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A Comparative Analysis of Walking Patterns between Genu Varum and Normal Subjects

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A COMPARATIVE ANALYSIS OF WALKING PATTERNS BETWEEN GENU VARUM AND NORMAL SUBJECTS

by

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A COMPARATIVE ANALYSIS OF WALKING PATTERNS BETWEEN GENU VARUM AND NORMAL SUBJECTS

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The problem was to compare angular and linear kinematics, ground reaction forces (GRF), temporal changes, and electromyography (EMG) of selected muscles while walking one gait cycle to a metronome set at 100 beats per minute (bpm) between genu varum and normal men, ages 20–25 years. Results indicated: (a) the Normal Group had a lower stride time than the Genu Varum Group, although the results were not significantly different; (b) the Normal Group showed greater range of motion in the ankle, knee, hip rotation, and tibial rotation angles—however, the results were not significantly different; (c) there was no significant difference in time to peak and peak EMG—however, the Normal Group showed a difference in EMG compared to the Genu Varum Group; (d) the Normal Group showed greater GRF than the Genu Varum Group during the braking, thrust, and propulsion phases—however, the results were not significant; (e) moments during the propulsion was greater for the Normal Group than the Genu Varum Group—however, moments during the braking phase was greater for the Genu Varum Group than the Normal Group; (f) there was no significant difference in moments measured around the vertical axis during the braking phase between the two groups; and (g) the Genu Varum Group showed a greater stride length than the Normal Group in the sagittal plane, although the results were not significantly different.

TABLE OF CONTENTS

CHAPTER

LIST OF TABLES

CHAPTER I

INTRODUCTION

The physical act of walking, despite its simplicity, is complex in nature. The human body's design features a relatively high center of gravity and a small base of support, similar to the structure of a top-side-down pyramid. Walking, also described as an intricate form of human locomotion, is the translation of the body from one point to another (Leveay, 1992). Gait is the single most significant milestone in motor development, and its characteristics have been researched more than any other motor skill. Research gives us knowledge and understanding of gait abnormalities that exist among individuals. The anatomical alignment of the bones in the lower extremities contribute to what is considered normal gait. Anomalous bone and joint alignment in the lower extremities may disrupt normal locomotion, hence producing an abnormal form of gait. Genu varum, commonly known as bowlegs, is an anatomical variance marked by distal and medial angulation of the leg in relation to the thigh, an outward bowing of the legs at the knee joint eventuate (Spraycar, 1995). Genu varum affects gait in various ways and may cause long-term effects. Measuring gait patterns of subjects with this characteristic allows us to learn more about abnormalities in gait and creative methods for intervention.

Statement of the Problem

The problem of this study was to compare angular and linear kinematics, ground reaction force (GRF), temporal changes, and electromyography (EMG) of selected muscles while walking one gait cycle to a metronome set at 100 beats per minute (bpm) between genu varum and normal men, ages 20–25 years. The study will focus on the stance and swing phases of the gait cycle.

Purpose of the Study

The purpose of this study was to provide comparative information concerning abnormal and normal gait patterns. The ability to ambulate efficiently results from a smooth biomechanical integration of numerous body segments such as the thigh, leg, trunk, and foot. In normal gait the patella should deviate internally only slightly from heel contact to midstance. With excessive external lower-extremity rotation the patella will rotate outward causing bowing of the knees (Gould, 1990). The condition associated with abnormal alignment is detected in most cases, before the age of 1 year. Research of major joint angles (in the lower extremities), GRF, linear displacement, EMG, and temporal changes could aid in the evaluation of genu varum. The results of this investigation will be helpful in the educational and clinical environments to broaden the opportunities of success in exercise physiology, physical therapy, and athletic training.

Need for the Study

Recent literature has indicated evidence of gait abnormality related to genu varum (Hoppenfeld, 1976). Earlier studies have not provided adequate evidence in the differences in gait patterns. The major effects of genu varum, such as irritation of the medial knee joint, have been studied, but the evaluation of biomechanical differences in gait patterns and genu varum is not available. There is a need to study genu varum gait patterns.

Delimitations

The study was delimited to the following:

1. Five genu varum male subjects and 5 normal knee males who reside in Kalamazoo, Michigan, were recruited as subjects.

2. A complete stride, right foot contact to the next right foot contact, was analyzed.

3. EMG data for the following six muscles of the right lower extremity were monitored for one stride: rectus femoris, vastus medialis, medial head of the gastrocnemius, peroneal group, biceps femoris, and semimembranosus/ semitendinosus groups.

4. Force platform data were collected for the right foot.

5. Three complete strides (trials) were analyzed.

6. Subjects walked to a metronome set at 100 bpm.

Limitations

The study was limited by the following:

1. The sample size of the study (N = 10 [5 genu varum, 5 normal]) was small, necessitating caution in extrapolation of the data to a larger sample.

2. The study consisted of three trials or three gait cycles per subject.

Assumptions

Assumptions for the study were the following:

1. Subjects were in good health at the time of the data collection.

2. All test instruments in the study were reliable and valid.

3. The walking patterns studied represented the subjects' normal walking patterns.

Hypotheses

The researcher addressed the following research hypotheses:

1. The range of motion at the joints of the lower extremities in the normal subjects will be larger than the range of motion of the joint angles in the lower extremities in the genu varum subjects.

2. The GRF of the normal subjects will be greater than the GRF of the genu varum subjects.

3. Linear displacement (stride length) of the normal subjects will be greater than the linear displacement of the genu varum subjects.

4. The EMG data will be different in the gait of normal subjects and genu varum subjects.

5. Temporal percentages in the stance and swing phases will be less for the normal subjects and greater for the genu varum subjects.

Definition of Terms

The following terms and definitions are applicable and important to the understanding of the study:

1. *Genu varum:* A deformity marked by medial angulation of the leg in relation to the thigh; an outward bowing of the leg at the knee joint (Spraycar, 1995). A combination of medial and lateral rotation of the hip joint with hyperextension of the knee joint (Kendall, 1986).

2. *Braking phase:* The first part of the stance phase where the center of gravity (COG) is behind the plant phase and the ground reaction forces decelerate the body. This phase begins at heel strike and ends at foot flat.

3. *Foot flat:* The point following heel strike where the sole of the shoe is completely in contact with the ground.

4. *Heel off:* The point following foot flat where the heel of the foot lifts off the ground to begin the push-off phase.

5. *Heel strike or foot strike:* A point in the gait cycle that occurred at the initial ground contact of any part of the foot during walking.

6. *Midstance phase:* The second part of the stance phase where the COG is over the support foot. This phase begins at foot flat and ends at heel off.

7. *Propulsion phase:* The third part of the stance phase where the COG is in front of the support foot and the ground reaction forces accelerate the body. This phase begins after heel off and ends at toe off.

8. *Stance phase:* The time that the right foot was in contact with the ground, defined as a percentage of a complete gait cycle.

9. *Swing phase:* The time that the right foot was not in contact with the ground, defined as a percentage of a complete gait cycle.

10. *Toe off:* The last point in the stance phase where the foot is in contact with the ground.

CHAPTER II

REVIEW OF RELATED LITERATURE

The problem in this study was to compare major joint angles in the lower extremities, ground reaction forces, linear displacement, temporal changes, and EMG, while walking one gait cycle between genu varum and normal men, ages 20–25 years. The following areas need to be reviewed: (a) walking actions, (b) postural genu varum, (c) kinematics of normal walking gait, (d) COG, (e) walking phases, (f) EMG interpretation, and (g) GRF.

