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The Effects of an Inclined and Declined Slope on Backward Locomotion: A Kinematic and Electromyographic Analysis of Retrowalking

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THE EFFECTS OF AN INCLINED AND DECLINED SLOPE ON BACKWARD LOCOMOTION: A KINEMATIC AND ELECTROMYOGRAPHIC ANALYSIS OF RETROWALKING

by

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Abstract

The effects of an inclined and declined slope on backward walking: A kinematic and electromyographic analysis of retrowalking

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The purpose of this study was to investigate the effects of an inclined and declined slope on kinematic properties and muscle activation magnitudes. This purpose was achieved by using a +10% grade for inclined backward walking (IBW) and -10% grade for declined backward walking (DBW) on a treadmill. Eleven participants (24.6 ± 4.1 yrs, 68.5 ± 14.6 kg, 1.7 ± 0.1 m) were recruited from the UNLV student body and were subject to a three day adaptation protocol to allow them to choose a preferred walking speed and to familiarize themselves with such a novel task. Two consecutive practice days included a trial that allowed participants to choose a preferred walking speed and practice for five minutes at each slope at that chosen speed. The third day included a final adaptation period in which the previous two walking speeds were averaged. For each slope condition, participants were allowed a three minute practice period before a thirty second data collection. The order in which participants walked on experimental slope conditions was counter balanced.

Participants walked on a motor-driven treadmill, with a 3-D motion video camera system. Participants were instrumented with surface electrodes to measure muscle (EMG) data. Joint range of motion (ROM), stride time, stride frequency, and integrated EMG were measured. One way repeated measure ANOVAs were conducted for each dependent variable using pairwise comparisons between each experimental condition and the level condition (α=.05). Results showed significant differences in ROM in the hip, knee, and ankle joint under both conditions ($p < .01$). Stride time exhibited differences under both experimental conditions ($p < .001$). Stride frequency was not significantly different at a decline ($p = .391$) but was at an incline ($p = .003$). Integrated EMG exhibited significant differences for the rectus femoris ($p = .024$), biceps femoris ($p < .001$), tibialis anterior ($p = .011$), gastrocnemius medialis ($p < .001$)) at an incline. At a decline, the rectus femoris ($p < .001$), tibialis anterior ($p = .006$), and gastrocnemius exhibited significant differences ($p < .001$), but the biceps femoris did not ($p = .052$). The results of this study suggest that inclined backward walking may be beneficial for treating physical conditions of the knee, due to the increased muscle activity induced by the slope as well as the increased knee range of motion. For hamstring overuse related injuries, both IBW and DBW have their own benefits in improving hamstring flexibility. The increase in knee ROM suggest further extensibility of the hamstrings muscles, while the added eccentric activity in DBW may also lead to increasing hamstring flexibility.

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Chapter 1

Introduction

The most effective rehabilitative and therapy techniques are those that derive from scientific literature, which have been deemed reliable. In addition to current evidence-based practice, many practitioners continually search for new, innovative ways to improve treatment plans. Backward walking (BW) is one modality that has recently shown potential to be useful for treating various conditions, such as in improving hamstring flexibility [2,5,13]. While there is evidence that supports its effectiveness in rehabilitation, there remain some unanswered questions to fully explain why BW may be an effective modality for therapists to include in their treatment plans.

In comparing forward walking (FW) to BW, many similarities are noted in their kinetic and kinematic properties as well as their muscle activation patterns. There is evidence to suggest that BW is almost exactly the same as FW, except that their characteristics are reversed with respect to the direction of the motion [3, 8,15,27,29,30,32]. The angular velocities of the hip, knee, and ankle joints have been found to be similar and the muscles that are activated are simply reversed [8,27]. The muscles that typically contract concentrically during FW are found to be eccentric in BW, and vice versa [8,27,30,32].

Some of the differences between FW and BW can be explained by asymmetrical nature of all the joints involved, with the ankle being most pronounced [8,29,32]. Because of the structural arrangement of the ankle joint relative to the foot, the synonymous gait pattern to the heel contact and toe off in FW would be seen in BW as the toe contact and heel off. Because of this change in position of the ankle joint when the heel leaves the ground during BW, the ankle is forced to expand its range of motion (ROM) in order to properly clear the ground as the body propels backward [8,30]. The hip and the knee show decreased ROM because they have less contribution in assisting foot clearance in comparison to FW [30].

Using this evidence as a basis, practitioners have adopted BW as a potential modality to intercede in a variety of diagnoses, including nonspecific chronic lower back pain (CLBP), or for other rehabilitative patients, such as those recovering from strokes. Dufek et al. [6] described that BW can be an effective modality to treat CLBP by increasing hamstring flexibility, which has been shown to be a major contributor to the pain experienced by patients [5, 26,31]. Yang et al. [33] provided evidence to show that stroke patients could improve several gait markers, including stride length, velocity, and symmetrical gait patterns by supplementing their therapy with BW.

These therapeutic interventions have shown potential in their effectiveness to reduce symptoms and improve overall functionality. Further research has modified this intervention by including backward running because evidence has shown that it can increase quadriceps muscle strength while putting less strain on the patellofemoral joint [7]. Backward walking on an incline has also been adopted because the added perturbation could enhance some of the beneficial properties that level BW provided [3,12]. While these studies show the effectiveness of BW as a potential modality, more thorough research could improve its reliability by better explaining which components of BW could specifically contribute to different diagnoses and symptoms.

Statement of the Problem

While there is evidence in the scientific literature that shows the effectiveness of BW as a rehabilitative modality for various physical conditions, there remains a gap in the literature that fails to explain which specific components of BW may contribute to the effectiveness of these treatment programs. Secondly, there is some research conducted focusing on the effects of inclined backward walking (IBW), but currently remains no research on the effects of declined backward walking (DBW). This study aims to provide a comprehensive kinematic and EMG comparison of IBW and DBW in relation to level BW.

Purpose of the Study

The purpose of this study was to investigate the effects of an inclined and declined slope on kinematic properties and muscle activation magnitudes. Specifically, how do concentric and eccentric muscle activity affect walking differently during BW under each condition? Many of the training studies in the scientific literature propose that the increased eccentric activity during BW may contribute to beneficial results, such as increased muscle strength [15,23]. By focusing on the effects of eccentric activity during BW under these conditions, a stronger relationship may be observed in support of these results.

Statistical Hypothesis

H0a: There will be no differences in lower extremity kinematics properties, including stride time, stride frequency, and range of motion between inclined, level, and declined BW.

H1a: There will be significant differences in kinematics properties, including stride time, stride frequency, and range of motion between at least two of the three conditions (inclined, level, and declined BW).

H0b: There will be no differences in EMG activity in the rectus femoris, biceps femoris, gastrocnemius medialis, or tibilias anterior between inclined, level, and declined BW.

H1b: There will be significant differences in EMG activity in the rectus femoris, biceps femoris, gastrocnemius medialis, or tibilias anterior between inclined and level conditions and/or between declined and level conditions.

