617045173620	0.017	0.762581023948805	23.805645166527400
		2.0	3.518989682539700	3.794617045173620	1.000	-8.002542388749600	15.040521753829000
PPLeftW6	1.0	2.0	-2.821585873015880	4.164362174787290	1.000	-15.601094085636600	9.957922339604810
		3.0	-0.510101944444450	4.164362174787290	1.000	-13.289610157065100	12.269406268176200
	2.0	1.0	2.821585873015880	4.164362174787290	1.000	-9.957922339604810	15.601094085636600
		3.0	2.311483928571430	3.970563541729100	1.000	-9.873299061119200	14.496266918262100
	3.0	1.0	0.510101944444450	4.164362174787290	1.000	-12.269406268176200	13.289610157065100
		2.0	-2.311483928571430	3.970563541729100	1.000	-14.496266918262100	9.873299061119200
PPLeftR6	1.0	2.0	0.397012962962947	4.887290693972360	1.000	-14.442185776192000	15.236211702117900
		3.0	-0.528388888888905	4.887290693972360	1.000	-15.367587628043900	14.310809850266100
	2.0	1.0	-0.397012962962947	4.887290693972360	1.000	-15.236211702117900	14.442185776192000
		3.0	-0.925401851851852	4.887290693972360	1.000	-15.764600591006800	13.913796887303100
	3.0	1.0	0.528388888888905	4.887290693972360	1.000	-14.310809850266100	15.367587628043900
		2.0	0.925401851851852	4.887290693972360	1.000	-13.913796887303100	15.764600591006800
PPLeftS6	1.0	2.0	-5.976386574074060	3.475134104916350	0.318	-16.527877953882900	4.575104805734740
		3.0	-8.349775859788350	3.475134104916350	0.089	-18.901267239597200	2.201715520020450
	2.0	1.0	5.976386574074060	3.475134104916350	0.318	-4.575104805734740	16.527877953882900
		3.0	-2.373389285714290	3.475134104916350	1.000	-12.924880665523100	8.178102094094510
	3.0	1.0	8.349775859788350	3.475134104916350	0.089	-2.201715520020450	18.901267239597200
		2.0	2.373389285714290	3.475134104916350	1.000	-8.178102094094510	12.924880665523100
PPRightW2	1.0	2.0	-10.138453042328000	4.210926472651170	0.088	-22.924018443769500	2.647112359113360
		3.0	-10.228099867724900	4.210926472651170	0.085	-23.013665269166300	2.557465533716550
	2.0	1.0	10.138453042328000	4.210926472651170	0.088	-2.647112359113360	22.924018443769500
		3.0	-0.089646825396816	4.210926472651170	1.000	-12.875212226838200	12.695918576044600
	3.0	1.0	10.228099867724900	4.210926472651170	0.085	-2.557465533716550	23.013665269166300