Walking Actions

Steindler suggested that walking is a succession of catastrophes which are narrowly prevented (Adrian & Cooper, 1989). First, there is a falling of the body forward, then the legs move under the body and prevent such an accident from occurring by establishing a new base of support with the feet. Human walking is also defined as movement by means of shifting weight from one foot to the other, with at least one foot contacting the surface at all times. This is a form of ambulation known as bipedal locomotion (Kendall, 1986).

Walking is a type of reflex action. The reflexes such as righting and stepping, displayed by infants are the very foundation on which walking is based. Reflexes are the first clues to later voluntary movement. The postural reflexes exhibited by the young child during the first months of life are evident during the standing and stepping actions induced by parents. They are the prelude to the walking action. The adult walking action is the epitome of horizontal joint action in conjunction with synchronization of muscle movement (Hennessy, Dixon, & Simon, 1984).

Postural Genu Varum

In contrast to the actual changes in the alignment of the bones, there may be changes in the joint position that give rise to postural genu varum. The knee joint, essentially a hinge joint, allows the knee to flex and extend. There is free flexion throughout a wide arc of motion. When the knee straightens in standing, the motion should stop a few degrees beyond the straight line. However, like some “spring” hinges, some knees go beyond straight and curve backward into a position of hyperextension, which may be mild, or moderate (Nordin & Frankel, 1989).

In normal gait the patellae should face straight ahead, but at times they face medially or laterally. Abnormal position of the patellae in a static situation often results from rotation of the femur at the tibia. A combination of medial or lateral rotation of the femur and tibia, with hyperextension of the knee joint accounts for postural genu varum. This leads to the physical appearance of the legs bowing outward at the knee joints.

The axis of the knee joint about which flexion and extension take place is in a coronal plane of the body when the patellae faces straight ahead, that is, when the femur and tibia are properly aligned. From this position flexion, extension, or even hyperextension will occur anteriorly or posteriorly.

With medial and lateral rotation of the lower extremity, the axis of the knee joint is oblique to a coronal plane of the body and flexion will occur in an antero-medial direction, and extension or hyperextension will occur in a postero-lateral direction. As a result, there will be an apparent bowing of the legs in hyperextension.

The appearance of postural genu varum may also result from the combination of knee flexion with rotation of the femur and tibia. With lateral rotation and slight flexion, legs will appear slightly bowed (Kendall, 1986).

Kinematics of the Normal Walking Gait

Many different techniques have been used to describe the motions occurring during human gait. Studies of gait have been conducted using high-speed filming and three-dimensional computer analysis of body motions combined with force platform and EMG data. Video tape analysis illustrates individual differences in gait patterns; however, certain commonalities have been discussed (Nordin & Frankel, 1989). The width of the base should be no more than 2 to 4 in. from heel to heel. Normal step length when walking is approximately 15 in. The body's COG lies 2 in. in front of the second sacral vertebra. In normal gait it oscillates no more than 2 in. in the vertical direction, in order to maintain a smooth pattern of gait as the body advances. The knee should remain flexed during all components of the stance phase (except in heel strike). Range of motion of the knee in the sagittal plane is from 0° to 70° for men during level walking. The pelvis and trunk shift laterally approximately 1 in. to the weight bearing side during gait. Motion of the thigh in the sagittal plane is from –3° to 41° and for the ankle is –25° to 8°. The average adult walks a cadence of approximately 90 to 120 steps per minute with an average energy cost of 100 calories per mile. During the swing phase, the pelvis rotates 40° forward while the hip joint on the opposite extremity acts as a fulcrum for rotation (Hoppenfeld, 1976). The many muscles responsible for walking contract to allow maintenance of upright posture against gravity or transfer and store energy between limb segments (Rose & Gamble, 1994).

Center of Gravity

The general body position for walking is the same as that for standing, the only difference being that the COG of the body is moved forward so that gravity helps to overcome the inertia of the body and force can be applied against the floor in the direction opposite to that desired movement (Zernick, 1979).

The bipedal position permits rapid initiation of the motion of walking. The COG is easily displaced in the desired direction because (a) it resides high (at approximately the second sacral segment) over a small base of support, and (b) the greater portion of the body weight is located in the trunk, head, and shoulders rather than the lower extremities. This inherently unstable situation necessitates close cooperation of the neuromusculoskeletal system in the act of walking (Leveay, 1992).

Walking Phases

Walking can be described as having two energy phases, a high- and low-energy phase also known as the stance and swing phase. The high energy phase of walking occurs during the stance phase which contains the actions of heel strike, midstance, and toe off. This phase consists of 60–65% of the walking cycle. The high energy phase is explained by the fact that the descending leg is decelerated just before and at the time of heel strike, thus preventing injury to the heel. In addition the shock of the heel as it strikes is absorbed by the lower limb and the entire body. Since the shock absorption enables the body to remain balanced during midstance, the energy cost is high. The toe off position of the stance phase initiates the forward propulsion of the body and therefore is high in energy requirements.

The low-energy phase occurs during the swing phase of the walking cycle. The swing phase begins after toe off and is comprised of the leg swing (acceleration), which is 35–40% of the walking cycle. The hip flexor and knee extensor help to keep the heel from rising too high. Dorsiflexion of the toes at midpoint of the swing in preparation for the heel strike prevents the toes from striking first. The hamstring muscles also expend energy to decelerate the leg during the latter stages of the swing. The pendulum action of the swinging leg assisted by gravity, accounts for less energy expended during the swing phase than for the stance phase (Adrian & Cooper, 1989; Kreighbaum & Barthels, 1996).

EMG Interpretation

EMG in active muscles can give information about muscle physiology and motor control beyond issues of timing during gait. Modern diagnostic EMG can identify neural injury or compression, denervated muscles, or primary myopathological processes. The EMG signal itself is a highly complex wave form whose shape depends on the type and location of electrodes, the number of motor unit action potentials detected, the spatial geometry of the motor unit itself, and filtering characteristics of muscle tissue. By electrically and mathematically processing the raw EMG signal, information is generated about forces, motor unit recruitment, and muscle fatigue. The total EMG signal can be analyzed by calculating the power density spectrum, which depends on the force, the time, and the individual firing rates when surface elctrodes were used. The noninvasive nature of this technique makes it particularly applicable to studies of muscle physiology in animals and humans (Rose & Gamble, 1994).

GRF

GRF gives us information about reaction forces of the individual pushing on the ground. GRF studies conducted for normal gait on horizontal and vertical forces exerted against a force platform, indicate the ground exerts equal and opposite forces against the body. Beginning with heel strike to midstance the vertical vector increases in magnitude to 120% of the total body weight. During the push-off phase the vertical forces again reach 120% of the total body weight and decrease to zero as the foot is lifted from the ground. From heel off to toe off there is a backward push against the platform, causing a forward reactive force of approximately 20% of total body weight. The foot pushes medially on the ground during heel strike and laterally on the ground during flexion at the knee (Adrian & Cooper, 1989).

Summary

Walking is the most efficient form of human translation. Its unique style disturbs the mechanical equilibrium of the body. The action of walking pushes the body forward while forming successive new bases by moving the legs forward alternately. It consists of two phases known as the high-energy stance phase, and the low-energy swing phase. The action of walking is a reflex action, used as the foundation for infant locomotion. However, this foundation can be altered as a direct result of abnormalities that may exist in bone alignment, or joint positioning. Genu varum, commonly known as bowlegs, is an example of a postural abnormality that may affect the smooth pattern of human locomotion. Studies of gait kinematics have been conducted with use of high-speed filming, three-dimensional computer analysis, GRF, and EMG data. Gait examinations analyzed through the use of these methods assist researchers in the detection and treatment of abnormalities in the walking cycle.