Delimitations

Because BW is a novel task, all participants will undergo a series of training sessions before the actual recording session. The goal of this accommodation procedure is to minimize any variability that may exist due to learning a new task. Second, all participants will be allowed to select a preferred walking speed on the level condition, but the same speed will be set for their inclined and declined conditions. This is to minimize variability in muscle activity and kinematic characteristics to better compare the effects of these conditions on the parameters. Jensen [12] was unable to find many significant differences in muscle activity, which contradicts the current literature. He attributed this to lack of control of the walking speed. Thus, the current study will control walking speed among conditions in order to have more controlled comparisons.

Definitions

Stride Time: The amount of time spent in one entire gait cycle, which in this study is defined as the moment the toe strikes the floor and ends just before the toe strikes the toe in the next cycle.

Stride Frequency: The number of gait cycles completed over time, which in this study is specified as the number of cycles per minute.

Range of Motion: The difference in the maximum joint angle flexion and the minimum joint angle flexion that occurs within one gait cycle.

Integrated EMG: The summation of voltage in EMG as time progress though a gait cycle.

Chapter 2

Review of Related Literature

Backward Walking

Backward walking (BW) has been adopted into clinical practices for various rehabilitative measures due to some of its unique characteristics that differ from forward gait. Evidence in the scientific literature has shown that BW may improve hamstring flexibility, which may help to reduce symptoms in individuals with chronic lower back pain (CLBP) [2,26]. BW has also shown to benefit certain neuromuscular conditions such as strokes and Parkinson's disease by improving gait characteristics after BW training programs [33].

While there is evidence to show that overall backward locomotion is similar to forward locomotion but in reverse [8,15,27,29], there are key differences in BW that contribute to its effectiveness as a modality in rehabilitation. To better understand some of these differences, it is important recognize some key features of forward walking in order to make proper comparisons. When analyzing gait, one complete cycle is typically observed in which the foot lifts off from the ground (swing phase), lands back on the ground to accept the weight change (stance phase), and ends just before entering the next swing phase. One complete forward gait cycle is completed through a combination of concentric and eccentric muscle contractions, but the rectus femoris (RF), biceps femoris (BF), gastrocnemius medialis (GM), and tibialis anterior (TA) are the major muscles that have the main focus.

Comparison studies of the biomechanical properties in forward and BW have discussed several similarities and differences between both walking patterns. The muscle activation pattern of backward walking reflects that of forward walking, but there is almost a complete reversal of activation patterns from flexors to extensors, and vice versa [8,27]. This Muscle Antagonist Theory suggests that antagonist muscles switch roles with respect to the direction of motion. Kinetic analyses have also revealed a reversal of joint power moments, meaning that in BW, joints that typically undergo a flexor moment during a specific phase of forward gait exhibit an extensor moment during the same phase in BW, and vice versa [8]. Many other kinematic characteristics have also shown to be almost identical, including angular displacement and angular velocity of the joints, stride length, and stride frequency [8,15,30].

Some minor differences have also been noted in the scientific literature, which can be attributed to the asymmetrical nature of the ankle position in relation to the foot. In forward gait, the plantar flexor muscles are typically relied upon for forward propulsion. According to the Muscle Antagonist Theory, dorsiflexor muscles would adopt this role in BW. However, dorsiflexor muscles typically have significantly less strength than their antagonists, making them unable to generate enough force to propel the body backward independently. Thus, during this specific phase of gait, EMG studies have revealed that knee extensor and hip extensor muscles are recruited to supplement the dorsiflexors to successfully generate enough force [3,8,15,27]. Kinetic analyses have also revealed less shock attenuation in the knee because of the change in its position relative to the point of foot contact during BW [15].

EMG and kinematic analyses comparing backward walking on a level plane to two other levels of inclination have also reveal some notable differences. With inclination, there was a significant increase in range of motion of the joints (most prominently seen in increased dorsiflexion), and increased activity in all major leg muscle groups, except for the hamstrings [3]. It was concluded that these adaptations were necessary for the body to overcome the nature of the inclination, by producing produce more flexion to be able to clear the ground, and to propel the body forward along that inclined path.

Chronic Lower Back Pain

Chronic lower back pain (CLBP) can affect both athletes and non-athletes. Regardless of a person's level of involvement in physical activity, the effects are similarly debilitating, preventing people from carrying on their everyday functions to their full extent. With chronic lower back pain, there are few treatment options, some of which are invasive and costly, such as surgery.

BW may provide an alternative that can supplement non-invasive methods of treatment, such as physical therapy, and is an activity that does not require much supervision. While there are many factors that may contribute to lower back pain, undefined CLBP is generally supported with equivocal theories that explain the specific causes. There is evidence to support that CLBP may be attributed to inflexible lumbar muscles, which may be caused by inflexible hamstring muscles producing a posterior pelvic tilt [9,26]. This theory would necessitate focus on the structures that surround it. An analysis of some gait characteristics of individuals with CBLP has found a decrease in hip flexion and extension, which may have led to a reduction in gait cycle durations, such as with shorter, slower strides [26,31]. There is evidence for overuse of the hamstrings muscles, as seen with their premature and extended stimulation during gait [24,26,31]. This has led to reports of increased hamstring stiffness and significantly lower trunk flexibility, both of which may have been contributed to an increased hip extensor moment during gait [31].

With the basis that overused hamstrings may greatly impact symptoms in CBLP, studies have reported that after incorporating a training protocol that implements BW for individuals with CLBP significantly lower subjective pain levels, exhibited significantly increased BW velocity, and increased lower back range of motion [2]. There is further evidence to show that this alleviation of pain found in individuals who undergo this three week training program is attributed to the increased flexibility in their hamstrings [5]. This coincides with the results of Tafazzoli et al. [26] who concluded that overused, stiff hamstrings are a major contributor to CLBP. However, this is still conjecture as there remains a gap in the literature that could provide a direct link between hamstring flexibility and CLBP from a BW training program.

The results supporting BW as an effective modality to relieve CLBP symptom provide some direction for future research in backward locomotion because of its potential clinical significance. Although BW is a novel task to most people, it is an activity that is generally easily adapted, but could help to significantly improve symptoms in individuals with CLBP, and could be done without the need for medical supervision. BW could potentially provide some basis to an alternative or supplemental non-invasive and inexpensive treatment or rehabilitation modality.

Physical Conditions of the Knee

The knee is one of the most used joints in the human body. The knee's ability to maintain high exposure to physical activity is crucial for human locomotion. Because of its flexibly and great ROM, it is one of the most vulnerable joints to injure. With knee-related surgeries being common among orthopedic treatments, there has been an increased demand for post-operative treatments that will reduce some of the adverse side effects, such as muscular atrophy, while also staying within the physical limitations for the knee to continue healing.

There is evidence in the literature to support BW as a potential alternative treatment to post-operative patients because of the reduced strain over the knee [4,7,28]. Training studies incorporating backward running have focused on their kinetic properties and have shown that there are less compressive patellofemoral forces [4,7,28], and that with both BW and backward running, there are reports of increased lower extremity strength, particularly in the quadriceps and plantar flexor muscles [4,7,16]. Backward running has also been shown to benefit individuals with anterior lateral rotary and anterior cruciate ligament conditions by improving their stability while continuing to increase quadriceps strength [7,16].

