6-1997

Comparative Analysis of Walking Patterns with Flip-Flops between American and Japanese Males

Ko Tada

COMPARATIVE ANALYSIS OF WALKING PATTERNS WITH FLIP-FLOPS BETWEEN AMERICAN AND JAPANESE MALES

by

Ko Tada

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Arts
Department of Health, Physical Education,
and Recreation

Western Michigan University
Kalamazoo, Michigan
June 1997

ACKNOWLEDGMENTS

I would like to take this opportunity to express my thanks from the bottom of my heart to my committee chair, Dr. Mary Dawson, and members, Dr. Roger Zabik and Dr. Patricia Frye, for their unstinting guidance and support throughout this study. Without their dedicated instruction and preserving help for not only this study but also my personal life during knee surgery, it would have been impossible to accomplish this thesis.

I would also like to thank my 10 subjects who completed the data collection. Without their time commitment and assistance this thesis would not be possible.

I thank my father and step-mother, Yoshiharu and Mutsumi Tada, for their support and help. I thank my fiancé, Ko Hasegawa, for the devoted support, encouragement, and love throughout my stay in the U.S. I thank all my friends, who are waiting my return, for encouragement and support.

Finally, I dedicate this thesis to my mother, Kyoko Kamenori, for her support and commitment in my development as a person. She is the person who eagerly hoped for my academic success. Without her guidance and love, I would not be here today.

Ko Tada

COMPARATIVE ANALYSIS OF WALKING PATTERNS WITH FLIP-FLOPS BETWEEN AMERICAN AND JAPANESE MALES

Ko Tada, M.A.

Western Michigan University, 1997

The problem was to compare the kinematic, kinetic, and electromyographical (EMG) aspects of walking gait while wearing flip-flops and barefoot between American and Japanese males, aged 20 to 25 years. Results indicated: (a) American stride lengths were greater than Japanese, although the results were not statistically significant; (b) Japanese ankle angle was smaller than Americans' for toe-off for barefoot, and foot strike for flip-flops; (c) the Japanese decreased the ankle angle from foot strike to toe-off, the Americans increased; (d) the Americans' foot angle was significantly different between barefoot and flip-flops; (e) the biceps femoris showed a significant difference in peak EMG between flip-flops and barefoot; (f) for flip-flops, the biceps femoris peak EMG was significantly different between the Americans and the Japanese; (g) a significant difference in the peroneal group's peak EMG existed between flip-flops and barefoot; and (h) there were no significant difference for the other muscles' peak and time to peak EMG. The conclusions were: (a) Americans and Japanese were more alike than not alike; (b) footwear had a greater influence on the gait patterns for the Americans; (c) the study provided evidence to support piston and swing system gait styles used by Asian and Western subjects, respectively.

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CHAPTER I

INTRODUCTION

Developmental factors of human beings are derived from their heredity, culture, and lifestyle. The difference of movement between Western people and Japanese are sometimes obvious, for example, Americans use a saw and plane pushing forward, but Japanese use them pulling backward. The American zipper has a receiving place on the right side, but the Japanese zipper has the receiving place on the left side (Ae & Yamamoto, 1993). Thus, there are some obvious differences between western people and Japanese.

Walking is the single most significant milestone in motor development, and its characteristics have been researched more than any other motor skill. Ae and Yamamoto (1993) have clearly stated the walking pattern is developed during childhood by education (environment) and footwear. For example, Ae's son grew up without wearing flip-flops and playing with toys that required the use of only the quadriceps. When the son was 6 years old, his walking pattern was illustrative of a swing system. On the other hand, a Japanese-American who was born and raised in the U.S. walked with a piston system. These examples show the educability of walking patterns. According to Whitall and Getchell (1995), change of speed does not affect the essential walking pattern, because movements, such as running or jumping, are controlled by the nervous system.

In other words, one's walking pattern influences future motor development and movement patterns in sports.

Many Japanese researchers in the biomechanics field pointed out the importance of running form and well-balanced muscle strength for Japanese runners. However, once the walking pattern is developed, it is not easy to change. Japanese runners who happened to have the walking pattern that utilizes a swing system (e.g.,Takano, 400-m run, and Fuwa, 100-m run) hold the Japanese records. Takano was a finalist for the Japanese in the Olympic Games in 1992.

There are many factors that need to be investigated to begin to understand why walking patterns are different between Western and Oriental people. This study focuses on the typical Japanese footwear, flip-flops, which most Japanese utilize in both inside and outside settings. Footwear is one of the most influential factors on sports skill results. Therefore, there is a need for studying the difference in gait between Americans and Japanese while wearing flip-flops and barefoot.

Statement of the Problem

The problem of this study was to compare the kinematic, kinetic, and electromyographical (EMG) aspects of the walking gait while wearing flip-flops and barefoot between American and Japanese males, aged 20 to 25 years. The study will focus on both the stance phase and the swing phase of the gait.

Purpose of the Study

The purpose of this investigation was to provide comparative information concerning the gait pattern and muscle activity pattern of walking. The gait pattern of western people (swing system) is thought to be appropriate for developing muscles for running faster. The Japanese gait pattern (piston system) is thought to be the reason why Japanese athletes cannot run faster than western athletes (Ae & Yamamoto, 1993). In this decade, many runners in short sprints have tried to change their running form to improve their performance. However, running forms that are derived mostly from the walking pattern cannot be changed in a short time. Moreover, the differences between the piston gait and the swing gait are too great to compensate for after the person becomes an adult. The results from kinetic, kinematic, and EMG analysis of Americans and Japanese could benefit young Japanese athletes and their parents in the training for walking or the selection of footwear during childhood. It was thought that the results of this investigation would be helpful in the educational environment to broaden the opportunity of success in sports for Japanese individuals.

Need for the Study

The literature has indicated evidence of the effects of wearing flip-flops to develop the piston walking pattern used by Japanese people. Some specialists have mentioned the difference between the walking gait pattern of western and Japanese people (Ae & Yamamoto, 1993). The earlier studies did not provide biomechanical evidence of differences in gait patterns (Shimizu, 1996). Therefore, they were not able to show conclusively that lifestyle (particularly the wearing of flip-flops) was a causal factor in any observed difference. There is a need to study the effect of wearing flip-flops with human subjects.

Delimitations

The study was delimited to the following:

1. Five American and 5 Japanese males who were not currently varsity collegiate athletes, 20 to 25 years old, and who presently resided in Kalamazoo, Michigan were recruited as subjects.

2. The Japanese males were raised in Japan and wore flip-flops for the first 18 years of their lives.

3. A complete stride, right foot contact to the next right foot contact, was analyzed for the kinematic and EMG data. The kinetic data were recorded for the support phase for the same stride.

4. Three complete strides were analyzed.

5. Kinematic data were measured from a video tape showing the gait pattern in the sagittal plane.

6. Electromyography 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 group.

7. Force platform data were collected for the right extremity.

Limitations

The study was limited by:

1. The sample size of the study (N = 10, [5 Americans and 5 Japanese]) was small, necessitating caution in extrapolation of the data to a larger population.

2. Past activity and lifestyle other than nationality were not considered.

3. All flip-flops used in the study were new and thus were not familiar to the subjects.

4. Walking speed was not controlled by the investigator and varied among the subjects.

Assumptions

Assumptions for the study were:

1. Subjects walked at their own comfortable speed in each condition.

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

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

4. The walking patterns studied were derived from the subjects' experience and footwear used in daily life.

Hypotheses

The researcher addressed the following hypotheses:

1. The Japanese gait with flip-flops is characterized by a smaller stride, larger ankle angle, smaller angle of foot segment to ground, and less-defined heel strike than the American gait with flip-flops.

2. The Japanese barefoot gait is characterized by a smaller stride, larger ankle angle, smaller angle of foot segment to ground, and less-defined heel strike than the American barefoot gait.

3. For Japanese, the gait with flip-flops will be shorter than the barefoot gait.

4. For Americans, the gait with flip-flops will be shorter than the barefoot gait.

5. For Japanese, the difference between walking with flip-flops and barefoot will be smaller than the difference for Americans.

6. The braking and propulsion forces will be different in the gait with flip-flops than in the barefoot gait.

7. The EMG patterns will be different in the gait with flip-flops than in the barefoot gait.

Definition of Terms

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

1. Foot strike or heel strike: Foot strike occurred at initial ground contact of any part of the foot during locomotion.

2. Midstance: Midstance occurred when the foot was firmly on the ground and could bear weight.

3. Stance phase: Stance was defined by the percentage of the cycle when the foot was in contact with the ground.

4. Swing phase: Swing phase was defined by the percentage of the cycle when the foot was in the air.

5.Toe-off: Toe-off was the end of the push-off phase that propels the body forward.

CHAPTER II

REVIEW OF LITERATURE

The problem in this study was to compare American and Japanese gait patterns with EMG, kinetic, and kinematic devices in order to understand the difference between them. The following areas needed to be reviewed: (a) running patterns, (b) walking patterns, (c) walking development, (d) kinematics of normal walking gait, (e) Asian footwear, (f) filming technique, and (g) EMG interpretation.

Running Patterns

Some researchers have shown that Japanese sprinters touch the foot to the ground with their knees bent and kick their foot backward, extending it when they run at their top speed. On the other hand, American and European runners touch the foot on the ground with the knee extended, and utilize the hip joint as the axis, reducing the braking force. Japanese runners utilize the quadriceps to sustain their weight when they touch the foot to the ground, but American and European runners use their hamstrings for this same purpose. The few Japanese sprinters who happened to have a running gait similar to American and European sprinters' gaits obtained better records than other Japanese sprinters (Ae & Yamamoto, 1993).

The differences in gait pattern and muscle strength in sprinters are thought to be the result of the differences in the basic skills of walking and running. Western people tend to show the ideal swing locomotion in walking, because of the long history of wearing shoes with flexible soles. In general terms, Japanese tend to walk leaning forward as the result of a long history of people wearing wooden sandals or slippers for a long period of time. For this reason, Japanese tend to plant the entire foot at the same time, but Americans and Europeans plant the heel first (Shimizu, 1996).

Traditionally, the pattern of Japanese walking has led to the lack of balance between hamstring and quadriceps strength. However, at least one Japanese sprinter recognized the tendency toward imbalance and made changes in his training to overcome the problem. An outstanding Japanese 400-m runner changed his running gait and weight training to develop well-balanced hamstrings and quadriceps muscles. He improved his personal best time from 47:15 to 46:54 within 1 year (Suzuki, 1992).

Walking Patterns

Human walking is 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 movement is a relatively unique form of ambulation in that it is bipedal. Although there are animal examples of bipedal locomotion (e.g., bears, primates, marsupials), the bipedal gait in man is uniquely efficient and functional (Rose & Gamble, 1994).

In general, western people (i.e., people from America and from Europe to the Arabian Peninsula) use the hip joint and pelvis in a swing system, but the Japanese use the hip joint in a piston system. These two systems are completely different in the movements created (Ae & Yamamoto, 1993). The swing system is a combination of (a) pelvic rotation, (b) pelvic tilt, (c) thigh flexion and extension, and (d) knee flexion. The piston system utilizes only thigh flexion and extension and a small amount of knee flexion.

Walking Development

Is the gait pattern hereditary and unchangeable from childhood? Motor development of human beings has a phylogenetic basis. The acquisition of skill in performing these movement patterns appears to be founded upon learning, not heredity. Movement patterns change during a person's lifespan (Adrian & Cooper, 1989). Although some infants may be observed taking their first independent steps at 8 or 9 months, most children do not walk independently with any degree of efficiency until approximately 13 months of age. Children do not achieve a mature walking pattern until the age of 4 or 5 years. Some of these changes occur as a function of growth and development of the human body, and others are learned, via practice and education (Gabbard, 1992). The maturation of the gait pattern is expressed in terms of energy expenditure. Older children tend to walk with decreased cadence and increased velocity, therefore, they take longer steps and spend slightly more time in single leg stance and less time with weight shift in double limb support. This is the pattern seen in adults, presumably to minimize energy expenditures with increasing gait velocity (Hennessy, Dixon, & Simon, 1984).