CHAPTER III

METHODS AND PROCEDURES

The problem of this study was to compare major joint angles in the lower extremities, GRFs, linear displacement, temporal changes, and EMG, while walking one gait cycle between genu varum and normal men, ages 20–25 years. The study focused on both the stance and swing phases of a gait cycle. The following topics are covered in this chapter: (a) human subjects approval, (b) subject selection, (c) instrumentation process, (d) EMG filming and force platform procedures, and (e) research design.

Human Subjects Approval

Approval to conduct the study was required by Western Michigan University's Human Subjects Institutional Review Board (HSIRB). The appropriate forms were submitted by the principal investigator to the HSIRB. After clarification and changes, the board granted approval for the study (see letter from HSIRB in Appendix A).

Subject Recruitment

The 10 subjects participating in the study were male students attending Western Michigan University in Kalamazoo. Five subjects possessed genu varum of the knees, and five were normal (nonbowlegged). All subjects were 20–25 years old. All those volunteering signed a consent form (see Appendix B).

Electromyography Procedures

The EMG responses in the following six muscles were measured during a cycle of the walking pattern and compared between the genu varum and normal subjects: (1) rectus femoris, (2) vastus medialis, (3) medial head of the gastrocnemius, (4) peroneal group, (5) biceps femoris, and (6) semimembranosus/ semitendinosus. Bipolar surface electrodes, Meditrace, 1 cm, silver/silver chloride (ECE 1801, Graphic Controls, Buffalo, NY) were placed at a point half the distance between the innervation zone (motor point) and the distal tendon surface. The electrodes were placed approximately 1 cm apart, parallel with the muscle fibers, and near the midline of the muscle. All sites were carefully identified, shaved, and prepped before electrode placement.

The EMG response for each muscle during the stance and swing phases of the gait pattern was analyzed to compare the differences between genu varum and normal subjects.

Ground Reaction Force Procedures

Braking and propulsion forces were measured for the right leg. The force platform was a Kistler Type 9281B (Kistler Instrument Corporation, Amherst, NY). Amplification of the signal and the range setting was controlled by the Kistler 9861A amplifier. The analog data were converted to a digital signal by an analog digital interface, 32 channel unit, connected to a analog-to-digital board. The analog-to-digital board was connected to an event and video control unit (EVCU) for matching force and EMG data to video data. The EVCU unit was used to trigger the interface equipment during data collection. A Gateway 2000 computer ran the Peak Motus

Analog Sampling Software (Peak Performance Technologies, Inc., Englewood, CO). The analog-digital interface unit and the EVCU unit were manufactured by Peak Performance Technologies, Inc., Englewood, CO.

Filming Procedures

A three-dimensional video analysis of each walking pattern was used. A Panasonic WV-D5100HS video camera and a Panasonic AG 450 video camera (Panasonic, Secaucus, NJ) set at 60 Hz were used to record the motion of the walking pattern. Maxell S-VHS ST-120N video tapes were used to record the motion. The video data were synchronized to the EMG data and the force platform data through the EVCU. The cameras were placed perpendicular and parallel to the sagittal plane of the subjects, 26 ft from the force platform. The camera's view was on the right side of the subjects. The camera lenses were set 1 m above the ground. Subjects performed in front of a contrasting background.

Data Collection Procedures

Data collection took place in the Biomechanics Laboratory in the University Recreation Center, Western Michigan University, Kalamazoo. Subjects were instructed to wear dark-colored shorts cut above the knee. They were videotaped wearing a pair of low-top sneakers. All information was collected and recorded on a data sheet.

Written instructions were read to each subject prior to participation, and a consent form was read and signed. The instructions were as follows:

1. You will be given a 5 min warm up prior to testing.

2. During the data collection, you will complete three trials of the walking conditions. A trial consists of five to six steps with the right foot contacting the force platform on the fourth or fifth step.

3. For each walking trial you will perform at a comfortable speed, 100 bpm set by a metronome.

4. In each trial you should walk as you do in daily life.

Video Digitizing

The digitizing began at the heel strike or foot strike of the right foot on the force platform. The digitizing ended at the next heel strike of the right foot. Segments digitized were the right upper arm, right forearm, right hand, right thigh, right calf, and right foot. The sequence of motion allowed a complete walking cycle to be broken down into a right stance phase and a right swing phase. All digitized data were smoothed using a Butterworth filter set at 6 Hz.

Phases of the walking motion were defined by the following:

1. Stance phase began at foot contact on the floor and continued through push off. The stance phase contained a heel strike, midstance, and toe off, identifiable points in every person's gait pattern.

2. Swing phase began at the end of the propulsion phase and continued until the next heel strike. The swing phase was subdivided into three parts: initial swing, midswing, and terminal swing. The initial swing was one third of the swing phase, beginning after toe off. The terminal swing phase was the last one third of the phase.

Research Design

The research design for the investigation was a split plot factorial ANOVA. Each subject respectively produced data for one level of the grouping variable, normal or genu varum. The study consisted of one research variable: trials with three levels. The investigation used three trials to determine if the subjects had a consistent gait pattern.

The dependent variables for the study included the following:

1. *Stride length:* The horizontal distance from right heel strike to the next right heel strike.

2. *Temporal data:* Time spent in the stance phase and swing phase; measured as a percent of the total stride time.

3. *Knee angle:* The angle formed in the sagittal plane between the thigh and leg; measured on the posterior side of the lower extremity.

4. *Ankle angle:* The angle in the frontal plane formed by the leg and foot; measured on the anterior side of the lower extremity.

5. *Hip displacement:* The linear displacement in the medial/lateral and vertical direction measured during a gait cycle.

6. *Hip rotation:* The motion of the hips in the transverse plane around the longitudinal axis. For the right hip, rotation will be measured in the medial and lateral directions.

7. *Tibial rotation:* The motion of the tibia in the transverse plane around the longitudinal axis (device: elongated marker).

8. *Braking force:* The ground reaction force that acts in the horizontal backward direction or against the desired direction of motion during the braking phase of the stance phase.

9. *Propulsion force:* The ground reaction force that acts in the horizontal forward direction or in the direction of the intended motion during the propulsion phase of the stance phase.

10. *Time to peak EMG:* The time from the beginning of the motion, heel strike, to when the muscle reaches its greatest magnitude; measured in microseconds.

11. *Area EMG:* The mean amplitude measured in microvolts times time (impulse) was recorded for each muscle during the gait cycle measured.

12. *Thrust force:* The ground reaction force that acts in the vertical direction propelling the body upward into the swing phase during the propulsion phase of the stance phase.

13. *Impact force:* The ground reaction force that acts in the vertical direction and stops the body's downward momentum during the braking phase of the stance phase.

14. *Moments:* The twisting action that is applied to the ground by the foot during the stance phase.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The problem of this study was to compare angular and linear kinematics, ground reaction forces (GRF), center of gravity (COG), temporal changes, and electromyography (EMG), while walking one gait cycle to a metronome set to 100 bpm between bowlegged and normal men, ages 20–25 years. The study focused on both the stance and swing phases of the gait cycle. In this chapter, the results are presented and discussed in the following order: (a) performance consistency, (b) kinematics, (c) kinetics, and (d) EMG. The discussion follows the results.