		2.0	0.089646825396816	4.210926472651170	1.000	-12.695918576044600	12.875212226838200
PPRightR2	1.0	2.0	-6.480471554834060	5.836853653422110	0.853	-24.202812376778100	11.241869267110000
		3.0	-6.904957996633000	5.836853653422110	0.766	-24.627298818577000	10.817382825311000
	2.0	1.0	6.480471554834060	5.836853653422110	0.853	-11.241869267110000	24.202812376778100
		3.0	-0.424486441798937	5.836853653422110	1.000	-18.146827263743000	17.297854380145100
	3.0	1.0	6.904957996633000	5.836853653422110	0.766	-10.817382825311000	24.627298818577000
		2.0	0.424486441798937	5.836853653422110	1.000	-17.297854380145100	18.146827263743000
PPRightS2	1.0	2.0	-8.089471266233770	5.766957670324850	0.543	-25.599588087357000	9.420645554889490
		3.0	-6.552395171957670	5.766957670324850	0.821	-24.062511993080900	10.957721649165600
	2.0	1.0	8.089471266233770	5.766957670324850	0.543	-9.420645554889490	25.599588087357000
		3.0	1.537076094276100	5.766957670324850	1.000	-15.973040726847200	19.047192915399400
	3.0	1.0	6.552395171957670	5.766957670324850	0.821	-10.957721649165600	24.062511993080900
		2.0	-1.537076094276100	5.766957670324850	1.000	-19.047192915399400	15.973040726847200
PPRightW3	1.0	2.0	-8.882031944444450	3.792964826306930	0.100	-20.398547411308400	2.634483522419500
		3.0	-7.207605026455020	3.792964826306930	0.230	-18.724120493319000	4.308910440408930
	2.0	1.0	8.882031944444450	3.792964826306930	0.100	-2.634483522419500	20.398547411308400
		3.0	1.674426917989430	3.792964826306930	1.000	-9.842088548874520	13.190942384853400
	3.0	1.0	7.207605026455020	3.792964826306930	0.230	-4.308910440408930	18.724120493319000
		2.0	-1.674426917989430	3.792964826306930	1.000	-13.190942384853400	9.842088548874520
PPRightR3	1.0	2.0	-3.981976579901570	5.288748792497920	1.000	-20.040115808275100	12.076162648472000
		3.0	-5.444412354312360	5.288748792497920	0.959	-21.502551582685900	10.613726874061200
	2.0	1.0	3.981976579901570	5.288748792497920	1.000	-12.076162648472000	20.040115808275100
		3.0	-1.462435774410790	5.288748792497920	1.000	-17.520575002784300	14.595703453962700
	3.0	1.0	5.444412354312360	5.288748792497920	0.959	-10.613726874061200	21.502551582685900
		2.0	1.462435774410790	5.288748792497920	1.000	-14.595703453962700	17.520575002784300
PPRightS3	1.0	2.0	-9.094623095238090	4.890401954232770	0.248	-23.943268501723600	5.754022311247400
		3.0	-9.118139761904770	4.890401954232770	0.246	-23.966785168390300	5.730505644580720
	2.0	1.0	9.094623095238090	4.890401954232770	0.248	-5.754022311247400	23.943268501723600
		3.0	-0.023516666666680	4.890401954232770	1.000	-14.872162073152200	14.825128739818800
	3.0	1.0	9.118139761904770	4.890401954232770	0.246	-5.730505644580720	23.966785168390300
		2.0	0.023516666666680	4.890401954232770	1.000	-14.825128739818800	14.872162073152200
PPRightW4	1.0	2.0	-7.561180639730640	3.959237695657250	0.226	-19.582547630213200	4.460186350751930
		3.0	-1.306795454545470	3.959237695657250	1.000	-13.328162445028000	10.714571535937100
	2.0	1.0	7.561180639730640	3.959237695657250	0.226	-4.460186350751930	19.582547630213200
		3.0	6.254385185185170	3.959237695657250	0.405	-5.766981805297390	18.275752175667700
	3.0	1.0	1.306795454545470	3.959237695657250	1.000	-10.714571535937100	13.328162445028000

		2.0	-6.254385185185170	3.959237695657250	0.405	-18.275752175667700	5.766981805297390
PPRightR4	1.0	2.0	-2.009730555555560	5.186596737636700	1.000	-17.757707213577400	13.738246102466200
		3.0	-3.585760317460330	5.186596737636700	1.000	-19.333736975482100	12.162216340561500
	2.0	1.0	2.009730555555560	5.186596737636700	1.000	-13.738246102466200	17.757707213577400
		3.0	-1.576029761904780	5.186596737636700	1.000	-17.324006419926600	14.171946896117000
	3.0	1.0	3.585760317460330	5.186596737636700	1.000	-12.162216340561500	19.333736975482100
		2.0	1.576029761904780	5.186596737636700	1.000	-14.171946896117000	17.324006419926600
PPRightS4	1.0	2.0	-6.802989880952380	4.830051124578150	0.538	-21.468393075874300	7.862413313969490
		3.0	-9.763684788359790	4.830051124578150	0.184	-24.429087983281700	4.901718406562090
	2.0	1.0	6.802989880952380	4.830051124578150	0.538	-7.862413313969490	21.468393075874300
		3.0	-2.960694907407400	4.830051124578150	1.000	-17.626098102329300	11.704708287514500
	3.0	1.0	9.763684788359790	4.830051124578150	0.184	-4.901718406562090	24.429087983281700
		2.0	2.960694907407400	4.830051124578150	1.000	-11.704708287514500	17.626098102329300
PPRightW5	1.0	2.0	-4.818644871794870	4.093161754948570	0.772	-17.246643236635700	7.609353493045920
		3.0	-2.546611959336950	4.093161754948570	1.000	-14.974610324177700	9.881386405503840
	2.0	1.0	4.818644871794870	4.093161754948570	0.772	-7.609353493045920	17.246643236635700
		3.0	2.272032912457920	4.093161754948570	1.000	-10.155965452382900	14.700031277298700
	3.0	1.0	2.546611959336950	4.093161754948570	1.000	-9.881386405503840	14.974610324177700
		2.0	-2.272032912457920	4.093161754948570	1.000	-14.700031277298700	10.155965452382900
PPRightR5	1.0	2.0	-5.469666767029260	6.652157389590390	1.000	-25.667500644603900	14.728167110545400
		3.0	-3.541745007770000	6.652157389590390	1.000	-23.739578885344600	16.656088869804600
	2.0	1.0	5.469666767029260	6.652157389590390	1.000	-14.728167110545400	25.667500644603900
		3.0	1.927921759259260	6.652157389590390	1.000	-18.269912118315400	22.125755636833900
	3.0	1.0	3.541745007770000	6.652157389590390	1.000	-16.656088869804600	23.739578885344600
		2.0	-1.927921759259260	6.652157389590390	1.000	-22.125755636833900	18.269912118315400
PPRightS5	1.0	2.0	-9.216421618566620	4.084339436005740	0.118	-21.617632924414900	3.184789687281700
		3.0	-10.706331256613800	4.084339436005740	0.058	-23.107542562462100	1.694880049234570
	2.0	1.0	9.216421618566620	4.084339436005740	0.118	-3.184789687281700	21.617632924414900
		3.0	-1.489909638047130	4.084339436005740	1.000	-13.891120943895400	10.911301667801200
	3.0	1.0	10.706331256613800	4.084339436005740	0.058	-1.694880049234570	23.107542562462100
		2.0	1.489909638047130	4.084339436005740	1.000	-10.911301667801200	13.891120943895400
PPRightW6	1.0	2.0	-5.515622784437790	5.719487538264990	1.000	-23.067467436607700	12.036221867732200
		3.0	0.579778092463066	5.719487538264990	1.000	-16.972066559706900	18.131622744633000
	2.0	1.0	5.515622784437790	5.719487538264990	1.000	-12.036221867732200	23.067467436607700
		3.0	6.095400876900860	5.453317397392040	0.847	-10.639626371193500	22.830428124995200
	3.0	1.0	-0.579778092463066	5.719487538264990	1.000	-18.131622744633000	16.972066559706900