Before infants start running, they have to acquire strength and balance. It is likely that these two factors contribute to the emergence of the ability to run. The infants who are about ready to run appear to have problems with generating both horizontal force and vertical force concurrently. Two pieces of evidence indicate that ankle control may be an important factor in this inability: (1) inconsistent ankle coordination and (2) a greater time spent in the stance phase than in the swing phase. These factors suggest that the ability to produce and regulate force by ankle extension may be a key control parameter for the emergence of running (Whitall & Getchell, 1995).

Kinematics of the Normal Walking 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. Although videotape analysis shows that individual differences exist in gait patterns, certain commonalities have been described. Motion in the sagittal plane for the knee is from 0° to 70°, for the thigh is from -3° to 41°, and for the ankle is from -25° to 8° for normal men during level walking (Nordin & Frankel, 1989). During level human walking, muscle contraction is controlled to produce maximum energy efficiency with appropriate forward movement. Many muscles responsible for walking contract isometrically, or while lengthening, to allow maintenance of upright posture against gravity or transfer and storage of energy between limb segments (Rose & Gamble, 1994).

Asian Footwear

Asian footwear has been developed to accommodate the climate of the region, mostly hot and dry in India and mostly hot and humid in China and Japan. Ancient Japanese developed a wooden sandal that is now rarely seen outside the rural villages of Japan. It can be easily made. Sandals worn in India are very different from Japanese sandals. In China, a reasonably good plastic sandal is available, and this sandal is very much like the sandals most commonly worn in Japan today. Another reason people in Asia have utilized sandals is economics. Traditionally sandals were constructed from natural materials, such as wood and straw. Today they are constructed from inexpensive plastics (Oswald, 1987).

Filming Technique

Recent technological advances have raised the possibility of further study of refinement and quantification of human movement. Analysis of the gait of adults has been performed in medical and bioengineering studies in laboratory settings. These techniques utilize high-speed filming and computer analysis of body motions combined with force platform and EMG data.

The filming procedures have taken place in many laboratory environments, even in field settings. A movement is filmed for each subject at 50-120 frames per second. The film records are later converted into quantitative form. Anatomical landmarks on the body are projected onto a grid. Each point is electronically recorded or digitized by a computer for storage, processing, and statistical analysis. The data analyzed include angle of joints, velocity of body parts, acceleration, displacement, and length of stance (Hennessy et al., 1984).

EMG Interpretation

EMG in active muscle 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 electrode, 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 generatied about forces, motor unit recruitment, and muscle fatigue. The total EMG signal can be analyzed by calculating the power density spectrum, which depends on force, time, and the individual firing rates. The noninvasive nature of this technique makes it particularly applicable to studies of muscle physiology in animals and humans (Rose & Gamble, 1994).

Methods and Procedures

The adult walking action is a remarkable accomplishment, considering the design of the human body, which features a high center of gravity and a small base of support (Adrian & Cooper, 1989). Most people acquire this action during infancy as a reflex action that is later changed to a voluntary movement. The action is smooth and beautiful to watch but extremely complex to analyze. During the process of the development of a walking pattern (from 12 or 13 months to 4 to 5 years of age), the general improvement is known as the maturation of gait. The following occur during the maturation process for the swing system: (a) narrowing the base of support, (b) changing the foot contact from flat-footed to the heel-toe pattern, (c) decreasing the foot angle of toeing-out, (d) changing the knee-lock pattern from single to double, (e) increasing the pelvic rotation, (f) lowering the arm position, (g) increasing the walking speed and decreasing the step frequency, and (h) increasing the step and stride length (Gabbard, 1992). Maturation occurs within the environment in which a person is born, usually with his or her parents and brothers and sisters. He or she has little choice about what kind of shoes to wear or the walking patterns used by people in the surrounding environment. From the onset of walking to the final stages of development, footwear influences the motor skill. In general, galloping and skipping are acquired at about 5 years of age. By this time, a person has acquired his or her walking and running patterns, which are the foundations of the human locomotor skills.

With the mature walking pattern, each leg alternates between a stance phase and a swing phase (Gabbard, 1992). Foot strike occurs while the opposite leg pushes the floor (toe off), shifting the weight forward. During the swing locomotion, the weight is transferred from the heel to the outside of the sole, the ball of the foot, and the big toe. The center of gravity reaches the highest position in single leg support, at the midstance position. The stance phase is approximately 60% of the walking cycle, and the swing phase, which is composed of toe clearance and leg swing, is 40% of the walking cycle. The stance phase is also called a high-energy phase, and the swing phase is called a low-energy phase. In the high-energy phase, power is required to absorb the shock of heel strike, to sustain the whole weight, and to propel the weight forward. On the other hand, a pendulum action is used to accelerate the leg in the air using less energy in the low-energy phase (Rose & Gamble, 1994).

In addition, a pressure pattern under the foot of a person during the stance phase of walking is explained by kinetics. The pressure on a foot goes from the heel to the big toe, changing the amount of weight exerted vertically downward. Each person has his or her own pressure pattern.

Summary

Japanese ancestors developed footwear that adjusted to the weather. People wore sandals that were made from natural sources for economic reasons. The walking gait pattern probably is derived from the environment, educational influences, and climate, not heredity. Therefore, the footwear influenced the walking pattern of people. Because the characteristics of locomotor movement are established in the developmental phase, the walking pattern is reflected in the running gait pattern. Thus, mature gait patterns are influenced by early developmental patterns. Therefore, the development of gait while wearing flip-flops has an influence on the mature gait patterns of Japanese. From an early age to later adolescence, the time is very critical to a person's walking gait development and basic muscle strength. Measuring the gait pattern with kinetic and kinematic devices is a relatively new and easy way to analyze the movement.

CHAPTER III

METHODS AND PROCEDURES

The problem of this study was to compare the kinetic, kinematic, and EMG aspects of the walking gait while wearing flip-flops and barefoot between American and Japanese males (aged 20 to 25 years). The study focused on both the stance phase and the swing phase of the gait.

The following topics were covered in this chapter: (a) human subjects approval; (b) subject selection; (c) instrumentation process; (d) EMG, filming, and force platform procedures; (e) data acquisition; (f) research design; and (g) statistical analysis.

Human Subjects Approval

Approval to conduct this 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 this study. See Appendix A for the HSIRB approval letter.

Subject Selection

The 10 subjects participating is this study were male students who were attending Western Michigan University, Kalamazoo. Five subjects were American, and another 5 subjects were Japanese who had been born and raised in Japan. All subjects were 20 to 25 years old and were not currently involved in competitive sports. All those volunteering to be subjects signed an informed consent form (see Appendix B).

Electromyography Procedures

The EMG responses in the following six muscles were measured during a cycle of the walking pattern with flip-flops and barefoot: (1) rectus femoris, (2) vastus medialis, (3) medial head of the gastrocnemius, (4) peroneal group, (5) biceps femoris, and (6) semimembranosus/semitendinosus group. 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 placement sites were carefully identified, shaved, and prepped before electrode placement. Resistance levels were checked with a multi-meter. Successful placement was gauged by an electrode resistance of less than 10 Kohms.

The EMG electrodes were linked to a Myosystem 2000 EMG data collection system (Noraxon, Phoenix, AZ) integrated with the analog-digital module in a Peak motion analysis hardware/software package (Peak Performance Technologies, Inc., Englewood, CO). The integrated EMG signal was filtered using a Butterworth data smoothing procedure (6 Hz). The filtered EMG data were then transferred to the Myosoft EMG analysis located on a Tenex 486 DX-2 personal computer. The EMG response for each muscle during the stance and swing phases of the gait pattern was analyzed to compare differences between American and Japanese walking patterns while wearing flip-flops and barefoot.

Force Platform 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 range setting was controlled by the Kistler 9861A amplifier. The analog data were converted to a digital signal by an analog-digital interface, 16 channel unit, connected to a DT2821 analog-to-digital board. The analog-to-digital board was connected to an Event Synchronization Unit (ESU) 4000D for matching force and EMG data to video data. The ESU unit was used to trigger the interfaced equipment during data collection. A Tenex 486 DX-2 computer ran the Peak 5.2 Analog Sampling Module Software, Peak Performance Technologies, Inc., Englewood, Co. The analog-digital interface unit and the ESU unit were manufactured by Peak Performance Technologies, Inc.

Filming Procedures

A two-dimensional video analysis of each walking pattern was used. A Panasonic WV-D5100HS video camera (Panasonic, Secaucus, NJ) set at 60 Hz was used to record the motion of the walking pattern. Fuji S-VHS ST-120N video tape was used. The video data were synchronized to the EMG data and the force platform data through an event synchronization unit . The camera was placed perpendicular to the sagittal plane of the subjects, 26 ft from the subjects' walking path. The camera's view was of the right side of the subjects. The camera lens was set 1 m above the ground. Subjects performed in front of a contrasting background, so that bony landmarks of the subjects could be seen and digitized.

Data Collection Procedures

Filming

Data collection took place in the Biomechanics Laboratory in the University Recreation Center, Western Michigan University, Kalamazoo. Subjects were instructed to wear light-colored shorts cut above the knee. They were video taped barefoot and wearing a pair of flip-flops that the investigator provided. All information collected was recorded on a data sheet (see Appendix C).

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

1. You will be given a 5-min warm-up prior to testing. To warm up, you will walk on the treadmill to find a comfortable speed.

2. During the data collection, you will complete 3 trials for each of 2 different walking conditions, a total of 6 trials for the day. A trial consists of 5 to 6 steps with the right foot contacting the force platform on the 4th or 5th step.

3. For each walking trial, you will perform at the comfortable speed you selected during the warm-up.

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

Video Digitizing

After data collection, the digitizing process was initiated. It was necessary to digitize 20 anatomical points to establish the total body center of gravity. The anatomical points were the distal metatarsals, lateral malleolus, knee joint midlines, greater trochanters of the femurs, distal metacarpals, midlines of the wrists, elbow joint midlines, greater tuberosities of humeri, sternum, tragus of ear, top of head, and crotch. Both the left and right sides of the body were digitized.

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. This sequence of motion allowed a complete walking cycle to be broken down into a right stance phase and a right swing phase. For this investigation, only data (kinetic, kinematic, and EMG) collected on the right leg were analyzed. All digitized data were smoothed using a Fast Fourier filter set at an optimal speed.

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 contains a heel strike, midstance, and toe-off, identifiable points in every person's gait pattern.

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

characterized by the deceleration of the limb. The midswing is the middle one-third of the swing phase.