Results

The study consisted of kinematic and kinetic dependent variables: stride length, ankle medial-lateral and vertical displacement, knee medial-lateral and vertical displacement, hip medial-lateral and vertical displacement, tibial rotation, ankle angle, knee angle, hip rotation, braking force, propulsion force, time to peak EMG, impact force, and moments. The researcher also investigated time to peak and peak EMG for six muscles: (1) bicep femoris, (2) gastrocnemius, (3) peroneal, (4) rectus femoris, (5) vastus medials, (6) semimembranosus/semitendinosus groups.

Each dependent variable was calculated by the use of a split-plot factorial ANOVA. Each ANOVA contained a grouping variable with two groups (genu varum and normal). Some of the ANOVAs for the kinematic data included a second research variable, phases with two levels (stance and swing) or position in phases with four levels (heel strike, foot flat, heel off, and toe off). To check for performance consistency, subjects repeated the gait cycle three times (trials).

Kinematics

Stride Length

Stride length was measured from foot strike of the right foot to the next foot strike for the right foot. An ANOVA summary table for stride length (measured in meters) is presented in Table 1. The results of the ANOVA were the following:

Table 1

ANOVA Summary for Stride Length

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	0.19	1	0.19	0.74	.42
Subj. w. groups	2.10	8	0.26		
Within Subjects					
Trials (T)	0.17	2	0.08	1.33	.29
T × G	0.03	2	0.01	0.02	.82
T × Subj. w. groups	1.01	16	0.06		

1. No significant differences in stride length was found between the two groups, $F(1, 8) = 0.74$, $p = .42$. The means for the Normal and Genu Varum Groups were 1.35 m, and 1.51 m, respectively.

2. No significant difference in stride length was found among the three trials, $F(2, 16) = .33$, $p = .29$. The means for the three trials, 1, 2, and 3, were 1.29 m, 1.43 m, and 1.33 m, respectively.

3. The interaction effect, trials by groups, was not significant at the .05 level.

Hip Displacement

Medial/Lateral Displacement. Hip medial/lateral displacement was measured for an entire stride. An ANOVA summary table for hip medial/lateral displacement (measured in meters) is found in Table 2. The results of the ANOVA were the following:

Table 2

ANOVA Summary of Hip Med/Lat

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	0.0007	1	0.0007	0.34	.58
Subj. w. groups	0.01	8	0.002		
Within Subjects					
Trials (T)	0.00007	2	0.00003	0.08	.92
T × G	0.002	2	0.0001	0.29	.76
T × Subj. w. groups	0.007	16	0.0004		

1. No significant difference was found in hip medial/lateral displacement between the two groups, $F(1,8) = 0.34$, $p = .58$. The means for the Normal and Genu Varum Groups were 0.09 m, and 0.08 m, respectively.

2. No significant difference in hip medial/lateral displacement was found among the three trials, $F(2,16) = 0.08$, $p = .92$. The means for Trials 1, 2, and 3, were 0.09 m, 0.10 m, and 0.09 m, respectively.

3. The interaction effect, trials by groups, was not significant at the .05 level.

Vertical Displacement. Hip vertical displacement was measured for an entire stride length. An ANOVA summary table for hip vertical displacement (measured in meters) is found in Table 3. The results of the ANOVA were the following:

Table 3

ANOVA Summary of Hip Vertical Displacement

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	0.00003	1	0.00003	0.06	.81
Subj. w. groups	0.0004	8	0.0006		
Within Subjects					
Trials (T)	0.0003	2	0.0001	0.37	.69
T × G	0.001	2	0.0005	1.42	.27
T × Subj. w. groups	0.006	16	0.0004		

1. No significant difference in hip vertical displacement was found between the two groups $F(1, 8) = 0.06$, $p = .81$. The means for Normal and Genu Varum Groups were 0.06 m and 0.07 m, respectively.

2. No significant difference in hip vertical displacement was found among the three trials, $F(2, 16) = 0.37$, $p = .69$. The means for Trials 1, 2, and 3 were 0.06 m, 0.06 m, and 0.07 m, respectively.

3. The interaction effect, trials by group, was not significant at the .05 level.

Angles

All angles were measured during the stance phase at heel strike, foot flat, heel off, and toe off.

Tibial Rotation. An ANOVA summary table for tibial rotation is found in Table 4. The results of the ANOVA were the following:

1. No significant difference in tibial rotation was found between the two groups, $F(1, 8) = 065$, $p = 0.44$. The means for Normal and Genu Varum Groups were 88.75° and 84.11°, respectively.

2. No significant difference in tibial rotation was found among the three trials $F(2,16) = 1.38$, $p = .28$. The means for Trials 1, 2, and 3 were 83.91°, 86.82°, and 88.56°, respectively.

3. A significant difference was found among the phases $F(3, 48) = 12.01$, $p = .00$. The means for heel strike, foot flat, heel off, and toe off were 91.13°, 85.82°, 72.92°, and 95.85°, respectively.

4. No significant differences were found for the first or second order interaction effects.

Table 4

ANOVA Summary for Tibial Rotation

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	647.11	1	647.11	0.65	.44
Subj. w. groups	7964.27	8	995.53		
Within Subjects					
Trials (T)	440.73	2	220.37	1.38	.28
T × G	396.57	2	198.28	1.24	.32
T × Subj. w. groups	2560.84	16	160.05		
Phases (P)	8814.28	3	2938.09	12.01	.00
P × G	1805.05	3	601.68	2.46	.09
P × Subj. w. groups	5869.42	24	244.56		
T × P	1053.52	6	175.59	1.74	.13
T × P × G	885.85	6	147.64	1.46	.21
TP × Subj. w. groups	4852.94	48	101.10		

Ankle. An ANOVA summary table for ankle angle is found in Table 5. The results of the ANOVA were the following:

1. No significant difference in ankle angles was found between the two groups, $F(1, 8) = 43.12$, $p = .12$. The means for the Normal and Genu Varum Groups were 124.46° and 117.97°, respectively.

Table 5

ANOVA Summary for Ankle Angles

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	1261.42	1	1261.42	43.12	.12
Subj. w. groups	3237.37	8	404.67		
Within Subjects					
Trials (T)	752.85	2	376.42	2.74	.09
T × G	11.73	2	5.87	0.04	.96
T × Subj. w. groups	2194.57	16	137.16		
Phases (P)	4739.52	3	1579.84	12.20	.00
P × G	155.85	3	51.95	0.40	.75
P × Subj. w. groups	3106.80	24	129.45		
T × P	685.95	6	114.33	0.64	.70
T × P × G	121.12	6	20.19	0.11	1.00
TP × Subj. w. groups	8641.41	48	180.13		

2. No significant difference in ankle angle was found among the trials, $F(2, 16) = 2.74$, $p = .09$. The means for Trials 1, 2, and 3 were 122.04°, 117.82°, and 123.79°, respectively.

3. A significant difference was found among the phases, $F(3, 48) = 12.20$, $p = .00$. The means for heel strike, foot flat, heel off, and toe off phases were 120.82°, 121.29°, 112.49°, and 130.25°, respectively.