		2.0	-6.095400876900860	5.453317397392040	0.847	-22.830428124995200	10.639626371193500
PPRightR6	1.0	2.0	-2.821026923076930	5.264278883298790	1.000	-18.804868576685200	13.162814730531400
		3.0	-1.824567663817680	5.264278883298790	1.000	-17.808409317426000	14.159273989790600
	2.0	1.0	2.821026923076930	5.264278883298790	1.000	-13.162814730531400	18.804868576685200
		3.0	0.996459259259250	5.264278883298790	1.000	-14.987382394349000	16.980300912867500
	3.0	1.0	1.824567663817680	5.264278883298790	1.000	-14.159273989790600	17.808409317426000
		2.0	-0.996459259259250	5.264278883298790	1.000	-16.980300912867500	14.987382394349000
PPRightS6	1.0	2.0	-9.431259537037040	4.509315501455090	0.162	-23.122818540509500	4.260299466435410
		3.0	-9.411350013227520	4.509315501455090	0.163	-23.102909016700000	4.280208990244930
	2.0	1.0	9.431259537037040	4.509315501455090	0.162	-4.260299466435410	23.122818540509500
		3.0	0.019909523809520	4.509315501455090	1.000	-13.671649479662900	13.711468527282000
	3.0	1.0	9.411350013227520	4.509315501455090	0.163	-4.280208990244930	23.102909016700000
		2.0	-0.019909523809520	4.509315501455090	1.000	-13.711468527282000	13.671649479662900

*. The mean difference is significant at the 0.025 level.

APPENDIX E: Bonferroni Adjustment ANOVA & T-Test Charts

EMG with Bonferroni - ANOVA

ANOVA < .025			
CH1	Walking	Running	Skipping
2	0.864	0.044	0.004
3	0.728	0.026	0.002
4	0.269	0.001	0.002
5	0.539	0.075	0.079
6	0.014	0.025	0.001
CH2			
2	0.001	0.000	0.000
3	0.001	0.000	0.000
4	0.006	0.000	0.000
5	0.002	0.000	0.000
6	0.000	0.000	0.000
CH3			
2	0.031	0.011	0.000
3	0.053	0.007	0.001
4	0.055	0.002	0.001
5	0.010	0.004	0.001
6	0.027	0.010	0.000
CH4			
2	0.692	0.103	0.052
3	0.934	0.151	0.014
4	0.762	0.040	0.026
5	0.472	0.054	0.013
6	0.094	0.080	0.014