Research Design

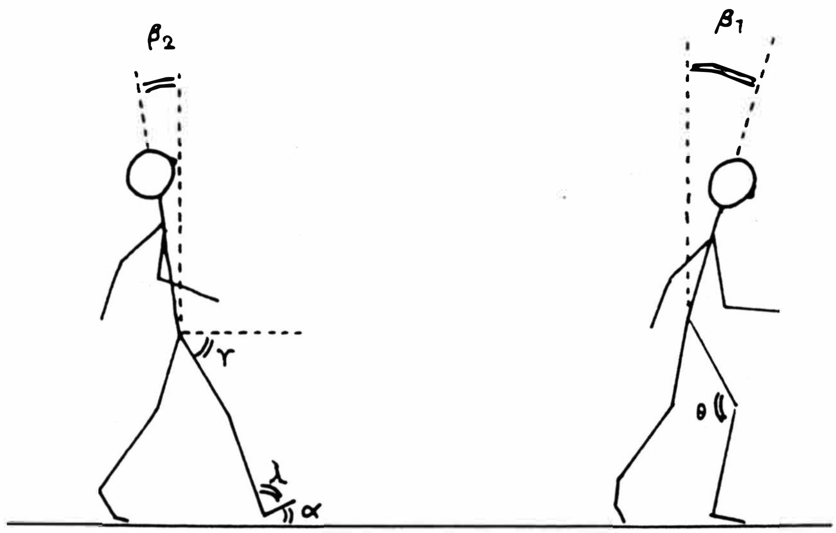
The research design for this investigation was a repeated measures. Each subject produced data for each of the research conditions. The study consisted of these research variables: (a) a grouping variable (culture), American and Japanese; (b) footwear, barefoot and flip-flop; and (c) trials, three. The investigation used the 3 trials to determine if the subjects had a consistent gait pattern. If there was no difference among the 3 trials, then the mean performance across all 3 trials for each dependent variable was used in the statistical analysis for this study. If there was a significant difference among the 3 trials, then trial was used as a research variable in the final statistical analysis.

The dependent variables for this study include the following:

1. The average velocity of the CG for the stance and swing phases.

2. Foot angle measured at foot strike. This angle was measured by the line formed between the distal metatarsals and the lateral malleoli of the right foot to the horizontal. See Figure 1 for a visual illustration of all angles measured.

3. Ankle angle measured at foot strike and toe-off. This angle was measured by two intersecting lines: (1) the line from the metatarsals to the lateral malleolus and (2) the line from the lateral malleolus to the knee joint midline. This angle was measured on the anterior of the body.



Note. α = foot angle, β_1 = a positive trunk angle, β_2 = a negative trunk angle, γ = thigh angle, θ = knee angle, λ = ankle angle.

Figure 1. Joint Angles; Foot, Ankle, Knee, Thigh, and Trunk, Measured During the Stance Phase.

4. Knee angle measured at foot strike, midpoint, and toe-off of the stance phase. This angle was measured by two intersecting lines: (1) the line from the lateral malleolus to the knee joint midline and (2) the line from the knee joint midline to the greater trochanter of the femur. This angle was measured on the posterior of the body.

5. Thigh angle measured at foot strike and toe-off. This angle was measured by two intersecting lines: (1) the line from the greater trochanter of the femur to the sternum and (2) a horizontal line through the greater trochanter. This angle was measured on the anterior of the body.

6. Trunk angle measured at foot strike and toe-off. This angle was measured by two intersecting lines: (1) the line from the greater trochanter of the femur to the sternum and (2) a vertical line through the greater trochanter. A positive angle indicated the trunk was leaning forward; a negative angle indicated the trunk was leaning backward.

7. Braking force for the right leg. The maximum horizontal force that occurred between the heel strike and midstance positions in the stance phase.

8. Propulsion force for the right leg. The maximum horizontal force that occurred between the midstance and toe-off positions in the stance phase.

9. Relative time to peak EMG recruitment for each of the six muscles. The percentage of time to peak EMG, calculated by dividing the time to peak EMG by stride time.

10. Peak EMG response for the six muscles. The maximum mV needed for each muscle during the gait stride measured.

11. Time to peak EMG for the six muscles. The actual time elapsed from the heel-strike position to peak EMG for each muscle.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The problem in this study was to compare the kinematic, kinetic, and electromyographical (EMG) aspects of the walking gait while wearing flip-flops and barefoot between American and Japanese males, aged 20 to 25 years. This study focused on both the stance phase and the swing phase of a single cycle in the gait pattern. 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 11 kinematic and kinetic dependent variables: (1) temporal data, (2) stride length in meters, (3) stride length as a percentage of leg length, (4) velocity, (5) trunk angle, (6) thigh angle, (7) knee angle, (8) ankle angle, (9) foot angle, (10) braking force, and (11) propulsion force. Also, the researcher investigated the peak EMG and the time to peak EMG for six muscles: (1) biceps femoris, (2) gastrocnemius, (3) peroneal group, (4) rectus femoris, (5) vastus medialis, and (6) semimembranosus/semitendinosus group.

For each dependent variable, a split-plot factorial ANOVA was calculated. Each ANOVA contained one grouping variable (cultural background) with two levels (Americans and Japanese) and one research variable, footwear condition, with two levels (flip-flops and barefoot). Some of the ANOVAs for the kinematic data included a second research variable, phases with two levels (stance and swing) or positions in phases with either two or three levels (foot strike and toe-off, or foot strike, midstance, and toe-off). To check for performance consistency, subjects repeated each condition, flip-flops and barefoot, three times (trials).

Performance Consistency

ANOVAs were calculated to determine if significant differences existed among the three trials. If the ANOVA indicated no significant difference, then the dependent variable was the mean for the three trials. If a significant difference existed among the 3 trials, then each trial was used in analyzing the data for that dependent variable.

In Table 1, the F-ratios for the main effect, trial, for all dependent variables are provided. There were no significant difference among the three trials for any dependent variable except for peak EMG for the gastrocnemius muscle, $F(2,16) = 3.62$, $p = .05$. For all the variables, except the peak EMG for the gastrocnemius muscles, subjects performed consistently across trials.

Table 1

ANOVA F Ratios for the Main Effect, Trials, for All Dependent Variables

Variables	df	F	p
Stride Time	2/16	1.74	.21
Stride Length (Meter)	2/16	0.80	.47
Stride Length (Percentage)	2/16	0.84	.45
Velocity	2/16	0.40	.68
Trunk Angle	2/16	1.45	.26
Thigh Angle	2/16	0.75	.49
Knee Angle	2/14	1.37	.29
Ankle Angle	2/18	0.31	.74
Foot Angle	2/16	0.17	.85
Braking Force	2/16	0.48	.62
Propulsion Force	2/16	1.19	.33
Biceps Femoris (Time)	2/16	1.10	.36
Biceps Femoris (Peak)	2/16	0.70	.51
Gastrocnemius (Time)	2/16	0.41	.67
Gastrocnemius (Peak)	2/16	3.62	.05*
Peroneal Group (Time)	2/16	1.30	.30
Peroneal Group (Peak)	2/16	0.40	.67
Rectus Femoris (Time)	2/16	0.54	.59

Table 1--Continued

Variables	df	F	p
Rectus Femoris (Peak)	2/16	0.62	.55
Vastus Medialis (Time)	2/16	1.38	.28
Vastus Medialis (Peak)	2/16	0.37	.69
S/S (Time)	2/16	1.82	.19
S/S (Peak)	2/16	0.26	.77

Note. Number for df indicates the degree of freedoms for the numerator/ degree of freedom for the denominator for the F-ratio. S/S refers to the semimembranosus/ semitendinosus group.

*Significant at the .05 level.

Kinematics

Temporal Data

Stride Time. Stride time was measured from foot strike of the right foot to the next foot strike for the right foot. An ANOVA summary table for stride time is presented in Table 2. No significant difference was found between the Americans' stride time, $M = 1.140$ s, and the Japanese stride time, $M = 1.134$ s, $F(1, 8) = 0.02$, $p = .89$. For the footwear condition, no significant difference in time was found between flip-flops, $M = 1.133$ s, and barefoot, $M = 1.141$ s, $F(1, 8) = 0.60$, $p = .46$. A significant difference existed between the mean time for the stance phase, $M = 0.684$ s, and the swing phase, M = 0.453 s, $F(1, 8) = 263.56$, $p = .00$. The stance phase comprised 60% of the total stride time, and the swing phase was 40% of the stride time for both conditions. The first- and second-order interaction effects for the ANOVA were not significant.

Table 2

ANOVA Summary Table for Stride Time

Source	SS	df	MS	F	p
Group (G)	0.000	1	0.000	0.02	.89
Subj. w. groups	0.037	8	0.005		
Footwear (F)	0.000	1	0.000	0.60	.46
F x G	0.000	1	0.000	0.22	.65
F x Subj. w. groups	0.002	8	0.000		
Phases (P)	0.532	1	0.532	263.56	.00*
P x G	0.001	1	0.001	0.55	.48
P x Subj. w. groups	0.016	8	0.002		
F x P	0.000	1	0.000	0.18	.68
F x P x G	0.001	1	0.001	1.48	.26
FP x Subj. w. groups	0.006	8	0.001		

*Significant at the .05 level.

Stance Time. Stance time was measured from foot strike of the right foot through midstance to toe-off of the right foot. An ANOVA summary table for stance time is presented in Table 3. No difference was found between the Americans' stance time, M = 343.80 ms, and the Japanese stance time, M = 338.45 ms, $F(1, 8) = 0.13$, $p = .73$. For the footwear condition, no difference in stance time was found between the flip-flops

Table 3

ANOVA Summary Table for Stance Time

Source	SS	df	MS	F	p
Group (G)	286.225	1	286.225	0.13	.73
Subj. w. Groups	18077.958	8	2259.745		
Phase (P)	81993.024	1	81993.024	11.71	.01*
P x G	13140.624	1	13140.624	1.88	.21
P x Subj. w. groups	56012.039	8	7001.505		
Footwear (F)	24.025	1	24.003	0.09	.78
F x G	632.025	1	632.025	2.29	.17
F x Subj. w. groups	2204.422	8	275.553		
P x F	807.003	1	807.003	1.24	.30
P x F x G	455.625	1	455.625	0.70	.43
PF x Subj. w. groups	5201.623	8	650.203		

* Significant at the .05 level.

condition, M = 341.90 ms, and the barefoot condition, M = 340.35 ms, $F(1, 8) = 0.09$, $p = .78$. A significant difference existed between the first phase (foot strike to midstance), M = 386.40 ms, and the second phase (midstance to toe-off), M = 295.85 ms, $F(1, 8) = 11.71$, $p = .01$. The first- and second-order interaction effects for the ANOVA were not significant.

Stride Length

Meters. 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 4. No difference in stride length was found between the American's stride length, M = 1.312 m, and the Japanese stride length, M = 1.299 m,

Table 4

ANOVA Summary Table for Stride Length (Meters)

Source	SS	df	MS	F	p
Group (G)	0.001	1	0.001	0.14	.72
Subj. w. groups	0.049	8	0.006		
Footwear (F)	0.002	1	0.002	0.42	.54
F x G	0.004	1	0.004	1.00	.35
F x Subj. w. groups	0.031	8	0.004		

F(1, 8) = 0.14, p = .72. For the footwear condition, no difference in stride length was found between flip-flops, M = 1.296 m, and barefoot, M = 1.314 m, F(1, 8) = 0.42, p =.54. The first-order interaction effect for the ANOVA was not significant.

Percentage. Stride length percentage was calculated by dividing the stride length in meters by leg length. Leg length was measured from the hip joint to the ankle joint for each subject. An ANOVA summary table for stride length percentage is presented in Table 5. No difference in percentage was found between the Americans' stride length, M = 157%, and the Japanese stride length, M = 151%, F(1, 8) = 0.62, p = .46. For the footwear condition, no difference in percentage was found between flip-flops, M = 153%, and barefoot, M = 155%, F(1, 8) = 0.33, p = .58. The first order interaction effect for the ANOVA was not significant.