4. No significant differences were found for the first or second order interaction effects.

Knee Angles. An ANOVA summary of the knee angle is found in Table 6. The results of the ANOVA were the following:

Table 6

ANOVA Summary for Knee Angles

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	1236.86	1	1236.86	4.65	.07
Subj. w. groups	1863.54	7	266.22		
Within Subjects					
Trials (T)	103.58	2	51.79	0.96	.41
T × G	77.95	2	38.98	0.72	.50
T × Subj. w groups	758.25	14	54.16		
Phases (P)	22062.40	3	7354.14	32.53	.00
P × G	880.70	3	293.57	1.30	.30
P × Subj. w. groups	4747.87	21	226.09		
T × P	829.08	6	138.18	1.60	.17
T × P × G	134.94	6	22.49	0.26	.95
TP × Subj. w. groups	3647.77	42	86.85		

1. No significant difference in knee angle was found between the groups, $F(1, 7) = 4.65$, $p = .07$. The means for the Normal and Genu Varum Groups were 161.58° and 154.77°, respectively.

2. No significant difference in knee angle was found among the three trials, $F(2, 14) = 0.96$, $p = .41$. The means for the Trials 1, 2, and 3 were 159.22°, 156.85°, and 158.44°, respectively.

3. A significant difference was found among the phases, $F(3, 42) = 32.42$, $p = .00$. The means for heel strike, foot flat, heel off, and toe off were 172.08°, 168.65°, 156.62°, and 135.33°, respectively.

4. No significant differences were found for the first or second order interaction effects.

Hip Rotation. An ANOVA summary table for hip rotation is presented in Table 7. The results of the ANOVA were the following:

1. No significant difference was found between the two groups, $F(1, 8) = 1.02$, $p = .34$. The means for the Normal and Genu Varum Groups were 76.21° and 71.20°, respectively.

2. A significant difference was found among the three trials for hip rotation, $F(2, 16) = 3.59$, $p = 0.05$. The means for Trials 1, 2, and 3 were 74.30°, 70.26°, and 76.57°, respectively.

3. A significant difference was found among the phases, $F(3, 48) = 32.48$, $p =.00$. The means for heel strike, foot flat, heel off, and toe off phases were 92.54°, 90.09°, 48.75°, and 63.45°, respectively.

4. No significant differences were found for the first or second order interaction effects.

Table 7

ANOVA Summary for Hip Rotation Angles

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	752.70	1	752.70	1.02	.34
Subj. w. groups	5876.17	8	734.52		
Within Subjects					
Trials (T)	817.67	2	408.84	3.59	.05
T × G	616.75	2	308.37	2.71	1.00
T × Subj. w groups	1820.80	16	113.80		
Phases (P)	40535.30	3	13511.77	32.48	.00
P × G	943.71	3	314.57	0.76	.53
P × Subj. w. groups	9985.57	24	416.07		
T × P	602.82	6	100.47	0.94	.47
T × P × G	684.59	6	114.10	1.07	.39
TP × Subj. w. groups	5116.58	48	106.60		

Temporal Data

Stride Time. Stride time was measured from heel strike of the right foot to the next heel strike for the right foot. An ANOVA summary table for stride time is presented in Table 8. The results of the ANOVA were the following:

Table 8

ANOVA Summary of Stride Time

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	0.005	1	0.005	1.20	.31
Subj. w. groups	0.030	8	0.004		
Within Subjects					
Trials (T)	0.008	2	0.004	0.75	.50
T × G	0.020	2	0.010	1.90	.19
T × Subj. w. groups	0.080	16	0.005		

1. No significant difference in stride length was found between the two groups, $F(1, 8) = 1.2$, $p = .31$. The means for the Normal and Genu Varum Groups were 1.18 s and 1.21 s, respectively.

2. No significant difference in stride time was found among the three trials $F(2, 16) = 0.75$, $p = .50$. The means for Trials 1, 2, and 3 were 1.21 s, 1.20 s, and 1.17 s, respectively.

3. The interaction effect, trials by groups, was not significant at the .05 level.

Stance Time. Stance time was measured as a percent of total stride time. An ANOVA summary table for the stance time is presented in Table 9. The results of the ANOVA were the following:

Table 9

ANOVA Summary of Stance Time

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	32.00	1	32.00	0.86	.38
Subj. w. groups	296.67	8	37.08		
Within Subjects					
Trials (T)	59.47	2	29.73	2.37	.13
T × G	20.27	2	10.13	0.81	.46
T × Subj. w. groups	200.93	16	12.56		

1. No significant difference in percent of stance time was found between the two groups, $F(1, 8) = 0.86$, $p = .38$. The means for the Normal and Genu Varum Groups were 66.53% and 68.60%, respectively.

2. No significant difference in percent stance time was found among the three trials, $F(2, 16) = 2.37$, $p = .13$. The means for Trials 1, 2, and 3 were 69.10%, 65.70%, and 67.90%, respectively.

3. The interaction effect, trials by groups, was not significant at the .05 level.

Swing Time. Swing time was measured as a percent of total stride time. An ANOVA summary table is presented in Table 10. The results of the ANOVA were the following:

Table 10

ANOVA Summary of Swing Time

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	32.00	1	32.00	0.86	.38
Subj. w. groups	296.67	8	37.08		
Within Subjects					
Trials (T)	59.47	2	29.73	2.37	.13
T × G	20.27	2	10.13	0.81	.46
T × Subj. w. groups	200.93	16	12.56		

1. No significant difference in swing time was found between the two groups, $F(1, 8) = 0.86$, $p = .38$. The means for the Normal and Genu Varum Groups were 33.47% and 31.40%, respectively.

2. No significant difference in the percent of time spent in swing phase was found among the three trials, $F(2, 16) = 2.37$, $p = .13$. The means for Trials 1, 2, and 3 were 30.90%, 34.30%, and 32.10%, respectively.

3. The interaction effect, trials by groups, was not significant at the .05 level.

EMG

The ANOVA used to analyze the EMG data was a split-plot factorial design. There were two dependent variables: (1) peak EMG, and (2) time to peak EMG. The peak EMG was the maximum μv of activity that occurred during the stride that was analyzed. Time to peak EMG indicated the time within the stride at which peak EMG occurred. The ANOVAs were comprised of a grouping variable, Normal and Genu Varum, and two research variables, trials and muscles.

Peak EMG

An ANOVA summary table for peak EMG is presented in Table 11. The results of the ANOVA were the following:

Table 11

ANOVA Summary for Peak EMG

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	0.21	1	0.21	0.33	.58
Subj. w. groups	4.32	7	0.62		
Within Subjects					
Trials (T)	4906.09	2	2453.05	0.24	.79
T × G	12175.81	2	6087.90	0.60	.56
T × Subj. w groups	161190.82	16	10074.43		
Muscles (M)	282379.42	5	56475.89	0.84	.53
M × G	112217.90	5	22443.58	0.33	.89
M × Subj. w. groups	2690698.80	40	67267.47		
T × M	35427.27	10	3542.72	0.95	.50
T × M × G	35151.10	10	3515.11	0.94	.50
TM × Subj. w. groups	299982.26	80	3749.78		

1. No significant difference was found between the two groups, $F(1, 7) = 0.33$, $p = .58$. The means for the Normal and Genu Varum Groups were 0.34 µv, and 0.27 µv, respectively.

2. No significant difference was found among the three trials for peak EMG, $F(2, 16) = 0.24$, $p = .79$. The means for Trials 1, 2, and 3 were 0.28 µv, 0.34 µv, and 0.30 µv, respectively.

3. No significant difference was found among the muscles, $F(5, 40) = 0.84$, $p = .53$. The means for rectus femoris, vastus medialis, gastrocnemius, peroneal, semimembranosus/semitendinosus and bicep femoris were 0.16 µv, 0.17 µv, 0.42 µv, 0.32 µv, 0.27 µv, and 0.50 µv, respectively.