EMG with Bonferroni – T-Tests

MARTIAN	0.025			LUNAR			
CH1	Walking	Running	Skipping	CH1	Walking	Running	Skipping
2	0.9977	0.1656	0.012	2	0.6724	0.0304	0.0078
3	0.5283	0.1656	0.0184	3	0.4455	0.0175	0.0038
4	0.6746	0.0134	0.0196	4	0.1492	0.0011	0.004
5	0.6905	0.1841	0.1114	5	0.2861	0.0588	0.0807
6	0.2586	0.1148	0.0069	6	0.9246	0.0155	0.0018
CH2				CH2			
2	0.0114	0.0025	1.55E-04	2	0.0038	0.0011	1.27E-05
3	0.0172	2.83E-04	0.0022	3	0.0046	7.19E-05	5.64E-04
4	0.0397	4.39E-04	0.004	4	0.0134	8.82E-05	0.0014
5	0.0162	4.29E-04	0.0018	5	0.0058	9.52E-05	2.97E-04
6	0.0025	0.0023	8.40E-04	6	0.0016	5.80E-04	7.60E-05
CH3				CH3			
2	0.0681	0.0492	0.0046	2	0.0278	0.0215	1.30E-03
3	0.202	0.0391	0.0126	3	0.0251	0.0156	5.20E-03
4	0.1727	0.0185	0.0106	4	0.0352	0.0082	0.0046
5	0.0609	0.0243	0.0127	5	0.013	0.0107	2.50E-03
6	0.0709	0.0366	0.0048	6	0.0321	0.0233	7.71E-04
CH4				CH4			
2	0.513	0.3175	0.0857	2	0.4277	0.0553	5.32E-02
3	0.731	0.2311	0.0416	3	0.7733	0.1263	2.16E-02
4	0.7216	0.1093	0.046	4	0.6767	0.0452	3.08E-02
5	0.7793	0.1707	0.037	5	0.2541	0.0408	1.85E-02
6	0.2673	0.2036	0.0417	6	0.0368	0.043	1.07E-02

Appendix E – Bonferroni Adjustment ANOVA & T-Test Charts

Dorsiflexion with Bonferroni – ANOVA

ANOVA < .025			
Left	Walking	Running	Skipping
2	0.637	0.534	0.658
3	0.806	0.4	0.386
4	0.324	0.064	0.405
5	0.056	0.02	0.324
6	0.333	0.006	0.343
Right			
2	0.981	0.336	0.071
3	0.881	0.453	0.106
4	0.192	0.087	0.215
5	0.029	0.003	0.003
6	0.091	0.001	0.661

Dorsiflexion with Bonferroni – T-Tests

MARTIAN	< .025			LUNAR			
Left	Walking	Running	Skipping	Left	Walking	Running	Skipping
2	0.3507	0.9152	0.73	2	0.4747	0.3503	0.3891
3	0.5626	0.5108	0.9023	3	0.8813	0.1882	0.2598
4	1.78E-01	0.3412	0.8744	4	0.4299	0.0473	0.2799
5	0.0259	0.0797	0.6535	5	0.1137	0.0137	0.1088
6	0.2074	0.1704	0.6388	6	0.7484	0.0064	0.1495
Right				Right			
2	0.8238	0.7001	0.0604	2	0.9328	0.3074	0.2024
3	0.6619	0.7132	0.2254	3	0.9897	0.268	0.0395
4	1.47E-01	0.3818	0.2563	4	0.073	3.98E-02	0.0752
5	0.0298	0.0266	0.1887	5	0.1724	6.50E-04	0.0014
6	0.0876	0.2694	0.7634	6	0.7124	5.73E-04	0.2298

Appendix E – Bonferroni Adjustment ANOVA & T-Test Charts

Plantar flexion with Bonferroni – ANOVA

ANOVA < .025			
Left	Walking	Running	Skipping
2	0.017	0.292	0.544
3	0.057	0.544	0.546
4	0.093	0.556	0.199
5	0.196	0.859	0.016
6	0.85	0.982	0.077
Right			
2	0.043	0.435	0.355
3	0.075	0.579	0.133
4	0.159	0.789	0.151
5	0.515	0.712	0.04
6	0.576	0.864	0.086

Plantar flexion with Bonferroni – T-Tests

MARTIAN	< .025			LUNAR			
Left	Walking	Running	Skipping	Left	Walking	Running	Skipping
2	0.0236	0.1377	0.4911	2	0.0049	0.1582	0.2109
3	0.0392	0.4028	0.4146	3	0.1154	0.2694	0.2175
4	2.80E-02	0.461	0.1499	4	0.5262	0.2489	0.0291
5	0.0258	0.6639	0.0288	5	0.9931	0.5873	0.0049
6	0.3241	0.9291	0.1131	6	0.9182	0.9121	0.0191
Right				Right			
2	0.0482	0.2637	0.1052	2	0.0101	0.2286	0.3059
3	0.0545	0.3516	0.0558	3	0.0427	0.3519	0.1045
4	3.19E-02	0.6496	0.1608	4	0.7619	4.97E-01	0.0518
5	0.172	0.4158	0.056	5	0.5751	5.38E-01	0.0141
6	0.2586	0.4655	0.0523	6	0.9246	7.63E-01	0.0602