Table 5

ANOVA Summary Table for Stride Length (Percentage)

Source	SS	df	MS	F	p
Group (G)	0.013	1	0.013	0.62	.46
Subj. w. groups	0.173	8	0.022		
Footwear (F)	0.002	1	0.002	0.33	.58
F x G	0.005	1	0.005	0.90	.37
F x Subj. w. groups	0.042	8	0.005		

Velocity

The velocity of the center of gravity from foot strike of the right foot to the next foot strike for the right foot was measured. An ANOVA summary table for center of gravity velocity is presented in Table 6. No difference was found between the Americans'

Table 6

ANOVA Summary Table for Velocity

Source	SS	df	MS	F	p
Group (G)	0.003	1	0.003	0.07	.80
Subj. w. groups	0.397	8	0.050		
Phase (P)	0.413	1	0.413	24.88	.00*
P x G	0.001	1	0.001	0.09	.78
P x Subj. w. groups	0.013	8	0.002		
Footwear (F)	0.000	1	0.000	0.05	.82
F x G	0.000	1	0.000	0.05	.84
F x Subj. w. groups	0.050	8	0.006		
P x F	0.001	1	0.001	0.94	.36
P x F x G	0.001	1	0.001	0.69	.43
FP x Subj. w. groups	0.007	8	0.001		

*Significant at the .05 level.

velocity, M = 1.168 mps, and the Japanese velocity, M = 1.150 mps, $F(1, 8) = 0.07$, $p = .80$. For the footwear condition, no significant difference existed between the mean velocities for flip-flops, M = 1.163 mps, and barefoot, M = 1.162 mps, $F(1, 8) = 0.05$, $p = .82$. A significant difference was found between the mean velocities for the stance phase, M = 1.127 mps, and the swing phase, M = 1.191 mps, $F(1, 8) = 24.88$, $p = .00$. The first- and second-order interaction effects for the ANOVA were not significant, $F(1, 8) = 0.09$, $p = .78$ for footwear by culture, $F(1, 8) = 0.05$, $p = .84$ for phase by culture, and $F(1, 8) = 0.69$, $p = .43$ for footwear by phase by culture.

Angles

Trunk. Trunk angle was measured at foot strike of the right foot and at toe-off for the right foot. An ANOVA summary table for trunk angle is presented in Table 7. No difference was found between the Americans' trunk angle, M = -3.546°, and the Japanese trunk angle, M = -2.496°, $F(1, 8) = 0.66$, $p = .44$. For the footwear condition, no difference in trunk angle was found between flip-flops, M = -2.969°, and barefoot, M = -3.073°, $F(1, 8) = 0.06$, $p = .82$. A significant difference in trunk angle existed between the means for foot strike, M = -5.196°, and toe-off, M = -0.847°, $F(1, 8) = 43.69$, $p = .00$. The first- and second-order interaction effect for the ANOVA were not significant.

Thigh. Thigh angle was measured at foot strike of the right foot and the next toe-off for the right foot. An ANOVA summary table for thigh angle is presented in Table

Table 7

ANOVA Summary Table for Trunk Angle

Source	SS	df	MS	F	p
Group (G)	11.029	1	11.029	0.66	.44
Subj. w. groups	134.492	8	16.812		
Footwear (F)	0.109	1	0.109	0.06	.82
F x G	2.518	1	2.518	1.31	.28
F x Subj. w. groups	15.361	8	1.920		
Position (P)	189.124	1	189.124	43.69	.00*
P x G	6.804	1	6.804	1.57	.24
P x Subj. w. groups	34.627	8	4.328		
F x P	1.194	1	1.194	0.94	.34
F x P x G	0.783	1	0.783	0.62	.46
FP x Subj. w. groups	10.172	8	1.272		

*Significant at the .05 level.

8. No difference in thigh angle was found between the Americans' thigh angle, M = 84.496°, and the Japanese thigh angle, M = 85.219°, $F(1, 8) = 0.47$, $p = .51$. For the footwear condition, no difference for thigh angle existed between flip-flops, M = 84.727°, and barefoot, M = 84.988°, $F(1, 8) = 0.57$, $p = .47$. A significant difference in thigh angle was found between foot strike, M = 71.405°, and toe-off, M = 98.307°, F(1,

8) = 472.40, p = .00. The first- and second-order interaction effects for the ANOVA were not significant.

Knee. Knee angle was measured at foot strike, midstance, and toe-off positions in thestance phase for the right foot. An AN●VA summary table for knee angle is

Table 8

ANOVA Summary Table for Thigh Angle

Source	SS	df	MS	F	p
Group (G)	5.222	1	5.222	0.47	.51
Subj .w. groups	89.348	8	11.169		
Position (P)	7235.024	1	7235.024	472.40	.00*
P x G	10.067	1	10.067	0.66	.44
P x Subj. w. groups	122.524	8	15.315		
Footwear (F)	0.679	1	0.679	0.57	.47
F x G	1.913	1	1.913	1.67	.24
F x Subj. w. groups	9.464	8	1.183		
P x F	0.853	1	0.853	0.15	.71
P x F x G	6.680	1	6.680	1.18	.31
PF x Subj. w. groups	45.233	8	5.654		

*Significant at the .05 level.

Table 9

ANOVA Summary Table for Knee Angle

Source	SS	df	MS	F	p
Group (G)	47.930	1	47.930	0.86	.38
Subj. w. groups	448.139	8	56.017		
Footwear (F)	15.701	1	15.701	2.51	.15
F x G	21.218	1	21.218	3.40	.10
F x Subj. w. groups	49.997	8	6.250		
Position (P)	18762.538	2	9381.269	292.96	.00*
P x G	10.459	2	5.230	0.16	.85
P x Subj. w. groups	512.359	16	32.022		
F x P	6.295	2	3.147	0.43	.66
F x P x G	38.478	2	19.239	2.65	.10
FP x Subj. w. groups	115.978	16	7.249		

*Significant at the .05 level.

presented in Table 9. No difference was found between the Americans' knee angle, M= 165.769°, and the Japanese knee angle, M = 167.556°, $F(1, 8) = 0.86$, $p = .38$. For the footwear condition, no difference in knee angle was found between flip-flops, M = 166.151°, and barefoot, M = 166.600°, $F(1, 8) = 2.51$, $p = .15$. A significant difference in knee angle existed among the means for foot strike, M = 179.267°, the midstance, M

= 179.070, and toe-off, M = 141.654°, $F(2, 16) = 292.96$, $p = .00$. The first- and second-order effects for the ANOVA were not significant.

Ankle. Ankle angle was measured at foot strike of the right foot and the next toe-off for the right foot. An ANOVA summary table for ankle angle is presented in Table

Table 10

ANOVA Summary Table for Ankle Angle

Source	SS	df	MS	F	p
Group (G)	35.219	1	35.219	0.73	.42
Subj. w. groups	386.583	8	48.323		
Footwear (F)	2.168	1	2.168	0.95	.36
F x G	0.168	1	0.168	0.07	.79
F x Subj. w. groups	18.283	8	2.285		
Position (P)	16.146	1	16.146	0.25	.63
P x G	65.161	1	65.161	1.00	.35
P x Subj. w. groups	521.257	8	65.157		
F x P	3.931	1	3.931	0.44	.52
F x P x G	63.051	1	63.051	7.09	.03*
FP x Subj. w. groups	71.157	8	8.895		

*Significant at the .05 level

10. No difference in ankle angle was found between the Americans' ankle angle, M = 110.169°, and the Japanese ankle angle, M = 108.292°, $F(1, 8) = 0.73$, $p = .42$. For the footwear condition, no difference in ankle angle was found between flip-flops, M = 109.464°, and barefoot, M = 108.998°, $F(1, 8) = 0.95$, $p = .36$. No difference was found between foot strike, M = 109.866°, and toe-off, M = 108.595°, $F(1, 8) = 0.25$, $p = .63$. The three first-order interaction effects for the ANOVA were not significant. However, the second-order interaction effect, condition by phase by group, was significant, $F(1, 8) = 7.09$, $p = .03$. A simple simple main effects test was calculated to analyze this significant interaction effect. The results of this analysis are presented in Table 11. The significant results of the simple, simple main effects were as follows:

1. A significant difference in ankle angle was found between the means for the barefoot condition at the toe-off position for Japanese, M = 105.27°, and the barefoot condition at the toe-off position for Americans, M = 112.08°, $F(1, 8) = 13.04$, $p < .05$.

2. A significant difference in ankle angle was found between the means for the flip-flops condition at the foot strike position for Japanese, M = 109.43°, and the flip-flops condition at the foot strike position for Americans, M = 111.39°, $F(1, 8) = 245.77$, $p < .05$.

3. A significant difference in ankle angle was found between the means for the barefoot condition at foot strike position for Japanese, M = 110.98°, and the barefoot condition at the toe-off position for Japanese, M = 105.27°, $F(1, 8) = 9.16$, $p < .05$.

4. A significant difference in ankle angle was found between the means for the barefoot condition at foot strike position for Americans, M = 107.66°, and the barefoot

Table 11

ANOVA Summary Table for Simple Simple Main Effects for Ankle Angle

Source	SS	df	MS	F
Con. for Japanese (FS)	5.99	1	5.99	0.67
Con. for Japanese (TO)	12.32	1	12.32	1.39
Con. for American (FS)	34.97	1	34.97	3.93
Con. for American (TO)	16.13	1	16.13	1.81
Cul. for barefoot (FS)	27.52	1	27.52	3.10
Cul. for barefoot (TO)	115.94	1	115.94	13.04*
Cul. for flip-flops (FS)	2184.88	1	2184.88	245.77*
Cul. for flip-flops (TO)	10.51	1	10.51	1.18
Pos. at barefoot (JP)	81.45	1	81.45	9.16*
Pos. at barefoot (AM)	48.84	1	48.84	5.49*
Pos. at flip-flops (JP)	9.41	1	9.41	1.06
Pos. at flip-flops (AM)	8.65	1	8.65	0.97
Error	71.16	8	8.89	

Note. Con. = Condition, Cul. = Culture, Pos. = Position, FS = Foot strike, TO = Toe-off, JP = Japanese, and AM = Americans.

*Significant at the .05 level.

condition at the toe-off position for Americans, $M = 112.08°$, $F(1, 8) = 5.49$, $p < .05$.

Foot. Foot angle was measured at foot strike of the right foot. An ANOVA summary table for foot angle is presented in Table 12. No difference in foot angle was found between the Americans' foot angle, M = -1.930°, and the Japanese foot angle, M = -2.501°, $F(1, 8) = 0.20$, $p = .67$. For the footwear condition, no difference in foot angle was found between flip-flops, M = -3.049°, and barefoot, M = -1.382°, $F(1, 8) = 5.02$, $p = .06$. The first-order interaction effect, condition by group, for the ANOVA was significant, $F(1, 8) = 5.75$, $p = .04$. A simple main effect test was calculated to analyze

Table 12

ANOVA Summary Table for Foot Angle

Source	SS	df	MS	F	p
Group (G)	1.626	1	1.626	0.20	.67
Subj. w. groups	66.416	8	8.302		
Footwear (F)	13.906	1	13.906	5.02	.06
F x G	15.907	1	15.907	5.75	.04*
F x Subj. w. groups	22.150	8	2.769		

*Significant at the .05 level.

this significant interaction effect. The results of this analysis are presented in Table 13. The results showed that a significant difference in foot angle existed between the means for the barefoot condition for the Americans, M = -0.205°, and the flip-flops condition

Table 13

ANOVA Summary Table for Simple Main Effects for Foot Angle

Source	SS	df	MS	F
Between Subject				
Footwear for Japanese	0.03	1	0.03	0.01
Footwear for American	29.79	1	29.79	5.38*
Within Cell	88.57	16	5.54	
Within Subjects				
Culture at Barefoot	13.85	1	13.85	5.00
Culture at Flip-flops	3.68	1	3.68	1.33
B. Subj. with groups	22.15	8	2.77	

for the Americans, $M = -3.656°$, $F(1, 16) = 5.38$, $p < .05$.