4. No differences were found for the first and second order interaction effects.

Time to Peak

An ANOVA summary table for time to peak EMG is presented in Table 12. The results of the ANOVA were the following:

1. No significant difference was found between the two groups $F(1, 7) = 0.33$, $p = .58$. The means for the Normal and Genu Varum Groups were 116.35 ms, and 114.05 ms, respectively.

2. No significant difference was found among the three trials for time to peak EMG, $F(2, 14) = 0.80$, $p = .47$. The means for Trials 1, 2, and 3 were 122.45 ms, 110.36 ms, and 112.80 ms, respectively.

3. No significant difference was found among the muscles, $F(5,35) = 1.74$, $p = .15$. The means for rectus femoris, vastus medialis, gastrocnemius, peroneal, semimembranosus/semitendinosus, and bicep femoris were 193.05 ms, 125.35 ms, 84.42 ms, 122.95 ms, 90.79 ms, and 74.64 ms, respectively.

4. No significant differences were found for the first or second order interaction effects.

Table 12

ANOVA Summary for Time to Peak EMG

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	0.21	1	0.21	0.33	.58
Subj. w. groups	4.32	7	0.62		
Within Subjects					
Trials (T)	0.10	2	0.05	0.80	.47
T × G	0.02	2	0.01	0.24	.79
T × Subj. w. groups	0.88	14	0.06		
Muscles(M)	2.38	5	0.48	1.74	.15
M × G	0.74	5	0.15	0.54	.74
M × Subj. w. groups	0.955	35	0.27		
T × M	0.38	10	0.03	0.31	.98
T × M × G	0.54	10	0.05	0.45	.92
TM × Subj. w. groups	8.42	70	0.12		

Kinetics

Braking Force

Braking force was measured at heel strike of the right foot. An ANOVA summary table for braking force is presented in Table 13. The results of the ANOVA were the following:

Table 13

ANOVA Summary of Braking Force

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	131.00	1	131.00	0.02	.88
Subj. w. groups	46027.79	8	5753.47		
Within Subjects					
Trials (T)	615.08	2	307.54	1.31	.30
T × G	72.29	2	36.14	0.15	.86
T × Subj. w. groups	3761.01	16	235.06		

1. No significant difference in braking force was found between the two groups, $F(1, 8) = 0.02$, $p = .88$. The means for the Normal and Genu Varum Groups were 169.65 N and 165.47 N, respectively.

2. No significant difference in braking force was found among the three trials, $F(2, 16) = 1.31$, $p = .30$. The means for Trials 1, 2, and 3 were 168.79 N, 161.50 N, and 172.38 N, respectively.

3. The interaction effect, trials by groups, was not significant at the .05 level.

Impact Force

Impact force was measured at heel off of the right foot. An ANOVA summary table for impact force is presented in Table 14. The results of the ANOVA were the following:

Table 14

ANOVA Summary of Impact Force

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	6107.50	1	6107.50	0.04	.85
Subj. w. groups	1292392.70	8	161549.09		
Within Subjects					
Trials (T)	105670.65	2	52835.33	1.92	.18
T × G	221629.75	2	110814.87	4.02	.04
T × Subj. w. groups	441098.03	16	27568.06		

1. No significant difference in impact force was found between the two groups, $F(1, 8) = 0.04$, $p = .85$. The means for the Normal and Genu Varum Groups were 899.33 N and 927.87 N, respectively.

2. No significant difference in impact force was found among the three trials, $F(2, 16) = 1.92$, $p = .18$. The means for Trials 1, 2, and 3 were 935.59 N, 972.75 N, and 832.46 N, respectively.

3. The interaction effect, trials by groups, was not significant at the .05 level.

Maximum Thrust Force

Thrust force was measured during the propulsion phase. An ANOVA summary table for thrust force is presented in Table 15. The results of the ANOVA were the following:

Table 15

ANOVA Summary of Thrust Force

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	75438.54	1	75438.54	0.74	.41
Subj. w. groups	814181.15	8	101772.64		
Within Subjects					
Trials (T)	13511.18	2	6755.59	1.26	.31
T × G	5069.64	2	2534.82	0.47	.63
T × Subj. w. groups	85717.81	16	5357.36		

1. No significant difference in thrust force was found between the two groups, $F(1, 8) = 0.74$, $p = .41$. The means for the Normal and Genu Varum Groups were 1030.08 N and 929.79 N, respectively.

2. No significant difference in thrust force was found among the three trials, $F(2, 16) = 1.26$, $p = .31$. The means for Trials 1, 2, and 3 were 950.68 N, 1000.36 N, and 988.77 N, respectively.

3. The interaction effect, trials by groups, was not significant at the .05 level.

Maximum Propulsion Force

Propulsion force was measured during the propulsion phase. An ANOVA summary table of propulsion force is presented in Table 16. The results of the ANOVA were the following:

Table 16

ANOVA Summary of Propulsion Force

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	35.75	1	35.75	0.00	.95
Subj. w. groups	74820.24	8	9352.53		
Within Subjects					
Trials (T)	18250.19	2	9125.10	0.84	.45
T × G	30431.38	2	15215.69	1.39	.28
T × Subj. w. groups	174641.36	16	10915.09		

1. No significant difference in propulsion force was found between the two groups, $F(1, 8) = 0.00$, $p = .95$. The means for the Normal and Genu Varum Groups were 144.78 N and 146.97 N, respectively.

2. No significant difference in propulsion force was found among the three trials, $F(2,16) = 0.84$, $p = .45$. The means for Trials 1, 2, and 3 were 116.16 N, 144.92 N, and 176.55 N, respectively.

3. The interaction effect, trials by groups, was not significant at the .05 level.

Moments During Braking Phase

Moments of the braking phase is the reaction to the torque applied to the ground during the braking phase. An ANOVA summary table for moments during this phase is presented in Table 17. The results of the ANOVA were the following:

Table 17

ANOVA Moments During Braking Phase

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	9.14	1	9.14	0.40	.55
Subj. w. groups	183.39	8	22.92		
Within Subjects					
Trials (T)	65.35	2	32.67	4.18	.04
T × G	24.02	2	12.01	1.53	.25
T × Subj. w. groups	125.09	16	7.82		

1. No significant difference was found in the moments between the two groups, $F(1, 8) = 0.40$, $p = .55$. The means for the Normal and Genu Varum Groups were 6.35 Nm, and 7.45 Nm, respectively.

2. No significant difference in the moments was found among the three trials, $F(2, 16) = 4.18$, $p = .04$. The means for Trials 1, 2, and 3 were 4.89 Nm, 7.42 Nm, and 8.39 Nm, respectively.

3. The interaction effect, trials by groups, was not significant at the .05 level.

Moments During Propulsion Phase

Moments of the propulsion phase is the reaction of the torque applied to the ground during the propulsion phase. An ANOVA summary table for moments during this phase is presented in Table 18. The results of the ANOVA were the following:

Table 18

ANOVA Moments During Propulsion Phase

Source	SS	df	MS	F	p
Between Subjects					
Groups (G)	2.67	1	2.67	0.04	.86
Subj. w. groups	609.02	8	76.13		
Within Subjects					
Trials (T)	134.01	2	67.00	2.31	.13
T × G	68.97	2	34.49	1.19	.33
T × Subj. w. groups	464.19	16	29.01		

1. No significant difference in moments was found between the two groups, $F(1, 8) = 0.04$, $p = .86$. The means for the Normal and Genu Varum Groups were 13.24 Nm and 12.64 Nm, respectively.