A more comprehensive analysis of the kinetic properties of backward running has revealed that there are lesser vertical compressive forces acting upon the knee due to the nature of backward locomotion [7]. In forward walking, the stance phase begins with heel contact and ends with toe-off. The knee heavily contributes to this particular phase of gait because its position during the initial portion of stance allows it to accept the weight and absorb the shock that is caused from vertical compressive forces. In BW, the direction of the foot is reversed, with the stance phase now beginning with toe contact, and ending with heel off. By beginning the stance phase with the toe, the knee is no longer in a position that would allow for it attenuate the shock [15,30], and so the force is then translated in into the ankle [15].

BW has also been shown to improve other physical conditions of the knee as an alternative treatment to surgery, rather than being a rehabilitative technique for post-operative patients. Some key symptoms in osteoarthritic (OA) knee patients is decreased walking speed, pain in the knee when walking, typically for a specific set of time until the pain becomes unbearable. In a ten day training study that incorporated BW to treat OA in the knee, patients showed a significant increase in their forward walking speed, overall less pain, and an increase in the distance that they could walk until the pain became tolerable [23].

The current research in BW and backward running is a recent development that has begun to show their potential as a clinical modality for various conditions of the knee. However, there remains little evidence that can explain the mechanisms by which these interventions are affecting these conditions. Further research is warranted to show that backward locomotion may supplement current rehabilitative therapy techniques for a wider range of physical knee conditions by improving lower extremity muscle strength, while staying within the physical constraints for the knee, such as weight-bearing restrictions.

Neuromuscular Conditions and Balance

As more evidence is provided for the effectiveness of BW in various rehabilitative programs, research is being conducted to apply BW to different physical conditions, especially in the older population. Stroke rehabilitation is one area of research that continues to grow, as it can be debilitating for patients, affecting a variety of their language and motor skills, including many typical walking patterns, such as gait symmetry, velocity, cadence, and stride length. All of these characteristics have been shown to improve after a training program that incorporates BW, which would positively impact their everyday normal functioning [33].

Normal gait patterns can also be affected in other older adults who do not suffer from strokes. With old age, balance can begin to diminish as older adults begin to show signs of decreased motor control, which puts them at risk of falls and may lead to other related physical conditions and injuries. Recent evidence has shown that when BW is incorporated into a training program, balance and stability can be improved in children [10], and both healthy young adults and healthy older adults [6]. Additional research could especially benefit the older population who fits the category for being at-risk of falling in that these falls may be prevented.

Summary

The evidence in the scientific literature supports treadmill BW as a potential and effective modality that can be incorporated into various rehabilitative programs. BW has been shown to improve symptoms of CLBP [2,5] and osteoarthritis [23], to be effective for rehabilitation in various physical knee conditions [7,16], to benefit gait characteristics in stroke patients [27], and to increase balance control [5,10]. More recently, there has been research focusing on some modifications to BW, such as inclined BW [3,12]. An analysis of the kinematic properties and EMG activity found that inclined BW may significantly increase ankle ROM and muscle strength because of the increased metabolic costs that come with an inclined slope [12]. Further research to support BW is important because it is a skill that is easily adapted, and if shown to be effective, may be an activity that the general population could adopt to significantly improve their lifestyle with little supervision.

As this area of research is relatively new, many questions remained unanswered. There currently is no evidence of any analysis of BW on a declined slope. There is also a lack of any evidence for comparisons between inclined, declined, and level BW to determine which of these modifications might be more appropriate for various rehabilitative programs. The purpose of this study is to make comparisons between these three conditions, focusing on the kinematic properties and EMG activity of major muscle groups involved, including the RF, BF, GM, and TA. A change in treadmill slope at ±10%, in both the incline and decline slopes, has been selected based on the evidence that has shown that significant changes in kinematic and EMG properties are not seen in any slope changes less than 10% [3,12].

Chapter 3

Purpose of the Study

The purpose of this study was to investigate the effect of an inclined and declined slope on kinematic properties and muscle activation magnitudes.

Subjects

Eleven participants (24.6 ± 4.1 yrs, 68.5 ± 14.6 kg, 1.7 ± 0.1 m, 5 males, 6 females) within the ages of fifteen to thirty-five years were recruited for this study. Exclusion criteria consisted of any pain in the ankle, knee, or hip joints, or a previous history of surgery in any of these joints. All participants were briefed on the study, and then signed an informed consent as approved by the Protection of Human Subjects Committee at the University of Nevada, Las Vegas. Participants were informed to wear tight fitting dark shorts and shirts, or were provided with such clothing for the duration of the laboratory measurement phase of the study. Participants were also encouraged to wear shoes that they are comfortable walking in for long durations.

Apparatus/Instrumentation

Participants walked on a motor-driven treadmill (AM6500-TM), with a Vicon 3-D motion video camera system (Version 2.1.1; 120 Hz), consisting of 12 infrared Bonita cameras, tracking their movement. Participants were instrumented with surface electrodes to collect EMG data using a Delsys wireless EMG system (2000 Hz; 16-bit, 64 channel A/D board). The electrodes (36x28mm) were digitally monitored and data were acquired using a Trigno Personal Monitor EMG System (Model DS-T02; 2000 Hz). The Delsys EMGWorks System software

(Version 4.1.7) was linked with Vicon Nexus Software (Version 2.1.1; 120 Hz), to capture both EMG and motion capture data in accordance to time, simultaneously. Reflective hemispheric markers (16 mm diameter spheres) were attached to participants following the guidelines of the Lower Body Plug-In Gait Model utilized by the Vicon Nexus Software (Version 2.1.1).

Procedure

Because backward walking on a treadmill is a novel task, all participants underwent three practice sessions to adapt to the skill as well as to choose a preferred walking speed. Before data collection, all participants underwent two days of practice sessions. A third session was incorporated just before data collection to ensure accommodation. Participants began with a backward walking trial on a level, 0% slope for up to two minutes. During this interval, participants were allowed to adjust their walking speed to a preferred velocity. Once confirmed, the participants were held to the specific velocity and performed a practice trial for five minutes. Then, participants performed two more 5-minute practice trials under each condition; one with an inclined, +10% slope, and one with a declined, -10% slope, at the same velocity specified during the first practice trial. These three practice trials were conducted for each session for two consecutive days prior to the day of data collection.

For an accurate anthropometric fit using the Plug-In Gait Model, each participant had their height and mass recorded, as well as their leg lengths and their knee and ankle widths on their first visit. The leg lengths were measured with a measuring tape from the anterior superior iliac spine down to the medial malleolus. The knee widths were measured by the width of the knee about the axis of flexion. The ankle widths were measured about the lateral and medial malleolus.