Kinetics

Braking Force

Braking force was measured at foot strike of the right leg. An ANOVA summary table for braking force is presented in Table 14. No difference in braking force was found between the Americans' braking force, $M = -139.100$ N, and the Japanese braking force, $M = -106.833$ N, $F(1, 8) = 1.09$, $p = .33$. For the footwear condition, no difference

Table 14

ANOVA Summary Table for Braking Force

Source	SS	df	MS	F	p
Group (G)	5205.689	1	5205.689	1.09	.33
Subj. w. groups	38368.957	8	4796.120		
Footwear (F)	341.689	1	341.689	0.76	.41
F x G	1467.755	1	1467.755	3.28	.11
F x Subj. w. groups	3579.889	8	447.486		

in braking force was found between flip-flops, M = -127.100 N, and barefoot, M = -118.833 N, $F(1, 8) = 0.76$, $p = .41$. The first-order interaction effect for the ANOVA was was not significant, $F(1, 8) = 3.28$, $p = .11$.

Propulsion Force

Propulsion force was measured at toe-off of the right leg. An ANOVA summary table for braking force is presented in Table 15. No difference in propulsion force was found between the Americans' propulsion force, M = 174.400 N, and the Japanese propulsion force, M = 134.800 N, $F(1, 8) = 1.16$, $p = .31$. For the footwear condition, no difference in propulsion force was found between flip-flops, M = 153.833 N, and bare-foot, M = 155.367 N, $F(1, 8) = 0.14$, $p = .72$. The first-order interaction effect for the ANOVA was not significant, $F(1, 8) = 0.32$, $p = .59$.

Table 15

ANOVA Summary Table for Propulsion Force

Source	SS	df	MS	F	p
Group (G)	7840.800	1	7840.800	1.16	.31
Subj. w. groups	53963.891	8	6745.486		
Footwear (F)	11.756	1	11.756	0.14	.72
F x G	27.222	1	27.222	0.32	.59
F x Subj. w. groups	678.467	8	84.808		

EMG

The ANOVAs for the EMG data were split-plot factorial designs. There were two dependent variables for each muscle: (1) peak EMG and (2) time to peak EMG. The peak EMG was the maximum mV 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, cultural background, and a research variable, footwear condition.

Biceps Femoris. An ANOVA summary table for biceps femoris (peak EMG) is presented in Table 16. No difference in peak EMG was found between the Americans' peak EMG, $M = 478.867$ mV, and the Japanese peak EMG, $M = 330.700$ mV, $F(1, 8) = 0.66$, $p = .44$. For the footwear condition, a significant difference in peak EMG existed between flip-flops, M = 499.800 mV, and barefoot, M = 309.767 mV, $F(1, 8) = 7.52$, $p = .03$. The first-order interaction effect for the ANOVA was not significant, $F(1, 8) = 0.15$, $p = .71$.

Table 16

ANOVA Summary Table for Biceps Femoris (Peak)

Source	SS	df	MS	F	p
Group (G)	109766.800	1	109766.800	0.66	.44
Subj. w. groups	1331432.269	8	166429.034		
Footwear (F)	180563.323	1	180563.323	7.52	.03*
F x G	3636.008	1	3636.008	0.15	.71
F x Subj. w. groups	191994.030	8	23999.254		

*Significant at the .05 level.

An ANOVA summary table for time to peak EMG for the biceps femoris is presented in Table 17. No difference was found between the Americans' time, M = 654.077 ms, and the Japanese time, M = 702.957 ms, $F(1, 8) = 0.15$, $p = .71$. For the footwear condition, no difference in time was found between flip-flops, M = 722.377 ms, and barefoot, M = 634.657 ms, $F(1, 8) = 1.39$, $p = .27$. The first-order interaction effect, footwear by group, for the ANOVA was significant, $F(1, 8) = 5.90$, $p = .04$. A simple main effects test was calculated to analyze this significant interaction effect. The

Table 17

ANOVA Summary Table for Biceps Femoris (Time)

Source	SS	df	MS	F	p
Group (G)	11946.280	1	11946.280	0.15	.71
Subj. w. groups	620604.401	8	77575.550		
Footwear (F)	38474.010	1	38474.010	1.39	.27
F x G	163732.638	1	163732.638	5.90	.04*
F x Subj. w. groups	222133.833	8	27766.729		

*Significant at the .05 level.

results of this analysis are presented in Table 18. The results of the simple main effect test indicated a significant difference in biceps femoris (time) existed between the means for the flip-flops condition for Americans, M = 607.457 ms, and the flip-flops condition for Japanese, M = 837.297 ms, $F(1, 8) = 4.76$, $p < .05$.

Gastrocnemius. An ANOVA summary table for gastrocnemius (peak) is presented in Table 19. No difference in peak EMG was found between the Americans' peak EMG, M = 192.767 mV, and the Japanese peak EMG, M = 129.900 mV, $F(1, 8) = 2.42$, $p = .16$. For the footwear condition, no difference in peak EMG was found between flip-flops, M = 168.033 mV, and barefoot, M = 154.633 mV, $F(1, 8) = 3.37$, $p = .10$. Trials were significant, $F(2, 16) = 3.62$, $p = .05$. The first- and second-order interaction effects for the ANOVA were not significant.

Table 18

ANOVA Table for Simple Main Effects for Biceps Femoris

Source	SS	df	MS	F
Between Subject				
Footwear for Japanese	180472.36	1	180472.36	3.43
Footwear for American	21720.33	1	21720.33	0.41
Within Cells	842738.28	16	52671.14	
Within Subjects				
Culture at Barefoot	43599.29	1	43599.29	1.57
Culture at Flip-flops	132050.78	1	132050.78	4.76*
B. Subj. w. groups	222133.83	1	27766.73	

An ANOVA summary table for time to peak EMG for the gastrocnemius is presented in Table 20. No difference was found between the Americans' time, $\underline{M}$ = 296.557 ms, and the Japanese time, $\underline{M}$ = 299.670 ms, $\underline{F}(1, 8) = 0.00$, $\underline{p} = .95$. For the footwear condition, no difference in time was found between flip-flops, $\underline{M}$ = 299.253 ms, and barefoot, $\underline{M}$ = 338.603 ms, $\underline{F}(1, 8) = 0.03$, $\underline{p} = .86$. The first-order interaction effect for the ANOVA was not significant, $\underline{F}(1, 8) = 3.15$, $\underline{p} = .11$.

Table 19

ANOVA Summary Table for Gastrocnemius (Peak)

Source	SS	df	MS	F	p
Group (G)	19761.089	1	19761.089	2.42	.16
Subj. w. groups	65316.023	8	8164.503		
Footwear (F)	897.800	1	897.800	3.37	.10
F x G	642.223	1	642.223	2.41	.16
F x Subj. w. groups	6401.267	8	800.158		
Trial (T)	7944.533	2	3972.267	3.62	.05*
T x G	6678.533	2	3339.267	3.04	.08
TG x Subj. w. groups	17551.933	16	1096.996		
F x T	1684.800	2	842.400	0.60	.56
F x T x G	5578.533	2	2789.267	2.00	.17
FT x Subj. w. groups	22336.333	16	1396.021		

*Significant at the .05 level.

Peroneal Group. An ANOVA summary table for peak EMG for the peroneal group is presented in Table 21. No difference in peak EMG was found between the Americans' peak EMG, M = 150.533 mV, and the Japanese peak EMG, M = 106.933 mV, $F(1, 8) = 4.42$, $p = .07$. For the footwear condition, a significant difference in peak EMG was found between flip-flops, M = 145.033 mV, and barefoot, M = 112.433 mV,

Table 20

ANOVA Summary Table for Gastrocnemius (Time)

Source	SS	df	MS	F	p
Group (G)	49.089	1	49.089	0.00	.95
Subj. w. groups	79246.912	8	9905.863		
Footwear (F)	26.450	1	26.450	0.03	.86
F x G	2418.537	1	2418.537	3.15	.11
F x Subj. w. groups	6139.195	8	767.399		

Table 21

ANOVA Summary Table for Peroneal Group (Peak)

Source	SS	df	MS	F	p
Group (G)	9504.801	1	9504.801	4.42	.07
Subj. w. groups	17199.889	8	2149.986		
Footwear (F)	5313.801	1	5313.801	5.79	.04*
F x G	2233.089	1	2233.089	2.43	.15
F x Subj. w. groups	7346.112	8	918.264		

*Significant at the .05 level.

$F(1, 8) = 5.79$, $p = .04$. The first-order interaction effect, condition by group, for the

ANOVA was not significant, $F(1, 8) = 2.43$, $p = .15$.

An ANOVA summary table for time to peak EMG for the peroneal group is presented in Table 22. No difference was found between the Americans' time, M = 321.430 ms, and the Japanese time, M = 463.463 ms, $F(1, 8) = 1.46$, $p = .26$. For the footwear condition, no difference was found between flip-flops, M = 329.097 ms, and barefoot, M = 455.797 ms, $F(1, 8) = 1.69$, $p = .23$. The first-order interaction effect, condition by group, for the ANOVA was not significant $F(1, 8) = 0.01$, $p = .93$.

Table 22

ANOVA Summary Table for Peroneal Group (Time)

Source	SS	df	MS	F	p
Group (G)	100867.338	1	100867.338	1.46	.26
Subj. w. groups	552781.622	8	69097.703		
Footwear (F)	80264.471	1	80264.471	1.69	.23
F x G	324.817	1	324.817	0.01	.93
F x Subj. w. groups	380523.913	8	47565.489		

Rectus Femoris. An ANOVA summary table for peak EMG for the rectus femoris is presented in Table 23. No difference was found between the Americans' peak EMG, M = 96.500 mV, and the Japanese peak EMG, M = 46.767 mV, $F(1, 8) = 1.86$, $p = .21$. For the footwear condition, no difference in peak EMG was found between flip-flops, M = 85.900 mV, and barefoot, M = 57.367 mV, $F(1, 8) = 1.17$, $p = .31$. The first-order interaction effect, condition by group, for the ANOVA was not significant, $F(1, 8) = 0.54$, $p = .48$.

Table 23

ANOVA Summary Table for Rectus Femoris (Peak)

Source	SS	df	MS	F	p
Group (G)	12367.023	1	12367.023	1.86	.21
Subj. w. groups	53286.514	8	6660.814		
Footwear (F)	4070.756	1	4070.756	1.17	.31
F x G	1881.800	1	1881.800	0.54	.48
F x Subj. w. groups	27906.336	8	3488.292		

An ANOVA summary table for time to peak EMG for the rectus femoris is presented in Table 24. No difference was found between the Americans' time, M = 221.403 ms, and the Japanese time, M = 219.590 ms, $F(1, 8) = 0.00$, $p = .99$. For the footwear condition, no difference was found between flip-flops, M = 294.053 ms, and barefoot, M = 146.940 ms, $F(1, 8) = 3.85$, $p = .09$. The first-order interaction effect, condition by group, for the ANOVA was not significant, $F(1, 8) = 2.09$, $p = .19$.