2. No significant difference in moments was found among the three trials, $F(2, 16) = 2.31$, $p = .13$. The means for the Trials 1, 2, and 3 were 10.29 Nm, 13.05 Nm, and 15.47 Nm, respectively.

3. The interaction effect, trials by groups, was not significant at the .05 level.

Discussion

The problem of the study was to compare angular and linear kinematics, GRF, temporal changes, and EMG while walking one gait cycle to a metronome set at 100 bpm between normal and genu varum subjects ages 20–25 years.

Temporal Data

Stride Time

There was no significant difference in stride time between the subjects. However, the Normal Group had a lower stride time than the Genu Varum Group, $\underline{M}$ = 1.18 ms and 1.21 ms, respectively. Changes in the smooth coordinated pattern of the gait cycle reduce efficiency and greatly increase energy cost. Pathology in the lower extremities, age, fatigue, or pain decreases the number of steps per minute (Hoppenfeld, 1976).

Percent of stride time (stance) and percent of flight time (swing) was calculated. There was no significant difference between the percent of time spent in the stance and swing phases. The means for the stance phase of the Normal and Genu Varum Groups were $\underline{M}$ = 66.53% and 68.60%, respectively. The means for the swing phase of the Normal and Genu Varum Groups were $\underline{M}$ = 33.47% and 31.40%, respectively. The normal subjects in this study were close to the average of 35% swing phase and 65% stance phase reported in the literature (Kreighbaum & Barthels 1996).

Angles

Ankle

There was no significant difference in plantar flexion and dorsiflexion between the normal and genu varum subjects. The Normal Group, however, did show a greater range of motion at the ankle joint in the sagittal plane compared to the Genu Varum Group, M = 124.46° and 117.92°, respectively. The bowing of the legs at the knee joint results in a relative lateral positioning of the lower extremities. This lateral positioning often results in a more supinated position of the subtalar joint during the midstance and propulsion phase, often prohibiting normal pronation . A lack of pronation may reduce the degree of dorsiflexion that occurs in the sagittal plane. An abnormal range of motion with the ankle joint is attributed to a decrease in total ankle joint motion. The greatest decrease in range of motion (ROM) takes place with dorsiflexion (Nordin & Frankel, 1989).

Knee

There was no significant difference in flexion and extension at the knee between the normal and genu varum subjects. The Normal Group, however, did show a greater knee angle, M = 161.58°, than the Genu Varum Group, 154.77°. During the gait cycle the knee joint experiences flexion and extension in the sagittal plane. Flexion motion promotes pronation, and extension motion promotes supination. In genu varum subjects during the motion of flexion, the lower extremities physiologically resist pronation due to the relative lateral positioning of the legs. The need for pronation is limited, attributing to a decrease in the knee joint motion.

Hip Rotation

There was no significant difference in the hip rotation angle between the Normal and Genu Varum Groups. The Normal Group, however, did show a greater range of motion at the hip joint in the sagittal plane when compared to the Genu Varum Group, M = 76.21° and 71.20°, respectively. Range of motion at the hip joint in the frontal and transverse plane during the gait cycle includes abduction, which occurs during the swing phase, reaches maximum at the end of the propulsion phase, reversing into adduction at heel strike and continuing until late in the stance phase. The hip joint is externally rotated throughout the swing phase rotating internally prior to heel strike. The joint remains internally rotated until late in the stance phase when it again rotates externally (Nordin & Frankel, 1989). The bowing of the legs in genu varum subjects follows a kinetic chain beginning with subtalar pronation moving up to internal rotation. The inability to pronate sufficiently during the gait cycle limits the amount of internal rotation in the stance phase, hence decreasing the range of motion at the hip joint.

Tibial Rotation

There was no significant difference in the tibial rotation between the Normal and Genu Varum Groups. The Normal Group, however, did show a greater range of motion at the tibia in the sagittal plane compared to the Genu Varum Group, M = 88.75° and 84.12°, respectively. The distal end of the tibia is connected to the talus, via a strong ligamentous connection and the proximal end of the tibia is connected to the femur. Pronation at the foot is controlled by the talus. If the talus in not allowed to migrate to its anterior-medial position during gait then the bones connected to it either directly (tibia) or indirectly (femur) will also be unable to move anterior-medially. The anterior-medial direction of the tibia and femur is internal rotation. Therefore, the Genu Varum Group displayed less internal rotation of the tibia when compared to the Normal Group.

EMG

Time to Peak

There was no significant difference in time to peak EMG between the Normal and Genu Varum Groups. The Normal Group did show a difference in time to peak EMG compared to the Genu Varum Group, M = 0.340 N and 0.269 N, respectively. The overall firing order of each muscle was different between the groups. The Normal Group followed the sequential firing order vastus medialis, rectus femoris, peroneal group, semimembraneous, semitendenous, bicep femoris, and gastrocnemius. The Genu Varum Group following the sequential order vastus medialis, rectus femoris, semimembranous, semitendenous, gastrocnemius, peroneal group, and bicep femoris.

Peak EMG

There were no significant differences in peak EMG between the Normal and Genu Varum Groups. The Normal Group showed a greater difference in peak EMG compared to the Genu Varum Group, M = 116.35 N and 114.05 N, respectively.

Kinetics

GRF

There were no significant differences in GRF between the Normal and Genu Varum Groups. However, the Normal Group showed slightly greater GRF than the Genu Varum Group: (a) during the braking phase, M = 169.65 N and 165.47 N, respectively; (b) for thrust force during the propulsion phase, M = 1030.08 N and 929.79 N, respectively; and (c) propulsion during the propulsion phase, M = –44.78 N and –146.97 N, respectively. These differences were therefore due to the difference between the angles of the foot, leg, and thigh found in the Normal and Genu Varum Groups.

The impact force during the braking phase was greater for the Genu Varum Group compared to the Normal Group, M = 927.87 N and 899.33 N, respectively. During midstance pronation generally occurs. In a genu varum subject the foot is naturally supinated and the ROM from supination to pronation during the stance phase may be smaller compared to a subject without genu varum. The more time spent in pronation would reduce the impact force for the Normal Group. This difference may contribute to the greater impact force exhibited by the Genu Varum Group in this study compared to the Normal Group.

Moments

The moments during propulsion (a lateral twisting), was greater for the Normal Group than for the Genu Varum Group. However, the moments during the braking phase (medial internal twisting) was greater for the Genu Varum Group than for the Normal Group. These small differences may be due to the genu varum versus no genu varum condition. The angle of the leg for the Genu Varum Group may have caused a greater internal twisting motion to compensate for a lack of pronation movement in the frontal plane during the braking phase.

There was no significant difference in moments measured around the vertical axis during the braking phase between Normal and Genu Varum Groups. The Genu Varum Group had moments of M = –7.45 N, and the Normal Group, M = –6.35 N. The greater twisting motion of the Normal Group is indicative of the foot's action (supination) at heel strike causing internal rotation. There was no significant difference in moments measured around the vertical axis during the propulsion phase between Normal and Genu Varum Groups. The Genu Varum Group had moments of M = 12.64 N, and the Normal Group's were M = 13.24 N. Moments were greater for the Genu Varum Group. This may be related to alignment of the lower extremities in relation to foot placement at heel off to toe off, or during the propulsion phase.