Upon laboratory arrival on the third day, participants were instrumented with electrodes and reflective markers for data collection. Prior to electrode placement, the skin was shaved at the area of placement, then cleaned and abraded at the muscle belly following procedures as specified by Konrad (2005). Electrodes were attached to the rectus femoris, biceps femoris, tibialis anterior, and medial gastrocnemius with double sided tape, aligning the direction of the muscle fibers, as detailed on the instructions manual of the Delsys EMG System. Sixteen reflective markers were attached with double-sided tape guided by the Lower Body Plug-In Gait Model in Vicon Nexus (Version 2.1.1).

After completion of marker placement, participants prepared for data collection. The walking speed was averaged from the recorded walking speeds from the previous two days of practice. This speed was used for all three conditions on the third day. For each independent variable condition, participants were instructed to walk and were allowed three minutes of practice to ensure adaptation. Following this practice trial, data were captured for a thirty second period. Participants were not notified of when this capture took place to prevent them from changing their perceived activity level. This procedure was conducted at the level slope, and the experimental conditions that followed were counterbalanced with a downhill (-10%) slope, and uphill (+10%) slope.

Data Processing

Data from the thirty second data collection were processed using Vicon Nexus software to calculate joint angles from the position markers. The kinematic data were then processed using MatLab with a butterworth filter with a frequency cutoff at 4 Hz. From the position and joint angular data extracted from the Vicon system, kinematic properties were calculated. These included joint range of motion, stride time, and stride frequency.

The EMG data were also processed through MatLab with a butterworth filter at a frequency cutoff of 25 Hz. These data were further processed using a full-wave rectified method by taking the absolute value of each data point. An integrated EMG (iEMG) value was calculated by summing the overall activation level across time.

The independent variable was the slope (0, -10%, and +10%). The dependent variables included:

1. The amount of change in EMG activity of each muscle (rectus femoris, biceps femoris, tibialis anterior and medial gastrocnemius) for the incline and decline conditions in comparison to the level condition.
2. Gait descriptors, including stride frequency, stride time, and joint range of motion.

Statistical Analysis

A one-way repeated measures ANOVA was conducted for each dependent kinematic variable across the three slope conditions to determine any significant differences within conditions, followed up with a pairwise comparison if found significant. Difference in muscle activity was analyzed using integrated EMG (iEMG), which was accomplished by calculating the overall summation of muscle activity over time. The end summation of the iEMG was then analyzed using a one-way repeated measures ANOVA to determine any significant differences in the overall muscle activation across the three slope conditions and followed up with a pairwise comparison for significant differneces..

Chapter 4: Results

The purpose of this study was to investigate the effects of an inclined and declined slope on kinematic properties and muscle activation magnitudes. All dependent variables, both kinematic and electromyographic (EMG), were measured during all three slope conditions.

Kinematics

Three kinematic properties were collected: joint range of motion (ROM), stride time (ST), and stride frequency (SF). The mean and standard deviation values for joint ROM can be found in Table 1. In all three joints, there were significant differences when comparing the ROM between a level condition and either an inclined or declined condition. In the hip joint, the ROM on an incline was significantly less ($p < .001$), while a decline exhibited a significant increase ($p < .001$). The knee joint showed a significant increase in ROM ($p < .001$) and a significant decrease at a decline ($p < .001$). In the ankle joint, both an incline ($p < .001$) and decline ($p = .006$) exhibited an increase in ROM.

Table 1. Average and standard deviation values of range of motion (degrees) across conditions.

	Incline	Level	Decline
Hip	21.6 ± 5.8*	29.6 ± 7.5	39.5 ± 8.8*
Knee	40.8 ± 8.6*	38.1 ± 9.44	36.5 ± 10.0*
Ankle	33.6 ± 7.2*	26.7 ± 5.6	27.4 ± 6.2*

* denotes significant difference from level condition at p <.05

The mean and standard deviation values for ST and SF can be found in Table 2. ST was measured, and significant differences were exhibited both at an incline ($p < .001$) and at a decline ($p < .001$). SF was collected for each leg in every participant, and the average between the two legs was used to determine the overall SF at each condition. A significant difference was found in SF at an incline (p = .003), but not at a decline (p = .391).

Table 2. Average and standard deviation values of stride time and stride frequency.

	Incline	Level	Decline
Stride Time (seconds)	.945 ± .16*	1.00 ± .17	1.03 ± .17*
Stride Frequency (steps)	49.7 ± 3.2*	46.7 ± 2.5	45.5 ± 2.4

* denotes significant difference from level condition at p <.05

EMG

The mean and standard deviation values for the iEMG values can be found in Table 3. In the RF, there were significant differences at an incline (p = .024) and at a decline (p < .001). A significant difference was seen between the level and incline conditions in the BF (p < .001), but not in comparison to the decline condition (p = .052). Significant differences were exhibited in the TA at both the incline (p = .011) and the decline (p < .006), as well as in the GM at both conditions (both at p < .001).

Table 3. Average and standard deviation values of integrated electromyographic (microvolts)

	Incline	Level	Decline
Rectus Femoris	175 ± 114*	153 ± 43	173 ± 57*
Biceps Femoris	171 ± 45*	190 ± 78	196 ± 84
Tibialis Anterior	94 ± 180*	62 ± 82	114 ± 260*
Gastrocnemius Medialis	143 ± 218*	89 ± 125	175 ± 294*

* denotes significant difference from level condition at p <.05

In summary, all three joints exhibited significant differences in ROM in both experimental conditions. There were also significant differences from both experimental conditions in ST. Significant differences in SF were only seen at an incline, but not at a decline. Significant iEMG differences between the BF, RF, TA, and GM were exhibited at an incline, while only the RF, TA, and GM exhibited significant differences at the decline condition in comparison to the level condition.

Chapter 5

Discussion

Backward locomotion has been recently found to have potential benefits to treat various conditions, such as in orthopedic rehabilitation of physical knee conditions, due to its muscle strengthening properties [3,8,13,15] . In comparison to forward locomotion, backward running has been shown to have less compressive strain on the knee, while also building muscle strength in the lower extremities [4,7], which may be beneficial for recent post-knee surgery patients. Treadmill BW has also shown benefits for patients with chronic osteoarthritis by increasing flexibility in knee joint function [23]. These effects may be attributed to the increased hamstring flexibility that is exhibited after undergoing a BW regiment [2]. Recent popularity in including backward walking for rehabilitation warrants further research to include variation in BW. One purpose of this study was to investigate changes in muscle activation magnitudes when changing the inclination of the treadmill surface. A ±10% grade was used for each experimental condition to evaluate performance.