Vastus Medialis. An ANOVA summary table for peak EMG for the vastus medialis is presented in Table 25. No difference was found between the Americans'

Table 24

ANOVA Summary Table for Rectus Femoris (Time)

Source	SS	df	MS	F	p
Group (G)	16.441	1	16.441	0.00	.99
Subj. w. groups	1108392.084	8	138549.011		
Footwear (F)	108211.668	1	108211.668	3.85	.09
F x G	58658.890	1	58658.890	2.09	.19
F x Subj. w. groups	224667.265	8	28083.408		

Table 25

ANOVA Summary Table for Vastus Medialis (Peak)

Source	SS	df	MS	F	p
Group (G)	2856.050	1	2856.050	0.65	.44
Subj. w. groups	35304.287	8	4413.036		
Footwear (F)	1473.472	1	1473.472	2.93	.13
F x G	322.672	1	322.672	0.64	.45
F x Subj. w. groups	4023.133	8	502.892		

peak EMG, M = 90.733 mV, and the Japanese peak EMG, M = 66.833 mV, $F(1, 8) = 0.65$, $p = .44$. For the footwear condition, no difference in peak EMG was found between flip-flops, M = 87.367 mV, and barefoot, M = 70.200 mV, $F(1, 8) = 2.93$, $p = .13$. The first-order interaction effect, condition by group, for the ANOVA was not significant, $F(1, 8) = 0.64$, $p = .45$.

An ANOVA summary table for time to peak EMG for the vastus medialis is presented in Table 26. No difference was found between the Americans' time, M = 161.640 ms, and the Japanese time, M = 125.473 ms, $F(1, 8) = 0.05$, $p = .83$. For the footwear condition, no difference in time was found between flip-flops, M = 156.103 ms, and barefoot, M = 131.010 ms, $F(1, 8) = 0.17$, $p = .69$. The first order interaction effect, condition by group, for the ANOVA was not significant, $F(1, 8) = 0.25$, $p = .63$.

Table 26

ANOVA Summary Table for Vastus Medialis (Time)

Source	SS	df	MS	F	p
Group (G)	6540.139	1	6540.139	0.05	.83
Subj. w. groups	1071068.916	8	133883.614		
Footwear (F)	3148.377	1	3148.377	0.17	.69
F x G	4659.384	1	4659.384	0.25	.63
F x Subj. w. groups	150260.638	8	18782.580		

Semimembranosus/Semitendinosus Group. An ANOVA summary table for peak EMG for the semimembranosus/semitendinosus group (peak) is presented in Table 27.

No difference was found between the Americans' peak EMG, M = 97.967 mV, and the Japanese peak EMG, M = 86.733 mV, F(1, 8) = 0.43, p = .53. For the footwear condition, no difference in peak EMG was found between flip-flops, M = 95.400 mV,

Table 27

ANOVA Summary Table for Semimembranosus/Semitendinosus Group (Peak)

Source	SS	df	MS	F	p
Group (G)	630.939	1	630.939	0.43	.53
Subj. w. groups	11787.332	8	1473.417		
Footwear (F)	186.050	1	186.050	2.24	.17
F x G	247.339	1	247.339	2.98	.12
F x Subj. w. groups	663.333	8	82.917		

and barefoot, M = 89.300 mV, F(1, 8) = 2.24, p = .17. The first-order interaction effect, condition by group, for the ANOVA was not significant, F(1, 8) = 2.98, p = .12.

An ANOVA summary table for time to peak EMG for the semimembranosus/ semitendinosus group is presented in Table 28. No difference was found between the Americans' time, M = 551.137ms, and the Japanese time, M = 258.013 ms, F(1, 8) = 1.97, p = .20. For the footwear condition, no difference in time was found between flip-flops, M = 423.557 ms, and barefoot, M = 385.593 ms, F(1, 8) = 0.20, p = .67. The first-order interaction effect, condition by group, for the ANOVA was not significant, F(1, 8)

= 0.54, $p = .48$.

Table 28

ANOVA Summary Table for Semimembranosus/Semitendinosus Group (Time)

Source	SS	df	MS	F	p
Group (G)	429606.508	1	429606.508	1.97	.20
Subj. w. groups	1747526.336	8	218440.792		
Footwear (F)	7206.060	1	7206.060	0.20	.67
F x G	19973.315	1	19973.315	0.54	.48
F x Subj. w. groups	293250.576	8	36656.322		

Discussion

Performance Consistency

Ten students (5 American and 5 Japanese) volunteered for the research study. Each subject completed 3 trials for each condition (barefoot and flip-flops). The results indicated that subjects were able to repeat trials with consistency. This result was expected. However, there was one exception. For peak EMG of the gastrocnemius muscle, subjects' performance were not consistent among the 3 trials. At the midstance, the center of gravity of the body reached its highest point and was moved forward by momentum (Rose & Gamble, 1994). It is possible that when the subjects reached midstance, they used the gastrocnemius for balance. Therefore, the results varied from trial to trial.

Rose and Gamble (1994) divided the gait cycle into a stance phase and a swing phase. They further labeled positions in the stance as initial contact, midstance, and terminal stance. According to these divisions of the stance phase, the gastrocnemius is active during the loading response (after foot strike and before midstance). This occurs to allow the body to accept weight at midstance, to preserve momentum, and to place the body in a position to accelerate the body from the midstance position to the toe-off position (accelerate mass). Other muscles are active across a gait cycle. However, the gastrocnemius was used for a longer time during the stance phase than the other prime moving muscles (10 total) that Rose and Gamble studied. It is also possible that because the time in which the gastrocnemius is active is longer than other muscles, the peak could be different due to impulse (derived from Newton's second law).

Kinematics

Temporal Data

Stride Time. There were no significant differences in stance time between cultural backgrounds or conditions. The results showed there was a significant difference between the mean time for the stance phase, M = 0.684 s, and the swing phase, M = 0.453 s. "The stance phase is approximately 60% of the walking cycle, and the swing phase is 40% of the walking cycle. Some of these percentages changed in stair ascent and descent, and running and jumping aspects of motion" (Adrian & Cooper, 1989, p. 280). For this study, the percentages for the stance phase were 59.95% and 60.34% for the barefoot and flip-flops conditions, respectively.

Although footwear was not statistically significant, interesting patterns in stride time and stride length existed. For footwear, the barefoot condition showed a longer stride time, M = 1141.00 ms, than the flip-flops condition, M =1133.30 ms. Also, the barefoot condition showed a longer stride length, M = 1.314 m, than the flip-flops condition, M = 1.297 m. Therefore, the barefoot condition would take longer to execute, because the stride length was longer.

Stance Time. There were no differences in stance time for both the cultural background or the footwear condition. A significant difference existed between the braking phase, M = 386.40 ms, and the propulsion phase, M = 295.85 ms. There is a horizontal backward reaction force that acts on the subjects when the heel strikes the ground. After heel strike, when the foot is flat, the center of the gravity is over the foot,and there is a forward reaction force that acts to push the person forward into the swing phase (Adrian & Cooper, 1989).

Although not statistically significant, the braking phase for the Americans, M = 407.20 ms, was longer than for the Japanese, M = 365.60 ms. Shimizu (1994) discussed gait differences between Germans and Japanese with a German foot doctor. The doctor stated that Germans use the heel in 80% of their stance phase for walking, but Japanese use the forefoot most of the time for walking. Thus, it would take a shorter time to brake when only the forefoot makes contact or when the foot plant is with the entire foot versus the German style of heel strike, foot-flat, heel-off, and toe-off (rolling action of the foot). The German and American foot strike technique is similar.

Stride Length

The results for stride length in meters and percentages did not show significant differences for either the cultural background or the footwear condition. As expected, the Americans' stride length percentage, M = 157%, was greater than the Japanese stride length percentage, M = 151%, and the barefoot condition, M = 155%, was slightly greater than the flip-flop condition, M = 153%. However, the difference was not great enough to be statistically different.

Velocity

There was no significant difference in velocity of the center of gravity for cultural background. The Japanese, who live in urban areas, walk about restlessly. The difference of walking speed among cities was studied by Yamazaki and Sato (1990). The difference (meters per minute) were: Osaka (100 m/min), Tokyo (94 m/min), Paris (88 m/min), and Manila (74 m/min) (Ikeda, 1996). The subjects in this study walked slower, M = 69.52 m/min), than any of the subjecs in Ikeda's study.

Angle

Trunk. There were no significant differences in trunk angle between cultural backgrounds or the footwear conditions in this study. A significant difference was found for positions, foot strike, M = -5.196°, and toe-off, M = -0.847°. This difference was thought to be a result of normal changes in motion during the gait pattern. When subjects put weight on the heel at foot strike at the end of the swing phase, the whole body respond to the braking force. Therefore, the trunk leans slightly backward, as the subject pushes on the floor. The center of gravity is then carried forward and slightly decelerated until midstance. After midstance, the center of gravity is accelerated. During this acceleration, the trunk leans forward to place the body's canter of gravity in front of the foot that is pushing off at the toe-off position.

Thigh. There were no significant differences in thigh angle for the cultural backgrounds or the footwear conditions. For position, the toe-off position showed a greater angle, M = 98.307°, than the foot strike position, M = 74.409°. According to Nordin and Frankel (1989), during level walking for normal males, the hip joint extended as the body moved forward at the beginning of the stance phase (35° to 40°). Maximum extension was reached at heel-off (after midstance and before toe-off) (0° to -5°). Therefore, the total range of motion about the hip joint was between 35° to 40°. Because the range of motion for thigh angle in this study was 23.90°, the thigh angle was smaller than that reported by Nordin and Frankel.

Knee. There were no differences in knee angle for the cultural backgrounds or the footwear conditions. Among the positions, significant differences existed, foot strike, M = 179.267°, midstance, M = 179.070°, and toe-off, M = 141.654°. These data were supported by the literature. During the entire gait cycle, the knee never fully extends (Nordin & Frankel, 1989). Greatest extension occurs at the beginning of the stance phase at heel strike and continues until after the midstance phase. At the end of the stance phase, just before toe-off, the knee begins to flex about 35° (Nordin & Frankel, 1989). This was true for both American and Japanese subjects in this study. At foot strike, the knee was close to full extension, so knee flexion occurred to absorb the shock of foot strike. The body's center of gravity reached its highest vertical point. At this point, the heel was lifted off the ground, the knee extended, and knee flexion began. At toe-off, the knee reached its maximum degree of knee flexion for the stance phase. According to Rose and Gamble (1994), "The knee is rapidly flexed beginning just after heel rise to a maximum in the swing phase just as the swinging foot passes its opposite side. This flexion effectively shortens the limb allowing for foot clearance of the swinging limb to prevent foot dragging" (p. 31).

Ankle. For ankle angle, there were no differences for the cultural background, the footwear conditions, or the positions. However, the simple simple main effects test for ankle angle showed significant differences. For the barefoot condition, the Japanese showed a smaller ankle angle, $M = 105.27°$, than the Americans, $M = 112.08°$, at toe-off. This result indicated that the Japanese subjects did not push down on the floor with the ankle in the same manner as the Americans. This could be true, because of the difference between piston system (Japanese) and the swing system (American). This difference between Japanese and Americans will be discussed later in conjunction with the EMG data.

Western people walk keeping the head and the back straight, swinging the arms, and extending the rear leg's knee. They walk using the whole body. But Japanese walk protruding the jaw forward, rounding the shoulders (a stoop), bending the knees, and shuffling the feet (Asaka & Harada, 1995). This description of cultural differences may explain the differences found in this study between American and Japanese ankle angles at the toe-off position.