Stride Length

There was no significant difference in stride length between the Normal and Genu Varum Groups. The Genu Varum Group, however, showed a greater stride length than the Normal Group in the sagittal plane, 1.511 m and 1.350 m, respectively. Pain, advancing age, fatigue, or pathology within the lower extremities may increase stride length (Hoppenfeld, 1976). This may also have been caused by a greater leg length for the Genu Varum Group compared to the Normal Group. However, the leg length was not compared.

CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The problem of this study was to compare angular and linear kinematics, ground reaction forces (GRF), temporal changes, and electromyography (EMG) while walking to a metronome set at 100 bpm between subjects with genu varum knees, and normal men, ages 20–25 years. Data were obtained from 10 subjects, 5 who have genu varum of the knees, and 5 normal men. The subjects completed three trials of a complete gait cycle that consisted of five to six steps. The study took place in the Biomechanics Laboratory at Western Michigan University. Data were obtained by a three-dimensional cinematographic analysis, EMG responses of six muscles, and a force platform. Data from the video, EMG, and the force platform were synchronized. The research variables were six muscles and two different walking patterns. Two-way or three-way repeated measures ANOVA were used to analyze all dependent variables. The level of significance was set at .05 for all tests.

Findings

Findings for this study include:

1. No significant differences were found between the two groups (genu varum and normal) for each of the dependent variables within the study.

2. A significant difference was found among the three trials for hip rotation, $F(2, 16) = 3.59$, $p = .05$. Therefore, subjects' hip rotation was not consistent among the trials. This could be caused by a combination of factors, such as stride length variations and changes in walking speed. These factors in combination would affect hip rotation but not show differences among trials for other factors.

3. A significant difference was found among the phases for tibial rotation, $F(3, 48) = 12.01$, $p = .00$. This difference was expected as tibial rotation would vary throughout the stance phase of a gait cycle.

4. A significant difference was found among the phases for the ankle angle, $F(3, 48) = 12.20$, $p = .00$; the knee ankle, $F(3, 42) = 32.42$, $p = .00$; and hip rotation, $F(3, 48) = 32.48$, $p = .00$. These differences would be expected due to the ROM each joint goes through during a gait cycle.

5. GRF were not significantly different between the groups. However, logical patterns existed for the Genu Varum Group bearing greater means than the Normal Group and vice versa. These patterns were logical due to the position of the limbs for the two groups.

Conclusions

The results of the study suggest the following conclusions:

1. The findings led the investigator to conclude that gait patterns between genu varum and normal subjects are more alike than different.

2. It is important to note that differences did exist in most variables that could be related to lower leg posture. However, when considering all variables collectively, these differences were individually not significant.

Recommendations

The following are recommendations for further research:

1. A larger randomly selected group would provide greater statistical power and thus more accurately indicate differences between genu varum and normal gait patterns.

2. Other age groups need to be studied to outline the developmental changes that occur.

3. A randomly selected group of females should be studied in a similar project to see if female gait patterns are similar to those found in males.

4. More data on different variables such as supination and pronation, medial and lateral GRF, and other muscle activity need to be investigated.

5. A multivariate analysis, MANOVA, should be considered for future studies.

Appendix A

Human Subjects Institutional Review Board
Letter of Approval

Human Subjects Institutional Review Board

Kalamazoo, Michigan 49008-3899

WESTERN MICHIGAN UNIVERSITY

Date: 15 January 1999

To: Mary Dawson, Principal Investigator
Roger Zabik, Co-Principal Investigator
Nerline Maurisseau, Student Investigator for thesis

From: Sylvia Culp, Chair

Re: HSIRB Project Number 98-11-06

This letter will serve as confirmation that your research project entitled "A Comparative Analysis of Walking Patterns Between Genu Varum and Normal Subjects" has been **approved** under the **expedited** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: 15 January 2000

Appendix B

Consent Form

Western Michigan University
Department of Health, Physical Recreation
Principal Investigator: Mary Dawson
Research Associate: Nerline Maurisseau
Consent Form

I have been invited to participate in a research project entitled Comparative analysis of walking patterns between genu varum and normal subjects. I have been told that this research project is intended to make comparisons in the gait cycle between subjects with abnormal knee joint alignment, genu varum, and subjects with normal knee joint alignment. Biomechanical variables to be investigated are the following: (1) ground reaction forces, (2) center of gravity, (3) electromyography, (4) linear displacement, (5) temporal changes, and (6) major joint angles of the lower extremities (trunk, thigh, shank, and foot). I have been told that this project is Nerline Maurisseau's thesis.

My consent to participate in this project indicates that I will be asked to attend one, 1-hr session with Nerline Maurisseau. I will be asked to meet with Nerline Maurisseau at the Biomechanics Lab at Western Michigan University. I will provide general information about myself such as age, height, and weight.

As a subject I will be asked to perform the simple task of walking to a metronome set to 100 beats per minute. I will perform 5 trials consisting of 5 to 6 steps of the right foot contacting the force platform on the 4 or 5 step. For each trial performed I will be video taped, and EMG and force platform data will be collected. I will be filmed in an anatomical position. This film will be used to measure the degree of genu varum in my lower extremities. Electrodes will be placed on the following muscles for EMG data: vastus medialis, medial head of the gastrocnemius, peroneal group, bicep femoris, and semimembranosus/semitendinosus. The electrode sites may need to be shaved to provide better electrode contact surface. The site of electrode placement will be scrubbed vigorously with a sterile alcohol pad.

As is all research there may be unforeseen risk to the participant. If an accidental injury occurs, appropriate emergency measures will be taken; however no compensation or treatment will be made available except as otherwise specified to me in this consent form. The risk to the research participant in this study include general risks associated with walking such as stumbling, or tripping. However this discomfort should be no greater than what is expected with everyday walking.

The current testing may be of no benefit to me as a subject. The results of this study may provide physical therapist, athletic trainers, and exercise physiologist with further knowledge concerning rehabilitative treatment for individuals who have genu varum.

All the information concerning my participation is confidential. This means that my name will not appear in any document related to this study. This form will be coded. Nerline Maurisseau will keep a separate master list with the names of all the participants and their code numbers. Once the data are collected and analyzed, the master list will be

WESTERN MICHIGAN UNIVERSITY
H. S. I. R. B.
Approved for use for one year from this date:
JAN 15 1999
x Sylvia Culp
HSIRB Chair

destroyed. The consent and data forms, a disk copy of electronic generated data, and the video tapes will be retained for a minimum of 3 years in a locked file in the principle investigator's laboratory. A second disk copy of the electronic data will be stored by Nerline Maurisseau for a minimum of 3 years.

I may refuse to participate or quit any time during the study without effects on grades or relationship with Western Michigan University. Furthermore all information will be kept confidential, and I will be able to receive a copy of my results upon request. If I have any questions or concerns about this study, I may contact either Dr. Mary Dawson at (616) 387-2546 or Nerline Maurisseau at (616) 353-8363. I may also contact the Chair of Human Subjects Review Board at (616) 387-8293 or the Vice President for Research at (616) 387-8298 with any concern that I may have. My signature below indicates that I have an understanding of the purpose and requirements of this study and I agree to participate.

This consent document has been approved for use for one year by the Human Subjects Institutional Review Board (HSIRB) as indicated by the stamped date and signature of the board chair in the upper right corner of both pages of this consent form. Subjects should not sign this document if the corners do not show a stamped date and signature.

__________________________ __________________

Signature Date

__________________________ __________________

Consent obtained by Date

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