Walking at a treadmill inclination of +10% grade has been shown to be the minimum angle in comparison to level grade at which significant differences have been observed in kinematic properties and muscle activation patterns [12]. In the current study, there were several observed differences with Inclined Backward Walking (IBW) and Declined Backward Walking (DBW) that may provide variation to further improve the current practice of backward walking as an intervention for various physical conditions of the knee. In comparison to forward locomotion, backward locomotion has been shown to have less compressive patellofemoral forces, which is a necessary consideration for knee joint rehabilitation, while also increasing muscle strength in lower extremity muscles [4,7,16,25,28]. IBW may serve as a subsequent exercise following BW on a level slope due to the increased range of motion involved for the knee joint, as well as the increased iEMG exhibited in the current study in major muscle groups in the lower extremity (RF, TA, and GM). Both of these results are supported by those of Cipriani et al. [3], which may serve to further improve rehabilitative techniques in improving conditions such as post-operative anterior cruciate ligament (ACL) patients, or patients with osteoarthritis [23]. If IBW would also exhibit the same decrease in compressive patellofemoral forces due to the mechanical positioning of the knee joint in force production [7,28], clinicians may be able to consider its use in rehabilitation. However further kinetic research is warranted to substantiate this conjecture.

The results of DBW in this study suggest that, while it may still be considered as a beneficial variation to BW on a level treadmill slope, IBW may be more effective in treating physical conditions of the knee. Similarly to IBW, the overall muscle activation was increased in the RF, TA, and GM, but not the BF muscle during DBW. The effects on joint ROM in this study also support IBW as a superior modality to treat various conditions of the knees. Shankar et al. [23] found that backward walking improves osteoarthritis by increasing strength in the major muscle groups surrounding the knee, while also helping to increase the range of motion of the knee. The results of this study show that IBW exhibits an increase in overall ROM in the knee while DBW exhibits a significant decrease. Thus, both the results of muscle activation magnitudes and in ROM suggest that treadmill IBW may be a superior modality in training for various physical conditions of the knee. However, further research is warranted for clinical application to determine if using these techniques have would show increases in muscle strength on patients with these symptoms, and also to verify if either IBW or DBW sustains a lower level of compressive patellofemoral forces.

The effects of slopes on the hamstring muscles is particularly important when considering conditions that pertain to hamstring muscle tightness, such as undefined chronic lower back pain (CLBP). Halbertsma et al. [9] found that patients with CLBP similarly suffer from hamstring stiffness, which may be caused by overuse and contributing to a posterior pelvic tilt, which then persists to become chronic pain in the lower back. This is also supported by Dufek et al. [6], who incorporated a BW training regimen and found that they could improve both hamstring flexibility and decrease pain symptoms in athletes with undefined CLBP. The results of the current study show that treadmill IBW may serve to be a more effective treatment option than BW on a level surface. The overall iEMG values for each of the four major muscle groups in IBW were significantly different, all exhibiting increased muscle activity, except in the BF, which was significantly decreased. This is supported by Myatt et al. [17], who found similar muscle activation patterns due to the increased metabolic needs imposed by the nature of the direction of motion. Due to the joint asymmetry involved when walking backward, much of the force production is contributed by the concentric contractions of the quadriceps muscles, leaving the hamstring muscles to exhibit lower muscle activation overall because it is consistently in a negative eccentric contraction [17]. The results of the current study show that there is more muscle activity in the quadriceps in IBW, which may suggest that the hamstring has overall less strain and is exhibiting more eccentric activity. The increased ROM of IBW observed in the current study may serve to contribute to improving the extensibility of the hamstring muscles in CLBP patients that were exhibited in the study by Dufek et al. [6]. This is supported by previous studies where it was observed that such regimens that incorporate dynamic range of motion training can effectively increase hamstring flexibility similarly to static stretching [1,19,20]. This combination of overall less hamstring strain and increased knee ROM suggest that treadmill IBW may be a superior variation to treadmill DBW for hamstrings overuse related injuries.

There were also changes in stride time exhibited in both treadmill slope conditions – in IBW, stride time significantly decreased, while increasing in DBW. Hunter et al. [11] found that downhill forward walking was correlated with changes in stride time and muscle activity, particularly in the added eccentric activity that was exhibited to help sustain the body's moving center of mass during locomotion. A similar pattern was seen in BW, which has been shown to be a reversal of muscle activation patterns in BW, particularly in the quadriceps and hamstring muscles [8,15,17]. Due to the nature of the direction of motion, BW exhibits higher concentric contractions in the quadriceps muscle to propel the body forward, leaving the hamstring muscles to eccentrically contract to help slow down and control knee extension [17]. This supports the increased stride time results in DBW in the current study that may attributed to more eccentric contractile activity in the hamstring muscles. This may be beneficial for those with hamstring overuse related injuries because eccentric training regimens targeting the hamstring muscle have been found to increase hamstring flexibility [17,15,20,21,22]. This would provide support for DBW as a potential rehabilitative treatment for patients with CLBL, which has been noted to be contributed by overuse of the hamstrings muscle, or hamstring stiffness [3,9,26,31].

The results from both IBW and DBW both have different potential benefits for hamstring rehabilitation. Further research is required to determine any direct benefits of both IBW and DBW as an eccentric training regimen for clinical applications.

Conclusions

BW has been shown to have success in various treatment modalities for conditions such as hamstring overuse related injuries [2,5] and in knee rehabilitation [7,16,28,23]. The purpose of the current study was to investigate muscle activation magnitudes and kinematic properties of backward walking when the slope condition was inclined and declined. It was hypothesized that there may be properties of BW on a changing slope that may enhance the effects caused by the increased eccentric contractile activity that has been shown to be beneficial properties of BW [17]. The results of this study show support for IBW as a superior variation to DBW for physical conditions of the knee due to the increased muscle activity exhibited in the RF, GM, and TA and the increased ROM. For treatments focusing on hamstrings overuse related injuries, the results of the current study support DBW to be a more effective treatment than IBW. This is seen in the changes of kinematic properties that suggest DBW to have more eccentric muscle training, which has been shown to increase hamstring flexibility and reduce pain symptoms [18,19,20,22].

The results of the current study suggest that there are benefits to both IBW and DBW, but that the specific goal of a treatment program would determine which variation would be more effective. While these results do suggest beneficial properties of each training variation, further research is warranted to determine if these modalities can be applied in a rehabilitative setting for various physical conditions.

Recommendations

Further research should examine kinetic properties of IBW and DBW. A focus on flexor and extensor moments relative of the joints will give a more comprehensive analysis of muscle contractile activity to better correlate these kinematic changes with concentric and eccentric patterns. Further kinetic research would also provide insight on some of the patellofemoral compressive forces that may change with each of these conditions. A limitation of the current study is the lack clinical application of these properties on actual participants who may suffer from these various physical conditions.

In the current study, a limitation was that integrated EMG values were averaged across gait cycles for analysis. This method does not allows the strides to be normalized and instead uses an absolute time value, which may influence how EMG values can be analyzed. Future investigation of muscle activation magnitudes could make further comparisons by normalizing stride time across gait cycles. Future research could also attempt to see if these activation magnitudes and patterns are changed in between the two stance and swing phases of BW.

Future directions of research could also focus on the potential benefits of BW on different slope levels on the hip and ankle joints. The current study found other significant changes in ROM that may have implications in other areas of rehabilitation, such as an increase of 5^{o} in the ankle at an incline, and 10^{o} at a decline in the hip joint. Further research is warranted to determine if these changes may have any clinical implications for rehabilitation in injuries related to these joints.