In Germany, most children learn to walk while wearing lace-type shoes. Parents teach their children, and they have programs to teach appropriate walking in school (kindergarten), (Shimizu, 1994). Asaka and Harada (1995) stated the development of the 26 foot bones is completed by adolescence. During childhood, children need appropriate stimulation for the growth and development of these bones. Around age 6 to 7 years, the tuberosity of the calcaneus begins developing toward a mature adult calcaneus. This bone has a big influence in changing the child's gait. Before the calcaneus develops (ages 1 to 6 years), the child walks in a foot flat position during the stance phase. As the calcaneus develops, the child's gait changes to a foot strike to toe-off or foot roll during the stance phase. When children do not learn to walk in an appropriate way, the stimulation for the bone may be too strong or to weak to develop properly. The literature indicated that too much stress on the tuberosity of the calcaneus becomes a factor of "Gorilla walking," bending the knee, rounded shoulders, and protruding the jaw. This walking pattern is characteristic of Japanese walking. For the flip-flop condition, at foot strike, the Japanese showed a significantly smaller angle, $\underline{M} = 109.43°$, than the

Americans, M = 111.39°. This result indicated that the ankle angle at foot strike and toe-off were changed with flip-flops. Many studies have pointed out taller skeletal dimensions in young Japanese people than in elderly Japanese people. Regardless of the taller physiques, Japanese tend to walk dragging their shoes (Shimizu, 1994). Japanese life-style was westernized about 50 years ago, however even today the life-style includes wearing slippers or flip-flops inside and outside of the house. Japanese currently learn to walk with this footwear, therefore they drag the heel (Ae & Yamamoto, 1993). The Japanese subjects in this study tended to walk dragging the heels of the flip-flops, but the Americans walked with a heel strike. Japanese subjects kept the ankle angle large, which would cause the flip-flops to drag. The Americans held the flip-flops more securely to the sole of the foot with the toes or inserting the foot farther into the flip-flops.

Another interesting point was found in the simple simple main effects test for ankle angle. The Americans' ankle angle for the barefoot condition increased from foot strike, M = 107.66°, to toe-off, M = 112.08°, and the Japanese ankle angle for the barefoot condition decreased from foot strike, M = 110.98°, to toe-off, M = 105.27°. Thus, during the stance phase, the Americans used the ankle motion to push off. They started the phase with a small angle and ended the phase with a larger angle. The Japanese did the opposite; the ankle motion decreased from foot strike to toe-off. Therefore, the Japanese did not use plantar flexion of the ankles to propel the body forward at the same magnitude as the Americans. Thus, the motion created by Japanese would have to come from the knee and hip joint movement. Nordin and Frankel (1989) stated that the ankle angle at heel strike was slightly plantar flexed (about 100° to 106°). The subjects in this study were slightly below this range. Nordin and Frankel (1989) stated that ankle angle at toe-off is also slightly plantar flexed (about 98° to 100°). Rose and Gamble (1994) study showed the opposite. The ankle was at the neutral position in the foot strike position when the heel strikes first. At toe-off, after rapid plantar flexion occurs, the ankle is 20° to 25° past the neutral position. It is difficult to conclude which group walked in a normal manner. However, it is true the Americans pushed off the ground harder, and the Japanese pulled the big toe at foot strike.

Foot. A significant simple main effect existed for the Americans between barefoot, $\underline{M} = -0.205°$, and flip-flops, $\underline{M} = -3.656°$, but the Japanese showed no difference, $\underline{M} = -2.559°$ and $\underline{M} = -2.44°$, respectively. The Japanese foot angle was not influenced by the change of footwear. Japanese are used to wearing flip-flops. Almost all schools in Japan require students to wear flip-flop-type sandals in school. In this environment, students in Japan can never walk like western people. Therefore, the gait pattern of the Japanese people that is learned at an early age wearing flip-flops influences their gait while wearing other types of footwear (Shimizu, 1994). The Americans were not used to walking while wearing flip-flops. Therefore, they changed the foot angle to help keep the flip-flop on the foot. This result indicated that the Americans' gait was restricted with flip-flops, and the Japanese was not. The Japanese group walked in both footwear conditions like the Americans walked while wearing flip-flops. However, the Americans changed their gait based on footwear.

Kinetics

There were no differences in cultural background and footwear condition for the braking force and propulsion force. However, as discussed before, interesting data existed concerning the midstance time. Braking forces start when the heel strikes the ground to decelerate the body. Propulsion forces start when the body's center of gravity passes over the midstance point. Propulsion forces push the body's mass forward. "The weight is centered on the heel, and then moves forward on the lateral edge of the foot and diagonally toward the undersurface of the big toe" (Adrian & Cooper, 1989, p. 283). This motion is called "roll" or "locomotion" of the foot. Shimizu (1996) pointed out that the ideal walking pattern utilizes the foot roll. He further explained that when using the heel for the foot strike, the braking phase occurs over a longer period of time. This longer time allows the foot to absorb the shock of landing. In other styles of foot strike, as with the Japanese, in which the foot is planted more flat-footed or on the forefoot, the impact forces are greater due to shorter time for the foot to absorb shock. Thus, the Japanese foot strike technique is associated with a greater potential for foot injury and potential for falling arches of the foot. Therefore, to lessen the magnitude of the impactforces, Japanese people take shorter strides or shuffle (Asaka & Harada, 1995), thus, reducing the magnitude of the braking force. Although, stride length and velocity were not significant for this study, the Americans took longer strides and were faster than the Japanese.

EMG

Biceps Femoris. For the peak EMG for the biceps femoris, there was no difference for cultural background. A significant difference was found for the footwear condition between flip-flops, M = 499.80 mV, and barefoot, M = 309.767 mV. It is possible that the subjects used the biceps femoris to hold the flip-flops on the foot.

For the time to peak EMG, the simple main effect test indicated a significant difference for the flip-flop condition between the Americans, M = 607.457 ms, and the Japanese, M = 837.297 ms. The interesting point is where in the gait cycle the time to peak EMG occurred. The total time for the gait cycle was 1137 ms, and the stance phase was 684 ms. The time to peak EMG for the Americans occurred in the stance phase, and the Japanese time to peak EMG occurred in the swing phase. The Americans' peak EMG with flip-flops occurred after the heel-rise, right before the push-off, but the Japanese peak EMG with flip-flops occurred in the beginning of the swing phase. The Japanese shuffled the feet, therefore the biceps femoris peaked in the swing phase. Thus, the biceps femoris was decelerating the hip flexor, reducing the distance the foot swung forward, allowing the forefoot to strike the ground in the next step. This shuffling action helped to keep the flip-flops on the foot. The Americans used the swing leg as a pendulum. Therefore, the activity of the biceps femoris would be at its lowest during the swing phase. To keep the flip-flops on during gait, the Americans were seen pushing their forefeet into the flip-flops, making a snug fit about the metatarsals. This was not the case with the Japanese, their feet fit very loosely into the flip-flops. This result provided evidence that Americans used a swing system and Japanese used a piston system when walking.

Other Muscles. For peak EMG, the gastrocnemius, peroneal group, rectus femoris, vastus medialis, and semimembranosus/semitendinosus group showed no differences for cultural background. Also, no significant difference was found for the footwear condition for the gastrocnemius, rectus femoris, vastus medialis, and semimembranosus/semitendinosus group. The peak EMG for the peroneal group showed a significant difference for the footwear condition, barefoot, M = 112.433 mV, and flip-flops, M = 145.033 mV. Although this difference was not significant, the Americans used the peroneal group more, M = 150.533 mV, than the Japanese, M = 106.933 mV. Also it is possible because since the Americans wore the flip-flops tightly, they tried to maintain a more normal gait pattern with respect to plantar flexion of the ankle. As previously discussed, the Americans used plantar flexion during the stance phase. Shimizu (1994) explained that: (a) at heel strike the motion of the ankle and knee absorb shock; (b) as the foot moves from the heel strike position to foot flat, the arch flattens and absorbs shock; (c) as the foot moves from the midstance position to toe-off, the toes spread or open to absorb the shock of toe-off. For the Americans, a greater plantar flexion occurred during the stance phase and a greater peak EMG for the peroneal group than for the Japanese were found. Therefore, the American gait patterns were similar to Shimizu's description.

Although, there were no significant difference for the time to peak EMG for the peroneal group, interesting results existed. The mean for peak EMG for the Americans was 321.430 ms, and for the Japanese, the mean was 463.483 ms. The time to peak EMG for the Americans occurred before the midstance, and for the Japanese, it occurred after heel-off. According to Rose and Gamble (1994), ankle dorsiflexors became more active at the end of the swing phase than at the beginning of the stance phase. This was true for the barefoot condition. Both groups, American and Japanese, showed different patterns. It is possible that the flip-flops changed their gait and the subjects used the peroneal group at different points in this study.

No significant differences for time to peak EMG for the muscles, gastrocnemius, peroneal groups, rectus femoris, vastus medialis, and semimembranosus/semitendinosus group were found. However, interesting results existed. Table 29 shows the mean firing order for the six muscles for all of the subjects, the American subjects, and the Japanese subjects. The firing patterns represent the time when the muscles reach their peak EMG response. Although the times were slightly different the Americans and all of the subjects had the same firing order for the six muscles. For the American subjects the hip flexors, vastus medialis and rectus femoris, fired first. This firing occurred shortly after foot strike. Next the plantar flexors, gastrocnemius and peroneal group, fired near the midstance position in the stance phase. Last to fire was the hip extensors, semi-membranosus/semitendinosus and biceps femoris, which occurred prior to toe-off. The firing pattern was slightly different for the Japanese subjects. The Japanese firing order started the same as the Americans with the hip flexor, vastus medialis and rectus femoris firing first and second following foot strike. Next to fire were the semimembranosus/

Table 29

Time to Peak EMG for All Muscles

Muscles	F.O.	All Subjects	F.O.	American	F.O.	Japanese
Vastus Medialis	1	143.557	1	161.640	1	125.473
Rectus Femoris	2	220.497	2	221.403	2	219.590
Gastrocnemius	3	298.104	3	296.537	4	299.670
Peroneal Group	4	392.447	4	321.430	5	463.483
Semimem./tendi.	5	404.447	5	551.137	3	258.013
Biceps Femoris	6	678.517	6	654.077	6	702.350

Note: F.O. = Firing order, measures are in ms.

semitendinosus group and the gastrocnemius muscles, both biarticulate muscles, with the common motion being knee flexion and the second motions, hip extension and plantar flexion, respectively. These muscles fired near the midstance point in the stance phase. The last of the six muscles to fire were the peroneal group and the biceps femoris, with planter flexion and hip extension/knee flexion motions, respectively. The peroneal group fired after midstance and before toe-off; the biceps femoris fired after the toe-off position of the stance phase.

Differences in firing order may be a result of the different walking patterns, the swing system and the piston system (Ae & Yamamoto, 1993). Americans use the swing system but Japanese use the piston system. For the Americans, after they absorb the shock of foot strike with the vastus medialis and the rectus femoris, the lower limb becomes active in moving the center of gravity over the support foot. At this time, ankle and knee motion work together to minimize the vertical displacement of the center of gravity and to place the center of gravity in a position in which the body can accelerate forward into the next step. (The knee flexes while the ankle plantar flexes.) This acceleration occurred after midstance and before toe-off, when the greatest activity of the hip extensor occurred. The Japanese used the vastus medialis and the rectus femoris at the same time and for the same reasons as Americans, to absorb the shock of foot strike. Next the Japanese used the knee flexor to keep the body's center of gravity over the base of support and low as the heel pushed down on the floor, (Plantar flexion decreased from foot strike to toe-off for the Japanese.) After toe-off, the hip extensor fired to decelerate the leg. This deceleration would keep the flip-flops from becoming a projectile.

CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The problem was to compare the kinematic, kinetic, and electromyographical (EMG) aspects of the walking gait while wearing flip-flops and barefoot between American and Japanese males, aged 20 to 25 years. Data were obtained from 10 subjects, 5 Americans and 5 Japanese. The subjects completed three trials for each of two different walking conditions, barefoot and flip-flops, a total of 6 trials for the day. The study took place in the Biomechanics Laboratory at Western Michigan University. Data were obtained from a two-dimensional cinematographic analysis, EMG responses of six muscles, and a force platform. Data from video, EMG, and the force platform were synchronized. The research variables were six muscles, two different walking patterns, and subject of two different cultures. 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. A simple main effects test or a simple simple main effects test was conducted when the ANOVA had significant first- or second-order interaction effects.