Appendix A

IRB Form

INFORMED CONSENT

Department of Kinesiology and Nutrition Sciences

TITLE OF STUDY: The Effects on an Inclined and Declined Slope on Backward Locomotion

INVESTIGATOR(S): Song Vo, Janet Dufek, PhD, Julia Silvernail, PhD, Szu-Ping Lee PT, PhD, Richard Tandy, PhD

For questions or concerns about the study, you may contact Dr. Janet Dufek at **(702) 895-0702** or Song Vo at **(714) 548-5986.**

For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted, contact **the UNLV Office of Research Integrity – Human Subjects at 702-895-2794, toll free at 877-895-2794 or via email at IRB@unlv.edu.**

Purpose of the Study
You are invited to participate in a research study. The purpose of this study is to investigate the effects on kinematic and electromyographic properties during backward walking on an incline and decline.

Participants
You are being asked to participate in the study because you fit these criteria: Healthy adult between the ages of 18 and 35 years, are free of any lower body joint or back pain, and have no history or surgery in the lower back or lower extremity joints.

Procedures

If you volunteer to participate in this study, you will be asked to attend three sessions across three consecutive days for practice and collection at the Sports Injury Research Center (SIRC).

- *Day One Preparation*: You will be asked to sign the informed consent on the first day. Body measurements will be taken (height, weight, age, gender, leg length, knee width, and ankle width).

Practice Schedule:

- *Day One & Two*: You will be allowed 2 minutes of backward walking on a level condition with the ability to change walking speeds until a comfortable speed has been met. After, a strict 5 minute practice trial will occur at the same walking speed. Then, you will be subject to two more strict-5 minute practice trials, once on an inclined and once on a declined slope condition, at the same walking speeds. Counterbalancing will determine which experimental slope condition you will practice on first.
- *Day Three*: You will be instrumented for data collection as well as given one last practice trial for adaptation. You will be instrumented with four surface electrodes (two on your upper leg, and two on your lower leg), and sixteen reflective markers on specific external anatomical locations, such as the knee joint and the ankle joint. For the surface electrodes, the skin in these areas will be shaved of any body hair and cleaned to remove excess skin oil and dirt. You will be subject to another practice trial for 3 minutes at the level slope condition. The speed will be determined as the average of the previous two chosen preferred walking speeds. Immediately following the practice trial will be a 30 second data collection. After, you will be subject to the same 3 minute practice trial and 30 second data collection on an inclined and declined slope condition. Counterbalancing will determine which experimental slope condition you attempt first.

Benefits of Participation

There may be no direct benefits to you as a participant in this study. However, you will be provided an opportunity to experience minimal exercise across three consecutive days. You might also gain benefit in learning how you respond to the task of backward walking in different slope conditions.

Risks of Participation

There are risks involved in all research studies. This study may include only minimal risks. You will be asked to walk backward on a treadmill, which occludes your normal range of vision during walking. In an attempt to minimalize and prevent risk, colored tape will be placed on the ground next to the treadmill to help guide participants of the specific area they should keep within to prevent any risk for physical injury, such as falls. Because this study involves minimal exercise, you may be subject to other physical risks, such as muscle soreness. There are minimal risks involved with the use of electrodes. Because the skin is being shaved and abraded, you may feel that the skin in these areas to be dry and raw. There are no risks involved with placement of reflective markers.

Cost /Compensation

There will not be financial cost to you to participate in this study. The study will take approximately thirty minutes of your time across three consecutive days.

Confidentiality

All information gathered in this study will be kept as confidential as possible. No reference will be made in written or oral materials that could link you to this study. All records will be stored in a locked facility at UNLV for three years after completion of the study. After the storage time the information gathered will be deleted or destroyed. All identifying data will be stored as digital computer files only, including consent documents which will be scanned and saved. Any paper copies will be shredded. Digital files will be retained for a period of 5 years. At this time all individual identifying information will be deleted from the computer hard drive as well as the backup drive.

Voluntary Participation

Your participation in this study is voluntary. You may refuse to participate in this study or in any part of this study. You may withdraw at any time without prejudice to your relations with UNLV. You are encouraged to ask questions about this study at the beginning or any time during the research study.

Participant Consent:

I have read the above information and agree to participate in this study. I have been able to ask questions about the research study. I am at least 18 years of age. A copy of this form has been given to me.

____ ____________________

Signature of Participant Date

____

Participant Name (Please Print)