Findings

The significant findings of the study were as follows:

1. A significant difference was found among the three trials for peak EMG for the gastrocnemius muscles, $F(2, 16) = 3.62$, $p = .05$.

2. No significant differences for stride time were found between the American and the Japanese, $F(1, 8) = 0.02$, $p = .89$, or between the footwear conditions, $F(1, 8) = 0.60$, $p = .46$.

3. A significant difference existed between the mean time for the stance phase and the swing phase, $F(1, 8) = 263.56$, $p = .00$. The stance phase was greater than the swing phase.

4. A significant difference existed between the phase times, stance and swing, $F(1, 8) = 11.71$, $p = .01$. The stance phase time was longer than the swing phase time.

5. No differences in stride length (in meters and in percentages) were found between the American and the Japanese, $F(1, 8) = 0.14$, $p = .72$ (meters), and $F(1, 8) = 0.62$, $p = .46$ (percentages), and the footwear condition, $F(1, 8) = 0.42$, $p = .54$ (meters), and $F(1, 8) = 0.33$, $p = .58$ (percentages), respectively.

6. A significant difference was found between the mean velocities for the stance phase and the swing phase, $F(1, 8) = 24.88$, $p = .00$. The swing phase was faster than the stance phase.

7. A significant difference in trunk angle existed between the means for foot strike and toe-off, $F(1, 8) = 43.69$, $p = .00$. Trunk angle at foot strike was greater than at the toe-off.

8. A significant difference for thigh angle was found between foot strike and toe-off, $F(1, 8) = 472.40$, $p = .00$. Thigh angle at foot strike was smaller than at the toe-off.

9. Significant differences for knee angle existed among the means for foot strike, midstance, and toe-off, $F(2, 16) = 292.96$, $p = .00$. Knee angle at foot strike and midstance were greater than at toe-off.

10. The second order interaction effect for ankle angle, condition by phase by group, was significant, $F(1, 8) = 7.09$, $p = .03$. The ankle angle for the Americans for the barefoot condition for toe-off was greater than for the Japanese. Also, the ankle angle for the Americans for the flip-flop condition for foot strike was greater than for the Japanese.

11. The first order interaction effect for foot angle, condition by group was significant, $F(1, 8) = 5.75$, $p = .04$. The foot angle for the flip-flops condition for the Americans was smaller than the barefoot condition for the Americans.

12. No significant differences for braking force and propulsion force were found for the cultures, $F(1, 8) = 1.09$, $p = .33$ and $F(1, 8) = 1.16$, $p = .33$, respectively, or for the footwear conditions, $F(1, 8) = 0.76$, $p = .41$ and $F(1, 8) = 0.14$, $p = .72$, respectively.

13. A significant difference for the biceps femoris peak EMG for the footwear condition existed between flip-flops and barefoot, $F(1, 8) = 7.52$, $p = .03$. The peak EMG for flip-flop condition was greater than for the barefoot condition.

14. The first order interaction effect for the biceps femoris time to peak EMG was significant, $F(1, 8) = 5.90$, $p = .04$. The time to peak EMG was longer for the Japanese than for the Americans.

15. A significant difference for the peroneal group's peak EMG for the footwear condition was found between flip-flops and barefoot, $F(1, 8) = 5.79$, $p = .04$. The peak

EMG for flip-flop condition was greater than for the barefoot condition.

16. No differences in peak EMG and in time to peak EMG were found for any other muscles.

Conclusions

The findings led the investigator to conclude the following:

1. The American and the Japanese gait patterns were more alike than different. Differences existed in foot and ankle motion during the stance phase and the time to peak recruitment for the biceps femoris. Velocity, stride length, stride time, trunk angle, thigh angle, and knee angle were not significantly different.

2. The footwear had a greater influence on the gait patterns of the Americans than on the Japanese. Thus, gait patterns learned by the Japanese at a young age, 1 to 6 years, while wearing flip-flops apparently influenced their gait patterns as adults.

3. The study provided evidence to support Ae and Yamamoto (1993) concerning the evidence of the piston and swing system gait styles used by Asian people and Western people, respectively.

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 the cultures.

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

both progressive, and regressive that occur over the lifespan of various cultures.

3. A randomly selected group of females should be studied in a similar project to see if female cross-cultural comparisons are similar to those found in males.

4. More data or different variables, (e.g., plotted-graphs, velocity for each body part, displacements) need to be investigated.

5. Other Asian and Western cultures need to be included in a similar study to describe possible cultural influences on gait patterns.

Appendix A

Human Subjects Institutional Review Board Approval

Human Subjects Institutional Review Board

Kalamazoo, Michigan 49008-3899
616 387-8293

WESTERN MICHIGAN UNIVERSITY

To: Dr. Mary L. Dawson
Ko Tada

From: Richard A. Wright, Chair
Human Subjects Institutional Review Board

Subject: HSIRB Project # 96-09-22

Date: October 9, 1996

This is to inform you that your project entitled "Comparative Analysis of Walking Pattern With Flip-Flops Between Americans and Japanese Males," has been approved under the expedited category of research. This approval is based upon your proposal as presented to the HSIRB, and you may utilize human subjects only in accord with this approved proposal.

Your project is approved for a period of one year from the above date. If you should revise any procedures relative to human subjects or materials, you must resubmit those changes for review in order to retain approval. Should any untoward incidents or unanticipated adverse reactions occur with the subjects in the process of this study, you must suspend the study and notify me immediately. The HSIRB will then determine whether or not the study may continue.

Please be reminded that all research involving human subjects must be accomplished in full accord with the policies and procedures of Western Michigan University, as well as all applicable local, state, and federal laws and regulations. Any deviation from those policies, procedures, laws or regulations may cause immediate termination of approval for this project.

Thank you for your cooperation. If you have any questions, please do not hesitate to contact me.

Project Expiration Date: October 9, 1997

Appendix B

Informed Consent Form

Western Michigan University
Department of HPER

Principal Investigator: Dr. Mary L. Dawson

Research Associate: Ko Tada

I have been invited to participate in a research project entitled "Comparative Analysis of Walking Pattern with Flip-flops Between American and Japanese Males". I understand that this research is intended to study the difference of walking pattern with flip-flops and barefoot between Americans and Japanese. I further understand that this project is Ko Tada's Master's thesis project.

My consent to participate in this project indicates that I will be asked to attend one 30-45 minute private session with the researchers. I will be asked to meet researchers for the session at the Biomechanics Laboratory in the University Recreation Center, Western Michigan University, Kalamazoo. I will provide general information about myself such as my age, height, and weight.

I understand I will be asked to walk for 6 trials, 3 barefoot and 3 with flip-flops that the researchers provide. The 6 trials consists of 5 to 6 steps. I further understand each trial will be video taped, and during each trial, EMG data and force platform data will be collected. For the EMG data electrodes will be placed over 6 of my muscles, rectus femoris, vastus medialis, medial heard of the gastrocnemius, peroneal group, biceps femoris and semimembranosus/semi-tendinosus group. The electrode placement sites will be prepared by rigorously rubbing my skin with a sterile alcohol pad. In some cases, there may be a need to shave the site to provide a better electrode contact surface.

As in all research, there may be unforeseen risks to the participant. If an accidental injury occurs, appropriate emergency measures will be taken; however, no compensation or treatment will be made available to me expect as otherwise specified in this consent form.

I understand that all the information collected from me is confidential. That means that my name will not appear on any papers on which this information is recorded. The forms will all be coded, and Ko Tada will keep a separate master list with the names of participants and the corresponding code numbers. Once the data are collected and analyzed, the master list will be destroyed. All other forms will be retained for three years in a locked file in the principal investigator's laboratory.
I understand that there are no direct benefits to me as a subject in this study.
I understand that I may refuse to participate or quit at any time during the study without prejudice or penalty. If I have any questions or concerns about this study, I may contact

either Dr. Marry L. Dawson at (616) 387-2720 or Ko Tada at (616) 387-5482. I may also contact the Chair of Human Subjects Institutional Review Board at (616) 387-8293 or the Vice President for Research at (616) 387-8298 with any concerns that I have. My signature below indicates that I understand the purpose and requirements of the study and that I agree to participate.

____________________________ ________________________

Signature Date

Appendix C

Data Sheet

Data Sheet - Ko

Subject # ________ Condition Barefoot Flip-flops Trial _________ Weight ______N

	Frame#			
1. .000	( )	Time stance phase began		
2. ______	( )	Midstance time		
3. ______	( )	Time stance phase ended	____________	Time stance phase
4. ______	( )	Time swing phase ended	____________	Time swing phase
5. ____________		Velocity CG stance phase		
6. ____________		Velocity CG swing phase		
7. ____________		Foot angle at foot strike		
8. ____________		Ankle angle at foot strike		
9. ____________		Ankle angle at toe-off	____________	Difference (Ankle)
10. ____________		Knee angle at foot strike		
11. ____________		Knee angle at midstance		
12. ____________		Knee angle at toe-off	____________	Difference (Knee)
13. ____________		Thigh angle at foot strike		
14. ____________		Thigh angle at toe-off	____________	Difference (Thigh)
15. ____________		Trunk angle at foot strike		
16. ____________		Trunk angle at toe-off	____________	Difference (Trunk)
17. ____________		Stride length (Second FS - First FS) (m)		

18. ____________ Leg length (m) Ankle X= , Y=

19. ____________ Thigh length (m) Knee X= , Y= L= (-)+(-)

Hip X= , Y= T= (-)+(-)

20. ____________ Stride length as a % of leg length (17 / [18+19])

21. ____________ Breaking force

22. ____________ Propulsion force

23. ____________ EMG

24. ____________ EMG

BIBLIOGRAPHY

Adrian, M., & Cooper, J. (1989). Biomechanics of human movement. Dubuque, IA: Brown & Benchmark.

Ae, M., & Yamamoto, T. (1993). Soryoku wo kyoka suru [The strength for sprinter]. Training Journal, 159,160, 20-25, 42-45.

Asaka, K., & Harada, S. (1995). Ashi to kutsu no hanashi [The study for foot and shoes] Nagoya, Japan: Reimei-shobo.

Gabbard, C. P. (1992). Lifelong motor development (2nd ed.). Dubuque, IA: Brown & Benchmark.

Hennessy, M. J., Dixon, S. D., & Simon, S. R. (1984). The development of gait: A study in African children ages one to five. Child Development, 55, 844-853.

Ikeda, K. (1996). Walking no hon [Walking book]. Tokyo: Iwanami-shoten.

Nordin, M., & Frankel, V. H. (1989). Basic biomechanics of the musculoskeletal system (2nd ed.). Philadelphia: Lea & Febiger.

Oswald, J. M. (1987). Vegetarian footwear (Issue No. RIEMAY 88). U.S. Pennsylvania. (ERIC Document Reproduction Service No. ED 289784)

Rose, J., & Gamble, J. G. (Eds.). (1994). Human walking (2nd ed.). Baltimore: Williams & Wilkins.

Shimizu, S. (1994). Arukukoto, ashi, soshite kutsu [Walking, foot, and shoes]. Tokyo: Futo-sha.

Shimizu, S. (1996).Ashi no mondai no kaisho no tameni [For the solution of foot problems]. Training Journal, 195, 11-21.

Suzuki, H. (1992). Kiroku tanshuku to sono training [Running form and training]. Training Journal, 155, 10-14.

Yamasaki, M., & Sato, H. (1990). Hito no hoko [Human walking]. Tokyo: Jinruigaku-zasshi.

Whitall, J., & Getchell, N. (1995). From walking to running: Applying a dynamical systems approach to the development of locomotor skills. Child Development, 66, 1541-1553.