Appendix B

Lower Extremity Joint Kinematics & iEMG by Groups across Conditions

Figure 1. Mean Hip Range of Motion by Group

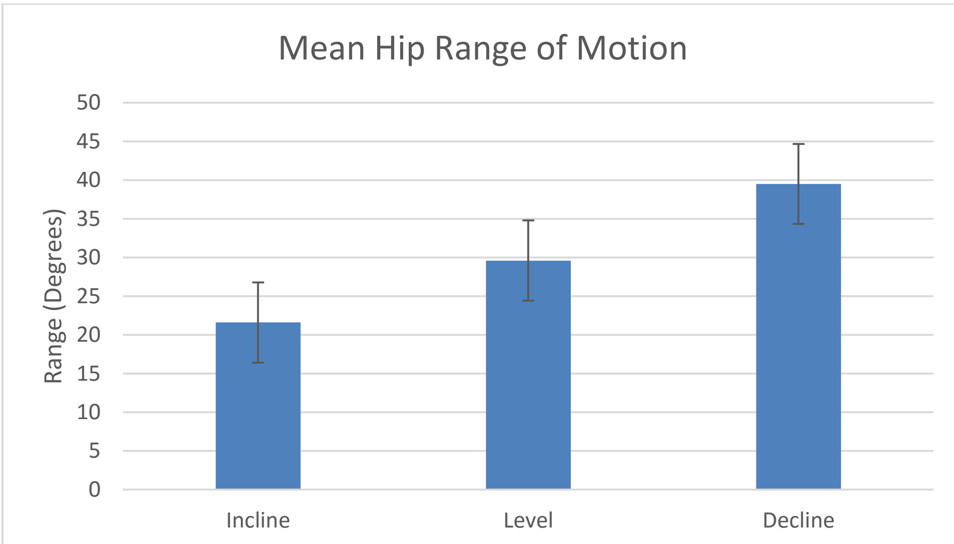


Figure 2. Mean Knee Range of Motion by Group

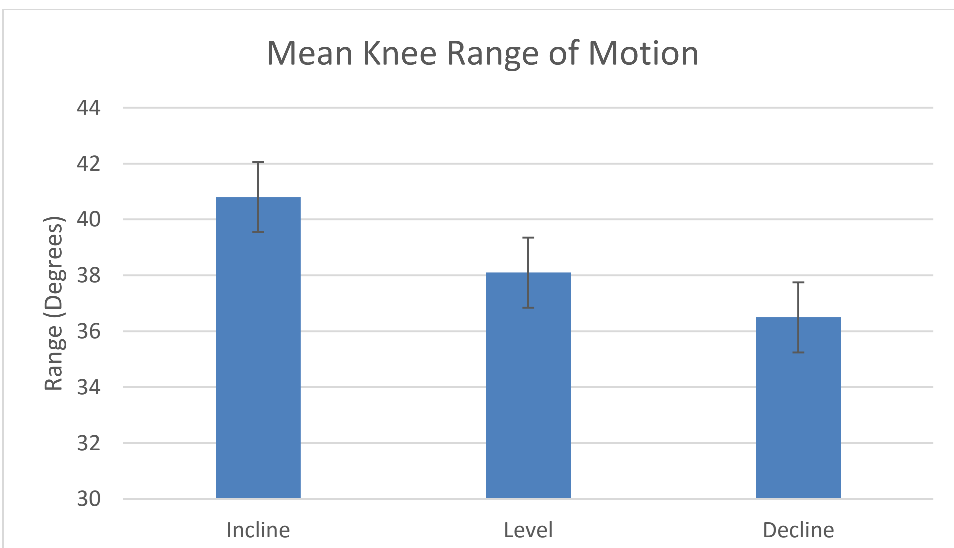


Figure 3. Mean Ankle Range of Motion by Group

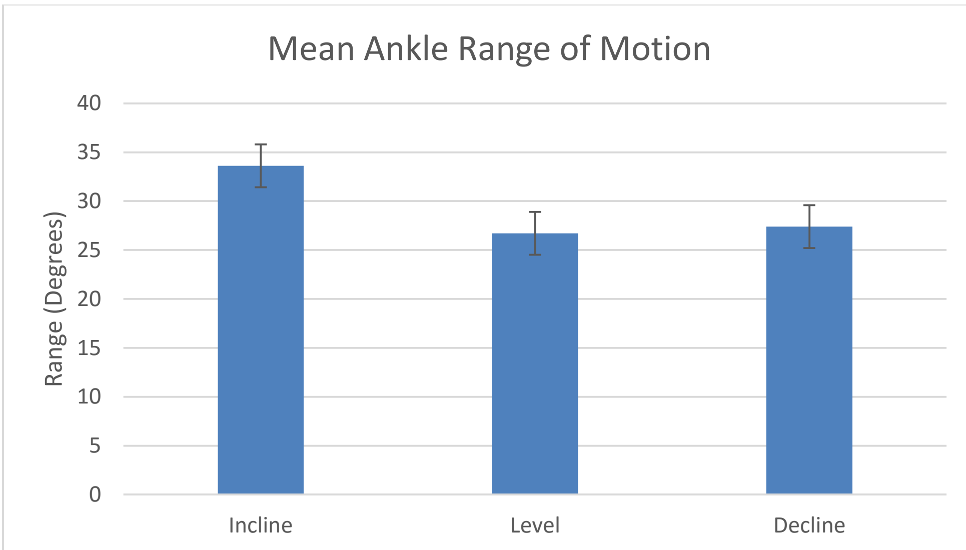


Figure 4. Mean Stride Time by Group

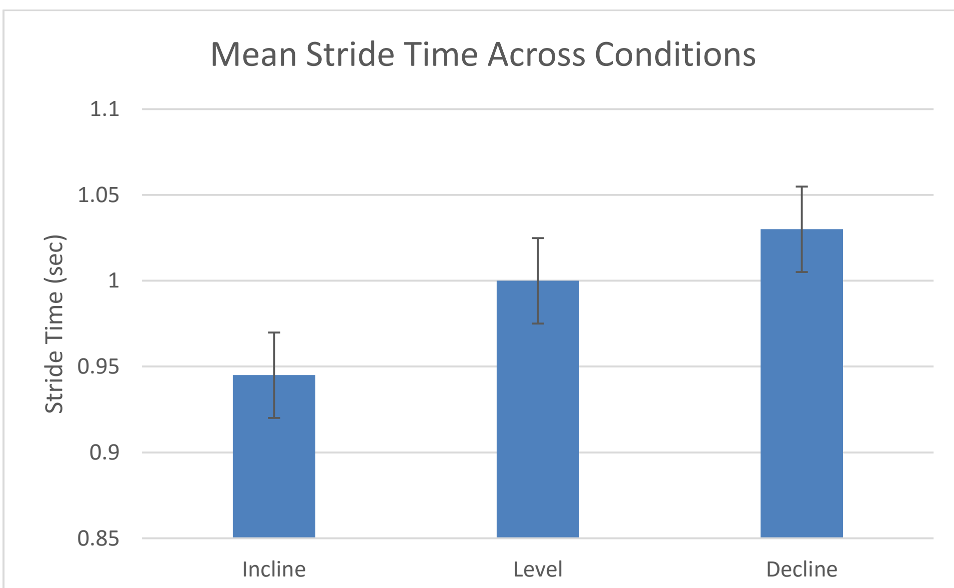


Figure 5. Mean Stride Frequency by Group

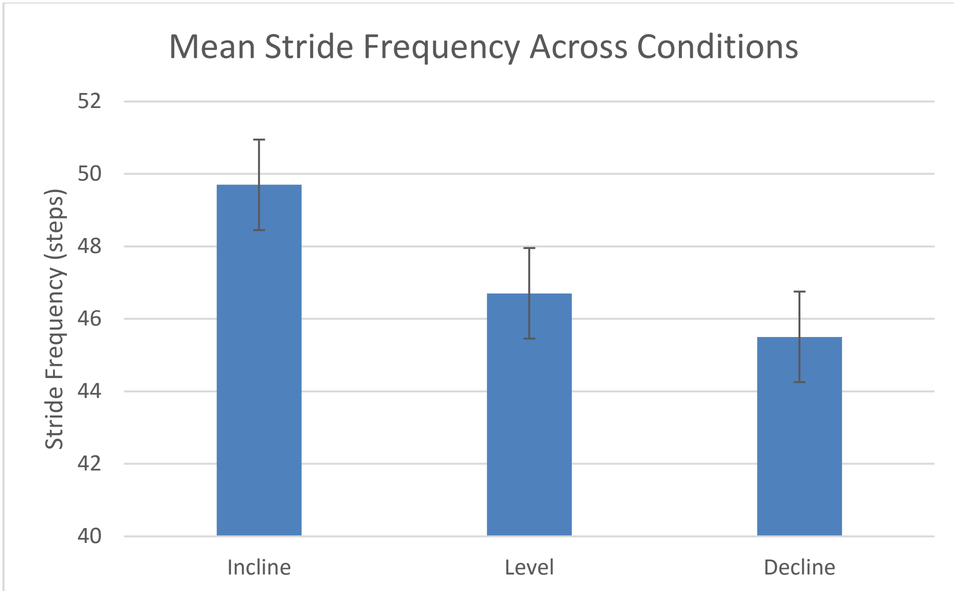


Figure 6. Mean iEMG of Rectus Femoris across Conditions

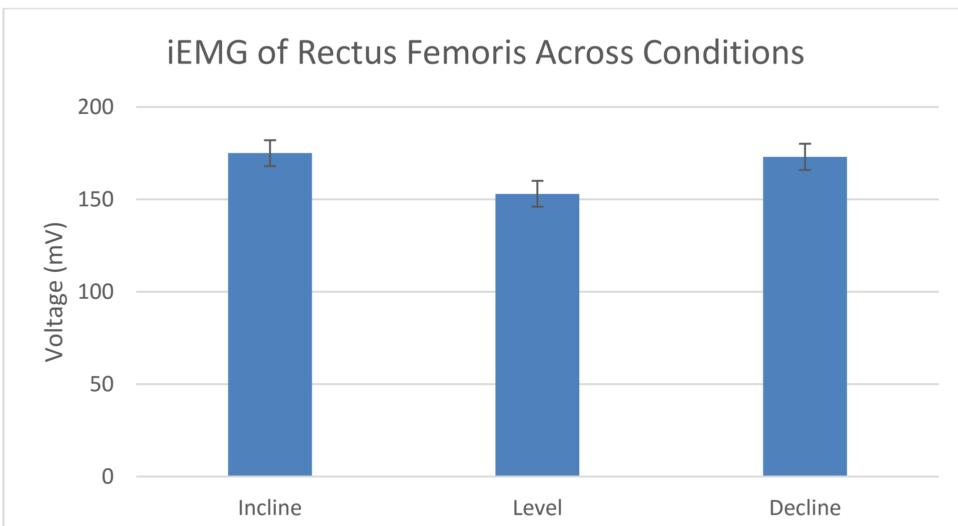


Figure 7. Mean iEMG of Biceps Femoris across Conditions

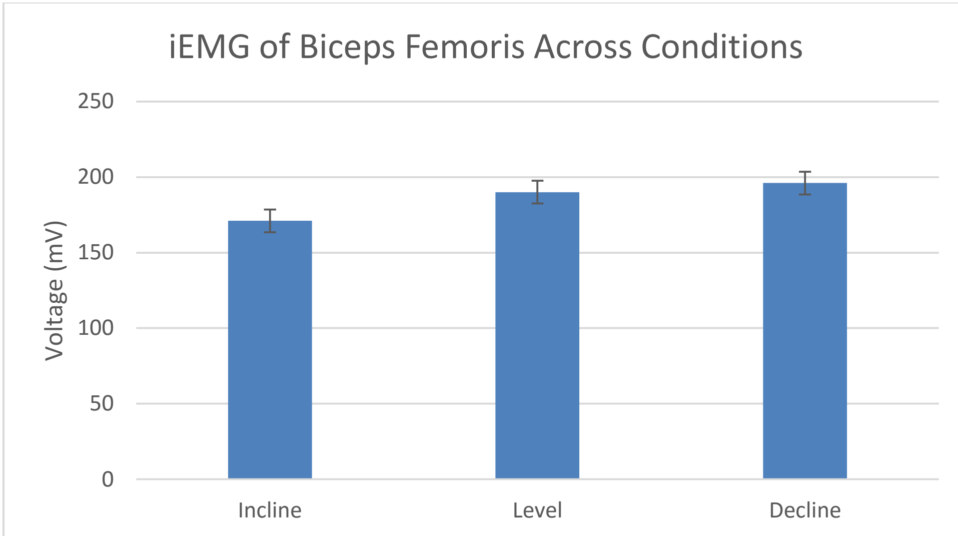


Figure 8. Mean iEMG of Tibialis Anterior across Conditions

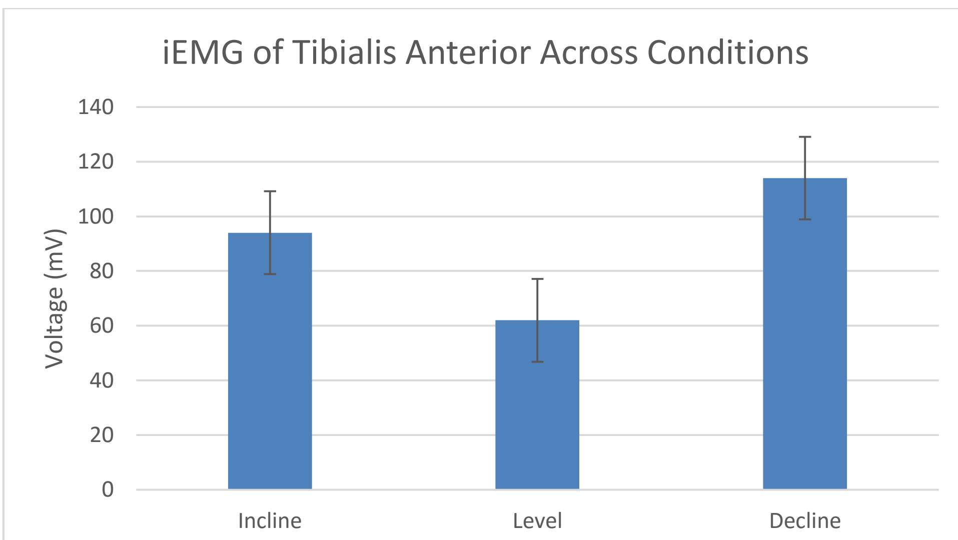
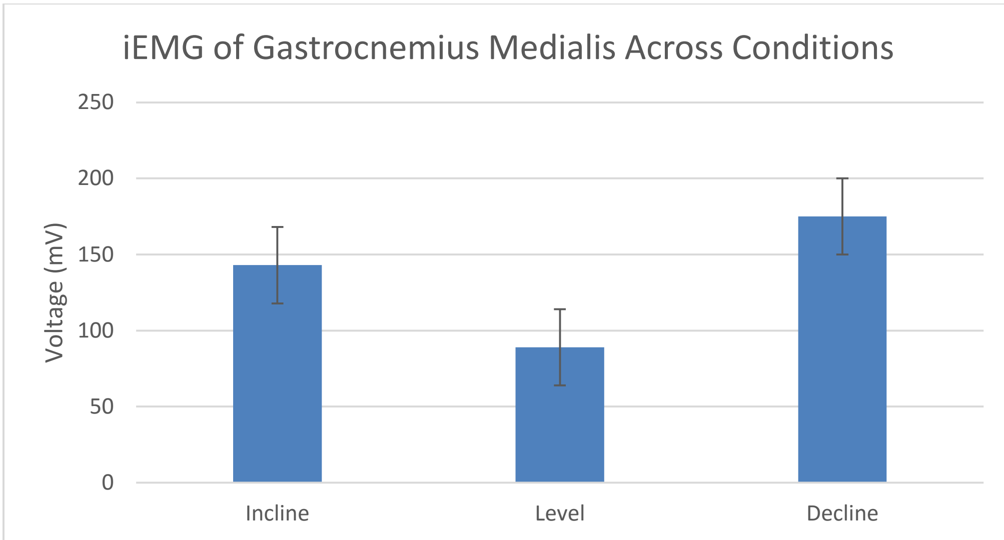


Figure 9. Mean iEMG of Tibialis Anterior across Conditions



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